MASTERS THESIS

NATURAL RESOURCE MANAGEMENT AND DEVELOPMENT (NRM)

TH KÖLN (UNIVERSITY OF APPLIED SCIENCES)

ITT - INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUB-TROPICS

<u>TITLE</u>:

ILLEGAL GOLD MINING AND WATER QUALITY; A CASE STUDY OF RIVER OFFIN IN THE CENTRAL REGION OF GHANA

RICHARD BOAMAH, ADU

2018

ITT
Institute for Technology and Resources Management in the Tropics and Subtropics

Technology Arts Sciences
TH Köln

ILLEGAL GOLD MINING AND WATER QUALITY; A CASE STUDY OF RIVER OFFIN IN THE CENTRAL REGION OF GHANA

A THESIS SUBMITTED TO THE INSTITUTE OF TECHNOLOGY AND RESOURCE

MANAGEMENT IN THE TROPICS AND SUB-TROPICS (ITT) IN PARTIAL

FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

NATURAL RESOURCE MANAGEMENT AND DEVELOPMENT (NRM)

DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES

BY

RICHARD BOAMAH, ADU

SUPERVISOR: PROF. DR. LARS RIBBE

DATE OF SUBMISSION

09-10-2018

Richard Boamah, Adu Student no.; 11117467 Email: Ritchieadu@yahoo.com

DECLARATION IN LIEU OF OATH

This is to confirm my master’s Thesis was independently composed/authored by myself, using solely the referred sources and support.

I additionally assert that this Thesis has not been part of another examination process.

Name: Richard Boamah Adu

Matriculation number: 11117467

Place and Date: Cologne, 09/10/2018

Signature:

DEDICATION

I dedicate this research work to my late dad Mr. Richard Kyei who saw me through the early stages of my life and education and was a friend and brother to me. It is such an unfortunate incidence that he cannot witness this moment with me, but, I am forever grateful to him. To my family especially my mum Madam Agnes Amoako who has been of great support to me, my sisters and all my lovely friends who have been in one form of support or the other to me throughout my study period in Germany.

ACKNOWLEDGEMENT

Glory and great honor be unto the name of our lord Jesus Christ for how far he has brought me. His words shall never leave my lips and as for me and my household, we shall forever remain indebted to him. My first appreciation and thanksgiving would therefore be to the most high God for leading me through these two years of my master course and bringing it to a successful end. I’m surely grateful father.

My second appreciation goes to my supervisor Prof. Dr. Lars Ribbe for his instrumental contribution and guidance in this research work. Besides his busy schedules and being the director of ITT, he managed to have free times to always discuss the progress of my research with me and offered helpful contributions when always necessary. I cannot go on without mentioning my sponsors DAAD who made it possible for me to come to Germany to pursue this academic degree. I truly appreciate your investments in me.

Special thanksgiving goes to my in-law Mr. Ansbeth Afranie and his wife. I’m also grateful to Mrs. Mary Adu-Sarpong for humbly receiving me to Germany when I knew nobody in my first week. Sometimes, not all people have the nerves to openly show public appreciation but there are some who equally appreciate special people like you in writing. To Mohammed Khalifa of ITT, I’m grateful for your support. To Miss Esther Agyemang, words cannot express how grateful I am for your patience and love towards me throughout my busy schedules during my education. Only God knows how much you mean to me.

To my closest friend Stephen Ampontuah, you are more than a brother. I owe you a lot senior. To Dennis, Kennedy of Ghana Police Force, Martin Lardner and all other persons who have contributed one way or the other to me getting here, I say, may God richly bless you, Amen.

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometer
EPA	Environmental Protection Agency
FC	Forestry Commission
FDI	Foreign Direct Investment
ICMM	International Council on Mining and Metals
ICP	Inductively Coupled Plasma
MCG	Minerals Commission of Ghana
MEST	Ministry Of Environment, Science and Technology
WHO	World Health Organisation
WRC	Water Resources Commission

ABSTRACT

Ghana as a country in the west of Africa is naturally endowed with many rich natural resources some of which includes; Gold, diamond, bauxite, manganese, cocoa, etc. Currently, it's the second leading producer of gold production in Africa after South Africa. Gold production has produced a lot of benefits to the nation but at the same time contributed to many negativities ranging from pollution (water and air), land degradation, ethnic conflicts and deforestation. Industrial gold mining itself was never a big issue that caused any panic in the country till illegal gold miners "Galamseyers" also commenced operating.

The sole objectives of this research were to determine the level of some specific heavy metal (Mercury, Lead, Arsenic and Zinc) concentrations within the Offin River in Dunkwa-on-Offin, Buabenso, Ayanfuri and Nkotumso. Results after the research revealed that, Ayanfuri recorded the highest level of concentrations. Nkotumso followed in that order before Buabenso with Dunkwa-on-Offin recording the least concentrations. It also became clear later that, even though the degree of intensiveness of the illegal mining "Galamsey" operations could have been a main factor for the increased concentrations, another finding was that, towns or communities that recorded higher concentrations throughout the study also showed to be towns that made use of inorganic fertilizers on its farms.

The Minerals and mining Act 2006 of Ghana was then analyzed and conclusion was that, though the country has very strong policies regarding illegal mining termed "Galamsey", there seemed to be institutional loop holes that have not been strong enough to combat illegal mining in the country. In recommending policy directives to improve the river quality, six (6) institutions including the Ministry of Lands and Natural Resources, Ministry of Environment, Science and Technology(MEST), Minerals Commission of Ghana, Environmental Protection Agency, Forestry Commission and the water Resources Commission were identified with detailed recommended roles clearly spelt out for each institution.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.0 Introduction

Ghana has a long tradition of gold mining with an estimated 2,488 metric tons (80 million ounces) of gold produced between the first documentation of gold mining in 1493 and 1997 (Amponsah –Tawiah, and Dartey-Baah, 2011**).** Records showed that Ghana produced 3.6 million ounces of gold in 2011 and 4.2million ounces in 2012 and the country also accounted for 36% of total world gold output (8,153,426 ounces) between 1493 and 1600 (Tsikata, 1997). It is the second largest gold producer in Africa after South Africa (Coakley, 1999).

Ghana has a variety of mineral resources and mining dates back well into the pre-colonial times. However, since the inception of the World Bank/IMF-led Mineral Sector Reforms in Ghana in the mid-1980's there has been a considerable increase in mining activities, particularly gold (Awudi, 2002).

Between 2000and 2007 several mineral rich nations found in Africa benefited from mining as the prices or value for metals and oil rose to a much more appreciative level. This motivated several of these companies to make provisions for new mines in order to meet the growing world demand for metals. However, this situation did not last for long as a result of the global economic meltdown which made prices for metals and oil to fall again. Most African countries have been through this succession of high and low prices in the pricing of oil and metals however other factors as political instability, corruption, bad management, and improper economic investments are all factors that further necessitated or enhanced this development in the continent thus; leaving the masses poor and only benefiting the few minority in higher positions in government.

The various benefits of minerals in our day to day activities are seen in the production of tools and utensils, weapons by industries and countries, ornaments and decorations, currencies for the payment of goods and services, structures and other devices. They are also used in energy even in the production of electricity, machinery (both large and small), electronics (computers, phones and home appliances) and nuclear fission. Direct development investment by mining industries has been labeled strategically as corporate social responsibilities. Most mining companies are seen undertaking such corporate social responsibilities notable among them which includes;

building secondary schools, clinics, water infrastructures, roads etc. Newmont Ghana Gold supported Ghana's Ahafo region through a partnership in the health sector by building housing for resident nurses and three community health compounds in local villages, and equipping 60 local health volunteers with bicycles and medical equipment (Chatham House, 2017).

