UNIVERSITY OF GHANA, LEGON

COLLEGE OF BASIC AND APPLIED SCIENCES

ECOLOGICAL FOOTPRINT OF ARTISANAL AND SMALL-SCALE GOLD MINING ON SOIL AND PROVISIONING ECOSYSTEM SERVICES IN MPOHOR WASSA EAST AND AMANSIE WEST DISTRICTS, GHANA

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN ENVIRONMENTAL SCIENCE

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

SEPTEMBER, 2021

DECLARATION

I, Stephen Twumasi Annan, hereby declare that this thesis is my own original work towards the award of Doctor of Philosophy in Environment Science. With the exception of quotations and references from other publications which have been duly acknowledged, this work has not been submitted, either in part or full for any other degree elsewhere.

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ABSTRACT

Issues of impacts of small-scale gold mining activities on the environment continue to take a center stage in environmental discourse in developing countries more especially sub-Saharan Africa. This study was carried out to assess ecological footprint of artisanal and small-scale gold mining on soil and provisioning ecosystem services in the Mpohor Wassa East and Amansie West Districts, Ghana. Composite samples of soil and water were taken in selected artisanal and small-scale mining areas for analysis. A total of one hundred and sixty-two (162) soil samples including control soil sample were analyzed over a period of three-months. Seventy-five (75) and eighty-seven (87) composite soil samples were taken from Amansie West and Mpohor Wassa East Districts, respectively. In addition, twenty-seven (27) water samples including control were taken and analyzed during the entire study period. From Mpohor Wassa East water samples, the mean pH ranged from 6.5 to7.1; Electrical Conductivity (EC); 58.7 to 152.3µS/cm; Total Dissolved Solids (TDS); 33.3 to 101mg/L, Total Suspended Solids (TSS); 5.3 to 645 mg/L; Dissolved Oxygen (DO); 5.4 to 12.9mg/L, Biological Oxygen Demand (BOD); 1.0 to 1.7mg/L. The DO, BOD and EC in most sampling sites exceeded the WHO permissible limit. The EC, TDS, alkalinity, and salinity values, however, were all within WHO recommended limits. The results of analysis of the water samples from Amansie West were also as follows: pH; 4.6 to 7.8; EC; 42.7 to 484.8µS/cm; TDS; 25.3 to 221.2mg/L; TSS; 12.5 to 390.7mg/L, DO; 4.3 to 11.8mg/L; BOD; 1.4 to 2.5mg/L. Mercury, arsenic, cadmium and nickel in water samples at both Mpohor Wassa East District sampling sites and Amansie West sampling sites exceeded the WHO and EPA (Ghana) acceptable limits. The concentrations of the following heavy metals in soils; Fe, Hg, Ni, Cu, Pb, Cr and As were above the FAO acceptable limit for agricultural soils. This suggests (which specifically?) that artisanal and small-scale gold activities have impacted on the soil. The study further revealed that change in land use due to artisanal and small-scale mining activities significantly influenced the following ecosystem services; drinking water, wood fuel, medicinal plants, raw material for construction and food crop production. However, in this study, all heavy metals analyzed with Atomic Absorption Spectrometer had Threshold Exceedance Ratio (TER) less than the total concentration when extracted with nitric acid. This translates that limited soil function might not occur since the TER values are smaller compared to the total concentrations and could not limit the function of the soil for agriculture purposes however, the re-mobility percentage especially, Cu was high and had higher percentage mobility in all sampling sites above 20% which suggest that, Cu has a higher potential to remobilized into the soil structure when environmental conditions are favorable. The geo-accumulation index showed that the soils in both study districts are moderately contaminated. The overall conclusion is that artisanal and small-scale mining activities have impacted on provisioning ecosystem services in the two study areas. Efforts aimed at restoring the provisioning ecosystem services therefore need to be considered by relevant authorities. Recommendations made from the study include mandated agencies such as Environmental Protection Agency (EPA) and Ministry of Minerals and Land Commission should regulate the activities of ASGM to stop the discharge of poisonous heavy metals into soil and water bodies. Also, Phytoextraction ability plants such as Sun flower (*Helianthus annuus*), Cannabis sativa, Tobacco (*Nicotiana tabacum*), Maize (*Zea mays*) can be cultivated to demobilize Cu and Hg in the soil and this can be championed by EPA and the Ministry of Agriculture in Ghana. Lastly, it was recommended that the Forestry Commission, relevant stakeholders or NGOs should champion Land reclamation activities such as reafforestation and afforestation should be encouraged at the mined sites to revamp provisioning ecosystem services supply.

DEDICATION

This work is dedicated to my lovely wife Rose line Addae and my children Boahen Twumasi Annan and Grace Twumasi Annan for their support and encouragement.

ACKNOWLEDGEMENT

I acknowledge the immense support, general guidance, suggestions and directions from my supervisors, Prof. F.K. Nyame, Dr. J.S. Ayivor and Dr. Yaw Agyeman Boafo. Their remarkable comments indeed taught me the basic tenets of research work. I will forever remain grateful to them. I owe a debt of gratitude to Mr. Bright Frimpong of Research Consults and his entire family for their selfless and valued support that contributed immensely to the successful completion of this study. My sincere gratitude goes to my wife Roseline Addae and my children Boahen and Twumwaa for their wonderful support and encouragement. I am thankful to Mr. and Mrs. Bondzie, Augustina Adjei, Francis Adarkwa, Collins Owusu-Fordjour, Dr. Charles K. Koomson, Prof. Ruby Hanson (UEW) and Mr. Samuel Armah for their valued support and contributions to the successful completion of this work. My appreciation also goes to Mr. Moses Mensah-Nyumutei, Mr. Akwasi Adu Frimpong, Dr. Ted Annang, Dr. D. Nukpezah, Dr. Benjamin Denkyira Ofori, Prof. Chris Gordon, Prof. Kwasi Appeaning Addo. Dr. Adelina Maria Mensah, Dr. Dzodzor Yirenya-Tawiah Dr. Benedicta Fosu-Mensah, Dr. Daniel Amoako Darko, Dr. Opoku Pabi, Dr. Samuel Senyo Koranteng, Dr. Philip-Neri Jayson-Quashigah all of IESS, University of Ghana, Legon. I am also grateful to my mother Miss. Christiana Gyan, my late father Mr. Thomas Kofi Annan of blessed memory and my siblings Thomas, Felicia, Veronica, Sarah and Michael for making me what I am today. Also, to the family of Mr. and Mrs. David Kumi Gyan, Mr. Okpoti Konney and Mr. Stephen Acheampong. I would like to thank the following personalities; Mr. Emmanuel Ansah, Robert Twene ESQ and Samuel Amoah for their encouragement and support. I acknowledge the financial support of the Carnegie Corporation of New York (CCNY) BANGA Project. Lastly, I am grateful to the authors of the books and materials I consulted during my study and all who contributed in diverse ways to ensure the successful completion of this research wo

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AGM	Artisanal Gold Mining
AIDS	Acquired Immunodeficiency Syndrome
ASM	Artisanal Small-Scale Mining
AWWA	American Water Works Association
BOPP	Benso Oil Palm Plantations
DFID	Department for International Development
DMC	Diamond Marketing Corporation
EPA	Environmental Protection Agency
ERP	Economic Recovery Programme
FCPF	Forest Carbon Partnership Project
GAEC	Ghana Atomic Energy Commission
GDP	Gross Domestic Product
GEPA	Ghana Export Promotion Authority
GIS	Geographic Information Systems
GNA	Ghana News Agency
GREL	Ghana Rubber Estates Limited
GSS	Ghana Statistical Service
HIV	Sexually Transmitted Diseases
ILO	International Labour Organization
INAA	Instrumental Neutron Activation Analysis
IQ	Intelligent Quotient
LI	Legislative Instrument
LULC	Land use and Land Cover Change
MES	Medical and Equipment Suppliers
NGOs	Non-Governmental Organization

NSR	National Skills Registry
PMMC	Precious Minerals Marketing Company
PNDC	Provisional National Defence Council
PNDCL	Provisional National Defence Council Law
PTFE	Polytetrafluoroethylene
SESA	Environmental and Social Assessment
SL	Sustainable Livelihood
UN	United Nation
UNCBD	United Nations Convention on Biological Diversity
UNCEP	United Nations Conference on Environment
UNEP	United Nation Environmental Program
UNESCO	United Nations Educational, Scientific, Cultural Organization
UNIDO	United Nation Industrial Development Organization
USAID	United State Agency for International Development
WACAM	Wassa Association of Communities Affected by Mining Changes
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Ghana's geological space is endowed with various mineral resources including gold, diamond, bauxite and manganese. Additionally, there are other minerals of industrial value such as salt, petroleum, limestone, kaolin, lime, silica, granite and iron ore (Aubynn, 2016). Among all minerals mined in Ghana, gold dominates the mining sector and Ghana is Africa's foremost important producer of gold (Bloch & Owusu, 2017). Although small-scale mining is legalized and regulated under the minerals and mining Amendment Act, 2015, the sector has a larger component of artisanal small-scale mining popularly known as '*galamsey*' (Rudke *et al.*, 2020). Artisanal and small-scale mining are estimated to provide direct and indirect employment to over one million people and contribute significantly to the national economy (Dzigbodi-Adjimah & Bansah, 2018). It is estimated that gold mining contributes approximately 7.2% to Ghana's GDP annually (2006-2014) and employs a large proportion of the labour force (GSS, 2010). Despite the fact that gold mining provides thousands of indigenous peoples with employment, environmental problems including land degradation, water pollution, and biodiversity loss have intensified within the regions of the mining sites (Akosa *et al*., 2018).

The Economic Recovery Programme (ERP) which was launched in 1983 by the government of the Provisional National Defence Council (PNDC) was responsible for the increase in gold output from both the small- and large-scale mining (Minerals Commission, 2006). Among the objectives of the Economic Recovery Programme (ERP) was the rejuvenation of mining activities in Ghana. These laws encouraged increased small-scale mining activities and many people, including the youth, women and children engaged in mining in many parts of the country. In 2006, the Minerals and Mining Act, 2006 (Act 703) was also enacted which again stated, among others, that despite a law to the contrary, a person shall not engage in or undertake a small-scale mining operation for a mineral unless there is in existence of the mining operation license granted by the Minister for Mines or by an officer authorized by the Minister (Minerals Commission, 2006).

Although Ghana's economy is predominantly agriculture based, many small-scale miners depend on mining for their livelihood (Aryee *et al.,* 2017; Akosa *et al.,* 2018; Ntibery *et al.,* 2003). Small-scale mining has been reported to be one of the major contributing factors to the rapid decline of forest resources in Ghana (FCPF, 2014). Forests play enormous roles in the maintenance and provision of goods and services that are beneficial to ecosystem and human livelihood. The rate of forest deforestation and degradation through mining in Ghana is very alarming knowing the various ecosystem services that the forest provides to the environment. From the country's 1950s forest cover of 8.2 million hectares from the onset of the last century, only an estimated 1.6 million hectares remain. Currently, the deforestation rate is about 2.5% of the total land area of Ghana leading to an annual loss of about 135,000 ha (Rudke *et al.*, 2020).

According to Akabzaa and Darimani (2001), the forests that are cleared for mining purposes are home to a large number of organisms and as such indiscriminate clearing of the forests leads to loss of habitat, loss of biodiversity and ecosystem services.

Predominant mainly large-scale mining regions of Ghana were for a long time the Ashanti, Eastern and Western Regions (Hilson, 2011). For the past two decades, however, there has been intensive Artisanal and Small-scale Mining (ASM) activities in these regions (Dzigbodi-Adjimah, 2018). As part of efforts to deal with the effects of artisanal gold mining on the environment and water bodies across Ghana, the government of Ghana through the Ministry of Lands and Natural Resources placed a ban through an executive instrument on all small-scale mining activities. The ban was to enable the government of Ghana to deal properly in order to streamline the activities of the licensed miners. Ghana government launched a joint military and police taskforce called Operation Vanguard to fight recalcitrant small-scale miners (Bloch & Owusu, 2017). Although mining is important for a country's development, it is said to be illegal when it is practiced without permit or in unapproved areas such as forest reserves, game reserves or near water resources even with secured permit (World Bank, 2002). However, issues of ecological footprint of artisanal and small-scale gold mining and the environmental consequences remain a significant challenge to be addressed because most of the communities around the mining areas potentially lose their livelihood through the degradation of natural ecosystem services that were readily available in their vicinity. Furthermore, the community members around these mining areas are also faced with environmental issues due to unsustainable use of environmental resources. It is against this backdrop that the project was initiated to assess ecological footprint of artisanal and small-scale gold mining on soil and provisioning ecosystems in the study areas in Ghana.

1.2 Problem Statement

Gold mining is one of the key areas of natural resource exploitation in most tropical countries that contributes immensely to the Gross Domestic Product of Ghana (Yaro, 2010). These contributions include employment opportunities, corporate social responsibilities through the provision of potable water and schools, among others. The environmental effects of artisanal gold mining footprints in most developing countries including Ghana have been well documented (Akosa *et al.*, 2018; Amponsah-Tawiah *et al.*, 2017; Agyensaim, 2016; Tetteh, 2010). The Mpohor Wassa East District of the Western Region and Amansie West District of the Ashanti Region have witnessed increased artisanal gold mining activity over the past three decades and currently receive national attention with many people including women and children actively engaged in it (Agyapong, 2018; Aryee *et al.*, 2003). During the mining processes, there are several wastes that are associated with the activities due to the mining methods and materials used in extracting and processing the gold bearing materials (Ntibery *et al.*, 2003). The small-scale and artisanal gold miners operate mostly along river banks and sometimes within river beds thus, affecting water quality, sediments load, turbidity and heavy metal concentrations. Major streams affected by small-scale mining operations in Ghana include Birim, Ankobra and Aboshyenso Rivers and their tributaries which serve as sources of drinking water for some communities (Dzigbodi-Adjimah & Bansah, 2018; Ntibery, 2004).

A lot of research work has been done in some mining communities in Ghana to emphasize the problem associated with mining. For instance, Bloch and Owusu (2017) reported major environmental problems faced by mining communities in the Tarkwa area in the Western Region resulting from lead, copper, nickel, mercury and cyanide and other heavy metal pollutions generally above recommended levels in both soil and water samples. Negative effects of mining including destruction of farmlands and water bodies, high cost of living and increase in social vices have also been reported in mining communities such as Obuasi, Tarkwa and Prestea (Agyapong, 2018; Dzigbodi-Adjimah & Bansah, 2018). Although numerous and quite exhaustive studies have been done on Artisanal and Small-Scale Gold (ASGM) activities in Ghana, especially on the socio-economic and environmental impacts, many of such studies did not specifically assess or address the issue of ecological footprint of artisanal and small-scale mining on soil and provisioning ecosystem services, let alone in the Amansie West and Mpohor Wassa East Districts in the Ashanti and Western Regions, respectively, in spite of their long history of ASGM. Thus, very little is known of the possible relationship between ecological footprint from ASGM activities, soil and provisioning ecosystem services in the two areas identified. In addition, the levels of contamination of the activities on the immediate environment using the threshold exceedance ratio (TER) and the heavy metal mobility coefficient potential have similarly not been studied and/or given much attention in research work. This study was therefore undertaken to partly address these knowledge gaps and to also contribute to existing literature on the subject.

1.3 Research questions

The following questions were formulated to guide the study:

1. What are the levels of physico-chemical parameters in soils and water in or near artisanal and small-scale gold mining sites?
2. What are the levels of heavy metals in artisanal and small-scale gold mined-out lands in Mpohor Wassa East and Amansie West Districts of Ghana?
3. What are the land use changes in the artisanal and small-scale mining areas over the past five (5) years?
4. What are the implications of artisanal and small-scale gold mining on provisional ecosystem services on the lives of people in the Mpohor Wassa East and Amansie West Districts?

1.4 Study Objectives

1.4.1 Objective of the study

The overall objective of the study was to assess the ecological footprint of artisanal and small-scale gold mining on soil and provisioning ecosystem services in the Mpohor Wassa East and Amansie West Districts, Ghana. Specifically, the study sought to;

- determine the levels of physico-chemical parameters in soils and water in artisanal and small-scale gold mine sites in the Mpohor Wassa East and Amansie West Districts.
- assess the hazard rating of heavy metals in soils in artisanal and small-scale gold mine lands in the study areas.

- explore the impact of small-scale and artisanal gold mining on land use and land cover changes.
- identify and examine the provisioning ecosystem services and livelihood activities likely impacted by small-scale and artisanal gold mining.

1.5 Significance of Study

In Ghana, there have been a number of studies on the activities of small-scale mining (Bloch & Owusu, 2017). However, little data is available on ecological footprint of artisanal and small-scale gold mining on soil and provisioning ecosystem services in areas such as Mpohor Wassa East and Amansie West District. This research therefore sought to bridge the knowledge gap by acquisition of data on physico-chemical parameters including heavy metal concentrations in water and soil as well as on land use and ecosystem services in the study areas. Analysis and interpretation of the data gathered have provided potentially valuable information for the government, environmental managers and other decision makers or stakeholders on the state and impacts of small-scale mining activities in the study area. The data obtained has, in particular, contributed to the body of knowledge on the impacts of artisanal and small-scale gold mining especially the illegal or '*galamsey*' segment of mining activity and the extent of loss of land use and land cover due to illegal mining activities.

Direct interaction with people in the study areas also provided in-depth knowledge on their livelihood status which could serve as a valuable source of information to inform policy-making towards the achievement of the United Nations Sustainable Development Goals, particularly poverty alleviation and food security which are goal one and goal two, respectively.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter deals with the review of pertinent literature in line with the objectives of the study. It focused on global perspectives of small-scale mining, overview of the modern Small-scale mining industry, major processes in small-scale mining activities, socio - economic effects of small-scale mining activities, methods of mining by small-scale miners, environmental impacts of artisanal small-scale gold mining, mining and land degradation, Illegal mining activities and their effect on water bodies, air pollution and transport of earth material, regulations on mining activities in Ghana.

2.2 Overview of the Mining industry in Ghana

Worldwide, artisanal gold miners (AGM) are the main consumers of mercury, using and losing almost 1000 tonnes of metallic mercury per annum or more than 30% of all mercury annually used by different industrial applications (Creek., 2016). Mercury emitted to the atmosphere and released to the environment has serious and detrimental environmental and health implications. There are now about 10 to 15 million artisanal and small gold miners worldwide. Their operations span more than 70 countries and they produce in the range of 350 tonnes of gold annually (Zhang *et al.*, 2014). Furthermore, Rudke *et al.*, (2020) suggested that organizations which aim to mitigate mercury releases require a deeper understanding of mine community dynamics, the organization of processing activities, the needs of operators and the nature of the ore (Lunt *et al.*, 1995).

Ghana abounds in a number of minerals especially in the south-west of the country and the most developed and sought-after mineral is gold. Gold mining has been associated with Ghana since time immemorial but documentation of this activity was captured by the

Portuguese around the 1470s (Junner, 2010). In the pre-independence period, it is documented that gold mining by indigenous people is said to pre-date Christian times and Ghana's modern mining history spans over six centuries, private Ghanaian gold miners were banned after 1933 from operating mines due to the promulgation of the Mercury Law. Large-scale mining by British and other foreign investors began in the late 19th century. British mining interests were a significant source of influence on the Colonial Office in London and its representatives in the territory and shaped the formulation and implementation of mineral policy in the colony (Akabzaa *et al.,* 2007).

Arah (2015) notes that the mining industry in Ghana dates back to pre-colonial times and some studies have shown that the industry has contributed significantly to the socio-economic development of the country in terms of employment and social infrastructure (Amponsh-Tawiah *et al.,* 2017; Ghana Chamber of Mines, 2008). Others argue that the negative impacts of mining, such as water, air and noise pollution, and the general deprivation of fertile land for agriculture, have left the population relatively much poorer than before (Queensland, 2019; Hilson *et al.*, 2009). This has had a general impact on the overall livelihoods of people living in these areas and working with pastoralists. It is therefore unclear whether mining in Ghana has actually contributed positively to the country's development. It is therefore important to determine the sustainability of the mining industry in Ghana by weighing the socio-economic benefits and negative impacts, particularly on the ecosystem services and livelihoods, examining the environmental, social and economic characteristics of small-scale gold mining and its impact on mining communities (Amansie West District) and suggesting possible solutions to improve the situation (Asante *et al.,* 2017).

2.3 Small-scale Mining in Ghana

In Ghana, small-scale mining is defined as mining by any method not involving substantial expenditure by an individual or group of persons not exceeding nine or by a cooperative society consisting of ten or more persons (Government of Ghana, 1989). According to a United Nations (UN) report, the definition includes what has been termed "artisanal," i.e., operations using only rudimentary/craft implements, as well as more sophisticated mining activities that operate at a relatively low level of production and generally require limited capital investment (UN, 2009). One country where the environmental impacts of small-scale gold mining activities are increasingly unmanageable is Ghana. Despite providing employment for thousands of indigenous people and contributing significantly to foreign exchange earnings, problems of mercury pollution, cyanide and soil degradation have intensified in the sector over the years (Hilson, 2011). According to Rambaud *et al.,* (2016), the first and obvious environmental problem in the area in question is related to the significant changes in land use. Most of this is due to industrial mining operations. The installation of sinkholes along local rivers strongly alters the discharge regime and increases the turbidity of downstream rivers. Erosion, emanating from excavations and tailings piles, is also easily identified by the orange colour of the water and can result in acid rock drainage through rainwater leachates from excavated soils. However, Sumarga *et al.,* (2020) went on to indicate that several metals from ore minerals dissolve in acidic water and can be released into adjacent rivers to cause water pollution.

2.4 Artisanal Gold Mining

Artisanal gold mining is often unplanned and carried out by workers who do not have the technical know-how. As a result, the pits, which can be up to 30 meters deep, are not secured and landslides claim many lives. A study by Babut *et al.*, (2002) clearly shows that abandoned pits are left unmarked, posing a danger to the population and livestock. Abandoned sites are not rehabilitated, leaving a barren and permanently destroyed habitat. For most miners, amalgamation is the simplest and most effective method of recovering the finest gold fraction. However, the process is known to be devastating to health, not only for the users, but also for those indirectly involved, including the unborn, through peripheral contamination and entry into the food chain. In recent years, life-threatening mercury contamination has been found in most developing countries where artisanal gold mining is practiced. In addition, gold panning and amalgamation are often conducted along rivers, resulting in water pollution and destruction of river banks. The resulting siltation reduces the quality of drinking water and affects all types of aquatic life (Creek, 2016; Armah *et al.*, 2013; Babut *et al.*, 2002).

2.5 Artisanal and Small-Scale Mining (ASM) Sector

According to Nyame and Danso (2006), small-scale miners are artisanal miners who are licensed to operate on a small parcel of land and who must market their production through the Precious Minerals Marketing Company (PMMC) or designated agents affiliated with the PMMC. In contrast, illegal miners, known as '*galamsey*,' pursue their trade without any regularization or licensing from regulatory agencies. They emphasized that the "theoretical" distinction between the two is, for all intents and purposes, blurred when visiting the mining sites where these individuals or groups of individuals operate. Again, Amponsah-Tawiah *et al.*, (2017) found it more convenient in their study to group the activities of both under the heading of ASM. However, they also frequently used the terms illegal mining (or miners), '*galamsey*' (the local terminology for illegal miners or mining) and ASM interchangeably (Tetteh, 2010). ASM is one of the fastest growing more or less informal economic sectors in the country. The ASM sector is the most difficult to regulate due to, among other things, the nomadic and often seasonal nature of its activities. In addition, these activities often take place outside the control of government or regulatory agencies (Nyame & Danso, 2006; Noestaller, 2011). Not only is the sector largely unregulated, but it is profusely "polluted" with illegal artisanal or ‘*galamsey*’ miners, whose numerical strength and areas of operation remain largely unknown, although one estimate puts the figure at approximately 100,000 to 200,000 (Aubynn, 2016). Apart from the few registered or licensed small-scale operators, no one knows exactly how many people are engaged in illegal gold and diamond mining in the country. The Ghana Minerals Commission estimates that small-scale miners generated about 4,500 jobs at the end of 2006. However, conservatively, it is possible that more than half a million participants are engaged in the illicit business at any given time throughout the country, especially in the dry season when these activities are most prominent. During peak periods, the sector attracts an army of migrants from across the subregion, partly indicative of the severe unemployment conditions in the region as a whole (Anon, 2010).

2.6 Historical background of Small-scale Mining in Ghana

Small-scale mining, also called artisanal or subsistence mining has been engaged in by the native people of Ghana well over 1500 years now. According to Agyapong (2018), vestiges of alluvial gold extraction and winning have been found as far back as the sixth century in the shores and forest belts of the Gold Coast. He asserted there was evidence that precious metals recovered from regional artisan activities attracted Arab traders to certain areas of the country as early as the seventh and eighth century AD, and that gold deposits in Western Sahara were largely responsible for the wealth and strength of ancient Ghana empires and cultures. Thus, by the fifteenth and sixteenth centuries, of the European colonial exploration, the country was agreeably labeled the Gold Coast. Small-scale mining in Ghana had been treated as an informal sector up until the 1980s, and this resulted in the decline of mineral production, as observed by (Botchway, 2015). Small-scale mining is often done by local people as well as nomadic immigrants who move from place to place for greener pastures (Amponsah-Tawiah *et al.*, 2011).

Nevertheless, this trend has taken a new dimension as the industry has now largely attracted foreigners, especially of Chinese origin, who undertake small-scale mining activities not only with improved local machines, but also with complex forms which are imported purposely for the operations (Appiah, 2015). This is especially true in developing countries such as Ghana where activities of Chinese citizens have called for much concern. More often, the foreigner may hide under the auspices of one or very few but highly influential citizens within the local setting to carry out such an obnoxious task with incomparable environmental pollution and related damages. Until the beginning of the new millennium, the activities of small-scale miners were much less, relative to large scale miners (Andoh, 2002).

Gold was mainly mined in large quantities by the colonial masters in most parts of Southern Ghana. Small-scale mining activities which have gained much popularity in recent years had only had a major turn at the beginning of the 21st century. It comes as a huge solution and indeed relief to the increasing amount of unemployment in most developing countries and the world at large (Appiah, 2015). More often than not, small-scale mining activities within a geographically defined region may be associated with a water body. Water is used in washing away the dirt (mostly soil) from which pure gold is extracted. As a result of this realization, small-scale mining activities have always had a major toll on water bodies from which their activities are carried out. The process is most detrimental to major water bodies which serve as the main recipient for other smaller streams and rivers which empty their contents into these large rivers. Among the major destructions caused is water pollution by chemicals such as mercury, cadmium, arsenic, copper and lead, and damage to vegetation cover. As a result of the nation's favourable geographical setting, which makes precious minerals available in most sections of the Ghanaian soil, small-scale mining of minerals, especially gold, is scattered across sections of the nation (Mineral Commission, 2006).

2.7 An Overview of the Modern Ghanaian Small-scale Mining Industry

The abundance of gold in the Ghanaian soil has been attributed mainly to tectonic processes several years ago, which resulted in folds and faults, as well as a series of metamorphic and igneous, sedimentary and erosion activities (Simon *et al.,* 2004). Erosion activities have resulted in the spread of rich soils which cover a sizable portion of the nation. Several gold belts cover Ghana's land surface. The first belt, covering about 15-40km in width, contains the Birimian gold. However, Birimian gold is found in West African rocks extending from Ghana to as far as Burkina Faso in the north, and Senegal and Mauritania in the western parts of the region. The belt contains such fine gold as Proterozoic greenstone type lobe gold deposits. This is variably complex and occurs as quartz-filled shear zone and altered shear zone forms (Tetteh, 2010). The Tarkwaian gold is found in the second gold belt. About 90% of this gold belt comprises Vein-quartz-pebbles and auriferous pebble deposits. Quartzite and phyllite particles constitute the remaining 10% (Hammond & Tabat, 2017). Due to the mineral-rich contents of the Ghanaian soil, huge monies are accrued from the modern Ghanaian small-scale mining industry. A good amount of gold either in fine particle forms or lump forms are mined from small-scale mining sites across the nation (Appiah, 2015). Generally, wealthy persons buy some acres of land after prospects are made on them to assess the level of their gold mineral deposits. The mineral is very costly. A small part of it may sell millions of cedi. Hence the vigorous involvement of the youth. The prospectors then hire high men and pay them wages (daily, weekly or specified days' interval). Currently, a minimum average daily wage may support an unmarried young man or a woman's moderate expenditure for at least four days, though the specific amount paid may differ widely from place to place. However, small-scale miners hardly economize. Thus, a day's wage may be spent on that particular day with very little or no amount kept. It is worth noting though, that few people involved enter this business with specific aims. Another important factor that makes modern small-scale mining a lucrative business is the high demands for gold and golden products both on the local and international markets (Hilson, 2009).

2.8 Major Processes in Small-scale Gold Mining Activities

A licensed operator may employ between five to twenty groups of tributes made up of between five to ten workers. Each group excavates the ore to process the mineral. Usually, the tributes keep two-thirds of the profit and give the remaining one-third to the concessionaire (Appiah, 2015). Small-scale mining activities in Ghana employ very simple implements and devices such as pick-axes, shovels, mattocks, sluice boxes and cutlasses. In some instances, mechanized machinery such as washing plants, Honda water pumps and explosives are employed (Hilson, 2009). Nonetheless, small-scale mining sites of such mechanized machinery operate largely rudimentarily. Generally, the processes involved in small-scale gold mining are crushing the ore into pebbles or powder under various stages, washing the crushed sediments with washing blanket or hands along riverbanks to separate the mineral, and panning (Amponsah-Tawiah *et al.*, 2017). Finally, as an inexpensive substitute for a gold pan, a krowa - a wooden bowl carved from a tree branch is used to further wash and separate crushed material. The concentrate obtained is amalgamated with mercury (Appiah, 2015; Bloch & Owusu, 2017). Mercury is used in the planning process, and the amalgamated gold is roasted on charcoal fire in the open air (Arah, 2015).

2.9 Socio - Economic Effects of Small-scale Mining Activities

Small-scale mining activities have immense contributions within the communities where they are operated (Aubynn, 2016). The impacts may be both positive and negative. These influences are realized in the increase in population in the area of work, due to increased employment opportunities, boost in economic activities and reduction in crime. Negative influences resulting from small-scale mining activities include child labour, promiscuity and high cost of living (Creek, 2016).

Small-scale mining activities bring about the influx of people to the areas of operation (Ayitey-Smith, 2012). These people are mostly young men and women who are aggressive in making quick money. Some of these people are apprentices in various vacations who may previously be learning one form of trade or the other. Students who fend for themselves or have minimal support from home are also sometimes involved. These people who come to the region for small-scale mining activities to work also take women, especially teenagers from the area and befriend them. This interaction often results in teenage pregnancy and birth to more children, most of whom do not receive the necessary support and parental guidance. Subsequently, this results in population increase. People, who previously farmed, also see the small-scale mining of gold as a quick form of acquiring wealth. Thus, farmers also abandon their farming activities and move to '*galamsey*' sites in search of quick wealth (ILO, 2015).

Small-scale mining activities provide employment opportunities to the people within the area of operation, favourably in very remote settings where there are less or no formal job opportunities (Aidoo, 2015). In developing countries, where employment is very much limited, and where farming is viewed as a job for the aged, the uneducated and the less active in the community, small-scale mining activities are seen as huge sources of alternative employment for the youth and the more active within the society. A United

Nations‟ Report on Small-scale Mining Activities (UN, 2009) indicated that more than over thirteen million or 20% of the world’s mining population was involved in small-scale mining operations. This was confirmed by research carried out by the International Labour Organization which stated in its Global Report on Artisanal and Small-scale Mining, that the number of the world’s population directly involved in small-scale mining activities was over thirteen million (ILO, 2015). Besides the direct job opportunities to people, small-scale mining activities create alongside much other employment through the boost in marketing activities (Agyapong, 2018). Women who were previously jobless now acquire a form of a job through petty trading or running errands at the sites of operation. Thus, all forms of population structure are at least able to meet their economic needs from the job opportunities created by the mining operation. Whilst it is not capital intensive, small-scale mining activities require sufficient manpower. Intensive- small-scale mining operations are economically beneficial; investment cost per job is estimated to be 10-12 percent the costs in large mining operations (Akabzaa *et al.*, 2007).

The cost of living in small-scale mining regions is often very high (Aryee *et al.*, 2017). This is because the operation fetches relatively much quicker money for its workers. Small-scale miners are often spindrifts. This is because they hardly plan ahead, and since the business is very fetching, they always have enough to spend. Traders in the area of operation sell their goods at very high prices, and this makes the cost of living very high for the ordinary people living in the area. Small-scale gold mining is a continuously growing business, very attractive to the young and active populations (Hilson *et al.*, 2009). Since these groups of people would prefer this business to farm, food cost is often very high as only fewer and less active people get involved in the production of crops. While the standard of living has very minimal effects on those engaged in small-scale mining due to the money earned, it adversely affects the vulnerable and inactive, native population who are not involved in this business (Amponsah-Tawiah *et al.,* 2011).

2.9.1 Socio-economic Impacts of Artisanal Mining

Artisanal mining is an attractive employment option for many in rural areas; the barriers to entry are minimal - low technology and little capital are needed. Activity levels are dynamic as precious minerals are often inversely correlated with economic opportunity and periods of economic crisis. Artisanal and small-scale mining generates income; minerals provide higher income than other traditional activities within rural mining communities in Sub- Saharan Africa (Agyensaim, 2016). However, Appiah (2015) stated that the presence of mining activities in Geita district in Tanzania has created market opportunities for local farmers and small traders, and employment opportunities for others. However, artisanal gold mining is associated with many social problems. The local populations are marginalized and oppressed, especially those from lower economic classes, by miners in the Geita district in Tanzania. Communities are exposed to chemical contaminants, heat stress, unsanitary conditions, malaria, prostitution, poor diets, drug-taking and alcoholism (Creek, 2016). Women and children are the most vulnerable and affected. The participation of women in artisanal gold mining varies depending on local beliefs from different countries and communities. Their role is not limited to mining activities and includes the supply of food, tools and equipment and sex services that expose them to sexually transmitted diseases and HIV/AIDS (ILO, 2015).

The environmental impacts of small-scale mining have been studied worldwide. The main impacts are deforestation and land degradation, open pits which are animal traps and health hazards, stagnant water in excavated holes that are abandoned by the miners that often serve as breeding grounds for mosquitoes, mercury use for gold amalgamation, inefficient extraction, dust and noise (Anon, 2010; Bloch & Owusu, 2017; Queenshland, 2019). One of the most significant environmental impacts is derived from the use of mercury (Hg). It is a pollutant causing growing concern because of its long-term impacts on ecosystems and human health. Artisanal and small-scale mining, in contrast to other sectors where mercury utilization is decreasing, remains a dangerous source of mercury pollution (Durkin *et al.,* 2008).

2.10 Environmental Impacts of Artisanal Small-Scale Gold Mining

There is a global consensus that mining and the waste generated by ore processing at active and inactive mining sites, and its impacts on human health and the environment, are a serious and persistent problem faced by government agencies, industry and the public worldwide (Durkin & Herrmann, 2008). They also emphasized that poverty is most prevalent in communities directly affected by mining activities. Spatial analysis of field data from districts with mining activities suggests that communities close to mining projects are generally poorer than those further away from mining, and also show a clear trend of decreasing poverty as a function of distance from the mine.

Gold mine production in developing countries has had a positive impact on employment, but at the same time has caused a multitude of environmental complications. A general problem is that most developing countries have only recently introduced national environmental legislation, and of the laws that pertain to mine-related activities, most are far from rigorous and do not regulate all aspects of the industry appropriately and effectively (Hilson *et al.,* 2009).

In the case of small-scale gold mining, environmental complications generally occur due to low safety awareness and low levels of training, poor exploitation of available resources due to selective mining of rich ores, low wages and chronic lack of capital, lack of environmental standards and use of very inefficient equipment. It is clear that small-scale resource exploitation is a source of livelihood for a significant number of people in sub-Saharan Africa (Nartey *et al.,* 2011; Lombe, 2003). However, it has the greatest impact on sustaining rural economies. To the extent that it is a source of livelihood, it also has an impact on the environment. The environmental effects associated with artisanal gold mining include the following;

2.10.1 Mining and Land Degradation.

According to UNEP (2006) land degradation is the temporary or permanent reduction in the productive capacity of land. It thus includes the various forms of land degradation, human encroachment on water resources, deforestation and reduction in the productive capacity of rangelands. According to Kusi-Ampofo *et al.,* (2012) rich vegetation has been cleared and ridges have been targeted and degraded from top to bottom through a series of benches. The degradation of large tracts of land by small-scale mining poses a major threat to community agriculture and economic survival.

Land degradation through illegal mining activities reduces biodiversity and may subsequently reduce the availability of medicinal plants (Bagstad *et al.,* 2016; Biodiversity Support Programme, 1993; Ayitey-Smith, 2012). Meanwhile, Forkuor and Coffie (2011) noted that the huge scale of mining has led to a complete change of landform suitable for agricultural and other subsistence activities. Huge craters have been formed and slopes and parts of mountains have been eroded, affecting the sources of many rivers and streams and also leading to deforestation. On the other hand, mine waste dumped were often occupying large areas and disfiguring the landscape, resulting in massive water pollution from rainfall.

With regard to artisanal gold mining, the World Bank (2002) pointed out that one of the environmental impacts of artisanal gold mining in Ghana is land degradation, more specifically the clearing of large areas of forest, the digging of ditches and the clearing of vegetation, which in turn leaves the land bare and exposed to erosion factors. About 15,000 ha of land is potentially affected by small-scale mining activities. Furthermore, Appiah (2015) explains, it is common for potential mining sites to be cleared and where there has been deep underground mining, the shafts are left uncovered and abandoned. However, Agyapong (2018), who conducted field research in Tarkwa in the Western Region of Ghana, reported that large areas of the region had been deforested as a result of small-scale gold mining. Artisanal miners, who are supposed to clear vegetation and then dig to extract ore, have left the landscape with ditches and graves dug which, in turn, makes the land unusable for any other purpose. Many of these pits are filled with water and serve as breeding grounds for malaria-infected mosquitoes. In addition, large areas of forest were removed in some places to create neighborhoods or "rest areas" for miners. Studies on the effects of small-scale resource exploitation have mainly focused on land use change studies (Pearson, 2019). However, Forest Carbon Partnership Facility (2014) reported that artisanal small-scale gold mining activities in Ghana resulted in the clearing of extensive forest areas, which in turn left potentially productive land bare and exposed mainly to erosion, heavy rainfall and wind. In addition to this, the World Bank (2002) reported that about 15,000 hectares were potentially affected by small-scale mining by residents.

In this regard, Agyapong (2018) explained that potential areas are generally devoid of vegetation and topsoil, and where there is deep underground mining, the pits tend to remain bare and abandoned. Furthermore, Aryee *et al.,* (2017), who carried out fieldwork in the Tarkwa area of Ghana, reports that large areas of the area have been deforested as a result of small-scale gold mining. The artisanal miners, who reportedly cleared the vegetation and then excavated mineral ore, marked the landscape with dug holes and trenches, which in turn made the land unusable for any other purpose.

2.10.2 Illegal Mining Activities and Effect on Water Bodies

Illegal mining activities of water bodies have been identified as one of the major causes affecting the production and supply of potable water in the Western Region. The Pra River, which serves as the major source of water for the production of potable water in the region, has been taken over by '*galamsey*' operators, whose inhuman activities pose a great danger to the continuous availability of potable water (Amponsah-Tawiah *et al.,* 2017). The deputy minister for Water Resources, Works and Housing on a working visit to assess the level of the water crisis in the region, admitted that illegal mining activities pose a great challenge to the operations of Ghana Water Company. She said that both the Ntweaban and the Daboase treatment plants have the capacity to produce six million gallons of water a day to serve the twin-city but production is low and inadequate. These illegal mining activities pose problems for the treatment plants and make the cost of production very high. She admitted that the current situation in the region was bad and could affect the industry and even household consumption (GNA, 2011).

Determination of heavy metals in water bodies in Tarkwa and Obuasi areas by the Wassa Association of Communities Affected by Mining Changes (WACAM), particularly on Nyam River in Obuasi showed that Arsenic concentration of 13.56mg/L as against 0.01mg/L required by the WHO and Environmental Protection Agency (EPA). This was due to pollution by small-scale mining activities. Data from Asuakoo River revealed that it had 22.72mg/L as against 0.4mg/L of Manganese prescribed by the WHO permissible guideline. The Executive Director, WACAM, said pollution of water bodies in the mining communities posed serious health implications to the people who were found to be suffering from various illnesses. He said the result of the research showed that most water bodies in the study areas were polluted with a high arsenic level ranging from 0.005 to 35.4mg/L. Manganese, lead and mercury are neurotoxic metals which could affect the IQ of children exposed to high levels in drinking water. In all 400 water samples, made up of 200 from Obuasi and 200 from Tarkwa areas were collected between May and September 2008 and each sample was analyzed separately for toxic chemicals including arsenic, manganese, cadmium, iron, copper, mercury, zinc and lead (Agyapong, 2018).

The physicochemical parameters such as pH, conductivity, turbidity and total dissolved solids were measured using standard methods of analysis as prescribed by the American Water Works Association (AWWA, 2000). The turbidity of some of the water bodies and alternate sources of water provided had low pH and high turbidity values, which exceeded the WHO and GEPA permissible limits (GNA, 2009). Studies conducted by the Ghana Atomic Energy Commission (GAEC) on water bodies and stream sediments as a result of small-scale mining activities at Tarkwa and its environs in the Western Region indicated excessive pollution of high mercury concentration, a toxic element that affects human health. The results suggested that the level of mercury detected from the water samples from the Western Region gold mining towns exceeded the WHO tolerable limit of 0.001mg/L for drinking water (GNA, 2009).

According to the GAEC, areas that contained high concentration of mercury are sites that experienced extensive '*galamsey*' gold mining activities, showing that mercury concentration varied between 6.80 and 19.82 for water, and 28.90 and 84.30mg/Kg in sediment at sites with extensive small-scale mining activities (Akosa *et al.*, 2018). At Prestea and its environs, total mercury concentrations in water were measured. The samples were analyzed by instrumental neutron activation analysis (INAA). Higher levels of total mercury concentration were found in samples at the sites with extensive small-scale gold mining activities than at the sites with low small-scale mining activities. Concentrations varied between 7.5 and 20.6mg/L with extensive small-scale mining activities. At low small-scale mining sites, mercury concentration varies between 0.50 and 9.10mg/L (Serfor-Armah *et al.*, 2006). At Bibiani-Anhwiaso-Bekwai District (a typical mining community in the southwestern part of Ghana), surface water and sediment samples were collected from seven streams that drain this mining community and analyzed for mercury concentration. The total mercury content of the water ranged between 0.125 and 1.341µg/l while sediment values ranged between 0.169 and 1.739 mg/Kg. Physico-chemical parameters were also determined for the water samples. The pH range varied from 8.4 to 7.1. Temperature also ranged from 32 22.7°C to 31.6°C. Conductivity also ranged from 2.77 to 0.21 µs/cm. Total dissolved solids were from 185.9 to 111 mg/L (Nartey *et al.,* 2011).

2.10.3 Air Pollution and Transport of Earth Material

According to Armah *et al.,* (2013), site clearance and road construction, topsoil removal and dumping, and transport of earth material in open-pit mines result in air pollution. The dust emitted pollutes the air in most mining communities, especially during the dry season. The dust produced during gold mining contains a high proportion of silica and can cause respiratory diseases such as silicosis, colds, tuberculosis and silico-tuberculosis (Aubynn, 2016; Owusu & Dwomoh, 2012).

Another issue of concern is social hazard. Issues about social hazards on gold mining have been raised by various authors however, Agyensaim (2016) stated that small-scale gold mining activities in Ghana are taking place in areas where agriculture is predominant. Miners compete with community members for agricultural land, forest products, domestic water resources, consumption, fishing and other aquatic products that are the source of livelihood for community members. Referring to Andoh (2002), most farmers are abandoning their land because the economic argument weighs in favour of the mining industry. Residents are therefore forced to free up agricultural land and settlements for open-pit mining. The influx of migrant workers leads to high costs of living, especially higher food and housing rents, disorientation of communities and distortion of cultural values, among others (Aidoo, 2015; Agyensaim, 2016). The focus on small-scale gold mining has shifted attention away from food production, primarily to '*galamsey*' operators. Land previously used for farming and other agricultural activities has been taken over by mining concessions, reducing food production and creating conditions for higher food prices (Bloch & Owusu, 2017; Tetteh, 2010; Noestaller, 2011). The business of '*galamsey*' which involves excessive physical exertion, is a challenge, and hence risky, due to high drug consumption. Smoking cigarettes increases exposure of the lungs to dust, making them more susceptible to silicosis, tuberculosis and pneumonia. Alcohol and drug abuse are important causes of mining accidents. Sexually transmitted diseases are prevalent in mining communities because of the activities of sex workers (Chambers & Conway, 2017).

2.10.4 Heavy Metals in the Environment

The presence of heavy metals in the environment has adverse effects on ecosystems (Mamo *et al.*, 2007). Minute amounts of heavy metals available in the environment are basically due to the weathering of rocks. This is the process by which rocks break down into pieces to generate soil. Like all metals, heavy metals circulate within the environment and are eventually assimilated by plants and animals (Armah *et al.*, 2013; Akabzaa *et al.*, 2007).

2.11 Methods of Mining by Small-scale Miners

Methods employed by small-scale gold miners vary according to the type of deposit being exploited and its location Due to the poor financial status of small-scale gold miners, the majority rely solely on traditional/manual methods of mining, which use simple equipment like shovels, pick-axes, pans, chisels and hammers (Ntibrey, 2004). One method is the shallow alluvial mining techniques, which are popularly called -dig and wash, or the Krowa method (wooden bowl carved out of tree stem to serve as a pan) are used to mine shallow alluvial deposits usually found in valleys or low-lying areas. Such deposits have depths not exceeding three meters. The area is initially cleared and the soil excavated until the gold-rich layer is reached. The mineralized material is removed and transported to nearby streams for sluicing to recover the gold. Gold from sluices is concentrated by using a smaller 'krowa' or the gold pan. Women are very effective in using the 'krowa' for the recovery of gold (Appiah, 2015). Illegal small-scale gold miners practice this method because of easy access.

Deep alluvial mining techniques or land dredges are also other types used to mine deep alluvial deposits found along the banks of major rivers such as the Ankobra, Tano, and Offin and certain older river courses. These methods involve excavating a pit and digging until the gold-bearing gravel horizon, which is typically located at depths of 7 to 12 metres, is reached (Noetstaller, 2011). The gold-bearing rocks are then removed and sluiced to recover the gold. In recent years, some of the richer owners have introduced large machinery to this method, bulldozing and back-hoeing pits to access layers of gold-bearing gravels more quickly or those formerly inaccessible by manual methods alone (Creek., 2016). In areas where hard rocks are encountered the ore is excavated manually and size reduction is carried out using a combination of jaw and rocker crushers and hammer

(Amankwah & Anim-Sackey, 2003). In some cases, explosives are commonly used, despite being prohibited throughout Ghana (Ntribrey, 2004).

2.12 Methods of Processing

Firstly, the ore is crushed into pebbles by physical or mechanical means. The pebbles undergo primary, secondary and tertiary grinding in preparation for washing. The ground ore is transferred to the riverside or pond in cloth bags to be refined (Amegbey & Eshun, 2003). The gold-containing material is washed on sluices where the heavier gold particles are caught and concentrated on carpets or jute sacks, due to gravity. The concentrate from the sluice box is re-assembled in rubber dishes or wooden pans (Krowa). Through panning, the undesirable sediments are separated from the gold particles until the latter clearly appear in the final concentrate. Next, mercury is poured into the concentrate inside the pan. Mercury is usually mixed by hand with the concentrate, forming a lump or ball of mercury-gold amalgam. Water is added several times to discard tailings and remove lighter particles until only the amalgam remains. The amalgam is then squeezed in a piece of cloth to recover excess mercury (often re-bottled and used again). Some miners put the fabric with the amalgam into their mouth to suck out additional mercury (Hilson *et al.,* 2009).

Finally, the amalgam is roasted in a coal pot for 15-40 min, depending on size. Burning can also take place with a blowtorch. During gold production, mercury losses occur at various stages: amalgamation, where mercury may be washed out during the gravity washing; and burning, where mercury, with its high volatility, is released into the atmosphere. After burning, a sponge-like gold substance stays behind in the tin. When the gold has cooled, it is weighed and at the end of the day sold (Akosa *et al.,* 2018).

2.13 Regulations on Mining Activities in Ghana

Mining activities in Ghana are regulated by a number of legal frameworks (Noetstaller, 2011). That mining activities are not properly monitored cannot be attributed to the lack of regulations on mining processes. Rather, this can be attributed to the fact that there are weaknesses in existing laws, and also the lack of commitment on the part of environmental agencies to enforce these laws. Environmental agencies may sometimes also lack the necessary equipment for monitoring. This makes monitoring very difficult, and the agency becomes limited in its mandates (Agyensaim, 2016). Some important mining regulations enshrined in the constitution of Ghana are reviewed here.

2.14 Mineral and Mining Law 1986 (PNDCL 153)

Section I "All minerals are the property of the Republic of Ghana, and the Government has the power to acquire compulsorily any land which may be required to secure the development or utilization of any mineral resources". This law makes the Government of Ghana the legal owner of minerals taken from the Ghanaian soil, and all lands suitable for mining processes. Section 14 subsection 2 (PNDCL 153, 1986) "The Secretary (now the Minister) for Lands and Natural Resources shall, on behalf of the Republic, have the power to negotiate, grant, revoke, suspend or renew any mineral right under this law". This makes it possible for the Minister of Lands and Natural Resources, on behalf of the Government of Ghana, to enact by-laws and prevent any such move or mining activity deemed detrimental to the environment, and ultimately citizens of the nation. PNDC Law 153 also makes it possible for mining organizations to have inspectors and monitors who sample materials and systems such as soil, tailings and water bodies in and around the site of work, so as to ensure that environmental standards are met.

2.15 The Mineral Commission Law 1986 (PNDCL 154)

The law was enacted to establish the Minerals Commission. The Minerals Commission is responsible for the formulation of policies regarding mineral exploration and its mining on Ghanaian soils. The Commission, therefore, has a contractual obligation with proponents in the country. Individuals holding the chairmanship, as well as the Chief Executive Officer of this Commission are appointed by the Government.

2.16 Small-scale Gold Mining Law 1989 (PNDCL 218)

Section I "No person shall engage in or undertake any small-scale mining operations unless there is existence, in respect of such operation, a license and granted by the Secretary (now the Minister) for Lands and Natural Resources or by an officer auditioned on that behalf". It is evidently clear from this law that small-scale mining operations without permits are not allowed to operate. The story, however, differs from current observation, as almost all small-scale mining activities across the nation either operate illegally or have not adequately followed due processes to acquire permits. This law does not make it possible for non-Ghanaians to have a license to operate, as stated in Section 2 of this regulation, except that such Ghanaians are 18 years and above. Nonetheless, they may participate in such operations where Ghanaian citizens are the majority stakeholders, as directed by the firm's code. Section 13 of the law forbids using explosives in small-scale gold mining operations. It states, "No small-scale gold miner shall use any explosive in his operations" Unfortunately, the lack of adequate supervision and monitoring has resulted in this aspect of the law being highly compromised. The purchase and use of mercury are however permitted, as specified in section 14 of this law 46.

2.17 Legal Framework for Small-scale Mining Activities in Ghana

An important move was made by the PNDC Government in 1989 to officially allow the mining of important minerals such as gold. This legalization of small-scale mining activity was an important landmark over previous regulations, which only permitted the small-scale mining of diamonds. Three important mining laws were passed as follows: The Small-scale Gold Mining Law (PNDCL 218): Provides for the registration of activity; the granting of gold-mining licenses to individuals or groups; the licensing of buyers to purchase products; and the establishment 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 (PNDC Law 219): This law transformed the Diamond Marketing Corporation (DMC) into the Precious Minerals Marketing Corporation (PMMC), which was authorized to buy and sell gold.

2.18 Processes of Application for Small-scale Mining Permit/License

Firstly, a notification is given to the Officer responsible for small-scale mining in the district. The Officer then follows up to the region to assess how suitable it would be for the activity before demarcating the site. The prospective miner prepares a site plan, and a notice of the intention is published at the Assembly, the local information center and the magistrate's court for 21 days. After the 21 days, and if no contrary opinions are expressed, the applicant completes an application form to fulfill other requirements of the Mineral Commission. Recommendations are submitted to the Secretary or Minister for Mines and Energy who then approves or rejects the application. A successful applicant is handed a code of environmental safety practices, and these include safety precautions at workplaces (protection at workplaces), land surface protection and general environmental protection guidelines (Mineral Commission, 2006).

2.19 Definition and Concepts of Ecosystem

2.19.1 Ecosystem and Ecosystem Services

The United Nations Convention on Biological Diversity defines ecosystems as a dynamic complex of interacting plant, animal and microbial communities and their abiotic environment as a functional unit. Ecosystems can generally be divided into two main categories: terrestrial and marine ecosystems. Humans are part of ecosystems and benefit from them, as their lives depend on ecosystem services. These systems interact and interconnect through various processes that create ecological balance and are linked at different scales to provide valuable ecosystem services to people (Daily *et al.*, 2009; Costanza *et al.,* 2014). Ecosystem services provide outputs or outcomes that directly and indirectly affect human well-being because these are the benefits that people derive from ecosystems. Therefore, ecosystem services are an integral part of nature that are enjoyed, consumed, or used directly or indirectly to create and satisfy human well-being (Mitchell *et al.,* 2017). Ecosystem processes, sometimes referred to as functions, express the complex physical and biological cycles, processes and interactions that underpin the nature we observe and result in ecosystem services. The specific outcome of these processes is the direct maintenance or enhancement of human life (de Groot *et al.,* 2002). Ecosystem services are the ability of natural processes and elements to provide goods and services that directly or indirectly meet human needs. Several competing definitions of ecosystem services come from different disciplines and approaches (Fisher *et al.,* 2017; Fu *et al.,* 2018). However, there are some general definitions of ecosystem services that are frequently used and cited.

- Daily *et al.,* (2009) defines ecosystem services as the conditions and processes by which natural ecosystems and their component species support and enable human life.

- Costanza *et al.*, (2014) define ecosystem services as the benefits that humans derive directly or indirectly from ecosystem functions.

- The Millennium Ecosystem Assessment (2005) defines ecosystem services as the benefits that ecosystems provide to humans, which include the following services: nutrition, regulation, support and cultural services. The definition shows that although there is broad agreement on the general definition of ecosystem services, some critical differences can be highlighted. Daily *et al.*, (2009) define ecosystem services as "states and processes" and "actual life-supporting functions". Again, Costanza *et al.*, (2014) define ecosystem services as functions provided by and used by people. Basically, provisioning services include firewood, bushmeat, freshwater, fruits, medicines, and fish. Once the functioning of ecosystems is known, the value of goods and services provided to human society can be analysed and assessed according to the functional aspects of ecosystems. To avoid confusion between the two concepts, it is argued that the difference lies in the fact that human beneficiaries are related to services and not to the activities considered in this paper. Those activities that benefit individuals and society are referred to as 'ecosystem goods and services. Ecosystem goods and services are based on the natural environment, such as soil, water and air (Hein *et al.*, 2018). Natural ecosystems provide a wide range of direct and indirect services and tangible benefits to humans and other organisms (Shackleton *et al.*, 2019).

Table 2.1: Classification of Ecosystem Services

Provisioning services: Products obtained from ecosystems, such as water, timber and non-timber forest products, or genetic resources including the following: Water, Medicinal plants, Bushmeat Food (Wildlife, fish, fruits, mushrooms and others) Raw materials such as building materials	**Cultural services** River for recreational use including non-material benefits, such as cultural, recreational or spiritual values
Supporting services: Services needed to produce the other three categories, primary production/soil and nutrient recycling.	**Regulatory services:** Benefits from the ecological processes such as carbon regulation

2.20 Ecosystem Services and Livelihoods

2.20.1 Ecosystem Services

According to Costanza *et al.,* (2011) ecosystem services benefit humans by transforming resources or environmental assets, including land, water, vegetation and atmosphere, into a flow of essential goods and services such as clean air, water and food. The Millennium Ecosystem Assessment (2005) also defines ecosystem service as the benefits derived from nature that are important for human well-being. In 2005, the Millennium Ecosystem Assessment identified and categorized ecosystems and their resulting services, identified the links between these services and human societies, and the direct and indirect drivers and feedback loops. The Millennium Ecosystem Assessment framework identified ecosystem services within four categories, namely; provisioning services such as food and water, regulating services, such as flood and disease control, support services, such as nutrient cycling, that maintain the conditions for life on Earth, and cultural services, such as spiritual, recreational, and cultural benefits (Wang *et al.,*2018).

Ecosystems are increasingly recognized for their contribution of services to human well-being. This has led to an interest by many researchers in understanding human-environment interactions against the backdrop of dwindling ecosystems (MA, 2005). Across the world, understanding ecosystems is an essential subject for scientific enquiry (Cowie *et al.,* 2011; Rounsevell *et al.,* 2010), mainly due to the growing costs of biodiversity loss and ecosystem degradation (TEEB, 2008). This is particularly true for developing countries whose population heavily depend on ecosystems for survival (due to high poverty levels) and have the highest rates of ecosystem degradation (MA, 2005), and is especially the case for the dryland systems of Sub-Saharan Africa (Bagstad *et al.,* 2018)

2.20.2 Ecosystem Services and Land Use Change

It has been noted in the Millennium Ecosystem Assessment (MA) Synthesis Report (2005) that degradation of ecosystem services significantly impacts human well-being and poses a direct threat to regional and global eco-safety (Daily *et al*., 2009). Land use refers to the deliberate management of land to achieve specified outcomes that are partially influenced by the natural characteristics of the land in question (Fu *et al.*, 2013). Human activity has substantially altered land cover globally and Crop land now accounts for almost 11 % of the total global land area. The area used for grazing livestock has increased from 324 million ha in 1700 to 3429 million ha in 2000, representing 25 % of the total global land area (Pielke *et al.,* 2011). Such land-use change strongly influences an ecosystem's capacity to provide services (MA, 2005; GLP, 2005; Lawler *et al.,* 2014). However, Costanza *et al.*, (2014) estimate that total global land-use changes between 1997 and 2011 resulted in a loss of ecosystem services worth $4.3–20.2 trillion every year. Researchers and international groups increasingly view ecosystem services, land use change, and the links between them as of central importance for ecosystem restoration, management, and conservation (Palmer *et al.*, 2004; GLP, 2005; MA, 2005; Sutherland *et al*., 2006; Crossman *et al.,* 2013; Maes *et al.,* 2013).

Initial research conducted on ESs was heavily focused on defining essential concepts and terminology (De Groot *et al*., 2002; Haines-Young *et al.,* 2011) and on attempting to value the ongoing provision of these services (Van Wilgen *et al.,* 1996; Costanza *et al.,* 2014; Ghaley *et al.,* 2014). More recently, research has focused on the quantitative modelling and spatially explicit mapping of ESs (Ayanu *et al.*, 2012; Martínez-Harms & Balvanera 2012; Hu *et al.,* 2014; Larondelle *et al.,* 2014; Sumarga & Hein, 2020), trade-off and synergy analysis between multiple ecosystem services (Rodríguez *et al.* 2006; Fu & Wang, 2018; Jia *et al.,* 2014; Kragt & Robertson, 2014; Lu *et al.,* 2014; Zheng *et al.,* 2014), spatial flow analysis of ecosystem services (Bagstad *et al*., 2018; Palomo *et al.,* 2013; Villamagna *et al.,* 2013; Schröter *et al.,* 2014; Serna-Chavez *et al.,* 2014), incorporation of ecosystem services into conservation and restoration programs (Egoh *et al.,* 2007; Trabucchi *et al.,* 2012; Zheng *et al.,* 2014), environmental decision-making and its implications (Daily *et al.,* 2009; Bateman *et al.*, 2013; von Stackelberg, 2013; Zheng *et al.,* 2014), and assessing payment options to account for ESs (Derissen & Latacz-Lohmann, 2013; Schomers & Matzdorf, 2013).

While ecosystem services have received increasing attention in the literature, much less attention has been given to studies linking ecosystem services with land-use changes. The studies that examined such links, most focus on the changing values of ecosystem services under altered patterns of land use. In practice, these valuations help raise awareness of the importance of ecosystem services to society and serve as a powerful and essential communication tool for informing decisions regarding the inherent trade-offs associated with policies that enhance the gross domestic product (GDP) but damage ecosystems as opposed to simply treating ecosystem services as commodities for trade-in established markets (Costanza *et al.*, 2014).

2.20.3 Provisioning Ecosystem Services

Provisioning services are the tangible goods or products obtained from ecosystems such as food, fresh water, timber and fiber (Fu *et al.,* 2018). Indeed, provisioning ecosystem services are vital to human survival, especially in rural communities in Africa that depend primarily on ecosystem services. Without provisioning ecosystem services such as wild fruits, bushmeat and other essential consumptive materials, their survival and livelihood will be highly affected. The question of food security under-provisioning ecosystem service in a primarily rural community is vital as demand increases and commodity markets become more volatile (Ghaley *et al.,* 2014). Over the years, access to gold through heavy machines and tools has significantly impacted the provisioning ecosystem services of the most vulnerable farmers across Africa. Ghana is among the countries in Africa that have suffered from over-exploitation of natural resources such as gold. Small-scale mining activities, popularly called '*galamsey*' has had a severe toll on the agricultural activity of community members. This situation has had dying down consequences on access to arable land for agricultural activities.

Agro-ecosystems, ranging from small-holdings to commercial scale, provide food for human consumption and underpin global food security have been affected due to land-use change activities. Much of the Earth's land surface is used for food production through crop cultivation and livestock rearing. Marine and freshwater fisheries and aquaculture also provide significant protein sources to the global population (FAO, 2014). Aquaculture depends on nutrient recycling and water purification services in coastal areas and inland water bodies (Asante *et al.,* 2017). In urban contexts, ecosystems can help meet energy needs and support agriculture (Martinez-Harms *et al.,* 2012). As well as the production of sufficient food in terms of quantity, the nutritional quality of food produced is also critical to human health and an essential component of food security (FAO, 2014). A range of ecosystems provides both wild and domestic sources of nutrition for humans (Obeng *et al.,* 2018). Where these resources are in decline, malnutrition can occur, for example, coastal communities relying on dwindling fisheries for protein intake. For communities worldwide, nutritional needs can be met through wild products identified and located through ecological knowledge, another ecosystem service (FAO, 2014). Water is used predominantly for agriculture, including livestock production, followed by industry and domestic uses (Fu *et al.,* 2013). Forest and mountain ecosystems are source areas for most renewable water supplies and regulate pollution and water quality. The link between the regulation of water supply and water quality is strong. However, vegetation, soils and soil organism activity are significant determinants of water flows and quality, and micro-organisms play an important role in groundwater quality.

While the general relationship between more intact biodiversity and water regulation is understood, the relationships between discrete species and changes in biodiversity with changes in water regulation are not. Land-use change, significant deforestation can affect the capacities of ecosystems to regulate and provide fresh water, which can be difficult to reverse (GLP, 2005). Large-scale land-use change activities such as mining and other related activities can potentially affect vapour formation and rainfall patterns in locally specific and highly variable ways. Rain-fed agricultural systems will potentially be influenced, in turn impacting food production and quality.

Agro-ecosystems can also interplay with human resilience in negative ways; for example, by impacting on ecosystem services nearby through nutrient pollution and barriers to migration and dispersal of organisms, sedimentation of waterways and loss of wildlife habitat (Schomers, 2013). The provision of fuels and fibres including timber, cotton, sisal, sugars and oils is an important ecosystem service for humans. Such natural materials are used to construct shelter and fuel for cooking and heating (MA, 2005). Biochemicals produced by plants, animals, and microorganisms are high-value medicinal resources for the production of pharmaceuticals and pesticides and other products. Pharmaceutical compounds have been derived from a range of ecosystems, including oceans, coastal areas, freshwater systems, forests, grasslands and agricultural land. Crop genetic diversity is critical for increasing and sustaining production levels and nutritional diversity throughout the full range of agro-ecological conditions (FAO, 2014).

Genetic diversity within crops contributes to food security by increasing yields and nutritional values. Humans have had a long history of improving varieties and replacing local varieties of domesticated plant species with high-yielding crops, thus eroding genetic resources. Agricultural genetic diversity also provides services for genetic diversity in non-domesticated species of plants, animals, and microorganisms linked to them within ecosystems. Advances in genetic modification are opening up opportunities to increase these effects by preserving genetic diversity in gene banks and creating improved strains or breeds. Genetic diversity of crops also decreases susceptibility to pests. Genetic resources in crop plants, livestock and fisheries will be increasingly crucial for resistance to diseases and adaptation to novel climatic conditions. Access to green space has been linked to reduced mortality, improved perceived and actual general health and psychological benefits (Tesfaye *et al.,* 2011).

2.20.4 Forest Provisioning Ecosystem Services

Ecosystems services are essential benefit that people obtain from ecosystems (MA, 2005). Provisioning ecosystem services are those products that can be harvested and quantified, such as food, fibre and fuel (Maass *et al.,* 2005). In Africa, various land-use change activities have rendered most forest lands useless. Most forests in Africa provide an essential day-to-day living for their inhabitants. They are a source of mushrooms, edible insects, indigenous fruits, seeds, wild vegetables, honey and oils (Shackleton & Gumbo, 2010). The woodlands are also a source of traditional medicine for primary health care (Cristecu, 2012) and poles, fibers and other materials used for constructing houses and barns (Clarke *et al.,* 1996). Wood fuel (firewood and charcoal) from the forest is an essential energy source, providing over 75% of Africa's total energy needs for urban and rural dwellers. The forest is a pharmacy, a supermarket, a building supply store, and a grazing resource. Over the last four decades, the accelerated conversion of forest and wetlands to mining areas has resulted in the total collapse of provisioning ecosystem supply by most forests in Africa. This situation has deepened the poverty situation of the rural Africa population.

2.20.5 Vulnerability of Rural Households to Provisioning Ecosystem Loss

Rural households are vulnerable to various stresses and shocks that affect their livelihood assets and options due to loss to provisioning ecosystem services (Debela *et al.,* 2012). Households experience different frequencies and types of idiosyncratic shocks such as death, sicknesses, loss of property and covariate shocks such as droughts, flooding, outbreaks of human and livestock diseases (McSweeney, 2004; Paumgarten & Shackleton, 2011). Rural households rarely have access to formal insurance institutions to help them cope with stresses and shocks. Therefore, a loss to ecosystem services provision due to land-use change activities such as mining often rendered most rural households vulnerable. In most parts of Africa, rural households cope with these stresses and shocks from selling productive assets, kinship, engaging in off-farm employment, or reducing the frequency and amount of consumption (Debela *et al.,* 2012; Dercon, 2002).

The coping capacity of households is determined by several factors such as nature and intensity of shock (Pattanayak & Sills, 2001), local environmental endowments and household socio-economic factors. Although households use various strategies to cope with idiosyncratic shocks (Heemskerk *et al.,* 2004; Maxwell *et al.,* 1999; Paumgarten & Shackleton, 2011), these strategies are often inadequate cope with extreme covariate shocks (Dercon, 2002; Heemskerk *et al.,* 2004). High frequency and intensity of shocks coupled with inadequate household's coping strategies are a common poverty trap for many rural households (Carter & Barrett, 2006; Zimmerman & Carter, 2003). The rising levels of human vulnerability to multiple stressors increase rural people's dependence on ecosystem services (Shackleton & Shackleton, 2012). Unfortunately, the forest and accompanying ecosystem services are being destroyed to accommodate other land uses such as mining, housing, etc. Although the use of forests to cope with stresses and shocks has been reported in some empirical studies, mainly in Latin America's tropical forests (Godoy *et al.*, 1998; McSweeney, 2004), only a few studies have been conducted in the dry forests of southern Africa (Paumgarten & Shackleton, 2011).

2.20.6 The contribution of provisioning ecosystem services to rural livelihood

Ecosystem services are defined as the benefits that people obtain from ecosystems (MA, 2005). Global policy interest in forest ecosystem services has increased due to their role in mitigating climate change and providing essential services to rural livelihoods in developing countries. The economical use of forest ecosystems has long been recognized (Whitford, 2015); however, forests worldwide are disappearing at alarming rates (FAO, 2014). This trend has prompted policymakers, researchers, and development agencies to promote the sustainable management of forests to reconcile economic development and biodiversity conservation (Paumgarten & Shackleton, 2011). Forests provide several products that underpin many rural livelihood strategies (Shackleton & Shackleton, 2004). These products are collectively referred to as 'provisioning services', defined as 'services supplying tangible goods, finite though renewable, that can be appropriated by people, quantified and traded' (Maass *et al.*, 2005). Because the value of vegetation to rural livelihoods is socially constructed and contested (Kragt, *et al.*, 2014), the direct-use value of FPES in households is a crucial determinant of their value, both in consumption and as a source of income (Mamo *et al.*, 2007; Shackleton & Shackleton 2006; Sunderlin *et al.*, 2005; Tesfaye *et al.*, 2011).

Although the importance of FPES to millions of rural households is increasingly being acknowledged, research regarding the impact of socio-economic factors on forest use shows mixed evidence. Wealthy households have been reported to consume more forest products than poorer households in Zimbabwe (Crossman *et al.*, 2013) however, studies in South Africa have reported that wealth does not significantly influence the consumption of forest products (Paumgarten & Shackleton, 2009; Shackleton & Shackleton, 2012). In terms of household income, middle-class and wealthy households have been reported to earn more income from the sale of FPES in Cameroon (Lawler *et al.,* 2014) and the Democratic Republic of Congo (Debela *et al.*, 2012), while a study in Dixie village in South Africa reported that household wealth did not influence the sale of FPES (Paumgarten & Shackleton, 2009). Research results concerning the influence of the head of the household gender on the use and sale of FPES are also mixed. Households headed by females have been reported to rely more on forest products in Cameroon (Fisher *et al.,* 2017) and southern Ethiopia (Zheng *et al.*, 2014), while in South Africa, studies have indicated a negligible gender effect (Paumgarten & Shackleton, 2009). It is evident that the use and sale of FPES about household wealth and head of the household gender varies across different case studies, and further empirical studies are required to explore these relationships and inform local policies and programmes. Understanding how the use and sale of provisioning services differ according to wealth and gender is essential in understanding people's reliance on forest ecosystems and their contributions to their livelihoods (Heubach *et al.,* 2011; Shackleton *et al.*, 2019). Research on the socio-economic differentiation of FPES use is essential in developing local management interventions to protect rural livelihoods and ensure sustainable forest use (Shackleton & Shackleton, 2006).

2.21 Loss of Land and Livelihood from Mining Activities

Global changes pressure people's ability to access and utilize land and natural resources in rural communal areas. Several ecological (drought, floods, exhausted soils) and social factors (legislation, privatization, over exploitation) govern the ability of people to access and derive livelihoods benefits from agriculture, livestock and natural resources in communal land ecosystems (Chirwa, 2008; Bagstad *et al.*, 2018). Losing the ability to derive these land-based benefits can increase the vulnerability of local communities and have devastating effects on their well-being and resilience. One such driver affecting land access and people's ability to utilize natural resources is mining, which has negatively affected rural communities and their livelihoods all around the world, leading to social-ecological change and conflict (Hilson, 2011; Kragt *et al.*, 2014; Bagstad *et al.*, 2014). Globally, rural communities rely heavily on access to land and the natural resources they provide to maintain their livelihoods. Agriculture, livestock and non-timber forest products (NTFPs) used on communal lands support the livelihoods of millions of people (Sumarga *et al.*, 2020; Shackleton *et al.*, 2019).

Livestock and crops provide poor rural households with food security, allow for cash savings, and in some cases, provide additional incomes; they are also important culturally in many communities (Bagstad *et al.*, 2014). Furthermore, ecosystems provide natural resources such as fruit, fuelwood, medicinal plants and others, commonly referred to as provisioning services (Shackleton *et al.*, 2019), as well as other supporting and cultural services which are important for people (De Groot *et al.*, 2002). However, non- timber forest products are harvested both for subsistence or personal use and for commercial use and can, therefore, provide poor rural households with a means to make an income (Shackleton *et al.*, 2019). Furthermore, these resources act as a safety net or a fallback option for households going through times of high vulnerability, often in response to socio-economic and ecological shocks (Shackleton & Shackleton, 2004). This fall-back option is significant for poor southern African households commonly affected by HIV/AIDS and drought shocks. In South Africa, communal land livelihoods still rely heavily on agriculture, livestock and the collection of non- timber forest products which act as primary livelihood strategies (Shackleton *et al.*, 2019). Subsistence agriculture, particularly maize production, in South Africa is important for local livelihoods within communal lands. It accounts for, on average, between a quarter to half of the household's food requirements (Mensah *et al.,* 2015). Most crop production is for home consumption or supplementing livestock diets, with very few households selling crops. Small amounts of maize or other produce are commonly given away in acknowledgement of kinship and community ties which aids households in building social and cultural assets (McSweeney, 2004). Livestock is also important and contributes to cash income or savings and is culturally significant for local people (Alvarez-Berrios *et al.,* 2015). Similarly, provisioning services in the form of non- timber forest products contribute an average of 20 % of households' total income in rural communal lands of southern Africa (Cristescu, 2012; Shackleton *et al.*, 2019).

Furthermore, non- timber forest products contribute between 100 and 12000 with an average of around 3500 per household per annum in communal areas (Shackleton, 2019). Ecosystems within communal lands also have significant cultural value (sacred sites), important for local culture and identity and well-being (Armstrong, 2018). Long-standing institutional arrangements, social and cultural norms and practices revolving around communal lands are key for managing local natural resources. They are important for local cultural identity, community cohesion, and social capital and resilience (Cowie *et al*., 2011). This highlights the highly dependent and integrated nature of rural communal livelihoods to land and the services it provides in southern Africa and the potential detrimental impacts of land loss or degradation on people's well-being. Mining is one major change that can affect land-based livelihoods negatively, through land rights and land tenure issues, degradation of the environment, human health challenges, social change and undermining of local institutions and practices, often leading to local conflicts (Hilson, 2009; Simon *et al.,* 2004; Li *et al.,* 2018). Furthermore, mines are increasingly mechanizing, reducing the demand for unskilled labour, thus leading to less local benefit to surrounding communities (TEEB, 2010; Bagstad *et al.*, 2018). Due to these negative effects, it is crucial that local people are properly compensated for their losses and that corporate social responsibility (CSR) is adequately implemented to ensure that it contributes positively to local livelihoods and development (Hussain, 2013).

This study assesses how the loss of communal land due to opencast mining has affected villagers' livelihoods in the Limpopo Province, South Africa. This is done by comparing a village that lost access to land and an adjacent village that did not. Based on the findings key, research and policy implications are highlighted to help mitigate harm to local communities impacted by mining.

2.22 Impact of Mining on Ecosystem Services

Mining activities throughout my life, from exploration and development to post-closure, impact social and environmental systems, including ecosystem services that contribute to human well-being (Crossman *et al.,* 2013; MEA, 2005). Although growing recognition of the value of ecosystem services and global efforts to conserve and manage them (Costanza *et al.,* 2014), the supply of many ecosystems service is declining (Creek, 2016; MEA, 2005) while demand is increasing due to population growth and economic development (Crossman *et al.,* 2013; MEA, 2005). As a result, managing threats to ecosystem services is increasingly included in mining industry performance standards (Hussain, 2013). Maintaining human wellbeing and the benefits of ecosystem services to people requires a comprehensive assessment of threats posed by mining activities. Current literature emphasizes a strong focus on the environmental and social impacts of mining, often due to land degradation (Sumarga, 2020), biodiversity loss (Hein *et al.,* 2018) and livelihood displacement (Hu *et al.,* 2014). While literature on the impacts to ecosystem services as a result of mining is emerging, little assessment on its remobilization after some time has been performed. The thesis section reviewed the impacts of mining on ecosystem services, a specific type of mining termed '*galamsey*' in Ghana or illegal mining. The section focuses on provisioning ecosystem services threats and illegal mining activity impacts on a global scale. Understanding the effects of mining on ecosystem services requires identifying and conceptualizing the complete ecosystem services chain, including four key components – supply, demand, flow and benefits (Jiang, 2019). Extracting mineral resources results in removing or modifying areas of natural ecosystems (Creek, 2016), affecting their capacity to supply ecosystem services.

The supply of ecosystem services is biophysical conditions and processes derived from natural capital to benefit society, irrespective of being realized or used by society (Haase *et al.*, 2018). Mining activities also can interact with human and social capital, which can impact the demand for ES by society (Lei *et al.*, 2018). For society to receive these benefits, there must be an interaction between people and ecosystems – i.e., an ecosystem services flow (Mitchell *et al.*, 2017). This interaction can be spatial or non-spatial, connecting areas supplying ecosystem services with people who demand them and resulting in the movement of people, species or matter across a landscape (Mitchell *et al.*, 2017). Ecosystem services flow can be affected by mediating factors, such as manufactured capital (building fences around a mining lease), which ultimately affect human access to the benefits of ecosystem services. The modification of natural areas resulting from mining activities can potentially impact each of these four components differently. It is critical to consider the drivers of ecosystem services change (through specific mining activities), which ES are impacted by these changes to better comprehend the impacts mining may have on people's wellbeing. The severity and distribution of impacts to ecosystem services are dynamic and depend on my type and stage.

Furthermore, damage to ecosystem services over the mine life is not limited to the grounds of a mine site but can extend spatially and temporally across the landscape (Strauss., 2017). External but related drivers of land-use change, such as associated railroads and roads constructed to facilitate mining operations, also have the potential to threaten ecosystem services supply and delivery through landscape fragmentation, biodiversity loss and shifts in ecosystem function (Fisher *et al*., 2017). This makes it necessary to identify and manage these diverse impacts and alter ecosystem services between individual mine sites. Just as mining is dynamic land use, the supply and demand for ecosystem services may vary across landscapes and social circumstances. Mining operations may have different impacts on different ecosystem services (and their human beneficiaries) at different locations.

The surrounding landscape may exhibit various categories of ecosystem services - provisioning, regulating, supporting and cultural services (based on TEEB classification complete definitions see Supplementary Information). Clear identification of the beneficiaries of ecosystem services impacted by mining operations and engaging with local stakeholders to determine how people benefit from their surrounding environment and ensure that all ecosystem services desired by individuals, particularly cultural services, which are often neglected, are managed (Leimona, 2015). Understanding the preferences of beneficiaries of ecosystem services in mining landscapes is crucial to ensure that mining operations can prevent, minimize or mitigate against any damages to ecosystem services that may arise across the life of a mine. This is particularly important for communities and people, such as those traditionally marginalized, who are dependent on particular ecosystem services for their wellbeing (Liiri *et al.,* 2018).

2.23 Impact of Illegal Mining Activity on Ecosystem Services in Ghana

Tropical forest ecosystems worldwide are being wiped out at a rate of 25 million acres per year (Bagstad *et al*., 2016). While agricultural activities and wood extraction are identified as significant drivers of deforestation and forest degradation in terms of spatial coverage (Lamarque *et al.,* 2017), degradation caused by mining tends to have long-term adverse effects on flora and fauna (Cristescu *et al.*, 2012). This is often due to the dumping of toxic chemicals and the severe mutilation of the earth's crust (Lei *et al.,* 2018), the combined effects of which inhibit vegetation growth for a long time. Moreover, Alvarez-Berríos and Aide (2015) identified mining as an activity that causes significant change to the environment but is often ignored in deforestation analysis. It mainly covers small areas compared to agriculture or wood extraction activities. The rise in demand and prices of gold in the last two decades triggered a wave of intense mining activities worldwide (World Gold Council, 2012).

Small-scale mining activities were still being carried out by illegal miners (Creek, 2016; Alvarez-Berríos & Aide, 2015), particularly in developing countries where regulatory capacities and institutions are weak. The small-scale mining sector in Ghana contributes to job creation for people in rural communities due to the lack of good-paying alternative jobs (Hilson & Banchirigah, 2009; Amponsah & Dartey-Baah, 2017). About 85% of the estimated one million people who are directly or indirectly employed in the small-scale mining sector are identified as illegal because they operate without a license (Akabzaa *et al.,* 2007; Ofosu-Mensah, 2010); a phenomenon popularly referred to as '*galamsey*' in Ghana. The havoc caused by '*galamsey*' activities includes destroying forest cover and soils by introducing toxic waste into soil and water bodies that often lead to health problems (Opoku-Ware, 2010). Furthermore, after mining, the restoration of mined areas is necessary to ensure that disturbed lands are returned to environmental conditions suitable for recommencement of one-time or new use (Tetteh, 2010).

Fundamentally, restoring mined sites aims to re-establish vegetal cover, stabilize the soil and water conditions, and bring back ecosystem goods and services (Asiedu, 2013). The

Minerals and Mining Act 2006 (Act 703) of Ghana requires all licensed operators to secure environmental impact assessment (EIA), which specifies the environmental safety for any intended mining projects in Ghana. The EIA should be accompanied by a land reclamation plan which must indicate, among others, how topsoil will be preserved, slopes will be stabilized and restored, progressive reclamation will be carried out, and how revegetation will be affected (Aseidu, 2013). Despite these legal items for protecting the environment, illegal mining and non-compliance remain the cause of mining-related environmental degradation in Ghana. Even though the extent of environmental degradation caused by mining in Ghana is well documented (Aryee *et al.,* 2003; Armah *et al.,* 2011; Armah *et al.,* 2013; Mensah *et al.,* 2015), little research has gone into looking at solutions to mining-imposed environmental problems such as chemical-laden effluent usually discharged by mining companies and chemical remobilization after. For instance, several years.

Again, Aseidu (2013) looked at reclamation of small-scale surface-mined lands in Ghana, focusing on the restoration process, methods and costs. The study seeks to broaden the horizon of knowledge on the subject matter by looking at how local communities will accept the challenge and responsibility of maintaining degraded landscapes as de facto owners and prime beneficiaries of natural resources within the landscapes. The feasibility (likely participation) of the concept of payment for ecosystem services (PES), a market-based compensatory program aimed at reducing the market imperfection brought by positive externalities associated with non-market ecosystem services (Engel *et al.,* 2008; Obeng *et al.,* 2018) is explored. PES programs encourage participation by providing monetary compensation to owners or managers for behaviours that protect and enhance the flow and quality of non-market ecosystem services and, ultimately, well-being (Leimona *et al.,* 2015; Wunder, 2015; Obeng *et al.,* 2018). Specifically, the study assessed the importance that mining communities place on forest ecosystem services and determined the perception and attitudes towards the impact of '*galamsey*' activities on forest ecosystem services at the community level. It further assessed the factors influencing communities willing to participate in restoration activities for improved ecosystem services within a PES framework. However, people are motivated by personal values to cherish the natural environment. Those who attach much importance to non-market ecosystem services are likely to subscribe to a PES scheme to restore degraded lands. Also, we expected people involved in illegal mining activities to show less likeliness to subscribe to a PES scheme for the restoration of degraded lands and demographic factors (age, gender, family size, education, residential status, income level) not to affect likeliness to subscribe to a degraded-land restoration PES scheme (Bagstad *et al.,* 2018).

2.24 Livelihood

Livelihoods are how people sustain their income. They result from how and why people organize themselves to use technology, labour, power, knowledge and social relationships to shape the environment to better meet their needs (Mitchell, 2017). People's livelihoods can be defined as "the skills, resources (physical and social) and activities necessary for their way of life" (Chambers & Conway, 2017).

In the last decade, the study of ecosystem services and resources has become an important research area, with an explosion in many publications on ecosystem services. Humans have always depended on the biosphere and its ecosystems to enjoy the services derived from various ecological processes. This explains why ecosystem services affect human well-being and are of high value to society (Fisher *et al.,* 2017).

Thus, people are an integral part of ecosystems and benefit more from ecosystem services. The concept of ecosystem services is a basic model for linking ecosystem functioning and human well-being. It is essential to understand this link in the broader context of decision-making. However, people, who are protected from the environment by cultural and technological developments and advances, ultimately depend entirely on ecosystem service flows. For more effective management, the link between society and ecosystem change needs to be emphasized, including indirect drivers of ecosystem change such as demographic and cultural factors (Derissen *et al.*, 2013).

Livelihood also means, activities, entitlements and assets by which people make a living, which is immediate and continuous. It is also a framework that seeks to build the capacity of people to continuously make a living and improve their quality of life without jeopardizing the livelihood option of others, either now or in the future by copying and adaptive strategies (Aubynn, 2016; Chirwa *et al.*, 2008). Moreover, Chambers and Conway (2017) also asserted that "A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when "it can cope with and recover from stresses and shocks." To function as an individual, therefore, demands some basic requirements, Moreover, the various contexts within which most people in developing countries earn their means of livelihood render them more vulnerable. Such contexts include economic, social and environmental factors. A farmer may work extremely hard to earn his livelihood but can lose it to the rigours of the weather such as drought and flooding. The market under which the poor person produces can be highly unpredictable and can offer very low prices to the poor person's produce and even push him into debt. This is especially for economies that allow the free market to allocate resources and this is why the Department for International Development (DFID) sustainable livelihood approach should have emphasized the component of market influence.

2.24.1 Sustainable Livelihood

The term 'sustainable livelihood' came to prominence as a development concept in the early 1990s, drawing on advances in the understanding of famine and food insecurity during the 1980s (Cowie *et al.,* 2011). The December 2000 DFID conference in Kathmandu sought to address striking issues of livelihood on the six main principles of the sustainable livelihoods approach people-cantered, responsive and participatory, multi-level, conducted in partnership, sustainable and dynamic linked as a framework and conceptual tool for understanding the context in which people make a living (Ellis, 2000).

2.24.2 Conceptual Framework on Livelihood

The sustainable livelihoods framework was adopted in this study. It is a tool for improving the general understanding of livelihoods of the poor and the vulnerable in society. The idea of sustainable livelihoods was first introduced by the Brundtland Commission on Environment and Development to link both socio-economic and ecological factors together for policy implementation. The United Nations Conference on Environment (UNCEP) in 1992 adopted and expanded the concept and advocated for the achievement of sustainable livelihoods as a broad goal for poverty eradication (Armstrong, 2008). It was later developed by the Sustainable Rural Livelihoods Advisory Committee of the United Kingdom after several months of deliberations. The committee relied on an earlier work of the Institute of Development Studies (Sumarga *et al.*, 2020). In a Natural Resource Advisors conference organized by the UK's Department for International Development (DFID) in 1999 which discussed early experience with implementing sustainable livelihoods approaches to poverty elimination, four agencies; DFID, Oxfam, CARE and UNDP discussed early experience with implementing sustainable livelihoods approaches to poverty elimination.

According to Armstrong (2008) one of the theorists that developed the framework, researchers and policymakers can adopt the framework to suit a particular study or circumstance. With this permission, the researcher adopted the conceptual sustainable livelihood form (Fisher *et al.*, 2017) approaches to examine and explains the impact of illegal mining activities in the environment. The framework shows the key factors that affect people's livelihood and typical relationships that exist between them. It can be used in both planning new development activities and assessing the contribution to livelihood sustainability made by existing activities. At the conference, the livelihood definition by Ellis (2000) was the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable when it can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the long and short term (Chambers & Conway, 2017). However, Hilson (2016) identified different types of livelihood activities namely; livelihood promotion, livelihood protection and livelihood provisioning.

2.24.3 Livelihood Promotion

This refers to the strategies for improving the resilience of households, for example through programs which focus on savings and credit, crop diversification and marketing, reproductive health, institutional development, personal empowerment or community involvement in service delivery activities. Most livelihood promotion activities are long term development projects that increasingly involve participatory methodologies and an empowerment philosophy (Nyame & Danso, 2006).

2.24.4 Livelihood Protection

This aims at helping to prevent a decline in household livelihood security, for example, programs which focus on early warning systems, cash or food for work, seeds and tools, health education and flood prevention. Members in a community may be informed in advance by specialists about the outbreak of diseases such as the Saint Paul Wilt disease which affects coconut plantation, the armyworm that attacks farm products and completely destroys them. Other examples that fall within this category are the announcement given to community members about the outbreak of diseases like cholera, project construction, chicken pox and measles (Yaro, 2010).

2.24.5 Livelihood Assets

The Sustainable Livelihood (SL) is centered on five major categories of livelihood assets represented by a pentagon to show interconnection and to mean also that livelihoods depend on a combination of assets of different kinds. It is important for analysts to find out how people get access to these assets; physical, human, financial, natural and social capitals (Ayanu *et al.,* 2012).

2.24.5.1 Natural Capital

This is made up of the natural resource stocks from which resource flows which are useful for livelihoods or survival such as land, water, wildlife, biodiversity and environmental resources are derived (Haase *et al.,* 2018).

2.24.5.2 Human Capital

Human capital refers to the skills, educational qualification and knowledge, ability to work and good health of an individual or a group deemed necessary for use to pursue different livelihood strategies. Households with high-quality human capital can use it to improve the economy when a natural resource is discovered in an area as reported by the (Heubach *et al*., 2011).

2.24.5.3 Financial Capital

Financial capital refers to the financial resources which are available to people to access credit facilities, good pension or even regular remittances which give access to different livelihoods options. Access to credit facilities, livestock rearing and saving also forms part of the financial capital. The ability to generate Financial Capital is also dependent on wages or proceeds of work and living costs in a household's ability to develop a livelihood strategy. In rural communities, income is usually earned by subsistence. Rural communities also need financial resources for development (Ellis, 2000).

2.24.5.4 Social Capital

This refers to the social networks or resources such as membership to a group, relationships of trust and access to broader institutions, interactions among individuals and households from which people derive their livelihood. As a result of the influx of people to mining communities in search of employment (Owusu *et al.,* 2012), and the pressure on infrastructure, landlords increase the cost of renting forcing those local residences who cannot afford such high cost to relocate to surrounding villages (Tetteh, 2010).

This also includes the migration of people from one community or area to the other. The influx of foreigners and workers from different backgrounds can have health consequences on oil producing countries (Serfor-Armah *et al.,* 2006) and it also disrupts the social network of community members thereby affecting the socio-cultural patterns of the community. Poverty and economic hardship lure some ladies into prostitution which can result in being infected with the HIV/AIDS virus (Aryee *et al.,* 2017).

2.24.5.5 Physical capital

Physical capital is the basic infrastructure such as transport, shelter, water, energy and communications and the assets like farming equipment and sewing machine tools and machines for the cultivation of the land for human survival. The influx of people in oil extracting communities also puts pressure on communities. This makes life unbearable for community members who cannot afford it. Some are even forcefully evacuated to new locations (Ellis, 2000).

2.25 Geographical Information System, Remote Sensing and Land Cover Change Detection.

Remote sensing and Geographic Information Systems (GIS) have become powerful tools for deriving accurate and timely information on the spatial distribution of land use/land cover change over large areas. Remote sensing imagery and image processing techniques also offer possible solutions to some of the problems of generating and updating shoreline maps (Prakasam, 2010). High resolution imagery from satellites such as IKONOS and Quickbird has been available for several years and has proven its usefulness in mapping and monitoring remote areas and developing countries. Geographic Information Systems (GIS) are an important tool for detecting land use change and play a role in improving the environment. Change detection involves the use of multi-date (time series) aerial photographs, topographic maps or satellite images of the study area, from which land use maps can be generated through visual interpretation or digital image processing (Prakasam, 2010).

Remote sensing is widely used to observe land use and land cover change and dynamics (LULC). It offers multiple advantages in LULC research and allows assessment of inaccessible locations such as very steep mountains, determination of the most recent land cover and investigation of historical LULC. To more effectively detect changes in land cover, remote sensing is often coupled with geographic information systems (GIS) technology. GIS is a technology used to create, store, analyze and manage data related to its attributes GIS is a technology used to create, store, analyze and manage spatial and temporal data related to its attributes (Longley, 2005). Both technologies provide the ability to map land use characteristics and dynamics by combining existing remote sensing data with historical maps in different contexts, such as tropical forests, urban areas and coastal zones, as well as different land transformations such as deforestation, urban development and desertification (Forest Partnership Facility, 2014). Land use and land cover (LULC) changes, especially those caused by human activities, is the most important component of global environmental change with impacts possibly greater than the other global changes (Jensen, 2005). Since the 1990s, global, regional, and local studies of LULC have greatly increased due to advances in observation and detection methods including remote sensing and related techniques.

The issue of land use changes has been considered in many international and interdisciplinary researches such as remote sensing, political ecology, and biogeography (Jensen, 2005; Kachhwala, 2015). Recent global data indicate that fifty percent of the ice-free terrestrial surface has been changed to other land uses; approximately forty percent of land is transformed to agricultural lands (Dwivedi *et al.*, 2005). Land use is generating worldwide interest as changes in land use are at a rapid rate and it is estimated by the Longley (2005) that by the year 2025, 80% of the world's population will live in cities. Most major metropolitan areas face the growing problems of land development; residential and commercial development is replacing undeveloped land at an unprecedented rate. Information on land in relation to how it is being used as well as changes in such land use has become a prime pre-requisite for the growth and development of any nation (Dwivedi *et al.*, 2005).

2.25.1 Land Use and Land Cover Change in Mining Landscapes

Mining areas are hotspots for the exploration of minerals which are important. However, these areas activities subsequently deteriorate the natural environment (Sun, *et al.,* 2018). Mining activities significantly damage the ecological environment, such as the landscape, vegetation, and agriculture. It also deposits metal particles into the soil, and can lead to soil erosion and pollution. The surface water, groundwater as well as air are also polluted (Sengupta, 1993). Remote sensing provides convenient conditions for monitoring environmental changes that take place in mining areas (Song *et al.,* 2020). With the further development and numerous applications of remote sensing technologies in recent years, remote sensing has been applied frequently in the monitoring of the ecological environment in mining sites. For example, some researchers have analyzed vegetation and its ecological environment in mining areas using hyperspectral remote sensing which has a higher spectral resolution hence provides detailed information. The result of this study was able to distinguish between stressed and unstressed vegetation within the mining areas (Zhang *et al.,* 2014).

In another study, southwest of the Brazilian Amazon state of Rondônia, the researchers made use of GIS and remote sensing to assess the impact of mining activities on environmental protected areas. Remote sensing imageries, Landsat 8 OLI imageries, were used to map the diverse land covers in the region and also evaluated the corresponding impact of mining activities. The research was able to assess that 26 km² of mining areas were within protected areas (Rudke *et al.*, 2020). In Song *et al.*, (2020) study, the boundaries of mining areas were identified and the land use or land cover changes in mining areas were monitored using remote sensing. Remote sensing was used in monitoring the biodiversity, landscape structure, vegetation change, soil environment, surface runoff conditions, and the atmospheric environment in mining areas (Turner *et al*., 2007).

2.25.2 Land Use and Land Cover Change Analysis

The land cover according to Prakasam (2010), is the most important property of the earth's surface which is defined by the physical condition and biotic component. Land use, on the other hand, is the modification of land cover as per human needs and actions. These modifications of the land cover bring about land use and land cover (LULC) changes. Land cover is influenced by both anthropogenic and natural changes which affect what use land is put to. It is also a matter of historical process as to how land is used by people (Tewabe & Fentahun, 2020). Therefore, there is the need to have prior knowledge about the LULC of an area to be able to detect changes that occur on the land over time.

The change detection technique is very valuable in many applications such as urban expansion and other fields that relate to LULC changes (Hegazy & Kaloop, 2015; Solaimani *et al.,* 2010). Using remote sensing images to detect land use and land cover changes detection have been widely applied in the field of research for monitoring and protecting the environment (Zhang *et al.,* 2014). Through the use of remotely sensed data studies on land, cover can be done in less time, cost-efficient and produces better results (Kachhwala, 2015). Combining remote sensing with GIS tends to provide a suitable platform for data analysis, updating and retrieval (Chilar, 2000). Understanding these changes is also essential for taking the appropriate measures and gives room for decision improvement (Rawat & Kumar, 2015). Classification of LULC is of importance because the information about LULC is needed in planning and to be able to deal with problems that may occur as a result of changes occurring on the land and in relation to this study the changes that ecological footprint of artisanal and small-scale gold mining has on the environment.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Overview

This chapter presents the research methods used to collect data for the study. These are the approach, the design, population size, sample size, target and study population, data collection instruments, data handling, analysis and interpretation. The mixed method approach and multistage sampling technique (Kothari, 2004) supplemented by household questionnaires, in-depth interviews and Focus Group Discussions were used to collect the data for the study.

3.2 Study Area

3.2.1 Mpohor Wassa East District

3.2.1.1 Location of the District

This district was selected for the study because in literature, it was found that numerous studies have been done on ASGM activities in Ghana, especially on the socio-economic and environmental impact, but there is no research that specifically assesses or addresses the issue of ecological footprint of artisanal and small-scale gold mining on soil and provisioning ecosystem services in this district. Mpohor Wassa East District is located at the South-Eastern end of the Western Region. It is bound to the North East and South East by the Twifo Hemang Lower Denkyira and Komenda Edina Eguafo Abrem Districts in the Central Region, in the west and northwest by the Tarkwa Nsuaem Municipality and Prestea Huni-Valley District and in the south by Sekondi-Takoradi Metropolis, Shama and Ahanta West Districts (Figure 1). The district falls within the tropical climate zone. The mean annual rainfall is 1500mm and ranges from 1300 to 2000mm, with an average annual temperature of 30^{0}C. The landscape is generally undulating with an average height of about 70 m (above mean sea level). The highest elevation ranges between 150 and 200 m above sea level (GSS, 2010). The drainage pattern is largely dendritic and there are medium and small rivers and streams distributed throughout the district most of which originate from the Akwapim Ranges and flow southwards towards the coast. The main rivers are the Pra, Subri, Butre, Brempong, Suhyen, Abetumaso, Hwini and Tipae.

3.2.1.2 Vegetation and Agriculture

The vegetation cover in the area is mainly tropical rainforest interspersed with shrubs. There are two large forest reserves namely, Subri River Forest Reserve which occupies 375 sq km and the Pra Suhyen Forest Reserve with 204 sq km. Just over half (64.0%) of the households in this district are engaged in agriculture. They are engaged in agriculture. Cultivation of crops is the main agricultural activity of more than 9 out of 10 households (95.6%). (95.4%) of the households are engaged in agriculture (Figure 1). Livestock rearing is 39.2% and plantation is 0.4%. In rural areas more than 7 out of 10 households (72.0%) are engaged in agriculture, while in urban areas 40.9% are. Poultry (chickens - 61.5%) are the main animals kept in the district.

3.2.1.3 Spatial Distribution and Occupation

According to the 2000 population census, the population of the district in 1970 was 27,573 and 55,801 in 1984. The total population in 2000 was 122,595 and estimated to be 163,512 in 2009 with an inter-censual growth rate of 3.2 percent, which is the same as the regional growth rate. Males form 52.5 percent of the total population (85,844) as against 47.5 percent (77,668) for females due to the mining and agricultural activities in the district. Subsistence and large-scale agriculture employ 71.5% of the workforce according to the 2000 population and housing census. The major staple food crops produced in the district include cassava, plantain, maize, cocoyam and vegetables. About 98 percent of the farmers rely on traditional methods of farming using slash and burn, simple farm tools such as hoe, cutlass and relying on natural climate conditions for cropping. The use of tractors and other heavy machinery is limited to the oil palm plantation companies. The predominant cash crops are cocoa, oil palm and coffee in some cases. Cocoa is usually cultivated in small to medium sized plantations, mostly by settler farmers while oil palm is cultivated on a large-scale by Benso Oil Palm Plantations (BOPP), NORPALM and Ayiem Oil Mills. The Ghana Rubber Estates Ltd (GREL) is promoting and encouraging the cultivation of rubber in the district and a number of out-grower farmers have cultivated rubber on medium and small-scale plantations in various parts of the district (Figure 1).

Agro-processing Company which is located in Ayiem, is involved in vegetable processing. Non-traditional crops like black pepper and pineapple which are cultivated in the district have high potential of becoming export crops. Other non-traditional crops with potential for high production are citrus, cashew and banana. The main staple food crops widely cultivated in the district are maize, rice, cowpea, cassava, cocoyam, sweet potatoes, yam and plantain. Local vegetables such as pepper, garden eggs, okra, tomatoes and other exotic types like cabbage are grown on a comparatively smaller scale. Livestock production forms an important agricultural activity in the district though not on a large scale as compared to crop production. It involves predominantly sheep and goat, pigs (mainly improved breeds), poultry (local and improved breeds) and few cattle (Asante *et al.,* 2017).

Some non-traditional stock such as grass-cutter, rabbits and bees are reared/kept on a comparatively small-scale by farmers and training is organized by some NGOs who also provide breeding stock and cages to farmers after the training. Important market centers in the district are located in Daboase, Mpohor, Sekyere Krobo, Senchem, Ateiku, Krofof rom, Adum Banso, Edwinase, New Subri, Atobasie, Ebukrom and Apeasuman. Very few of these market centers have well- developed structures. Large and medium scale Agricultural enterprises operating in the district include Benso Oil Palm Plantation (BOPP) in Adum Banso, Norpalm Ghana Limited in Mpohor, Golden Star Wassa Oil Palm Plantation in Ateiku, Ayiem Oil Mills in Ayiem and West- West Agro-processing factory in Ayiem. Out-grower farmer's schemes have been established by the large-scale agricultural enterprises for farmers in various areas. Through these schemes farmers are assisted with special packages including inputs, credit and capacity building. The Ghana Rubber Estates Limited (GREL) has also established a similar scheme for out-grower farmers involved in rubber cultivation. A number of micro- enterprises for agro-processing that are located in various parts of the districts include processing facilities for oil palm in Adum Banso, Mpeasem, Ateiku, Aboaboso, Atobiase and Ayiem and facilities for cassava processing in Kwabaa, Awiadaso, Akotosu, Adiembra and Abroadzewurum (GSS, 2010).

3.2.1.4 Climate

The district falls within the tropical climate zone. The average annual rainfall is 1500 mm and varies from 1300 to 2000 mm. The wet season in the district is between March and July while November to January is dry. In general, the rainfall pattern favours agricultural activities (GSS, 2010).

3.2.1.5 Relief and drainage

The district is located in the low-lying areas of the country, with most parts below 150 meters above sea level. The landscape is generally undulating with an average height of about 70 metres. The maximum height varies between 150 and 200 metres above sea level.

The drainage pattern of the Mpohor district is largely dendritic. There are a number of rivers and streams in the district (Subri, Butre and Hwini) (GSS, 2010).

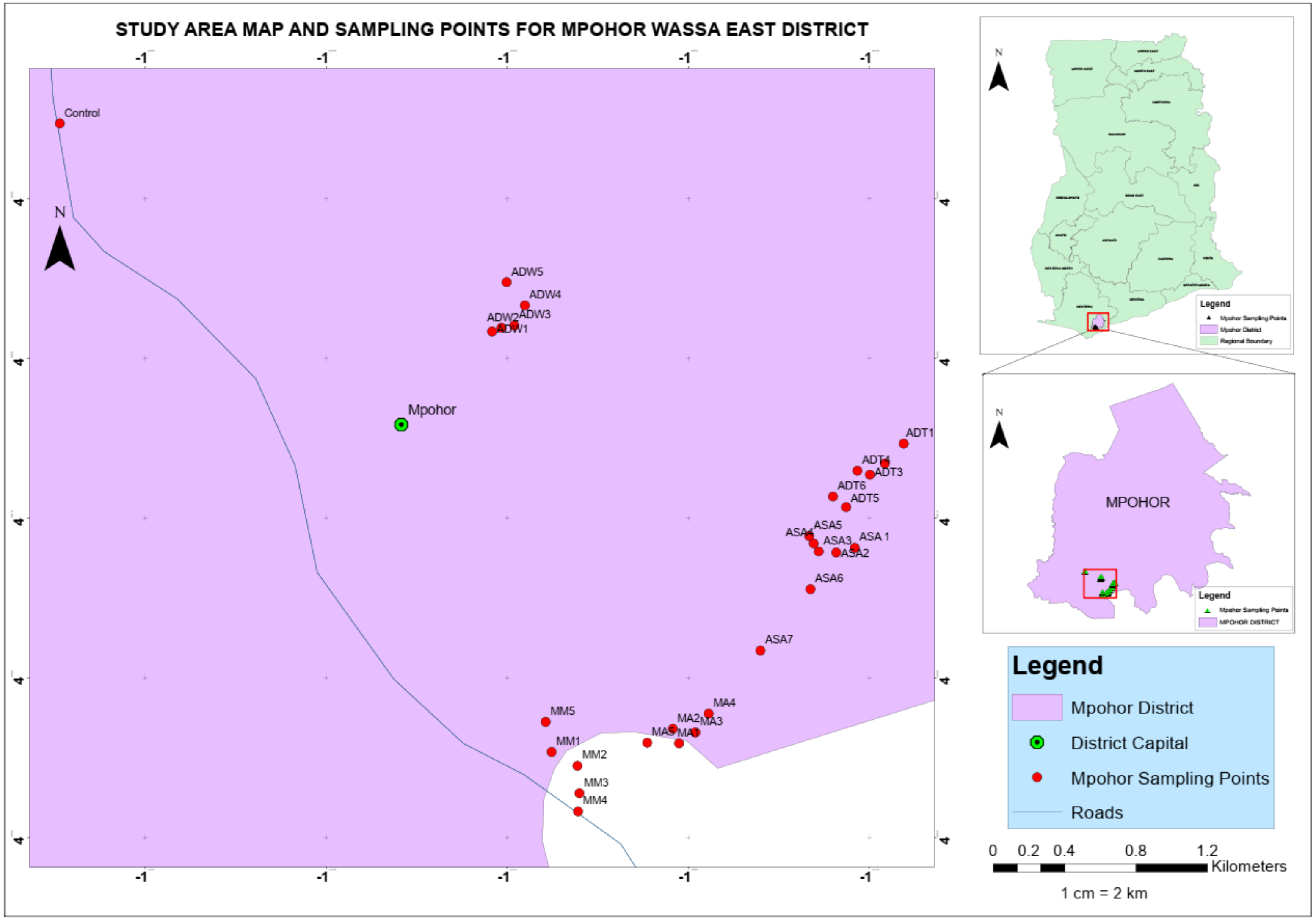

Figure 1: Study Area and Sampling Point Map of Mpohor Wassa East District

3.2.2 Amansie West District (Ashanti Region)

3.2.2.1 Location and Size of the District

This district was selected because in literature, it was found that numerous studies have been done on ASGM activities in Ghana, especially on the socio-economic and environmental impact, but there is no research that specifically assess or address the issue of ecological footprint of artisanal and small-scale mining on soil and provisioning ecosystem services in this district. Amansie West District was separated from the former Amansie District in 1988. It shares a common boundary with eight other districts, Atwima Nuwabiagya and Atwima Mponua, to the west, Bekwai Municipality, Amansie Central and Obuasi Municipality to the east, Atwima Kwawhoma to the north, Upper Denkyira and Bibiani to the south (Figure 2) This district serves as the regional boundary between the Ashanti Region on the one hand and the Central and Western Regions on the other. Specifically, it is located at latitudes 6.05°W, 6.35°N, 1.40°S and 2.35°N. It lies between latitudes 1.40°S and 2.05°E. The Amansie West District is one of the largest districts in the Ashanti Region, covering an area of about 1,364 square kilometers and accounting for about 5.4% of the total area of the Ashanti Region Manso Nkwanta is the capital of the district and is located about 65 kilometers from Kumasi. Other major settlements include Abole, Agroisum, Awerewa, Ankamu, Antakrom, Aponapong, Datano, Esase, Esowin, Kenyago, Mpatuam, Moseaso, Nipankieremia, Odaho, Pakii No.1 and No.2 and Watreso. This district is the gateway to Ashanti from the western and central regions. As such, it has great potential for the promotion of the hospitality industry, including hotels, restaurants and handicrafts. Large areas of land are planted to rice, citronella, cocoa, orange and oil palm plantations, contributing to the local agricultural-based industry (Hilson *et al.*, 2016).

3.2.2.2 Relief and Drainage

The terrain of the district is generally hilly and lies at an altitude of 210 metres above sea level (Figure 2). The most striking feature is the hilly area in the north-western part of the district, especially around Manso-Nkwanta and Arbor. The rivers Offin and Oda and their tributaries, such as the Jeni, Pumpim and Emuna, flow through the northern part of the district. The drainage pattern of the district allows for irrigated rice cultivation, vegetable cultivation and fish farming.

3.2.2.3 Climatic Condition

The climate is humid and semi-equatorial. It has a dual maximum rainfall regime, with the main rainy season occurring between March and July. The minor rainy season occurs between September and November. The average annual rainfall varies between 855 mm and 1500 mm. The average number of rainy days during the year varies between 110 and 120 days. December to March is usually dry and is characterized by high temperatures, humidity/early morning fog and cold weather conditions. Temperatures are generally high throughout the year, with monthly averages of around 27ºC. The rainy season is characterized by high humidity. However, records from December to February show very low humidity. These climatic conditions are suitable for growing commercial and food crops such as cocoa, lemongrass, oranges, bananas and vegetables for the agro-based industries in the region and beyond.

However, it should be noted that current trends in climatic conditions in the region are becoming unpredictable due to climate change. However, this has also affected agricultural planning. This situation requires measures to reduce the over-dependence of agricultural production on climate, such as irrigation. The region's climate is humid and semi-equatorial. It has a dual maximum rainfall regime, with the main rainy season occurring between March and July. The minor rainy season occurs between September and November. The average annual rainfall varies between 855 mm and 1500 mm. The average number of rainy days during the year varies between 110 and 120 days. December to March is usually dry and is characterized by high temperatures, humidity/early morning fog and cold weather conditions. Temperatures are generally high throughout the year, with monthly averages of around 27ºC. The rainy season is characterized by high humidity. However, records from December to February show very low humidity. These climatic conditions are suitable for growing commercial and food crops such as cocoa, lemongrass, oranges, bananas and vegetables for the agro-based industries in the region and beyond. However, it should be noted that current trends in climatic conditions in the region are becoming unpredictable due to climate change. However, this has also affected agricultural planning. This situation requires measures to reduce the over-dependence of agricultural production on climate, such as irrigation.

3.2.2.4 Vegetation of the Area

The vegetation of the region is mainly of the rainforest type and has characteristics of a semi-glacial wetland. This makes the land very fertile and suitable for agricultural investment. Food and commercial crops such as cassava, rice, maize, cocoa, cocoa, citrus, palm oil, lemongrass and others are widely grown in the area. As a result of poor practices such as shifting cultivation, the method of curtailment, illegal mining and illegal logging, it was gradually destroyed and replaced by a mosaic of secondary forests. Fortunately for the region, there are four main forest reserves in the area (Figure 2). These are Oda River Forest Reserve, Apanprama Forest Reserve, Jimira Forest Reserve and Gyeni River Forest Reserve.

3.2.2.5 Soil Condition

There are six (6) main soil types in the area. These are the Bekwai-Oda compound association. The constituents of this association occur in a definite topographical sequence. On the summits, upper and middle slopes are found the red, well drained Bekwai series and brown moderately well drained Nzima series. The valley bottoms are occupied by grey poorly drained clays (Oda series). The second soil type is the Ahawam-Kakum-Chichiwere structure. This soil type is reddish brown, deep, well-drained clay to loam. This series may be found in the district's south-western corner, as well as in the Nyamebekyere, Britcherkrom, and Adagya localities (Figure 2).

The third group of soils found in the district is the Mim-Oda compound association. This is slightly different from Bekwai-Oda because of the presence of large amounts of gravel. This soil is found in the southern part of the Datano and Aboaboso areas. The fourth is the Bekwai-Zongo-Oda complex, found primarily in the Esaase's northern region The fifth soil type is the Nyanoo-Tinkong complex. This range is characterized by relatively thin soil on eroded hilltops and slopes. They are found in the Abore's hilly terrain. The sixth type is the Kobeda-Eschiem-Subinso-Oda complex. The distinctive feature of this range is that its use is limited by its shallow depth, which makes it vulnerable to drought. They are found in the northern part of Manso-Nkwanta and in the areas around Essuowin and Bayerebon. The soil types have the potential to support food and cash crops such as cassava, plantain, coca, lemongrass, palm oil, etc. It is no wonder that the region ranks third in cocoa production. However, where soil fertility is low, soil fertility practices and the use of fertilizers are needed to increase and sustain production and productivity.

3.2.2.6 Mineral Deposits

Among the resources found in the area are potentially rich deposits (gold). Areas with such deposits include Bontesso, Jeninso, Mpatum, Esouwen, Tonto Krom and others (Figure 2). A significant area of the district has been acquired by a number of companies and concessions for prospecting have been granted. However, there are still areas in the district with gold deposits that have not yet been acquired. These areas include, in particular, the massive deposits of the Jeni bonte River, estimated to contain approximately 21,361,400 cubic metres and 5,209,866 grams of gold in the Jeni bonte River. In addition to the companies with large concessions in the area, there are other parties interested in mining. There are small mining groups in the area that use very crude methods to extract gold, although a large proportion of young people are involved in their activities. The activities of these different groups are not well regulated or organized and cannot be considered as part of the overall development efforts in the area (Asante *et al.,* 2017).

3.2.2.7 Spatial Distribution

Population and Housing Census has shown that the total population of the district was 108,726. This population is spread over more than three hundred towns, villages and hamlets in the district. The most populous town in the district is Mpatuam, with a population of 5,425. The distribution of the district's population is tilting towards the north-eastern part of the district. These areas include Pakyi No.1, Antoakrom and Esuowin. The population growth in these areas can be attributed to the very good road network. For example, the Kumasi-Obuasi highway passes through Pakyi No. 1 and Pakyi No. 2. These two communities have become dormitory towns, providing accommodation for the Kumasi workforce (GSS, 2010). This situation has provided the conditions for the creation of weekend and night markets to cater for this workforce, in addition to the intervention of real estate developers. The hinterland has been reduced to scattered agricultural villages, some of which are connected to the communities by roads in poor condition. These areas are characterized by migrant farmers working on the farms of the local population. These areas coincide with the food basket of the district. However, some larger communities have emerged in these areas as a result of mining activities (Figure 2). These communities include Daatano, Watereso, Abore, Bonsaaso and Tontokrom. mining activities have attracted the population of these areas. These communities are centers of growth in the surrounding hinterland. The area needs effective and efficient planning to cater for the growing population and to prevent pressure on the few existing facilities.

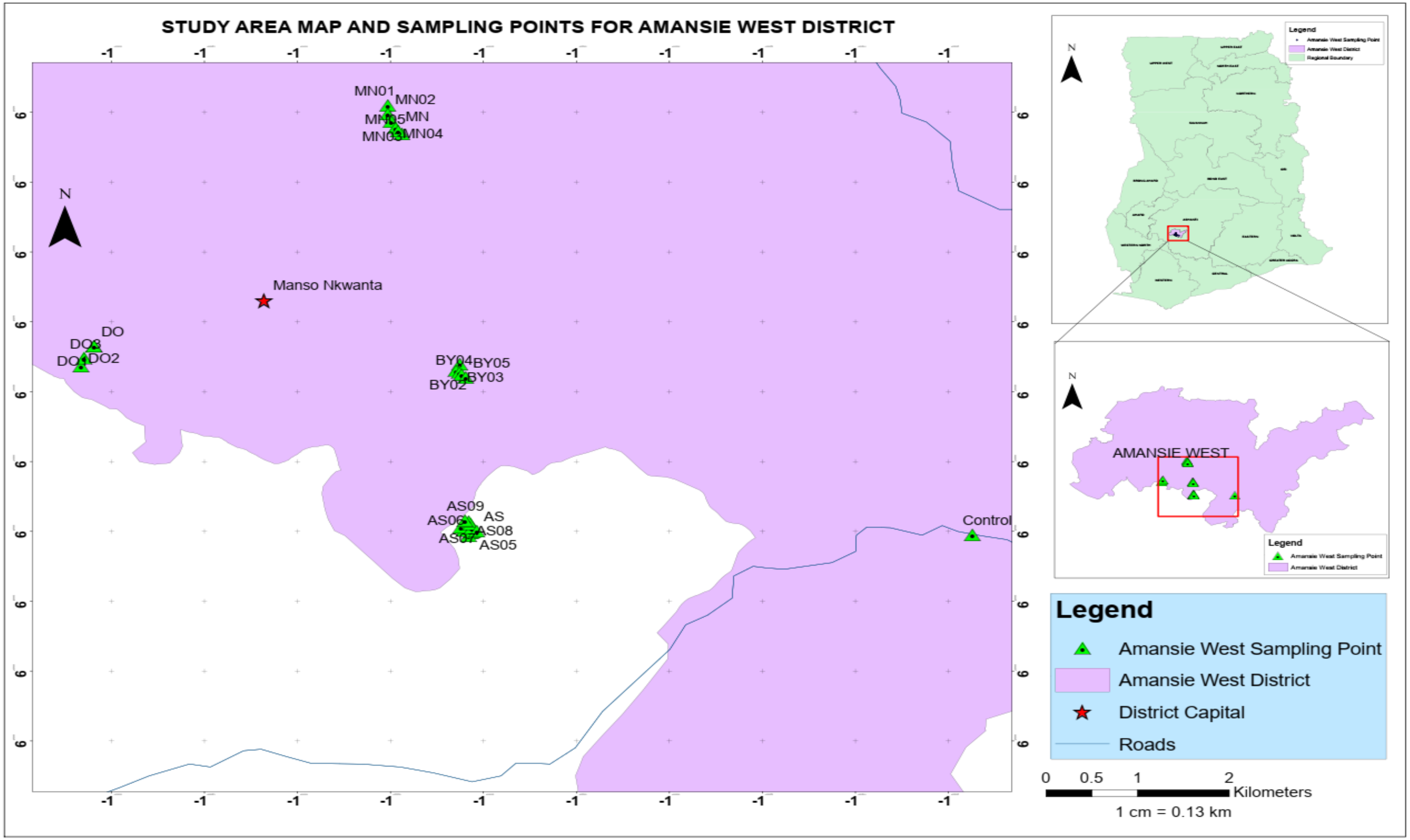

Figure 2: Study area and Sampling points Map of Amansie West District

3.3 Research Approach

The mixed methods approach of combining both qualitative and quantitative methods in a particular study was used as the main research method. The qualitative and quantitative approach was embedded in collecting and analyzing the data. This approach generally uses qualitative and quantitative methods as a means to offset the weakness within one method with the strength of the other (or conversely, the strength of one adds to the strength of the other (Creswell, 2009). Combining the two methods provides better results and understanding of the phenomenon than just relying on one method. Furthermore, Johnson *et al.,* (2007) defined mixed methods research as the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration. The matrix in (Table 3.1) shows the objectives of the study, the methods used and the analytical tool employed.

Table 3.1: Matrix Showing Objectives, Methods Used and the Analytical Tool

Objectives	Methods Used	Analytical tool
1. Determine the concentrations of physico-chemical parameters in soils and water at artisanal and small-scale gold mine sites.	Soil analysis using Atomic Absorption Spectrophotometry (AAS)	Descriptive statistics, Analysis of variance (ANOVA), Pearson's product moment correlation, Principal component analysis (PCA)
2. Assess the hazard rating of heavy metals in soils at artisanal and small-scale gold mine sites.	Chemical extraction of heavy metals using Ammonium Nitrate and Nitric acid.	Regression analysis
3. Explore the impact of small-scale and artisanal gold mining on land use and land cover changes	GIS Mapping	ArcGIS (Geographic information System)
4. To identify and examine the socio-economic and livelihood activities impacted by small-scale and artisanal gold mining	Use of structured questionnaire and key informant interviews	Use of chi-square and regression analysis

Source: Authors Fieldwork, 2020

3.4 Research Design

The study used the concurrent triangulation design, one of the options in mixed method study. The purpose of this design is “to obtain different but complementary data on the same topic” (Morse, 1991) to best understand the research problem. The intent in using this design is to bring together the differing strengths and nonoverlapping weaknesses of quantitative methods with those of qualitative methods. Combining the two methods provides better results and understanding of the phenomenon than just relying on one method.

3.5 Sampling Procedure

The research involved both cluster sampling and purposive sampling. For administrative purposes, the Mpohor Wassa East District was divided into zonal councils. All the communities in the zonal councils that had illegal mining activities within the district were visited. Based on the reconnaissance survey, five (5) communities were purposively selected namely, Asowuo Ayipa (ASA), Adum Tokoro (ADT), Mpohor Adansi (MA), Mpohor Motorway (MM) and Mpohor Adawotwe (ADW). These communities were purposely selected because active illegal mining activities had taken place in those communities. Site evaluation was done and it was observed that the control site was a forested area and had not been cultivated. The control site was selected to eliminate any extraneous factors that could influence the parameters under investigation. At each sampling site in the Mpohor Wassa East District, the area was gridded and divided into various segments. The grid was done by using wooden pegs. Four square pegs were made and a composite sample was taken within each grid. Based on this technique, seven (7) sites were identified at ASA, six (6) at ADT, five (5) at MA, five (5) at MM and five (5) at ADW (Figures 1 and 2).

In each segment soil samples were taken at different positions within the grid at a depth of 15cm with soil auger and put into a cleaned plastic bowl and mixed thoroughly to form a composite sample to represent that particular site. The 15cm depth was taken since most heavy metals have been found to be within the first 15cm of the soil profile.

The auger was cleaned immediately after each sampling point to avoid cross contamination which could influence the results. Furthermore, about 30g of each soil composite sample from each segment was taken and put into a labeled plastic zip lock polythene bag.

A control site was selected in Mpohor Wassa East District where soil samples were picked in triplicates. Together with the soil samples from the other sites, a total of eighty-seven (87) soil samples were collected during the entire study period in the Mpohor Wassa East District. The same sampling procedure was repeated at Amansie West District in the Ashanti Region. Four (4) communities were purposely selected based on active illegal mining activities that had taken place namely; Manso Nkwanta (MN), Domenase (DO), Brofoyedru (BYO), and Asaman (AS). Apparently, nine (9) sites were identified at AS, five (5) at MN, five (5) at BYO, three (3) at DO, and the researcher had access to 3 control sites where control soil samples were taken at Manso. In all, twenty-five (25) soil samples were taken from Amansie West District in triplicates summing up to seventy-five (75) soil samples. Within these two study areas, a total of one hundred and sixty-two (162) soil samples were taken for analysis over a period of three-month.

In water sampling, out of the four (4) communities identified in Amansie West district, one community (BYO) did not have a water body (river, stream, lakes) and so relied on water tanks, a control site was also selected. Water samples were picked in triplicates from the control site and the 3 communities namely DO, AS and MN giving a total of 12 water samples for analysis. The same sampling procedure was repeated in Mpohor Wassa East district, out of the 5 communities identified, one community (MA) was not close to a water body (river, stream, lake) and relied on water tank, a control site was selected and water samples were collected in triplicates from the control and the four sites giving a total of 15 water samples for analysis. In all, a total of twenty-seven (27) water samples were taken and analyzed during the entire study period.

The geographical locations of the sampling sites were determined using a global positioning system (GPS) device (Model, GARMIN etrex 20). Both soil and water samples were taken monthly within a period of three months. The sampling sites with their geographical coordinates are shown in (Appendix C). For the water sampling, polyethylene sample containers of 500ml capacity with stoppers were used for collecting the water samples. The containers were pretreated by washing with acetone to get rid of organic substances such as grease and fat residues. Each bottle was then washed with detergents and finally rinsed with deionized water. The sampling containers were then soaked in 1.0M nitric acid solution for 24 hours. The containers were finally rinsed three times with distilled water before transporting them to the sampling site. At the sampling site, the sampling bottles were rinsed thoroughly with the source water from where the sample was to be collected and the rinsed water was discarded away from the area being sampled. A clean water sampler was introduced into the water and the water was fetched out. At each of the sampling sites, the water sample was collected into a pretreated clean plastic bucket for in-situ measurements. For the in-situ measurement, the water was fetched into a pre-treated plastic bucket and the electrodes of a multiprobe instrument (Horiber H 50 series) was inserted into the water for measurement. The samples that were not measured in-situ were put into an ice chest preserved with ice blocks and transported to the laboratory for analysis. The analysis was done at the Ecological Laboratory of the Institute for Environment and Sanitation Studies of University of Ghana, Legon.

3.6 Parameters Measured and Analytical Procedure

The parameters that were determined are: pH, Electrical conductivity (EC), moisture content, total nitrogen (N), available phosphorus (P), Cation Exchange capacity or Exchangeable bases (Mg, Na, Ca, K), soil particle size distribution (% clay, % silt and % sand), organic carbon/organic matter content of the soils and heavy metals (Fe, Hg, As, Co, Cr, Cu, Ni, Cd, Pb, Zn).

3.6.1 Soil sample Collection

Three soil samples were collected within a particular radius at the sampling sites and were composited. However, 30g of each soil composite sample was taken in triplicates and put into a labeled plastic zip lock polythene bag. In all, a total number of 162 soil samples were analyzed during the entire study period in the two study areas. The samples were transported to Ecological Laboratory of University of Ghana for analysys.

3.6.2 Soil sample preparation and Acid digestion

The soil samples were initially dried, composited and ground, using a pestle and mortar to ensure homogeneity and representativeness. The soil samples were then sieved through 2 mm steel sieves to remove all debris and stones. Approximately 0.4 g (0.24 - 0.26 mg/Kg) of the dry sample was weighed into Teflon tubes and 4 ml of concentrated nitric acid (HNO_3) was added to the Teflon tubes slowly. Nitric acid was used in order to prevent adsorption to the container wall and the capillary tube of the Atomic Absorption Spectrophotometer (AAS). Due to the oxidizing nature of nitric acid, it is also able to convert metal ions in the soil into their nitrate salts which are highly soluble. These were to ensure that all heavy metals in soils are dissolved completely and are able to be assessed by the AAS. The tubes were closed and placed in stainless steel bombs. The bombs were placed on a hot plate and heated at 60^0C for 1 hour by which time all the metal ions would have dissolved into solution. Before opening the bombs, the samples were allowed to cool to room temperature and the pressure released carefully. The samples were transferred into graduated polypropylene tubes. The Teflon tube was rinsed three times with deionized water to ensure that any species that could have formed and been deposited on the inner walls of the tube and the lid were transferred to the polypropylene tube. The sample was diluted to the 50 ml mark with deionized water and mixed thoroughly. The sample was left overnight to allow all the particles to settle before the final analysis. Three (3) blanks were used for high accuracy and precision of analytical measurements and one certified material (triplicate) was carried through the sample procedure. Certified materials are ‘controls or standards used to check the quality of data, to validate analytical measurement methods, or for the calibration of instruments (Atiemo *et al*., 2011).

3.6.3 Soil pH and Electrical conductivity

The pH and EC of the fine earth fraction (< 2 mm) of each air-dried soil sample was determined in a 1:1 soil to distilled water ratio using a microprocessor pH meter. A 10 g soil was weighed into a 50 ml polythene beaker and 10 ml of distilled water added. The soil-distilled water solution was stirred vigorously with a magnetic stirrer for 30 minutes and allowed to stand for one hour for the suspended soil particles to settle. After calibrating the pH meter with standard buffer solution of pH 4.0 and pH 7.0, the electrode was then inserted into the supernatant (the upper part) of the soil solution. Soil pH and conductivity value was then recorded. The test was then duplicated for each sample and the means taken. Readings were recorded after stabilization. The stabilization state was determined when the signal became steady after 2 minutes. The electrode was rinsed with distilled water after each sample measurement before being used for other measurements.

3.6.4 Soil particle size

The particle size analysis of the soil was determined using the Bouyoucos Hydrometer method modified by (Day, 1965). Forty (40) grams of the air-dried and sieved soil sample was weighed into a plastic bottle and 100 ml of 5% Sodium hexametaphosphate $(NaPO_3)_6$ solution was added. The content of the bottle was shaken on a mechanical shaker for 2 hours after which it was transferred into a 1.0 litre measuring cylinder and topped up to the mark with distilled water. The suspension was agitated with a plunger and five minutes after, the density of the suspension (silt and clay) was taken using a hydrometer. The hydrometer reading of the suspension was taken again after eight hours. The contents of the cylinder after the eight-hour reading were emptied onto a 47-μm sieve and effluent discarded. The sand retained on the sieve was washed off into a moisture can and dried at 105 ºC for 24 hours, after which the dry weight of the sand was recorded (Day, 1965; FAO, 2014). Blank sample hydrometer readings at five minutes and five hours were also taken for the 5 % calgon solution topped up to 1.0 L. The particle size distribution was then determined using the formulae below. Temperature of the suspensions at T1 and T2 = 28 °C

$$\% \, clay = \frac{hydrometer \ reading \ at \ 5 \ hrs}{40 \ g} \times 100$$

$$\% \, silt = \frac{hydrometer \ reading \ at \ 5 \ min - \ hydrometer \ reading \ at \ 5hrs}{40 \ g} \times 100$$

$$\% \, sand = \frac{weight \ of \ oven \ dried \ sample}{40 \ g} \times 100$$

Where 40 = weight of soil sample in grams

Temperature effect on density of the soil particles was accounted for using the relation provided by Day (1965): for every 1 °C increase in temperature, above 19.5°C, there is an increase of 0.3 in the density of the particles in suspension.