In spite of the benefits, the sector is faced with many socio-economic, political and environmental problems which have raised questions of its importance as far as the total cost and benefit analysis of the operations of the mining industries within the various communities are concerned. There is also the environmental degradation issue resulting from the inability of mining companies to sustain the environmental quality of the communities in which they operate. These environmental concerns have been exacerbated by the activities of small scale illegal mining operations. Degradation of the environment is made evident through several characteristics exhibited in the environment. Ore related heavy metals including the spread of arsenic and lead and the discharge of cyanide are very clear examples whilst mercury exposure from small scale mining activities is another serious threat the environment is exposed to (Punam et al., 2017). In Ghana, air pollution around industrial gold mines has also been linked to increased cough incidence in surrounding vicinities of these mining companies (Aragón and Rud 2015).

Illegal small scale mining activity popularly known as "Galamsey" started way before the country had its independence in 1957. The name was originally adapted from illegal gold mining. The colonial masters seeing how Ghanaians gathered the gold they got from their activities and sold them to others gave the activity a name "Gather them and sell". Thus instead of saying, "gather them and sell" by the Ghanaians, they pronounced the name "Galamsey". "Galamsey" therefore got it emergence or came into the system as the meaning of illegal small scale mining. Galamsey in Ghana is normally concentrated in towns, villages, and forested areas of mineralized regions, and it is operated along major rivers and because of its illegal nature, Galamsey used to be confined to hidden and remote locations, and sometimes performed under the cover of darkness (Mantey et al., 2016).

1.1 Problem statement

During mining, a fine grind of the ore is necessary to release the minerals. Normally the ore is grounded into fine fractions and mineral extractions done with mercury and water passing through several machines. This is particularly seen with small scale miners. Because the washing is done several times, it's usually best for the operators to carry out their operation with the aid of a flowing water or water source. Several backwashing are done until the final concentrates begins to come out. The final concentrates are then washed out into a bowl of water containing mercury to extract the gold from the sand (Amegbey and Eshun 2003).

Visual impacts mostly noticed after the mining include surface and ground water pollution, depletion of surface water resources, mercury contaminations, hydrocarbon spills, littering challenges, abandoned structures, deforestation and land degradation, unreclaimed sites etc. These situations were however not in abundance until the introduction of illegal small scale mining or "Galamsey" operations in the country which further worsened these impacts of mining.

1.1 Objectives

1.1.1 General Objectives

The general objective of this study is to assess the impact of Illegal gold mining on water quality in the Offin River in the central region of Ghana.

1.1.2 Specific Objectives

A. To find out the concentrations of Mercury, Arsenic, Zinc, and Iron in the Offin River at Dunkwa, Buabenso, Nkotumso and Ayanfuri all located in the central region of Ghana and to determine which of these towns have higher concentrations of these heavy metals aforementioned.

B. To find out how illegal miners in the four communities operate that tends to destroy the Offin River.
C. To recommend institutional strategies to help reverse the issue of water quality destruction arising from illegal mining activities.

1.2 Research Questions

To achieve the above-mentioned objectives, the study is guided by the following research questions.

Research Question 1: Which of the communities being studied has the largest amount of Zinc, Lead, Arsenic and Mercury and what could be the possible reasons for this?

Research Question 2: How is illegal mining done within the four communities that tend to pollute the Offin River?

Research Question 3: What are the already instituted policies to address the issue of illegal mining, could there be any missing gaps, and what could be added or suggested to bridge these gaps?

1.3 Justification

Mining is an activity that brings development in many forms to the economy of nations. This is as a result of the economic benefits that are made available to the various nations that are involved in the extraction of mineral resources. However most often, several institutions and nations only tend to acknowledge the measurable benefits of mineral extraction paying little or no attention to the negative effects of such activities on the wellbeing of the environment.

The research work seeks to undertake a study into heavy metals concentration in the Offin River in four communities in the central region of Ghana, discuss the process used in “Galamsey” mining operations, how they affect water quality of the Offin River around and devise or recommend institutional policy directives to improve the river quality.

CHAPTER TWO

2.0 The mining industry in Ghana

Ghana has a long history of gold mining and has contributed to quite a good amount of the world's gold production (Hilson, 2002). Gold production in Ghana dates back from colonial rule. The first rush for gold happened between 1982 and 1901 and immediately after the First World War. Gold production was said to have reduced in 1957 during the independence of the country and continued to stay like that until the 1980s. The country then again experienced another season of gold rush over the last 20 years and the annual production of gold has hence increased by 700 percent since then as illustrated in the figure below (Chuhan-Pole et al., 2015).

Figure 1: Annual production of gold in Ghana.

The major gold producing companies in Ghana are: Goldfields Ghana Ltd (Tarkwa and Abosso mines); Anglo Gold Ashanti (Obuasi and Iduapriem mines); Central Africa Gold (formerly, AngloGold Ashanti Bibiani Mines) Golden Star Resources (Bogosu/Prestea and Akyempim mines); Redback Mining Ltd (Chirano mine) and Newmont Ghana Gold Ltd (Ahafo and Akyemmines). Ghana Consolidated Diamonds Akwatia diamond mine is also the only operating diamond mine in Ghana (Amponsah –Tawiah and Dartey-Baah 2011). The table below demonstrates the various mining companies in Ghana, the type of production and annual output in 2013.

Mining company name	**Location in Ghana**	**Type of Operation**	**Annual Output**
Adamus Resources	Teleku-Bokazo and Nkroful (Western Region	Gold	2982.8 Kilograms
AngloGold Ashanti	Obuasi (Ashanti Region) and Iduapriem (Western Region)	Gold	6777 Kilograms
Chirano Gold Mines	Chirano (Western Region)	Gold	7787.13 Kilograms
Ghana Bauxite Company	Awaso (Western Region)	Bauxite	23444.9 Kilograms
Ghana Manganese Company	Nsuta (Western Region)	Manganese	56639.8 Kilograms
Gold Fields Ghana	Tarkwa and Damang (Western Region)	Gold	22266.31 Kilograms
Golden Star Resources	Prestea and Wassa (Western Region)	Gold	9378.22 Kilograms

Newmont Ghana	Kenyasi (Brong Ahafo) and New Abirem (Eastern Region)	Gold	19826.7 Kilograms
Perseus Mining [Ghana]	Ayanfuri (Central Region)	Gold	5630.4 Kilograms
Prestea Sankofa Gold	Prestea (Western Region)	Gold	647.87 Kilograms

Table 1: Major mining operating companies in Ghana (ICMM, 2015).

The mining royalty paid by mining companies in Ghana was 3 percent until 2010, which was the average rate for gold production in Africa (Gajigo, Mutambatsere and Mdiaye, 2012), but increased to 5 percent in 2010 (Standing and Hilson, 2013). Of this money, 80 percent goes to the general government budget, 10 percent goes to the administration of mining oversight, and 10 percent supports district administration (Garvin et al. 2009). The figure below demonstrates annual gold production of Ghana between 1960 and 2010.

Figure 2: Gold production projections in Ghana, 1960–2010 (ICMM, 2015).

In Africa, gold and the mining of other minerals exist in several countries within the west of Africa and the southern part of Africa, however, gold mining always dominate in the production of precious minerals within the continent.