Hence, increase in weight = (T2 – T1) × 0.3 = (28 – 28) × 0.3 = 0.

Correction for temperature = blank hydrometer reading – increase in weight of particles.

Thus = blank hydrometer reading - 0.

Hence, Correction for temperature = blank hydrometer reading.

With the percentages of sand, silt and clay, each soil sample was assigned a textural class using the United States Department of Agriculture textural triangle. Average proportions of the soil types in each soil core were determined and the corresponding average textural class was determined.

3.6.5 Soil organic carbon/ Organic matter

The organic carbon content of the soil was determined using the wet combustion method of (Walkley & Black, 1934). Approximately 0.5g of soil was sieved and measured into 250 titration flask after which 10ml of 0.167 M potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml of concentrated sulphuric acid (H_2SO_4) were added to it. The flask was then swirled to ensure full contact of the soil with the solution after which the mixture was allowed to stand for 30 minutes. The unreduced $K_2Cr_2O_7$ remaining in solution after the oxidation of the oxidizable organic material in the soil sample was titrated with 0.2 M ferrous ammonium sulphate solution after adding 10ml of orthophosphoric acid and 2ml of barium diphenylamine sulphonate indicator from a dirty brown colour to a bright green end point. A standardization titration of the $K_2Cr_2O_7$ with the ferrous ammonium sulphate was done and the amount of oxidizable organic carbon was then calculated by subtracting the moles of unreduced $K_2Cr_2O_7$ from that of $K_2Cr_2O_7$ present in the standardized titration. The titre value was used to calculate the percent carbon (% C) as:

$$\%OC = \frac{0.3 \times (10 - TN) \times 1.33}{W} \times 100$$

Where %OC = Percent organic carbon

X = Titre value of the ferrous ammonium sulphate

N = Molar mass of the ferrous ammonium sulphate (0.2M)

W = The weight of the soil sample.

0.3= 0.003 x 100

0.003= Milliequivalent weight of carbon (g)

1.33= correction factor (*f*)

The % Organic C was then converted to organic matter using the equation:

% Organic Matter (OM) = % Organic carbon x 1.724.

3.6.6 Total Nitrogen

The Kjeldahl (1983) method was used in the determination of total nitrogen. One (1) gram of soil will be weighed into a Kjeldahl flask and a tablet of a digestion accelerator (selenium catalyst) will be added. This was followed by the addition of 5ml of concentrated H_2SO_4. The mixture was digested until the digest became clear. The test tube was cooled and its content transferred into a 100 ml volumetric flask. Distilled water was added to the digest in the volumetric flask till it got to the 100 ml mark. An aliquot of 5 ml of the digest was taken into a Markham distillation apparatus and 10 ml of 40 % NaOH was added and the mixture distilled. The distillate (liberated ammonia) was collected in 5 ml of 2 % boric acid (H_3BO_3). Three drops of a mixed indicator containing methylene blue and methyl red were added to the solution and then back titrated with 0.01 M HCl from green to reddish end point. The percent N was calculated as follows:

$$\% N = \frac{0.01 \times titre\ value \times 0.014 \times volume\ of\ extract\ \times 100}{Sample\ weight\ (g) \times volume\ of\ aliquot\ (mL)}$$

Where; 0.01 = Molarity of HCl, and 0.014 = Milliequivalent of Nitrogen

3.6.7 Available phosphorus

The available phosphorus in soil samples was determined using 0.03 M ammonium fluoride (NH4F) in acid solution, potassium hydroxide, sulphuric acid and hydrochloric acid (Bray & Kurtz, 1945). A 0.1 g of soil sample was weighed and put into a centrifuge bottle and 50 ml of Bray 1 solution (0.03N NH_4F + 0.025N HCL) was added. The mechanical shaker was used to mix the suspension by shaking for five minutes and left to settle overnight for the suspension. The suspension was then filtered into a 100 ml volumetric flask and made up to the volume. The available phosphorus in the filtrate was determined using molybdate-ascorbic acid method. Five ml of the aliquot was taken into a 50 ml volumetric flask and the pH was adjusted by adding P-nitrophenol indicator and drops of 4M NH_4OH until the colour changed to yellow. Then 40 ml of distilled water was added to dilute the solution. A solution which is made from a mixture of 12 g ammonium, 0.29 g potassium antimony tartrate, 140 ml of concentrated H_2SO_4 and 1.056 g of ascorbic acid (reagent B) was prepared. Eight ml of the reagent B was added to the solution and mixed thoroughly by shaking and allowing it to settle for 15 minutes until the colour changed to different shades of blue depending on the P content in the samples. A blank of was prepared using distilled water and 8 ml of reagent B. A Philips PU 8620 spectrophotometer was used to measure the intensity of the P content at a wavelength of 712 nm this was calculated using:

$$P\left(\frac{mg}{Kg}\right) = \frac{spectrophotometer\ reading\ (mgL^{-1}) \times volume\ of\ extract}{volume\ of\ aliquot \times weight\ of\ soil\ sample}$$

3.6.8 Extraction of Exchangeable bases (Ca, Mg, Na, K)

Ten grams (10 g) of the soil samples (2 mm sieved) was weighed into 100 ml extraction bottles. Hundred (100) ml of 1M ammonium acetate (NH_4OAc) solution buffered at pH 7.0 was added. The bottles were covered and then placed on a reciprocating shaker and shaken for 1 hour at 180 strokes per min. The soil suspension was then decanted and filtered. The filtrates were used for the determination of Ca, Mg, K and Na however, 5 ml aliquot of the filtrates was pipetted into 50 ml volumetric flask and made up to the mark with deionized water. The Perkin Elmer atomic absorption spectrometer (Analyst 800) was calibrated with the appropriate standards for Ca, Mg and Na respectively and the absorbance for each element in the filtrate determined. Exchangeable bases were calculated as below:

$$Ca\ (cmol_cKg^{-1}) = \frac{R\ \times Vol.of\ extract \times 10^3\ (g) \times 10^2 (cmol) \times E}{Weight\ of\ soil \times 10^6\ (\mu g) \times 40}$$

Where 40 = Atomic mass of Ca and

R = AAS (Atomic absorption spectroscopy) reading in mg L^{-1}

E = Charge of Ca

$$Mg\ (cmol_cKg^{-1}) = \frac{R\ \times Vol.of\ extract \times 10^3 (g) \times 10^2 (cmol) \times E}{Weight\ of\ soil \times 10^6 (\mu g) \times 24}$$

Where 24 = Atomic mass of Mg

R = AAS (Atomic absorption spectroscopy) reading in mg L^{-1}

E = Charge of Mg

$$Na\ (cmol_cKg^{-1}) = \frac{R \times Vol.of\ extract \times 10^3\ (g) \times 10^2\ (cmol) \times E}{Weight\ of\ soil \times 10^6\ (\mu g) \times 23}$$

Where;

R = AAS (Atomic absorption spectroscopy) reading on mg L^{-1}

23 = Atomic weight of Na

E = Charge of Na

The K content in the diluted soil extracts was measured with the standardized flame photometer. The flame photometer was standardized to give a 100 full scale deflection at

10 mg/Kg of K. The values obtained was then be used to calculate the amount of potassium contained in the soils as shown in the formula below:

$$K\ (cmol_c Kg^{-1}) = \frac{R \times\ Vol.of\ extract \times 10^3(g) \times 10^2(cmol) \times E}{Weight\ of\ soil \times 10^6(\mu g) \times 39.1}$$

Where;

R is the flame photometer reading (ppm)

39.1 = Atomic weight of K

E = Charge of K

3.7 Determination of Heavy Metals in Soils

3.7.1 Extraction of heavy metals from soils using NH_4NO_3-Solution Extraction Technique

The German DIN 19730 (1997) described the use of NH_4NO_3 method for the extraction of readily available heavy metals from soil as one of the most effective methods especially for sequential extraction of soils. The extraction was done by shaking the soil with 1 *M* NH_4NO_3-solution. Cadmium (Cd), Pb, Zn, Ni, Cu, As, Co and Hg were extracted by 1 *M* NH_4NO_3 (Gryschko *et al.*, 2000). The resulting solution was then determined using VARIAN AA240FS-Atomic Absorption Spectrophotometer AA240FS.

The chemical mechanisms involved in heavy metal extraction in mine soils using this technique have been documented across the world. This has been used to create requirements to improve environmental risk assessment for soil contaminations. The chemical mechanisms involved when soil is extracted with 1 *M* $NH4NO_3$-solution have been evaluated and this was followed by a laboratory experiment to quantify the formation of soluble metal ammine complexes during the extraction.

3.7.2 Acid Digestion of Soil

A 1.5g of the dried soil sample was weighed into an acid wash labeled 100ml polytetrafluoroethylene (PTFE) Teflon beaker. About 6ml of concentrated nitric acid (HNO_3), 65%), 3ml of concentrated hydrochloric acid (HCl, 35%) and 0.25ml of hydrogen peroxide (H_2O_2, 30%) was added to each sample in a fume chamber. The sample was then placed on a microwave carousel. The vessel cap was then tightly secured using a wrench. The complete assembly was microwave irradiated for 26minutes using milestone microwave lab station ETHOS 900, INSTR: MLS-1200 MEGA (Gryschko *et al.*, 2000).

3.7.3 Determination of Heavy Metals using AAS

After digestion of soil sample, the Teflon beaker was mounted on the microwave carousel and was cooled in a water bath to reduce internal pressure to allow the volatilized material to re-stabilize. The digestate was made up to 20ml with double distilled water and an analytical blank was prepared for each sample. A series of calibration solutions (standard) containing a known amount of analyte elements were also prepared and used to calibrate the VARIAN AA240FS-Atomic Absorption Spectrophotometer AA240FS.

Blanks were atomized followed by the standards and calibration graphs plotted showing response from the AAS. The concentrations were then calculated based on the absorbance obtained using the Beer Lambert law. Responses of standards were used to establish accurate performance of the machine and accurate values of elements. The machine was calibrated after every three elemental analyses. Light was generated from hollow cathode lamps at wavelength characteristics to each analyte. Each analyte was then atomized using an atomizer to create free atoms from the samples. Air-acetylene gas was used as a source of energy for the production of free atoms for the elements, Fe, Hg, As, Ba, Co, Cr, Cu, Ni, Cd, Pb, Sn and Zn. The sample was introduced as an aerosol into the flame and the burner aligned in the optical path to allow the light beam to pass through the flame where the light was absorbed. The light was then directed into a monochromator which then isolates the specific analytical wavelength of the light emitted by the hollow cathode lamp from the non-analytical. The sensitive light detector then measures the light and translates the response into the analytical measurements. Calculation of the concentration of heavy metals was determined using;

Final conc (mg/L or mg/Kg) = Conc. (analytical measurement) ×Nominal volume/Sample weight in grammes.

Where conc. =instrumental measurement

Nominal volume=final volume of digestate sample solution

Conc. (mg/Kg) = concentration of metals in soil

3.8 Land Use and Land Cover (LULC) Change Analysis

3.8.1 Data and Methodology

This section identifies and analyzes land use and land cover (LULC) change patterns in the studied communities. The primary focus of this analysis was to better appreciate and understand the role of mining in driving LULC change trends over time.

The workflow to detect changes that have occurred over the years is presented schematically in (Figure 3). The steps involved were, data acquisition, pre-processing, image classification and change detection using ArcGIS Pro. The Satellite scenes used for this were Landsat 8 OLI images for 2015 and 2020 acquired from the United States Geological Service (USGS) website (www.usgs.glovis.com). The Landsat 8 Collection 2 level-2 products which were already radiometrically, geometrically and atmospherically corrected were acquired for this analysis. Pre-processing for this study therefore focused on sub-setting. The images have a resolution of 30 m for the multispectral band.

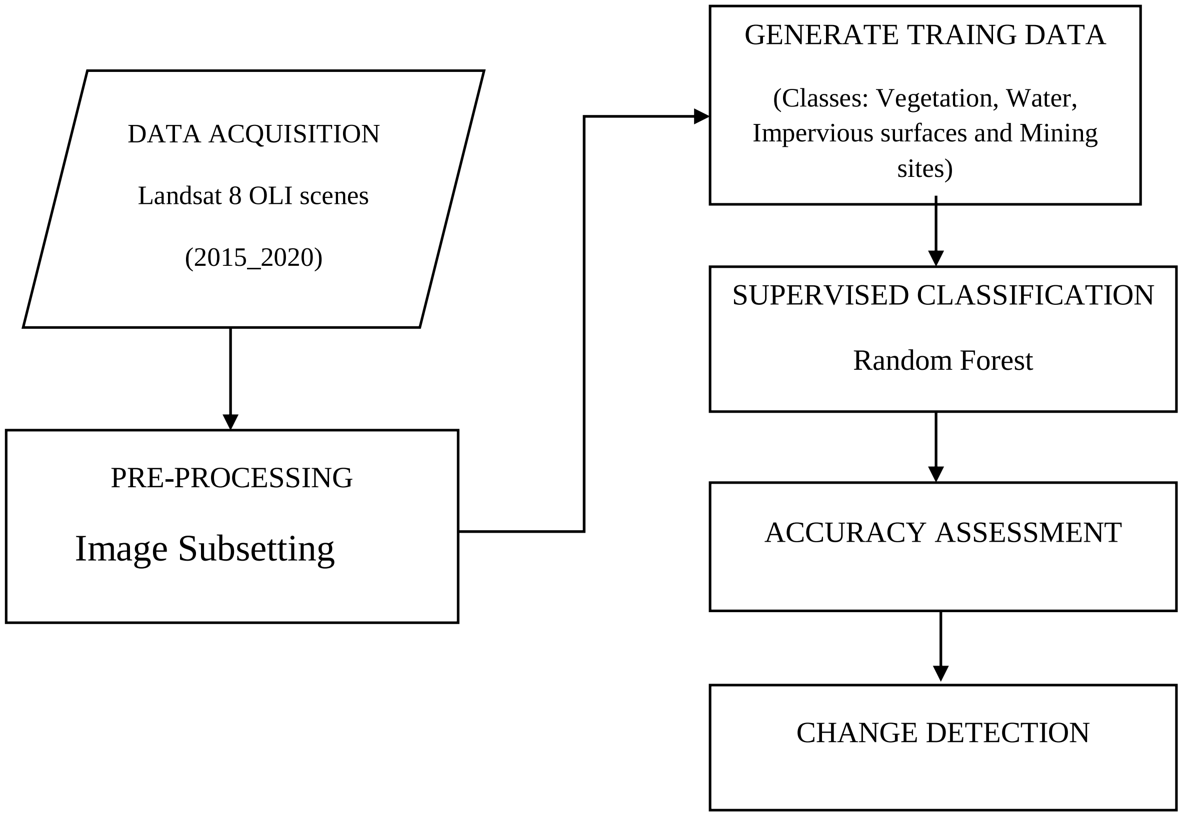

Figure 3: Methodology for land use cover change

A total of four classes were identified for training namely (i) vegetation, (ii) water, (iii) impervious surfaces and (iv) mining sites. Training data was generated from ground truthing data and high-resolution images from google earth pro. An average of 10 training sites was identified for each class. Here there is a need to have prior knowledge about the terrain so as to avoid misclassification. The Random Forest algorithm was used for the image classification, producing a land use land cover map for each year in respect to the selected study areas.

The accuracy of each classification map was assessed using the confusion matrix model. This compares the pixels in the classified map to those within the training samples. Producer and user accuracies and Kappa coefficient which measures the agreement and reliability of the classification were calculated (Forkuor & Cofie, 2011). The land cover classification of 2015 and 2020 was used for the change detection analysis. The researcher was interested in accessing land cover change between 2015 and 2020 to get the recent changes in land cover. The raster was converted to a shape file (feature type) using the Raster to Polygon tool in ArcGIS Pro. This allows calculation of the area for each class to be able to detect changes that have occurred over the years. A unique ID is generated for each polygon. The merge tool was used to join polygons of the same class. After merging, a new field was added to the attribute table and the area of each class in square meters was calculated using Calculate Geometry.

The Intersect tool was then used to compute the geometric intersection of 2015 and 2020 input features. Classes that overlap in all layers were written to an output feature class, which is the change detection. The output consists of areas where a polygon from one of the input features classes (vegetation, water, impervious surfaces or mining areas) or a layer (2015 or 2020) intersects a polygon from the other input feature class or layer. This generated classes with changes and without changes. For instance, with the vegetation class, the change detection generated were *Vegetation_Vegetation* (no change occurred), *Vegetation_Water* (changes occurred), *Vegetation_Impevious* surfaces (changes occurred) and *Vegetation_Mining* sites (changes occurred). A change detection map was generated from the output, this was presented and discussed in the following chapters. The importance of detecting the changes is to help determine which land cover is changing to what (Rawat & Kumar, 2015).

3.9 Study Population for Social Survey

According to this research, the study population was Ghanaians from the age of 30 years to 70 years and above who have stayed in the selected study communities for at least ten years. That is, people who have stayed in the area from the ten years and beyond who meet the inclusion criteria were recruited into the study. The basis for choosing this age range is cognizance of the researcher's aim of studying the prevailing conditions before and after the ban of illegal mining activities by the government of Ghana. A thirty (30) year old person was at least 18 years then, an age recognized in Ghana for someone to vote or to make a decision (Article 42 of the 1992 constitution of Ghana). Again, a 70-year-old person today was also still less than 60 years of which he or she was still in active service (even if that person was working in the formal sector) in his or her occupation and could therefore tell the prevailing condition before and after the illegal mining activities. The researcher is interested in this study population because it takes someone who has stayed in the study area for a certain number of years to be able to tell the "Before" and "After" conditions of the impact of mining on their livelihoods in the study area. It is this population therefore that the researcher from whom information was gathered in order to draw a valid conclusion.

3.10 Sampling for Qualitative Respondents

There are four major types of qualitative sampling which are snowballing, convenience sampling, purposeful sampling and quota sampling (Scheyvens & Storey, 2003) of which a researcher can use to sample his or her respondents depending on the objectives and research questions of the study. Many researchers however, opt for purposive sampling to select respondents for their studies because they are of the conviction that such respondents are of relevance to the study and can also provide them with the information needed (Campbell *et al.*, 2020). The study adopted purposive and snowballing sampling to sample respondents for the qualitative data because the researcher is of the conviction that these respondents were of relevance to the study and could provide him with the information needed (Kitchin & Tate, 2000). These respondents were selected during questionnaire administration. The researcher was directed to other respondents who are of relevance to the study; that is, the snowball sampling where a researcher is led by a respondent to another respondent of relevance to the study. The purposive sampling method was adopted to select the mining communities because not all the communities in the districts had experienced ASGM and the researcher was interested in locating communities that had mining activities. Qualitative data was collected using Focus Group Discussion, Key informant interview and observations.

3.10.1 Focus Group Discussion

Separate Focus Group Discussions (FGD) for community members, farmers from each community were conducted. Focus Group Discussion (a minimum of 4 and a maximum of 5) was organized for these groups because they are the people whose economic activities have been mostly affected by the 'galamsey' operations. In Amansie West and Mpohor Wassa East District. In all, a total of forty-five (45) people were involved in the Focus Group Discussions for farmers in the nine (9) selected communities. The reason for using Focus Group Discussion (FGD) was to enable the researcher to organize the discussion with a selected group of individuals in order to obtain information about their views on the topic under study. It was also to gather diverse views from respondents about the topic being studied. Also, attitudes, feelings, beliefs and experiences of some individuals are properly exhibited in a group rather than on an individual basis. With this method, a large amount of information can be gathered within a very short period. Each was conducted separately for males and females to avoid the traditional male dominance over females in matters that affect them. Mixing males and females together in studies like this could prevent females from freely expressing their opinions on the issues being discussed.

3.10.2 Key Informant Interview

Key informant interviews also gave the researcher in-depth information about issues of relevance to the study which could not be provided by other respondents. This method was used for relevant stakeholders in the mining industry including community leaders and opinion leaders such as assemblymen, unit committee members, women leaders and traditional rulers and the District Assemblies, in all thirty (30) individuals were selected and interviewed as key informants among the two districts.

3.11 Data Collection Instruments

Instruments for data collection are fact finding strategies and tools used by researchers to collect data for their study. Some of them are interviews, questionnaires and observations (Annum, 2017). In every research, the researcher adopts a certain approach for the study (Silverman, 2012). Questionnaire was used to collect the quantitative data. Questionnaires are used to collect key information about the population; besides, it is also used to cover a wide population in a short time (Mugenda & Mugenda, 2005). A survey instrument with both closed- ended and open-ended questionnaires was used in collecting the data. Questionnaires also serve as efficient data collection tools especially when the researcher knows exactly what he or she wants and knows what variables to use (Sekaran, 2003). With this in mind, the researcher carefully prepared questionnaires that answered the research objectives.

3.11.1 Face-to-Face Interview

In the course of administering the questionnaire, the researcher used face-to-face interviews for respondents who could not read nor write and asked the researcher to guide them fill the questionnaire. This ensured the quality of the data obtained through the information acquired during the conversation. Interviews were constructed in the English language and then translated into the various languages by the researcher himself for better understanding of the questions by respondents.

3.12 Sampling Size for Quantitative Study

Researchers may have the desire to collect information from as many people as they can but are constrained in many instances by time and resources. As a result, they devise means to select a small group of the population which is representative and is of relevance to the study (Bryman & Cramer, 1995). Sample size refers to the number of items or respondents to be selected from the population to be studied (Kothari, 2004). These respondents are made up of both males and females but of different socio-economic background.

3.12.1 Sample Size Determination

The sample size for the study was calculated using the Cochran (1977) formula; n = $\frac{Z^2 \times PQ}{d^2}$

Where: n= desired sample size

Z= Reliability coefficient for 95% confidence level usually set at 1.96

P = the proportion of respondents in the study area that was interviewed, as a rule of thumb, 50 % (0.5) was used because there is no reasonable estimate available in literature about the number of people affected by the illegal mining operations in each household in the Ghana Demographic health survey report in the communities selected for the study.

Q=1-p

d=degree of accuracy desired set at 0.05 probability level.

Based on the formula above, a sample size of 404 was used for the study after allowing 5% margin of error for non-responses. The respondents were selected from each community using a ratio. A ratio of sampling sites in a community to sampling sites in both districts was used to share the total questionnaire. Using the ratio, the questionnaire distribution in Mpohor Wassa District was ASA (57), ADT (48), MM (40), ADW (40) and MA (40) giving a total of 225 questionnaires administered. However, using the same ratio in Amansie West District, the questionnaire distribution was DO (24), AS (75), MN (40) and DYO (40) giving a total of 179 questionnaires administered.

3.13 Qualitative Data Handling

Data from qualitative sources was handled through editing, coding and transcribing of information. The data collected was edited and grouped into themes, analyzed, interpreted and discussed. For the qualitative part of the study, interviews were recorded digitally and the audio files labeled appropriately for easy retrieval. Each recording was transcribed into English. The researcher validated the transcripts by listening to a sample of the tapes to check accuracy of content and translation quality. The transcripts were analyzed using qualitative data analysis software (NVIVO 11). The software is good for data organization and retrieval and allows easy and efficient retrieval of data. The transcriptions were coded using identified themes from the interview guide and themes that emerged from the data.

3.14 Quantitative Data Analysis and Processing

The data collected from quantitative data was edited, coded and entered into Microsoft Excel and finally imported onto STATA software version 16 for statistical analysis. Descriptive statistics such as mean ± SD, range, 95% confidence interval and tables were used to describe the data. One-way analysis of variance (ANOVA) at 95% confidence level was used to test differences in means among the sampling sites in each of the two studied regions. Where differences exist, Tukey's HSD multiple comparisons was used to determine where the differences lie. The Pearson product moment correlation coefficient (r) was estimated to test the degree of relationship between the parameters. Factor analysis was conducted by using Principal Component Analysis (PCA) as the extraction technique with an Eigenvalue greater than 1 to obtain the latent factors or components responsible for water quality variations. Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity were used to determine the factorability of data.

3.15 Ethical Issues

Ethical clearance was sought from the Ethics Committee of the University of Ghana, Legon. This committee is tasked with the responsibility of ensuring that graduate students follow ethical issues to ensure the safety and confidentiality of respondents. The committee also looks at data collection methods and any other issues related to the study. Clearance is given to the researcher (student) upon meeting the requirements and satisfaction of the committee with the issuing of a letter of clearance (Appendix M).

The researcher met participants and discussed the purpose of the research, the expected time commitments and the procedure for the research activities. All participants were given a guarantee of confidentiality and anonymity in reporting the information provided for the study. Additionally, ethical issues governing human subjects in research were strictly adhered to. The names of respondents were not captured in the research. The features of the questionnaires such as ease of completion and sensitivity of the questionnaire were all considered. There were no biases towards any religion, race or culture. Permission was sought from participants to involve them in the study. One cannot conduct research among any group of people without their consent. This is part of the ethical considerations in social research. In this regard, the researcher sought the consent and permission of respondents before obtaining information from them. This was done through self-introduction by the researcher, the purpose of the study, what it would be used for and how beneficial it is expected to be to the communities under study. They were also assured that the information being sought from them would be strictly kept in confidentiality and that their identities were not be disclosed anywhere.

3.16 Contamination Assessment and Hazard Rating

The current contamination situation at the illegal mining sites in the study areas was investigated by using the threshold exceedance ratio (TER) and the trace element mobility coefficient. The threshold exceedance ratio was calculated as follows (Prüeß *et al.*, 1991):

$$TER = \frac{E \times C}{BC} \quad \text{Eq (1)}$$

Where ExC is the NH_4NO_3 extractable concentration and BC is a given background concentration. The rule of thumb is that a threshold exceedance ratio (TER) value higher than the total concentration (TC) can limit the functioning of the soil. Limited soil functioning might occur if the threshold value is exceeded, causing a reduction in plant growth and, thus, increased soil erosion. The mobility (bioavailability) of trace elements (MOB in %) was derived by comparing the extractable ratio of an element with the total concentration by using the following formula:

$$MOB = \frac{E \times C}{Tot\ C} \quad \text{Eq (2)}$$

Where TotC is the total concentration measured in soil samples. The MOB value gives the percentage value of the concentration that could be remobilized and is thus bioavailable in the soil.

3.17 Geoaccumulation Index (Igeo)

The Igeo values were calculated in order to determine metal contamination in soils at the study sites. The index of geoaccumulation is a widely used index in the estimation and evaluation of soil contamination by comparing the levels of metals obtained to the background levels originally used with bottom sediment (Atiemo, 2011). It was estimated by using the modified equation (Taylor & Meclennan, 2010). The Igeo values were calculated in order to determine metal contamination in soils at the study sites. The index of geoaccumulation is a widely used index in the estimation and evaluation of soil contamination by comparing the levels of metals obtained to the background levels originally used with bottom sediment (Atiemo, 2011). It was estimated by using the modified equation (Taylor & Meclennan, 2010).

$$Igeo = \log_2 (Cn/1.5Bn)$$

Where Cn is the measured heavy metal levels in the soil sample. Bn is the geochemical background levels of the heavy metal. The constant 1.5 is introduced to minimize the effects of possible variations in the background value, which may be attributed to lithologic variation in the sediments (Lu *et al.*, 2009). The geochemical background values for metals are Cr (67.30 mg/Kg), Cd (0.10 mg/Kg), Zn (65.40 mg/Kg), Pb (21 mg/Kg), Cu (22.50 mg/Kg) and Fe (125) (Taylor & Meclenan, 2010). The following classification is given for the geoaccumulation index as shown in Table 3.2.

Table 3.2: Categorization of Igeo

Igeo values	Igeo class	Designation of soil quality
>5	6	Extremely contaminated
4-5	5	Strongly to extremely contaminated
3-4	4	Strongly contaminated
2-3	3	Moderately to strongly contaminated
1-2	2	Moderately contaminated
0-1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

Source: Muller, 1997

3.18 Quality Control

The sensitivity of methods used in the analysis of the metals was determined using recovery and reproducibility studies, which were conducted using certified standard reference solutions for As, Cd, Pb and Hg manufactured by BDH Chemicals (London, UK). In between the analysis, certified reference materials of the toxicants were analyzed to verify the calibration curve. The standard for the ASS calibration was prepared by diluting standard (1000 ppm) supplied by MES Equipment Ghana. All the results obtained were expressed in mg/L.

3.18.1 Analytical Technique and Accuracy Check

Nine (9) heavy metals namely arsenic (As), total chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), zinc (Zn), and iron (Fe) was measured using dual atomizer and hydride generator atomic absorption spectrophotometer (model ASC-7000 No A309654, Shimadzu, Japan). All reagents used were of the analytical grade from MES Equipment Ghana. Ultrapure metal free deionized water was used for all analysis.

All glassware and plastic were cleaned by soaking them in warm 5% (V/V) aqueous nitric acid for 6-7 hours and rinsed with ultrapure deionized water.

3.18.2 Chemical and Sample Digestion

Deionized water supplied by Medical and Equipment Suppliers (MES) Equipment Limited Ghana was used in all the analysis. All standard solutions used were of the highest purity supplied. The nitric and hydrochloric acids that were used for the digestion were of analytical grades and supplied by MES equipment.

3.18.3 Quality Control for Social Survey

The structured questionnaire for the social survey was pretested at Manso Nkwanta and Mpohor Wassa and all errors detected were rectified. The questionnaire was validated by allowing an expert to go through. The internal consistency of the questionnaire was tested with Cronbach alpha and a value of 0.85 was obtained which indicates a good reliability of the questionnaire.

CHAPTER FOUR

RESULTS

4.0 Overview

This chapter presents the results of water quality and soil analyses, social survey of households, land use and land cover change assessments from the studied locations. The first section explored the physical parameters of the surface water, the second section deals with physical parameters of soils and the third section deals with land use and land cover changes and the last deals with social survey of impacts of mainly artisanal and small-scale mining on ecosystem services.

4.1 Physical Parameters in Surface water Samples, Mpohor Wassa East District

4.1.1 pH

The mean pH values of the surface water sample from Mpohor Wassa East ranged from 6.5 at sampling site ASA (Asowuo Ayipa) and MM (Mpohor Motorway) to 7.1 SD at control sampling site (Mpohor Anomabo) with standard deviations of 0.32 and 0.17 respectively (Figure 4). Analysis of variance at 95% confidence level did not show any statistically significant differences in pH among sampling locations and the control sites ($p>0.05$) (Appendix B).

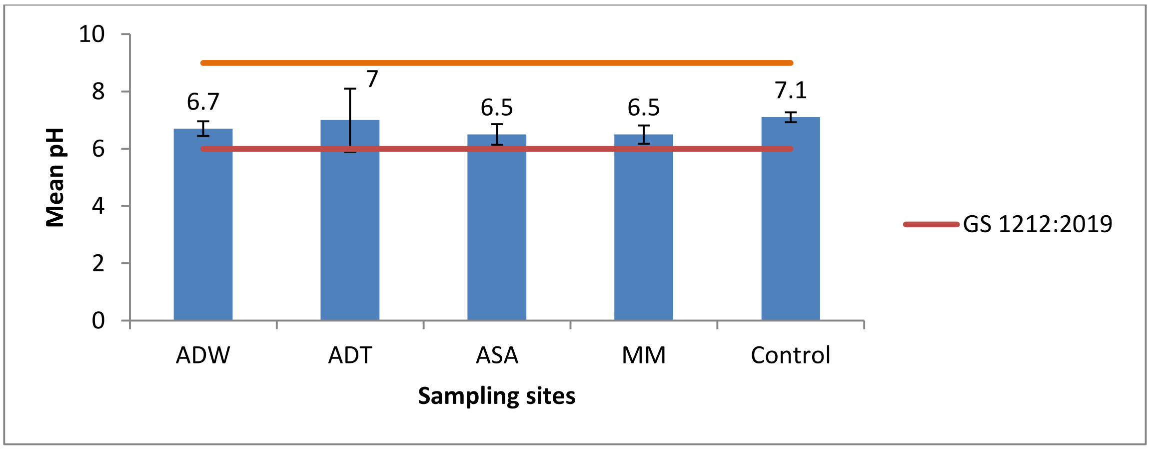

Figure 4: pH Variations across surface water locations, Mpohor Wassa East

4.1.2 Electrical Conductivity

The highest conductivity value was recorded in surface water samples at sampling site MM (Mpohor Motorway) with mean value of 152.3±24.4 μS/cm and the lowest was recorded at the control sampling site with mean value of 58.7 ± 3.4µS/cm (Figure 5). There was a statistically significant difference in conductivity among sampling sites (Appendix B). Pair wise comparison using Tukey's HSD revealed statistically significant differences among the following; ADW and control (p=0.001), ADT and control (*p*=0.002), MM and control (p=0.004) and (*p*=0.017) (Appendix C).

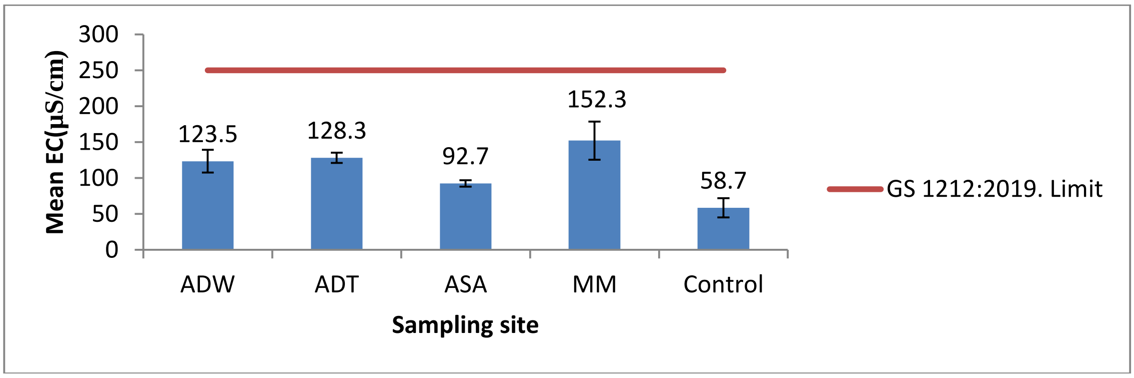

Figure 5: Conductivity Variations across surface water locations, Mpohor Wassa East

4.1.3 Total Dissolved Solids

At Mpohor Wassa East sampling sites in the Western region however, the highest TDs value was recorded in surface water samples at sampling site MM (Mpohor Motorway) with mean value of 101±17.2mg/L and the lowest was recorded at the control sampling site with mean value of 33.3± 9.1mg/L (Figure 6). The TDS of water samples differed significantly among sampling sites (F=21.8; *p*=0.0001) (Appendix B).

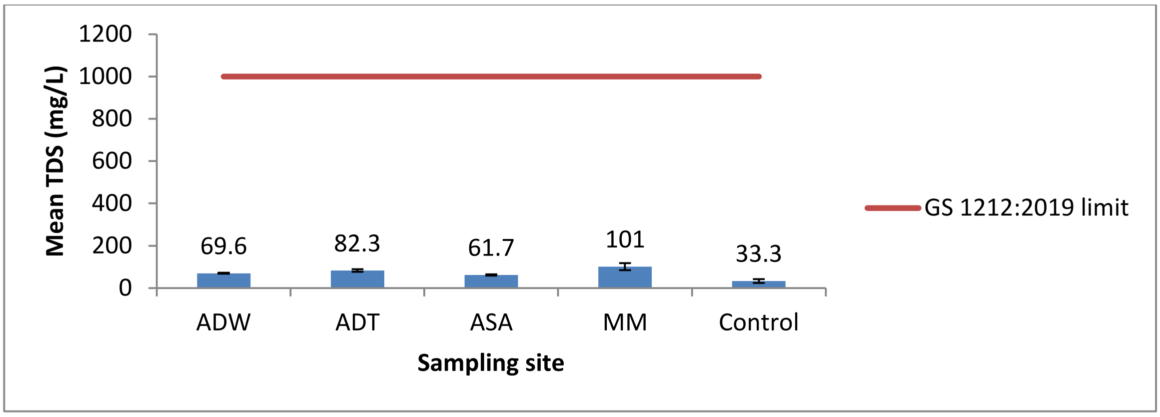

Figure 6: TDS Variations across surface water locations, Mpohor Wassa East District

4.1.4 Total Suspended Solids

The TSS of water samples obtained from the Mpohor Wassa East surface water in the Western Region is illustrated in Figure 7. The highest TSS value was recorded in surface water samples at sampling site MM with mean value of 645.3 ±14.8mg/L and the lowest was recorded at the control sampling site with mean value of 5.3± 0.5 mg/L (Figure 7). There was a statistically significant differences in TSS among sampling sites (F=178; *p*=0.0001) (Appendix B). Pair wise comparison using Tukey's HSD revealed statistically significant differences and the results are shown in (Appendix C).

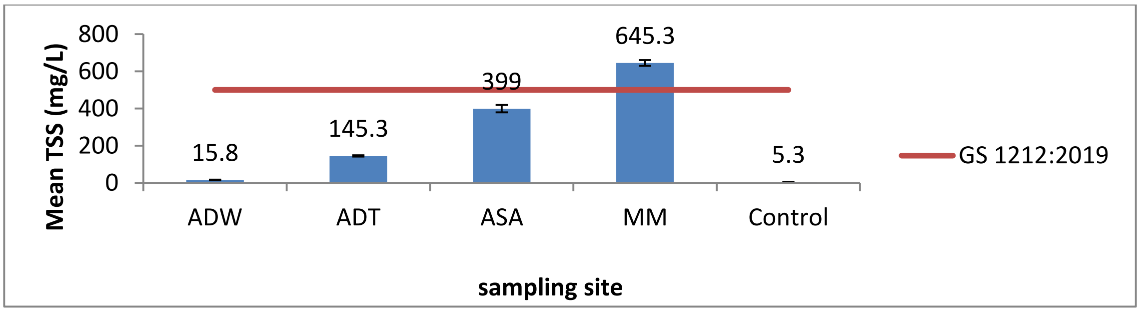

Figure 7: TSS Variations across surface water locations, Mpohor Wassa East District

4.1.5 Total Alkalinity

The highest total alkalinity of the surface water samples from Mpohor Wassa East recorded at control sampling site with mean value of 64.3±8.0mg/L whilst the lowest was recorded at sampling site ASA with mean value of 9.0 ± 2.6 mg/L (Appendix A). The total alkalinity of the water samples differed significantly among sampling sites (F=160.4, *p*=0.0001) (Appendix B). The pairwise comparison using Tukey's HSD significant differences are shown in (Appendix C).

4.1.6 Temperature

The lowest temperature of water samples at Mpohor Wassa East District of Western region however, was recorded at sampling site ADT with mean value of 24.6 ^{0}C and the highest mean value of 25.4 ^{0}C at sampling site ADW (Appendix A). The temperature values did not differ significantly among sampling sites ($p>0.05$) (Appendix B).

4.1.7 Dissolved Oxygen (DO)

The highest DO of the surface water samples from Mpohor Wassa East was recorded at control sampling site with mean value of 12.9±3.7 mg/L whilst the lowest was recorded at sampling site ASA with mean value of 5.4 ± 0.91 mg/L (Appendix A). Analysis of variance at 95% confidence level revealed that the dissolved oxygen differed significantly among sampling sites (p=0.02) (Appendix B).

4.1.8 Biological Oxygen demand (BOD)

The highest BOD of the surface water samples from Mpohor Wassa East was recorded at sampling site ADW with mean value of 1.7±0.60 mg/L whilst the lowest was recorded at control sampling site with mean value of 1.0 ± 0.42 mg/L (Appendix A). There were no statistically significant differences in BOD among sampling sites (*p*=0.349) (Appendix B).

4.1.9 Salinity

The lowest salinity of the surface water samples from Mpohor Wassa recorded at control sampling site with mean value of 0.00mg/L whilst the highest was recorded at sampling site ADT with mean value of 2.0 ± 0.06mg/L (Appendix A). There was a statistically significant difference in salinity among sampling sites (*p*=0.013) (Appendix B).

4.1.10 Total Hardness

Concerning water samples at Mpohor Wassa sampling site, the highest total hardness of the surface water samples was recorded at sampling site ADT with mean value of 72.6±0.67 mg/L whilst the lowest was recorded at control sampling site with mean value of 11.7 ± 2.8 SD mg/L (Appendix A). There was a statistically significant differences in total harness among sampling sites (*p*=0.001) (Appendix B).

4.1.11 Turbidity

The mean turbidity values in surface water samples obtained from Mpohor Wassa East District however, also ranged from 2.5±0.7 SD at the control sampling site and 299.2 ±12.2 SD. There was a statistically significant difference in total hardness among sampling sites (p=0.001) (Appendix B).

4.2 Heavy metals in water, Mpohor Wassa East District

The heavy metals in surface water samples obtained from Mpohor Wassa East sampling sites are as illustrated in Table 4.1. The lowest Fe concentration was recorded in water samples obtained from ASA and ranged from 0.41 to 0.49mg/L with a mean value of 0.460.04SD mg/L, whilst the highest Fe concentrations were recorded at the control sampling site and ranged from 1.28 to 3.17mg/L with a mean value of 2.40.97SD mg/L. Cobalt was not detected in control water samples and the highest was recorded at sampling site ADT and ranged from 0.01 to 0.04 mg/L with a mean value of 0.030.00 SD mg/L. Copper was not detected in water samples and the highest was recorded at sampling site ADT and ranged from 0.20 to 0.38 mg/L with a mean value of 0.320.01SD mg/L. Chromium was not detected both at sampling site ADW and the control sampling site. The highest value, however, was recorded at sampling site ADT and ranged from 0.004 to 0.008 mg/L with a mean value of 0.006±0.00 SD mg/L. The highest Ni concentration was recorded at sampling site ADT and ranged from 0.22 to 0.39 mg/L with a mean value of 0.31±0.08 SD mg/L. The lowest Zn concentration was recorded in water samples from control sampling sites and ranged from ND to 0.01 mg/L with a mean value of 0.003±0.001 SD mg/L, whilst the highest was recorded at sampling site ADT and ranged from 0.27 to 0.93 mg/L with a mean value of 0.49±0.01SD mg/L. Mercury (Hg) and arsenic were not detected in water samples obtained from control sampling sites. However, mean values of 0.0003±0.00 SD mg/L each were recorded for mercury and arsenic. The lowest Cd concentration was recorded in water samples from control sampling sites and ranged from 0.05 to 0.07 mg/L with a mean value of 0.06±0.01SD mg/L and the highest was recorded in water samples at sampling site ADW and ranged from 0.11 to 0.54 mg/L with a mean value of 0.3±0.02 SD mg/L. Lastly, the lowest Pb concentration was recorded in water samples from control sampling sites with a mean value of 0.0003±0.00 mg/L and the highest was recorded in water samples at sampling site ASA with a mean value of 0.02±0.0001SD mg/L.

Table 4.1: Heavy Metals in Surface Water Samples from the Mpohor Wassa East District

Var	ADW	ADT	ASA	MM	Control
Fe	1.44±1.0.2(1.30-1.54)	0.75±0.2(0.64-0.88)	0.46±0.04(0.41-0.49)	1.8±0.1(1.72-1.93)	2.4±0.97(1.28-3.17)
Co	0.01±0.00 (0.001-0.02)	0.03±0.00(0.01-0.04)	0.02±0.00(0.01-0.03)	0.01±0.00 (0.004-0.008).	ND
Cu	0.0002±0.03(0.0001-0.0003)	0.32±0.01(0.20-0.38)	0.0002±0.01(0.0001-0.0003)	0.0001±0.00 (ND-0.0003)	ND
Cr	ND	0.006±0.00(0.004-0.008)	0.001±0.00(0.002-0.001)	0.003±0.00 (0.0001-0.0005)	ND
Ni	0.02± 0.01 (0.01-0.03)	0.31±0.08(0.22-0.39)	0.29±0.03(0.28-0.233)	0.21±0.06(0.17-0.27)	0.02±0.01(0.01-0.03)
Zn	0.08± 0.02 (0.06-0.09)	0.49±0.01(0.27-0.93)	0.04±0.002(0.002-0.0.006)	0.002±0.00(0.001-0.005)	0.003±0.001(ND-0.01)
As	0.00006±0.00	0.0003±0.00	0.0002±0.00	0.00001±0.00	ND
Hg	0.0002±0.00	0.0003±0.00	0.0002±0.00		ND
Mn	0.4±0.05(0.42-0.52)	0.41±0.07(0.35-0.49)	0.38±0.33(0.37-0.43)	0.43±0.08(0.35-0.53)	0.2±0.02(0.17-0.22)
Cd	0.3±0.02(0.11-0.54)	0.2±0.06 (0.12-0.54)	0.1±0.009(0.11-0.28)	0.2±0.04(0.12-0.29)	0.06±0.01(0.05-0.07)
Pb	0.006±0.002	0.005±0.001	0.02±0.0001	0.003±0.000	0.0003±0.00

Mean ± SD (Range) ADW: Adawotwe; ADT: Adum Tokoro; ASA: Asowuo Ayipa
MM: Mpohor motorway
Source: Field Data, Annan (2021)

4.3 Factor Analysis of Physicochemical Parameters of Surface Water at Mpohor Wassa East District

Factor Analysis using Principal Component Analysis (PCA) and rotated with Varimax rotation with Kaiser Normalization using an Eigenvalue of 1 was used to identify which parameters mostly or significantly influence the water quality variations within and source apportionment at Mpohor Wassa East (Table 4.2). In all, a total of 25 principal components were extracted. However, the first six components cumulatively explained 88.611% of the total variance and were therefore retained in the model. These six principal components whose eigenvalues were greater than one (>1) were selected in accordance with Liang et al., (2014); Bhat et al., 2014; Winkler et al., (2013) and Köse (2016), who reported that for PCA analysis, any factor with an eigenvalue greater than one (>1) is considered significant for further analysis. Each of the remaining six factors had eigenvalues of less than one and were considered insignificant and were therefore rejected.

The first principal component (PC-1) contributed 22.501% of the total variance and was strongly loaded by turbidity, Co, Cr, Cu, As and Cd and moderately loaded by total hardness, Ni, Zn, Hg, Mg, Pb and Fe. However, the 2nd principal component, PC-2, explains that 21.490% of the total variance is highly loaded by EC, TDS, salinity, Mn and Na and moderately loaded by total alkalinity, As, Mg, Pb and Cd. The 3rd principal component, PC-3, contributed 20.185% of the total variance and was strongly loaded by alkalinity, bicarbonates, Ca and Pb and moderately loaded by total Fe and Zn. Furthermore, the 4th component (PC-4) explains 9.273% of the total variance, and was strongly loaded by pH and moderately loaded by Zn. Again, the 5th component (PC-5) contributed 7.830% of the total variance and was highly loaded by TSS. The last principal component, which is PC-6, explains 7.330% of the total variance and is strongly loaded by Hg and K. With the exception of the parameters mentioned above that had strong and moderate factor loadings and contributed significantly to the variation in water quality parameters in the surface water, all other variables were observed to have weak factor loadings. The communalities of the data set also revealed that with the exception of *As* that contributed 69.2% to the variation in water quality parameters, all the other individual physicochemical parameters contributed more than 70% each of the total variance. Table 4.2 illustrates the rotated component matrix. For the purposes of making interpretation of the relevant factors, factor rotation was computed. Mostly, factors with loadings of 0.5 are qualified to be retained. However, to obtain stronger loadings, this study adopted a factor loading of 0.5 as the minimum and classified as moderately loaded.

Table 4. 2: Rotated Component Matrix of physico-Chemical Parameters, Mpohor Wassa East

Variable			**Components**				**communalities**
	PC1	PC2	PC3	PC4	PC5	PC6	
Temperature	-0.169	0.149	-0.119	0.409	-0.205	0.142	0.782
EC	0.135	0.912*	-0.117	0.134	0.211	0.147	0.947
TDS	0.255	0.720*	-0.076	-0.037	0.507	0.049	0.850
pH	0.395	-0.188	0.278	0.742*	-0.004	-0.161	0.846
Salinity	0.286	0.855*	0.188	-0.260	-0.065	-0.023	0.921
TSS	-0.140	0.327	-0.110	-0.041	0.875*	0.242	0.965
Alkalinity	0.063	-0.005	0.970*	-0.011	0.046	-0.055	0.950
Bicarbonates	0.098	0.023	0.965*	-0.069	0.085	0.046	0.956
Turbidity	0.894*	0.111	0.042	0.342	0.154	-0.026	0.954
Total Hardness	0.609**	0.694**	0.200	-0.150	0.142	0.120	0.950
Fe	-0.553**	-0.001	0.689**	0.164	-0.157	-0.105	0.842
Co	0.750*	0.040	-0.436	-0.301	0.032	0.309	0.941
Cu	0.910*	0.223	0.176	-0.216	-0.160	0.018	0.981
Cr	0.961*	0.180	0.143	0.051	-0.054	-0.005	0.982
Ni	0.553**	0.227	-0.315	-0.254	0.458	0.214	0.777
Zn	0.566**	0.305	0.052**	-0.661**	-0.338	0.068	0.971
As	0.723*	0.585**	0.033	0.347	0.087	0.393	0.692
Hg	0.624**	0.197	-0.531	0.121	0.005	0.715**	0.917
Mg	0.669**	0.656**	0.174	-0.081	0.059	0.111	0.930
Mn	0.107	0.732*	-0.552	-0.141	0.057	0.150	0.898
Ca	0.254	-0.157	0.903*	-0.071	-0.113	-0.018	0.923
K	0.075	0.064	0.254	-0.065	0.267	0.776*	0.751
Na	0.399	0.760*	-0.001	-0.039	0.461	0.175	0.982
Pb	0.603**	-0.540**	-0.721*	-0.173	0.288	0.321	0.737
Cd	0.757*	0.670**	-0.370	0.095	-0.138	-0.301	0.708
Eigenvalue	8.530	5.218	3.308	2.082	1.806	1.209	
% of variance	22.501	21.490	20.185	9.273	7.830	7.330	
% Cumulative	22.501	43.992	64.177	73.450	81.281	88.611	

*Strong (factor score>0.75); **Moderate (0.5≤score≤0.75), Weak (Score<0.5)
Source: Field data, Annan (2021)

4.3.1 Scree plot

Scree plot is a technique that can be used to determine the exact number of factors to retain for further analysis. The scree plot helps the researcher to know the number of principal components that summarize the data by plotting a graph. According to Cartell (1997) the scree plot gives a plot of the eigenvalues of the various factors. The elbow effect is always used to determine the exact number of factors to extract. It is a rule of thumb that all factors above the elbow are to be retained. In this study, even though six factors had eigenvalues > 1 the elbow effect was very clear at the fourth factor (Figure 8).

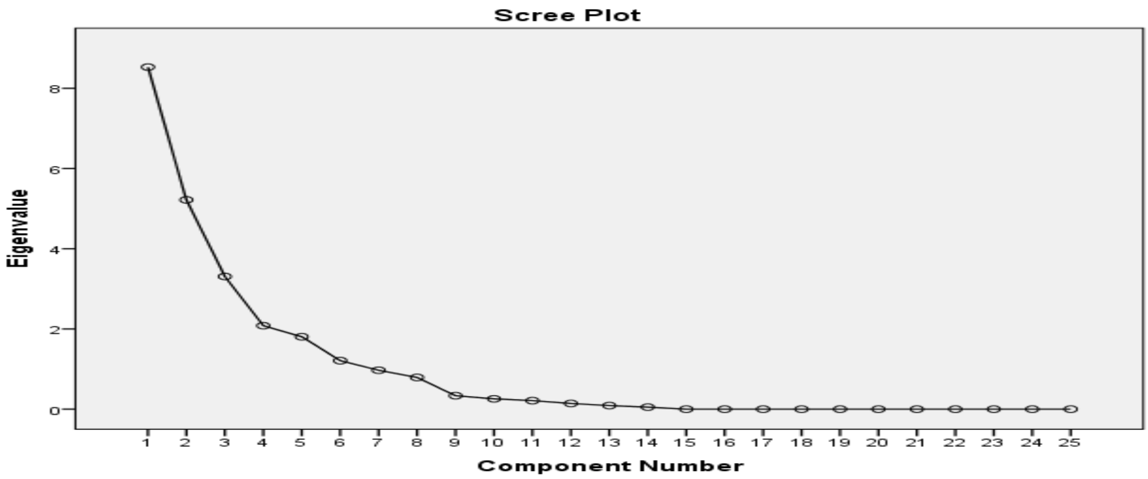

Figure 8: Scree plot of physico-chemical parameters, Mpohor Wassa East

4.4 Correlation of Physico-Chemical Parameters of Surface Water at Mpohor Wassa East District

To investigate the association, the direction and strength of the physico-chemical parameters of the surface water samples from Mpohor Wassa East sampling sites, Karl Pearson's correlation coefficient was used. Table 4.3 shows the correlation matrix of the physico-chemical parameters. Significant positive correlation was observed between the following physico-chemical variables; EC and TDS (r=0.820), EC and salinity (r=0.720), EC and total hardness (r=0.727), EC and manganese (r=0.737), EC and magnesium (r=0.708), EC and Na (r=0.870), Alkalinity and Bicarbonates (r=0.983), TDS and TSS (r=0.632), Salinity and Total hardness (r=0.790), Ca and hardness (r=0.884), Ca and bicarbonates(r=0.888), Na and TDS (r=0.910). There was a negative weak correlation between pH and all heavy metals analyzed in surface water samples obtained from the Mpohor Wassa Sampling site.

Table 4.3: Correlation between Physicochemical Parameters in Water Samples, Mpohor Wassa East District

Parameter	*EC*	*TDS*	*TSS*	*Sal*	*Na*	*Mg*	*Ca*	*Alkal*	*Bicar*	*Hardness*
EC	1									
TDS	0.820**	1								
TSS	0.487	0.632*	1							
Sal	0.720*	0.646*	0.195	1						
Na	0.870**	0.940**	0.631*	0.711*	1					
Mg	0.708	0.700*	0.171	0.754*	0.837*	1				
Ca	-0.280	0.228	-0.285	0.122	0.070	0.232	1			
Alkalinity	-0.112	0.078	-0.091	0.202	0.016	0.166	0.884*	1		
Bicarbonates	-0.049	-0.022	-0.039	0.232	0.096	0.235	0.888*	0.983**	1	
Hardness	0.727	0.775	-0.265	0.790*	0.248	0.977*	0.211	0.210		1

***Correlation is significant at p < 0.01 level (2-tailed).*
**Correlation is significant at p < 0.05 level (2-tailed)*
Source: Field data, Annan (2021)

4.5 Soil Physical Parameters, Mpohor Wassa East District

4.5.1 pH

Soil samples from sampling site ADW Mpohor at Wassa East recorded the lowest pH with mean value of 4.6±0.4 whilst the highest value was recorded in soils samples from the control sample with mean value of 7.3±0.3 (Table 4.4). Analysis of variance at 95% confidence level revealed a statistically significant difference in pH among soil samples obtained from the sampling sites (p=0.0001) (Appendix A).

4.5.2 Conductivity

The highest value of conductivity was recorded in soils samples obtained from ADW with mean value of 38.9±5.9 µS/cm whilst the lowest value was recorded in soils samples from the control samples with mean value of 14.2±1.7µS/cm (Table 4.4). There was a statistically significant difference in conductivity among soil samples obtained from the sampled sites (P =0.0001).

4.5.3 Available phosphorus

At Mpohor Wassa East, the highest available phosphorus in soil was recorded in soil samples obtained from the control sampling site with mean value of 43.3±3.9 mg/Kg whilst the lowest value was recorded in soil samples from MM sampling site with a mean value of 18.4±4.2mg/Kg (Table 4.4). There was a statistically significant difference in available phosphorus levels among soil samples obtained from the sampled sites (p=0.0001).

4.5.4 Organic Carbon (%)

Table 4.4 shows the mean values of % organic carbon in soil obtained from Mpohor Wassa East sampling sites. The highest percentage organic carbon was recorded in soils from the control site with mean value of 5.8±0.94 % whilst the lowest value was recorded in ADT sampling site with mean value of 0.54±0.2%. There was a statistically significant difference in % organic carbon among soils from the various sampling sites (p = 0.0001).

4.5.5 Percentage Sand, Silt and Clay

With reference to Mpohor Wassa East, the highest value of % sand was recorded in soils from control sampling site with mean value 49.5±2.7 % whilst the lowest was recorded in ADT sampling site with mean value of 35.8±7.2 %. The percentage sand differed significantly among the sampling sites at 95% confidence level (p=0.04) (Appendix A).

The highest percentage of silt was recorded in soils from the control sampling site with mean value 47.0±5.3 % whilst the lowest was recorded in soil samples from ADT with mean value of 33.8±6.1%. There was a statistically significant difference in percentage silt among soil samples obtained from the various sampling sites (p=0.01) (Appendix A).

The highest percentage clay was recorded in soils obtained from control sampling sites with mean value of 37.3±1.8% whilst the lowest was recorded at ADT sampling site with mean value of 14.4±2.0%. The percentage clay in soil samples obtained from the sampling sites daggered significantly (p=0.001) (Appendix A).

4.5.6 Exchangeable K, Ca, Mg and Na

The highest exchangeable potassium in soil was recorded in the control site with mean value of 1.4±0.32 cmol (+)/Kg whilst the lowest value with mean value of 0.06±0.01 cmol (+)/Kg each was recorded at sampling sites ADT and MM. There was no statistically significant difference in exchangeable potassium in soils obtained from Mpohor Wassa East sampling sites (p=0.0001) (Appendix A).

The control sampling site recorded the highest exchangeable calcium in soil and ranged from mean value of 8.1±1.8Cmol (+)/Kg whilst the lowest value was recorded in sampling site ASA with mean value of 4.71±0.8 cmol (+)/Kg. The exchangeable calcium differed significantly among the sampling sites at 95% confidence level (p=0.0001) (Appendix A).

The highest exchangeable magnesium in soil was recorded in control sample sites with mean value of 9.52±0.56 cmol (+)/Kg whilst the lowest value was recorded at ASA sample site AS with mean value of 4.7±0.8Cmol (+)/Kg. Analysis of variance revealed a statistically significant difference in exchangeable magnesium in soils obtained from the sampling sites (p=0.0001).

The highest exchangeable sodium in soil was recorded in soil samples obtained from ASA sample site with mean value of 0.70±0.3 cmol (+)/Kg whilst the lowest value ranged from control sample site with mean value 0.23±0.04 cmol (+)/Kg. There was no statistically significant difference in exchangeable sodium in soils obtained from the sampling sites (p=0.14).

Table 4.4: Physico-Chemical Parameters in Soil, Mpohor Wassa East District

	ASA	ADT	MA	MM	ADW	Control
Cr	0.69±0.015 (0.41-0.0.95)	0.75±0.75(0.51-0.95)	0.67±0.14(0.46-0.95)	0.70±0.17(0.41-0.94)	0.64±0.11(0.46-0.85)	0.07±0.01(ND-0.11)
As	5.5±0.7 (4.1-6.7)	5.8±0.8(3.8-6.9)	5.5±0.5(2.5-6.1)	5.3±0.6(1.8-6.2)	4.8±0.3(2.7-6.6)	ND
Cd	32.2±1.8 (18.9-50.6)	30.7±1.2(20.0-38.7)	32.8±2.1(22.0-50.8)	34.8±2.2(18.7-50.9)	31.6±2.2(22.1-50.2)	ND
Hg	5.7±0.8(4.8-6.9)	6.4±0.4(5.5-6.7)	5.5±0.9(4.2-6.5)	4.6±0.7 (4.4-6.4)	5.7±0.9 (4.1-6.9	ND
Ni	0.51± 0.15 (0.31-0.72)	0.65±0.11(0.42-0.92)	0.47±0.12(0.27-0.75)	0.48±0.16(0.21-0.82)	0.32±0.11(0.28-0.62	0.10±0.01(0.05-0.18)
Zn	41.0± 2.2 (22.5-57.9)	36.9±2.2(22.7-49.2)	42.9±2.9(22.3-57.6)	42.7±2.4(29.5-57.8)	41.7±2.8(22.8-57.6	70.3±2.2(65-73.2)
Cu	0.68± 0.1 (0.43-0.87)	0.67±0.1 (0.53-0.93)	0.67±0.1(0.56-0.84)	0.65±0.2(0.53-0.88)	062±0.22(0.51-0.0.89)	ND-0.005
Pb	1.2± 0.3 (0.58-1.77)	1.3±0.5(0.50-1.93)	1.1±0.3(0.55-1.73)	1.1±0.4(0.54-1.86)	1.2±0.4(0.58-1.74)	ND
Fe	3916±201(2295-5287)	3940±144(2869-5277)	3913±248(2395-5277)	3878±223(2395-5277)	4048±146(2495-5267)	1534±128(1352-1824
Co	5.7±1.3(3.2-9.0)	6.4±0.9 (4.7-7.8)	5.7±1.4(3.1-9.0)	5.2±0.9(3.3-7.2)	5.8±1.6(3.5-9.5	0.01±0.0(ND-0.04
Ca	2.4±0.8 (1.4-4.7)	3.4±0.8 (1.7-4.6)	2.5±0.9(1.3-4.9)	2.4±0.9(1.4-4.3)	2.4±0.9(1.5-4.6)	8.1±1.8(5.2-11.5)
Mg	4.71±0.8(3.2-6.8)	4.94±0.6(4.1-6.2)	4.76±0.9(3.1-6.2)	4.91±0.8(3.1-6.4)	4.82±0.8(3.3-6.8)	9.52±2.4(7.9-12.3)
Na	0.70±0.3 (0.35-1.81)	0.63±0.1(0.32-0.93)	0.69±0.3(0.37-1.71)	0.59±0.2(0.34-0.87)	0.76±0.4(0.35-1.91)	0.23±0.04(0.19-0.28)
K	0.07±0.01(0.05-0.09)	0.06±0.01(0.004-0.08)	0.07±0.01(0.05-0.08)	0.06±0.01(0.05-0.09	0.07±0.01(0.05-0.09	1.4±0.32(0.04-0.08)
% silt	39.5±6.2(28.0-54.0)	33.8±6.1(23.0-44.0)	38.4±3.6(32.0-44.0)	39.1±5.6(28.0-49.0)	39.2±3.3(33.0-44.0)	47.0±5.3(42.0-52.8
% sand	37.2±7.1(18.0-49.0)	35.8±7.2(24.0-47.0)	37.9±5.2(32.0-45.0)	36.3±7.6(17.0-42.0)	36.2±4.5(34.0-45.0)	49.5±2.7(46.0-53.3)
% clay	27.4±1.9 (12.0-48.0)	37.3±1.8(22.0-49.0)	28.1±1.2(22.0-38.0)	28.6±2.5(15.0-46.0)	27.9±1.2(25.0-38.0)	14.4±2.0(11.7-18.5)
% OC	0.73±0.1(0.22-0.97)	0.54±0.2(0.25-0.98)	0.73±0.2(0.23-0.28)	0.74±0.1(0.26-0.97)	0.70±0.2(0.27-0.91)	5.8±0.9(4.88-6.40)
EC	38.4±5.5 (31.3-49.5)	37.7±5.3(32.3-47.4)	38.1±5.3(30.3-55.5)	38.3±5.9(31.3-46.5)	38.9±5.9(34.3-43.5)	14.2±1.7(12.3-15.8)
pH	4.7±0.4(4.1-5.4)	4.9±0.5(4.2-5.2)	4.8±0.5 (4.4-5.1)	4.6±0.4(4.5-5.5)	4.8±0.4(4.6-5.9)	7.2±0.3(6.9-7.5)
Avail P	20.2±4.9(11.6-29.8)	24.8±3.2(18.4-29.8)	20.5±4.9(13.5-29.8)	18.4±4.2(11.2-25.7)	20.6±4.8(13.8-29.6)	43.3±3.9(39.5-47.4)
Total N	0.06±0.01(0.02-0.08)	0.06±0.02(0.02-0.09)	0.05±0.01(0.01-0.07)	0.06±0.01(0.04-0.09)	0.05±0.011(0.03-0.08)	4.4±0.7(3.8-5.2)

Mean ± SD (Range) ND: Not detected

Source: Field data, Annan (2021)

4.6 Geoaccumulation Index of Heavy Metal Contaminations in Soils, Mpohor Wassa East District

From Mpohor Wassa East, the Igeo values recorded for Cr ranged from a minimum of 0.1 in soils at control sample site and the highest value of 2.6 was recorded at MM (Mpohor Motorway) sampling site. The Igeo values for Arsenic levels ranged from 0.3 in soils at control sampling site to a maximum of 2.5 at sampling site ADT. The Igeo values for Cd ranged from a minimum of 0.2 at control sampling site to a maximum of 3.2 at Sampling site MM. The Igeo values recorded for mercury varied from a minimum of 0.05 in soils at the control site and the highest value of 2.3 was recorded at sample site ASA. The Igeo values recorded for nickel also ranged from a minimum of 0.1 in soils at the control sample site and the highest value of 0.8 was recorded at sampling site ASA. The Igeo values for cobalt ranged from 0.1 in soils at control sample sites and the highest value of 1.1 was recorded in soils sampled at ADT sampling site. The Igeo values recorded for copper varied from a minimum of 0.5 in soils at control sampling and the highest value of 2.8 was recorded in soils at sampling site MM. Lastly, the Igeo values recorded for lead ranged from a minimum of 0.6 in soils at the control sampling site and the highest value of 2.2 was recorded in soils at sampling site MM (Table 4.5). However, Table 4.12 shows the Igeo classification with their absolute values.

Table 4.5: Geoaccumulation Index (Igeo) Values for Soil Samples in Mpohor Wassa District

Community	Cr	As	Cd	Hg	Ni	Co	Cu	Pb
ASA	1.3	1.8	1.9	2.3	0.8	0.4	1.2	1.4
ADT	2.2	2.5	1.5	1.4	0.6	1.1	1.7	1.9
ADW	2.3	1.8	1.5	2.1	1.7	0.8	1.9	1.2
MA	1.7	1.2	2.7	1.3	0.4	0.8	2.4	2.1
MM	2.6	1.6	3.2	1.8	0.5	0.5	2.8	2.2
Control	0.1	0.3	0.2	0.05	0.1	0.1	0.5	0.6

Source: Field data, Annan (2021)

4.7 Contamination Assessment and Hazard Rating of Heavy Metals in Soils, Mpohor Wassa East District

Table 4.6 gives the threshold exceedance ratio and the percentage mobility of the various heavy metals in soil samples in selected sampling sites at Mpohor Wassa East District sampling site in the Western region. The results showed that cobalt has a percentage mobility of 5.2, 4.8, 4, 4.3 and 5.0% for sampling sites ADW, ADT, ASA, MM, and MA respectively. Copper has percentage mobility of 22.9, 37.8, 30.7, 18.6 and 29.2 respectively. Chromium has % mobility of 3.8, 5.8, 8.8,4.9 and 9.4 respectively. Nickel has % mobility of 8.9, 5.1, 9.3, 2.4, and 3.3% respectively. Arsenic has percentage mobility of 15.9, 8.6, 8.3, 9.7and 14.7% respectively.

Table 4.6: Hazard Rating of Heavy Metals in Soil, Mpohor Wassa Sampling Site

Parameter	ADW	ADT	ASA	MM	MA
Cobalt					
NH_4NO_3 Extractable	6.8	14.8	9.5	11.7	9.2
HNO_3 Extractable	3.5	8.2	6.3	7.2	4.9
TER	0.18	0.395	0.25	0.312	0.245
MOB	0.05	0.048	0.041	0.043	0.05
MOB (%)	5.2	4.8	4.1	4.3	5.0
Copper					
NH_4NO_3 Extractable	2.48	1.62	1.52	1.43	1.85
HNO_3 Extractable	0.48	0.19	0.22	0.34	0.28
TER	0.11	0.072	0.07	0.063	0.082
MOB	0.229	0.378	0.307	0.186	0.292
MOB (%)	22.9	37.8	30.7	18.6	29.2
Chromium					
NH_4NO_3 Extractable	0.72	1.38	2.92	1.72	1.85
HNO_3 Extractable	0.28	0.35	0.49	0.52	0.29
TER	0.011	0.021	0.043	0.026	0.027
MOB	0.038	0.058	0.088	0.049	0.094
MOB (%)	3.8	5.8	8.88	4.9	9.4
Nickel					
NH_4NO_3 Extractable	1.46	1.48	1.65	0.82	0.92
HNO_3 Extractable	0.25	0.44	0.27	0.54	0.42
TER	0.022	0.023	0.025	0.013	0.014
MOB	0.089	0.051	0.093	0.023	0.033
MOB (%)	8.9	5.1	9.3	2.4	3.3
Arsenic					
NH_4NO_3 Extractable	5.85	4.92	4.82	3.91	4.98
HNO_3 Extractable	2.37	3.68	3.76	2.58	2.18
TER	0.377	0.317	0.311	0.252	0.321
MOB	0.159	0.086	0.083	0.097	0.147
MOB (%)	15.9	8.6	8.3	9.7	14.7
Mercury					
NH_4NO_3 Extractable	6.14	4.29	7.22	5.84	5.91
HNO_3 Extractable	5.48	3.27	4.28	3.63	2.75
TER	2.456	2.552	3.276	2.28	1.73
MOB	0.314	0.346	0.228	0.349	0.282
MOB (%)	31.4	34.6	22.8	34.9	28.2
Cadmium					
NH_4NO_3 Extractable	35.9	27.3	55.2	62.9	54.3
HNO_3 Extractable	19.2	17.4	45.8	47.4	38.9
TER	2.53	1.73	5.47	6.25	4.28
MOB	0.163	0.123	0.173	0.152	0.143
MOB (%)	16.3	12.3	17.3	15.2	14.3
Lead					
NH_4NO_3 Extractable	1.43	1.82	0.95	1.35	0.76
HNO_3 Extractable	0.38	1.22	0.26	0.21	0.35
TER	0.08	0.05	0.09	0.05	0.032
MOB	0.180	0.072	0.146	0.161	0.142
MOB (%)	18.0	7.2	14.6	16.1	14.2

Source: Field data, Annan (2021)

4.7.1 Physical Parameters of Surface Water, Amansie West District

The mean pH values of the surface water sample (Suben river) from Amansie West ranged from 4.6± 0.25 SD at sampling site DO (Domenase community) to 7.8± 0.5 SD at the control sampling site (Manso) (Figure 9). The pH of surface water samples differed significantly among the sampling locations at a 95% confidence level (F = 64.835; p = 0.0001) (Appendix E). The pairwise comparison using Tukey's HSD showed that there were differences among the following sampling locations: DO and control (p = 0.001); MN (Manso) and control (p = 0.002); AS (Asaman community) and control (p = 0.017). There were, however, no statistically significant differences between sampling sites DO and AS (p = 0.819) and DO and MN (p = 0.549) (Appendix F).

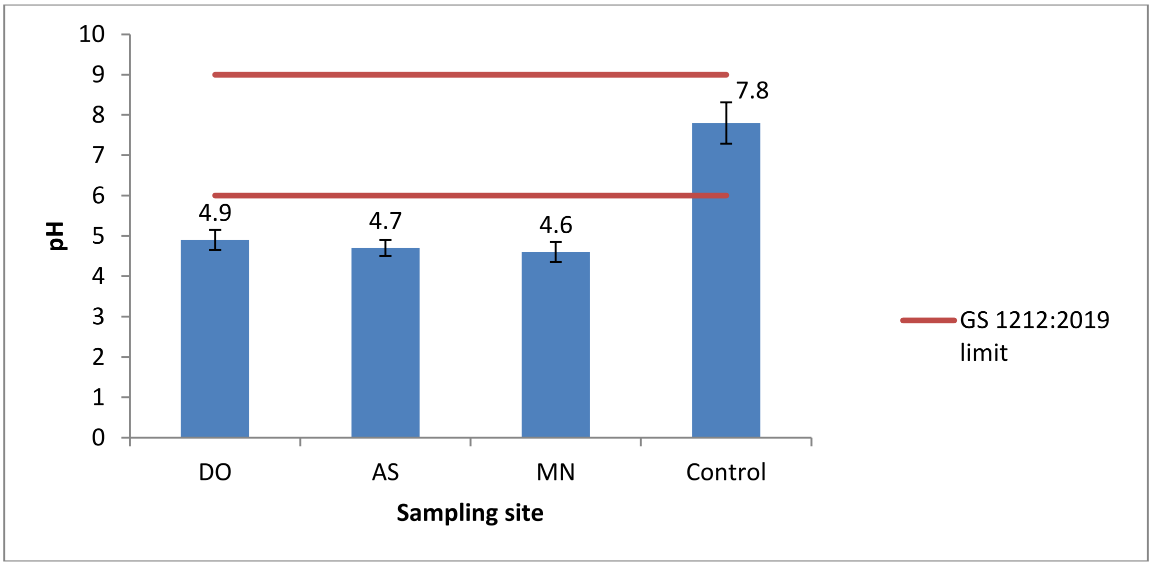

Figure 9: pH Variations across Surface Water Locations at Amansie West District

4.7.2 Electrical Conductivity

With reference to the Amansie West District, the highest conductivity value was recorded at sampling site MN (Manso Nkwanta) with a mean value of 484.8±34.4 µS/cm and the lowest was recorded at the control sampling site with a mean value of 42.7±4.5 S/cm (Figure 10). There was a statistically significant differences in conductivity among sampling sites at 95% confidence level (F=284.146; *p*=0.0001) (Appendix E). Pair wise comparison using Tukey's HSD revealed statistically significant differences among the following; DO and control (p=0.001), MN (Manso Nkwanta) and control (p=0.002), AS (Asaman community) and control (p=0.017). There were also differences between DO and AS and DO and MN (p=0.029) (Appendix F).

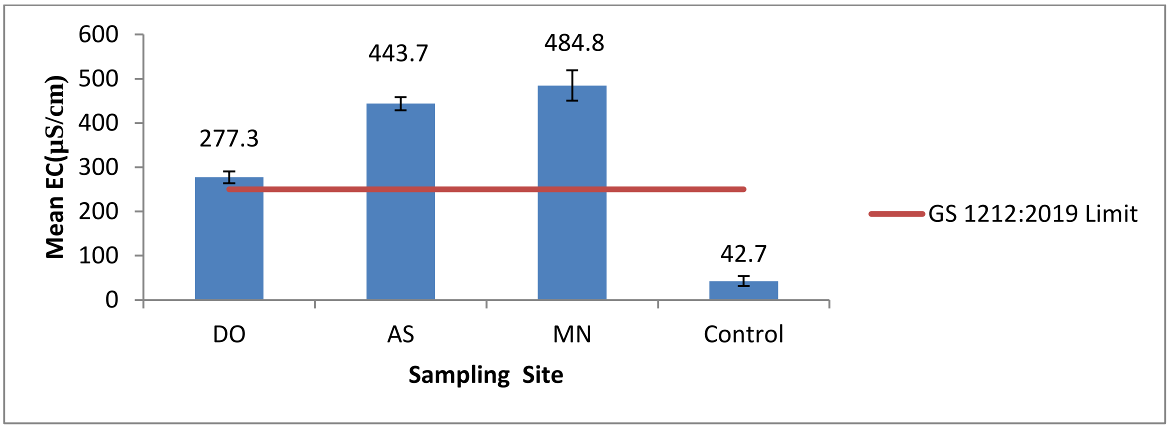

Figure 10: Conductivity Variations across Surface Water Locations, Amansie West District

4.7.3 Total Dissolved Solids

At Amansie West District, the highest conductivity value was recorded in surface water samples at sampling site MN (Manso Nkwanta) with mean value of 226±20.7mg/L and the lowest was recorded at the control sampling site with mean value of 25.33± 6.4mg/L (Figure 11). There was statistically significant difference in conductivity among sampling sites at 95% confidence level (F=124.523; p=0.0001) (Appendix D). Pairwise comparison using Tukey's HSD are shown in (Appendix F).

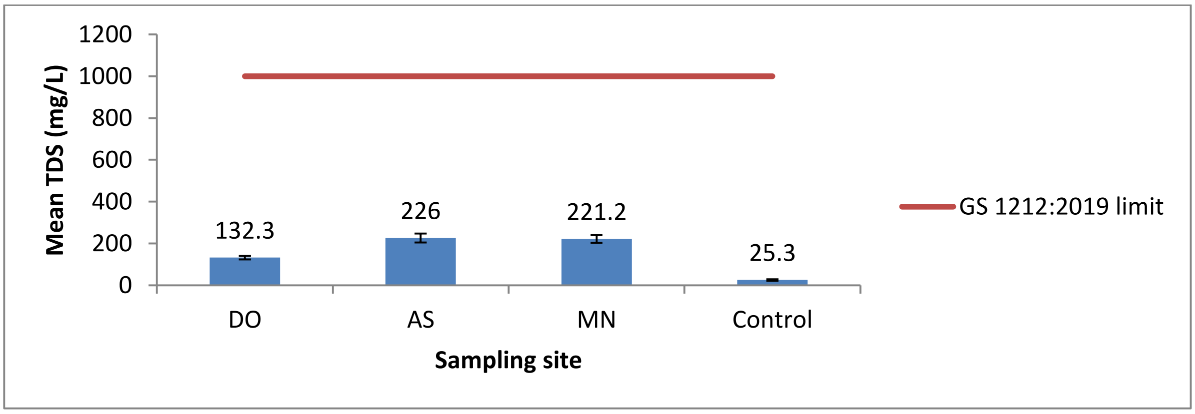

Figure 11: TDS Variations across Surface Water Locations, Amansie West District

4.7.4 Total Suspended Solids

At Amansie West District sampling site in the Ashanti Region, the highest TSS value was recorded in surface water samples at sampling site AS with mean value of 390.7±19.4mg/L and the lowest was recorded at the control sampling site with mean value of 12.5± 0.7mg/L (Figure 12). There was statistically significant difference in TSS among sampling sites at 95% confidence level (F=191.9; *p*=0.0001) (Appendix E). Pair wise comparison using Tukey's HSD revealed statistically significant differences among the following; DO and control (*p*=0.001), DO and AS (*p*=0.001). There were however no differences between DO and MN (*p*=0.830) (Appendix F).

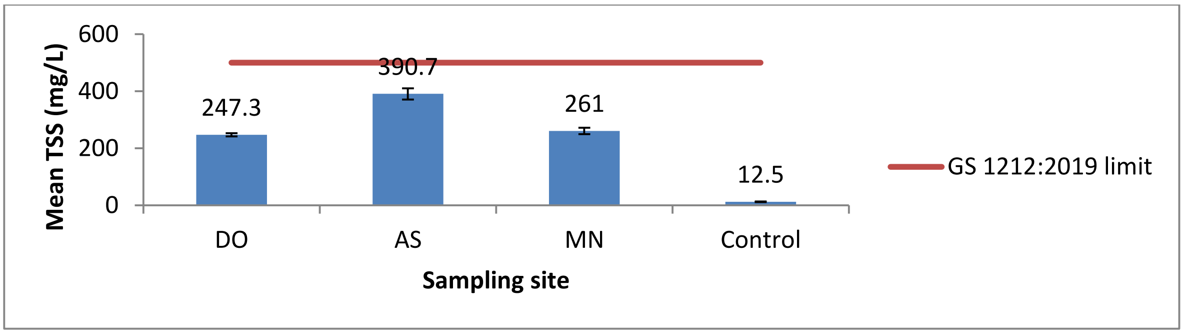

Figure 12: TSS Variations Across Surface Water Locations, Amansie West District

4.7.5 Total Alkalinity

The highest total alkalinity of the surface water samples from Amansie West District was recorded at control sampling site with mean value of 53.3±9.01mg/L whilst the lowest was recorded at sampling site DO with mean value of 2.2 ± 0.72mg/L (Appendix D). The total alkalinity of the water samples differed significantly among sampling sites (F=95.408, *p*=0.0001) (Appendix E). The pairwise comparison using Tukey's HSD showed that there were differences among the following sampling sites; DO and control (p=0.001), MN (Manso) and control(*p*=0.0001), AS (Asaman community) and control (*p*=0.0001). There were however, no statistically significant differences between sampling sites DO and AS and DO and MN as shown in (Appendix F).

4.7.6 Dissolved Oxygen (DO)

The highest DO of the surface water samples from Amansie West District was recorded at control sampling site with mean value of 11.8±2.12mg/L whilst the lowest was recorded at sampling site DO with mean value of 4.3 ± 0.56 mg/L (Appendix D). The Dissolved oxygen differed significantly among sampling sites at 95% confidence level (p=0.001) (Appendix E). There were differences among all sampling sites and the control samples ($p<0.05$) (Appendix F).

4.7.7 Biological Oxygen demand (BOD)

The lowest BOD of the surface water samples from Amansie West District was recorded at control sampling site with mean value of 1.4±0.06mg/L whilst the highest was recorded at sampling site DO (Dominase) with mean value of 2.5±0.57 mg/L (Appendix D). The BOD did not differ significantly among sampling sites (p=0.530) (Appendix E).

4.7.8 Salinity

The lowest salinity of the surface water samples from Amansie West district was recorded at control sampling site with mean value of 0.00mg/L whilst the highest was recorded at sampling site AS with mean value of 0.3 ± 0.01mg/ l (Appendix D). The salinity of the water samples differed significantly among sampling sites (p=0.008) (Appendix E).

4.7.9 Total Hardness

At Amansie West District sampling site in the Ashanti Region, the highest total hardness in water samples was recorded at sampling site MN with mean value of 935.2±48.4mg/L and the lowest was recorded at the control sampling site with mean value of 11.9±4.2mg/L. There was statistically significant difference in total hardness among sampling sites (p=0.0001) (Appendices E and E).

4.7.10 Turbidity

The mean turbidity values of the surface water sample from Amansie West District ranged from a minimum of 2.1±0.7 SD at the control sampling site to a maximum of 822.7± 70.59 SD at sampling site AS. The turbidity values differed significantly among sampling sites (*p*=0.001) (Appendices E and E).

4.8 Heavy Metals in Water, Amansie West District

The heavy metals in surface water samples obtained from Amansie West District sampling sites are as illustrated in Table 4.7. The lowest Fe concentration was recorded in water samples obtained from MN sampling site and ranged from 1.07 to 1.53mg/L with mean value of 1.36±0.25 SD mg/L whilst the highest Fe concentrations was recorded at sampling site AS and varied from (9.73 to 12.28mg/L with mean value of 30.7±2.41 SD mg/L. The lowest Co concentration was recorded in water samples obtained from control sampling sites with values below detection limit (<0.0001) and the highest was recorded at sampling site DO and ranged from 0.13 to 0.27mg/L with mean value of 0.19±0.07SD mg/L.

The lowest Cu concentration was recorded in water samples obtained from control sampling sites with values below detection limit (<0.0001) and the highest was recorded at sampling site DO and ranged from 0.17 to 0.23mg/L with mean value of 0.20±0.03SD mg/L.

With regards to Cr, it was not detected at control sampling sites and the highest value was recorded at sampling site AS and ranged from 0.01 to 0.04 mg/L with mean value of 0.02±0.00 SD mg/L. The lowest Ni concentration was recorded in water samples from control sampling sites and ranged from 0.01 to 0.03mg/L with mean value of 0.02±0.001SD mg/L whilst the highest was recorded at sampling site DO and ranged from 0.52 to 0.63mg/L with mean value of 0.59± 0.06 SD mg/L.

The lowest Zn concentration was recorded in water samples from control sampling sites and ranged from ND to 0.01mg/L with mean value of 0.003±0.001 SD mg/L whilst the highest was recorded at sampling site AS and ranged from 0.35 to 0.45 mg/L with mean value of 0.39±0.05 SD mg/L. Mercury (Hg) was not detected at the control sampling sites whilst the highest Hg concentrations were recorded at sampling site AS and ranged from 0.0019 to 0.0037 mg/L with mean value of 0.0028±0.00 SD mg/L. The lowest Mn concentration was recorded in water samples from control sampling sites and ranged from 0.17 to 0.22mg/L with mean value of 0.2±0.02 SD mg/L whilst the highest was recorded at sampling site AS and ranged from 14.22 to 15.63 mg/L with mean value of 14.9±0.7 SD mg/L (Table 4.7).

Last but not the least, the lowest Cd concentration was recorded in water samples from control sampling sites and ranged from 0.03 to 0.06 mg/L with mean value of 0.04±0.01 SD mg/L and the highest was recorded in water samples at sampling site AS and ranged from 0.27 to 0.39 with mean value of 0.33±0.03SD mg/L.

Lastly, the lowest Pb concentration was recorded in water samples from control sampling sites with mean value of 0.0002±0.00 mg/L and the highest was recorded in water samples at sampling site MN and ranged from 0.005 to 0.04 mg/L with mean value of 0.02±0.01 SD mg/L.

Table 4.7: Heavy Metals in Surface Water, Amansie West District

Var	DO	AS	MN	Control
Fe	10.7±1.36(9.73-12.28)	30.7±2.41(9.73-12.28)	1.36±0.25(1.07-1.53)	22.0±6.7(15.17-28.67)
Co	0.19±0.07 (0.13-0.27)	0.13±0.008(0.13-0.14)	0.003±0.00(ND-0.0001)	<0.0001
Cu	0.20±0.03(0.17-0.23)	0.16±0.07(0.113-0.24)	0.04±0.01(0.03-0.04)	<0.0001
Cr	0.02±0.00 (0.01-0.03)	0.02±0.00(0.01-0.04)	0.01±0.00(0.01-0.02)	ND
Ni	0.59± 0.06 (0.52-0.63)	0.73±0.11(0.63-0.85)	0.06±0.01(0.05-0.07)	0.02±0.001(0.01-0.03)
Zn	0.38± 0.04 (0.35-0.42)	0.39±0.05(0.35-0.45)	0.03±0.01(0.01-0.04)	0.003±0.001(ND-0.01)
As	0.004±0.00(0.003-0.004)	0.004±0.00(0.003-0.005)	0.011±0.00(0.002-0.003)	0.0001±0.00
Hg	0.0028±0.00(0.0019-0.0037)	0.0027±0.00(0.002-0.003)	0.0004±0.00 (0.002-0.006)	ND
Mn	14.0±1.3(12.68-15.28)	14.9±0.7(14.22-15.63)	13.4±0.8(12.65-14.32)	0.2±0.02(0.17-0.22)
Cd	0.30±0.07 (0.18-0.50)	0.33±0.03 (0.27-0.39)	0.23±0.06(0.16-0.28)	0.04±0.01(0.03-0.06)
Pb	0.002±0.00 (0.001-0.003)	0.004±0.00 (0.003-0.005)	0.02±0.01(0.005-0.04)	0.0002±0.00

Mean ± SD (Range) DO: Dominase, AS: Asaman MN: Manso Nkwanta
Source: Field data, Annan (2021)

4.9 Factor Analysis

Principal Component Analysis (PCA) is a data reduction technique. It checks the features of the data that are redundant and condenses the information into principal components without losing information from the original data (Pallant, 2005). Factor Analysis (FA) is an interdependent approach that defines the underlying variables or dimensions that explain most of the variance in the large data set. In this study, PCA was computed to reduce the large data set of physico-chemical parameters into principal components. After which Factor Analysis was computed to find the distinct number of factors to retain.

A data set must satisfy some statistical assumptions before factor analysis can be computed (Pallant, 2005). One of the assumptions to determine whether a data set is suitable for factor analysis is the sample size. A sample size of 150 or more is ideal for factor analysis (Pallant, 2005). Furthermore, it is a rule of thumb that a correlation coefficient of r = 0.3 or better is required for factor analysis (Pallant, 2005). Kaiser Meyer-Olkin (KMO) and Bartlett’s test of sphericity can also be used to determine the factorability of data. Bartlett's test of sphericity must be significant ($p < 0.05$), before factor analysis can be computed (Pallant, 2005). The coefficient of the KMO test must be between 0 and 1, with 0.6 as the threshold for factor analysis (Tabachnick & Fidell, 2007). The data set for this study satisfied all the assumptions stated above. Bartlett's test of sphericity was found significant ($p = 0.000$) and the coefficient of the KMO test was also high (0.817).

4.9.1 Factor Analysis of Physicochemical Parameters of Surface Water, Amansie West District

In all, a total of 25 principal components were extracted from Amansie West District; however, the first five components cumulatively explained 95.327% of the total variance and were therefore retained in the model. The first principal component (*PC-1*) contributed 43.835 % of the total variance and was strongly loaded by the following variables; EC, TDS, pH, salinity, TSS, Alkalinity, Bicarbonates, Total hardness, Cr, Hg, Mg, Mn, Ca and K. Nickel, As, Pb, and Cd were also moderately loaded in the first *PC-1*. The 2nd principal component, *PC*-2 contributed 29.484 % of the total variance and was highly loaded by turbidity, Co, Cu, Ni, Zn, As, Hg and Na. The 3rd principal component, *PC*-3 contributed 8.863 % of the total variance and was strongly loaded by two heavy metals; Arsenic and lead. The 4th component (*PC*-4) explains 8.213% of the total variance and was strongly loaded by only iron (Fe). The 5th component (*PC*-5) contributed 4.932% of the total variance and all variables were observed to have weak factor loadings. The communalities of the data set also revealed that the individual physicochemical parameters contributed more than 70% each of the total variance (Table 4.8). Concerning the scree plot, even though five factors had eigenvalues > 1 the elbow effect was very clear at the fourth factor (see Figure 13).

Table 4.8: Component Matrix of physico-Chemical parameters, Amansie West

Variable	Components					
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**Communalities**
Temperature	0.197	-0.082	0.288	-0.049	**0.427**	0.950
EC	0.972*	0.055	0.205	-0.057	0.064	0.997
TDS	0.935*	0.129	0.306	0.058	0.048	0.990
pH	-0.878*	-0.338	-0.127	0.248	-0.127	0.980
Salinity	0.872*	0.236	-0.210	0.218	0.177	0.940
TSS	0.874*	0.432	0.109	0.133	-0.049	0.983
Alkalinity	-0.821*	-0.427	-0.198	0.248	0.056	0.961
Bicarbonates	-0.830*	-0.401	-0.184	0.287	0.005	0.967
Turbidity	0.417	0.794*	-0.092	0.402	-0.042	0.976
Total Hardness	0.939*	0.268	0.166	0.088	-0.010	0.989
Fe	-0.177	0.291	-0.232	0.892*	-0.072	0.970
Co	0.154	0.948*	-0.120	-0.068	0.038	0.943
Cu	0.316	0.900*	-0.080	-0.020	0.150	0.939
Cr	0.743*	0.199	-0.127	-0.249	0.320	0.773
Ni	0.670**	0.874*	-0.116	0.283	-0.017	0.994
Zn	0.310	0.927*	-0.103	0.157	-0.059	0.994
As	0.725**	0.747*	0.912*	-0.080	0.203	0.932
Hg	0.818*	0.909*	-0.011	0.096	-0.136	0.955
Mg	0.858*	0.361	0.257	-0.120	0.025	0.948
Mn	0.815*	0.496	0.203	-0.186	0.058	0.990
Ca	-0.825*	-0.303	-0.172	0.284	-0.246	0.942
K	0.811*	0.397	-0.010	0.408	-0.062	0.986
Na	0.313	0.774*	0.055	-0.526	-0.032	0.978
Pb	0.538**	-0.336	0.821*	-0.219	0.089	0.958
Cd	0.583**	0.568**	0.234	0.014	-0.284	0.799
Eigenvalue	15.136	4.776	1.779	1.115	1.026	
% of variance	43.835	29.484	8.863	8.213	4.932	
% Cumulative	43.835	73.318	82.181	90.394	95.327	

*Strong (factor score>0.75); **Moderate (0.5≤score≤0.75), Weak

Source: Field data, Annan (2021)

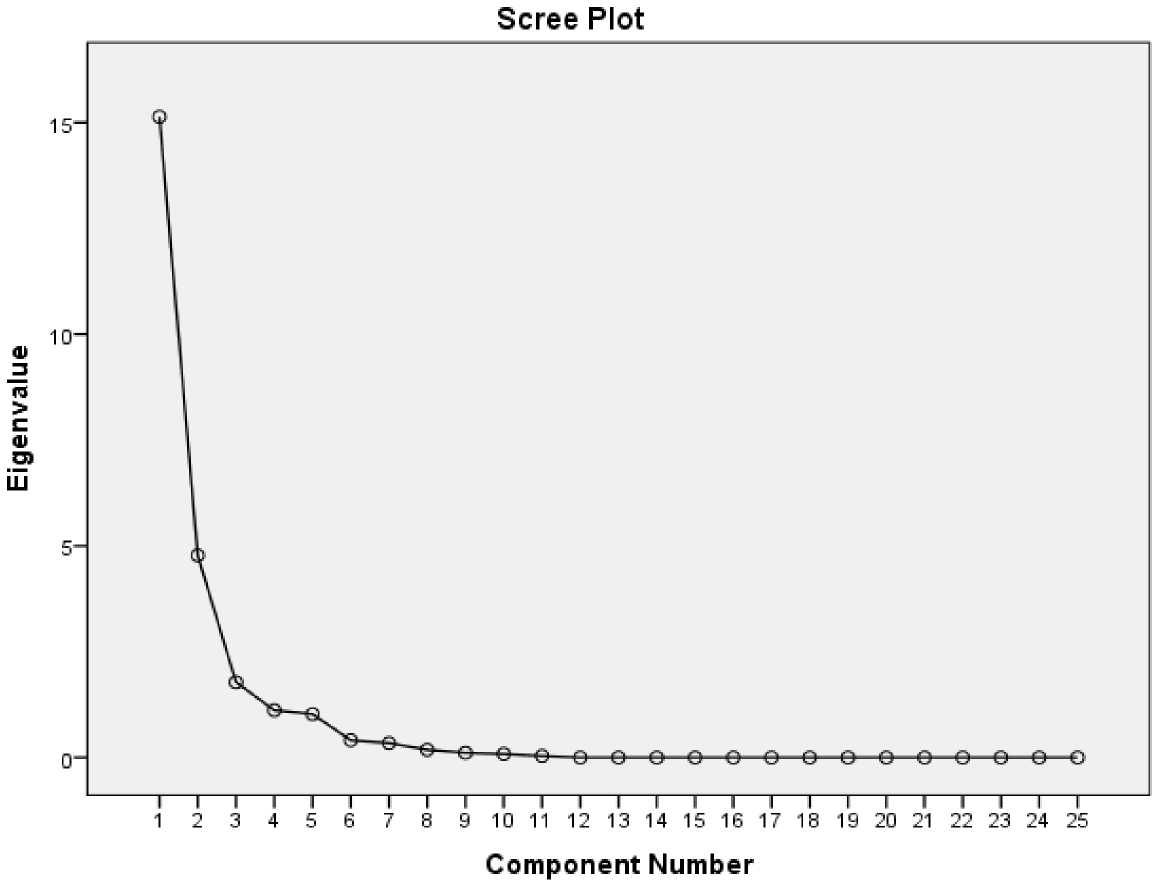

Figure 13: Scree plot of physico-Chemical Parameters, Amansie West District

4.10 Correlation of Physico-Chemical Parameters of Surface Water, Amansie West

Table 4.10 illustrates the summary of Karl Pearson's product moment correlation matrix between physico-chemical parameters and surface water samples from Amansie West District sampling sites. The correlation analysis of samples obtained from Amansie West surface water samples revealed that there was a significant positive correlation between the following variables; EC and TDS (r=0.976), EC and salinity (r=0.720), EC and total hardness (r=0.959), EC and magnesium (r=0.876), Alkalinity and Bicarbonates (r=0.936), TDS and TSS (r=0.632), Salinity and Total hardness (r=0.850), Ca and hardness (r=0.866), Ca and bicarbonates(r=0.944). There was a strong negative correlation between pH and the following heavy metals (Cr, Ni, Cd and Zn with correlation coefficient of at least ($r \geq 0.5$) in surface water samples obtained from Amansie West Sampling sites, pH- Fe (r=0.311), pH- Co(r=-0.463), pH- Cu (r-0.573), pH - Cr(r=-0.781), pH- Ni(r=0.615), pH- Zn (r=-0.524), pH-As (r=-0.326), pH-Hg (r=-0.543), pH-Pb (r=-0.348) and pH-Cd(r=-0.688).

Table 4.9: Correlation between Physico-Chemical Parameters in Water Samples, Amansie West District

Parameter	*EC*	*TDS*	*TSS*	*Sal*	*Na*	*Mg*	*Ca*	*Alkal*	*Bicar*	*Hardness*
EC	1									
TDS	0.976**	1								
TSS	0.888**	0.902**	1							
Sal	0.720*	0.818**	0.833*	1						
Na	0.390	0.372	0.554	0.304	1					
Mg	0.876*	0.881**	0.920*	0.762*	0.643	1				
Ca	-0.088*	-0.871	0.823*	-0.723	0.637	0.883*	1			
Alkalinity	-0.877*	-0.865*	0.889*	0.713*	-0.752	-0.96*	0.875	1		
Bicarbonates	-0.881*	-0.871*	0.568	0.714	-0.420	-0.93*	0.94**	0.936**	1	
Hardness	0.959**	0.962**	0.977*	0.850*	0.475	-0.94*	0.86*	0.898*	0.896*	1

***Correlation is significant at p < 0.01 level (2-tailed).*
**Correlation is significant at p < 0.05 level (2-tailed)*
Source: Field data, Annan (2021)

4.11 Soil Physical Parameters, Amansie West District

4.11.1 pH

With regards to Amansie West sampling sites, MN recorded the lowest pH with mean value of 4.56±0.51 whilst the highest value was recorded in the control sample with mean value of 7.2±1.1 (Table 4.10). Analysis of variance at 95% confidence level revealed statistically significant difference in pH among soil samples obtained from the sampling sites (P < 0.05) (Appendix K).

4.11.2 Conductivity

From Amansie West District, the highest value of conductivity was recorded in soil samples obtained from BYO with mean value of 74±2.5 µS/cm whilst the lowest value was recorded in soils samples from the control samples with mean value of 3.5±0.05µS/cm (Table 4.10). There was statistically significant difference in conductivity among soil samples obtained from the sampled sites (*P* <0.05) (Appendix K).

4. 11.3 Available phosphorus

The highest available phosphorus in soil was recorded from the control soil samples at Amansie West District with mean value of 18.2±1.24 mg/Kg whilst the lowest value was recorded in soil samples from BYO with a mean value of 12.4±0.50mg/Kg (Table 4.10). There was a statistically significant difference in available phosphorus levels among soil samples obtained from the sampled sites' waste dump sites ($P < 0.05$).

4.11.4 Organic Carbon (%)

Table 4.4 from Amansie West District, indicates the mean values of % organic carbon in soil obtained from the sampling sites. The highest percentage organic carbon was recorded in soils from the control site with mean value of 2.8±0.09 % whilst the lowest value was recorded in DO sampling site with mean value of 0.05±0.01% (Table 4.10). There was a statistically significant difference in % organic carbon among soils from the various sampling sites ($P < 0.05$) (Appendix K).

4.11.5 Percentage Sand, Silt and Clay

From Amansie West District, the highest value of % sand was recorded in soils from DO sampling site with mean value 62.1±5.1 % whilst the lowest was recorded in MN sampling site with mean value of 31.86±5.16 %. The percentage sand differed significantly among the sampling sites studied at 95% confidence level ($P < 0.05$) (Appendix K).

The highest percentage of silt was recorded in soils from the control sampling site with mean value 45.0±4.2 % whilst the lowest was recorded in soil samples from BYO with mean value of 15.0±2. % (Table 4.10). There was a statistically significant difference in percentage silt among soil samples obtained from the various sampling sites ($P < 0.05$) (Appendix K).

The highest % clay was recorded in soils obtained from sampling site BYO with mean value of 26.0±3.8% whilst the lowest was recorded in the control sampling point with mean value of 16.0±1.4%. The percentage of sand in soil samples obtained from the sampling sites daggered significantly (*P* <0.05) (Appendix K).

4.11.6 Exchangeable K, Ca, Mg and Na

The highest exchangeable potassium in soil was recorded in the control site at Amansie West District ranged from 0.23 to 0.35 cmol (+)/Kg with mean value of 0.28 cmol (+)/Kg whilst the lowest value ranged from 0.01 to 0.04 cmol (+)/Kg with mean value of 0.02±0.001 cmol (+)/Kg (Table 4.10). There was no statistically significant difference in exchangeable potassium in soils obtained from sampling sites (P >0.05) (Appendix K).

The control sampling site recorded the highest exchangeable calcium in soil and ranged from 5.72 to 7.48 cmol (+)/Kg with mean value of 6.72±0.59 cmol (+)/Kg whilst the lowest value ranged from 0.25 to 0.78 (4.85 to 4.94 cmol (+)/Kg and was recorded in sampling site AS with mean value of 0.41±0.08 cmol(+)/Kg (Figure 4.10). The exchangeable calcium differed significantly among the sampling sites at 95% confidence level (P <0.05) (Appendix K).

The highest exchangeable potassium in soil was recorded in the DO Sampling site and ranged from 3.91 to 5.89 cmol (+)/Kg with mean value of 4.57±0.56 cmol (+)/Kg whilst the lowest value ranged from 0.21 to 0. cmol (+)/Kg and was recorded in sampling site AS with mean value of 0.28±0.07 cmol (+)/Kg. Analysis of variance revealed a statistically significant difference in exchangeable magnesium in soils obtained from the sampling sites (P <0.05) (Appendix A).

The highest exchangeable sodium in soil was recorded in soil samples obtained from DO and ranged from 0.24 to 0.62 cmol (+)/Kg with mean value of 0.40±0.13 cmol (+)/Kg whilst the lowest value ranged from 0.12 to 0.28 cmol (+)/Kg and was recorded in BYO sampling site with mean value of 0.16±0.03 cmol (+)/Kg (Table 4.10). There was a statistically significant difference in exchangeable sodium in soils obtained from the sampling sites (P <0.05).

Table 4.10: Physico-Chemical Parameters in Soil, Amansie West District

	MN	DO	BYO	AS	Control
Cr	0.47±0.06 (0.37-0.59)	0.42±0.09(0.28-0.56)	0.64±0.08(0.50-0.80)	0.58±0.14(0.33-0.43)	0.28±0.02(0.12-0.42)
As	3.58±0.57 (2.5-4.5)	3.49±1.04(1.8-4.9)	3.26±0.42(2.40-3.80)	2.95±0.41(2.10-3.70)	1.11±0.43(0.5-1.17
Cd	28.9±5.77 (22.8-40.2)	23.01±1.6(20.7-25.3)	58.02±5.06(50.2-67.2)	59.5±14.4(39.5-436)	8.16±1.24(4.8-15.8)
Hg	6.44±0.47 (5.30-7.20)	4.67±0.55(3.9-5.5)	6.2±0.68(5.2-7.2)	4.6±0.75(3.2-6.3)	ND
Ni	0.39± 0.05 (0.30-0.49)	0.54±011(0.30-0.72)	0.25±0.01(0.16-0.380)	0.46±0.15(0.20-0.65)	0.18±0.04(0.18-0.)
Zn	48.4± 6.45 (37.8-59.5)	5.1±1.52(1.8-6.9)	15.7±1.36(13.47-18.5)	20.7±4.7(12.48-27.4)	68.5±4.8(6.5-75.4)
Cu	0.25± 0.02 (0.21-0.35)	0.15±0.04 (0.10-0.22)	0.18±0.05(0.10-0.27)	0.26±0.04(0.1-0.35)	0.06±0.01(0.01-0.08)
Pb	0.53± 0.11 (0.37-0.72)	1.5±0.31(1.1-2.2)	0.31±0.08 (0.21-0.46)	0.34±0.09(0.23-0.56)	0.03±0.0(0.01-0.04)
Fe	4251.5±363.8 (3549-4727)	5374.6±1054(4016-6725)	4868±592.8(4164-5723)	3847±428(3175-4734)	5796.1±587(4835-6745
Co	4.20±0.79 (3.20-6.20)	9.6±2.0 (7.4-12.4)	7.3±0.85(5.4-8.8)	8.9±0.84(7.2-11.4)	2.6±0.7(1.3-3.9)
Ca	2.05±0.39 (1.59-2.74)	3.99±0.62 (3.02-4.7)	0.62±0.10(0.47-0.78)	0.41±0.08 (0.25-0.78)	6.72±0.59(5.72-7.48)
Mg	4.19±0.71(2.68-2.740)	4.57±0.56(3.91-5.89)	0.41±0.08(0.28-0.51)	0.28±0.07(0.21-0.54)	4.55±0.46(4.0-5.3)
Na	0.26±0.04 (0.212-0.372)	0.40±0.13(0.24-0.62)	0.16±0.03(0.12-0.28)	0.22±0.11(0.00-0.482)	0.29±0.1(0.16-0.34)
K	0.04±0.007(0.027-0.052)	0.03±0.01(0.01-0.08)	0.06±0.003(0.04-0.08)	0.02±0.001(0.01-0.04	0.28±0.01(0.23-0.35)
% silt	40.0±5.76 (28.0-49.0)	24.8±5.7(21.0-29.0)	15.0±2.7(11.0-22.0)	34.0±1.8(22.0-38.0)	45.0±4.2(12.0-18.0
% sand	31.86±5.16 (23.0-41.0)	62.1±5.1(53.0-68.0)	59.1±4.3(51.0-62.5)	44.0±4.8(33.0-48.0)	39±2.1(32-49)
% clay	25.4±4.03 (18.0-32.0)	17.1±4.0 (12.0-23.0)	26.0±3.8(14.0-38.0)	23±2.5(18.0-41.0)	16.0±1.4(12-25)
% OC	0.62±0.17 (0.36-0.92)	0.05±0.01(0.01-0.08)	0.64±0.12(0.44-0.92)	0.15±0.04(0.12-0.28)	2.8±0.09(1.2-3.8)
EC	45.0±5.7 (36.4-56.70)	25±1.6(22.8-27.9)	74±2.5(62.4-82.5)	13.0±0.9(11.2-18.6)	3.5±0.05(2.5-4.9)
pH	4.56±0.51(3.80-5.30)	6.5±0.5(6.2-6.9)	4.8±0.4 (3.8-5.4)	5.8±0.8(5.2-6.4)	7.2±1.1(6.8-7.5)
Avail P	15.86±0.93(14.20-17.10)	15.2±0.93(14.7-16.3)	12.4±0.50(10.4-13.8)	14.6±0.82(11.8-16.2)	18.2±1.24(16.5-24.3)
Total N	0.05±0.002(0.01-0.09)	0.04±0.01(0.01-0.08)	0.08±0.02(0.03-1.24)	0.02±0.00(0.0-0.04)	2.8±0.04(1.25-3.26)

Mean ± SD (Range) ND: Not detected
Source: Field data, Annan (2021)

4.12 Geoaccumulation Index of Heavy Metal Contaminations in Soils, Amansie West District

Table 4.11 illustrates the Igeo values for soils in the various sampling sites at Amansie West District and Table 4.12 shows the Igeo classification with their absolute values. The Igeo values recorded for Cr ranged from a minimum of 0.8 in soils at control sampling site and the highest value of 2.0 was recorded at BYO sampling site. The Igeo values for Arsenic levels ranged from 0.0 in soils at control sampling sites to a maximum of 0.1 at sampling sites MN and DO. The Igeo values for Cd ranged from a minimum of 0.1 at controlling sampling site to a maximum of 1.2 at Sampling site BYO. The Igeo values recorded for mercury varied from a minimum of 0.1 in soils at the control site and the highest value of 0.5 was recorded at sampling sites BYO and MN. The Igeo values recorded for nickel also ranged from a minimum of 0.2 in soils at the control sampling site and the highest value of 5.0 was recorded at sampling site DO. The Igeo values for cobalt ranged from 0.3 in soils at control sampling sites and the highest value of 1.2 was recorded in soils sampled at DO sampling site. Last but not the least, the Igeo values recorded for copper varied from a minimum of 0.01 in soils at sampling site DO and the control sampling site and the highest value of 0.03 was recorded in soils at sampling site AS. Lastly, the Igeo values recorded for lead ranged from a minimum of 0.03 in soils at the control sampling site and the highest value of 0.2 was recorded in soils at sampling site DO.

Table 4.11: Geoaccumulation Index (Igeo) Values for Soil Samples in Amansie West District

Community	Cr	As	Cd	Hg	Ni	Co	Cu	Pb
MN	1.4	0.1	0.6	0.5	3.6	0.7	0.02	0.07
DO	1.3	0.1	0.5	0.4	5.0	1.2	0.01	0.2
BYO	2.0	0.0	1.2	0.5	2.1	0.6	0.02	0.04
AS	1.7	0.0	1.1	0.4	4.2	0.5	0.03	0.05
Control	0.8	0.0	0.1	0.1	0.2	0.3	0.01	0.03

Source: Field data, Annan (2021)

Table 4.12: Suggested Igeo classification and absolutes

Igeo values	Igeo class	Designation of soil quality
>5	6	Extremely contaminated
4-5	5	Strongly to extremely contaminated
3-4	4	Strongly contaminated
2-3	3	Moderately to strongly contaminated
1-2	2	Moderately contaminated
0-1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

Source: Atiemo, (2011)

4.13 Contamination Assessment and Hazard Rating of soils, Amansie West District

The current contamination situation at Amansie West District was investigated by using the threshold excedance ratio (TER) and the trace element mobility coefficient (MOB) which was expressed in percentage points. “The geochemical background values for heavy metals used are; Cr (67.30mg/Kg), Cd (10 mg/Kg), Ni (65.40mg/Kg) and Pb (21mg/Kg), Cu (22.50mg/Kg) and *As* (15.5mg/Kg), Hg (2.5 mg/Kg) and Co (37.5mg/Kg) (Taylor and Meclenan, 1985). Table 4.13 illustrates the results of the threshold excedance ratio and the percentage mobility of the various heavy metals in soil samples in selected sampling sites at Amansie West in the Ashanti Region. The results showed that cobalt has a percentage mobility of 4.76, 3.55, 4.23, 3.83 and 5.02 for sampling sites MN, DO, BYO and AS respectively. This is an indication that when environmental conditions are favorable, cobalt has the percentage potential of remobilizing back into the soil the above percentage points in the studied sampling communities. Copper has % mobility of 22.7, 45.3, 33.33% and 24.78 for sampling sites; MN, DO, BYO and AS respectively. Chromium has % mobility of 2.91, 4.57, 4.48, and 3.56 for sampling sites; MN, DO, BYO and AS respectively. Nickel has % mobility of 4.94, 3.91, 3.64 and 3.10 for sampling sites; MN, DO, BYO and AS respectively. Arsenic has %mobility of 9.42, 8.73, 9.54 and 8.55 for sampling sites; MN, DO, BYO and AS respectively. Finally, Mercury has % mobility of 5.14, 5.46, 5.28 and 4.90 for sampling sites; MN, DO, BYO and AS respectively (Table 4.13).

Table 4.13: Hazard rating of heavy metals in soil, Amansie West District sampling sites

Parameter	MN	DO	BYO	AS
Cobalt				
NH_4NO_3 Extractable	7.5	12.8	11.6	12.8
HNO_3 Extractable	4.2	9.6	7.3	8.9
TER	0.20	0.341	0.309	0.341
MOB	0.047	0.035	0.042	0.038
MOB (%)	4.76	3.55	4.23	3.83
Copper				
NH_4NO_3 Extractable	1.28	1.53	1.35	1.45
HNO_3 Extractable	0.25	0.15	0.18	0.26
TER	0.06	0.068	0.06	0.064
MOB	0.228	0.453	0.333	0.247
MOB (%)	22.71	45.33	33.33	24.78
Chromium				
NH_4NO_3 Extractable	0.92	1.26	1.93	1.39
HNO_3 Extractable	0.47	0.42	0.64	0.58
TER	0.013	0.018	0.028	0.020
MOB	0.029	0.044	0.044	0.035
MOB (%)	2.91	4.57	4.48	3.56
Nickel				
NH_4NO_3 Extractable	1.26	1.38	1.45	0.92
HNO_3 Extractable	0.39	0.54	0.23	0.46
TER	0.019	0.021	0.022	0.014
MOB	0.049	0.039	0.096	0.031
MOB (%)	4.94	3.91	9.64	3.1
Arsenic				
NH_4NO_3 Extractable	5.28	4.72	4.82	3.91
HNO_3 Extractable	3.58	3.49	3.26	2.95
TER	0.337	0.305	0.311	0.25
MOB	0.094	0.087	0.095	0.085
MOB (%)	9.42	8.73	9.54	8.55
Mercury				
NH_4NO_3 Extractable	8.28	6.38	8.19	5.72
HNO_3 Extractable	6.44	4.67	6.20	4.6
TER	3.312	2.552	3.276	2.28
MOB	0.0514	0.0546	0.0528	0.049
MOB (%)	5.14	5.46	5.28	4.90
Cadmium				
NH_4NO_3 Extractable	35.3	64.7	62.5	9.4
HNO_3 Extractable	28.9	58.02	59.5	8.16
TER	3.53	6.47	6.25	0.94
MOB	0.122	0.112	0.111	0.115
MOB (%)	12.21	11.20	11.10	11.52
Lead				
NH_4NO_3 Extractable	1.38	0.82	1.22	0.59
HNO_3 Extractable	0.53	0.31	0.34	0.23
TER	0.06	0.04	0.06	0.028
MOB	0.130	0.126	0.171	0.122
MOB (%)	13.01	12.6	17.00	12.22

TER: Threshold Exceedance Ratio; MOB: Mobility
Source: Field data, Annan (2021)

4.14 Land use and Land Cover Change

The Land use and Land cover changes in the two studied artisanal and small-scale mining sites were investigated. The results of the land cover classification are shown in Figure 4.11 For the study area in Amansie East District (a and b in Figure 4.11), an overall accuracy of 97% was obtained for 2015 with an overall Kappa statistic of 0.95. With 2020, an overall accuracy of 95% was attained and a Kappa statistic of 0.93 was attained. A Kappa value ranging between 0.81 and 1.00 shows that there is almost a perfect agreement with the classification. For the study area in Mpohor Wassa East District in the graphical representation (c and d in Figure 14). An overall accuracy of 95% was obtained for both years with an overall Kappa statistic of 0.91.

Through the analyses of temporal Landsat TM and ETM satellite images, field verification, and monitoring of LULC changes, it has become clear that there have been changes in the land cover in the studied area. Comparing the two study areas, it shows that the study area in Amansie East District is more developed than that of Mpohor Wassa East District. The impervious surfaces in the former are greater than the latter. The impervious surfaces comprise mainly of settlement and roads and these are the areas in red (Figure 14). However, from both classifications, the dominant land cover was the vegetation cover.

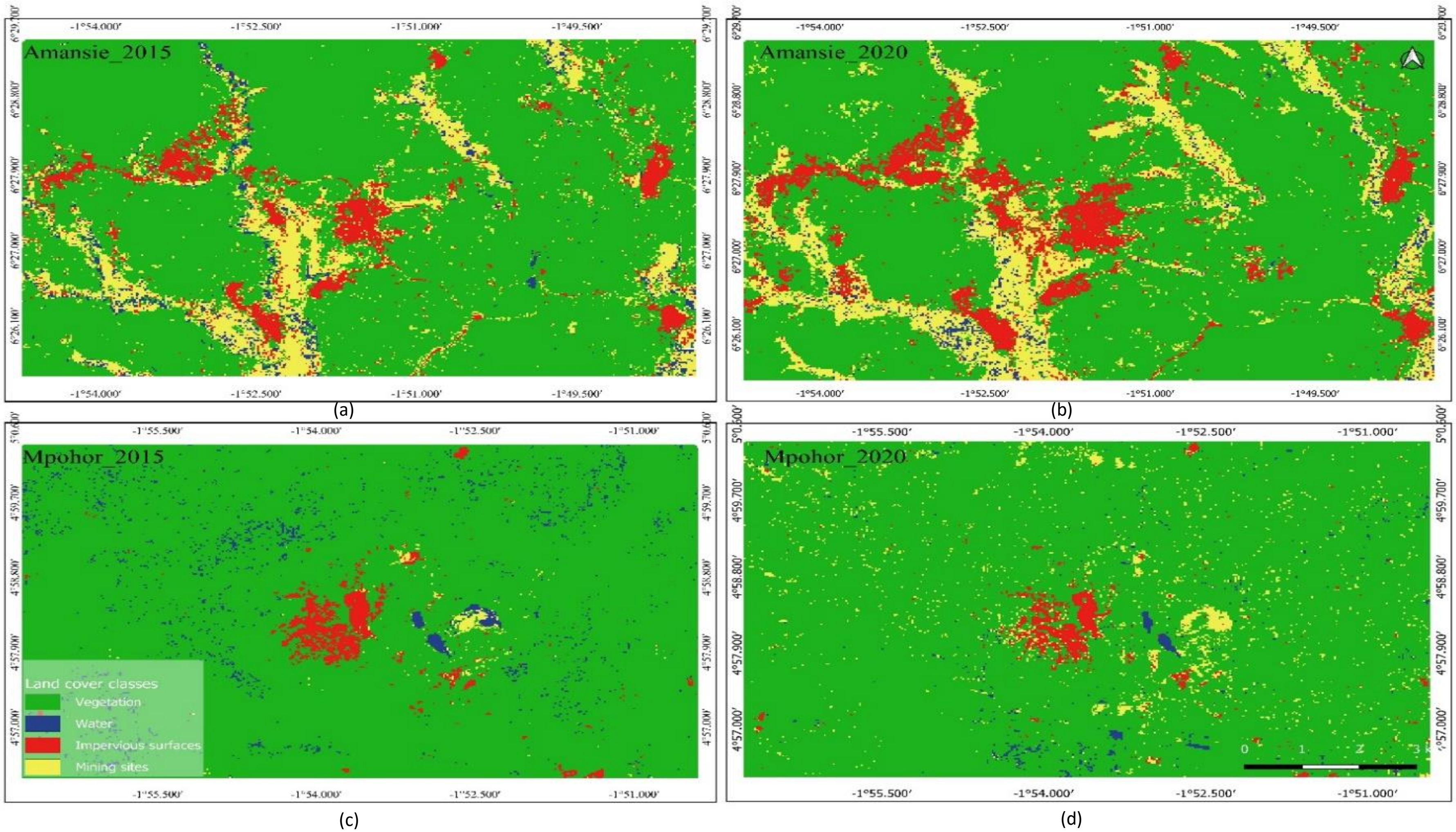

Figure 14: Land cover classification map for 2015 and 2020, Amansie East District (Top Row, a and b) and Mpohor Wassa East District (Bottom Row, c and d)

Source: Field data, Annan (2021)

It can also be seen from the results of the land cover classification maps that the Amansie East District is engaged in mining more than the Mpohor Wassa East District. This land cover is represented by the gold colour in the classification maps. Due to the fact that impervious surfaces and mining sites in the study area in the Amansie East District are more than those in the second study area in the Mpohor Wassa East District, the majority of the vegetation cover in the latter is intact. Therefore, not many trees have been cut down to make way for settlement or mining in this area. However, Figure 15 and 16 are the change detection maps of the selected areas in the Amansie East District and Mpohor Wassa for the five years. They describe the land cover change patterns and changes in the land use over the span of five years. Again, Figure 17 is a graphical representation of the area of each class in km^2.

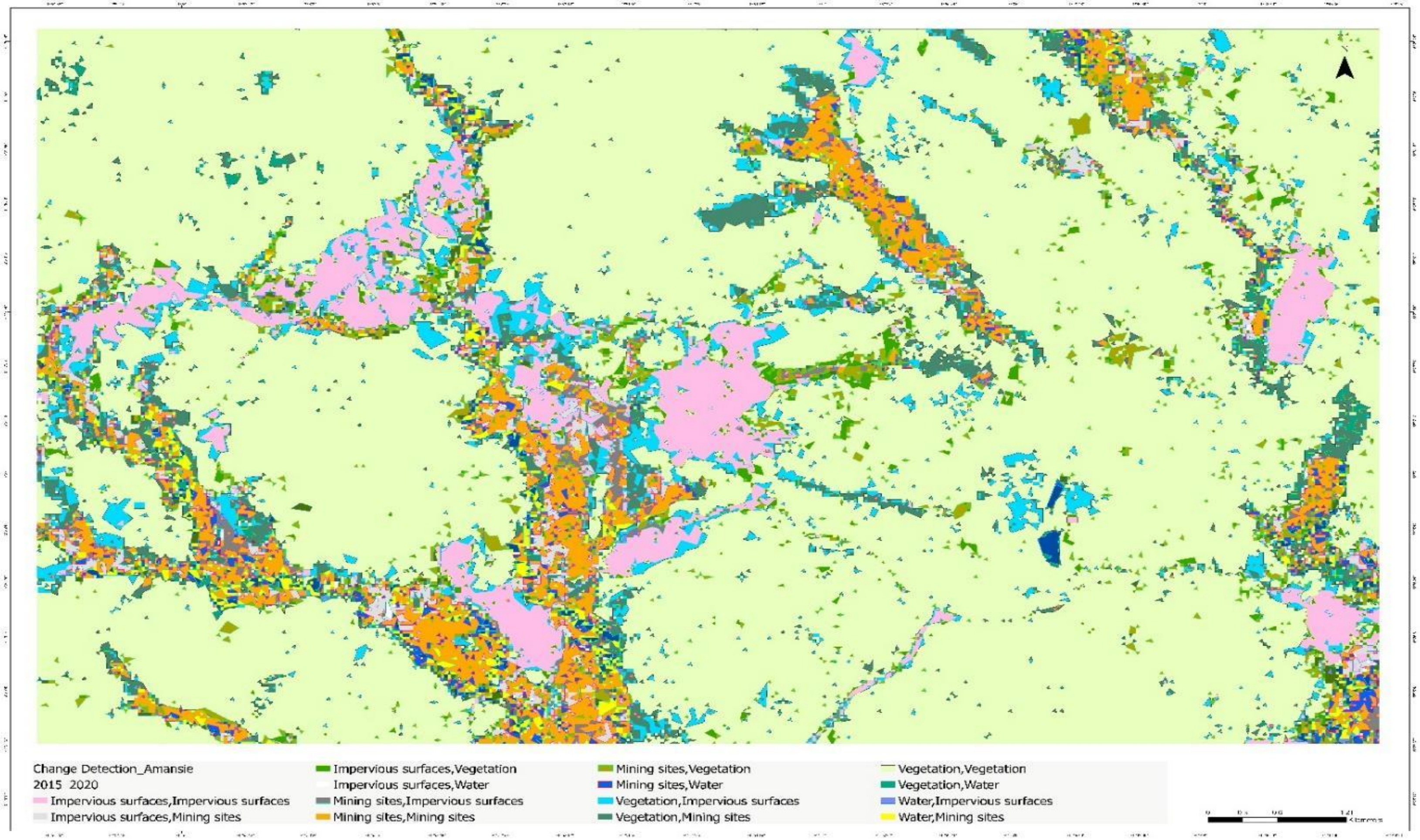

Figure 15: Change detection map of selected area in the Amansie West District

Source: Field data, Annan (2021)

The result of the change detection shows that in the area that lies within the Amansie West District, within five years, the vegetation cover reduced from 67.46 to 63.89 km^2 which is about 4% reduction whereas the other classes generally increased. Mining sites which are the focus of this study increased from 7.70 to 9.79 km^2 representing approximately a 3% increase. With the reduction in the vegetation cover, a greater portion of vegetation lost was taken over by mining. The increase in the water class from 1.96 to 2.02 km^2 can be attributed to the clearing of vegetation cover and diverting water to those areas near the mining sites. Impervious surfaces increased from 7.76 to 9.20 km^2 showing the expansion of settlement in this region.

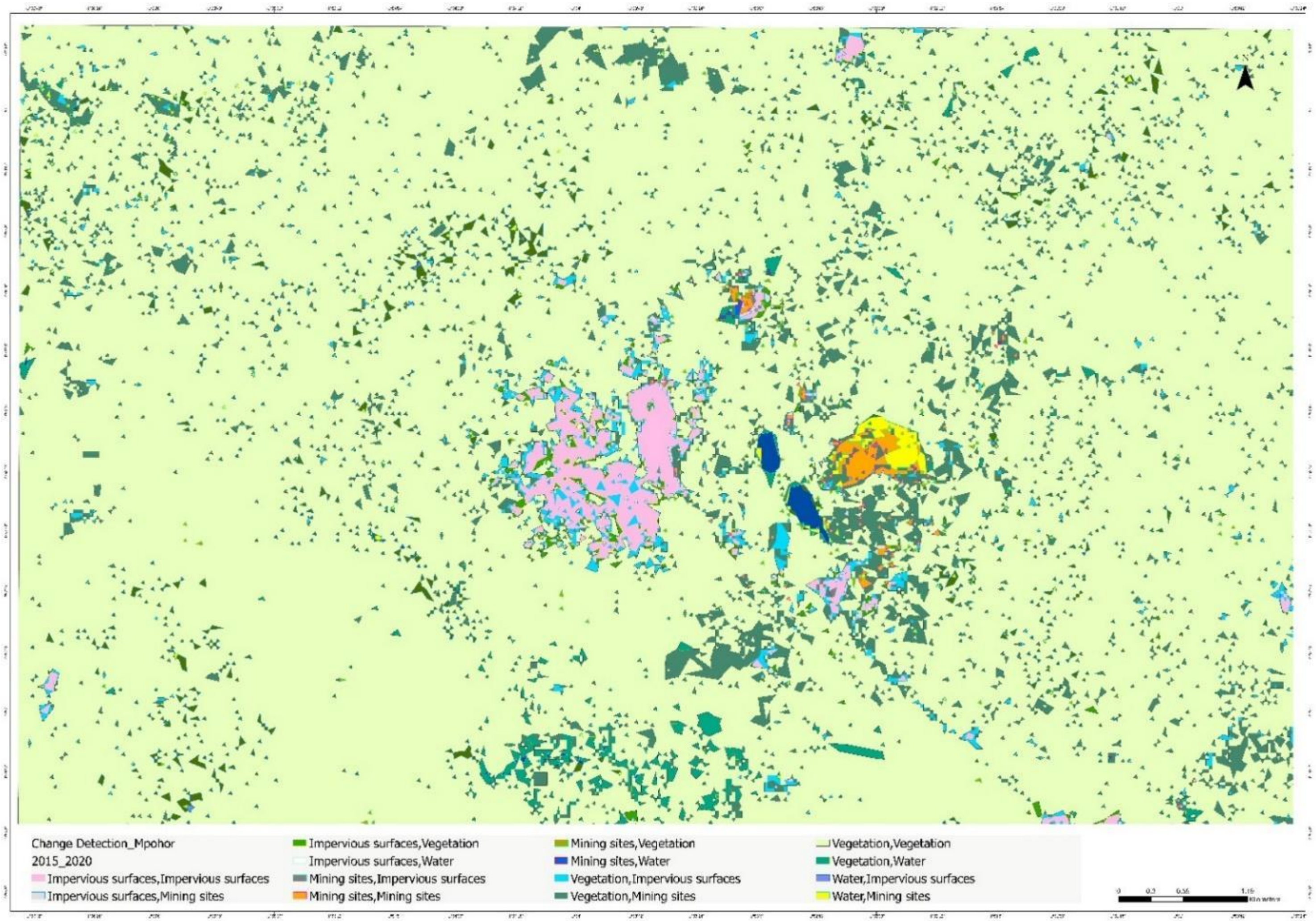

Figure 16: Change detection map of selected area in the Mpohor Wassa East district
Source: Field data, Annan (2021)

On the other hand, in the area that lies within the Mpohor Wassa East district, the vegetation cover increased from 77.76 to 81.90 km² whereas that of the mining sites decreased from 4.87 to 0.42 km^2. Water increased from 1.01 to 1.78 km² and impervious surfaces on the other hand decreased. This can be attributed to the misclassification for 2015 which was a result of the issue with cloud cover.