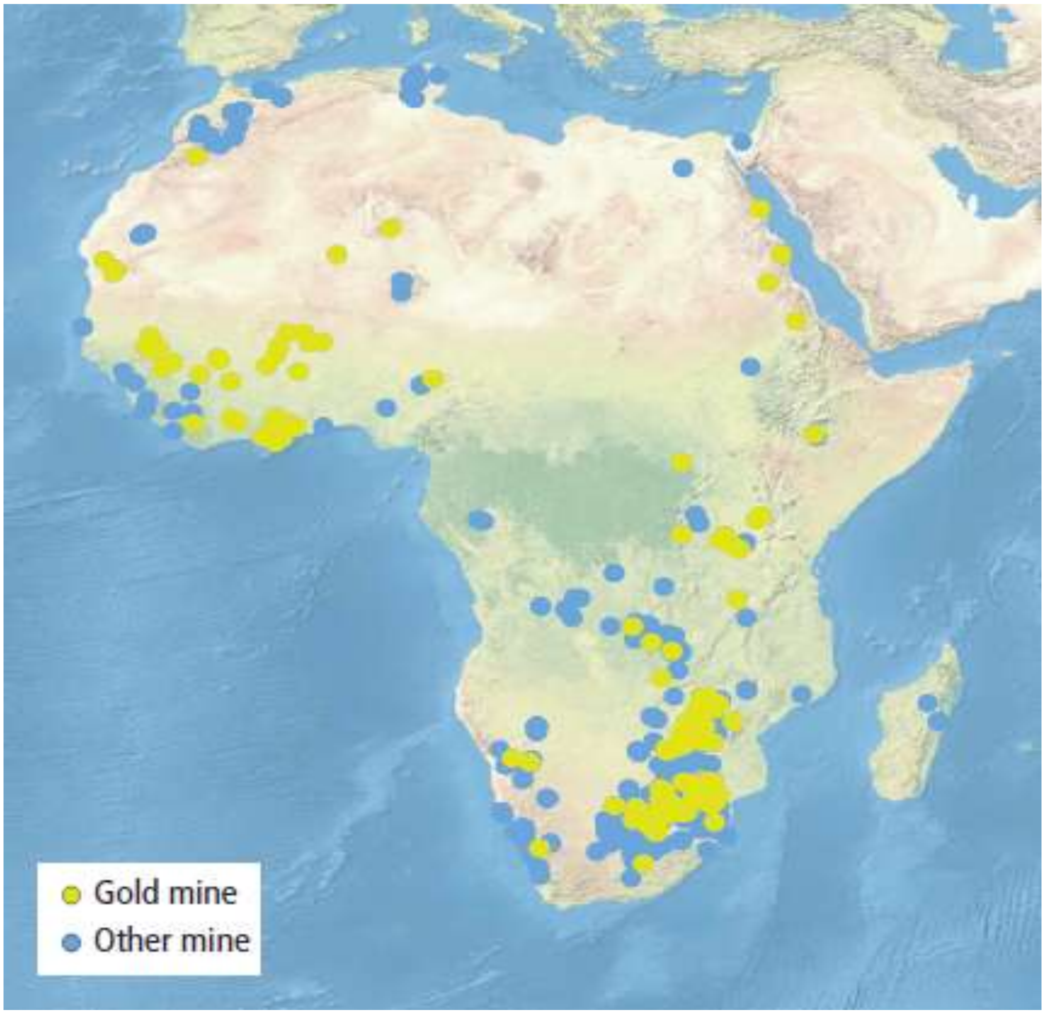


Figure 3: A map of Africa showing all large-scale mines in production at any point between 1975 and 2012 (Chatham House, 2017).

2.1 Impact of the mining Industry in Ghana

Minerals are considered a blessing to any country in which they are found. They are a gift of nature available to be developed, sold and used to better the lot of a nation's citizens (Eggert, 2002). Benefits that can be generated from the mineral industry productions include the generation of income and foreign exchange through exports. This further has the tendencies to stimulate the local economy through the local purchase of inputs. They provide employment to people within the country and the government on the other hand also receives tax revenues from mineral production which further goes to help several sectors as the health sector, education sector, utility supply, better roads and several forms of development within the country. Between 1983 and 1998, the mining industry brought approximately US$ 4 billion in FDI to Ghana, representing more than 60% of all such investment in the country (Ghana Minerals Commission, 2000).The sector continues to be one of the highest contributors to the Internal Revenue Service through the payment of mineral royalties, employee income taxes, corporate taxes and ancillary levies (Amponsah –Tawiah and Dartey-Baah., 2011)

With all these positive contribution of the mining industry to the economy of the country, the main elements of the environment (i.e., land, water and air) have been severely affected by their operations within the country in areas where the mining activies dominate. Large tracts of land for farming activities have been acquired by mining companies for large scale surface mining operations depriving mining communities of their source of livelihood (Akabzaa & Darimani, 2001). Cyanide contamination of water bodies, mercury contaminations from small-scale and illegal mining activities and other dangerous heavy metal contaminations on land and water bodies are likely features visible at mining towns.

Statistics from the Inspectorate Division of the Minerals Commission on occupational health problems caused by mining activities from 2000-2004 includes malaria and upper respiratory tract infection, the two topmost causes of outpatient morbidity between 2000 -2006 (Ghana Health Service, 2007). Other health and social impacts created by mining activities includes hearing losses and silicosis, conditions created by the blasting and drilling activities with their resultant noise and dust, which have become nuisance in the mining region.

2.2 Mining

Mining is the process of digging into the earth to extract naturally occurring minerals. It is the world’s second oldest and most important industry after agriculture (Down & Stocks, 1977). As one of the largest industry in the world, it plays very vital role in the world’s economic development of nations. However mining used here means the extraction of any naturally occurring mineral substances being it in the form of solid, liquid or gas from the earth (Vasantha, 2013). Mining stages mostly commence from initial prospecting or exploration, development, extraction/production/operation, mine closure to final stage of reclamation and rehabilitation (Ramani, 2012).

The Exploration stage involves determining the exact location of the area to be mined, mapping, reconnaissance survey or prospecting, remote sensing procedures that can sense ore bearing rocks. The development may also include several feasibility studies (cost benefit analysis), filing for permit to mine and Environmental Impact statement. It may also involve constructing access roads, transport system etc.

The Extraction is the process of taking from the ground the ore bearing rocks by the various methods of mining (Surface and underground) in large scale production. The last stage which involves reclamation and rehabilitation involves removal of plants and structures, reclamation of waste and tailings storage facilities and monitoring of discharges. It is the last stage often described as the closure of a mine.

Minerals extracted from mining activities are also used in various fields of life as described below;

Need or Use	**Purpose**
Tools and utensils	Food and shelter
Weapons	Hunting. Defense and warfare
Ornaments and decoration	Jewelry, cosmetics, dye
Currency	Monetary Exchange
Structures and devices	Shelter, transport
Energy	Heat, power
Machinery	Industry
Electronics	Computers, communications

Nuclear Fission	Power and warfare

Table 2: Human uses of minerals[1]

2.3 Factors influencing the choice of mining method

1. Depth of the deposit
2. Shape of the deposit
3. Thickness of the deposit
4. Gradient of the deposit
5. Availability of machineries
6. Economic value of minerals

2.4 Types of mining

There are two kinds of mining; surface and underground mining.