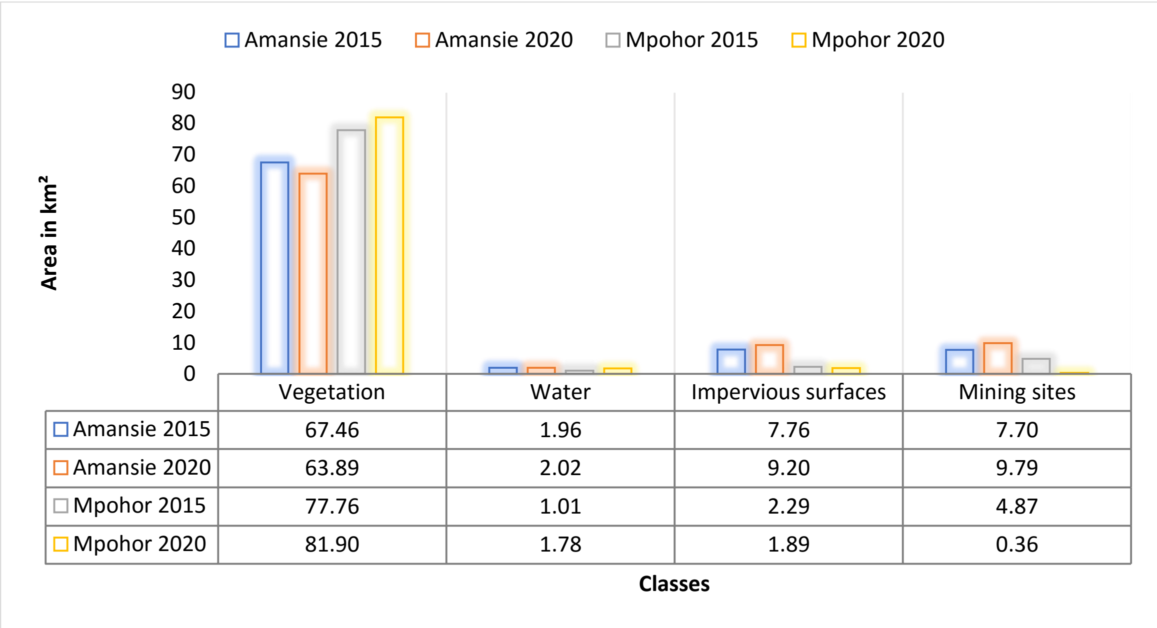

Figure 17: Bar Chart Showing the Extent of each Class in km² for 2015 and 2020
Source: Field data Annan (2021)

Table 4.14: Percentage (%) Cover of the Various Land Cover Classes

Class	**Vegetation**	**Water**	**Impervious Surfaces**	**Mining Sites**
Amansie 2015	79.47	2.31	9.14	9.08
Amansie 2020	75.26	2.38	10.84	11.53
Mpohor 2015	90.49	1.18	2.66	5.67
Mpohor 2020	95.30	2.07	2.20	0.42

Source: Field data Annan (2021)

4.15 Socio-Demographic Characteristics of Respondents (Mpohor Wassa East and Amansie West District)

The socio-demographic data of the respondents were illustrated in Table 4.15. The results showed that majority 142 (35.1%) of respondents were between the ages of 30-39, 128 (31.7%) aged 20-29 years, 75 (18.6%) aged less than 20 years, 42 (10.4%) aged 40-49 years and 17(4.2%) were between the ages of 50 and 59 years. The mean age was 35.2± 0.34SD. Majority, 292 (72.3%) were males and the remaining 112 (27.7%) were females. Most respondents 122 (30.2%) were single, 103 (25.5%) were cohabiting, 96 (23.8%) were married, 45 (11.1%) were widowed and 38(9.4%) were divorced. With regards to the educational level, 147 (36.4%) had had basic education, 122 (30.2%) had secondary education, 88 (21.8%) had no formal education, 28 (6.9%) had vocational/Technical education and 19 (4.7%) had tertiary education. Concerning family size, most respondents 159 (39.4%) had a family size of 2-4, 127(31.4%) had a family size of 5-6 and 118 (29.2%) had a family size of at least 7 (Table 4.15).

Table 4.15: Socio-Demographic Characteristics of Respondent's (N=404)

Variable	Frequency	%
Age of respondents (Yrs.)		
>20	75	18.6
20-29	128	31.7
30-39	142	35.1
40-49	42	10.4
50-59	17	4.2
Mean ± SD 35.2± 0.34 (95% CI: 33.6-36.5)		
Sex		
Male	292	72.3
Female	112	27.7
Marital status		
Married	96	23.8
Single	122	30.2
Cohabitation	103	25.5
Divorced	38	9.4
Widowed	45	11.1
Educational level		
No formal education	88	21.8
Basic	147	36.4
Secondary	122	30.2
Vocational/Technical	28	6.9
Tertiary	19	4.7
Family size		
Small (2-4)	159	39.4
Medium (5-6)	127	31.4
Large (≥7)	118	29.2

SD represent standard deviation; CI: Confidence interval

Source: Field data, Annan (2021)

4.16 Effect of Artisanal and Small-scale Mining on Provisioning Ecosystem Services

Table 4.16: Effects of Artisanal and Small-scale Mining on Provisioning Ecosystem Services

Ecosystem Provisioning services	Coefficient	Std. Err.	t-value	p-value	[95% Conf. Interval]
Drinking water	2.573	0.261	2.20	0.027*	1.742-3.889
Wood fuel	-0.007	0.271	-0.23	0.035*	1.451-3.436
Medicinal plants	1.425	0.240	-0.52	0.028*	1.225-4.832
Raw material for construction	-0.463	0.223	-2.07	0.017*	1.307-5.381
Recreational and Tourism	0.360	0.295	1.22	0.437	-3.389-4.110
Spiritual benefits	0.264	0.401	0.66	0.629	-4.842-5.371
Food crop	1.343	0.141	1.41	0.003*	1.237-2.475
Loss of Timber	-0.198	0.304	-0.65	0.633	-4.072-3.675
Bush meat	0.948	0.398	2.38	0.253	-4.119-6.016
_constant	0.426	0.794	0.54	0.686	-9.663-10.516

Adjusted R^2= 0.873 * Significant ($p<0.05$)
Source: Field data, Annan (2021)

Land use due to Artisanal and small-scale mining activities were observed to significantly influence provisional ecosystem services. This was tested at 95% confidence level. The results revealed that, the following ecosystem services were significantly influenced by change in land use due to Artisanal and small-scale mining; drinking water, wood fuel, medicinal plants, raw material for construction and food crop. The coefficient of determination was determined and from the regression results, an adjusted R^2 value of 0.873 was produced, which translates that these ecosystem provisional services accounted for 87.3% of the total variation of services affected by illegal mining activities in the study area (Table 4.16).

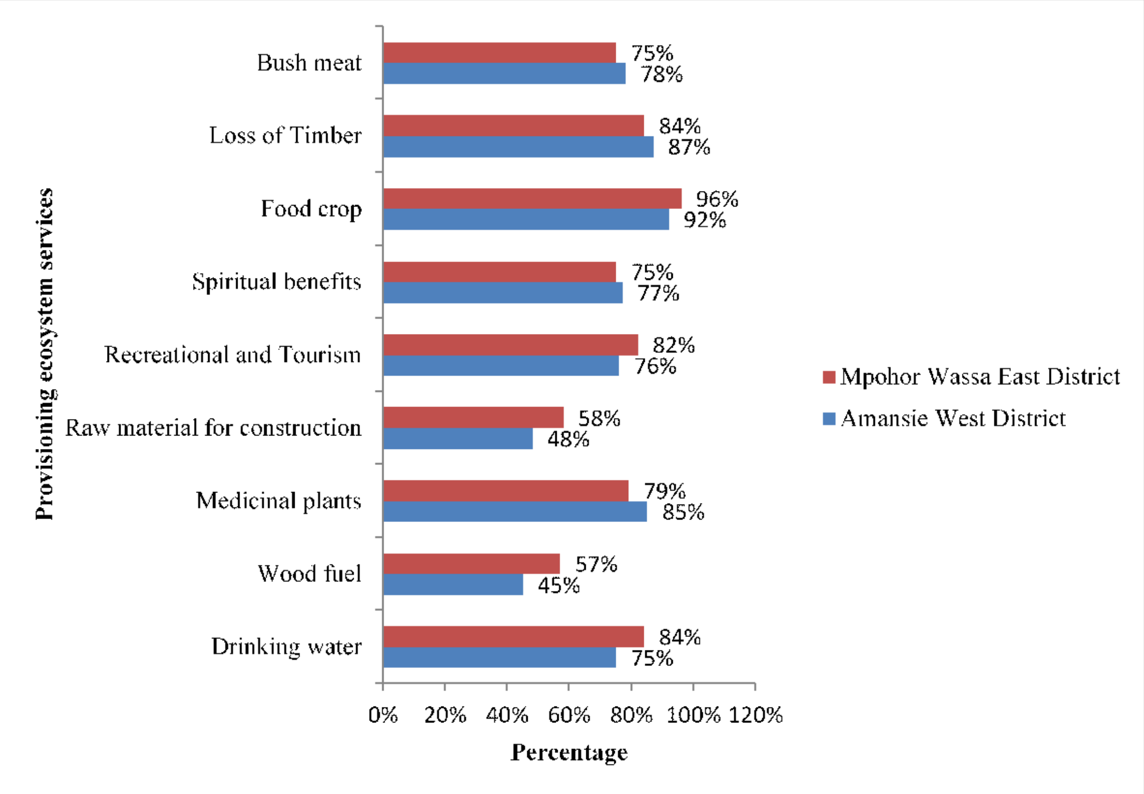

Figure 18: Ecosystem Services Affected Due to Artisanal and Small-scale Mining Activities in the Study Area

Figure 18 shows how respondents perceived that ecosystem services have been affected in both Mpohor Wassa East District and Amansie West District of Ghana. The results showed that with respect to the provision of bush meat, 78% of respondents in communities at Amansie West District were affected and 75% at Mpohor Wassa District were affected. Eighty-seven (87%) and 84% asserted that there is a loss of timber for Amansie West District Mpohor and Wassa District respectively. Most people also asserted that their source of drinking water, food crop, medical plants among other ecosystem services have been affected. The respondents were asked whether the cost of living had increased compared to the commencement of the intensive artisanal and small-scale mining activities, the results indicated that, 45% perceived it was high, 25% asserted it was very high, 18% moderate and 12% perceived cost of living was very low. This is a clear indication that the livelihoods of the inhabitants have been significantly affected (Figure 19 and Plate 4.1 and 4.2).

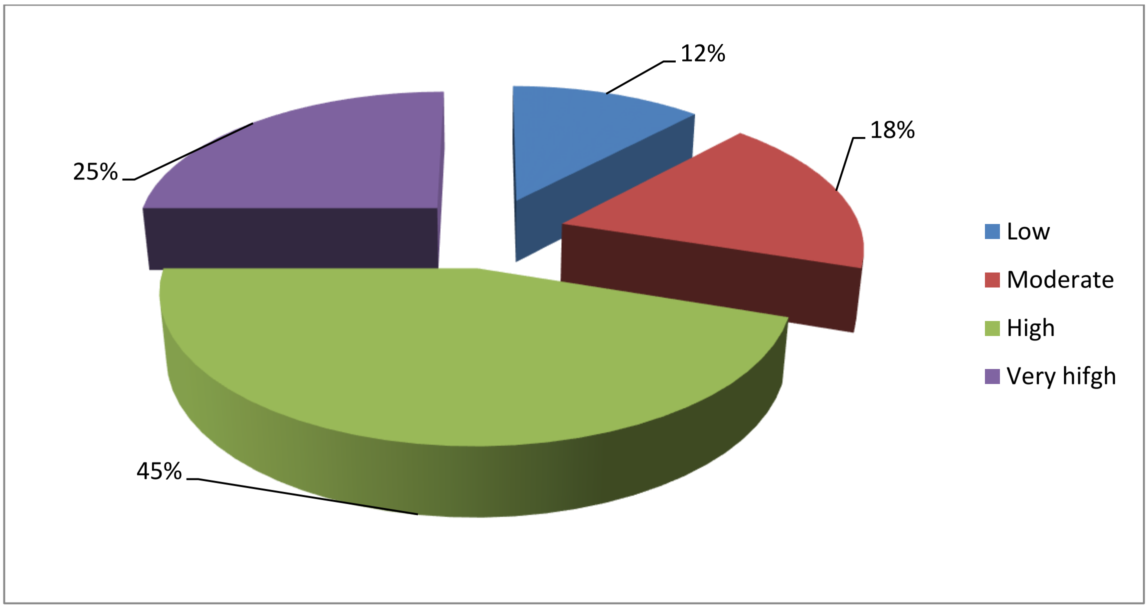

Figure 19: Cost of Living in Artisanal and Small-scale Mining Communities

The respondents were further asked the type of water source they used for drinking purposes prior to the intensive illegal mining activities. The results showed that 65% were drinking water from rivers, 18% from boreholes, 12% from hand-dug wells and 5% from pipe- borne water (Figure 20). However, after the intensive illegal mining activities, the majority has shifted to the use of boreholes as a water source representing 83% and only 2% depends on rivers (Figure 21). This is the clear indication of the impact of illegal mining activities on the water provisioning ecosystem (Plate 4.5).

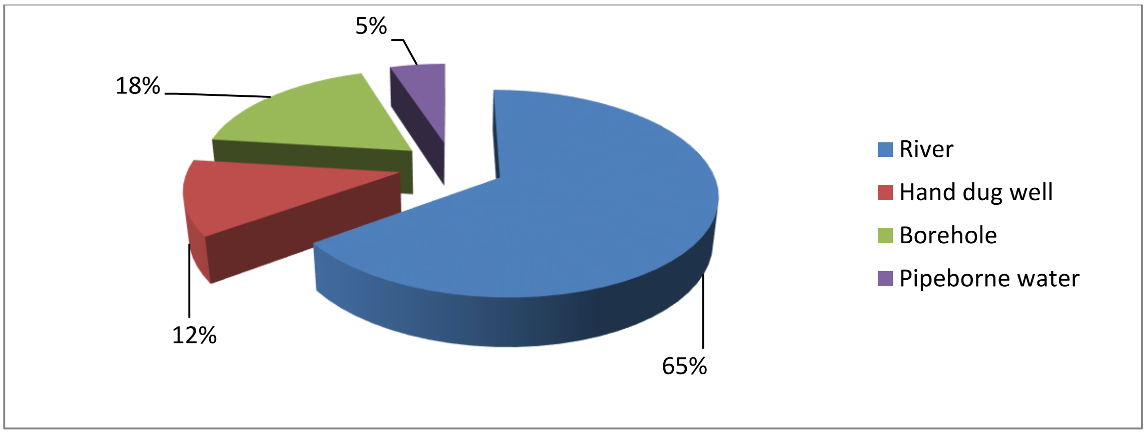

Figure 20: Source of Water in Artisanal and Small-scale mining communities 5-10 years ago

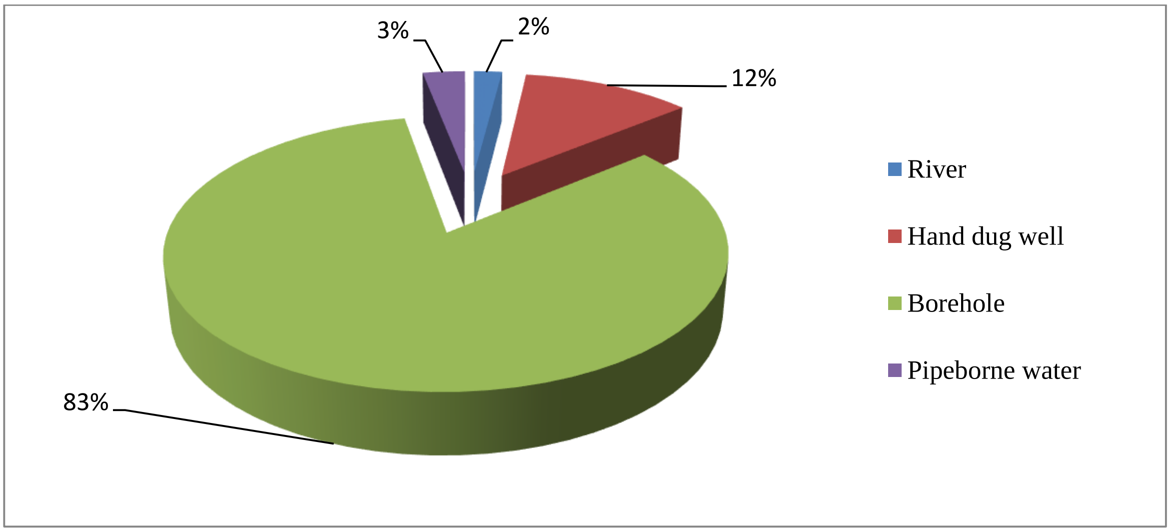

Figure 21: Source of Water prior to Artisanal and Small-scale mining activities

4.17 Interview with Key stakeholders

On the extent of perception of stakeholders on the impacts of artisanal and small-scale mining activities on livelihoods; the following views were expressed. The interviewee was asked how the illegal mining activities in the communities have affected their livelihoods and ecosystem services. The following were the quotes;

> "*Interviewee had extensive knowledge of how the 'galemsey' activities have impacted significantly on livelihoods in the study area. First, we used to get a lot of resources from the forest, things that we got included; bush meat, medicinal plants, fuel wood, food crop and timber for construction, but due to the mining activities, there is hunger since all these resources are no more (Assembly man, Mpohor Motorway-Mpohor Wassa District)*".

"*Interviewee highlighted that as part of the 'galamsey' activities, some of our farmlands have been sold and we were compensated and now they have destroyed our food crops including plantain, palm tree and cocoa trees (Plate 4.1 and plate 4.2). Our water bodies have been contaminated and now we cannot drink the water anymore so we have to depend on boreholes and hand-dug wells as drinking water sources, we are really suffering" (Assembly Man, Dominase*- Amansie West *District).*

Asked whether Artisanal and small-scale mining activities have benefited them in any way? the following represent the quotes;

"*Interviewee responded Yes. He however stated that the only way it has benefited us is by creating employment (Plate 4.3). Though we get money from 'galamsey' activities, food is scarce here, you have money but there is no food to buy and it is worrying. We also don't have good and portable drinking water in our community since they are all polluted by the 'galamsey' activities (Plate 4.5 and 4.8). My husband used to get medicinal plants for sale since he is a herbalist but now they are all destroyed. So, the 'galamsey' activities have really affected us*" (FGD: Female participant at Asaman, Mpohor Wassa East District).

"We get money from the 'galamsey' activities, but it is not sustainable. We don't have water to drink and other domestic purposes. All our water is polluted by the 'galamsey' activities. First, I used to get fuel wood from my farm but now my farm is no more so I have to resort to the use of kerosene stoves and gas which has increased my expenditure. Also, during the afternoon, you will have no food to buy as the young ones that farms are all into mining activities and only the aged go to farm (Plate 4.8). So, the 'galamsey' activities have really caused more harm than good to us" (FGD: Male participant at Amansie West District).

Key personality from the Environmental Protection Agency, Forestry commission was asked if there is any legal requirement available to stop artisanal and small-scale mining activities and the role the EPA is playing in the fight against artisanal and small-scale mining activities. The following quote were observed;

*"Interviewee responded that mostly, those that engage in artisanal and small-*scale *mining activities often come for prospecting license as part of the licensing regime. But they later end up mining illegally though they have not secured the requisite permit from the appropriate organization and this is a source of worry. Instead of doing the prospecting and later proceed to conduct environmental Impact assessment, they finally end up doing 'galamsey'. I believe fighting these illegal activities is a collective effort and not only the government. The communities, traditional authorities all have a role to play so as to compliment government efforts" (Participant A, Environmental Protection Agency).*

"There is a legal requirement that needs to be fulfilled by parties who engage in activities that encroach into forest lands. He concluded by stating that, the Forestry Commission has an intensive monitoring programme to ensure companies who work in forest areas strictly comply with permit requirements issued by the commission or risk having their permits revoked" (Participant A, Forestry Commission).

Plate 4.2: Destruction of oil palm crops by illegal small - scale gold miners at the study site

Plate 4.1: Destruction of food crops by small - scale gold mining activities at the study site

Plate 4.4: Casual workers at the mining site for their source of livelihood

Plate 4.3: Land degradation as a result of small - scale mining activities at study site

Plate 4.6: Water pollution as result of small - scale mining activities at the mining site

Plate 4.5: Depletion of vegetation cover due to small - scale gold mining activities

Plate 4.8: Dug pit left after mining serving as a dead trap to human and animals

Plate 4.7: Children engaging in small - scale gold mining activities

CHAPTER FIVE

DISCUSSION

5.0 Overview

This chapter presents the discussions of the study. The research objectives have been addressed in relation with the findings of the study, the physico-chemical quality of water, heavy metals in water and soil and the assessment of the impact of illegal mining activities on provisioning ecosystems.

5.1 Physico-Chemical Quality of Surface Water

Water samples obtained from Mpohor Wassa sampling sites were observed to be neutral to alkaline in nature and were within acceptable range of pH 6.0-9.0 as set by the WHO (2010) and Ghana Standard authority standard (GS 1212:2019) for drinking water. Comparatively pH of surface water samples obtained from communities in Amansie West District tends to be acidic compared to those that are found in Mpohor Wassa District. However, Akosa *et al.,* (2017) reported that pH values lower than 6.5 are considered too acidic for human consumption and can cause significant health problems such as acidosis and adverse effects on the digestive and lymphatic system. A drop in pH could also be harmful since metals have higher dissolution in low pH waters and thus could contain elevated levels of toxic metals posing a health hazard to consumers (Annan *et al.,* 2018). The lower pH obtained in Amansie West District could be an indication of the excessive artisanal and small-scale gold mining activities in the district. This finding is not surprising since acid mine drainage or “yellow boy” were observed during field observation in the artisanal and small-scale gold mining sites and this could have entered into the surface water sources (Plate 4.5). This implies that the artisanal and small-scale gold mining activities were significantly impacting on water resources which is a provisioning ecosystem services in the Amansie West Districts compared to Mpohor Wassa District

(Plate 4.5). The pH values obtained in surface water samples at Mpohor Wassa sampling sites was good since a drop in pH could be harmful due to higher dissolution of heavy metals in low pH waters which could contain elevated levels of toxic heavy metals posing a health hazard to consumers and aquatic organisms (Asante *et al.*, 2017). However, the pH of water obtained from Amansie West District sampling sites were acidic and not suitable for human consumption and aquatic life in general.

The results for temperature of water showed no significant variation among sampling sites at both Mpohor Wassa District and Amansie West District. The natural background limit for WHO and GS 1212:2019 limit is between 22 to 27℃ (WHO, 2010). The temperature values obtained from sampled water for the entire study period were within the natural background limit. Temperature is a critical factor of significant importance for aquatic ecosystems as it affects the water organism as well as the physico-chemical properties of water (Bloch & Owusu, 2017; Attuah *et al.*, 2014).

With regards to water samples at Mpohor Wassa East District sampling site, the highest Dissolve oxygen (DO) of the surface water samples was recorded at control sampling site with mean value of 12.9 mg/L whilst the lowest was recorded at sampling site ASA with mean value of 5.4 mg/L. The DO obtained for water samples in the two districts were comparatively lower and this is an indication of higher organic loads in the water due to anthropogenic effects possibly from the illegal mining activities.

The highest dissolved oxygen (DO) of the surface water samples from Amansie West District however was recorded at a control sampling site. The World Health Organization does not have a specific guideline for DO in drinking water. However, a provisional health-based guideline value of at least 7.5mg/L was indicated for the purpose of public health protection (WHO, 2010). DO of almost all the water samples analyzed for the entire study period fell below the guideline value. The concentration of dissolved oxygen is a critical parameter relating to the overall quality of any watercourse. According to Akosa *et al*., (2018) the minimum acceptable limit for maintaining life in an aquatic environment is about 5 mg/L. The low DO recorded in the water samples may be due to high levels of oxidizable substances in the water sample such as organic matter. Oxygen levels are naturally low where organic matter accumulates, because aerobic decomposer microorganisms require and so consume oxygen (Annan *et al.,* 2018; Hutchinson & Meema, 2017). This low DO levels may encourage anaerobic respiration activities and could lead to bad odour in the water rendering it unwholesome for human consumption (Lenn, 2017). According to Amegbey and Eshun (2003), the parameter is noted as the most essential factor with regards to the study of lakes and other freshwater or inland water bodies. Even though the diversity of organisms in water is greatest at higher *DO* concentrations, *DO* levels, when too low (< 3 mg/L), can be very detrimental to aquatic life and subsequently affect the quality of water (FEI, 2014).

Biological Oxygen demand (BOD) is a measure of organic matter contamination of water and therefore a good measure of the relative oxygen depleting effect of biodegradable pollutants in water. The World Health Organization recommends that water considered to be safe for drinking should not have any material of organic origin (WHO, 2010). Though the BOD at the control sites were relatively lower all the values exceeded the WHO permissible zero limit per 100ml rendering the water unsuitable for drinking purposes as it could pose health problems if not treated. The higher levels recorded may be due to the possibility of poor mixing of atmospheric oxygen into the water due to higher levels of organic matter pollution as a result of anthropogenic inputs possibly from illegal mining activities. The use of the water samples in communities in the two study areas without adequate treatment may pose a public health hazard to consumers (Annan *et al.,* 2018; Attuah *et al.,* 2014).

Alkalinity of water is its capacity and ability to resist changes in acidity. Total alkalinity for portable drinking water according to WHO (2014) is 400mg/L. The concentrations in the water for the entire study period was within the WHO permissible limit. Alkalinity of 500 mg/L is also accepted by the USEPA and Ghana water company (GWC). Alkalinity is apparently unrelated to public health but is very important in pH control. The major ionic species that contribute to alkalinity in water include carbonates, bicarbonates, hydroxides, phosphates, borate and organic acids. The low levels of alkalinity recorded for the entire study period may be attributed to the geology of the study area. The study area is characterized by sedimentary rocks composed of limestone and sandstone which is very rich in carbonates and bicarbonate ions (Akabzaa *et al.,* 2007).

Salinity is a measure of the total soluble or dissolved salt in water. It is normally a measure of the total dissolved solids or the electrical conductivity of the water. The WHO recommends that water that is considered to be safe for human consumption should not have salinity levels exceeding 200 mg/L as it will induce a salty taste in the water (WHO, 2014). All the water samples analyzed for the entire study period were within the WHO permissible limit. This confirms results obtained from the social survey where 85% of the respondents asserted that the water is not saline.

Electrical conductivity is the measure of the total dissolved ions in water. The conductivity of all water samples obtained from Mpohor Wassa East District sampling sites were within the acceptable limit of 250µS/cm set by WHO and Ghana standard. The values recorded during the study period for surface water samples at Amansie West District sampling sites however, far exceeded the WHO regulatory limit and it ranged from a minimum of 277.3

μS/cm at Dominase community to a maximum of 484.8 μS/cm at Manso Nkwanta community. The high values indicated that the dissolved ions in the water were too high for human consumption. Research has found that there is a positive correlation between conductivity and total dissolved solids (TDS) and the latter may be obtained by multiplying conductivity by a factor between the ranges of 0.55 to 0.75 (Chapman, 1992).

Total dissolved solids are a measure of the total organic and inorganic substances dissolved in water (Akosa *et al*., 2018). Water samples from sampling sites in communities within the two study areas had TDS values within the WHO guideline limit of 1000mg/L. Consumers may object to total dissolved solids levels above 1000 mg/L (WHO, 2010).

Total suspended solids relatively measure the visual observation of a water sample. The WHO value guideline dictates that water must have a TSS value not exceeding 500 mg/L for it to be considered safe (WHO, 2014). The highest TSS of the sampled water was recorded at Mpohor Motorway (MM) in Mpohor Wassa district, with a mean value of 645.3 mg/L. Water samples obtained from Amansie West District, however, were within the WHO acceptable limit, an indication of an excellent measure of the quality of the water.

The WHO guideline for turbidity in drinking water is 5 NTU (Nephelometric turbidity units). The highest turbidity value of 299.2NTU was recorded at the Mpohor Wassa sampling site and 822.7 NTU was recorded at Amansie West sampling site. With the exception of the control sampling site, all water samples obtained in communities from both study areas fell above the WHO and Ghana Standard Authority permissible limit of 5NTU. The value recorded is very alarming as far as this research is concerned, the increase may have arisen from soil disturbance from illegal mining activities that were impacting significantly on the surface water sources. During rainfall, soil and other particulate matter (silt, clay, and organic materials) from the illegal mining sites could enter the surface water sources thereby increasing the turbidity subsequently. In communities where the turbidity is high, if persistent without interventions, it may cause sedimentation and siltation (Armah *et al.,* 2013). This may subsequently affect the habitat for the fisheries and other aquatic life resulting in low productivity and loss of species.

5.2 Heavy Metals in Water

A typical mining effluent has arsenic (As), mercury (Hg), lead (Pb), copper (Cu), and cadmium (Cd) as its constituents (Creek, 2016). These heavy metals are among ten (10) toxic heavy metals with major public health concerns (WHO, 2014). Heavy metal pollution in rivers and streams is primarily caused due to industrialization with which illegal mining is a significant source of concern (Queensland, 2019). According to the World Health Organization, Hg, As, Pb, Cd and Cu in drinking water sources should be 0.002, 0.01, 0.01, 0.005 and 1.3 mg/L respectively.

The level of mercury from the water samples at both Mpohor Wassa District sampling sites and Amansie West sampling sites exceeded the acceptable limit of EPA guideline value and WHO limits of 0.002mg/L. The pollution of mercury in surface water bodies was an indication of anthropogenic impacts of illegal mining footprints on provisioning ecosystem services in the study area. The mean value for the control sample fell within WHO and EPA limits (Amegbey *et al.,* 2003).

The Arsenic concentrations in surface water samples in communities in the two study areas were above the WHO recommended limit of 0.01mg/L. The high arsenic concentration in the surface water could be due to runoff from the illegal mining operations. At Mpohor Motorway where a significant arsenic level was recorded, it was realized that the majority of the inhabitants depend on this stream of water for bathing and other domestic use. The arsenic contamination is not surprising since the gold bearing ores in the two study areas thus the Mpohor Wassa district and Amansie West district happened to be mineralized pyrites and arsenopyrite (Rambaud *et al*., 2016; Simon *et al.,* 2004; Serfor-Armah *et al*., 2006). Processing of the ore such as roasting, it leads to the production of arsenic trioxide gas which is distributed throughout the study area and may drop onto soils through atmospheric deposition and can contaminate soils and subsequently leach into surface water and groundwater aquifers (Sumaraga *et al.,* 2020; Annan *et al.,* 2018). During oxidation, arsenic is released into the environment which can contaminate environmental media (Amponsah-Tawiah *et al.,* 2017). According to WHO (2010), arsenic may be found in water which has flowed through arsenic rich rocks. Arsenic is released into ground and surface waters by the erosion, dissolution and weathering of rocks. The high level of arsenic in surface water samples suggest that the illegal mining activities have released arsenic footprints which have impact on the provisioning ecosystem services in the study area.

Arsenic compounds cause acute and chronic effects in individuals, populations and communities at concentrations ranging from a few micrograms to milligrams per liter, depending on species, time of exposure and end-points measured. These effects include lethality, inhibition of growth, photosynthesis and reproduction, and behavioral effects such as mental retardation (FEI, 2014).

The cadmium and lead levels in surface water samples, both Mpohor Wassa East and Amansie West sampling sites exceeded the WHO recommended limit of 0.005 and 0.01mg/L, respectively. This suggests anthropogenic impacts possibly from the illegal mining activities since the principal component analysis (PCA) showed that both cadmium and lead were of the same origin. Nickel in this study was higher at Mpohor Wassa sampling sites compared to sampling communities in the Amansie West District. This finding is consistent with the study of Asante *et al.,* (2017) in a mining community in

Jharkhand, India. The levels of Ni obtained in surface water samples in this study are higher than the study by Kacmaz and Nakoman (2010) in Turkey and lower compared to that of Asante *et al.,* (2017) in Tarkwa, Ghana.

The findings obtained for heavy metals in this study are consistent with those of Asante *et al.,* (2017), and Wongsasuluk *et al.,* (2013) who reported high levels of As, Fe, As, Cr, Pb and Ni in surface water samples in some illegal mining communities at Obuasi. The high levels of heavy metals detected in the water samples could be attributed to illegal mining operations in the study area (Obiri, 2007).

The PCA of water samples in Mpohor Wassa sampling site showed that the first principal component 1 (*PC-1*) contributed 22.5% of the total variance and was strongly loaded by Co, Cr, Cu, As and Cd and moderately loaded by Ni, Zn, Hg, Mg, Pb and Fe. The PCA of water samples from Amansie West district also showed that the first principal component (*PC-1*) contributed 43.8% of the total variance and was strongly loaded by the following heavy metals; Cr, Hg, Mg, Mn, Nickel, As, Pb, and Cd. This suggests that these heavy metals were considered most significant parameters which always contribute to water quality variations in the studied surface water. Therefore, based on a correlation coefficient selection criterion, the physico-chemical parameters considered important in contributing to water quality variations in a particular district may or may not be considered important in another district due to differences in mining activities. Hence, this may serve as information for the management of the surface waters so as to find out which parameters need to be monitored in different districts in Ghana.

5.3 Heavy Metals in Soil

Heavy metals pose potential and significant human health challenges when levels are high and exceed recommended limits established by regulatory agencies such as the World

Health organization (WHO) and Food and Agriculture Organization) (FAO) in agricultural soils. The concentrations of heavy metals determined in soils for Fe, Hg, Ni, Cu, Pb, Cr and *As* were above the FAO acceptable limit with the exception of the control sampling sites (WHO/FAO, 2014). However, WHO/FAO (2014) guidelines stipulates that Ni, Cu, Pb, Cr, As, Zn and Hg levels in agricultural soils should not be more than 0.20mg/Kg, 0.30, 0.50, 0.20, 0.01, 300 and 0.001mg/Kg respectively. The findings for high levels of Hg, As, Cu and Pb and Ni in this study agrees and is consistent with the study of Akosa *et al.,* (2018) who found increased levels of Cu, Hg, As and Pb in soils obtained at some illegal mining sites in Dhaka city. The higher concentrations of Pb, Hg, As, Cr, Ni and Cu recorded in this study could partly be attributed to the illegal mining operations since these metals are typical components in a mining effluent (Bloch & Owusu, 2017). The arsenic and mercury levels in soil exceeded the WHO and EPA limits of 0.01mg/Kg and 0.001mg/Kg respectively. This could be attributed to the exposure of underlying rocks in the soil. Mining, smelting of non-ferrous metals and burning of fossil fuel are the major industrial processes that contribute to anthropogenic arsenic contamination of air, water and soil. The mean Fe concentrations in soils obtained from illegal mining sites at both Amansie West District and Mpohor Wassa East District in this study were below the recommended guideline by WHO/FAO (2014) permissible limit of 425.5 mg/Kg for agricultural soils. Iron (Fe) is abundant in nature in the earth crust and useful in the formation of red blood cells. Elevated levels therefore could partly be attributed to lithogenic influence. The presence of mercury in the soil could be due to washing of mine waste onto soils (Annan *et al*., 2018; Hutchinson *et al.,* 2017). Mercury can harm fish even at low concentrations. It finds its way into fish and shellfish and eventually into the human food chain (Kachhwala, 2015). Over exposure to mercury can cause a variety of ailments, including dizziness, fatigue, loss of appetite, headaches, convulsions and even death (Andoh, 2002). Mercury also weakens the immune system, potentially making miners and dependents more susceptible to other ailments, such as malaria, which necessitate the purchase of costly medicines (Bagstad *et al.,* 2016).

General health effects associated with arsenic exposure include cardiovascular and peripheral vascular disease, developmental anomalies, neurologic and neurobehavioral disorders, diabetes, hearing loss, portal fibrosis, hematological disorders and cancers (Centeno *et al.,* 2018; Abenathy *et al.,* 2017).

Comparatively, this study found higher levels of heavy metals occurring in mine waste soil than in surface waters. In aquatic environments, the main processes governing distribution of metals include adsorption and sedimentation (Hughes, 2020). Thus, in the course of distribution of metals, permanent or temporary storage takes place in the soils or sediments. The highest concentrations of heavy metals occurred in soils compared to water which may have possible adverse impacts on ecosystem services (Belton *et al.,* 2005). The results from the land use land cover change (LULC) analysis show that vegetation is the predominant land cover in both areas including forest and grassland. For Amansie West, the vegetation cover reduced over the period being converted to mining areas which increased by about 3%. This finding is supported by data from the social survey which revealed that drinking water, wood fuel, medicinal plants, raw materials for construction and food crops were affected due to change in land use (Plates 4.1 and 4.2). There was also an increase in impervious surfaces which give an indication of expansion in settlement and other construction activities. Site visits confirm active '*galamsey'* activities in the area (Song *et al.,* 2020).

For the area in Mpohor Wassa East, there was an increase in vegetation cover and a reduction in mining sites by over 5%. Field observations revealed that some of the mining sites had been abandoned and vegetation was slowly recovering or growing back at some of the mined-out sites. Comparison of the two sites analyzed show that there were more mining activities within the Amansie West District compared to the Mpohor Wassa East area (Annan *et al.,* 2019). In all the heavy metal analysis, the threshold exceedance ratio (TER) was less than the total concentration when extracted with Nitric acid. The rule of thumb is that a threshold exceedance ratio (TER) value higher than the total concentration (TC) can limit the functioning of the soil (Liang *et al.*, 2014). Limited soil functioning might occur if the threshold value is exceeded, causing a reduction in plant growth and, thus, increased soil erosion. In this study, limited soil function might not occur since the TER values are smaller compared to the total concentrations and could not limit the function of the soil for agriculture purposes. However, the re-mobility percentage, especially Cu, was high with higher percentage mobility in all sampling sites above 20% which could indicate that they have a higher potential to be remobilized back into the soil structure when environmental conditions are favourable.

5.4 Assessment of Impact of Illegal Mining Activities on Provisioning Ecosystem

In illegal mining activities, the vegetation cover and topsoil are often removed which led to degradation of the environment and resulting in soil erosion, among others. In addition, soil compaction may also occur due to use of heavy machines or equipment by miners. Notwithstanding, World Bank (2002) reported that one of the environmental effects of illegal mining of gold mining in Ghana is land degradation (Plate 4.4), more specifically, clearing vast forest, digging trenches and up-turning of vegetation which in turn leaves land bare and exposed to agents of erosion. There is also the destruction of beneficial microorganisms in soil that could help in the decomposition of organic materials in the soil to enrich it fertility. Furthermore, Akabzaa (2000) reported that degradation of large tracts of land by illegal mining constitutes a major threat to agriculture in the communities and their economic survival (Plates 4.1, 4.2, 4.4 and 4.4.6). Moreover, studies by the Biodiversity Support Program (2014) and Ayitey-Smith (2012) revealed that land degradation from illicit mining activities reduces biodiversity and can subsequently decrease the availability of medicinal plants in the environment. In this current study, the findings of the social survey revealed that residents in the study area used to get a lot of resources from the forest such as bush meat, medicinal plants, fuel wood, food crops and timber for construction. According to people interviewed in the study communities, the illegal mining activities had seriously affected ready availability of these vital ecosystem resources to the extent that they have increasingly become rare to obtain. Some of these resources served as medicinal plants for a variety of ailments including anemia, asthma, gonorrhea, measles, and typhoid in the study area. One participant at the time of the in-depth interviews confirmed even though it was still possible to find the herbs or plants, he often had to travel longer distances to obtain plants that were once found near the village or in his farm (Amponsah-Tawiah *et al.*, 2017).

The activities of the illegal or "*galamsey"* mining operators in the studied communities were also observed to impact significantly on the provisioning ecosystem including soil and surface water bodies which may also have greatly affected their ability to support aquatic life (Plate 4.5). Interpretations of data from the social surveys indicate that many respondents in the study area are of the opinion dug pits from illegal mining (Plate 4.8) serves as breeding grounds for mosquitoes. The environmental implications of the mining operations are best viewed from the environmental effects on health. However, Agyapong (2018) estimated that for daily reported illnesses in Ghana, 72% including malaria are environmentally related. Malaria accounted for an average of 32% of all cases followed by acute respiratory infection, skin diseases, ulcers and typhoid fever. With the use of mercury in illegal mining, the respondents admitted that they use mercury to extract gold from the ore. Interestingly, they obtain the mercury from friends, drug stores and gold dealers. There is a convention called the Minamata Convention on Mercury which is a global treaty to protect human health and the environment from the adverse effects of mercury. What the convention seeks to achieve include a ban on new mercury mines, the phase-out of existing ones, the phase-out and phase-down of mercury use in a number of products and processes, control measures on emissions to air and releases to land and water, and the regulation of the informal sector of artisanal and small-scale gold mining. The convention also addresses interim storage of mercury and its disposal once it becomes waste after use, sites contaminated by mercury as well as public health implications. All these regulations are not duly followed and adhered to in the mining communities studied suggesting that mercury pollution may be rampant. Once in the body, inorganic mercury is transformed into toxic methylmercury, which poses a serious threat to humans. Over-exposure to mercury can cause a variety of ailments, including dizziness, fatigue, and a loss of appetite, headaches, convulsions and even death (Belton *et al.*, 2005). During the course of data collection, poor mercury management practices were observed throughout the studied communities in both Mpohor Wassa East and Amansie west Districts of the Western and Ashanti Regions, respectively.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

6.1.1 Heavy Metals in water

Arsenic, Cd, Ni, and Mn concentrations in surface water samples at Amansie West and Ni and Cd at Mpohor Wassa East were above the WHO recommended limit. The pollution of mercury in surface water bodies was an indication of anthropogenic impacts of illegal mining footprints on provisioning ecosystem services in the study area. The high arsenic concentration in the surface water could be due to runoff from the illegal mining operations, and this could possibly suggest that the illegal mining activities have released arsenic footprints which have impact on the provisioning ecosystem services in the study area. The high level of cadmium suggests anthropogenic impacts possibly from the illegal mining activities since the principal component analysis (PCA) showed that both cadmium and lead were of the same origin. Nickel in this study was higher at Mpohor Wassa sampling sites compared to sampling communities in the Amansie West District.

6.1.2 Hazard Rating of Heavy Metals in Soils

The concentrations of Fe, Hg, Ni, Cu, Pb, Cr and *As* determined in soils at Mpohor Wassa sampling sites were above the FAO acceptable limit with the exception of the control sampling sites. In all the heavy metal analysis, threshold exceedance ratio (TER) was less than the total concentration when extracted with nitric acid and may indicate that limited soil function for agricultural purposes might not occur since the TER values are smaller compared to the total concentrations. The re-mobility percentages of Cu and Hg were above 29% and 19% respectively at all study areas which suggests higher potential for remobilization back into the soil structure when environmental conditions are favorable. The geo-accumulation index of heavy metals in soils at both study areas were found to range from Igeo values (1-2), uncontaminated to moderate contamination; this suggests potentially moderate contamination of heavy metals in soils in both sampling sites.

6.1.3 Impact of Artisanal and Small-Scale Mining Activities on Provisioning Ecosystem

ASGM affected 87.3% of the provisioning ecosystem services supply. The following provisioning ecosystem services were significantly influenced by change in land use due to illegal mining; drinking water, wood fuel, medicinal plants, raw material for construction and food crops. It can therefore be concluded that illegal mining footprints have impacted significantly on provisioning ecosystem services in the two study areas.

6.1.4 Impact of Artisanal and Small-scale Gold mine on Land use and Land Cover Changes

Vegetation is the predominant land cover in both areas including forest and grassland. Within a period of (2015-2020) the vegetative cover has reduced by 4.21% and mining sites increased by 2.45% at Amansie West District. Comparison of the two sites studied shows that there are more mining activities within the Amansie West as compared to the Mpohor Wassa East district. For the area in Mpohor Wassa East, there was an increase in vegetation cover and a reduction in mining sites by over 5%. Observations during the period of study revealed that some of the mining sites had been abandoned and vegetation was recovering at some of the sites.

6.2 Recommendation

6.2.1 Recommendations for Government (Policy and Decision-makers)

- Based on the study, the pH of water samples was high at Amansie West. It is therefore recommended that periodic monitoring should be done by the Water Resources Commission and other relevant institutions.

- The Environmental Protection Agency needs to come out with a stiffer punishment on the indiscriminate use of mercury in illegal mining activities which tend to pollute water and soil resources.
- The forestry commission must ensure that reforestation projects should be undertaken in all communities where these illegal mining activities have taken place so as to restore the land use.
- Phytoextraction-ability plants such as Sun flower (*Helianthus annuus*), Cannabis sativa, Tobacco (*Nicotiana tabacum*), Maize (*Zea mays*) can be cultivated to demobilize Cu and Hg in the soil and this can be championed by EPA and the Ministry of Agriculture in Ghana
- The Environmental Protection Agency (EPA), Ministry of Lands and Natural Resources and Land Commission should regulate the activities of ASGM to stop the discharge of poisonous heavy metals into soil and water bodies.

6.2.2 Recommendation for Academia

Academic institutions need to collaborate with the government to conduct intensive studies in all illegal mining sites in Ghana so as to establish the extent of contamination and its impacts on the ecosystem services.

6.2.3 Recommendation for Local Communities and Households

Since livelihoods have been significantly affected as a result of change in land use, the district assemblies should have alternative livelihood projects for affected community members so as to improve their livelihoods

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APPENDICES

Appendix A: Descriptive Statistics of Physico-Chemical Parameters of Water Sample, Mpohor Wassa

Descriptive

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum
Temperature	ADW	3	25.3967	1.00271	.57892	22.9058	27.8875	24.33
	ADT	3	24.5833	1.22255	.70584	21.5463	27.6203	23.29
	ASA	3	25.1133	.54638	.31545	23.7560	26.4706	24.66
	MM	3	24.9567	1.31546	.75948	21.6889	28.2244	23.90
	Control	3	24.9733	.81027	.46781	22.9605	26.9861	24.32
	Total	15	25.0047	.90277	.23309	24.5047	25.5046	23.29
Conductivity	ADW	3	123.5000	15.74008	9.08754	84.3995	162.6005	106.00
	ADT	3	128.3000	7.04060	4.06489	110.8102	145.7898	122.00
	ASA	3	92.6667	4.50925	2.60342	81.4651	103.8683	88.00
	MM	3	152.3333	26.57693	15.34420	86.3126	218.3541	127.00
	Control	3	58.6667	13.50309	7.79601	25.1231	92.2102	45.00
	Total	15	111.0933	35.98524	9.29135	91.1654	131.0213	45.00
Total Dissolved solids	ADW	3	69.6333	2.12211	1.22520	64.3617	74.9049	67.90
	ADT	3	82.3333	6.02771	3.48010	67.3597	97.3070	76.00
	ASA	3	61.6667	3.05505	1.76383	54.0775	69.2558	59.00
	MM	3	101.0000	17.34935	10.01665	57.9018	144.0982	86.00
	Control	3	33.3333	9.07377	5.23874	10.7928	55.8738	25.00
	Total	15	69.5933	24.56177	6.34182	55.9915	83.1952	25.00
pH	ADW	3	6.7000	.26458	.15275	6.0428	7.3572	6.40
	ADT	3	7.0000	2.00000	1.15470	2.0317	11.9683	5.00
	ASA	3	6.5000	.36056	.20817	5.6043	7.3957	6.20
	MM	3	6.5333	.32146	.18559	5.7348	7.3319	6.30
	Control	3	7.1000	.17321	.10000	6.6697	7.5303	6.90
	Total	15	6.7667	.82606	.21329	6.3092	7.2241	5.00
Salinity	ADW	3	.1000	.10000	.05774	-.1484	.3484	.00
	ADT	3	.2000	.10000	.05774	-.0484	.4484	.10
	ASA	3	.0000	.00000	.00000	.0000	.0000	.00
	MM	3	.1667	.05774	.03333	.0232	.3101	.10
	Control	3	.0000	.00000	.00000	.0000	.0000	.00
	Total	15	.0933	.10328	.02667	.0361	.1505	.00
Total Suspended solids	ADW	3	5.3333	.57735	.33333	3.8991	6.7676	5.00
	ADT	3	145.3333	3.51188	2.02759	136.6093	154.0573	142.00
	ASA	3	399.0000	20.07486	11.59023	349.1313	448.8687	385.00
	MM	3	645.3333	14.84363	8.56997	608.4597	682.2070	629.00
	Control	3	15.8000	1.96723	1.13578	10.9131	20.6869	14.00
	Total	15	242.1600	255.34650	65.93018	100.7538	383.5662	5.00
Alkalinity	ADW	3	18.0000	4.00000	2.30940	8.0634	27.9366	14.00
	ADT	3	47.6667	4.50925	2.60342	36.4651	58.8683	43.00
	ASA	3	9.0000	2.64575	1.52753	2.4276	15.5724	7.00
	MM	3	48.6667	3.05505	1.76383	41.0775	56.2558	46.00
	Control	3	64.3333	8.02081	4.63081	44.4085	84.2581	56.00
	Total	15	37.5333	21.80389	5.62974	25.4587	49.6079	7.00
Bicarbonates	ADW	3	18.3560	1.15508	.66689	15.4866	21.2254	17.07
	ADT	3	55.6537	2.90107	1.67493	48.4470	62.8603	52.72
	ASA	3	9.2940	.51125	.29517	8.0240	10.5640	8.74
	MM	3	56.8163	.90259	.52111	54.5742	59.0585	56.08
	Control	3	69.6667	7.02377	4.05518	52.2187	87.1147	63.00

	Total	15	41.9573	24.67015	6.36981	28.2955	55.6192	8.74
Turbidity	ADW	3	23.8667	1.05040	.60645	21.2573	26.4760	22.80
	ADT	3	299.2667	220.44322	127.27295	-248.3446	846.8780	44.80
	ASA	3	89.9667	3.61156	2.08513	80.9951	98.9383	85.90
	MM	3	59.6667	2.51661	1.45297	53.4151	65.9183	57.00
	Control	3	2.5000	.65574	.37859	.8710	4.1290	1.90
	Total	15	95.0533	138.11919	35.66222	18.5655	171.5412	1.90
Total hardness	ADW	3	33.570333	3.4904626	2.0152195	24.899543	42.241123	29.5430
	ADT	3	72.628000	.6761745	.3903895	70.948289	74.307711	71.9300
	ASA	3	17.683000	.5662570	.3269286	16.276340	19.089660	17.1690
	MM	3	55.458667	2.8459208	1.6430932	48.389007	62.528326	52.9180
	Control	3	11.666667	4.8686069	2.8108915	-.427623	23.760957	6.3000
	Total	15	38.201333	23.8719358	6.1637073	24.981496	51.421171	6.3000
Iron	ADW	3	1.432667	.1178233	.0680253	1.139977	1.725356	1.3060
	ADT	3	.746333	.1216895	.0702575	.444040	1.048627	.6380
	ASA	3	.465333	.0470567	.0271682	.348438	.582229	.4110
	MM	3	1.826333	.1010264	.0583276	1.575370	2.077297	1.7240
	Control	3	2.373333	.9793025	.5654005	-.059389	4.806056	1.2800
	Total	15	1.368800	.8141143	.2102034	.917959	1.819641	.4110
Cobalt	ADW	3	.008133	.0085594	.0049418	-.013129	.029396	.0027
	ADT	3	.026000	.0065574	.0037859	.009710	.042290	.0190
	ASA	3	.019333	.0077675	.0044845	.000038	.038629	.0130
	MM	3	.006333	.0020817	.0012019	.001162	.011504	.0040
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000
	Total	15	.011960	.0109686	.0028321	.005886	.018034	.0000
Copper	ADW	3	.000230	.0001127	.0000651	-.000050	.000510	.0001
	ADT	3	21.320033	1.2110607	.6992062	18.311592	24.328475	20.0001
	ASA	3	.000200	.0001000	.0000577	-.000048	.000448	.0001
	MM	3	.000133	.0001528	.0000882	-.000246	.000513	.0000
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000
	Total	15	4.264119	8.8391341	2.2822546	-.630830	9.159069	.0000
Chromium	ADW	3	.000000	.0000000	.0000000	.000000	.000000	.0000
	ADT	3	.006000	.0020000	.0011547	.001032	.010968	.0040
	ASA	3	.000567	.0004041	.0002333	-.000437	.001571	.0002
	MM	3	.000267	.0002082	.0001202	-.000250	.000784	.0001
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000
	Total	15	.001367	.0025294	.0006531	-.000034	.002767	.0000
Nickel	ADW	3	.020333	.0070946	.0040961	.002709	.037957	.0140
	ADT	3	.310000	.0867583	.0500899	.094480	.525520	.2160
	ASA	3	.295000	.0302655	.0174738	.219816	.370184	.2710
	MM	3	.210300	.0559917	.0323268	.071209	.349391	.1650
	Control	3	.020000	.0100000	.0057735	-.004841	.044841	.0100
	Total	15	.171127	.1385345	.0357695	.094409	.247845	.0100
Zinc	ADW	3	.080667	.0172143	.0099387	.037904	.123429	.0610
	ADT	3	.495000	.3733135	.2155327	-.432362	1.422362	.2730
	ASA	3	.003667	.0020817	.0012019	-.001504	.008838	.0020
	MM	3	.002667	.0020817	.0012019	-.002504	.007838	.0010
	Control	3	.003333	.0057735	.0033333	-.011009	.017676	.0000
	Total	15	.117067	.2432701	.0628121	-.017652	.251785	.0000
Arsenic	ADW	3	.000567	.0001528	.0000882	.000187	.000946	.0004
	ADT	3	.000333	.0002082	.0001202	-.000184	.000850	.0001
	ASA	3	.000267	.0001528	.0000882	-.000113	.000646	.0001
	MM	3	.001533	.0021385	.0012347	-.003779	.006846	.0002
	Control	3	.000133	.0000577	.0000333	-.000010	.000277	.0001
	Total	15	.000567	.0009686	.0002501	.000030	.001103	.0001

Mercury	ADW	3	.000233	.0001528	.0000882	-.000146	.000613	.0001
	ADT	3	.000233	.0000577	.0000333	.000090	.000377	.0002
	ASA	3	.000267	.0002082	.0001202	-.000250	.000784	.0001
	MM	3	.000200	.0001000	.0000577	-.000048	.000448	.0001
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000
	Total	15	.000187	.0001457	.0000376	.000106	.000267	.0000
Magnesium	ADW	3	5.780000	.4950758	.2858321	4.550164	7.009836	5.2900
	ADT	3	11.506667	.9078179	.5241289	9.251522	13.761811	10.7200
	ASA	3	3.001000	.2272356	.1311945	2.436516	3.565484	2.8070
	MM	3	8.015333	.8470138	.4890236	5.911234	10.119432	7.2750
	Control	3	2.166667	1.1930353	.6887993	-.796997	5.130331	1.2000
	Total	15	6.093933	3.5932108	.9277630	4.104080	8.083787	1.2000
Manganese	ADW	3	.454000	.0540278	.0311929	.319788	.588212	.4170
	ADT	3	.412667	.0712835	.0411555	.235589	.589745	.3540
	ASA	3	.389667	.0332315	.0191862	.307115	.472218	.3690
	MM	3	.437333	.0877971	.0506897	.219233	.655433	.3540
	Control	3	.192667	.0241937	.0139682	.132566	.252767	.1740
	Total	15	.377267	.1101093	.0284301	.316290	.438243	.1740
Calcium	ADW	3	4.166000	.7624356	.4401924	2.272005	6.059995	3.2900
	ADT	3	10.546667	.9373544	.5411818	8.218149	12.875184	9.6500
	ASA	3	2.587000	.3456313	.1995503	1.728404	3.445596	2.2470
	MM	3	7.639667	.5536030	.3196229	6.264440	9.014893	7.2540
	Control	3	12.566667	2.6388129	1.5235193	6.011492	19.121841	10.8000
	Total	15	7.501200	4.0388839	1.0428353	5.264541	9.737859	2.2470
Potassium	ADW	3	.295667	.0320052	.0184782	.216161	.375172	.2640
	ADT	3	.511000	.0671789	.0387857	.344118	.677882	.4390
	ASA	3	.455333	.4084046	.2357925	-.559200	1.469867	.1580
	MM	3	.624333	.0461122	.0266229	.509784	.738882	.5720
	Control	3	.456667	.1517674	.0876229	.079656	.833678	.3200
	Total	15	.468600	.2006788	.0518150	.357468	.579732	.1580
Sodium	ADW	3	8.503333	.9736387	.5621306	6.084681	10.921986	7.4370
	ADT	3	15.586667	1.1399269	.6581371	12.754931	18.418402	14.3200
	ASA	3	8.344000	.6839656	.3948877	6.644935	10.043065	7.5920
	MM	3	17.503333	1.1154072	.6439807	14.732508	20.274159	16.5500
	Control	3	2.200000	.4358899	.2516611	1.117189	3.282811	1.7000
	Total	15	10.427467	5.7666367	1.4889392	7.234010	13.620924	1.7000
Lead	ADW	3	.006333	.0020817	.0012019	.001162	.011504	.0040
	ADT	3	.004667	.0030551	.0017638	-.002922	.012256	.0020
	ASA	3	.015933	.0142553	.0082303	-.019479	.051345	.0048
	MM	3	.003667	.0020817	.0012019	-.001504	.008838	.0020
	Control	3	.000267	.0001528	.0000882	-.000113	.000646	.0001
	Total	15	.006173	.0078315	.0020221	.001836	.010510	.0001
Cadmium	ADW	3	.281200	.2250893	.1299554	-.277953	.840353	.1143
	ADT	3	.191033	.0642965	.0371216	.031312	.350755	.1168
	ASA	3	.190400	.0900457	.0519879	-.033286	.414086	.1093
	MM	3	.209300	.0902910	.0521296	-.014995	.433595	.1079
	Control	3	.060000	.0120000	.0069282	.030190	.089810	.0480
	Total	15	.186387	.1250673	.0322922	.117127	.255647	.0480

Appendix B: Analysis of Variance (ANOVA) of Physico-Chemical Parameters, Mpohor Wassa East

ANOVA

		Sum of Squares	df	Mean Square	F	p-value
Temperature	Between Groups	1.039	4	.260	.250	.903
	Within Groups	10.371	10	1.037		
	Total	11.410	14			
Conductivity	Between Groups	15716.489	4	3929.122	16.286	.000
	Within Groups	2412.640	10	241.264		
	Total	18129.129	14			
Total Dissolved solids	Between Groups	7578.923	4	1894.731	21.854	.000
	Within Groups	867.007	10	86.701		
	Total	8445.929	14			
pH	Between Groups	.887	4	.222	.256	.900
	Within Groups	8.667	10	.867		
	Total	9.553	14			
Salinity	Between Groups	.103	4	.026	5.500	.013
	Within Groups	.047	10	.005		
	Total	.149	14			
Total Suspended solids	Between Groups	911545.936	4	227886.484	1780.725	.000
	Within Groups	1279.740	10	127.974		
	Total	912825.676	14			
Alkalinity	Between Groups	6421.733	4	1605.433	68.608	.000
	Within Groups	234.000	10	23.400		
	Total	6655.733	14			
Bicarbonates	Between Groups	8400.309	4	2100.077	174.542	.000
	Within Groups	120.320	10	12.032		
	Total	8520.628	14			
Turbidity	Between Groups	169844.511	4	42461.128	4.367	.027
	Within Groups	97232.247	10	9723.225		
	Total	267076.757	14			
Total hardness	Between Groups	7888.643	4	1972.161	220.285	.000
	Within Groups	89.528	10	8.953		
	Total	7978.170	14			
iron	Between Groups	7.279	4	1.820	9.097	.002
	Within Groups	2.000	10	.200		
	Total	9.279	14			
Cobalt	Between Groups	.001	4	.000	9.137	.002
	Within Groups	.000	10	.000		
	Total	.002	14			
Copper	Between Groups	1090.891	4	272.723	929.736	.000
	Within Groups	2.933	10	.293		
	Total	1093.824	14			
Chromium	Between Groups	.000	4	.000	24.116	.000
	Within Groups	.000	10	.000		
	Total	.000	14			
Nickel	Between Groups	.245	4	.061	26.136	.000
	Within Groups	.023	10	.002		
	Total	.269	14			
Zinc	Between Groups	.549	4	.137	4.913	.019

	Within Groups	.279	10	.028		
	Total	.829	14			
Arsenic	Between Groups	.000	4	.000	1.018	.443
	Within Groups	.000	10	.000		
	Total	.000	14			
Mercury	Between Groups	.000	4	.000	2.146	.149
	Within Groups	.000	10	.000		
	Total	.000	14			
Magnesium	Between Groups	174.233	4	43.558	66.774	.000
	Within Groups	6.523	10	.652		
	Total	180.756	14			
Manganese	Between Groups	.135	4	.034	9.695	.002
	Within Groups	.035	10	.003		
	Total	.170	14			
Calcium	Between Groups	210.678	4	52.669	29.759	.000
	Within Groups	17.698	10	1.770		
	Total	228.376	14			
Potassium	Between Groups	.169	4	.042	1.069	.421
	Within Groups	.395	10	.039		
	Total	.564	14			
Sodium	Between Groups	457.259	4	114.315	137.750	.000
	Within Groups	8.299	10	.830		
	Total	465.557	14			
Lead	Between Groups	.000	4	.000	2.351	.124
	Within Groups	.000	10	.000		
	Total	.001	14			
Cadmium	Between Groups	.077	4	.019	1.344	.320
	Within Groups	.142	10	.014		
	Total	.219	14			

Appendix C: Tukey's HSD Comparison, Mpohor Wassa East

Dependent Variable	(I) Sampling site	(J) Sampling site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Temperature	ADW	ADT	.81333	.83151	.859	-1.9232	3.5499
		ASA	.28333	.83151	.997	-2.4532	3.0199
		MM	.44000	.83151	.982	-2.2966	3.1766
		Control	.42333	.83151	.985	-2.3132	3.1599
	ADT	ADW	-.81333	.83151	.859	-3.5499	1.9232
		ASA	-.53000	.83151	.965	-3.2666	2.2066
		MM	-.37333	.83151	.990	-3.1099	2.3632
		Control	-.39000	.83151	.989	-3.1266	2.3466
	ASA	ADW	-.28333	.83151	.997	-3.0199	2.4532
		ADT	.53000	.83151	.965	-2.2066	3.2666
		MM	.15667	.83151	1.000	-2.5799	2.8932
		Control	.14000	.83151	1.000	-2.5966	2.8766
	MM	ADW	-.44000	.83151	.982	-3.1766	2.2966
		ADT	.37333	.83151	.990	-2.3632	3.1099
		ASA	-.15667	.83151	1.000	-2.8932	2.5799
		Control	-.01667	.83151	1.000	-2.7532	2.7199
	Control	ADW	-.42333	.83151	.985	-3.1599	2.3132
		ADT	.39000	.83151	.989	-2.3466	3.1266
		ASA	-.14000	.83151	1.000	-2.8766	2.5966
		MM	.01667	.83151	1.000	-2.7199	2.7532
Conductivity	ADW	ADT	-4.80000	12.68238	.995	-46.5387	36.9387
		ASA	30.83333	12.68238	.184	-10.9054	72.5721
		MM	-28.83333	12.68238	.230	-70.5721	12.9054
		Control	64.83333*	12.68238	.003	23.0946	106.5721
	ADT	ADW	4.80000	12.68238	.995	-36.9387	46.5387
		ASA	35.63333	12.68238	.105	-6.1054	77.3721
		MM	-24.03333	12.68238	.378	-65.7721	17.7054

		Control	69.63333*	12.68238	.002	27.8946	111.3721
	ASA	ADW	-30.83333	12.68238	.184	-72.5721	10.9054
		ADT	-35.63333	12.68238	.105	-77.3721	6.1054
		MM	-59.66667*	12.68238	.006	-101.4054	-17.9279
		Control	34.00000	12.68238	.127	-7.7387	75.7387
	MM	ADW	28.83333	12.68238	.230	-12.9054	70.5721
		ADT	24.03333	12.68238	.378	-17.7054	65.7721
		ASA	59.66667*	12.68238	.006	17.9279	101.4054
		Control	93.66667*	12.68238	.000	51.9279	135.4054
	Control	ADW	-64.83333*	12.68238	.003	-106.5721	-23.0946
		ADT	-69.63333*	12.68238	.002	-111.3721	-27.8946
		ASA	-34.00000	12.68238	.127	-75.7387	7.7387
		MM	-93.66667*	12.68238	.000	-135.4054	-51.9279
Total Dissolved solids	ADW	ADT	-12.70000	7.60266	.491	-37.7210	12.3210
		ASA	7.96667	7.60266	.828	-17.0543	32.9876
		MM	-31.36667*	7.60266	.014	-56.3876	-6.3457
		Control	36.30000*	7.60266	.005	11.2790	61.3210
	ADT	ADW	12.70000	7.60266	.491	-12.3210	37.7210
		ASA	20.66667	7.60266	.120	-4.3543	45.6876
		MM	-18.66667	7.60266	.178	-43.6876	6.3543
		Control	49.00000*	7.60266	.001	23.9790	74.0210
	ASA	ADW	-7.96667	7.60266	.828	-32.9876	17.0543
		ADT	-20.66667	7.60266	.120	-45.6876	4.3543
		MM	-39.33333*	7.60266	.003	-64.3543	-14.3124
		Control	28.33333*	7.60266	.025	3.3124	53.3543
	MM	ADW	31.36667*	7.60266	.014	6.3457	56.3876
		ADT	18.66667	7.60266	.178	-6.3543	43.6876
		ASA	39.33333*	7.60266	.003	14.3124	64.3543
		Control	67.66667*	7.60266	.000	42.6457	92.6876
	Control	ADW	-36.30000*	7.60266	.005	-61.3210	-11.2790
		ADT	-49.00000*	7.60266	.001	-74.0210	-23.9790
		ASA	-28.33333*	7.60266	.025	-53.3543	-3.3124
		MM	-67.66667*	7.60266	.000	-92.6876	-42.6457
pH	ADW	ADT	-.30000	.76012	.994	-2.8016	2.2016

		ASA	.20000	.76012	.999	-2.3016	2.7016
		MM	.16667	.76012	.999	-2.3349	2.6683
		Control	-.40000	.76012	.983	-2.9016	2.1016
	ADT	ADW	.30000	.76012	.994	-2.2016	2.8016
		ASA	.50000	.76012	.961	-2.0016	3.0016
		MM	.46667	.76012	.970	-2.0349	2.9683
		Control	-.10000	.76012	1.000	-2.6016	2.4016
	ASA	ADW	-.20000	.76012	.999	-2.7016	2.3016
		ADT	-.50000	.76012	.961	-3.0016	2.0016
		MM	-.03333	.76012	1.000	-2.5349	2.4683
		Control	-.60000	.76012	.928	-3.1016	1.9016
	MM	ADW	-.16667	.76012	.999	-2.6683	2.3349
		ADT	-.46667	.76012	.970	-2.9683	2.0349
		ASA	.03333	.76012	1.000	-2.4683	2.5349
		Control	-.56667	.76012	.940	-3.0683	1.9349
	Control	ADW	.40000	.76012	.983	-2.1016	2.9016
		ADT	.10000	.76012	1.000	-2.4016	2.6016
		ASA	.60000	.76012	.928	-1.9016	3.1016
		MM	.56667	.76012	.940	-1.9349	3.0683
Salinity	ADW	ADT	-.10000	.05578	.427	-.2836	.0836
		ASA	.10000	.05578	.427	-.0836	.2836
		MM	-.06667	.05578	.754	-.2502	.1169
		Control	.10000	.05578	.427	-.0836	.2836
	ADT	ADW	.10000	.05578	.427	-.0836	.2836
		ASA	.20000*	.05578	.032	.0164	.3836
		MM	.03333	.05578	.972	-.1502	.2169
		Control	.20000*	.05578	.032	.0164	.3836
	ASA	ADW	-.10000	.05578	.427	-.2836	.0836
		ADT	-.20000*	.05578	.032	-.3836	-.0164
		MM	-.16667	.05578	.080	-.3502	.0169
		Control	.00000	.05578	1.000	-.1836	.1836
	MM	ADW	.06667	.05578	.754	-.1169	.2502
		ADT	-.03333	.05578	.972	-.2169	.1502
		ASA	.16667	.05578	.080	-.0169	.3502

		Control	.16667	.05578	.080	-.0169	.3502
	Control	ADW	-.10000	.05578	.427	-.2836	.0836
		ADT	-.20000*	.05578	.032	-.3836	-.0164
		ASA	.00000	.05578	1.000	-.1836	.1836
		MM	-.16667	.05578	.080	-.3502	.0169
Total Suspended solids	ADW	ADT	-140.00000*	9.23667	.000	-170.3986	-109.6014
		ASA	-393.66667*	9.23667	.000	-424.0653	-363.2680
		MM	-640.00000*	9.23667	.000	-670.3986	-609.6014
		Control	-10.46667	9.23667	.786	-40.8653	19.9320
	ADT	ADW	140.00000*	9.23667	.000	109.6014	170.3986
		ASA	-253.66667*	9.23667	.000	-284.0653	-223.2680
		MM	-500.00000*	9.23667	.000	-530.3986	-469.6014
		Control	129.53333*	9.23667	.000	99.1347	159.9320
	ASA	ADW	393.66667*	9.23667	.000	363.2680	424.0653
		ADT	253.66667*	9.23667	.000	223.2680	284.0653
		MM	-246.33333*	9.23667	.000	-276.7320	-215.9347
		Control	383.20000*	9.23667	.000	352.8014	413.5986
	MM	ADW	640.00000*	9.23667	.000	609.6014	670.3986
		ADT	500.00000*	9.23667	.000	469.6014	530.3986
		ASA	246.33333*	9.23667	.000	215.9347	276.7320
		Control	629.53333*	9.23667	.000	599.1347	659.9320
	Control	ADW	10.46667	9.23667	.786	-19.9320	40.8653
		ADT	-129.53333*	9.23667	.000	-159.9320	-99.1347
		ASA	-383.20000*	9.23667	.000	-413.5986	-352.8014
		MM	-629.53333*	9.23667	.000	-659.9320	-599.1347
Alkalinity	ADW	ADT	-29.66667*	3.94968	.000	-42.6654	-16.6679
		ASA	9.00000	3.94968	.228	-3.9987	21.9987
		MM	-30.66667*	3.94968	.000	-43.6654	-17.6679
		Control	-46.33333*	3.94968	.000	-59.3321	-33.3346
	ADT	ADW	29.66667*	3.94968	.000	16.6679	42.6654
		ASA	38.66667*	3.94968	.000	25.6679	51.6654
		MM	-1.00000	3.94968	.999	-13.9987	11.9987
		Control	-16.66667*	3.94968	.012	-29.6654	-3.6679
	ASA	ADW	-9.00000	3.94968	.228	-21.9987	3.9987

		ADT	-38.66667*	3.94968	.000	-51.6654	-25.6679
		MM	-39.66667*	3.94968	.000	-52.6654	-26.6679
		Control	-55.33333*	3.94968	.000	-68.3321	-42.3346
	MM	ADW	30.66667*	3.94968	.000	17.6679	43.6654
		ADT	1.00000	3.94968	.999	-11.9987	13.9987
		ASA	39.66667*	3.94968	.000	26.6679	52.6654
		Control	-15.66667*	3.94968	.018	-28.6654	-2.6679
	Control	ADW	46.33333*	3.94968	.000	33.3346	59.3321
		ADT	16.66667*	3.94968	.012	3.6679	29.6654
		ASA	55.33333*	3.94968	.000	42.3346	68.3321
		MM	15.66667*	3.94968	.018	2.6679	28.6654
Bicarbonates	ADW	ADT	-37.29767*	2.83219	.000	-46.6186	-27.9767
		ASA	9.06200	2.83219	.058	-.2590	18.3830
		MM	-38.46033*	2.83219	.000	-47.7813	-29.1394
		Control	-51.31067*	2.83219	.000	-60.6316	-41.9897
	ADT	ADW	37.29767*	2.83219	.000	27.9767	46.6186
		ASA	46.35967*	2.83219	.000	37.0387	55.6806
		MM	-1.16267	2.83219	.993	-10.4836	8.1583
		Control	-14.01300*	2.83219	.004	-23.3340	-4.6920
	ASA	ADW	-9.06200	2.83219	.058	-18.3830	.2590
		ADT	-46.35967*	2.83219	.000	-55.6806	-37.0387
		MM	-47.52233*	2.83219	.000	-56.8433	-38.2014
		Control	-60.37267*	2.83219	.000	-69.6936	-51.0517
	MM	ADW	38.46033*	2.83219	.000	29.1394	47.7813
		ADT	1.16267	2.83219	.993	-8.1583	10.4836
		ASA	47.52233*	2.83219	.000	38.2014	56.8433
		Control	-12.85033*	2.83219	.007	-22.1713	-3.5294
	Control	ADW	51.31067*	2.83219	.000	41.9897	60.6316
		ADT	14.01300*	2.83219	.004	4.6920	23.3340
		ASA	60.37267*	2.83219	.000	51.0517	69.6936
		MM	12.85033*	2.83219	.007	3.5294	22.1713
Turbidity	ADW	ADT	-275.40000*	80.51180	.041	-540.3709	-10.4291
		ASA	-66.10000	80.51180	.918	-331.0709	198.8709
		MM	-35.80000	80.51180	.991	-300.7709	229.1709

		Control	21.36667	80.51180	.999	-243.6043	286.3376
	ADT	ADW	275.40000*	80.51180	.041	10.4291	540.3709
		ASA	209.30000	80.51180	.144	-55.6709	474.2709
		MM	239.60000	80.51180	.081	-25.3709	504.5709
		Control	296.76667*	80.51180	.027	31.7957	561.7376
	ASA	ADW	66.10000	80.51180	.918	-198.8709	331.0709
		ADT	-209.30000	80.51180	.144	-474.2709	55.6709
		MM	30.30000	80.51180	.995	-234.6709	295.2709
		Control	87.46667	80.51180	.810	-177.5043	352.4376
	MM	ADW	35.80000	80.51180	.991	-229.1709	300.7709
		ADT	-239.60000	80.51180	.081	-504.5709	25.3709
		ASA	-30.30000	80.51180	.995	-295.2709	234.6709
		Control	57.16667	80.51180	.949	-207.8043	322.1376
	Control	ADW	-21.36667	80.51180	.999	-286.3376	243.6043
		ADT	-296.76667*	80.51180	.027	-561.7376	-31.7957
		ASA	-87.46667	80.51180	.810	-352.4376	177.5043
		MM	-57.16667	80.51180	.949	-322.1376	207.8043
Total hardness	ADW	ADT	-39.0576667*	2.4430524	.000	-47.097953	-31.017381
		ASA	15.8873333*	2.4430524	.001	7.847047	23.927619
		MM	-21.8883333*	2.4430524	.000	-29.928619	-13.848047
		Control	21.9036667*	2.4430524	.000	13.863381	29.943953
	ADT	ADW	39.0576667*	2.4430524	.000	31.017381	47.097953
		ASA	54.9450000*	2.4430524	.000	46.904714	62.985286
		MM	17.1693333*	2.4430524	.000	9.129047	25.209619
		Control	60.9613333*	2.4430524	.000	52.921047	69.001619
	ASA	ADW	-15.8873333*	2.4430524	.001	-23.927619	-7.847047
		ADT	-54.9450000*	2.4430524	.000	-62.985286	-46.904714
		MM	-37.7756667*	2.4430524	.000	-45.815953	-29.735381
		Control	6.0163333	2.4430524	.176	-2.023953	14.056619
	MM	ADW	21.8883333*	2.4430524	.000	13.848047	29.928619
		ADT	-17.1693333*	2.4430524	.000	-25.209619	-9.129047
		ASA	37.7756667*	2.4430524	.000	29.735381	45.815953
		Control	43.7920000*	2.4430524	.000	35.751714	51.832286
	Control	ADW	-21.9036667*	2.4430524	.000	-29.943953	-13.863381

		ADT	-60.9613333*	2.4430524	.000	-69.001619	-52.921047
		ASA	-6.0163333	2.4430524	.176	-14.056619	2.023953
		MM	-43.7920000*	2.4430524	.000	-51.832286	-35.751714
Iron	ADW	ADT	.6863333	.3651748	.385	-.515487	1.888154
		ASA	.9673333	.3651748	.134	-.234487	2.169154
		MM	-.3936667	.3651748	.814	-1.595487	.808154
		Control	-.9406667	.3651748	.149	-2.142487	.261154
	ADT	ADW	-.6863333	.3651748	.385	-1.888154	.515487
		ASA	.2810000	.3651748	.934	-.920820	1.482820
		MM	-1.0800000	.3651748	.084	-2.281820	.121820
		Control	-1.6270000*	.3651748	.008	-2.828820	-.425180
	ASA	ADW	-.9673333	.3651748	.134	-2.169154	.234487
		ADT	-.2810000	.3651748	.934	-1.482820	.920820
		MM	-1.3610000*	.3651748	.025	-2.562820	-.159180
		Control	-1.9080000*	.3651748	.003	-3.109820	-.706180
	MM	ADW	.3936667	.3651748	.814	-.808154	1.595487
		ADT	1.0800000	.3651748	.084	-.121820	2.281820
		ASA	1.3610000*	.3651748	.025	.159180	2.562820
		Control	-.5470000	.3651748	.586	-1.748820	.654820
	Control	ADW	.9406667	.3651748	.149	-.261154	2.142487
		ADT	1.6270000*	.3651748	.008	.425180	2.828820
		ASA	1.9080000*	.3651748	.003	.706180	3.109820
		MM	.5470000	.3651748	.586	-.654820	1.748820
Cobalt	ADW	ADT	-.0178667*	.0049116	.029	-.034031	-.001702
		ASA	-.0112000	.0049116	.228	-.027365	.004965
		MM	.0018000	.0049116	.996	-.014365	.017965
		Control	.0081333	.0049116	.498	-.008031	.024298
	ADT	ADW	.0178667*	.0049116	.029	.001702	.034031
		ASA	.0066667	.0049116	.665	-.009498	.022831
		MM	.0196667*	.0049116	.017	.003502	.035831
		Control	.0260000*	.0049116	.003	.009835	.042165
	ASA	ADW	.0112000	.0049116	.228	-.004965	.027365
		ADT	-.0066667	.0049116	.665	-.022831	.009498
		MM	.0130000	.0049116	.134	-.003165	.029165

		Control	.0193333*	.0049116	.018	.003169	.035498
	MM	ADW	-.0018000	.0049116	.996	-.017965	.014365
		ADT	-.0196667*	.0049116	.017	-.035831	-.003502
		ASA	-.0130000	.0049116	.134	-.029165	.003165
		Control	.0063333	.0049116	.703	-.009831	.022498
	Control	ADW	-.0081333	.0049116	.498	-.024298	.008031
		ADT	-.0260000*	.0049116	.003	-.042165	-.009835
		ASA	-.0193333*	.0049116	.018	-.035498	-.003169
		MM	-.0063333	.0049116	.703	-.022498	.009831
Copper	ADW	ADT	-21.3198033*	.4422168	.000	-22.775175	-19.864431
		ASA	.0000300	.4422168	1.000	-1.455342	1.455402
		MM	.0000967	.4422168	1.000	-1.455275	1.455469
		Control	.0002300	.4422168	1.000	-1.455142	1.455602
	ADT	ADW	21.3198033*	.4422168	.000	19.864431	22.775175
		ASA	21.3198333*	.4422168	.000	19.864461	22.775205
		MM	21.3199000*	.4422168	.000	19.864528	22.775272
		Control	21.3200333*	.4422168	.000	19.864661	22.775405
	ASA	ADW	-.0000300	.4422168	1.000	-1.455402	1.455342
		ADT	-21.3198333*	.4422168	.000	-22.775205	-19.864461
		MM	.0000667	.4422168	1.000	-1.455305	1.455439
		Control	.0002000	.4422168	1.000	-1.455172	1.455572
	MM	ADW	-.0000967	.4422168	1.000	-1.455469	1.455275
		ADT	-21.3199000*	.4422168	.000	-22.775272	-19.864528
		ASA	-.0000667	.4422168	1.000	-1.455439	1.455305
		Control	.0001333	.4422168	1.000	-1.455239	1.455505
	Control	ADW	-.0002300	.4422168	1.000	-1.455602	1.455142
		ADT	-21.3200333*	.4422168	.000	-22.775405	-19.864661
		ASA	-.0002000	.4422168	1.000	-1.455572	1.455172
		MM	-.0001333	.4422168	1.000	-1.455505	1.455239
Chromium	ADW	ADT	-.0060000*	.0007489	.000	-.008465	-.003535
		ASA	-.0005667	.0007489	.937	-.003031	.001898
		MM	-.0002667	.0007489	.996	-.002731	.002198
		Control	.0000000	.0007489	1.000	-.002465	.002465
	ADT	ADW	.0060000*	.0007489	.000	.003535	.008465

		ASA	.0054333*	.0007489	.000	.002969	.007898
		MM	.0057333*	.0007489	.000	.003269	.008198
		Control	.0060000*	.0007489	.000	.003535	.008465
	ASA	ADW	.0005667	.0007489	.937	-.001898	.003031
		ADT	-.0054333*	.0007489	.000	-.007898	-.002969
		MM	.0003000	.0007489	.994	-.002165	.002765
		Control	.0005667	.0007489	.937	-.001898	.003031
	MM	ADW	.0002667	.0007489	.996	-.002198	.002731
		ADT	-.0057333*	.0007489	.000	-.008198	-.003269
		ASA	-.0003000	.0007489	.994	-.002765	.002165
		Control	.0002667	.0007489	.996	-.002198	.002731
	Control	ADW	.0000000	.0007489	1.000	-.002465	.002465
		ADT	-.0060000*	.0007489	.000	-.008465	-.003535
		ASA	-.0005667	.0007489	.937	-.003031	.001898
		MM	-.0002667	.0007489	.996	-.002731	.002198
Nickel	ADW	ADT	-.2896667*	.0395447	.000	-.419812	-.159522
		ASA	-.2746667*	.0395447	.000	-.404812	-.144522
		MM	-.1899667*	.0395447	.005	-.320112	-.059822
		Control	.0003333	.0395447	1.000	-.129812	.130478
	ADT	ADW	.2896667*	.0395447	.000	.159522	.419812
		ASA	.0150000	.0395447	.995	-.115145	.145145
		MM	.0997000	.0395447	.161	-.030445	.229845
		Control	.2900000*	.0395447	.000	.159855	.420145
	ASA	ADW	.2746667*	.0395447	.000	.144522	.404812
		ADT	-.0150000	.0395447	.995	-.145145	.115145
		MM	.0847000	.0395447	.275	-.045445	.214845
		Control	.2750000*	.0395447	.000	.144855	.405145
	MM	ADW	.1899667*	.0395447	.005	.059822	.320112
		ADT	-.0997000	.0395447	.161	-.229845	.030445
		ASA	-.0847000	.0395447	.275	-.214845	.045445
		Control	.1903000*	.0395447	.005	.060155	.320445
	Control	ADW	-.0003333	.0395447	1.000	-.130478	.129812
		ADT	-.2900000*	.0395447	.000	-.420145	-.159855
		ASA	-.2750000*	.0395447	.000	-.405145	-.144855

		MM	-.1903000*	.0395447	.005	-.320445	-.060155
Zinc	ADW	ADT	-.4143333	.1364802	.074	-.863501	.034834
		ASA	.0770000	.1364802	.977	-.372168	.526168
		MM	.0780000	.1364802	.976	-.371168	.527168
		Control	.0773333	.1364802	.977	-.371834	.526501
	ADT	ADW	.4143333	.1364802	.074	-.034834	.863501
		ASA	.4913333*	.1364802	.031	.042166	.940501
		MM	.4923333*	.1364802	.031	.043166	.941501
		Control	.4916667*	.1364802	.031	.042499	.940834
	ASA	ADW	-.0770000	.1364802	.977	-.526168	.372168
		ADT	-.4913333*	.1364802	.031	-.940501	-.042166
		MM	.0010000	.1364802	1.000	-.448168	.450168
		Control	.0003333	.1364802	1.000	-.448834	.449501
	MM	ADW	-.0780000	.1364802	.976	-.527168	.371168
		ADT	-.4923333*	.1364802	.031	-.941501	-.043166
		ASA	-.0010000	.1364802	1.000	-.450168	.448168
		Control	-.0006667	.1364802	1.000	-.449834	.448501
	Control	ADW	-.0773333	.1364802	.977	-.526501	.371834
		ADT	-.4916667*	.1364802	.031	-.940834	-.042499
		ASA	-.0003333	.1364802	1.000	-.449501	.448834
		MM	.0006667	.1364802	1.000	-.448501	.449834
Arsenic	ADW	ADT	.0002333	.0007888	.998	-.002363	.002829
		ASA	.0003000	.0007888	.995	-.002296	.002896
		MM	-.0009667	.0007888	.738	-.003563	.001629
		Control	.0004333	.0007888	.980	-.002163	.003029
	ADT	ADW	-.0002333	.0007888	.998	-.002829	.002363
		ASA	.0000667	.0007888	1.000	-.002529	.002663
		MM	-.0012000	.0007888	.573	-.003796	.001396
		Control	.0002000	.0007888	.999	-.002396	.002796
	ASA	ADW	-.0003000	.0007888	.995	-.002896	.002296
		ADT	-.0000667	.0007888	1.000	-.002663	.002529
		MM	-.0012667	.0007888	.526	-.003863	.001329
		Control	.0001333	.0007888	1.000	-.002463	.002729
	MM	ADW	.0009667	.0007888	.738	-.001629	.003563

		ADT	.0012000	.0007888	.573	-.001396	.003796
		ASA	.0012667	.0007888	.526	-.001329	.003863
		Control	.0014000	.0007888	.436	-.001196	.003996
	Control	ADW	-.0004333	.0007888	.980	-.003029	.002163
		ADT	-.0002000	.0007888	.999	-.002796	.002396
		ASA	-.0001333	.0007888	1.000	-.002729	.002463
		MM	-.0014000	.0007888	.436	-.003996	.001196
Mercury	ADW	ADT	.0000000	.0001033	1.000	-.000340	.000340
		ASA	-.0000333	.0001033	.997	-.000373	.000307
		MM	.0000333	.0001033	.997	-.000307	.000373
		Control	.0002333	.0001033	.235	-.000107	.000573
	ADT	ADW	.0000000	.0001033	1.000	-.000340	.000340
		ASA	-.0000333	.0001033	.997	-.000373	.000307
		MM	.0000333	.0001033	.997	-.000307	.000373
		Control	.0002333	.0001033	.235	-.000107	.000573
	ASA	ADW	.0000333	.0001033	.997	-.000307	.000373
		ADT	.0000333	.0001033	.997	-.000307	.000373
		MM	.0000667	.0001033	.964	-.000273	.000407
		Control	.0002667	.0001033	.148	-.000073	.000607
	MM	ADW	-.0000333	.0001033	.997	-.000373	.000307
		ADT	-.0000333	.0001033	.997	-.000373	.000307
		ASA	-.0000667	.0001033	.964	-.000407	.000273
		Control	.0002000	.0001033	.359	-.000140	.000540
	Control	ADW	-.0002333	.0001033	.235	-.000573	.000107
		ADT	-.0002333	.0001033	.235	-.000573	.000107
		ASA	-.0002667	.0001033	.148	-.000607	.000073
		MM	-.0002000	.0001033	.359	-.000540	.000140
Magnesium	ADW	ADT	-5.7266667*	.6594579	.000	-7.896997	-3.556337
		ASA	2.7790000*	.6594579	.012	.608670	4.949330
		MM	-2.2353333*	.6594579	.043	-4.405663	-.065003
		Control	3.6133333*	.6594579	.002	1.443003	5.783663
	ADT	ADW	5.7266667*	.6594579	.000	3.556337	7.896997
		ASA	8.5056667*	.6594579	.000	6.335337	10.675997
		MM	3.4913333*	.6594579	.003	1.321003	5.661663

		Control	9.3400000*	.6594579	.000	7.169670	11.510330
	ASA	ADW	-2.7790000*	.6594579	.012	-4.949330	-.608670
		ADT	-8.5056667*	.6594579	.000	-10.675997	-6.335337
		MM	-5.0143333*	.6594579	.000	-7.184663	-2.844003
		Control	.8343333	.6594579	.717	-1.335997	3.004663
	MM	ADW	2.2353333*	.6594579	.043	.065003	4.405663
		ADT	-3.4913333*	.6594579	.003	-5.661663	-1.321003
		ASA	5.0143333*	.6594579	.000	2.844003	7.184663
		Control	5.8486667*	.6594579	.000	3.678337	8.018997
	Control	ADW	-3.6133333*	.6594579	.002	-5.783663	-1.443003
		ADT	-9.3400000*	.6594579	.000	-11.510330	-7.169670
		ASA	-.8343333	.6594579	.717	-3.004663	1.335997
		MM	-5.8486667*	.6594579	.000	-8.018997	-3.678337
Manganese	ADW	ADT	.0413333	.0481641	.906	-.117179	.199845
		ASA	.0643333	.0481641	.677	-.094179	.222845
		MM	.0166667	.0481641	.996	-.141845	.175179
		Control	.2613333*	.0481641	.002	.102821	.419845
	ADT	ADW	-.0413333	.0481641	.906	-.199845	.117179
		ASA	.0230000	.0481641	.988	-.135512	.181512
		MM	-.0246667	.0481641	.984	-.183179	.133845
		Control	.2200000*	.0481641	.007	.061488	.378512
	ASA	ADW	-.0643333	.0481641	.677	-.222845	.094179
		ADT	-.0230000	.0481641	.988	-.181512	.135512
		MM	-.0476667	.0481641	.854	-.206179	.110845
		Control	.1970000*	.0481641	.015	.038488	.355512
	MM	ADW	-.0166667	.0481641	.996	-.175179	.141845
		ADT	.0246667	.0481641	.984	-.133845	.183179
		ASA	.0476667	.0481641	.854	-.110845	.206179
		Control	.2446667*	.0481641	.003	.086155	.403179
	Control	ADW	-.2613333*	.0481641	.002	-.419845	-.102821
		ADT	-.2200000*	.0481641	.007	-.378512	-.061488
		ASA	-.1970000*	.0481641	.015	-.355512	-.038488
		MM	-.2446667*	.0481641	.003	-.403179	-.086155
Calcium	ADW	ADT	-6.3806667*	1.0862297	.001	-9.955538	-2.805796

		ASA	1.5790000	1.0862297	.611	-1.995871	5.153871
		MM	-3.4736667	1.0862297	.058	-7.048538	.101204
		Control	-8.4006667*	1.0862297	.000	-11.975538	-4.825796
	ADT	ADW	6.3806667*	1.0862297	.001	2.805796	9.955538
		ASA	7.9596667*	1.0862297	.000	4.384796	11.534538
		MM	2.9070000	1.0862297	.128	-.667871	6.481871
		Control	-2.0200000	1.0862297	.395	-5.594871	1.554871
	ASA	ADW	-1.5790000	1.0862297	.611	-5.153871	1.995871
		ADT	-7.9596667*	1.0862297	.000	-11.534538	-4.384796
		MM	-5.0526667*	1.0862297	.006	-8.627538	-1.477796
		Control	-9.9796667*	1.0862297	.000	-13.554538	-6.404796
	MM	ADW	3.4736667	1.0862297	.058	-.101204	7.048538
		ADT	-2.9070000	1.0862297	.128	-6.481871	.667871
		ASA	5.0526667*	1.0862297	.006	1.477796	8.627538
		Control	-4.9270000*	1.0862297	.007	-8.501871	-1.352129
	Control	ADW	8.4006667*	1.0862297	.000	4.825796	11.975538
		ADT	2.0200000	1.0862297	.395	-1.554871	5.594871
		ASA	9.9796667*	1.0862297	.000	6.404796	13.554538
		MM	4.9270000*	1.0862297	.007	1.352129	8.501871
Potassium	ADW	ADT	-.2153333	.1622719	.682	-.749384	.318717
		ASA	-.1596667	.1622719	.857	-.693717	.374384
		MM	-.3286667	.1622719	.321	-.862717	.205384
		Control	-.1610000	.1622719	.853	-.695050	.373050
	ADT	ADW	.2153333	.1622719	.682	-.318717	.749384
		ASA	.0556667	.1622719	.997	-.478384	.589717
		MM	-.1133333	.1622719	.952	-.647384	.420717
		Control	.0543333	.1622719	.997	-.479717	.588384
	ASA	ADW	.1596667	.1622719	.857	-.374384	.693717
		ADT	-.0556667	.1622719	.997	-.589717	.478384
		MM	-.1690000	.1622719	.831	-.703050	.365050
		Control	-.0013333	.1622719	1.000	-.535384	.532717
	MM	ADW	.3286667	.1622719	.321	-.205384	.862717
		ADT	.1133333	.1622719	.952	-.420717	.647384
		ASA	.1690000	.1622719	.831	-.365050	.703050

		Control	.1676667	.1622719	.835	-.366384	.701717
	Control	ADW	.1610000	.1622719	.853	-.373050	.695050
		ADT	-.0543333	.1622719	.997	-.588384	.479717
		ASA	.0013333	.1622719	1.000	-.532717	.535384
		MM	-.1676667	.1622719	.835	-.701717	.366384
Sodium	ADW	ADT	-7.0833333*	.7438054	.000	-9.531258	-4.635409
		ASA	.1593333	.7438054	.999	-2.288591	2.607258
		MM	-9.0000000*	.7438054	.000	-11.447925	-6.552075
		Control	6.3033333*	.7438054	.000	3.855409	8.751258
	ADT	ADW	7.0833333*	.7438054	.000	4.635409	9.531258
		ASA	7.2426667*	.7438054	.000	4.794742	9.690591
		MM	-1.9166667	.7438054	.149	-4.364591	.531258
		Control	13.3866667*	.7438054	.000	10.938742	15.834591
	ASA	ADW	-.1593333	.7438054	.999	-2.607258	2.288591
		ADT	-7.2426667*	.7438054	.000	-9.690591	-4.794742
		MM	-9.1593333*	.7438054	.000	-11.607258	-6.711409
		Control	6.1440000*	.7438054	.000	3.696075	8.591925
	MM	ADW	9.0000000*	.7438054	.000	6.552075	11.447925
		ADT	1.9166667	.7438054	.149	-.531258	4.364591
		ASA	9.1593333*	.7438054	.000	6.711409	11.607258
		Control	15.3033333*	.7438054	.000	12.855409	17.751258
	Control	ADW	-6.3033333*	.7438054	.000	-8.751258	-3.855409
		ADT	-13.3866667*	.7438054	.000	-15.834591	-10.938742
		ASA	-6.1440000*	.7438054	.000	-8.591925	-3.696075
		MM	-15.3033333*	.7438054	.000	-17.751258	-12.855409
Lead	ADW	ADT	.0016667	.0054312	.998	-.016208	.019541
		ASA	-.0096000	.0054312	.440	-.027475	.008275
		MM	.0026667	.0054312	.986	-.015208	.020541
		Control	.0060667	.0054312	.795	-.011808	.023941
	ADT	ADW	-.0016667	.0054312	.998	-.019541	.016208
		ASA	-.0112667	.0054312	.301	-.029141	.006608
		MM	.0010000	.0054312	1.000	-.016875	.018875
		Control	.0044000	.0054312	.922	-.013475	.022275
	ASA	ADW	.0096000	.0054312	.440	-.008275	.027475

		ADT	.0112667	.0054312	.301	-.006608	.029141
		MM	.0122667	.0054312	.235	-.005608	.030141
		Control	.0156667	.0054312	.094	-.002208	.033541
	MM	ADW	-.0026667	.0054312	.986	-.020541	.015208
		ADT	-.0010000	.0054312	1.000	-.018875	.016875
		ASA	-.0122667	.0054312	.235	-.030141	.005608
		Control	.0034000	.0054312	.967	-.014475	.021275
	Control	ADW	-.0060667	.0054312	.795	-.023941	.011808
		ADT	-.0044000	.0054312	.922	-.022275	.013475
		ASA	-.0156667	.0054312	.094	-.033541	.002208
		MM	-.0034000	.0054312	.967	-.021275	.014475
Cadmium	ADW	ADT	.0901667	.0974364	.881	-.230505	.410838
		ASA	.0908000	.0974364	.878	-.229871	.411471
		MM	.0719000	.0974364	.942	-.248771	.392571
		Control	.2212000	.0974364	.231	-.099471	.541871
	ADT	ADW	-.0901667	.0974364	.881	-.410838	.230505
		ASA	.0006333	.0974364	1.000	-.320038	.321305
		MM	-.0182667	.0974364	1.000	-.338938	.302405
		Control	.1310333	.0974364	.672	-.189638	.451705
	ASA	ADW	-.0908000	.0974364	.878	-.411471	.229871
		ADT	-.0006333	.0974364	1.000	-.321305	.320038
		MM	-.0189000	.0974364	1.000	-.339571	.301771
		Control	.1304000	.0974364	.676	-.190271	.451071
	MM	ADW	-.0719000	.0974364	.942	-.392571	.248771
		ADT	.0182667	.0974364	1.000	-.302405	.338938
		ASA	.0189000	.0974364	1.000	-.301771	.339571
		Control	.1493000	.0974364	.566	-.171371	.469971
	Control	ADW	-.2212000	.0974364	.231	-.541871	.099471
		ADT	-.1310333	.0974364	.672	-.451705	.189638
		ASA	-.1304000	.0974364	.676	-.451071	.190271
		MM	-.1493000	.0974364	.566	-.469971	.171371

*. The mean difference is significant at the 0.05 level.

Appendix D: Descriptives for physico-Chemical Parameters in Water, Amansie West

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Temperature	DO	3	23.4800	1.02059	.58924	20.9447	26.0153	22.48	24.52
	AS	3	23.6467	.97675	.56392	21.2203	26.0730	22.81	24.72
	MN	3	24.5367	1.23525	.71317	21.4681	27.6052	23.22	25.67
	Control	3	23.3033	2.22541	1.28484	17.7751	28.8315	21.32	25.71
	Total	12	23.7417	1.33664	.38586	22.8924	24.5909	21.32	25.71
Conductivity	DO	3	277.3333	13.65040	7.88106	243.4239	311.2428	265.00	292.00
	AS	3	443.6667	14.57166	8.41295	407.4687	479.8647	430.00	459.00
	MN	3	484.8333	34.38958	19.85483	399.4049	570.2618	458.00	523.60
	Control	3	42.6667	11.01514	6.35959	15.3035	70.0298	32.00	54.00
	Total	12	312.1250	182.47146	52.67497	196.1882	428.0618	32.00	523.60
Total Dissolved solids	DO	3	132.3333	8.73689	5.04425	110.6297	154.0370	125.00	142.00
	AS	3	226.0000	20.66398	11.93035	174.6678	277.3322	204.00	245.00
	MN	3	222.1733	17.81000	10.28261	177.9308	266.4158	210.82	242.70
	Control	3	25.3333	6.42910	3.71184	9.3626	41.3041	18.00	30.00
	Total	12	151.4600	86.45271	24.95675	96.5306	206.3894	18.00	245.00
pH	DO	3	4.9333	.25166	.14530	4.3082	5.5585	4.70	5.20
	AS	3	4.7000	.20000	.11547	4.2032	5.1968	4.50	4.90
	MN	3	4.5667	.25166	.14530	3.9415	5.1918	4.30	4.80
	Control	3	7.7667	.51316	.29627	6.4919	9.0414	7.20	8.20
	Total	12	5.4917	1.40677	.40610	4.5978	6.3855	4.30	8.20
Salinity	DO	3	.1333	.05774	.03333	-.0101	.2768	.10	.20
	AS	3	.3000	.10000	.05774	.0516	.5484	.20	.40
	MN	3	.2000	.10000	.05774	-.0484	.4484	.10	.30
	Control	3	.0000	.00000	.00000	.0000	.0000	.00	.00
	Total	12	.1583	.13114	.03786	.0750	.2417	.00	.40
Total Suspended solids	DO	3	247.3333	5.68624	3.28295	233.2079	261.4587	241.00	252.00
	AS	3	390.6667	33.60556	19.40218	307.1858	474.1475	354.00	420.00
	MN	3	261.0000	19.67232	11.35782	212.1313	309.8687	243.00	282.00
	Control	3	12.4667	1.26623	.73106	9.3212	15.6122	11.50	13.90
	Total	12	227.8667	143.41099	41.39919	136.7477	318.9857	11.50	420.00
Alkalinity	DO	3	2.2000	.72111	.41633	.4087	3.9913	1.60	3.00
	AS	3	2.3333	.57735	.33333	.8991	3.7676	2.00	3.00
	MN	3	1.7000	.65574	.37859	.0710	3.3290	1.00	2.30
	Control	3	53.3333	9.01850	5.20683	30.9301	75.7365	44.00	62.00

	Total	12	14.8917	23.50425	6.78509	-.0422	29.8256	1.00	62.00
Bicarbonates	DO	3	2.7147	.40700	.23498	1.7036	3.7257	2.44	3.18
	AS	3	2.4153	.13012	.07513	2.0921	2.7386	2.28	2.53
	MN	3	1.3480	.11849	.06841	1.0536	1.6424	1.22	1.45
	Control	3	42.3333	8.96289	5.17472	20.0683	64.5984	32.00	48.00
	Total	12	12.2028	18.57551	5.36229	.4005	24.0051	1.22	48.00
Turbidity	DO	3	513.5600	17.86795	10.31607	469.1736	557.9464	493.86	528.72
	AS	3	822.6667	70.59981	40.76082	647.2870	998.0463	750.00	891.00
	MN	3	44.5333	1.50111	.86667	40.8044	48.2623	43.00	46.00
	Control	3	2.1667	.75056	.43333	.3022	4.0311	1.40	2.90
	Total	12	345.7317	357.23495	103.12485	118.7554	572.7079	1.40	891.00
Total hardness	DO	3	539.320046	30.2014776	17.4368312	464.295416	614.344675	510.4800	570.7200
	AS	3	935.173339	48.3781803	27.9311554	814.995277	1055.351401	880.5800	972.7230
	MN	3	758.062867	13.8039978	7.9697418	723.771836	792.353898	745.6000	772.9000
	Control	3	11.966667	4.1645328	2.4043941	1.621394	22.311940	7.2000	14.9000
	Total	12	561.130730	362.9628062	104.7783369	330.515165	791.746294	7.2000	972.7230
iron	DO	3	10.723333	1.3651496	.7881695	7.332114	14.114553	9.7300	12.2800
	AS	3	30.726667	2.4160781	1.3949233	24.724796	36.728537	28.7500	33.4200
	MN	3	1.360000	.2505674	.1446651	.737556	1.982444	1.0720	1.5280
	Control	3	22.040000	6.7531992	3.8989614	5.264123	38.815877	15.1700	28.6700
	Total	12	16.212500	12.0332290	3.4736940	8.566951	23.858049	1.0720	33.4200
Cobalt	DO	3	.195000	.0739121	.0426732	.011392	.378608	.1260	.2730
	AS	3	.136667	.0087369	.0050442	.114963	.158370	.1270	.1440
	MN	3	.002633	.0009609	.0005548	.000246	.005020	.0016	.0035
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000	.0000
	Total	12	.083575	.0940949	.0271628	.023790	.143360	.0000	.2730
Copper	DO	3	.190667	.0330807	.0190992	.108490	.272844	.1650	.2280
	AS	3	.158000	.0728080	.0420357	-.022865	.338865	.1130	.2420
	MN	3	.039667	.0020817	.0012019	.034496	.044838	.0380	.0420
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000	.0000
	Total	12	.097083	.0896310	.0258742	.040135	.154032	.0000	.2420
Chromium	DO	3	.020000	.0100000	.0057735	-.004841	.044841	.0100	.0300
	AS	3	.020000	.0100000	.0057735	-.004841	.044841	.0100	.0300
	MN	3	.023333	.0152753	.0088192	-.014612	.061279	.0100	.0400
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000	.0000
	Total	12	.015833	.0131137	.0037856	.007501	.024165	.0000	.0400
Nickel	DO	3	.580667	.0578389	.0333933	.436987	.724346	.5180	.6320
	AS	3	.731667	.1101514	.0635959	.458035	1.005298	.6250	.8450
	MN	3	.057800	.0128888	.0074413	.025783	.089817	.0480	.0724

	Control	3	.020000	.0100000	.0057735	-.004841	.044841	.0100	.0300
	Total	12	.347533	.3317843	.0957779	.136728	.558339	.0100	.8450
Zinc	DO	3	.383333	.0351188	.0202759	.296093	.470573	.3500	.4200
	AS	3	.390333	.0558062	.0322197	.251703	.528964	.3460	.4530
	MN	3	.027000	.0155242	.0089629	-.011564	.065564	.0110	.0420
	Control	3	.003333	.0057735	.0033333	-.011009	.017676	.0000	.0100
	Total	12	.201000	.1964610	.0567134	.076175	.325825	.0000	.4530
Arsenic	DO	3	.003733	.0008021	.0004631	.001741	.005726	.0029	.0045
	AS	3	.004467	.0007024	.0004055	.002722	.006211	.0038	.0052
	MN	3	.011667	.0167479	.0096694	-.029938	.053271	.0016	.0310
	Control	3	.000133	.0000577	.0000333	-.000010	.000277	.0001	.0002
	Total	12	.005000	.0083846	.0024204	-.000327	.010327	.0001	.0310
Mercury	DO	3	.002833	.0009018	.0005207	.000593	.005074	.0019	.0037
	AS	3	.002733	.0005686	.0003283	.001321	.004146	.0021	.0032
	MN	3	.000400	.0002000	.0001155	-.000097	.000897	.0002	.0006
	Control	3	.000000	.0000000	.0000000	.000000	.000000	.0000	.0000
	Total	12	.001492	.0014343	.0004140	.000580	.002403	.0000	.0037
Magnesium	DO	3	11.703333	1.4108272	.8145415	8.198644	15.208022	10.5600	13.2800
	AS	3	13.943333	1.3469348	.7776532	10.597362	17.289305	12.4600	15.0900
	MN	3	13.433333	.8551218	.4937048	11.309093	15.557574	12.5700	14.2800
	Control	3	2.066667	1.2423097	.7172478	-1.019402	5.152735	1.3000	3.5000
	Total	12	10.286667	5.1407699	1.4840124	7.020377	13.552956	1.3000	15.0900
Manganese	DO	3	14.040000	1.3041472	.7529498	10.800319	17.279681	12.6800	15.2800
	AS	3	14.853333	.7229338	.4173860	13.057466	16.649201	14.2000	15.6300
	MN	3	13.400000	.8478797	.4895236	11.293750	15.506250	12.6500	14.3200
	Control	3	.192667	.0241937	.0139682	.132566	.252767	.1740	.2200
	Total	12	10.621500	6.3540351	1.8342519	6.584339	14.658661	.1740	15.6300
Calcium	DO	3	5.701667	.5452140	.3147795	4.347280	7.056053	5.2900	6.3200
	AS	3	5.407667	.7081288	.4088383	3.648577	7.166756	4.5900	5.8200
	MN	3	4.469333	.2219039	.1281163	3.918094	5.020573	4.2980	4.7200
	Control	3	12.516667	2.6899504	1.5530436	5.834459	19.198874	10.6500	15.6000
	Total	12	7.023833	3.5590855	1.0274195	4.762498	9.285168	4.2980	15.6000
Potassium	DO	3	2.675667	.4583474	.2646270	1.537069	3.814265	2.3360	3.1970
	AS	3	5.999000	.2824376	.1630654	5.297386	6.700614	5.8280	6.3250
	MN	3	2.926000	.6789904	.3920153	1.239294	4.612706	2.5280	3.7100
	Control	3	.413333	.1001665	.0578312	.164506	.662161	.3100	.5100
	Total	12	3.003500	2.1086019	.6087009	1.663758	4.343242	.3100	6.3250
Sodium	DO	3	17.426667	.8161699	.4712159	15.399188	19.454145	16.7200	18.3200
	AS	3	9.201333	.7731813	.4463964	7.280644	11.122022	8.4380	9.9840

	MN	3	8.435000	.9579796	.5530898	6.055247	10.814753	7.4600	9.3750
	Control	3	2.033333	.6350853	.3666667	.455694	3.610973	1.3000	2.4000
	Total	12	9.274083	5.7522904	1.6605432	5.619252	12.928914	1.3000	18.3200
Lead	DO	3	.002000	.0010000	.0005774	-.000484	.004484	.0010	.0030
	AS	3	.004000	.0010000	.0005774	.001516	.006484	.0030	.0050
	MN	3	.022733	.0179113	.0103411	-.021761	.067227	.0052	.0410
	Control	3	.000233	.0001528	.0000882	-.000146	.000613	.0001	.0004
	Total	12	.007242	.0121616	.0035108	-.000485	.014969	.0001	.0410
Cadmium	DO	3	.300067	.1760878	.1016643	-.137360	.737493	.1842	.5027
	AS	3	.328933	.0560019	.0323327	.189817	.468050	.2732	.3852
	MN	3	.226133	.0579346	.0334485	.082216	.370051	.1642	.2790
	Control	3	.043333	.0160416	.0092616	.003484	.083183	.0280	.0600
	Total	12	.224617	.1426488	.0411792	.133982	.315251	.0280	.5027
Dissolved oxygen	DO	3	4.3000	.55678	.32146	2.9169	5.6831	3.80	4.90
	AS	3	5.0667	.51316	.29627	3.7919	6.3414	4.50	5.50
	MN	3	4.7333	.95044	.54874	2.3723	7.0944	3.80	5.70
	Control	3	4.5000	.40000	.23094	3.5063	5.4937	4.10	4.90
	Total	12	4.6500	.62158	.17944	4.2551	5.0449	3.80	5.70
Biological Oxygen demand	DO	3	2.5667	.57735	.33333	1.1324	4.0009	1.90	2.90
	AS	3	1.7000	.20000	.11547	1.2032	2.1968	1.50	1.90
	MN	3	2.0333	.20817	.12019	1.5162	2.5504	1.80	2.20
	Control	3	1.4333	.05774	.03333	1.2899	1.5768	1.40	1.50
	Total	12	1.9333	.52107	.15042	1.6023	2.2644	1.40	2.90

Appendix E: ANOVA for Physico-Chemical Parameters, Amansie West

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Temperature	Between Groups	2.705	3	.902	.426	.740
	Within Groups	16.948	8	2.118		
	Total	19.653	11			
Conductivity	Between Groups	362848.896	3	120949.632	284.146	.000
	Within Groups	3405.287	8	425.661		
	Total	366254.183	11			
Total Dissolved solids	Between Groups	80491.058	3	26830.353	124.523	.000
	Within Groups	1723.726	8	215.466		
	Total	82214.783	11			
pH	Between Groups	20.909	3	6.970	64.835	.000
	Within Groups	.860	8	.108		
	Total	21.769	11			
Salinity	Between Groups	.143	3	.048	8.143	.008
	Within Groups	.047	8	.006		
	Total	.189	11			
Total Suspended solids	Between Groups	223133.307	3	74377.769	191.909	.000
	Within Groups	3100.540	8	387.567		
	Total	226233.847	11			
Alkalinity	Between Groups	5911.716	3	1970.572	95.408	.000
	Within Groups	165.233	8	20.654		
	Total	6076.949	11			
Bicarbonates	Between Groups	3634.485	3	1211.495	60.176	.000
	Within Groups	161.060	8	20.132		
	Total	3795.545	11			
Turbidity	Between Groups	1393172.067	3	464390.689	350.060	.000
	Within Groups	10612.827	8	1326.603		
	Total	1403784.894	11			
Total hardness	Between Groups	1442241.043	3	480747.014	555.701	.000
	Within Groups	6920.943	8	865.118		

	Total	1449161.985	11			
iron	Between Groups	1486.045	3	495.348	37.126	.000
	Within Groups	106.739	8	13.342		
	Total	1592.785	11			
Cobalt	Between Groups	.086	3	.029	20.772	.000
	Within Groups	.011	8	.001		
	Total	.097	11			
Copper	Between Groups	.076	3	.025	15.745	.001
	Within Groups	.013	8	.002		
	Total	.088	11			
Chromium	Between Groups	.001	3	.000	3.154	.086
	Within Groups	.001	8	.000		
	Total	.002	11			
Nickel	Between Groups	1.179	3	.393	99.876	.000
	Within Groups	.031	8	.004		
	Total	1.211	11			
Zinc	Between Groups	.415	3	.138	119.810	.000
	Within Groups	.009	8	.001		
	Total	.425	11			
Arsenic	Between Groups	.000	3	.000	.994	.443
	Within Groups	.001	8	.000		
	Total	.001	11			
Mercury	Between Groups	.000	3	.000	22.975	.000
	Within Groups	.000	8	.000		
	Total	.000	11			
Magnesium	Between Groups	278.544	3	92.848	61.092	.000
	Within Groups	12.158	8	1.520		
	Total	290.703	11			
Manganese	Between Groups	438.226	3	146.075	198.545	.000
	Within Groups	5.886	8	.736		
	Total	444.111	11			
Calcium	Between Groups	123.170	3	41.057	20.316	.000

	Within Groups	16.168	8	2.021		
	Total	139.338	11			
Potassium	Between Groups	47.386	3	15.795	83.034	.000
	Within Groups	1.522	8	.190		
	Total	48.908	11			
Sodium	Between Groups	358.807	3	119.602	185.071	.000
	Within Groups	5.170	8	.646		
	Total	363.977	11			
Lead	Between Groups	.001	3	.000	4.053	.050
	Within Groups	.001	8	.000		
	Total	.002	11			
Cadmium	Between Groups	.148	3	.049	5.238	.027
	Within Groups	.076	8	.009		
	Total	.224	11			
Dissolved oxygen	Between Groups	.977	3	.326	.796	.530
	Within Groups	3.273	8	.409		
	Total	4.250	11			
Biological Oxygen demand	Between Groups	2.147	3	.716	6.815	.014
	Within Groups	.840	8	.105		
	Total	2.987	11			

Appendix F: Tukey's HSD Comparison of Physico-Chemical Parameters, Amansie West

Dependent Variable	(I) Sampling site	(J) Sampling site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Temperature	DO	AS	-.16667	1.18841	.999	-3.9724	3.6390
		MN	-1.05667	1.18841	.811	-4.8624	2.7490
		Control	.17667	1.18841	.999	-3.6290	3.9824
	AS	DO	.16667	1.18841	.999	-3.6390	3.9724
		MN	-.89000	1.18841	.875	-4.6957	2.9157
		Control	.34333	1.18841	.991	-3.4624	4.1490
	MN	DO	1.05667	1.18841	.811	-2.7490	4.8624
		AS	.89000	1.18841	.875	-2.9157	4.6957
		Control	1.23333	1.18841	.734	-2.5724	5.0390
	Control	DO	-.17667	1.18841	.999	-3.9824	3.6290
		AS	-.34333	1.18841	.991	-4.1490	3.4624
		MN	-1.23333	1.18841	.734	-5.0390	2.5724
Conductivity	DO	AS	-166.33333*	16.84559	.000	-220.2788	-112.3878
		MN	-207.50000*	16.84559	.000	-261.4455	-153.5545
		Control	234.66667*	16.84559	.000	180.7212	288.6122
	AS	DO	166.33333*	16.84559	.000	112.3878	220.2788
		MN	-41.16667	16.84559	.145	-95.1122	12.7788
		Control	401.00000*	16.84559	.000	347.0545	454.9455
	MN	DO	207.50000*	16.84559	.000	153.5545	261.4455
		AS	41.16667	16.84559	.145	-12.7788	95.1122
		Control	442.16667*	16.84559	.000	388.2212	496.1122
	Control	DO	-234.66667*	16.84559	.000	-288.6122	-180.7212
		AS	-401.00000*	16.84559	.000	-454.9455	-347.0545
		MN	-442.16667*	16.84559	.000	-496.1122	-388.2212
Total Dissolved solids	DO	AS	-93.66667*	11.98515	.000	-132.0473	-55.2860
		MN	-89.84000*	11.98515	.000	-128.2207	-51.4593
		Control	107.00000*	11.98515	.000	68.6193	145.3807
	AS	DO	93.66667*	11.98515	.000	55.2860	132.0473
		MN	3.82667	11.98515	.988	-34.5540	42.2073
		Control	200.66667*	11.98515	.000	162.2860	239.0473
	MN	DO	89.84000*	11.98515	.000	51.4593	128.2207
		AS	-3.82667	11.98515	.988	-42.2073	34.5540
		Control	196.84000*	11.98515	.000	158.4593	235.2207
	Control	DO	-107.00000*	11.98515	.000	-145.3807	-68.6193

		AS	-200.66667*	11.98515	.000	-239.0473	-162.2860
		MN	-196.84000*	11.98515	.000	-235.2207	-158.4593
pH	DO	AS	.23333	.26771	.819	-.6240	1.0906
		MN	.36667	.26771	.549	-.4906	1.2240
		Control	-2.83333*	.26771	.000	-3.6906	-1.9760
	AS	DO	-.23333	.26771	.819	-1.0906	.6240
		MN	.13333	.26771	.957	-.7240	.9906
		Control	-3.06667*	.26771	.000	-3.9240	-2.2094
	MN	DO	-.36667	.26771	.549	-1.2240	.4906
		AS	-.13333	.26771	.957	-.9906	.7240
		Control	-3.20000*	.26771	.000	-4.0573	-2.3427
	Control	DO	2.83333*	.26771	.000	1.9760	3.6906
		AS	3.06667*	.26771	.000	2.2094	3.9240
		MN	3.20000*	.26771	.000	2.3427	4.0573
Salinity	DO	AS	-.16667	.06236	.106	-.3664	.0330
		MN	-.06667	.06236	.717	-.2664	.1330
		Control	.13333	.06236	.220	-.0664	.3330
	AS	DO	.16667	.06236	.106	-.0330	.3664
		MN	.10000	.06236	.428	-.0997	.2997
		Control	.30000*	.06236	.006	.1003	.4997
	MN	DO	.06667	.06236	.717	-.1330	.2664
		AS	-.10000	.06236	.428	-.2997	.0997
		Control	.20000*	.06236	.050	.0003	.3997
	Control	DO	-.13333	.06236	.220	-.3330	.0664
		AS	-.30000*	.06236	.006	-.4997	-.1003
		MN	-.20000*	.06236	.050	-.3997	-.0003
Total Suspended solids	DO	AS	-143.33333*	16.07415	.000	-194.8084	-91.8582
		MN	-13.66667	16.07415	.830	-65.1418	37.8084
		Control	234.86667*	16.07415	.000	183.3916	286.3418
	AS	DO	143.33333*	16.07415	.000	91.8582	194.8084
		MN	129.66667*	16.07415	.000	78.1916	181.1418
		Control	378.20000*	16.07415	.000	326.7249	429.6751
	MN	DO	13.66667	16.07415	.830	-37.8084	65.1418
		AS	-129.66667*	16.07415	.000	-181.1418	-78.1916
		Control	248.53333*	16.07415	.000	197.0582	300.0084
	Control	DO	-234.86667*	16.07415	.000	-286.3418	-183.3916
		AS	-378.20000*	16.07415	.000	-429.6751	-326.7249
		MN	-248.53333*	16.07415	.000	-300.0084	-197.0582
Alkalinity	DO	AS	-.13333	3.71072	1.000	-12.0164	11.7497

		MN	.50000	3.71072	.999	-11.3830	12.3830
		Control	-51.13333*	3.71072	.000	-63.0164	-39.2503
	AS	DO	.13333	3.71072	1.000	-11.7497	12.0164
		MN	.63333	3.71072	.998	-11.2497	12.5164
		Control	-51.00000*	3.71072	.000	-62.8830	-39.1170
	MN	DO	-.50000	3.71072	.999	-12.3830	11.3830
		AS	-.63333	3.71072	.998	-12.5164	11.2497
		Control	-51.63333*	3.71072	.000	-63.5164	-39.7503
	Control	DO	51.13333*	3.71072	.000	39.2503	63.0164
		AS	51.00000*	3.71072	.000	39.1170	62.8830
		MN	51.63333*	3.71072	.000	39.7503	63.5164
Bicarbonates	DO	AS	.29933	3.66356	1.000	-11.4327	12.0313
		MN	1.36667	3.66356	.981	-10.3653	13.0987
		Control	-39.61867*	3.66356	.000	-51.3507	-27.8867
	AS	DO	-.29933	3.66356	1.000	-12.0313	11.4327
		MN	1.06733	3.66356	.991	-10.6647	12.7993
		Control	-39.91800*	3.66356	.000	-51.6500	-28.1860
	MN	DO	-1.36667	3.66356	.981	-13.0987	10.3653
		AS	-1.06733	3.66356	.991	-12.7993	10.6647
		Control	-40.98533*	3.66356	.000	-52.7173	-29.2533
	Control	DO	39.61867*	3.66356	.000	27.8867	51.3507
		AS	39.91800*	3.66356	.000	28.1860	51.6500
		MN	40.98533*	3.66356	.000	29.2533	52.7173
Turbidity	DO	AS	-309.10667*	29.73890	.000	-404.3411	-213.8722
		MN	469.02667*	29.73890	.000	373.7922	564.2611
		Control	511.39333*	29.73890	.000	416.1589	606.6278
	AS	DO	309.10667*	29.73890	.000	213.8722	404.3411
		MN	778.13333*	29.73890	.000	682.8989	873.3678
		Control	820.50000*	29.73890	.000	725.2656	915.7344
	MN	DO	-469.02667*	29.73890	.000	-564.2611	-373.7922
		AS	-778.13333*	29.73890	.000	-873.3678	-682.8989
		Control	42.36667	29.73890	.520	-52.8678	137.6011
	Control	DO	-511.39333*	29.73890	.000	-606.6278	-416.1589
		AS	-820.50000*	29.73890	.000	-915.7344	-725.2656
		MN	-42.36667	29.73890	.520	-137.6011	52.8678
Total hardness	DO	AS	-395.8532932*	24.0155202	.000	-472.759442	-318.947144
		MN	-218.7428213*	24.0155202	.000	-295.648971	-141.836672
		Control	527.3533791*	24.0155202	.000	450.447230	604.259528
	AS	DO	395.8532932*	24.0155202	.000	318.947144	472.759442

		MN	177.1104719*	24.0155202	.000	100.204323	254.016621
		Control	923.2066723*	24.0155202	.000	846.300523	1000.112822
	MN	DO	218.7428213*	24.0155202	.000	141.836672	295.648971
		AS	-177.1104719*	24.0155202	.000	-254.016621	-100.204323
		Control	746.0962003*	24.0155202	.000	669.190051	823.002350
	Control	DO	-527.3533791*	24.0155202	.000	-604.259528	-450.447230
		AS	-923.2066723*	24.0155202	.000	-1000.112822	-846.300523
		MN	-746.0962003*	24.0155202	.000	-823.002350	-669.190051
iron	DO	AS	-20.0033333*	2.9824361	.001	-29.554144	-10.452523
		MN	9.3633333	2.9824361	.055	-.187477	18.914144
		Control	-11.3166667*	2.9824361	.022	-20.867477	-1.765856
	AS	DO	20.0033333*	2.9824361	.001	10.452523	29.554144
		MN	29.3666667*	2.9824361	.000	19.815856	38.917477
		Control	8.6866667	2.9824361	.075	-.864144	18.237477
	MN	DO	-9.3633333	2.9824361	.055	-18.914144	.187477
		AS	-29.3666667*	2.9824361	.000	-38.917477	-19.815856
		Control	-20.6800000*	2.9824361	.001	-30.230810	-11.129190
	Control	DO	11.3166667*	2.9824361	.022	1.765856	20.867477
		AS	-8.6866667	2.9824361	.075	-18.237477	.864144
		MN	20.6800000*	2.9824361	.001	11.129190	30.230810
Cobalt	DO	AS	.0583333	.0303871	.293	-.038977	.155644
		MN	.1923667*	.0303871	.001	.095056	.289677
		Control	.1950000*	.0303871	.001	.097690	.292310
	AS	DO	-.0583333	.0303871	.293	-.155644	.038977
		MN	.1340333*	.0303871	.010	.036723	.231344
		Control	.1366667*	.0303871	.009	.039356	.233977
	MN	DO	-.1923667*	.0303871	.001	-.289677	-.095056
		AS	-.1340333*	.0303871	.010	-.231344	-.036723
		Control	.0026333	.0303871	1.000	-.094677	.099944
	Control	DO	-.1950000*	.0303871	.001	-.292310	-.097690
		AS	-.1366667*	.0303871	.009	-.233977	-.039356
		MN	-.0026333	.0303871	1.000	-.099944	.094677
Copper	DO	AS	.0326667	.0326590	.754	-.071919	.137252
		MN	.1510000*	.0326590	.007	.046414	.255586
		Control	.1906667*	.0326590	.002	.086081	.295252
	AS	DO	-.0326667	.0326590	.754	-.137252	.071919
		MN	.1183333*	.0326590	.028	.013748	.222919
		Control	.1580000*	.0326590	.006	.053414	.262586
	MN	DO	-.1510000*	.0326590	.007	-.255586	-.046414

		AS	-.1183333*	.0326590	.028	-.222919	-.013748
		Control	.0396667	.0326590	.635	-.064919	.144252
	Control	DO	-.1906667*	.0326590	.002	-.295252	-.086081
		AS	-.1580000*	.0326590	.006	-.262586	-.053414
		MN	-.0396667	.0326590	.635	-.144252	.064919
Chromium	DO	AS	.0000000	.0084984	1.000	-.027215	.027215
		MN	-.0033333	.0084984	.978	-.030548	.023881
		Control	.0200000	.0084984	.165	-.007215	.047215
	AS	DO	.0000000	.0084984	1.000	-.027215	.027215
		MN	-.0033333	.0084984	.978	-.030548	.023881
		Control	.0200000	.0084984	.165	-.007215	.047215
	MN	DO	.0033333	.0084984	.978	-.023881	.030548
		AS	.0033333	.0084984	.978	-.023881	.030548
		Control	.0233333	.0084984	.095	-.003881	.050548
	Control	DO	-.0200000	.0084984	.165	-.047215	.007215
		AS	-.0200000	.0084984	.165	-.047215	.007215
		MN	-.0233333	.0084984	.095	-.050548	.003881
Nickel	DO	AS	-.1510000	.0512263	.072	-.315045	.013045
		MN	.5228667*	.0512263	.000	.358822	.686911
		Control	.5606667*	.0512263	.000	.396622	.724711
	AS	DO	.1510000	.0512263	.072	-.013045	.315045
		MN	.6738667*	.0512263	.000	.509822	.837911
		Control	.7116667*	.0512263	.000	.547622	.875711
	MN	DO	-.5228667*	.0512263	.000	-.686911	-.358822
		AS	-.6738667*	.0512263	.000	-.837911	-.509822
		Control	.0378000	.0512263	.879	-.126245	.201845
	Control	DO	-.5606667*	.0512263	.000	-.724711	-.396622
		AS	-.7116667*	.0512263	.000	-.875711	-.547622
		MN	-.0378000	.0512263	.879	-.201845	.126245
Zinc	DO	AS	-.0070000	.0277549	.994	-.095881	.081881
		MN	.3563333*	.0277549	.000	.267452	.445214
		Control	.3800000*	.0277549	.000	.291119	.468881
	AS	DO	.0070000	.0277549	.994	-.081881	.095881
		MN	.3633333*	.0277549	.000	.274452	.452214
		Control	.3870000*	.0277549	.000	.298119	.475881
	MN	DO	-.3563333*	.0277549	.000	-.445214	-.267452
		AS	-.3633333*	.0277549	.000	-.452214	-.274452
		Control	.0236667	.0277549	.828	-.065214	.112548
	Control	DO	-.3800000*	.0277549	.000	-.468881	-.291119

		AS	-.3870000*	.0277549	.000	-.475881	-.298119
		MN	-.0236667	.0277549	.828	-.112548	.065214
Arsenic	DO	AS	-.0007333	.0068512	1.000	-.022673	.021207
		MN	-.0079333	.0068512	.667	-.029873	.014007
		Control	.0036000	.0068512	.951	-.018340	.025540
	AS	DO	.0007333	.0068512	1.000	-.021207	.022673
		MN	-.0072000	.0068512	.726	-.029140	.014740
		Control	.0043333	.0068512	.919	-.017607	.026273
	MN	DO	.0079333	.0068512	.667	-.014007	.029873
		AS	.0072000	.0068512	.726	-.014740	.029140
		Control	.0115333	.0068512	.391	-.010407	.033473
	Control	DO	-.0036000	.0068512	.951	-.025540	.018340
		AS	-.0043333	.0068512	.919	-.026273	.017607
		MN	-.0115333	.0068512	.391	-.033473	.010407
Mercury	DO	AS	.0001000	.0004428	.996	-.001318	.001518
		MN	.0024333*	.0004428	.003	.001015	.003851
		Control	.0028333*	.0004428	.001	.001415	.004251
	AS	DO	-.0001000	.0004428	.996	-.001518	.001318
		MN	.0023333*	.0004428	.003	.000915	.003751
		Control	.0027333*	.0004428	.001	.001315	.004151
	MN	DO	-.0024333*	.0004428	.003	-.003851	-.001015
		AS	-.0023333*	.0004428	.003	-.003751	-.000915
		Control	.0004000	.0004428	.804	-.001018	.001818
	Control	DO	-.0028333*	.0004428	.001	-.004251	-.001415
		AS	-.0027333*	.0004428	.001	-.004151	-.001315
		MN	-.0004000	.0004428	.804	-.001818	.001018
Magnesium	DO	AS	-2.2400000	1.0065811	.196	-5.463427	.983427
		MN	-1.7300000	1.0065811	.375	-4.953427	1.493427
		Control	9.6366667*	1.0065811	.000	6.413240	12.860094
	AS	DO	2.2400000	1.0065811	.196	-.983427	5.463427
		MN	.5100000	1.0065811	.955	-2.713427	3.733427
		Control	11.8766667*	1.0065811	.000	8.653240	15.100094
	MN	DO	1.7300000	1.0065811	.375	-1.493427	4.953427
		AS	-.5100000	1.0065811	.955	-3.733427	2.713427
		Control	11.3666667*	1.0065811	.000	8.143240	14.590094
	Control	DO	-9.6366667*	1.0065811	.000	-12.860094	-6.413240
		AS	-11.8766667*	1.0065811	.000	-15.100094	-8.653240
		MN	-11.3666667*	1.0065811	.000	-14.590094	-8.143240
Manganese	DO	AS	-.8133333	.7003474	.665	-3.056092	1.429425

		MN	.6400000	.7003474	.798	-1.602759	2.882759
		Control	13.8473333*	.7003474	.000	11.604575	16.090092
	AS	DO	.8133333	.7003474	.665	-1.429425	3.056092
		MN	1.4533333	.7003474	.239	-.789425	3.696092
		Control	14.6606667*	.7003474	.000	12.417908	16.903425
	MN	DO	-.6400000	.7003474	.798	-2.882759	1.602759
		AS	-1.4533333	.7003474	.239	-3.696092	.789425
		Control	13.2073333*	.7003474	.000	10.964575	15.450092
	Control	DO	-13.8473333*	.7003474	.000	-16.090092	-11.604575
		AS	-14.6606667*	.7003474	.000	-16.903425	-12.417908
		MN	-13.2073333*	.7003474	.000	-15.450092	-10.964575
Calcium	DO	AS	.2940000	1.1607310	.994	-3.423069	4.011069
		MN	1.2323333	1.1607310	.721	-2.484736	4.949403
		Control	-6.8150000*	1.1607310	.002	-10.532069	-3.097931
	AS	DO	-.2940000	1.1607310	.994	-4.011069	3.423069
		MN	.9383333	1.1607310	.849	-2.778736	4.655403
		Control	-7.1090000*	1.1607310	.001	-10.826069	-3.391931
	MN	DO	-1.2323333	1.1607310	.721	-4.949403	2.484736
		AS	-.9383333	1.1607310	.849	-4.655403	2.778736
		Control	-8.0473333*	1.1607310	.001	-11.764403	-4.330264
	Control	DO	6.8150000*	1.1607310	.002	3.097931	10.532069
		AS	7.1090000*	1.1607310	.001	3.391931	10.826069
		MN	8.0473333*	1.1607310	.001	4.330264	11.764403
Potassium	DO	AS	-3.3233333*	.3561167	.000	-4.463744	-2.182922
		MN	-.2503333	.3561167	.893	-1.390744	.890078
		Control	2.2623333*	.3561167	.001	1.121922	3.402744
	AS	DO	3.3233333*	.3561167	.000	2.182922	4.463744
		MN	3.0730000*	.3561167	.000	1.932589	4.213411
		Control	5.5856667*	.3561167	.000	4.445256	6.726078
	MN	DO	.2503333	.3561167	.893	-.890078	1.390744
		AS	-3.0730000*	.3561167	.000	-4.213411	-1.932589
		Control	2.5126667*	.3561167	.000	1.372256	3.653078
	Control	DO	-2.2623333*	.3561167	.001	-3.402744	-1.121922
		AS	-5.5856667*	.3561167	.000	-6.726078	-4.445256
		MN	-2.5126667*	.3561167	.000	-3.653078	-1.372256
Sodium	DO	AS	8.2253333*	.6563791	.000	6.123376	10.327290
		MN	8.9916667*	.6563791	.000	6.889710	11.093624
		Control	15.3933333*	.6563791	.000	13.291376	17.495290
	AS	DO	-8.2253333*	.6563791	.000	-10.327290	-6.123376

		MN	.7663333	.6563791	.662	-1.335624	2.868290
		Control	7.1680000*	.6563791	.000	5.066043	9.269957
	MN	DO	-8.9916667*	.6563791	.000	-11.093624	-6.889710
		AS	-.7663333	.6563791	.662	-2.868290	1.335624
		Control	6.4016667*	.6563791	.000	4.299710	8.503624
	Control	DO	-15.3933333*	.6563791	.000	-17.495290	-13.291376
		AS	-7.1680000*	.6563791	.000	-9.269957	-5.066043
		MN	-6.4016667*	.6563791	.000	-8.503624	-4.299710
Lead	DO	AS	-.0020000	.0073353	.992	-.025490	.021490
		MN	-.0207333	.0073353	.085	-.044223	.002757
		Control	.0017667	.0073353	.995	-.021723	.025257
	AS	DO	.0020000	.0073353	.992	-.021490	.025490
		MN	-.0187333	.0073353	.125	-.042223	.004757
		Control	.0037667	.0073353	.954	-.019723	.027257
	MN	DO	.0207333	.0073353	.085	-.002757	.044223
		AS	.0187333	.0073353	.125	-.004757	.042223
		Control	.0225000	.0073353	.060	-.000990	.045990
	Control	DO	-.0017667	.0073353	.995	-.025257	.021723
		AS	-.0037667	.0073353	.954	-.027257	.019723
		MN	-.0225000	.0073353	.060	-.045990	.000990
Cadmium	DO	AS	-.0288667	.0793272	.982	-.282900	.225167
		MN	.0739333	.0793272	.789	-.180100	.327967
		Control	.2567333*	.0793272	.048	.002700	.510767
	AS	DO	.0288667	.0793272	.982	-.225167	.282900
		MN	.1028000	.0793272	.590	-.151234	.356834
		Control	.2856000*	.0793272	.029	.031566	.539634
	MN	DO	-.0739333	.0793272	.789	-.327967	.180100
		AS	-.1028000	.0793272	.590	-.356834	.151234
		Control	.1828000	.0793272	.176	-.071234	.436834
	Control	DO	-.2567333*	.0793272	.048	-.510767	-.002700
		AS	-.2856000*	.0793272	.029	-.539634	-.031566
		MN	-.1828000	.0793272	.176	-.436834	.071234
Dissolved oxygen	DO	AS	-.76667	.52228	.497	-2.4392	.9059
		MN	-.43333	.52228	.839	-2.1059	1.2392
		Control	-.20000	.52228	.980	-1.8725	1.4725
	AS	DO	.76667	.52228	.497	-.9059	2.4392
		MN	.33333	.52228	.917	-1.3392	2.0059
		Control	.56667	.52228	.708	-1.1059	2.2392
	MN	DO	.43333	.52228	.839	-1.2392	2.1059

		AS	-.33333	.52228	.917	-2.0059	1.3392
		Control	.23333	.52228	.968	-1.4392	1.9059
	Control	DO	.20000	.52228	.980	-1.4725	1.8725
		AS	-.56667	.52228	.708	-2.2392	1.1059
		MN	-.23333	.52228	.968	-1.9059	1.4392
Biological Oxygen demand	DO	AS	.86667*	.26458	.045	.0194	1.7139
		MN	.53333	.26458	.259	-.3139	1.3806
		Control	1.13333*	.26458	.011	.2861	1.9806
	AS	DO	-.86667*	.26458	.045	-1.7139	-.0194
		MN	-.33333	.26458	.610	-1.1806	.5139
		Control	.26667	.26458	.750	-.5806	1.1139
	MN	DO	-.53333	.26458	.259	-1.3806	.3139
		AS	.33333	.26458	.610	-.5139	1.1806
		Control	.60000	.26458	.185	-.2473	1.4473
	Control	DO	-1.13333*	.26458	.011	-1.9806	-.2861
		AS	-.26667	.26458	.750	-1.1139	.5806
		MN	-.60000	.26458	.185	-1.4473	.2473

*. The mean difference is significant at the 0.05 level.