2.4.1 Surface mining

Surface mining, also called open-pit mining or strip mining is undertaken if the mineral deposit lies on the surface of the earth. This is done by removing (stripping) surface vegetation, dirt, and, if necessary, layers of bedrock in order to reach buried ore deposits (or) surface mining is the process of extraction of minerals by removal of overburden (Kumari et al., 2017). The overburden is the rock or waste material which is lying on the mineral to be owned. Surface mining takes a greater proportion of mining methods used in producing greater percentage of the world's minerals. Records have it that, almost 95% of non-metallic minerals and more than 90% metallic minerals are mined by surface methods (Ramani, 2012).

2.4.2 Advantages of surface mining

1. Like Underground Mining no minerals are blocked as shaft pillars, supports, roadways etc.

[1] www.cienciaviva.pt/img/upload/Introduction%20to%20mining.pdf Accessed on 30th July 2018.

2. Roof control and ventilation is not required.
3. Low cost as compared to Underground Mining.
4. Low labor requirement than Underground Mining.
5. Hazards and dangers are lesser than Underground Mining.
6. Quality control is easy.
7. Female laborers can work in Surface Mining.
8. High degree of mechanization is possible.
9. High explosives can be used.

Figure 4: Kagem Open-pit Emerald Mine in Zambia[2]

2.5 Underground Mining

Underground mining is a technique used to access ores and valuable minerals in the ground by digging into the ground to extract them in an economical way. Underground mining is carried

[2] https://www.gia.edu/gia-news-research-kagem-emerald-mine-zambia. Accessed on 6th August 2018

out when the rocks, minerals, or precious stones are located at a distance far beneath the ground and it is not economical to be extracted with surface mining[3].

2.5.1 Factors influencing the decision to adopt Underground mining

1. The ore deposit is deep.
2. Grade is high enough to mine profitably.
3. Where surface mining is not economical.
4. Certain conditions which surface mining is not permissible such as:
   a. If there is reserve forest.
   b. If there is river flow
   c. If there is habitation area.

Depending upon the type of rock the method of working will be chosen. Underground Mining Methods are usually classified into two categories which are as follows:

I. Underground Mining (Hard Rock). Underground hard rock mining refers to various underground mining techniques used to excavate hard minerals such as those containing metals like gold, copper, zinc, nickel and lead or gems such as diamonds. Mining under this method can also be done by short hole and long hole mining method, selective and unselective mining methods, supported and unsupported underground mining methods (Hassan Z.H., 2010).

II**.** Underground Mining (Soft Rock). Underground mining (soft rock) refer to a group of underground mining techniques used to extract minerals such as: coal, oil shale, Salt, Uranium, Phosphate and other minerals or geological materials from sedimentary (soft rocks)[4].

[3] https://www.greatmining.com/Underground-Mining.html accessed on 31st July 2018.
[4] https://www.revolvy.com/main/index.php?s=Underground+mining+(soft+rock) Accessed on 31st July, 2018.

Figure 5: Underground mining[5]

2.6 Illegal Gold mining and Forest reserves

Over the years, there have been several arguments over mining and mining in forest reserves in Ghana. This is because, mining was seen to be deteriorating some of the other rich natural resources in Ghana, however other mineral reserves were also forecasted to be lying beneath the forest reserves that needed to be mined for economic development. The government then came out in 2003 to make a statement that concluded limited mining in some selected forest reserves in the country due to findings of exploratory work that had being carried out by some mining industries in the country (Tetteh, 2015). So much debates and discussions went on with regard to this new development. However, the most important consideration was that, the cumulated benefits including the jobs that could be created from the mining was more than the little

[5] https://pctechmag.com/2018/03/government-to-implement-online-mining-licensing-system/ Accessed on 6th August 2018

destruction that could be caused. That notwithstanding, other impact assessments and reclamation and rehabilitation are supposed to be carried out after every mine activity. It is only after these activities are ignored especially reclamation (afforestation) that caused worry for the environment and society. The table below describes key mineral export commodities linked to forest degradation and forestry percentage of gross domestic product in 2011 with mining percentage of GDP in 2012.

Country	**Key Mineral export commodities (those linked to deforestation are in bold)***	**Forestry, % of GDP, 2011**	**Mining, % of GDP, 2012**	**Tree cover loss, million ha (and% of total national tree cover) 2001-13**
Indonesia	**Tin, nickel, gold, copper, aluminium (bauxite)**	1.7	1.7	17(10%)
Brazil	Iron ore	1.1	2.9	36(7%)
DRC	**Copper, gold, tin, tantalum, tungsten,** cobalt	0.6	18	7(3%)
Cameroon	Aluminium (bauxite), **gold**	2.8	02	0.5(2%)
Ghana	**Gold**, manganese	3.5	13	0.5(7%)
Guyana	Aluminium (bauxite), **gold**	4.1	22	0.1(0.5%)
Liberia	Iron ore, **gold**	15.2	29	0.6(7%)
Peru	**Gold, tin,**	0.8	13	2(2%)

	copper, zinc, lead, silver			

Table 3: Country overview: Key mineral exports, contribution of forest and mining sector to GDP and tree cover loss 2001–13 (Chatham House, 2015).

2.7 Illegal Gold mining and water quality

Small scale mining in Ghana is an activity mostly engaged by the majority of youth in the Ghana. The technique mostly used for the process is amalgamation. It is practiced all year long in the western region of Ghana and some other regions like Eastern, Ashanti and the Brong ahafo region. Today, the colors of some major rivers have turned brown and galamseyers are still on rafts with their pumps still submerged for the mining of gold ore. In some worst scenarios, the activities are done right inside the water bodies. That is the operators build their structures in the middle of the rivers. The water regulatory commission in Ghana measures the quality of water with an index. This index has 100 indicating the highest.

A major impact of mining on water resources that is considered a major threat is Acid mine drainage (AMD). The chemistry of Acid mine drainage from an angle appears very simple but becomes extremely complex with time as geochemistry and physical characteristics can vary greatly from place to place (Younger, 2001). It's being noticed as one of the most challenging threats associated with the mining of sulphide-rich mineral deposits and as such seen to be responsible for the contamination of surface and groundwater in many vicinities of mining areas (Olias and Nieto, 2015). Normally, it's described as the interaction between many physical, chemical and biological factors thus, the association of sulphides with air, water and microorganisms (Simate and Ndlovu, 2014).

Acid Mine Drainage basically implies the release of chemical pollutants into water bodies turning them acidic. Problems derived from Acid mine drainage includes contamination of water bodies, pollution of lands for agriculture, disrupted and stunted growth of aquatic fauna and flora (Ochieng et. al., 2010).

Figure 6: Illegal mining being carried out in a water body[6]

Figure 7: Ongoing 'Galamsey' activity with visible effect on surrounding water body[7]

[6] https://www.modernghana.com/news/506988/1/an-assessment-of-an-environmental-problem-in-ghana.html assessed on 10-06-2018
[7] https://www.todaygh.com/one-dead-several-others-trapped-galamsey-pit-ntotroso/ assessed on 10-06-2018

Figure 8: Polluted Offin River with destroyed vegetation due to illegal gold mining from Google map

2.8 The Gold Extraction Process

The process of gold extraction used by small scale miners in Ghana and many other developing African countries are mostly the same. There might sometimes be small differences but these difference are really not much. Most small scale mining operations start from extraction of rocks or rock sediments suspected to be containing gold concentrates. These extracted rocks are sent to the mining sites where the process of crushing of the rocks begins. Those that have bigger or sophisticated machines normally do this with their machines but few small scale miners can afford such equipment so normally, the crushing is done manually by hand to break the rocks into smaller sizes. After the crushing, the next process involves milling the smaller rock particles. Though not all small scale have the millers, those that do not have continue to further break down the small particles until they are much smaller to be washed with washing plants. After the milling or further breaking down of the rock particles, mercury is added to form an amalgam. This process is normally termed Amalgamation. At this form, most of the gold and mercury have been bonded together. The resulting Amalgam is burnt to solidify the gold and to vaporize the mercury. The gold is then sent out into refinery shops for further refinement.