Appendix G: PCA of Physico-Chemical Parameters of Water Sample from Mpohor Wassa

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.530	34.118	34.118	8.530	34.118	34.118	5.625	22.501	22.501
2	5.218	20.873	54.991	5.218	20.873	54.991	5.373	21.490	43.992
3	3.308	13.231	68.222	3.308	13.231	68.222	5.046	20.185	64.177
4	2.082	8.328	76.551	2.082	8.328	76.551	2.318	9.273	73.450
5	1.806	7.225	83.775	1.806	7.225	83.775	1.958	7.830	81.281
6	1.209	4.836	88.611	1.209	4.836	88.611	1.833	7.330	88.611
7	.970	3.881	92.492						
8	.791	3.163	95.656						
9	.335	1.341	96.997						
10	.257	1.029	98.026						
11	.212	.848	98.874						
12	.141	.564	99.438						
13	.089	.355	99.794						
14	.052	.206	100.000						
15	1.050E-15	4.200E-15	100.000						
16	5.042E-16	2.017E-15	100.000						
17	2.968E-16	1.187E-15	100.000						
18	1.938E-16	7.753E-16	100.000						
19	1.173E-16	4.694E-16	100.000						
20	5.021E-17	2.009E-16	100.000						
21	-1.477E-16	-5.906E-16	100.000						
22	-2.530E-16	-1.012E-15	100.000						
23	-2.749E-16	-1.100E-15	100.000						
24	-5.010E-16	-2.004E-15	100.000						
25	-8.791E-16	-3.516E-15	100.000						

Extraction Method: Principal Component Analysis.

Appendix H: Descriptive statistics for parameters in soil

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Calcium	Asowuo Ayipa(ASA)	21	2.39543	.841992	.183738	2.01216	2.77870	1.339	4.680
	Adum Tokoro(ADT)	18	3.38494	.854537	.201416	2.95999	3.80990	1.750	4.560
	Mpohor Adansi(MA)	15	2.48073	.909360	.234796	1.97715	2.98432	1.284	4.680
	Mpohor Motorway(MM)	15	2.46733	.917148	.236807	1.95943	2.97523	1.424	4.350
	Mpohor Adawotwe (ADW)	15	2.49593	.954074	.246341	1.96758	3.02428	1.529	4.480
	control	3	8.07000	3.184918	1.838813	.15823	15.98177	5.280	11.540
	Total	87	2.84026	1.448042	.155246	2.53164	3.14888	1.339	11.540
Magnesium	Asowuo Ayipa(ASA)	21	4.71971	.877245	.191430	4.32040	5.11903	3.286	6.852
	Adum Tokoro(ADT)	18	4.94739	.593508	.139891	4.65224	5.24253	4.196	6.220
	Mpohor Adansi(MA)	15	4.76340	.922011	.238062	4.25281	5.27399	3.290	6.552
	Mpohor Motorway(MM)	15	4.90793	.895035	.231097	4.41228	5.40359	3.290	6.852
	Mpohor Adawotwe (ADW)	15	4.82700	.854184	.220549	4.35397	5.30003	3.290	6.752
	control	3	9.52067	2.402591	1.387136	3.55230	15.48903	7.892	12.280
	Total	87	4.99085	1.232662	.132155	4.72813	5.25357	3.286	12.280
Sodium	Asowuo Ayipa(ASA)	21	.70059	.321657	.070191	.55417	.84700	.346	1.812
	Adum Tokoro(ADT)	18	.63800	.152735	.036000	.56205	.71395	.321	.926
	Mpohor Adansi(MA)	15	.69493	.343568	.088709	.50467	.88520	.346	1.812
	Mpohor Motorway(MM)	15	.59569	.157637	.040702	.50839	.68298	.346	.872
	Mpohor Adawotwe (ADW)	15	.76780	.449798	.116137	.51871	1.01689	.346	1.812
	control	3	.23000	.045826	.026458	.11616	.34384	.190	.280
	Total	87	.66394	.307924	.033013	.59831	.72957	.190	1.812
Potassium	Asowuo Ayipa(ASA)	21	.07314	.015612	.003407	.06604	.08025	.051	.097
	Adum Tokoro(ADT)	18	.06589	.014016	.003304	.05892	.07286	.041	.082
	Mpohor Adansi(MA)	15	.07367	.016766	.004329	.06438	.08295	.050	.097
	Mpohor Motorway(MM)	15	.06947	.014861	.003837	.06124	.07770	.051	.092
	Mpohor Adawotwe (ADW)	15	.07207	.015854	.004094	.06329	.08085	.041	.097
	control	3	1.43333	.321455	.185592	.63479	2.23187	1.200	1.800
	Total	87	.11782	.255255	.027366	.06341	.17222	.041	1.800
Iron	Asowuo Ayipa(ASA)	21	3916.14286	925.217936	201.899106	3494.98870	4337.29701	2295.000	5287.000
	Adum Tokoro(ADT)	18	3940.22222	611.264798	144.076495	3636.24739	4244.19706	2869.000	4972.000
	Mpohor Adansi(MA)	15	3913.93333	864.791838	223.288293	3435.02758	4392.83909	2595.000	5287.000

	Mpohor Motorway(MM)	15	3878.60000	963.286695	248.719555	3345.14961	4412.05039	2295.000	5287.000
	Mpohor Adawotwe (ADW)	15	4058.93333	863.843113	223.043333	3580.55296	4537.31370	2595.000	5287.000
	control	3	1534.66667	253.435067	146.320804	905.09906	2164.23427	1352.000	1824.000
	Total	87	3856.77011	931.079814	99.822234	3658.33008	4055.21015	1352.000	5287.000
Zinc	Asowuo Ayipa(ASA)	21	41.02619	10.276607	2.242540	36.34833	45.70405	22.500	57.600
	Adum Tokoro(ADT)	18	36.90278	9.349418	2.203679	32.25342	41.55213	22.500	49.200
	Mpohor Adansi(MA)	15	42.90667	11.060755	2.855875	36.78142	49.03191	22.500	57.600
	Mpohor Motorway(MM)	15	42.75333	9.362968	2.417508	37.56829	47.93837	29.500	57.600
	Mpohor Adawotwe (ADW)	15	41.27333	11.123862	2.872169	35.11314	47.43352	22.500	57.600
	control	3	70.33333	3.894012	2.248209	60.66007	80.00660	65.900	73.200
	Total	87	41.84828	11.423974	1.224779	39.41350	44.28306	22.500	73.200
Nickel	Asowuo Ayipa(ASA)	21	.51762	.158994	.034695	.44525	.58999	.310	.720
	Adum Tokoro(ADT)	18	.65278	.112397	.026492	.59688	.70867	.420	.920
	Mpohor Adansi(MA)	15	.45400	.124258	.032083	.38519	.52281	.270	.720
	Mpohor Motorway(MM)	15	.47933	.163028	.042094	.38905	.56962	.310	.820
	Mpohor Adawotwe (ADW)	15	.47067	.126065	.032550	.40085	.54048	.280	.620
	control	3	.10333	.068069	.039299	-.06576	.27243	.050	.180
	Total	87	.50563	.170066	.018233	.46939	.54188	.050	.820
Cobalt	Asowuo Ayipa(ASA)	21	5.76667	1.302050	.284131	5.17398	6.35935	3.200	9.000
	Adum Tokoro(ADT)	18	6.44444	.970883	.228839	5.96164	6.92725	4.700	7.800
	Mpohor Adansi(MA)	15	5.68667	1.435204	.370568	4.89188	6.48146	3.100	9.000
	Mpohor Motorway(MM)	15	5.21333	.956830	.247052	4.68346	5.74321	3.300	7.200
	Mpohor Adawotwe (ADW)	15	5.85333	1.653078	.426823	4.93789	6.76878	3.500	9.500
	control	3	.01433	.022279	.012863	-.04101	.06968	.000	.040
	Total	87	5.61429	1.671103	.179161	5.25813	5.97045	.000	9.000
Copper	Asowuo Ayipa(ASA)	21	.67905	.100693	.021973	.63321	.72488	.530	.870
	Adum Tokoro(ADT)	18	.67056	.115324	.027182	.61321	.72790	.530	.930
	Mpohor Adansi(MA)	15	.66600	.095454	.024646	.61314	.71886	.530	.840
	Mpohor Motorway(MM)	15	.67533	.105618	.027271	.61684	.73382	.530	.870
	Mpohor Adawotwe (ADW)	15	.65800	.099585	.025713	.60285	.71315	.530	.840
	control	3	.00167	.002887	.001667	-.00550	.00884	.000	.005
	Total	87	.64741	.158174	.016958	.61370	.68113	.000	.930
Lead	Asowuo Ayipa(ASA)	21	1.18871	.390221	.085153	1.01109	1.36634	.582	1.767
	Adum Tokoro(ADT)	18	1.30283	.479052	.112914	1.06461	1.54106	.500	1.932
	Mpohor Adansi(MA)	15	1.12780	.388199	.100233	.91282	1.34278	.582	1.737
	Mpohor Motorway(MM)	15	1.14500	.408449	.105461	.91881	1.37119	.582	1.767

	Mpohor Adawotwe (ADW)	15	1.20233	.403510	.104186	.97888	1.42579	.582	1.737
	control	3	.00000	.000000	.000000	.00000	.00000	.000	.000
	Total	87	1.15564	.459236	.049235	1.05777	1.25352	.000	1.932
Chromium	Asowuo Ayipa(ASA)	21	.69452	.156897	.034238	.62311	.76594	.410	.950
	Adum Tokoro(ADT)	18	.74789	.140220	.033050	.67816	.81762	.514	.952
	Mpohor Adansi(MA)	15	.66833	.142808	.036873	.58925	.74742	.462	.950
	Mpohor Motorway(MM)	15	.70100	.169673	.043809	.60704	.79496	.410	.950
	Mpohor Adawotwe (ADW)	15	.63833	.107244	.027690	.57894	.69772	.462	.852
	control	3	.06667	.058595	.033830	-.07889	.21222	.000	.110
	Total	87	.67083	.184464	.019777	.63151	.71014	.000	.952
Cadmium	Asowuo Ayipa(ASA)	21	32.22857	8.367505	1.825939	28.41973	36.03741	18.900	50.600
	Adum Tokoro(ADT)	18	30.73889	5.433354	1.280654	28.03695	33.44083	20.900	38.700
	Mpohor Adansi(MA)	15	32.79333	8.368177	2.160654	28.15919	37.42748	22.300	50.800
	Mpohor Motorway(MM)	15	34.84000	8.503176	2.195511	30.13110	39.54890	18.700	50.900
	Mpohor Adawotwe (ADW)	15	31.61333	8.606216	2.222115	26.84737	36.37930	22.100	50.200
	control	3	.00000	.000000	.000000	.00000	.00000	.000	.000
	Total	87	31.25057	9.715283	1.041588	29.17997	33.32118	.000	50.200
Mercury	Asowuo Ayipa(ASA)	21	5.70905	.896838	.195706	5.30081	6.11728	4.200	6.900
	Adum Tokoro(ADT)	18	6.38778	.411990	.097107	6.18290	6.59266	5.500	6.900
	Mpohor Adansi(MA)	15	5.56600	.934985	.241412	5.04822	6.08378	4.200	6.900
	Mpohor Motorway(MM)	15	5.55933	.947979	.244767	5.03436	6.08431	4.200	6.900
	Mpohor Adawotwe (ADW)	15	5.70600	.968709	.250120	5.16955	6.24245	4.200	6.900
	control	3	.00000	.000000	.000000	.00000	.00000	.000	.000
	Total	87	5.60161	1.375197	.147437	5.30851	5.89470	.000	6.900
Arsenic	Asowuo Ayipa(ASA)	21	5.51429	.750524	.163778	5.17265	5.85592	4.100	6.700
	Adum Tokoro(ADT)	18	5.84444	.746145	.175868	5.47340	6.21549	4.100	6.700
	Mpohor Adansi(MA)	15	5.58000	.771085	.199093	5.15299	6.00701	4.100	6.500
	Mpohor Motorway(MM)	15	5.27333	.699456	.180599	4.88599	5.66068	4.100	6.700
	Mpohor Adawotwe (ADW)	15	5.64667	.779988	.201392	5.21472	6.07861	4.100	6.500
	control	3	.00000	.000000	.000000	.00000	.00000	.000	.000
	Total	87	5.38506	1.263764	.135490	5.11571	5.65440	.000	6.700
% Silt	Asowuo Ayipa(ASA)	21	39.5714	6.20944	1.35501	36.7449	42.3979	28.00	54.00
	Adum Tokoro(ADT)	18	33.8333	6.16680	1.45353	30.7667	36.9000	23.00	44.00
	Mpohor Adansi(MA)	15	38.4000	3.56170	.91963	36.4276	40.3724	32.00	44.00
	Mpohor Motorway(MM)	15	39.0667	5.68792	1.46861	35.9168	42.2165	28.00	49.00
	Mpohor Adawotwe (ADW)	15	39.2000	3.36367	.86850	37.3373	41.0627	33.00	44.00
	control	3	47.0000	5.33573	3.08058	33.7453	60.2547	42.30	52.80
	Total	87	38.2874	5.81173	.62308	37.0487	39.5260	23.00	54.00

% clay	Asowuo Ayipa(ASA)	21	27.4286	9.09710	1.98515	23.2876	31.5695	12.00	48.00
	Adum Tokoro(ADT)	18	37.3333	7.97053	1.87867	33.3697	41.2970	22.00	48.00
	Mpohor Adansi(MA)	15	28.0667	4.80278	1.24007	25.4070	30.7264	22.00	38.00
	Mpohor Motorway(MM)	15	28.6000	9.86190	2.54633	23.1387	34.0613	15.00	48.00
	Mpohor Adawotwe (ADW)	15	27.9333	4.80278	1.24007	25.2736	30.5930	22.00	38.00
	control	3	14.3667	3.62951	2.09550	5.3505	23.3829	11.70	18.50
	Total	87	29.4264	8.84619	.94841	27.5411	31.3118	11.70	48.00
% sand	Asowuo Ayipa(ASA)	21	37.2381	7.18961	1.56890	33.9654	40.5108	18.00	49.00
	Adum Tokoro(ADT)	18	35.8333	7.20498	1.69823	32.2504	39.4163	24.00	49.00
	Mpohor Adansi(MA)	15	37.8667	5.20805	1.34471	34.9825	40.7508	32.00	49.00
	Mpohor Motorway(MM)	15	36.9333	7.61077	1.96509	32.7186	41.1480	18.00	45.00
	Mpohor Adawotwe (ADW)	15	36.2667	4.51136	1.16483	33.7684	38.7650	32.00	45.00
	control	3	49.4667	2.70986	1.56454	42.7350	56.1983	46.90	52.30
	Total	87	37.2575	6.74466	.72310	35.8200	38.6950	18.00	52.30
Moisture content	Asowuo Ayipa(ASA)	21	1.6976	.28721	.06267	1.5669	1.8284	1.29	2.57
	Adum Tokoro(ADT)	18	2.0050	.38181	.08999	1.8151	2.1949	1.47	2.61
	Mpohor Adansi(MA)	15	1.6053	.14317	.03697	1.5260	1.6846	1.44	1.97
	Mpohor Motorway(MM)	15	1.7787	.29672	.07661	1.6144	1.9430	1.44	2.57
	Mpohor Adawotwe (ADW)	15	1.5787	.10329	.02667	1.5215	1.6359	1.44	1.77
	control	3	4.6000	.81854	.47258	2.5666	6.6334	3.70	5.30
	Total	87	1.8389	.61769	.06622	1.7072	1.9705	1.29	5.30
%organic matter	Asowuo Ayipa(ASA)	21	1.9601	.32355	.07060	1.8129	2.1074	1.55	2.54
	Adum Tokoro(ADT)	18	2.0400	.44607	.10514	1.8182	2.2618	1.24	2.71
	Mpohor Adansi(MA)	15	1.9547	.29756	.07683	1.7899	2.1194	1.63	2.54
	Mpohor Motorway(MM)	15	1.8780	.28013	.07233	1.7229	2.0331	1.55	2.54
	Mpohor Adawotwe (ADW)	15	1.9027	.26464	.06833	1.7561	2.0492	1.63	2.54
	control	3	4.8667	1.05040	.60645	2.2573	7.4760	3.80	5.90
	Total	87	2.0519	.64591	.06925	1.9142	2.1895	1.24	5.90
% organic carbon	Asowuo Ayipa(ASA)	21	.7389	.16739	.03653	.6627	.8151	.22	.97
	Adum Tokoro(ADT)	18	.5422	.21295	.05019	.4363	.6481	.25	.98
	Mpohor Adansi(MA)	15	.7333	.19352	.04997	.6262	.8405	.22	.97
	Mpohor Motorway(MM)	15	.7493	.19241	.04968	.6428	.8559	.26	.97
	Mpohor Adawotwe (ADW)	15	.7323	.17878	.04616	.6333	.8313	.22	.97
	control	3	5.8273	.90666	.52346	3.5751	8.0796	4.88	6.40
	Total	87	.8734	.97210	.10422	.6662	1.0806	.22	6.40
Available phosphorus	Asowuo Ayipa(ASA)	21	20.2524	4.98775	1.08842	17.9820	22.5228	11.60	29.80
	Adum Tokoro(ADT)	18	24.7500	3.22294	.75965	23.1473	26.3527	18.40	29.80
	Mpohor Adansi(MA)	15	20.5000	4.90772	1.26717	17.7822	23.2178	13.50	29.80

	Mpohor Motorway(MM)	15	18.4133	4.17405	1.07773	16.1018	20.7248	11.20	25.70
	Mpohor Adawotwe (ADW)	15	20.6467	4.87499	1.25872	17.9470	23.3463	13.80	29.60
	control	3	43.2667	3.96274	2.28789	33.4227	53.1107	39.50	47.40
	Total	87	21.7701	6.31171	.67669	20.4249	23.1153	11.60	47.40
Total Nitrogen	Asowuo Ayipa(ASA)	21	.0581	.01778	.00388	.0500	.0662	.02	.08
	Adum Tokoro(ADT)	18	.0556	.02064	.00487	.0453	.0658	.02	.09
	Mpohor Adansi(MA)	15	.0540	.01724	.00445	.0445	.0635	.02	.08
	Mpohor Motorway(MM)	15	.0640	.01298	.00335	.0568	.0712	.04	.08
	Mpohor Adawotwe (ADW)	15	.0527	.01870	.00483	.0423	.0630	.02	.08
	control	3	4.4333	.70946	.40961	2.6709	6.1957	3.80	5.20
	Total	87	.2078	.81062	.08691	.0350	.3806	.02	5.20
Conductivity	Asowuo Ayipa(ASA)	21	38.3981	5.51189	1.20279	35.8891	40.9071	31.30	49.50
	Adum Tokoro(ADT)	18	37.7100	5.32806	1.25584	35.0604	40.3596	32.30	47.40
	Mpohor Adansi(MA)	15	38.1253	5.53307	1.42863	35.0612	41.1894	30.30	44.50
	Mpohor Motorway(MM)	15	38.3187	5.95981	1.53882	35.0182	41.6191	31.30	46.50
	Mpohor Adawotwe (ADW)	15	38.9147	5.94109	1.53398	35.6246	42.2047	34.30	43.50
	control	3	14.2333	1.77858	1.02686	9.8151	18.6516	12.30	15.80
	Total	87	37.4508	6.99173	.74959	35.9607	38.9409	12.30	49.50
pH	Asowuo Ayipa(ASA)	21	4.7895	.47069	.10271	4.5753	5.0038	4.10	5.40
	Adum Tokoro(ADT)	18	4.9744	.50479	.11898	4.7234	5.2255	4.20	5.20
	Mpohor Adansi(MA)	15	4.7893	.53130	.13718	4.4951	5.0836	4.40	5.10
	Mpohor Motorway(MM)	15	4.6800	.43785	.11305	4.4375	4.9225	4.50	5.50
	Mpohor Adawotwe (ADW)	15	4.8787	.59907	.15468	4.5469	5.2104	4.60	5.90
	control	3	7.2000	.30000	.17321	6.4548	7.9452	6.90	7.50
	Total	87	4.9074	.66246	.07102	4.7662	5.0485	4.20	7.50

ANOVA for Parameters in Soil, Amansie West

		Sum of Squares	df	Mean Square	F	Sig.
Calcium	Between Groups	333.700	4	83.425	688.878	.000
	Within Groups	8.477	70	.121		
	Total	342.177	74			
Magnesium	Between Groups	306.913	4	76.728	464.546	.000
	Within Groups	11.562	70	.165		
	Total	318.475	74			
Sodium	Between Groups	.374	4	.094	10.379	.000
	Within Groups	.631	70	.009		
	Total	1.005	74			
Potassium	Between Groups	.461	4	.115	324.011	.000
	Within Groups	.025	70	.000		
	Total	.485	74			
Iron	Between Groups	36296723.339	4	9074180.835	27.371	.000

	Within Groups	23206581.407	70	331522.592		
	Total	59503304.747	74			
Zinc	Between Groups	29245.727	4	7311.432	368.719	.000
	Within Groups	1388.048	70	19.829		
	Total	30633.775	74			
Nickel	Between Groups	.910	4	.227	46.548	.000
	Within Groups	.342	70	.005		
	Total	1.252	74			
Cobalt	Between Groups	457.559	4	114.390	103.145	.000
	Within Groups	77.632	70	1.109		
	Total	535.191	74			
Copper	Between Groups	.144	4	.036	16.896	.000
	Within Groups	.149	70	.002		
	Total	.293	74			
Lead	Between Groups	10.981	4	2.745	150.543	.000
	Within Groups	1.276	70	.018		
	Total	12.257	74			
Chromium	Between Groups	.964	4	.241	20.983	.000
	Within Groups	.804	70	.011		
	Total	1.768	74			
Cadmium	Between Groups	28248.900	4	7062.225	3.331	.015
	Within Groups	148411.964	70	2120.171		
	Total	176660.864	74			
Mercury	Between Groups	199.201	4	49.800	121.793	.000
	Within Groups	28.622	70	.409		
	Total	227.823	74			
Arsenic	Between Groups	40.526	4	10.132	32.630	.000
	Within Groups	21.735	70	.310		
	Total	62.261	74			
% silt	Between Groups	1793.230	4	448.307	18.800	.000
	Within Groups	524.622	22	23.846		
	Total	2317.852	26			
% clay	Between Groups	440.178	4	110.044	6.947	.001
	Within Groups	348.489	22	15.840		
	Total	788.667	26			
%sand	Between Groups	5407.378	4	1351.844	55.216	.000
	Within Groups	538.622	22	24.483		
	Total	5946.000	26			
% moisture	Between Groups	.944	3	.315	17.240	.000
	Within Groups	.402	22	.018		
	Total	1.346	25			
% organic matter	Between Groups	9.609	3	3.203	178.215	.000
	Within Groups	.395	22	.018		
	Total	10.005	25			
% organic crabon	Between Groups	1.890	3	.630	31.851	.000
	Within Groups	.435	22	.020		
	Total	2.326	25			
conductivity	Between Groups	4092.318	3	1364.106	61.960	.000
	Within Groups	484.354	22	22.016		
	Total	4576.672	25			
pH	Between Groups	21.744	3	7.248	37.908	.000

	Within Groups	4.206	22	.191		
	Total	25.950	25			
available phosphorus	Between Groups	13.093	3	4.364	6.729	.002
	Within Groups	14.269	22	.649		
	Total	27.362	25			
Total Nitrogen	Between Groups	.002	3	.001	.970	.424
	Within Groups	.014	22	.001		
	Total	.016	25			

Tukey's HSD Comparison in soil, Amansie West

Dependent Variable	(I) Sampling site	(J) Sampling site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Calcium	Manso(MN)	Dominase(DO)	-1.938933*	.146729	.000	-2.34980	-1.52807
		Brofoyedru(BYO)	1.436533*	.127071	.000	1.08072	1.79235
		Asaman(AS)	1.652119*	.112066	.000	1.33832	1.96592
		Control	-4.664489*	.146729	.000	-5.07535	-4.25363
	Dominase(DO)	Manso(MN)	1.938933*	.146729	.000	1.52807	2.34980
		Brofoyedru(BYO)	3.375467*	.146729	.000	2.96460	3.78633
		Asaman(AS)	3.591052*	.133945	.000	3.21599	3.96612
		Control	-2.725556*	.164048	.000	-3.18491	-2.26620
	Brofoyedru(BYO)	Manso(MN)	-1.436533*	.127071	.000	-1.79235	-1.08072
		Dominase(DO)	-3.375467*	.146729	.000	-3.78633	-2.96460
		Asaman(AS)	.215585	.112066	.315	-.09822	.52939
		Control	-6.101022*	.146729	.000	-6.51189	-5.69016
	Asaman(AS)	Manso(MN)	-1.652119*	.112066	.000	-1.96592	-1.33832
		Dominase(DO)	-3.591052*	.133945	.000	-3.96612	-3.21599
		Brofoyedru(BYO)	-.215585	.112066	.315	-.52939	.09822
		Control	-6.316607*	.133945	.000	-6.69167	-5.94154
	Control	Manso(MN)	4.664489*	.146729	.000	4.25363	5.07535
		Dominase(DO)	2.725556*	.164048	.000	2.26620	3.18491
		Brofoyedru(BYO)	6.101022*	.146729	.000	5.69016	6.51189
		Asaman(AS)	6.316607*	.133945	.000	5.94154	6.69167
Magnesium	Manso(MN)	Dominase(DO)	-.384244	.171357	.177	-.86407	.09558
		Brofoyedru(BYO)	3.787200*	.148400	.000	3.37166	4.20274
		Asaman(AS)	3.906015*	.130876	.000	3.53954	4.27249
		Control	-.360911	.171357	.229	-.84074	.11892
	Dominase(DO)	Manso(MN)	.384244	.171357	.177	-.09558	.86407
		Brofoyedru(BYO)	4.171444*	.171357	.000	3.69162	4.65127
		Asaman(AS)	4.290259*	.156427	.000	3.85224	4.72828
		Control	.023333	.191583	1.000	-.51313	.55980
	Brofoyedru(BYO)	Manso(MN)	-3.787200*	.148400	.000	-4.20274	-3.37166
		Dominase(DO)	-4.171444*	.171357	.000	-4.65127	-3.69162
		Asaman(AS)	.118815	.130876	.893	-.24766	.48529

		Control	-4.148111*	.171357	.000	-4.62794	-3.66828
	Asaman(AS)	Manso(MN)	-3.906015*	.130876	.000	-4.27249	-3.53954
		Dominase(DO)	-4.290259*	.156427	.000	-4.72828	-3.85224
		Brofoyedru(BYO)	-.118815	.130876	.893	-.48529	.24766
		Control	-4.266926*	.156427	.000	-4.70495	-3.82891
	Control	Manso(MN)	.360911	.171357	.229	-.11892	.84074
		Dominase(DO)	-.023333	.191583	1.000	-.55980	.51313
		Brofoyedru(BYO)	4.148111*	.171357	.000	3.66828	4.62794
		Asaman(AS)	4.266926*	.156427	.000	3.82891	4.70495
Sodium	Manso(MN)	Dominase(DO)	-.138189*	.040023	.008	-.25026	-.02612
		Brofoyedru(BYO)	.103480*	.034661	.031	.00642	.20054
		Asaman(AS)	.044800	.030568	.588	-.04080	.13040
		Control	-.030078	.040023	.943	-.14215	.08199
	Dominase(DO)	Manso(MN)	.138189*	.040023	.008	.02612	.25026
		Brofoyedru(BYO)	.241669*	.040023	.000	.12960	.35374
		Asaman(AS)	.182989*	.036536	.000	.08068	.28530
		Control	.108111	.044747	.123	-.01719	.23341
	Brofoyedru(BYO)	Manso(MN)	-.103480*	.034661	.031	-.20054	-.00642
		Dominase(DO)	-.241669*	.040023	.000	-.35374	-.12960
		Asaman(AS)	-.058680	.030568	.317	-.14428	.02692
		Control	-.133558*	.040023	.012	-.24563	-.02149
	Asaman(AS)	Manso(MN)	-.044800	.030568	.588	-.13040	.04080
		Dominase(DO)	-.182989*	.036536	.000	-.28530	-.08068
		Brofoyedru(BYO)	.058680	.030568	.317	-.02692	.14428
		Control	-.074878	.036536	.254	-.17718	.02743
	Control	Manso(MN)	.030078	.040023	.943	-.08199	.14215
		Dominase(DO)	-.108111	.044747	.123	-.23341	.01719
		Brofoyedru(BYO)	.133558*	.040023	.012	.02149	.24563
		Asaman(AS)	.074878	.036536	.254	-.02743	.17718
Potassium	Manso(MN)	Dominase(DO)	.009647	.007948	.743	-.01261	.03190
		Brofoyedru(BYO)	-.021187*	.006883	.024	-.04046	-.00191
		Asaman(AS)	.012176	.006071	.274	-.00482	.02917
		Control	-.236653*	.007948	.000	-.25891	-.21440
	Dominase(DO)	Manso(MN)	-.009647	.007948	.743	-.03190	.01261
		Brofoyedru(BYO)	-.030833*	.007948	.002	-.05309	-.00858
		Asaman(AS)	.002530	.007256	.997	-.01779	.02285
		Control	-.246300*	.008886	.000	-.27118	-.22142

	Brofoyedru(BYO)	Manso(MN)	.021187*	.006883	.024	.00191	.04046
		Dominase(DO)	.030833*	.007948	.002	.00858	.05309
		Asaman(AS)	.033363*	.006071	.000	.01636	.05036
		Control	-.215467*	.007948	.000	-.23772	-.19321
	Asaman(AS)	Manso(MN)	-.012176	.006071	.274	-.02917	.00482
		Dominase(DO)	-.002530	.007256	.997	-.02285	.01779
		Brofoyedru(BYO)	-.033363*	.006071	.000	-.05036	-.01636
		Control	-.248830*	.007256	.000	-.26915	-.22851
	Control	Manso(MN)	.236653*	.007948	.000	.21440	.25891
		Dominase(DO)	.246300*	.008886	.000	.22142	.27118
		Brofoyedru(BYO)	.215467*	.007948	.000	.19321	.23772
		Asaman(AS)	.248830*	.007256	.000	.22851	.26915
Iron	Manso(MN)	Dominase(DO)	-1123.133333*	242.770158	.000	-1802.92691	-443.33976
		Brofoyedru(BYO)	-617.200000*	210.245124	.035	-1205.91851	-28.48149
		Asaman(AS)	404.459259	185.418771	.199	-114.74166	923.66018
		Control	-1544.577778*	242.770158	.000	-2224.37135	-864.78420
	Dominase(DO)	Manso(MN)	1123.133333*	242.770158	.000	443.33976	1802.92691
		Brofoyedru(BYO)	505.933333	242.770158	.239	-173.86024	1185.72691
		Asaman(AS)	1527.592593*	221.617820	.000	907.02880	2148.15639
		Control	-421.444444	271.425288	.532	-1181.47677	338.58788
	Brofoyedru(BYO)	Manso(MN)	617.200000*	210.245124	.035	28.48149	1205.91851
		Dominase(DO)	-505.933333	242.770158	.239	-1185.72691	173.86024
		Asaman(AS)	1021.659259*	185.418771	.000	502.45834	1540.86018
		Control	-927.377778*	242.770158	.003	-1607.17135	-247.58420
	Asaman(AS)	Manso(MN)	-404.459259	185.418771	.199	-923.66018	114.74166
		Dominase(DO)	-1527.592593*	221.617820	.000	-2148.15639	-907.02880
		Brofoyedru(BYO)	-1021.659259*	185.418771	.000	-1540.86018	-502.45834
		Control	-1949.037037*	221.617820	.000	-2569.60083	-1328.47324
	Control	Manso(MN)	1544.577778*	242.770158	.000	864.78420	2224.37135
		Dominase(DO)	421.444444	271.425288	.532	-338.58788	1181.47677
		Brofoyedru(BYO)	927.377778*	242.770158	.003	247.58420	1607.17135
		Asaman(AS)	1949.037037*	221.617820	.000	1328.47324	2569.60083
Zinc	Manso(MN)	Dominase(DO)	43.246667*	1.877552	.000	37.98923	48.50410
		Brofoyedru(BYO)	32.641800*	1.626008	.000	28.08873	37.19487
		Asaman(AS)	27.644074*	1.434004	.000	23.62864	31.65950
		Control	-20.066667*	1.877552	.000	-25.32410	-14.80923
	Dominase(DO)	Manso(MN)	-43.246667*	1.877552	.000	-48.50410	-37.98923

		Brofoyedru(BYO)	-10.604867*	1.877552	.000	-15.86230	-5.34743
		Asaman(AS)	-15.602593*	1.713963	.000	-20.40195	-10.80324
		Control	-63.313333*	2.099167	.000	-69.19132	-57.43534
	Brofoyedru(BYO)	Manso(MN)	-32.641800*	1.626008	.000	-37.19487	-28.08873
		Dominase(DO)	10.604867*	1.877552	.000	5.34743	15.86230
		Asaman(AS)	-4.997726*	1.434004	.007	-9.01316	-.98230
		Control	-52.708467*	1.877552	.000	-57.96590	-47.45103
	Asaman(AS)	Manso(MN)	-27.644074*	1.434004	.000	-31.65950	-23.62864
		Dominase(DO)	15.602593*	1.713963	.000	10.80324	20.40195
		Brofoyedru(BYO)	4.997726*	1.434004	.007	.98230	9.01316
		Control	-47.710741*	1.713963	.000	-52.51010	-42.91138
	Control	Manso(MN)	20.066667*	1.877552	.000	14.80923	25.32410
		Dominase(DO)	63.313333*	2.099167	.000	57.43534	69.19132
		Brofoyedru(BYO)	52.708467*	1.877552	.000	47.45103	57.96590
		Asaman(AS)	47.710741*	1.713963	.000	42.91138	52.51010
Nickel	Manso(MN)	Dominase(DO)	-.156000*	.029470	.000	-.23852	-.07348
		Brofoyedru(BYO)	.158267*	.025521	.000	.08680	.22973
		Asaman(AS)	-.070815*	.022508	.020	-.13384	-.00779
		Control	.141778*	.029470	.000	.05926	.22430
	Dominase(DO)	Manso(MN)	.156000*	.029470	.000	.07348	.23852
		Brofoyedru(BYO)	.314267*	.029470	.000	.23175	.39679
		Asaman(AS)	.085185*	.026902	.019	.00986	.16051
		Control	.297778*	.032948	.000	.20552	.39004
	Brofoyedru(BYO)	Manso(MN)	-.158267*	.025521	.000	-.22973	-.08680
		Dominase(DO)	-.314267*	.029470	.000	-.39679	-.23175
		Asaman(AS)	-.229081*	.022508	.000	-.29211	-.16606
		Control	-.016489	.029470	.980	-.09901	.06603
	Asaman(AS)	Manso(MN)	.070815*	.022508	.020	.00779	.13384
		Dominase(DO)	-.085185*	.026902	.019	-.16051	-.00986
		Brofoyedru(BYO)	.229081*	.022508	.000	.16606	.29211
		Control	.212593*	.026902	.000	.13726	.28792
	Control	Manso(MN)	-.141778*	.029470	.000	-.22430	-.05926
		Dominase(DO)	-.297778*	.032948	.000	-.39004	-.20552
		Brofoyedru(BYO)	.016489	.029470	.980	-.06603	.09901
		Asaman(AS)	-.212593*	.026902	.000	-.28792	-.13726
Cobalt	Manso(MN)	Dominase(DO)	-5.488889*	.444027	.000	-6.73223	-4.24555
		Brofoyedru(BYO)	-3.104000*	.384538	.000	-4.18077	-2.02723

		Asaman(AS)	-4.725926*	.339131	.000	-5.67554	-3.77631
		Control	1.588889*	.444027	.006	.34555	2.83223
	Dominase(DO)	Manso(MN)	5.488889*	.444027	.000	4.24555	6.73223
		Brofoyedru(BYO)	2.384889*	.444027	.000	1.14155	3.62823
		Asaman(AS)	.762963	.405339	.336	-.37205	1.89797
		Control	7.077778*	.496437	.000	5.68768	8.46788
	Brofoyedru(BYO)	Manso(MN)	3.104000*	.384538	.000	2.02723	4.18077
		Dominase(DO)	-2.384889*	.444027	.000	-3.62823	-1.14155
		Asaman(AS)	-1.621926*	.339131	.000	-2.57154	-.67231
		Control	4.692889*	.444027	.000	3.44955	5.93623
	Asaman(AS)	Manso(MN)	4.725926*	.339131	.000	3.77631	5.67554
		Dominase(DO)	-.762963	.405339	.336	-1.89797	.37205
		Brofoyedru(BYO)	1.621926*	.339131	.000	.67231	2.57154
		Control	6.314815*	.405339	.000	5.17980	7.44983
	Control	Manso(MN)	-1.588889*	.444027	.006	-2.83223	-.34555
		Dominase(DO)	-7.077778*	.496437	.000	-8.46788	-5.68768
		Brofoyedru(BYO)	-4.692889*	.444027	.000	-5.93623	-3.44955
		Asaman(AS)	-6.314815*	.405339	.000	-7.44983	-5.17980
Copper	Manso(MN)	Dominase(DO)	.107556*	.019448	.000	.05310	.16201
		Brofoyedru(BYO)	.075000*	.016843	.000	.02784	.12216
		Asaman(AS)	.003481	.014854	.999	-.03811	.04507
		Control	.092000*	.019448	.000	.03754	.14646
	Dominase(DO)	Manso(MN)	-.107556*	.019448	.000	-.16201	-.05310
		Brofoyedru(BYO)	-.032556	.019448	.456	-.08701	.02190
		Asaman(AS)	-.104074*	.017754	.000	-.15379	-.05436
		Control	-.015556	.021744	.952	-.07644	.04533
	Brofoyedru(BYO)	Manso(MN)	-.075000*	.016843	.000	-.12216	-.02784
		Dominase(DO)	.032556	.019448	.456	-.02190	.08701
		Asaman(AS)	-.071519*	.014854	.000	-.11311	-.02993
		Control	.017000	.019448	.905	-.03746	.07146
	Asaman(AS)	Manso(MN)	-.003481	.014854	.999	-.04507	.03811
		Dominase(DO)	.104074*	.017754	.000	.05436	.15379
		Brofoyedru(BYO)	.071519*	.014854	.000	.02993	.11311
		Control	.088519*	.017754	.000	.03881	.13823
	Control	Manso(MN)	-.092000*	.019448	.000	-.14646	-.03754
		Dominase(DO)	.015556	.021744	.952	-.04533	.07644
		Brofoyedru(BYO)	-.017000	.019448	.905	-.07146	.03746

		Asaman(AS)	-.088519*	.017754	.000	-.13823	-.03881
Lead	Manso(MN)	Dominase(DO)	-.969000*	.056937	.000	-1.12843	-.80957
		Brofoyedru(BYO)	.230667*	.049309	.000	.09259	.36874
		Asaman(AS)	.193778*	.043486	.000	.07201	.31555
		Control	.300667*	.056937	.000	.14124	.46010
	Dominase(DO)	Manso(MN)	.969000*	.056937	.000	.80957	1.12843
		Brofoyedru(BYO)	1.199667*	.056937	.000	1.04024	1.35910
		Asaman(AS)	1.162778*	.051976	.000	1.01724	1.30832
		Control	1.269667*	.063657	.000	1.09142	1.44792
	Brofoyedru(BYO)	Manso(MN)	-.230667*	.049309	.000	-.36874	-.09259
		Dominase(DO)	-1.199667*	.056937	.000	-1.35910	-1.04024
		Asaman(AS)	-.036889	.043486	.914	-.15866	.08488
		Control	.070000	.056937	.734	-.08943	.22943
	Asaman(AS)	Manso(MN)	-.193778*	.043486	.000	-.31555	-.07201
		Dominase(DO)	-1.162778*	.051976	.000	-1.30832	-1.01724
		Brofoyedru(BYO)	.036889	.043486	.914	-.08488	.15866
		Control	.106889	.051976	.251	-.03865	.25243
	Control	Manso(MN)	-.300667*	.056937	.000	-.46010	-.14124
		Dominase(DO)	-1.269667*	.063657	.000	-1.44792	-1.09142
		Brofoyedru(BYO)	-.070000	.056937	.734	-.22943	.08943
		Asaman(AS)	-.106889	.051976	.251	-.25243	.03865
Chromium	Manso(MN)	Dominase(DO)	.042911	.045186	.876	-.08362	.16944
		Brofoyedru(BYO)	-.171133*	.039132	.000	-.28071	-.06156
		Asaman(AS)	-.110274*	.034511	.017	-.20691	-.01364
		Control	.193133*	.045186	.001	.06661	.31966
	Dominase(DO)	Manso(MN)	-.042911	.045186	.876	-.16944	.08362
		Brofoyedru(BYO)	-.214044*	.045186	.000	-.34057	-.08752
		Asaman(AS)	-.153185*	.041249	.004	-.26869	-.03768
		Control	.150222*	.050519	.032	.00876	.29168
	Brofoyedru(BYO)	Manso(MN)	.171133*	.039132	.000	.06156	.28071
		Dominase(DO)	.214044*	.045186	.000	.08752	.34057
		Asaman(AS)	.060859	.034511	.403	-.03578	.15750
		Control	.364267*	.045186	.000	.23774	.49079
	Asaman(AS)	Manso(MN)	.110274*	.034511	.017	.01364	.20691
		Dominase(DO)	.153185*	.041249	.004	.03768	.26869
		Brofoyedru(BYO)	-.060859	.034511	.403	-.15750	.03578
		Control	.303407*	.041249	.000	.18790	.41891

	Control	Manso(MN)	-.193133*	.045186	.001	-.31966	-.06661
		Dominase(DO)	-.150222*	.050519	.032	-.29168	-.00876
		Brofoyedru(BYO)	-.364267*	.045186	.000	-.49079	-.23774
		Asaman(AS)	-.303407*	.041249	.000	-.41891	-.18790
Cadmium	Manso(MN)	Dominase(DO)	5.908889	19.414409	.998	-48.45443	60.27220
		Brofoyedru(BYO)	-29.100000	16.813371	.422	-76.18001	17.98001
		Asaman(AS)	-30.617037	14.828000	.247	-72.13770	10.90363
		Control	20.762222	19.414409	.821	-33.60109	75.12554
	Dominase(DO)	Manso(MN)	-5.908889	19.414409	.998	-60.27220	48.45443
		Brofoyedru(BYO)	-35.008889	19.414409	.380	-89.37220	19.35443
		Asaman(AS)	-36.525926	17.722850	.249	-86.15262	13.10076
		Control	14.853333	21.705969	.959	-45.92670	75.63337
	Brofoyedru(BYO)	Manso(MN)	29.100000	16.813371	.422	-17.98001	76.18001
		Dominase(DO)	35.008889	19.414409	.380	-19.35443	89.37220
		Asaman(AS)	-1.517037	14.828000	1.000	-43.03770	40.00363
		Control	49.862222	19.414409	.088	-4.50109	104.22554
	Asaman(AS)	Manso(MN)	30.617037	14.828000	.247	-10.90363	72.13770
		Dominase(DO)	36.525926	17.722850	.249	-13.10076	86.15262
		Brofoyedru(BYO)	1.517037	14.828000	1.000	-40.00363	43.03770
		Control	51.379259*	17.722850	.039	1.75257	101.00595
	Control	Manso(MN)	-20.762222	19.414409	.821	-75.12554	33.60109
		Dominase(DO)	-14.853333	21.705969	.959	-75.63337	45.92670
		Brofoyedru(BYO)	-49.862222	19.414409	.088	-104.22554	4.50109
		Asaman(AS)	-51.379259*	17.722850	.039	-101.00595	-1.75257
Mercury	Manso(MN)	Dominase(DO)	1.768889*	.269614	.000	1.01393	2.52385
		Brofoyedru(BYO)	.213333	.233493	.891	-.44048	.86715
		Asaman(AS)	1.793704*	.205921	.000	1.21709	2.37031
		Control	5.413333*	.269614	.000	4.65837	6.16829
	Dominase(DO)	Manso(MN)	-1.768889*	.269614	.000	-2.52385	-1.01393
		Brofoyedru(BYO)	-1.555556*	.269614	.000	-2.31052	-.80059
		Asaman(AS)	.024815	.246123	1.000	-.66437	.71400
		Control	3.644444*	.301438	.000	2.80037	4.48852
	Brofoyedru(BYO)	Manso(MN)	-.213333	.233493	.891	-.86715	.44048
		Dominase(DO)	1.555556*	.269614	.000	.80059	2.31052
		Asaman(AS)	1.580370*	.205921	.000	1.00376	2.15698
		Control	5.200000*	.269614	.000	4.44504	5.95496
	Asaman(AS)	Manso(MN)	-1.793704*	.205921	.000	-2.37031	-1.21709

		Dominase(DO)	-.024815	.246123	1.000	-.71400	.66437
		Brofoyedru(BYO)	-1.580370*	.205921	.000	-2.15698	-1.00376
		Control	3.619630*	.246123	.000	2.93045	4.30881
	Control	Manso(MN)	-5.413333*	.269614	.000	-6.16829	-4.65837
		Dominase(DO)	-3.644444*	.301438	.000	-4.48852	-2.80037
		Brofoyedru(BYO)	-5.200000*	.269614	.000	-5.95496	-4.44504
		Asaman(AS)	-3.619630*	.246123	.000	-4.30881	-2.93045
Arsenic	Manso(MN)	Dominase(DO)	.097778	.234946	.994	-.56011	.75566
		Brofoyedru(BYO)	.326667	.203469	.499	-.24308	.89641
		Asaman(AS)	.638519*	.179443	.006	.13605	1.14099
		Control	2.476667*	.234946	.000	1.81878	3.13455
	Dominase(DO)	Manso(MN)	-.097778	.234946	.994	-.75566	.56011
		Brofoyedru(BYO)	.228889	.234946	.866	-.42900	.88677
		Asaman(AS)	.540741	.214475	.098	-.05982	1.14130
		Control	2.378889*	.262677	.000	1.64335	3.11443
	Brofoyedru(BYO)	Manso(MN)	-.326667	.203469	.499	-.89641	.24308
		Dominase(DO)	-.228889	.234946	.866	-.88677	.42900
		Asaman(AS)	.311852	.179443	.418	-.19062	.81432
		Control	2.150000*	.234946	.000	1.49212	2.80788
	Asaman(AS)	Manso(MN)	-.638519*	.179443	.006	-1.14099	-.13605
		Dominase(DO)	-.540741	.214475	.098	-1.14130	.05982
		Brofoyedru(BYO)	-.311852	.179443	.418	-.81432	.19062
		Control	1.838148*	.214475	.000	1.23758	2.43871
	Control	Manso(MN)	-2.476667*	.234946	.000	-3.13455	-1.81878
		Dominase(DO)	-2.378889*	.262677	.000	-3.11443	-1.64335
		Brofoyedru(BYO)	-2.150000*	.234946	.000	-2.80788	-1.49212
		Asaman(AS)	-1.838148*	.214475	.000	-2.43871	-1.23758

*. The mean difference is significant at the 0.05 level.

Appendix I: ANOVA of Parameters in Soil, Mpohor Wassa East

		Sum of Squares	df	Mean Square	F	Sig.
Calcium	Between Groups	97.350	5	19.470	19.006	.000
	Within Groups	82.977	81	1.024		
	Total	180.327	86			
Magnesium	Between Groups	64.417	5	12.883	15.750	.000
	Within Groups	66.256	81	.818		
	Total	130.673	86			
Sodium	Between Groups	.851	5	.170	1.888	.105
	Within Groups	7.303	81	.090		
	Total	8.154	86			
Potassium	Between Groups	5.378	5	1.076	386.475	.000
	Within Groups	.225	81	.003		
	Total	5.603	86			
Iron	Between Groups	17045089.586	5	3409017.917	4.802	.001
	Within Groups	57509137.816	81	709989.356		
	Total	74554227.402	86			
Zinc	Between Groups	2922.679	5	584.536	5.704	.000
	Within Groups	8300.938	81	102.481		
	Total	11223.617	86			
Nickel	Between Groups	.947	5	.189	9.959	.000
	Within Groups	1.540	81	.019		
	Total	2.487	86			
Cobalt	Between Groups	110.318	5	22.064	13.764	.000
	Within Groups	129.844	81	1.603		
	Total	240.162	86			
Copper	Between Groups	1.300	5	.260	24.737	.000
	Within Groups	.851	81	.011		

	Total	2.152	86			
Lead	Between Groups	4.465	5	.893	5.291	.000
	Within Groups	13.672	81	.169		
	Total	18.137	86			
Chromium	Between Groups	1.243	5	.249	11.967	.000
	Within Groups	1.683	81	.021		
	Total	2.926	86			
Cadmium	Between Groups	3185.529	5	637.106	10.464	.000
	Within Groups	4931.728	81	60.886		
	Total	8117.257	86			
Mecury	Between Groups	105.711	5	21.142	30.081	.000
	Within Groups	56.930	81	.703		
	Total	162.640	86			
Arsenic	Between Groups	92.930	5	18.586	33.891	.000
	Within Groups	44.421	81	.548		
	Total	137.351	86			
% Silt	Between Groups	641.240	5	128.248	4.589	.001
	Within Groups	2263.516	81	27.945		
	Total	2904.756	86			
% clay	Between Groups	1960.973	5	392.195	6.661	.000
	Within Groups	4768.956	81	58.876		
	Total	6729.929	86			
% sand	Between Groups	505.576	5	101.115	2.404	.044
	Within Groups	3406.596	81	42.057		
	Total	3912.173	86			
Moisture content	Between Groups	25.675	5	5.135	58.280	.000
	Within Groups	7.137	81	.088		
	Total	32.812	86			

%organic matter	Between Groups	24.878	5	4.976	36.632	.000
	Within Groups	11.002	81	.136		
	Total	35.879	86			
% organic carbon	Between Groups	76.802	5	15.360	278.626	.000
	Within Groups	4.465	81	.055		
	Total	81.268	86			
Available phosphorus	Between Groups	1806.664	5	361.333	18.074	.000
	Within Groups	1619.379	81	19.992		
	Total	3426.042	86			
Total Nitrogen	Between Groups	55.479	5	11.096	871.192	.000
	Within Groups	1.032	81	.013		
	Total	56.511	86			
Conductivity	Between Groups	1687.473	5	337.495	10.863	.000
	Within Groups	2516.574	81	31.069		
	Total	4204.046	86			
pH	Between Groups	17.138	5	3.428	13.475	.000
	Within Groups	20.603	81	.254		
	Total	37.741	86			

Appendix J: Tukey's HSD Comparison of Parameters in soil, Mpohor Wassa East

Dependent Variable	(I) Sampling site	(J) Sampling site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Calcium	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.989516*	.325105	.036	-1.93852	-.04052
		Mpohor Adansi(MA)	-.085305	.342163	1.000	-1.08410	.91349
		Mpohor Motorway(MM)	-.071905	.342163	1.000	-1.07070	.92689
		Mpohor Adawotwe (ADW)	-.100505	.342163	1.000	-1.09930	.89829
		control	-5.674571*	.624702	.000	-7.49811	-3.85103
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.989516*	.325105	.036	.04052	1.93852
		Mpohor Adansi(MA)	.904211	.353844	.121	-.12868	1.93710
		Mpohor Motorway(MM)	.917611	.353844	.111	-.11528	1.95050
		Mpohor Adawotwe (ADW)	.889011	.353844	.133	-.14388	1.92190
		control	-4.685056*	.631175	.000	-6.52749	-2.84262
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.085305	.342163	1.000	-.91349	1.08410
		Adum Tokoro(ADT)	-.904211	.353844	.121	-1.93710	.12868
		Mpohor Motorway(MM)	.013400	.369578	1.000	-1.06542	1.09222
		Mpohor Adawotwe (ADW)	-.015200	.369578	1.000	-1.09402	1.06362
		control	-5.589267*	.640129	.000	-7.45784	-3.72070
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	.071905	.342163	1.000	-.92689	1.07070
		Adum Tokoro(ADT)	-.917611	.353844	.111	-1.95050	.11528
		Mpohor Adansi(MA)	-.013400	.369578	1.000	-1.09222	1.06542
		Mpohor Adawotwe (ADW)	-.028600	.369578	1.000	-1.10742	1.05022
		control	-5.602667*	.640129	.000	-7.47124	-3.73410
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.100505	.342163	1.000	-.89829	1.09930
		Adum Tokoro(ADT)	-.889011	.353844	.133	-1.92190	.14388
		Mpohor Adansi(MA)	.015200	.369578	1.000	-1.06362	1.09402
		Mpohor Motorway(MM)	.028600	.369578	1.000	-1.05022	1.10742
		control	-5.574067*	.640129	.000	-7.44264	-3.70550
	control	Asowuo Ayipa(ASA)	5.674571*	.624702	.000	3.85103	7.49811
		Adum Tokoro(ADT)	4.685056*	.631175	.000	2.84262	6.52749
		Mpohor Adansi(MA)	5.589267*	.640129	.000	3.72070	7.45784
		Mpohor Motorway(MM)	5.602667*	.640129	.000	3.73410	7.47124
		Mpohor Adawotwe (ADW)	5.574067*	.640129	.000	3.70550	7.44264

Magnesium	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.227675	.290507	.970	-1.07568	.62033
		Mpohor Adansi(MA)	-.043686	.305749	1.000	-.93619	.84881
		Mpohor Motorway(MM)	-.188219	.305749	.990	-1.08072	.70428
		Mpohor Adawotwe (ADW)	-.107286	.305749	.999	-.99979	.78521
		control	-4.800952*	.558219	.000	-6.43043	-3.17148
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.227675	.290507	.970	-.62033	1.07568
		Mpohor Adansi(MA)	.183989	.316188	.992	-.73898	1.10696
		Mpohor Motorway(MM)	.039456	.316188	1.000	-.88351	.96242
		Mpohor Adawotwe (ADW)	.120389	.316188	.999	-.80258	1.04336
		control	-4.573278*	.564004	.000	-6.21964	-2.92692
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.043686	.305749	1.000	-.84881	.93619
		Adum Tokoro(ADT)	-.183989	.316188	.992	-1.10696	.73898
		Mpohor Motorway(MM)	-.144533	.330247	.998	-1.10854	.81948
		Mpohor Adawotwe (ADW)	-.063600	.330247	1.000	-1.02761	.90041
		control	-4.757267*	.572005	.000	-6.42698	-3.08755
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	.188219	.305749	.990	-.70428	1.08072
		Adum Tokoro(ADT)	-.039456	.316188	1.000	-.96242	.88351
		Mpohor Adansi(MA)	.144533	.330247	.998	-.81948	1.10854
		Mpohor Adawotwe (ADW)	.080933	.330247	1.000	-.88308	1.04494
		control	-4.612733*	.572005	.000	-6.28245	-2.94302
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.107286	.305749	.999	-.78521	.99979
		Adum Tokoro(ADT)	-.120389	.316188	.999	-1.04336	.80258
		Mpohor Adansi(MA)	.063600	.330247	1.000	-.90041	1.02761
		Mpohor Motorway(MM)	-.080933	.330247	1.000	-1.04494	.88308
		control	-4.693667*	.572005	.000	-6.36338	-3.02395
	control	Asowuo Ayipa(ASA)	4.800952*	.558219	.000	3.17148	6.43043
		Adum Tokoro(ADT)	4.573278*	.564004	.000	2.92692	6.21964
		Mpohor Adansi(MA)	4.757267*	.572005	.000	3.08755	6.42698
		Mpohor Motorway(MM)	4.612733*	.572005	.000	2.94302	6.28245
		Mpohor Adawotwe (ADW)	4.693667*	.572005	.000	3.02395	6.36338
Sodium	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	.062586	.096448	.987	-.21895	.34412
		Mpohor Adansi(MA)	.005652	.101508	1.000	-.29066	.30196
		Mpohor Motorway(MM)	.104899	.101508	.905	-.19141	.40121
		Mpohor Adawotwe (ADW)	-.067214	.101508	.986	-.36352	.22909
		control	.470586	.185328	.125	-.07040	1.01157
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-.062586	.096448	.987	-.34412	.21895
		Mpohor Adansi(MA)	-.056933	.104974	.994	-.36336	.24949