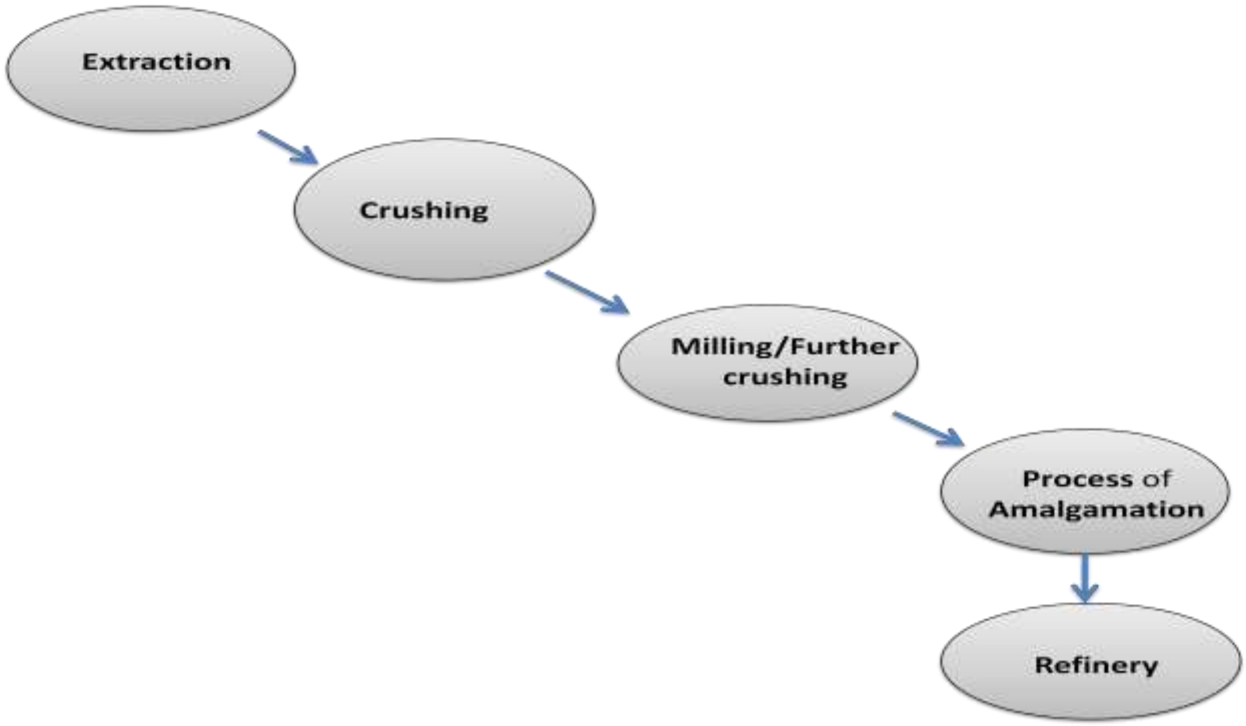


Figure 9: The process of gold extraction used by small scale miners

2.9 Contaminants involved in illegal gold mining

The most consistent chemicals found to be normally used in the extraction of the gold are Cyanide, arsenic and mercury with mercury being the most dangerous of them all to human health when in water bodies. Mercury, when used in the extraction process, forms an amalgam and turns into a stable methyl-mercury a compound which when ingested, inhaled or absorbed by fauna and flora becomes toxic to living organisms (Hilson, 2001). When mercury is exposed to water bodies, it is absorbed by phytoplankton and also ingested by zooplankton and fishes. Through this process, it contaminates the food chain (WHO, 2007).

Cyanide a highly toxic compound is used mostly to separate gold from rocks and other sediments. At lower concentrations, effects include the inhibition of germination and growth, although sometimes cyanide enhances seed germination by stimulating the pentose phosphate pathway and inhibiting catalase (Eisler and Wiemeye, 2004).

2.10 Heavy metals and water quality

Heavy metals are sometimes called “trace elements”. They are the metallic elements of the periodic table. Heavy metals are naturally occurring elements, and are present in varying concentrations in all ecosystems. There are a huge number of heavy metals. They are found in elemental form and in a variety of other chemical compounds. The main anthropogenic sources of heavy metals are various industrial processes, mining, foundries, smelters, combustion of fossil fuel and gasoline, and waste incinerators (Ilyin, 2004).

2.11 Sources of heavy metals (Rashmi and Dwivedi, 2013)

1. Chromium (Cr) - Mining, industrial coolants, chromium salts manufacturing, leather tanning
2. Lead (Pb) - lead acid batteries, paints, E-waste, Smelting operations, coal- based thermal power plants, ceramics, bangle industry
3. Mercury (Hg) - Chlor-alkali plants, thermal power plants, fluorescent lamps, hospital waste (damaged thermometers, barometers, sphygmomanometers), electrical appliances etc.
4. Arsenic (As) - Geogenic/natural processes, smelting operations, thermal power plants, fuel
5. Copper (Cu) - Mining, electroplating, smelting operations
6. Vanadium (Va) - Spent catalyst, sulphuric acid plant
7. Nickel (Ni) - Smelting operations, thermal power plants, battery industry
8. Cadmium (Cd) - Zinc smelting, waste batteries, e-waste, paint sludge, incinerations & fuel combustion
9. Molybdenum (Mo) - Spent catalyst
10. Zinc (Zn) - Smelting, electroplating

2.12 Lead:

Lead is one of the commonest elements in nature. Several stable isotopes of lead exist in nature, including, in order of abundance, ^{208}Pb, ^{206}Pb, ^{207}Pb and ^{204}Pb with a melting point of 327ºC (WHO, 2011). It's used in the production of substances as alloys, plastic stabilizers and even in batteries (WHO, 1989). The concentration however in drinking water can be decreased with the addition of lime and pH adjustment in distribution systems mainly from <7 to 8–9 (Moore, et al., 1981, Sherlock et al., 1984). In drinking water, the maximum permissible limit is 0.01mg/l (WHO, 2011). Lead is a potent poison and is harmful in even very small amount. Lead is an important environmental contaminant because of its known toxicity to humans and other living organisms (Tiwali et.al. 2013).

Other means of exposure include through soils and household dust, but contaminated areas may range from < 5µg/g to tens of milligrams per gram (WHO, 2011).

2.12.1 Effects in Animals

1. Neurological effects such as impairment of activity, attention, adaptability, learning ability and memory, as well as increased distractibility.
2. Reproductive toxicity, embryo toxicity, and teratogenicity: Effects on sperm counts and on the testicles (testicular atrophy) in male rats and on estrous cycles in female rats (Rice and Karpinski, 1988).
3. Mutagenicity and related end-points :
4. Carcinogenicity eg. renal tumors in rats

2.12.2 Effects in Humans

1. Effects on cardiovascular functioning in humans (Vaziri, 2002).
2. Effect on renal functioning (Gonick, 2002).
3. Effect on kidney, lungs and may lead to brain cancer with time (Steenland and Boffetta, 2000).

4. All effects of lead are of health concern for human however, children are at most risk during early childhood (P.de Voigt (ed), 2016).
5. Headache and restlessness are also common symptoms (Beattie et al. 1972).