		Mpohor Motorway(MM)	.042313	.104974	.999	-.26411	.34874
		Mpohor Adawotwe (ADW)	-.129800	.104974	.818	-.43622	.17662
		control	.408000	.187249	.259	-.13859	.95459
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.005652	.101508	1.000	-.30196	.29066
		Adum Tokoro(ADT)	.056933	.104974	.994	-.24949	.36336
		Mpohor Motorway(MM)	.099247	.109642	.944	-.22080	.41930
		Mpohor Adawotwe (ADW)	-.072867	.109642	.985	-.39292	.24718
		control	.464933	.189905	.152	-.08941	1.01928
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.104899	.101508	.905	-.40121	.19141
		Adum Tokoro(ADT)	-.042313	.104974	.999	-.34874	.26411
		Mpohor Adansi(MA)	-.099247	.109642	.944	-.41930	.22080
		Mpohor Adawotwe (ADW)	-.172113	.109642	.621	-.49216	.14794
		control	.365687	.189905	.394	-.18866	.92003
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.067214	.101508	.986	-.22909	.36352
		Adum Tokoro(ADT)	.129800	.104974	.818	-.17662	.43622
		Mpohor Adansi(MA)	.072867	.109642	.985	-.24718	.39292
		Mpohor Motorway(MM)	.172113	.109642	.621	-.14794	.49216
		control	.537800	.189905	.062	-.01654	1.09214
	control	Asowuo Ayipa(ASA)	-.470586	.185328	.125	-1.01157	.07040
		Adum Tokoro(ADT)	-.408000	.187249	.259	-.95459	.13859
		Mpohor Adansi(MA)	-.464933	.189905	.152	-1.01928	.08941
		Mpohor Motorway(MM)	-.365687	.189905	.394	-.92003	.18866
		Mpohor Adawotwe (ADW)	-.537800	.189905	.062	-1.09214	.01654
Potassium	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	.007254	.016945	.998	-.04221	.05672
		Mpohor Adansi(MA)	-.000524	.017834	1.000	-.05258	.05154
		Mpohor Motorway(MM)	.003676	.017834	1.000	-.04838	.05574
		Mpohor Adawotwe (ADW)	.001076	.017834	1.000	-.05098	.05314
		control	-1.360190*	.032561	.000	-1.45524	-1.26514
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-.007254	.016945	.998	-.05672	.04221
		Mpohor Adansi(MA)	-.007778	.018443	.998	-.06161	.04606
		Mpohor Motorway(MM)	-.003578	.018443	1.000	-.05741	.05026
		Mpohor Adawotwe (ADW)	-.006178	.018443	.999	-.06001	.04766
		control	-1.367444*	.032898	.000	-1.46348	-1.27141
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.000524	.017834	1.000	-.05154	.05258
		Adum Tokoro(ADT)	.007778	.018443	.998	-.04606	.06161
		Mpohor Motorway(MM)	.004200	.019263	1.000	-.05203	.06043
		Mpohor Adawotwe (ADW)	.001600	.019263	1.000	-.05463	.05783

		control	-1.359667*	.033365	.000	-1.45706	-1.26227
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.003676	.017834	1.000	-.05574	.04838
		Adum Tokoro(ADT)	.003578	.018443	1.000	-.05026	.05741
		Mpohor Adansi(MA)	-.004200	.019263	1.000	-.06043	.05203
		Mpohor Adawotwe (ADW)	-.002600	.019263	1.000	-.05883	.05363
		control	-1.363867*	.033365	.000	-1.46126	-1.26647
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.001076	.017834	1.000	-.05314	.05098
		Adum Tokoro(ADT)	.006178	.018443	.999	-.04766	.06001
		Mpohor Adansi(MA)	-.001600	.019263	1.000	-.05783	.05463
		Mpohor Motorway(MM)	.002600	.019263	1.000	-.05363	.05883
		control	-1.361267*	.033365	.000	-1.45866	-1.26387
	control	Asowuo Ayipa(ASA)	1.360190*	.032561	.000	1.26514	1.45524
		Adum Tokoro(ADT)	1.367444*	.032898	.000	1.27141	1.46348
		Mpohor Adansi(MA)	1.359667*	.033365	.000	1.26227	1.45706
		Mpohor Motorway(MM)	1.363867*	.033365	.000	1.26647	1.46126
		Mpohor Adawotwe (ADW)	1.361267*	.033365	.000	1.26387	1.45866
Iron	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-24.079365	270.652674	1.000	-814.12954	765.97081
		Mpohor Adansi(MA)	2.209524	284.853718	1.000	-829.29429	833.71334
		Mpohor Motorway(MM)	37.542857	284.853718	1.000	-793.96096	869.04667
		Mpohor Adawotwe (ADW)	-142.790476	284.853718	.996	-974.29429	688.71334
		control	2381.476190*	520.069356	.000	863.36487	3899.58751
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	24.079365	270.652674	1.000	-765.97081	814.12954
		Mpohor Adansi(MA)	26.288889	294.578473	1.000	-833.60202	886.17980
		Mpohor Motorway(MM)	61.622222	294.578473	1.000	-798.26869	921.51314
		Mpohor Adawotwe (ADW)	-118.711111	294.578473	.999	-978.60202	741.17980
		control	2405.555556*	525.458820	.000	871.71209	3939.39902
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-2.209524	284.853718	1.000	-833.71334	829.29429
		Adum Tokoro(ADT)	-26.288889	294.578473	1.000	-886.17980	833.60202
		Mpohor Motorway(MM)	35.333333	307.677181	1.000	-862.79343	933.46010
		Mpohor Adawotwe (ADW)	-145.000000	307.677181	.997	-1043.12677	753.12677
		control	2379.266667*	532.912509	.000	823.66547	3934.86786
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-37.542857	284.853718	1.000	-869.04667	793.96096
		Adum Tokoro(ADT)	-61.622222	294.578473	1.000	-921.51314	798.26869
		Mpohor Adansi(MA)	-35.333333	307.677181	1.000	-933.46010	862.79343
		Mpohor Adawotwe (ADW)	-180.333333	307.677181	.992	-1078.46010	717.79343
		control	2343.933333*	532.912509	.000	788.33214	3899.53453
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	142.790476	284.853718	.996	-688.71334	974.29429

		Adum Tokoro(ADT)	118.711111	294.578473	.999	-741.17980	978.60202
		Mpohor Adansi(MA)	145.000000	307.677181	.997	-753.12677	1043.12677
		Mpohor Motorway(MM)	180.333333	307.677181	.992	-717.79343	1078.46010
		control	2524.266667*	532.912509	.000	968.66547	4079.86786
	control	Asowuo Ayipa(ASA)	-2381.476190*	520.069356	.000	-3899.58751	-863.36487
		Adum Tokoro(ADT)	-2405.555556*	525.458820	.000	-3939.39902	-871.71209
		Mpohor Adansi(MA)	-2379.266667*	532.912509	.000	-3934.86786	-823.66547
		Mpohor Motorway(MM)	-2343.933333*	532.912509	.000	-3899.53453	-788.33214
		Mpohor Adawotwe (ADW)	-2524.266667*	532.912509	.000	-4079.86786	-968.66547
Zinc	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	4.123413	3.251678	.801	-5.36841	13.61524
		Mpohor Adansi(MA)	-1.880476	3.422292	.994	-11.87034	8.10938
		Mpohor Motorway(MM)	-1.727143	3.422292	.996	-11.71700	8.26272
		Mpohor Adawotwe (ADW)	-.247143	3.422292	1.000	-10.23700	9.74272
		control	-29.307143*	6.248222	.000	-47.54605	-11.06824
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-4.123413	3.251678	.801	-13.61524	5.36841
		Mpohor Adansi(MA)	-6.003889	3.539127	.538	-16.33480	4.32702
		Mpohor Motorway(MM)	-5.850556	3.539127	.566	-16.18146	4.48035
		Mpohor Adawotwe (ADW)	-4.370556	3.539127	.818	-14.70146	5.96035
		control	-33.430556*	6.312972	.000	-51.85847	-15.00264
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	1.880476	3.422292	.994	-8.10938	11.87034
		Adum Tokoro(ADT)	6.003889	3.539127	.538	-4.32702	16.33480
		Mpohor Motorway(MM)	.153333	3.696498	1.000	-10.63695	10.94362
		Mpohor Adawotwe (ADW)	1.633333	3.696498	.998	-9.15695	12.42362
		control	-27.426667*	6.402522	.001	-46.11598	-8.73735
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	1.727143	3.422292	.996	-8.26272	11.71700
		Adum Tokoro(ADT)	5.850556	3.539127	.566	-4.48035	16.18146
		Mpohor Adansi(MA)	-.153333	3.696498	1.000	-10.94362	10.63695
		Mpohor Adawotwe (ADW)	1.480000	3.696498	.999	-9.31028	12.27028
		control	-27.580000*	6.402522	.001	-46.26932	-8.89068
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.247143	3.422292	1.000	-9.74272	10.23700
		Adum Tokoro(ADT)	4.370556	3.539127	.818	-5.96035	14.70146
		Mpohor Adansi(MA)	-1.633333	3.696498	.998	-12.42362	9.15695
		Mpohor Motorway(MM)	-1.480000	3.696498	.999	-12.27028	9.31028
		control	-29.060000*	6.402522	.000	-47.74932	-10.37068
	control	Asowuo Ayipa(ASA)	29.307143*	6.248222	.000	11.06824	47.54605
		Adum Tokoro(ADT)	33.430556*	6.312972	.000	15.00264	51.85847
		Mpohor Adansi(MA)	27.426667*	6.402522	.001	8.73735	46.11598

		Mpohor Motorway(MM)	27.580000*	6.402522	.001	8.89068	46.26932
		Mpohor Adawotwe (ADW)	29.060000*	6.402522	.000	10.37068	47.74932
Nickel	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.135159*	.044295	.035	-.26446	-.00586
		Mpohor Adansi(MA)	.063619	.046619	.748	-.07246	.19970
		Mpohor Motorway(MM)	.038286	.046619	.963	-.09780	.17437
		Mpohor Adawotwe (ADW)	.046952	.046619	.914	-.08913	.18304
		control	.414286*	.085114	.000	.16583	.66274
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.135159*	.044295	.035	.00586	.26446
		Mpohor Adansi(MA)	.198778*	.048211	.001	.05805	.33951
		Mpohor Motorway(MM)	.173444*	.048211	.007	.03271	.31417
		Mpohor Adawotwe (ADW)	.182111*	.048211	.004	.04138	.32284
		control	.549444*	.085996	.000	.29842	.80047
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.063619	.046619	.748	-.19970	.07246
		Adum Tokoro(ADT)	-.198778*	.048211	.001	-.33951	-.05805
		Mpohor Motorway(MM)	-.025333	.050354	.996	-.17232	.12165
		Mpohor Adawotwe (ADW)	-.016667	.050354	.999	-.16365	.13032
		control	.350667*	.087216	.002	.09608	.60526
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.038286	.046619	.963	-.17437	.09780
		Adum Tokoro(ADT)	-.173444*	.048211	.007	-.31417	-.03271
		Mpohor Adansi(MA)	.025333	.050354	.996	-.12165	.17232
		Mpohor Adawotwe (ADW)	.008667	.050354	1.000	-.13832	.15565
		control	.376000*	.087216	.001	.12141	.63059
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.046952	.046619	.914	-.18304	.08913
		Adum Tokoro(ADT)	-.182111*	.048211	.004	-.32284	-.04138
		Mpohor Adansi(MA)	.016667	.050354	.999	-.13032	.16365
		Mpohor Motorway(MM)	-.008667	.050354	1.000	-.15565	.13832
		control	.367333*	.087216	.001	.11274	.62192
	control	Asowuo Ayipa(ASA)	-.414286*	.085114	.000	-.66274	-.16583
		Adum Tokoro(ADT)	-.549444*	.085996	.000	-.80047	-.29842
		Mpohor Adansi(MA)	-.350667*	.087216	.002	-.60526	-.09608
		Mpohor Motorway(MM)	-.376000*	.087216	.001	-.63059	-.12141
		Mpohor Adawotwe (ADW)	-.367333*	.087216	.001	-.62192	-.11274
Cobalt	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.677778	.406682	.558	-1.86491	.50935
		Mpohor Adansi(MA)	.080000	.428021	1.000	-1.16942	1.32942
		Mpohor Motorway(MM)	.553333	.428021	.788	-.69608	1.80275
		Mpohor Adawotwe (ADW)	-.086667	.428021	1.000	-1.33608	1.16275
		control	5.752333*	.781455	.000	3.47122	8.03344

	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.677778	.406682	.558	-.50935	1.86491
		Mpohor Adansi(MA)	.757778	.442633	.528	-.53429	2.04985
		Mpohor Motorway(MM)	1.231111	.442633	.071	-.06096	2.52318
		Mpohor Adawotwe (ADW)	.591111	.442633	.764	-.70096	1.88318
		control	6.430111*	.789553	.000	4.12536	8.73486
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.080000	.428021	1.000	-1.32942	1.16942
		Adum Tokoro(ADT)	-.757778	.442633	.528	-2.04985	.53429
		Mpohor Motorway(MM)	.473333	.462315	.909	-.87619	1.82286
		Mpohor Adawotwe (ADW)	-.166667	.462315	.999	-1.51619	1.18286
		control	5.672333*	.800753	.000	3.33489	8.00978
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.553333	.428021	.788	-1.80275	.69608
		Adum Tokoro(ADT)	-1.231111	.442633	.071	-2.52318	.06096
		Mpohor Adansi(MA)	-.473333	.462315	.909	-1.82286	.87619
		Mpohor Adawotwe (ADW)	-.640000	.462315	.736	-1.98952	.70952
		control	5.199000*	.800753	.000	2.86156	7.53644
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.086667	.428021	1.000	-1.16275	1.33608
		Adum Tokoro(ADT)	-.591111	.442633	.764	-1.88318	.70096
		Mpohor Adansi(MA)	.166667	.462315	.999	-1.18286	1.51619
		Mpohor Motorway(MM)	.640000	.462315	.736	-.70952	1.98952
		control	5.839000*	.800753	.000	3.50156	8.17644
	control	Asowuo Ayipa(ASA)	-5.752333*	.781455	.000	-8.03344	-3.47122
		Adum Tokoro(ADT)	-6.430111*	.789553	.000	-8.73486	-4.12536
		Mpohor Adansi(MA)	-5.672333*	.800753	.000	-8.00978	-3.33489
		Mpohor Motorway(MM)	-5.199000*	.800753	.000	-7.53644	-2.86156
		Mpohor Adawotwe (ADW)	-5.839000*	.800753	.000	-8.17644	-3.50156
Copper	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	.008492	.032933	1.000	-.08764	.10462
		Mpohor Adansi(MA)	.013048	.034661	.999	-.08813	.11422
		Mpohor Motorway(MM)	.003714	.034661	1.000	-.09746	.10489
		Mpohor Adawotwe (ADW)	.021048	.034661	.990	-.08013	.12222
		control	.677381*	.063281	.000	.49266	.86210
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-.008492	.032933	1.000	-.10462	.08764
		Mpohor Adansi(MA)	.004556	.035844	1.000	-.10007	.10919
		Mpohor Motorway(MM)	-.004778	.035844	1.000	-.10941	.09985
		Mpohor Adawotwe (ADW)	.012556	.035844	.999	-.09207	.11719
		control	.668889*	.063937	.000	.48225	.85553
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.013048	.034661	.999	-.11422	.08813
		Adum Tokoro(ADT)	-.004556	.035844	1.000	-.10919	.10007

		Mpohor Motorway(MM)	-.009333	.037438	1.000	-.11862	.09995
		Mpohor Adawotwe (ADW)	.008000	.037438	1.000	-.10128	.11728
		control	.664333*	.064844	.000	.47505	.85362
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.003714	.034661	1.000	-.10489	.09746
		Adum Tokoro(ADT)	.004778	.035844	1.000	-.09985	.10941
		Mpohor Adansi(MA)	.009333	.037438	1.000	-.09995	.11862
		Mpohor Adawotwe (ADW)	.017333	.037438	.997	-.09195	.12662
		control	.673667*	.064844	.000	.48438	.86295
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.021048	.034661	.990	-.12222	.08013
		Adum Tokoro(ADT)	-.012556	.035844	.999	-.11719	.09207
		Mpohor Adansi(MA)	-.008000	.037438	1.000	-.11728	.10128
		Mpohor Motorway(MM)	-.017333	.037438	.997	-.12662	.09195
		control	.656333*	.064844	.000	.46705	.84562
	control	Asowuo Ayipa(ASA)	-.677381*	.063281	.000	-.86210	-.49266
		Adum Tokoro(ADT)	-.668889*	.063937	.000	-.85553	-.48225
		Mpohor Adansi(MA)	-.664333*	.064844	.000	-.85362	-.47505
		Mpohor Motorway(MM)	-.673667*	.064844	.000	-.86295	-.48438
		Mpohor Adawotwe (ADW)	-.656333*	.064844	.000	-.84562	-.46705
Lead	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.114119	.131964	.954	-.49933	.27109
		Mpohor Adansi(MA)	.060914	.138888	.998	-.34451	.46634
		Mpohor Motorway(MM)	.043714	.138888	1.000	-.36171	.44914
		Mpohor Adawotwe (ADW)	-.013619	.138888	1.000	-.41904	.39180
		control	1.188714*	.253574	.000	.44852	1.92891
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.114119	.131964	.954	-.27109	.49933
		Mpohor Adansi(MA)	.175033	.143629	.827	-.24423	.59430
		Mpohor Motorway(MM)	.157833	.143629	.880	-.26143	.57710
		Mpohor Adawotwe (ADW)	.100500	.143629	.981	-.31876	.51976
		control	1.302833*	.256201	.000	.55497	2.05070
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.060914	.138888	.998	-.46634	.34451
		Adum Tokoro(ADT)	-.175033	.143629	.827	-.59430	.24423
		Mpohor Motorway(MM)	-.017200	.150016	1.000	-.45511	.42071
		Mpohor Adawotwe (ADW)	-.074533	.150016	.996	-.51244	.36337
		control	1.127800*	.259836	.001	.36933	1.88627
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.043714	.138888	1.000	-.44914	.36171
		Adum Tokoro(ADT)	-.157833	.143629	.880	-.57710	.26143
		Mpohor Adansi(MA)	.017200	.150016	1.000	-.42071	.45511
		Mpohor Adawotwe (ADW)	-.057333	.150016	.999	-.49524	.38057

		control	1.145000*	.259836	.000	.38653	1.90347
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.013619	.138888	1.000	-.39180	.41904
		Adum Tokoro(ADT)	-.100500	.143629	.981	-.51976	.31876
		Mpohor Adansi(MA)	.074533	.150016	.996	-.36337	.51244
		Mpohor Motorway(MM)	.057333	.150016	.999	-.38057	.49524
		control	1.202333*	.259836	.000	.44386	1.96081
	control	Asowuo Ayipa(ASA)	-1.188714*	.253574	.000	-1.92891	-.44852
		Adum Tokoro(ADT)	-1.302833*	.256201	.000	-2.05070	-.55497
		Mpohor Adansi(MA)	-1.127800*	.259836	.001	-1.88627	-.36933
		Mpohor Motorway(MM)	-1.145000*	.259836	.000	-1.90347	-.38653
		Mpohor Adawotwe (ADW)	-1.202333*	.259836	.000	-1.96081	-.44386
Chromium	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.053365	.046301	.858	-.18852	.08179
		Mpohor Adansi(MA)	.026190	.048730	.994	-.11606	.16844
		Mpohor Motorway(MM)	-.006476	.048730	1.000	-.14872	.13577
		Mpohor Adawotwe (ADW)	.056190	.048730	.857	-.08606	.19844
		Control	.627857*	.088969	.000	.36815	.88756
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.053365	.046301	.858	-.08179	.18852
		Mpohor Adansi(MA)	.079556	.050394	.615	-.06755	.22666
		Mpohor Motorway(MM)	.046889	.050394	.937	-.10021	.19399
		Mpohor Adawotwe (ADW)	.109556	.050394	.261	-.03755	.25666
		Control	.681222*	.089891	.000	.41883	.94362
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.026190	.048730	.994	-.16844	.11606
		Adum Tokoro(ADT)	-.079556	.050394	.615	-.22666	.06755
		Mpohor Motorway(MM)	-.032667	.052635	.989	-.18631	.12098
		Mpohor Adawotwe (ADW)	.030000	.052635	.993	-.12364	.18364
		Control	.601667*	.091166	.000	.33555	.86779
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	.006476	.048730	1.000	-.13577	.14872
		Adum Tokoro(ADT)	-.046889	.050394	.937	-.19399	.10021
		Mpohor Adansi(MA)	.032667	.052635	.989	-.12098	.18631
		Mpohor Adawotwe (ADW)	.062667	.052635	.840	-.09098	.21631
		Control	.634333*	.091166	.000	.36821	.90045
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.056190	.048730	.857	-.19844	.08606
		Adum Tokoro(ADT)	-.109556	.050394	.261	-.25666	.03755
		Mpohor Adansi(MA)	-.030000	.052635	.993	-.18364	.12364
		Mpohor Motorway(MM)	-.062667	.052635	.840	-.21631	.09098
		Control	.571667*	.091166	.000	.30555	.83779
	control	Asowuo Ayipa(ASA)	-.627857*	.088969	.000	-.88756	-.36815

		Adum Tokoro(ADT)	-.681222*	.089891	.000	-.94362	-.41883
		Mpohor Adansi(MA)	-.601667*	.091166	.000	-.86779	-.33555
		Mpohor Motorway(MM)	-.634333*	.091166	.000	-.90045	-.36821
		Mpohor Adawotwe (ADW)	-.571667*	.091166	.000	-.83779	-.30555
Cadmium	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	1.489683	2.506360	.991	-5.82652	8.80589
		Mpohor Adansi(MA)	-.564762	2.637868	1.000	-8.26484	7.13532
		Mpohor Motorway(MM)	-2.611429	2.637868	.920	-10.31151	5.08865
		Mpohor Adawotwe (ADW)	.615238	2.637868	1.000	-7.08484	8.31532
		Control	32.228571*	4.816066	.000	18.17021	46.28693
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-1.489683	2.506360	.991	-8.80589	5.82652
		Mpohor Adansi(MA)	-2.054444	2.727923	.974	-10.01740	5.90851
		Mpohor Motorway(MM)	-4.101111	2.727923	.663	-12.06407	3.86185
		Mpohor Adawotwe (ADW)	-.874444	2.727923	1.000	-8.83740	7.08851
		Control	30.738889*	4.865975	.000	16.53484	44.94294
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.564762	2.637868	1.000	-7.13532	8.26484
		Adum Tokoro(ADT)	2.054444	2.727923	.974	-5.90851	10.01740
		Mpohor Motorway(MM)	-2.046667	2.849223	.979	-10.36371	6.27037
		Mpohor Adawotwe (ADW)	1.180000	2.849223	.998	-7.13704	9.49704
		Control	32.793333*	4.934999	.000	18.38780	47.19887
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	2.611429	2.637868	.920	-5.08865	10.31151
		Adum Tokoro(ADT)	4.101111	2.727923	.663	-3.86185	12.06407
		Mpohor Adansi(MA)	2.046667	2.849223	.979	-6.27037	10.36371
		Mpohor Adawotwe (ADW)	3.226667	2.849223	.866	-5.09037	11.54371
		Control	34.840000*	4.934999	.000	20.43446	49.24554
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.615238	2.637868	1.000	-8.31532	7.08484
		Adum Tokoro(ADT)	.874444	2.727923	1.000	-7.08851	8.83740
		Mpohor Adansi(MA)	-1.180000	2.849223	.998	-9.49704	7.13704
		Mpohor Motorway(MM)	-3.226667	2.849223	.866	-11.54371	5.09037
		Control	31.613333*	4.934999	.000	17.20780	46.01887
	control	Asowuo Ayipa(ASA)	-32.228571*	4.816066	.000	-46.28693	-18.17021
		Adum Tokoro(ADT)	-30.738889*	4.865975	.000	-44.94294	-16.53484
		Mpohor Adansi(MA)	-32.793333*	4.934999	.000	-47.19887	-18.38780
		Mpohor Motorway(MM)	-34.840000*	4.934999	.000	-49.24554	-20.43446
		Mpohor Adawotwe (ADW)	-31.613333*	4.934999	.000	-46.01887	-17.20780
Mecury	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.678730	.269285	.130	-1.46479	.10733
		Mpohor Adansi(MA)	.143048	.283415	.996	-.68426	.97035
		Mpohor Motorway(MM)	.149714	.283415	.995	-.67759	.97702

		Mpohor Adawotwe (ADW)	.003048	.283415	1.000	-.82426	.83035
		Control	5.709048*	.517442	.000	4.19861	7.21949
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.678730	.269285	.130	-.10733	1.46479
		Mpohor Adansi(MA)	.821778	.293090	.067	-.03377	1.67732
		Mpohor Motorway(MM)	.828444	.293090	.063	-.02710	1.68399
		Mpohor Adawotwe (ADW)	.681778	.293090	.196	-.17377	1.53732
		Control	6.387778*	.522804	.000	4.86168	7.91387
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.143048	.283415	.996	-.97035	.68426
		Adum Tokoro(ADT)	-.821778	.293090	.067	-1.67732	.03377
		Mpohor Motorway(MM)	.006667	.306123	1.000	-.88692	.90026
		Mpohor Adawotwe (ADW)	-.140000	.306123	.997	-1.03359	.75359
		Control	5.566000*	.530220	.000	4.01826	7.11374
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.149714	.283415	.995	-.97702	.67759
		Adum Tokoro(ADT)	-.828444	.293090	.063	-1.68399	.02710
		Mpohor Adansi(MA)	-.006667	.306123	1.000	-.90026	.88692
		Mpohor Adawotwe (ADW)	-.146667	.306123	.997	-1.04026	.74692
		Control	5.559333*	.530220	.000	4.01159	7.10708
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.003048	.283415	1.000	-.83035	.82426
		Adum Tokoro(ADT)	-.681778	.293090	.196	-1.53732	.17377
		Mpohor Adansi(MA)	.140000	.306123	.997	-.75359	1.03359
		Mpohor Motorway(MM)	.146667	.306123	.997	-.74692	1.04026
		Control	5.706000*	.530220	.000	4.15826	7.25374
	control	Asowuo Ayipa(ASA)	-5.709048*	.517442	.000	-7.21949	-4.19861
		Adum Tokoro(ADT)	-6.387778*	.522804	.000	-7.91387	-4.86168
		Mpohor Adansi(MA)	-5.566000*	.530220	.000	-7.11374	-4.01826
		Mpohor Motorway(MM)	-5.559333*	.530220	.000	-7.10708	-4.01159
		Mpohor Adawotwe (ADW)	-5.706000*	.530220	.000	-7.25374	-4.15826
Arsenic	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.330159	.237869	.734	-1.02451	.36419
		Mpohor Adansi(MA)	-.065714	.250350	1.000	-.79650	.66507
		Mpohor Motorway(MM)	.240952	.250350	.928	-.48983	.97174
		Mpohor Adawotwe (ADW)	-.132381	.250350	.995	-.86317	.59840
		Control	5.514286*	.457074	.000	4.18006	6.84851
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.330159	.237869	.734	-.36419	1.02451
		Mpohor Adansi(MA)	.264444	.258896	.909	-.49129	1.02018
		Mpohor Motorway(MM)	.571111	.258896	.246	-.18462	1.32684
		Mpohor Adawotwe (ADW)	.197778	.258896	.973	-.55795	.95351
		Control	5.844444*	.461810	.000	4.49639	7.19249

	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.065714	.250350	1.000	-.66507	.79650
		Adum Tokoro(ADT)	-.264444	.258896	.909	-1.02018	.49129
		Mpohor Motorway(MM)	.306667	.270408	.866	-.48267	1.09600
		Mpohor Adawotwe (ADW)	-.066667	.270408	1.000	-.85600	.72267
		Control	5.580000*	.468361	.000	4.21283	6.94717
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.240952	.250350	.928	-.97174	.48983
		Adum Tokoro(ADT)	-.571111	.258896	.246	-1.32684	.18462
		Mpohor Adansi(MA)	-.306667	.270408	.866	-1.09600	.48267
		Mpohor Adawotwe (ADW)	-.373333	.270408	.738	-1.16267	.41600
		Control	5.273333*	.468361	.000	3.90616	6.64051
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.132381	.250350	.995	-.59840	.86317
		Adum Tokoro(ADT)	-.197778	.258896	.973	-.95351	.55795
		Mpohor Adansi(MA)	.066667	.270408	1.000	-.72267	.85600
		Mpohor Motorway(MM)	.373333	.270408	.738	-.41600	1.16267
		Control	5.646667*	.468361	.000	4.27949	7.01384
	control	Asowuo Ayipa(ASA)	-5.514286*	.457074	.000	-6.84851	-4.18006
		Adum Tokoro(ADT)	-5.844444*	.461810	.000	-7.19249	-4.49639
		Mpohor Adansi(MA)	-5.580000*	.468361	.000	-6.94717	-4.21283
		Mpohor Motorway(MM)	-5.273333*	.468361	.000	-6.64051	-3.90616
		Mpohor Adawotwe (ADW)	-5.646667*	.468361	.000	-7.01384	-4.27949
% Silt	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	5.73810*	1.69799	.014	.7816	10.6946
		Mpohor Adansi(MA)	1.17143	1.78709	.986	-4.0452	6.3880
		Mpohor Motorway(MM)	.50476	1.78709	1.000	-4.7118	5.7214
		Mpohor Adawotwe (ADW)	.37143	1.78709	1.000	-4.8452	5.5880
		Control	-7.42857	3.26276	.216	-16.9527	2.0956
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-5.73810*	1.69799	.014	-10.6946	-.7816
		Mpohor Adansi(MA)	-4.56667	1.84810	.145	-9.9614	.8280
		Mpohor Motorway(MM)	-5.23333	1.84810	.063	-10.6280	.1614
		Mpohor Adawotwe (ADW)	-5.36667	1.84810	.052	-10.7614	.0280
		Control	-13.16667*	3.29657	.002	-22.7895	-3.5438
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-1.17143	1.78709	.986	-6.3880	4.0452
		Adum Tokoro(ADT)	4.56667	1.84810	.145	-.8280	9.9614
		Mpohor Motorway(MM)	-.66667	1.93027	.999	-6.3012	4.9679
		Mpohor Adawotwe (ADW)	-.80000	1.93027	.998	-6.4346	4.8346
		Control	-8.60000	3.34333	.116	-18.3594	1.1594
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.50476	1.78709	1.000	-5.7214	4.7118
		Adum Tokoro(ADT)	5.23333	1.84810	.063	-.1614	10.6280

		Mpohor Adansi(MA)	.66667	1.93027	.999	-4.9679	6.3012
		Mpohor Adawotwe (ADW)	-.13333	1.93027	1.000	-5.7679	5.5012
		Control	-7.93333	3.34333	.178	-17.6927	1.8260
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.37143	1.78709	1.000	-5.5880	4.8452
		Adum Tokoro(ADT)	5.36667	1.84810	.052	-.0280	10.7614
		Mpohor Adansi(MA)	.80000	1.93027	.998	-4.8346	6.4346
		Mpohor Motorway(MM)	.13333	1.93027	1.000	-5.5012	5.7679
		Control	-7.80000	3.34333	.193	-17.5594	1.9594
	control	Asowuo Ayipa(ASA)	7.42857	3.26276	.216	-2.0956	16.9527
		Adum Tokoro(ADT)	13.16667*	3.29657	.002	3.5438	22.7895
		Mpohor Adansi(MA)	8.60000	3.34333	.116	-1.1594	18.3594
		Mpohor Motorway(MM)	7.93333	3.34333	.178	-1.8260	17.6927
		Mpohor Adawotwe (ADW)	7.80000	3.34333	.193	-1.9594	17.5594
% clay	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-9.90476*	2.46465	.002	-17.0992	-2.7103
		Mpohor Adansi(MA)	-.63810	2.59397	1.000	-8.2100	6.9339
		Mpohor Motorway(MM)	-1.17143	2.59397	.998	-8.7434	6.4005
		Mpohor Adawotwe (ADW)	-.50476	2.59397	1.000	-8.0767	7.0672
		Control	13.06190	4.73592	.075	-.7625	26.8863
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	9.90476*	2.46465	.002	2.7103	17.0992
		Mpohor Adansi(MA)	9.26667*	2.68253	.011	1.4362	17.0971
		Mpohor Motorway(MM)	8.73333*	2.68253	.020	.9029	16.5638
		Mpohor Adawotwe (ADW)	9.40000*	2.68253	.009	1.5696	17.2304
		Control	22.96667*	4.78500	.000	8.9990	36.9343
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.63810	2.59397	1.000	-6.9339	8.2100
		Adum Tokoro(ADT)	-9.26667*	2.68253	.011	-17.0971	-1.4362
		Mpohor Motorway(MM)	-.53333	2.80181	1.000	-8.7120	7.6453
		Mpohor Adawotwe (ADW)	.13333	2.80181	1.000	-8.0453	8.3120
		Control	13.70000	4.85288	.064	-.4658	27.8658
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	1.17143	2.59397	.998	-6.4005	8.7434
		Adum Tokoro(ADT)	-8.73333*	2.68253	.020	-16.5638	-.9029
		Mpohor Adansi(MA)	.53333	2.80181	1.000	-7.6453	8.7120
		Mpohor Adawotwe (ADW)	.66667	2.80181	1.000	-7.5120	8.8453
		Control	14.23333*	4.85288	.048	.0675	28.3991
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.50476	2.59397	1.000	-7.0672	8.0767
		Adum Tokoro(ADT)	-9.40000*	2.68253	.009	-17.2304	-1.5696
		Mpohor Adansi(MA)	-.13333	2.80181	1.000	-8.3120	8.0453
		Mpohor Motorway(MM)	-.66667	2.80181	1.000	-8.8453	7.5120

		Control	13.56667	4.85288	.068	-.5991	27.7325
	control	Asowuo Ayipa(ASA)	-13.06190	4.73592	.075	-26.8863	.7625
		Adum Tokoro(ADT)	-22.96667*	4.78500	.000	-36.9343	-8.9990
		Mpohor Adansi(MA)	-13.70000	4.85288	.064	-27.8658	.4658
		Mpohor Motorway(MM)	-14.23333*	4.85288	.048	-28.3991	-.0675
		Mpohor Adawotwe (ADW)	-13.56667	4.85288	.068	-27.7325	.5991
% sand	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	1.40476	2.08307	.984	-4.6758	7.4854
		Mpohor Adansi(MA)	-.62857	2.19237	1.000	-7.0282	5.7711
		Mpohor Motorway(MM)	.30476	2.19237	1.000	-6.0949	6.7044
		Mpohor Adawotwe (ADW)	.97143	2.19237	.998	-5.4282	7.3711
		Control	-12.22857*	4.00270	.035	-23.9127	-.5445
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-1.40476	2.08307	.984	-7.4854	4.6758
		Mpohor Adansi(MA)	-2.03333	2.26722	.946	-8.6515	4.5848
		Mpohor Motorway(MM)	-1.10000	2.26722	.997	-7.7181	5.5181
		Mpohor Adawotwe (ADW)	-.43333	2.26722	1.000	-7.0515	6.1848
		Control	-13.63333*	4.04418	.014	-25.4385	-1.8281
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.62857	2.19237	1.000	-5.7711	7.0282
		Adum Tokoro(ADT)	2.03333	2.26722	.946	-4.5848	8.6515
		Mpohor Motorway(MM)	.93333	2.36803	.999	-5.9791	7.8457
		Mpohor Adawotwe (ADW)	1.60000	2.36803	.984	-5.3124	8.5124
		Control	-11.60000	4.10155	.063	-23.5726	.3726
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.30476	2.19237	1.000	-6.7044	6.0949
		Adum Tokoro(ADT)	1.10000	2.26722	.997	-5.5181	7.7181
		Mpohor Adansi(MA)	-.93333	2.36803	.999	-7.8457	5.9791
		Mpohor Adawotwe (ADW)	.66667	2.36803	1.000	-6.2457	7.5791
		Control	-12.53333*	4.10155	.035	-24.5060	-.5607
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.97143	2.19237	.998	-7.3711	5.4282
		Adum Tokoro(ADT)	.43333	2.26722	1.000	-6.1848	7.0515
		Mpohor Adansi(MA)	-1.60000	2.36803	.984	-8.5124	5.3124
		Mpohor Motorway(MM)	-.66667	2.36803	1.000	-7.5791	6.2457
		Control	-13.20000*	4.10155	.022	-25.1726	-1.2274
	control	Asowuo Ayipa(ASA)	12.22857*	4.00270	.035	.5445	23.9127
		Adum Tokoro(ADT)	13.63333*	4.04418	.014	1.8281	25.4385
		Mpohor Adansi(MA)	11.60000	4.10155	.063	-.3726	23.5726
		Mpohor Motorway(MM)	12.53333*	4.10155	.035	.5607	24.5060
		Mpohor Adawotwe (ADW)	13.20000*	4.10155	.022	1.2274	25.1726
Moisture content	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.30738*	.09535	.022	-.5857	-.0291

		Mpohor Adansi(MA)	.09229	.10035	.940	-.2006	.3852
		Mpohor Motorway(MM)	-.08105	.10035	.965	-.3740	.2119
		Mpohor Adawotwe (ADW)	.11895	.10035	.843	-.1740	.4119
		Control	-2.90238*	.18321	.000	-3.4372	-2.3676
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.30738*	.09535	.022	.0291	.5857
		Mpohor Adansi(MA)	.39967*	.10377	.003	.0967	.7026
		Mpohor Motorway(MM)	.22633	.10377	.258	-.0766	.5293
		Mpohor Adawotwe (ADW)	.42633*	.10377	.001	.1234	.7293
		Control	-2.59500*	.18511	.000	-3.1353	-2.0547
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.09229	.10035	.940	-.3852	.2006
		Adum Tokoro(ADT)	-.39967*	.10377	.003	-.7026	-.0967
		Mpohor Motorway(MM)	-.17333	.10839	.601	-.4897	.1431
		Mpohor Adawotwe (ADW)	.02667	.10839	1.000	-.2897	.3431
		Control	-2.99467*	.18773	.000	-3.5427	-2.4467
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	.08105	.10035	.965	-.2119	.3740
		Adum Tokoro(ADT)	-.22633	.10377	.258	-.5293	.0766
		Mpohor Adansi(MA)	.17333	.10839	.601	-.1431	.4897
		Mpohor Adawotwe (ADW)	.20000	.10839	.443	-.1164	.5164
		Control	-2.82133*	.18773	.000	-3.3693	-2.2733
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.11895	.10035	.843	-.4119	.1740
		Adum Tokoro(ADT)	-.42633*	.10377	.001	-.7293	-.1234
		Mpohor Adansi(MA)	-.02667	.10839	1.000	-.3431	.2897
		Mpohor Motorway(MM)	-.20000	.10839	.443	-.5164	.1164
		Control	-3.02133*	.18773	.000	-3.5693	-2.4733
	control	Asowuo Ayipa(ASA)	2.90238*	.18321	.000	2.3676	3.4372
		Adum Tokoro(ADT)	2.59500*	.18511	.000	2.0547	3.1353
		Mpohor Adansi(MA)	2.99467*	.18773	.000	2.4467	3.5427
		Mpohor Motorway(MM)	2.82133*	.18773	.000	2.2733	3.3693
		Mpohor Adawotwe (ADW)	3.02133*	.18773	.000	2.4733	3.5693
%organic matter	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.07986	.11838	.984	-.4254	.2657
		Mpohor Adansi(MA)	.00548	.12459	1.000	-.3582	.3692
		Mpohor Motorway(MM)	.08214	.12459	.986	-.2815	.4458
		Mpohor Adawotwe (ADW)	.05748	.12459	.997	-.3062	.4212
		Control	-2.90652*	.22747	.000	-3.5705	-2.2425
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.07986	.11838	.984	-.2657	.4254
		Mpohor Adansi(MA)	.08533	.12884	.986	-.2908	.4614
		Mpohor Motorway(MM)	.16200	.12884	.807	-.2141	.5381

		Mpohor Adawotwe (ADW)	.13733	.12884	.893	-.2388	.5134
		Control	-2.82667*	.22983	.000	-3.4975	-2.1558
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.00548	.12459	1.000	-.3692	.3582
		Adum Tokoro(ADT)	-.08533	.12884	.986	-.4614	.2908
		Mpohor Motorway(MM)	.07667	.13457	.993	-.3162	.4695
		Mpohor Adawotwe (ADW)	.05200	.13457	.999	-.3408	.4448
		Control	-2.91200*	.23309	.000	-3.5924	-2.2316
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.08214	.12459	.986	-.4458	.2815
		Adum Tokoro(ADT)	-.16200	.12884	.807	-.5381	.2141
		Mpohor Adansi(MA)	-.07667	.13457	.993	-.4695	.3162
		Mpohor Adawotwe (ADW)	-.02467	.13457	1.000	-.4175	.3682
		Control	-2.98867*	.23309	.000	-3.6691	-2.3083
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.05748	.12459	.997	-.4212	.3062
		Adum Tokoro(ADT)	-.13733	.12884	.893	-.5134	.2388
		Mpohor Adansi(MA)	-.05200	.13457	.999	-.4448	.3408
		Mpohor Motorway(MM)	.02467	.13457	1.000	-.3682	.4175
		Control	-2.96400*	.23309	.000	-3.6444	-2.2836
	control	Asowuo Ayipa(ASA)	2.90652*	.22747	.000	2.2425	3.5705
		Adum Tokoro(ADT)	2.82667*	.22983	.000	2.1558	3.4975
		Mpohor Adansi(MA)	2.91200*	.23309	.000	2.2316	3.5924
		Mpohor Motorway(MM)	2.98867*	.23309	.000	2.3083	3.6691
		Mpohor Adawotwe (ADW)	2.96400*	.23309	.000	2.2836	3.6444
% organic carbon	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	.19663	.07542	.107	-.0235	.4168
		Mpohor Adansi(MA)	.00552	.07938	1.000	-.2262	.2372
		Mpohor Motorway(MM)	-.01048	.07938	1.000	-.2422	.2212
		Mpohor Adawotwe (ADW)	.00652	.07938	1.000	-.2252	.2382
		Control	-5.08848*	.14492	.000	-5.5115	-4.6654
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-.19663	.07542	.107	-.4168	.0235
		Mpohor Adansi(MA)	-.19111	.08209	.195	-.4307	.0485
		Mpohor Motorway(MM)	-.20711	.08209	.130	-.4467	.0325
		Mpohor Adawotwe (ADW)	-.19011	.08209	.200	-.4297	.0495
		Control	-5.28511*	.14642	.000	-5.7125	-4.8577
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.00552	.07938	1.000	-.2372	.2262
		Adum Tokoro(ADT)	.19111	.08209	.195	-.0485	.4307
		Mpohor Motorway(MM)	-.01600	.08574	1.000	-.2663	.2343
		Mpohor Adawotwe (ADW)	.00100	.08574	1.000	-.2493	.2513
		Control	-5.09400*	.14850	.000	-5.5275	-4.6605

	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	.01048	.07938	1.000	-.2212	.2422
		Adum Tokoro(ADT)	.20711	.08209	.130	-.0325	.4467
		Mpohor Adansi(MA)	.01600	.08574	1.000	-.2343	.2663
		Mpohor Adawotwe (ADW)	.01700	.08574	1.000	-.2333	.2673
		Control	-5.07800*	.14850	.000	-5.5115	-4.6445
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.00652	.07938	1.000	-.2382	.2252
		Adum Tokoro(ADT)	.19011	.08209	.200	-.0495	.4297
		Mpohor Adansi(MA)	-.00100	.08574	1.000	-.2513	.2493
		Mpohor Motorway(MM)	-.01700	.08574	1.000	-.2673	.2333
		Control	-5.09500*	.14850	.000	-5.5285	-4.6615
	control	Asowuo Ayipa(ASA)	5.08848*	.14492	.000	4.6654	5.5115
		Adum Tokoro(ADT)	5.28511*	.14642	.000	4.8577	5.7125
		Mpohor Adansi(MA)	5.09400*	.14850	.000	4.6605	5.5275
		Mpohor Motorway(MM)	5.07800*	.14850	.000	4.6445	5.5115
		Mpohor Adawotwe (ADW)	5.09500*	.14850	.000	4.6615	5.5285
Available phosphorus	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-4.49762*	1.43621	.028	-8.6900	-.3052
		Mpohor Adansi(MA)	-.24762	1.51157	1.000	-4.6600	4.1647
		Mpohor Motorway(MM)	1.83905	1.51157	.828	-2.5733	6.2514
		Mpohor Adawotwe (ADW)	-.39429	1.51157	1.000	-4.8066	4.0181
		Control	-23.01429*	2.75973	.000	-31.0701	-14.9585
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	4.49762*	1.43621	.028	.3052	8.6900
		Mpohor Adansi(MA)	4.25000	1.56317	.083	-.3130	8.8130
		Mpohor Motorway(MM)	6.33667*	1.56317	.002	1.7737	10.8997
		Mpohor Adawotwe (ADW)	4.10333	1.56317	.103	-.4597	8.6663
		Control	-18.51667*	2.78833	.000	-26.6560	-10.3774
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	.24762	1.51157	1.000	-4.1647	4.6600
		Adum Tokoro(ADT)	-4.25000	1.56317	.083	-8.8130	.3130
		Mpohor Motorway(MM)	2.08667	1.63268	.796	-2.6792	6.8526
		Mpohor Adawotwe (ADW)	-.14667	1.63268	1.000	-4.9126	4.6192
		Control	-22.76667*	2.82788	.000	-31.0214	-14.5119
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-1.83905	1.51157	.828	-6.2514	2.5733
		Adum Tokoro(ADT)	-6.33667*	1.56317	.002	-10.8997	-1.7737
		Mpohor Adansi(MA)	-2.08667	1.63268	.796	-6.8526	2.6792
		Mpohor Adawotwe (ADW)	-2.23333	1.63268	.746	-6.9992	2.5326
		Control	-24.85333*	2.82788	.000	-33.1081	-16.5986
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.39429	1.51157	1.000	-4.0181	4.8066
		Adum Tokoro(ADT)	-4.10333	1.56317	.103	-8.6663	.4597

		Mpohor Adansi(MA)	.14667	1.63268	1.000	-4.6192	4.9126
		Mpohor Motorway(MM)	2.23333	1.63268	.746	-2.5326	6.9992
		Control	-22.62000*	2.82788	.000	-30.8748	-14.3652
	control	Asowuo Ayipa(ASA)	23.01429*	2.75973	.000	14.9585	31.0701
		Adum Tokoro(ADT)	18.51667*	2.78833	.000	10.3774	26.6560
		Mpohor Adansi(MA)	22.76667*	2.82788	.000	14.5119	31.0214
		Mpohor Motorway(MM)	24.85333*	2.82788	.000	16.5986	33.1081
		Mpohor Adawotwe (ADW)	22.62000*	2.82788	.000	14.3652	30.8748
Total Nitrogen	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	.00254	.03625	1.000	-.1033	.1084
		Mpohor Adansi(MA)	.00410	.03815	1.000	-.1073	.1155
		Mpohor Motorway(MM)	-.00590	.03815	1.000	-.1173	.1055
		Mpohor Adawotwe (ADW)	.00543	.03815	1.000	-.1059	.1168
		Control	-4.37524*	.06966	.000	-4.5786	-4.1719
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-.00254	.03625	1.000	-.1084	.1033
		Mpohor Adansi(MA)	.00156	.03945	1.000	-.1136	.1167
		Mpohor Motorway(MM)	-.00844	.03945	1.000	-.1236	.1067
		Mpohor Adawotwe (ADW)	.00289	.03945	1.000	-.1123	.1181
		Control	-4.37778*	.07038	.000	-4.5832	-4.1723
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.00410	.03815	1.000	-.1155	.1073
		Adum Tokoro(ADT)	-.00156	.03945	1.000	-.1167	.1136
		Mpohor Motorway(MM)	-.01000	.04121	1.000	-.1303	.1103
		Mpohor Adawotwe (ADW)	.00133	.04121	1.000	-.1190	.1216
		Control	-4.37933*	.07138	.000	-4.5877	-4.1710
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	.00590	.03815	1.000	-.1055	.1173
		Adum Tokoro(ADT)	.00844	.03945	1.000	-.1067	.1236
		Mpohor Adansi(MA)	.01000	.04121	1.000	-.1103	.1303
		Mpohor Adawotwe (ADW)	.01133	.04121	1.000	-.1090	.1316
		Control	-4.36933*	.07138	.000	-4.5777	-4.1610
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	-.00543	.03815	1.000	-.1168	.1059
		Adum Tokoro(ADT)	-.00289	.03945	1.000	-.1181	.1123
		Mpohor Adansi(MA)	-.00133	.04121	1.000	-.1216	.1190
		Mpohor Motorway(MM)	-.01133	.04121	1.000	-.1316	.1090
		Control	-4.38067*	.07138	.000	-4.5890	-4.1723
	control	Asowuo Ayipa(ASA)	4.37524*	.06966	.000	4.1719	4.5786
		Adum Tokoro(ADT)	4.37778*	.07038	.000	4.1723	4.5832
		Mpohor Adansi(MA)	4.37933*	.07138	.000	4.1710	4.5877
		Mpohor Motorway(MM)	4.36933*	.07138	.000	4.1610	4.5777

		Mpohor Adawotwe (ADW)	4.38067*	.07138	.000	4.1723	4.5890
Conductivity	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	.68810	1.79039	.999	-4.5382	5.9144
		Mpohor Adansi(MA)	.27276	1.88434	1.000	-5.2277	5.7732
		Mpohor Motorway(MM)	.07943	1.88434	1.000	-5.4211	5.5799
		Mpohor Adawotwe (ADW)	-.51657	1.88434	1.000	-6.0171	4.9839
		Control	24.16476*	3.44031	.000	14.1223	34.2072
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	-.68810	1.79039	.999	-5.9144	4.5382
		Mpohor Adansi(MA)	-.41533	1.94867	1.000	-6.1036	5.2729
		Mpohor Motorway(MM)	-.60867	1.94867	1.000	-6.2969	5.0796
		Mpohor Adawotwe (ADW)	-1.20467	1.94867	.989	-6.8929	4.4836
		Control	23.47667*	3.47596	.000	13.3301	33.6232
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.27276	1.88434	1.000	-5.7732	5.2277
		Adum Tokoro(ADT)	.41533	1.94867	1.000	-5.2729	6.1036
		Mpohor Motorway(MM)	-.19333	2.03532	1.000	-6.1345	5.7479
		Mpohor Adawotwe (ADW)	-.78933	2.03532	.999	-6.7305	5.1519
		Control	23.89200*	3.52527	.000	13.6015	34.1825
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.07943	1.88434	1.000	-5.5799	5.4211
		Adum Tokoro(ADT)	.60867	1.94867	1.000	-5.0796	6.2969
		Mpohor Adansi(MA)	.19333	2.03532	1.000	-5.7479	6.1345
		Mpohor Adawotwe (ADW)	-.59600	2.03532	1.000	-6.5372	5.3452
		Control	24.08533*	3.52527	.000	13.7949	34.3758
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.51657	1.88434	1.000	-4.9839	6.0171
		Adum Tokoro(ADT)	1.20467	1.94867	.989	-4.4836	6.8929
		Mpohor Adansi(MA)	.78933	2.03532	.999	-5.1519	6.7305
		Mpohor Motorway(MM)	.59600	2.03532	1.000	-5.3452	6.5372
		Control	24.68133*	3.52527	.000	14.3909	34.9718
	control	Asowuo Ayipa(ASA)	-24.16476*	3.44031	.000	-34.2072	-14.1223
		Adum Tokoro(ADT)	-23.47667*	3.47596	.000	-33.6232	-13.3301
		Mpohor Adansi(MA)	-23.89200*	3.52527	.000	-34.1825	-13.6015
		Mpohor Motorway(MM)	-24.08533*	3.52527	.000	-34.3758	-13.7949
		Mpohor Adawotwe (ADW)	-24.68133*	3.52527	.000	-34.9718	-14.3909
pH	Asowuo Ayipa(ASA)	Adum Tokoro(ADT)	-.18492	.16200	.862	-.6578	.2880
		Mpohor Adansi(MA)	.00019	.17050	1.000	-.4975	.4979
		Mpohor Motorway(MM)	.10952	.17050	.987	-.3882	.6072
		Mpohor Adawotwe (ADW)	-.08914	.17050	.995	-.5868	.4085
		control	-2.41048*	.31128	.000	-3.3191	-1.5018
	Adum Tokoro(ADT)	Asowuo Ayipa(ASA)	.18492	.16200	.862	-.2880	.6578

		Mpohor Adansi(MA)	.18511	.17632	.899	-.3296	.6998
		Mpohor Motorway(MM)	.29444	.17632	.555	-.2202	.8091
		Mpohor Adawotwe (ADW)	.09578	.17632	.994	-.4189	.6105
		control	-2.22556*	.31451	.000	-3.1436	-1.3075
	Mpohor Adansi(MA)	Asowuo Ayipa(ASA)	-.00019	.17050	1.000	-.4979	.4975
		Adum Tokoro(ADT)	-.18511	.17632	.899	-.6998	.3296
		Mpohor Motorway(MM)	.10933	.18416	.991	-.4282	.6469
		Mpohor Adawotwe (ADW)	-.08933	.18416	.997	-.6269	.4482
		control	-2.41067*	.31897	.000	-3.3418	-1.4796
	Mpohor Motorway(MM)	Asowuo Ayipa(ASA)	-.10952	.17050	.987	-.6072	.3882
		Adum Tokoro(ADT)	-.29444	.17632	.555	-.8091	.2202
		Mpohor Adansi(MA)	-.10933	.18416	.991	-.6469	.4282
		Mpohor Adawotwe (ADW)	-.19867	.18416	.888	-.7362	.3389
		control	-2.52000*	.31897	.000	-3.4511	-1.5889
	Mpohor Adawotwe (ADW)	Asowuo Ayipa(ASA)	.08914	.17050	.995	-.4085	.5868
		Adum Tokoro(ADT)	-.09578	.17632	.994	-.6105	.4189
		Mpohor Adansi(MA)	.08933	.18416	.997	-.4482	.6269
		Mpohor Motorway(MM)	.19867	.18416	.888	-.3389	.7362
		control	-2.32133*	.31897	.000	-3.2524	-1.3902
	control	Asowuo Ayipa(ASA)	2.41048*	.31128	.000	1.5018	3.3191
		Adum Tokoro(ADT)	2.22556*	.31451	.000	1.3075	3.1436
		Mpohor Adansi(MA)	2.41067*	.31897	.000	1.4796	3.3418
		Mpohor Motorway(MM)	2.52000*	.31897	.000	1.5889	3.4511
		Mpohor Adawotwe (ADW)	2.32133*	.31897	.000	1.3902	3.2524

*. The mean difference is significant at the 0.05 level.

Appendix K : Sampling Sites and the Geographical Coordinates, Mpohor Wassa East

Sampling point	Code	GPS Location Latitude/Longitude
Asowuo Ayipa	ASA 1	N 04^0 58. 324^1 W 001^0 52. 041^1
Asowuo Ayipa	ASA2	N 04^0 58.310^1 W 001^0 52.097^1
Asowuo Ayipa	ASA3	N 04^0 58.313^1 W 001^0 52.150^1
Asowuo Ayipa	ASA4	N 04^0 58.337^1 W 001^0 52.165^1
Asowuo Ayipa	ASA5	N 04^0 58.360^1 W 001^0 52.179^1
Asowuo Ayipa	ASA6	N 04^0 58.199^1 W 001^0 52.175^1
Asowuo Ayipa	ASA7	N 04^0 58.013^1 W 001^0 52.326^1
Adum Tokoro	ADT1	N 04^0 58.639^1 W 001^0 51.893^1
Adum Tokoro	ADT2	N 04^0 58.579^1 W 001^0 51.950^1
Adum Tokoro	ADT3	N 04^0 58.545′ W 001^0 51.995′
Adum Tokoro	ADT4	N 04^0 58.557′ W 001^0 52.033′
Adum Tokoro	ADT5	N 04^0 58.447′ W 001^0 52.067′
Adum Tokoro	ADT6	N 04^0 58.479′ W 001^0 52.107′
Mpohor Adansi	MA1	N 04^0 57.733′ W 001^0 52.572′
Mpohor Adansi	MA2	N 04^0 57.777′ W 001^0 52.591′
Mpohor Adansi	MA3	N 04^0 57.766′ W 001^0 52.523′
Mpohor Adansi	MA4	N 04^0 57.823′ W 001^0 52.483′
Mpohor Adansi	MA5	N 04^0 57.735′ W 001^0 52.668′
Mpohor Motorway	MM1	N 04^0 57.707^1 W 001^0 52.957^1
Mpohor Motorway	MM2	N 04^0 57.665^1 W 001^0 52.879^1
Mpohor Motorway	MM3	N 04^0 57.582^1 W 001^0 52.873^1
Mpohor Motorway	MM4	N 04^0 57.527^1 W 001^0 52.877^1
Mpohor Motorway	MM5	N 04^0 57.798^1 W 001^0 52.975^1
Mpohor Adawotwe	ADW1	N 04^0 58.978^1 W 001^0 53.137^1
Mpohor Adawotwe	ADW2	N 04^0 58.989^1 W 001^0 53.109^1
Mpohor Adawotwe	ADW3	N 04^0 58.996^1 W 001^0 53.070^1
Mpohor Adawotwe	ADW4	N 04^0 59.057^1 W 001^0 53.038^1
Mpohor Adawotwe	ADW5	N 04^0 59.127′ W 001^0 53.093′
Mpohor Anomabo	Control	N 04^0 59.607′ W 001^0 54.443′

Sampling sites and the geographical coordinates at Amansie West

Sampling point	Code	GPS Location Latitude/Longitude
Manso Nkwanta	MN01	N 06^0 29.22′ W01^0 52.561′
Manso Nkwanta	MN02	N 06^0 29.159′ W01^0 52.560′
Manso Nkwanta	MN03	N 06^0 29.107′ W01^0 52.540′
Manso Nkwanta	MN04	N 06^0 29.065′ W01^0 52.515′
Manso Nkwanta	MN05	N 06^0 29.021′ W01^0 52.477′
Water (Manso suben River)	MN	N 06^0 29.043′ W01^0 52.499′
Domenase	DO1	N 06^0 27.555′ W01^0 54.288′
Domenase	DO2	N 06^0 27.418′ W01^0 54.365′
Domenase	DO3	N 06^0 27.473′ W01^0 54.346′
Domenase Suben River	DO	N 06^0 27.555′ W01^0 54.288′
Brofoyedru	BY01	N 06^0 27.430′ W01^0 52.136′
Brofoyedru	BY02	N 06^0 27.389′ W01^0 52.159′
Brofoyedru	BY03	N 06^0 27.375′ W01^0 52.139′
Brofoyedru	BY04	N 06^0 27.357′ W01^0 52.127′
Brofoyedru	BY05	N 06^0 27.340′ W01^0 52.102′
Asaman	AS01	N 06^0 26.263′ W01^0 52.074′
Asaman	AS02	N 06^0 26.246′ W01^0 52.084′
Asaman	AS03	N 06^0 26.281′ W01^0 52.112′
Asaman	AS04	N 06^0 26.304′ W01^0 52.130′
Asaman	AS05	N 06^0 26.273′ W01^0 52.063′
Asaman	AS06	N 06^0 26.300′ W01^0 52.064′
Asaman	AS07	N 06^0 26.328′ W01^0 52.073′
Asaman	AS08	N 06^0 26.344′ W01^0 52.084′
Asaman	AS09	N 06^0 26.352′ W01^0 52.106′
Suben River	AS	N 06^0 26.278′ W01^0 52.037′
Control soil (Manso)	Soil	N 06^0 26.250′ W01^0 49.121′

Appendix L: Questionaire

I am STEPHEN TWUMASI ANNAN, a PhD student at the University of Ghana, Legon. I am conducting research on the Assessment of ecological footprint of artisanal and small-scale gold mining on soil and provision ecosystem services at Mpohor Wassa East and Amansie West District, Ghana. I would be grateful if you could contribute to this research by responding to some questions. Be assured that whatever information you give will be strictly kept confidential.

Name of Community/village …………………………………………………………………..

A. SOCIO – DEMOGRAPHIC BACKGROUND OF RESPONDENTS

1. Sex
   Male [ ]
   Female [ ]
2. Age …………………………………
3. Marital Status
   Single [ ]
   Married [ ]
   Divorced [ ]
   Widow / Widower [ ]
4. Level of Education
   None [ ]
   Basic Level [ ]
   Secondary Level [ ]
   Vocational/Technical [ ]
   Tertiary Level [ ]
5. Family Size
   Small (2 – 4) [ ]
   Medium (5 – 6) [ ]
   Large (7 and above) [ ]

B. MIGRATION, EMPLOYMENT AND INCOME

6. Are you a native of this community
   Yes [ ]
   No [ ]

(If yes to question 6, proceed to question 9. if no to question 6 continue the questions)

7. If no, where do you come from?
   Town/village...……………………… District………………………………

   Region……………………………….. Country…………………………….

8. Reasons for moving to this community?
   ………………………………………………………………………………
   ………………………………………………………………………………
9. What is your previous occupation? Trader [ ] Farmer [ ] Fisherman [ ]
   Other, specify………………………………………………………………….

10. What work do you do now? ………………………………………………….
11. Which other activities do you undertake to get income?

    Food crop farming [ ]

    Cocoa farming [ ]

    Livestock farming [ ]

    Others …………………….

12. If others specify: ………………………………………………………………...
13. How long have you engaged in your main occupation in the community

    Less than 1 yr [ ]

    1 – 3 yrs [ ]

    4 – 6 yrs above [ ]

14. How is the cost of living in your community?

    Low [ ]
    Moderate [ ]

    High [ ]

    Very high [ ]

15. If high / very high why
    ………………………………………………………………………………
    ………………………………………………………………………………
    ………………………………………………………………………………

16. Do you have any knowledge about small-scale gold mining?

    Yes [ ]

    No [ ]

17. If yes, what kind of knowledge? ……………………………………………
18. Do you do mining

    Yes [ ]
    No [ ]

19. Which type of mining Small – Scale ("Galamsey") [ ]

Large Scale (Mining Company) [ ]

C. Mention any five (5) common ailments that normally affect people in this community:

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

20. Are there some accidents/injuries during the mining? Yes [ ]
No [ ]

21. If yes, what type (s) of injuries/accidents have you witnessed or experienced?
…………………………………………………………………………………………

D. ASSESSMENT OF SOIL, BIODIVERSITY AND WATER QUALITY.

22. Has your farm land been destroyed/ reduced by the activities of these miners?

Yes [ ]

No [ ]

23. Do you get access to farmland?

Yes [ ]

No [ ]

24. What is the state of the farmland in the community?

…………………………………………………….....................................
………………………………………………………………………………..

25. Has your farm land been degraded?

Yes [ ]

No [ ]

26. What indication shows that your farm land has been degraded?

……………………………………………………………………………….
………………………………………………………………………………

27. Has the forest been destroyed by the activities of these small-scale miners?

Yes [ ]

No [ ]

28. Can you name any medicinal plant that was common in the environment but cannot be seen again? ………………………………………………………………………………

29. What species of animals/fish used to be seen but cannot be seen in the environment?
……………………………………………………………………………….

30. Do you use chemicals in your mining? Yes [ ]
No [ ]

31. If yes, mention the type of chemicals you frequently use, where do you obtain them, how and where do you dispose of your waste?

Type of chemical	Frequency of use	Sources	Mode of disposal	Site of disposal

32. Indicate the sources of water to the people of your community over the past 5 years.

Type of facility	Last year	2 years ago	3 years ago	4 years ago	5 years ago
Pond					
River					
Well					
Bore-hole					
Pipe-borne water					

33. Do you think mining activities affect the water quality? Yes [ ]
No [ ]

34. If yes, how do these affect the quality of your water? Colour [ ]
Taste [ ]
Scent [ ]
Others [ ]

35. Has the activities of these small-scale gold miners affected the taste of the water?
Yes [ ]
No [ ]

36. How has the taste been affected?

……………………………………………………………………………..

37.Has the mining activities affected the colour of the water?
Yes [ ]
No [ ]

38. How has the colour of the water been affected by the activities of the small-scale gold miners?

………………………………………………………………………………………….

E. CONCERNS

39. What are some of the problems you face living in this small-scale mining area?
    a. ………………………………………………………………………..
    b. ………………………………………………………………………..
    c. ………………………………………………………………………..
    d. ………………………………………………………………………..
40. What suggestions do you have for improvements
    a. ………………………………………………………………………..
    b. ………………………………………………………………………..
    c. ………………………………………………………………………..
    d. ………………………………………………………………………..

Thank you for your cooperation!!!

Appendix M: Ethical Clearance

UNIVERSITY OF GHANA

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)

P. O. Box LG 1195, Legon-Accra

Ref. No: ECBAS 042/19-20

2nd March, 2020

Mr. Stephen Twumasi Annan
Institute for Environment
and Sanitation Studies
University of Ghana
Legon, Accra

Dear Mr. Annan,

ECBAS 042/19-20: ASSESSMENT OF SMALL SCALE AND ARTISANAL GOLDMINING FOOTPRINTS ON THE ENVIRONMENT, GHANA

This is to inform you that the above reference study has been presented to the Ethics Committee for Basic and Applied Sciences for a full board review and the following actions taken subject to the conditions and explanation provided below:

Expiry Date:	11/03/2021
On Agenda for:	Initial Submission
Date of Submission:	12/12/2019
ECBAS Action:	Approved
Reporting:	Quarterly

Please accept my congratulations.

Yours sincerely,

Professor Daniel Bruce Sarpong
ECBAS Chairperson

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES
APPROVED
0 2 MAR 2020
UNIVERSITY OF GHANA