2.13 Zinc:

Small amounts of Zinc are mostly contained in all igneous rocks with zinc ores being sulphides as sphalerite and wurzite (Elinder et.al., 1986*)*. Naturally occurring zinc in soils is 1–300 mg/kg (WHO, 2003). Zinc has several uses ranging from galvanizing of steel to the production of corrosion resistant alloys and brass (WHO, 2003). Its concentration is normally below 10 μg/litre in natural surface waters and 10–40 μg/litre in groundwater (Elinder et.al., 1986*)*. Zinc may enter water and soils through both natural processes and through human activities such as release of mine drainage and through the release of industrial and municipal wastes. It may also find its way through the groundwater by some mineral fertilizers (Noulas et. al., 2018).

2.13.1 Effects on Humans

1. Symptoms of acute toxic effects of inhaled zinc include pulmonary distress, fever, chills, and gastroenteritis (Elinder et.al., 1986).
2. Respiratory disorder
3. Elevated risk of prostate disorder (Lauara et. al. 2010)

2.14 Mercury:

It exists in several forms: inorganic mercury, which includes metallic mercury and mercury vapor (Hg^0) and mercurous (Hg^{2++}) or mercuric (Hg^{++}) salts; and organic mercury, which includes compounds in which mercury is bonded to a structure containing carbon atoms (methyl, ethyl, phenyl, or similar groups) (Bernhoft., 2011). Mercury is or has been used for the cathode in the electrolytic production of chlorine and caustic soda, in laboratory apparatus and as a raw material for various mercury compounds (WHO, 2005). They are mostly used as fungicides, in pharmaceuticals, etc.

Levels of mercury in rainwater are in the range 5–100 ng/litre, but mean levels as low as 1 mg/litre have been reported (IPCS, 1990). In drinking water, the maximum permissible limit is 0.001mg/l (WHO, 2011).

2.14.1 Effects in Humans

1. Mercury will cause severe disruption of any tissue with which it comes into contact insufficient concentration, but the two main effects of mercury poisoning are neurological and renal disturbances (WHO, 2005).
2. Ingestion of 500 mg of mercury (II) chloride causes severe poisoning and sometimes death in humans (Bidstrup, 1964).
3. Acute effects result from the inhalation of air containing mercury vapour at concentrations in the range of 0.05–0.35 mg/m3 (Teisinger and Fiserova-Bergerova, 1965; Neilsen-Kudsk, 1972).
4. Kidney damage

2.15 Arsenic

Arsenic is made available to water through the dissolution of rocks, mineral and ore, both industrial and from waste from mining and also from atmospheric deposition (WHO, 2011). They are used for a variety of purposes including the hide tanning process and in pharmaceuticals. In natural waters, concentrations may range from 0.001-0.002mg/l but activities such as volcanic activities may increase its concentrations. Other activities such as mining could raise its concentration to about 0.12mg/l (Grispan and Biagini, 1985). In drinking water, the permissible limit set by WHO is 0.01mg/l (WHO, 2011).

2.15.1 Effects in Humans

1. Acute intoxification

2. Abdominal pains
3. Nausea
4. Skin cancer
5. Bladder and lung cancer
6. Muscular cramps

CHAPTER THREE

3.0 Introduction

Having reviewed literature in detailed on mining history of Ghana, the impact of the mining industry in Ghana, heavy metals and the their effects to humans and animals, this chapter focuses on a detailed description of the study area and approach for realizing the research objectives.

3.1 Description of Study Area

The study was carried out in the central region of Ghana where illegal gold mining popularly known as 'Galamsey' and water or river quality has been a very delicate subject for several decades. The Offin River has geographical coordinate's 5.964156 ° N, -1.895271 ° W 06°. The river lies on the Dunkwa-on-Offin town and extends to other towns as Ntobroso, Treposo, Subin, Ayanfuri, Buabenso, Nkotumso, Atuntuma and many others and several other towns in the Ashanti region of Ghana. The Offin River is an easterly-flowing waterway in Ghana which flows through the Tano Ofin Reserve in Ghana's Atwima Mponua District. Being 90 metres above mean sea level, the Ofin has cut steep side channels, average depth 12–15 metres, into the rolling terrain over which it flows.[8] It also shares boundaries between the Ashanti region and the Central region.

[8] https://en.wikipedia.org/wiki/Ofin_River Accessed on 24-09-2018

Figure 10: A geographical map of Ghana showing its neighboring countries and major cities[9]

[9] http://www.nationsonline.org/oneworld/map/ghana_map.htm accessed on 30-09-2018

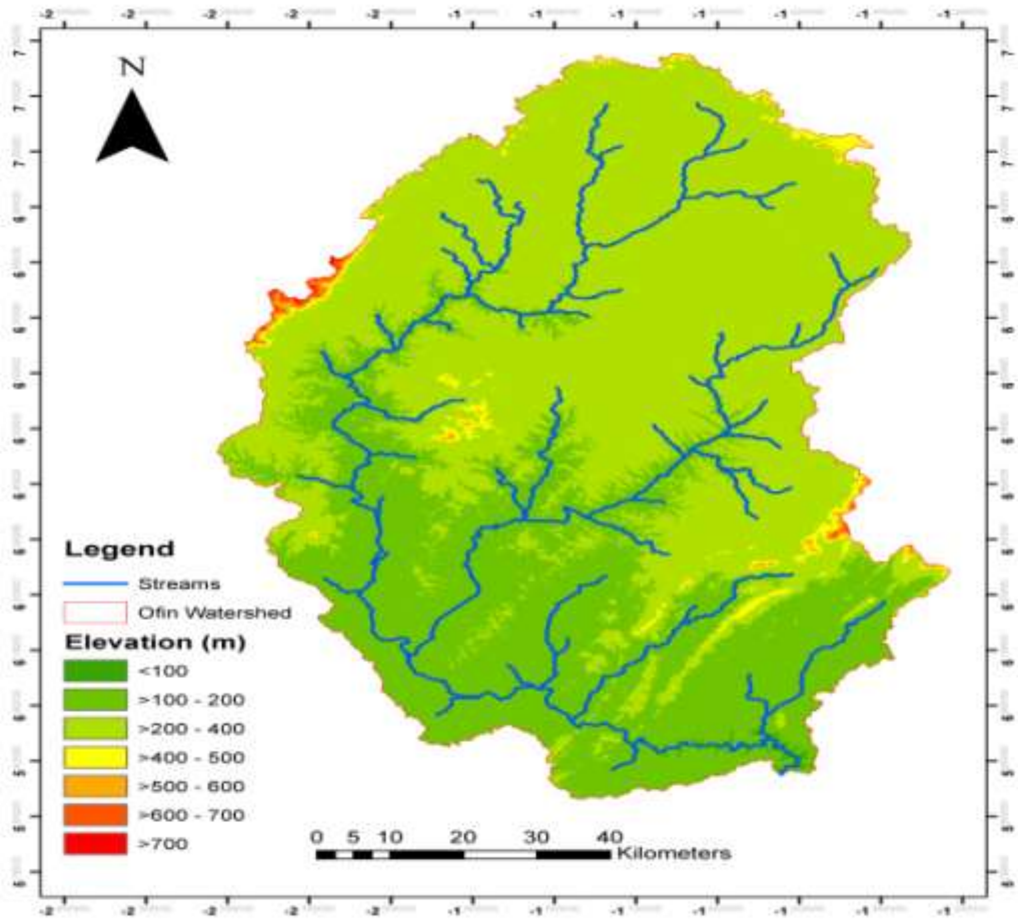


Figure 11: The Offin River Delineation

3.2 Instruments

Instruments used for conducting the research included; Field notebook, Cleaned plastic containers, Camera, and GPS device.

3.3 Water Sampling Technique

The research was conducted in the central region of Ghana on the Offin River. Water samples were collected upstream and downstream in four communities along the Offin River. Sampling bottles were also washed with deionized water before the samples were taken. In each community, the samples were taken at two locations within the river; thus the upstream and the downstream. One water sample each was taken upstream and downstream in each four communities making it two samples for each community.

The water samples were sent to the laboratory to analyze for Mercury (Hg), Arsenic (As), Lead (Pb) and Zinc (Zn). Another sample was collected from the Offin River in Dunkwa as a control. This place was particularly chosen because, there has and still is treatment of the River there which makes its quality a little better than all other locations. This resulted in nine (9) samples and each of these samples was analyzed for the four parameters as illustrated below. Again, Digestion was done on all samples collected before Atomic Absorption Spectrometry (AAS) and Induction Coupled Plasma (ICP) analysis were done.

Town	**Geographical coordinates**	**Sampling Locations**	**Perimeter under study**
Dunkwa – On - Offin	5.969812º N, -1.783097º W	Upstream and downstream	Hg, AS, Pb, Zn
Buabenso	5.955425º N, -1.738065º W	Upstream and downstream	Hg, AS, Pb, Zn
Ayanfuri	5.964156º N, -1.895271º W	Upstream and downstream	Hg, AS, Pb, Zn

Nkotumso	5.999747º N, -1.918473º W	Upstream and downstream	Hg, AS, Pb, Zn
Control (The Offin River under treatment at Dunkwa)	5.964156 º N -1.895271 º W	Midstream	Hg, AS, Pb, Zn

Table 4: Sampling structure of communities under study

3.4 Research Design

The study also considered field survey for getting its primary field data. Individuals considered to be involved in "Galamsey" activities were contacted and these individuals were able to give very specific locations where the activities were done within the communities. This approach was considered very suitable because it offered the opportunity to meet directly with people involved in "Galamsey" operations. It should be stressed here however that, not all people were willing to talk. In several instances, I had to keep searching for people to give me information, which changed my sampling strategy to "who was willing to talk". This approach was to help collect water samples to answer our first research question which was, to find out the concentrations of Mercury, Arsenic, Zinc, and Iron in the Offin River at certain specific communities located in the central region of Ghana and to determine which of these towns have higher concentrations of these metals aforementioned and possible reasons why. Analysis of response from questionnaire also helped to achieve this objective.

The next approach to answering the second research question was basically field observation to help understand how the "Galamsey" is actually done and how it tends to pollute water bodies around it.

The final approach to meeting the last research question was identifying relevant institutions that have a stake in mining issues in Ghana, their roles towards mining and the environment, analyze the Ghana minerals and mining policy of 2006, compare them to what is seen on the field, find the missing link and recommend other roles or policies to bridge this gap.

3.5 Data Collection Techniques

Selection of respondents for questionnaire was based on who was available to talk during my three day stay in each community. It must however be emphasized that, getting people to respond to questionnaire wasn't an easy task which prolonged my stay in other communities. Each one was afraid to open up since previously, security personnel within the region has been on the watch out for people involved in such Illegal mining. Other people had in the past been severely punished for involvement in illegal mining activities and other heavy machines burnt and destroyed. It therefore took several persuasion and trust for some people to privately respond to my questionnaire. There were instances when I had to grease the palms of people before they could talk to me. These respondents were classified into farmers, students, Gold miners, Government workers and the unemployed.

3.6 Data Analysis

The data collected was analyzed with the aid of Excel to compare upstream and downstream concentrations of the heavy metals of the respective communities with sample taken from control point. Mean total concentrations of the heavy metals of the respective communities were also determined to find out the community with the highest accumulation of which heavy metals. Also Excel Correlation function was used to determine if these concentrations correlate statistically and if they are, in what form.

3.7 Limitations of the study

1. A major challenge faced in conducting this research was the lack of cooperation between members of the various communities. According to the various communities, several other people from government and non governmental bodies come to them occasionally for similar interviews but no measurable positive feedback has come into the development of the communities. It therefore took several hours of persuasion and trust to get a few people ready to answer some questions and even those that obliged did not answer all questions.
2. Lack of education also affected the quality of answers provided by some community members.
3. Access to information was difficult in rural communities
4. People particularly the miners were scared to freely give information about their communities because of the ban on illegal mining “Galamsey’ in Ghana recently.
5. Analysis of the water sample was expensive and so not so many heavy metals and parameters as sediments or biota were able to be analyzed due to limited financial resources.
6. Population data from communities (Ayanfuri, Buabenso, and Nkotumso) were not available at the community level. Data present were only that of the District Assembly level.

CHAPTER FOUR

4.0 Introduction

In this chapter, primary data were critically analyzed according to the stated objectives, other observations were made and all other important literature with regards to this study gathered and presented in tables, graphs and figures. The chapter clearly discuses findings from water samples collected from the four communities and the concentrations of the heavy metals being discussed in each sample. It also provides information from interviews and questionnaires sent out to these communities in the course of the study. Graphs, charts and tables are used to interpret these findings.

Based on the three objectives set to achieve the general purpose of the study, water samples were taken to the laboratory to determine the level of concentrations of Zn, Lead, Arsenic and Mercury in each sample taken from each community. This was to determine the town with the highest or least concentrations of these metals in its waters. Questionnaire and field observations were useful to determine other causes for higher or lower concentrations recorded from the various communities.

Again, field observations and interviews were undertaken out to find out how illegal mining activities are undertaken, how they tend to destroy water quality.

Lastly, I tried to gather data on the relevant institutions and their policies towards illegal mining, the missing link and finally make suggestions or recommendations for the study. The data obtained from water sample analysis and interactions with people from the different communities are thus thematically presented in the chapters below.

4.1 Results from Water Analysis

The analysis for Zinc was done by Atomic Absorption spectrometer (AAS) at the Kwame Nkrumah University of Science and Technology in Kumasi whilst analysis for Arsenic, Mercury and Lead were done at SGS- Laboratory in Tema-Ghana using Inductively Coupled Plasma (ICP) analysis for heavy metals concentrations in samples. It is important to note that digestion was done on water samples before AAS and ICP analysis were carried out.

	AAS	**ICP**		
	Zn (mg/l)	**As (mg/l)**	**Hg (mg/l)**	**Pb (mg/l)**
	Conc.	**Conc.**	**Conc.**	**Conc.**
Dunkwa Upstream	1.74	0.0978	0.0009	0.0909
Dunkwa Downstream	0.5163	0.0854	0.0006	0.0455
Buabenso Upstream	1.017	0.1687	0.0015	0.1156
Buabenso Downstream	0.4511	0.0977	0.0011	0.0534
Ayanfuri Upstream	1.582	0.1851	0.0083	0.71
Ayanfuri Downstream	1.648	0.188	0.0057	0.1592
Nkotumso Upstream	1.3421	0.3251	0.0073	0.1825
Nkotumso Downstream	1.5142	0.35	0.0061	0.1649
Treated Offin River (Control)	0.1393	0.0714	0.0008	0.03345
WHO permissible Standard for drinking water 2011	3	0.01	0.006	0.01

**AAS – Atomic Absorption Spectrometer, ICP – Inductively Coupled Plasma

Table 5: Concentrations of heavy metals from the various sampling points in Mg/l

4.2 Upstream Concentrations

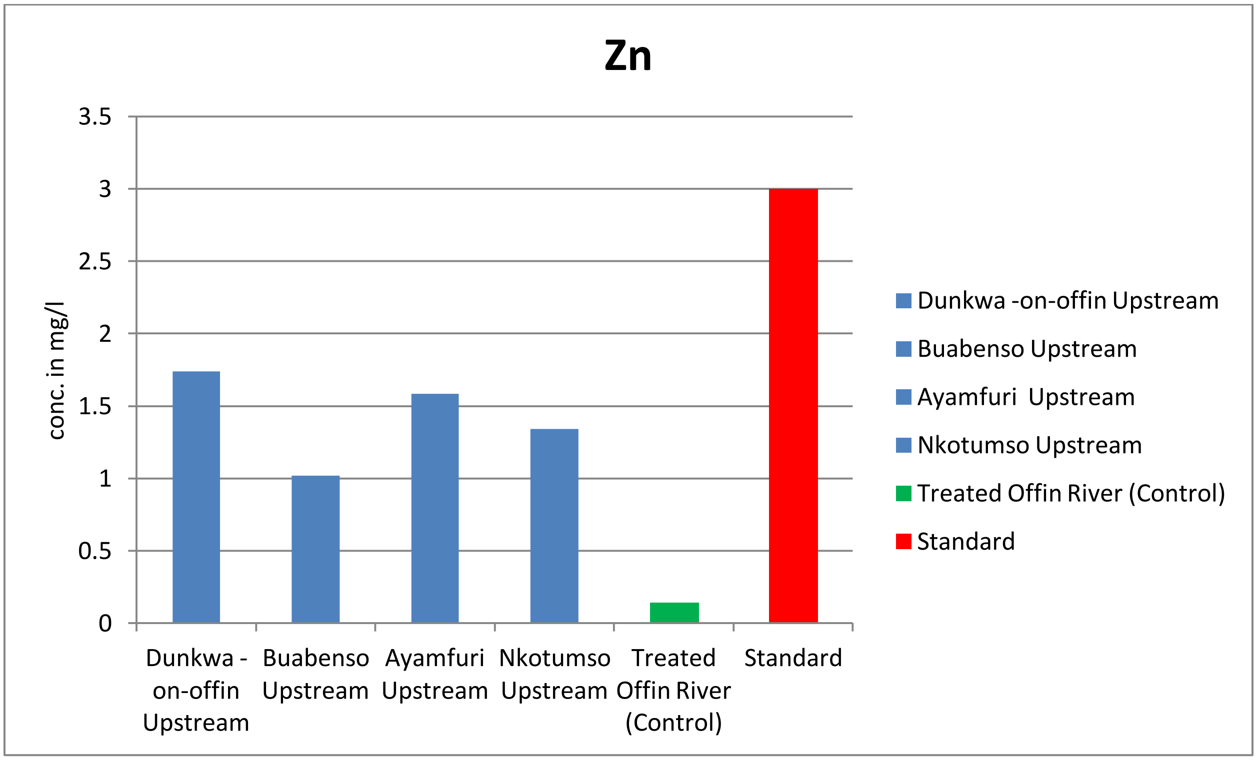


Figure 12: Upstream concentrations of Zn compared with control and standard

4.2.1 Zinc

From the graph above the concentrations taken up the upstream points were all below the standard set by WHO to be 3.0mg/l. This implies that, the concentrations of Zinc were not higher or in a state that will cause for public panicking.

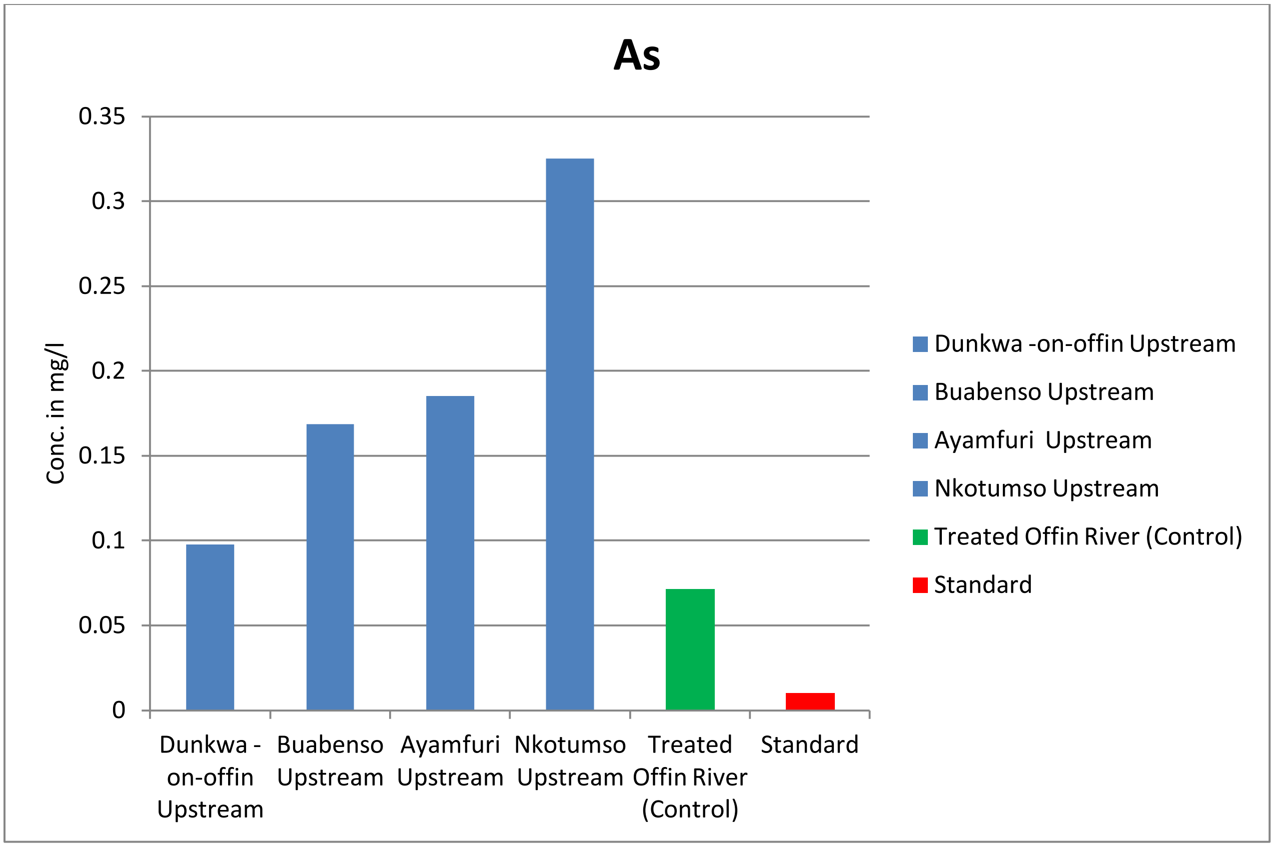


Figure 13: Upstream concentrations of As compared with control and standard

4.2.2 Arsenic

From the table above, it was clear that, concentrations of Arsenic for samples taken at the upstream points of Dunkwa-on-Offin, Buabenso, Ayanfuri and Nkotumso were all higher than the standard values assigned by W.H.O. Even the treated Offin River recorded values higher than the 0.01mg/l assigned by W.H.O as the permissible limit in drinking water.

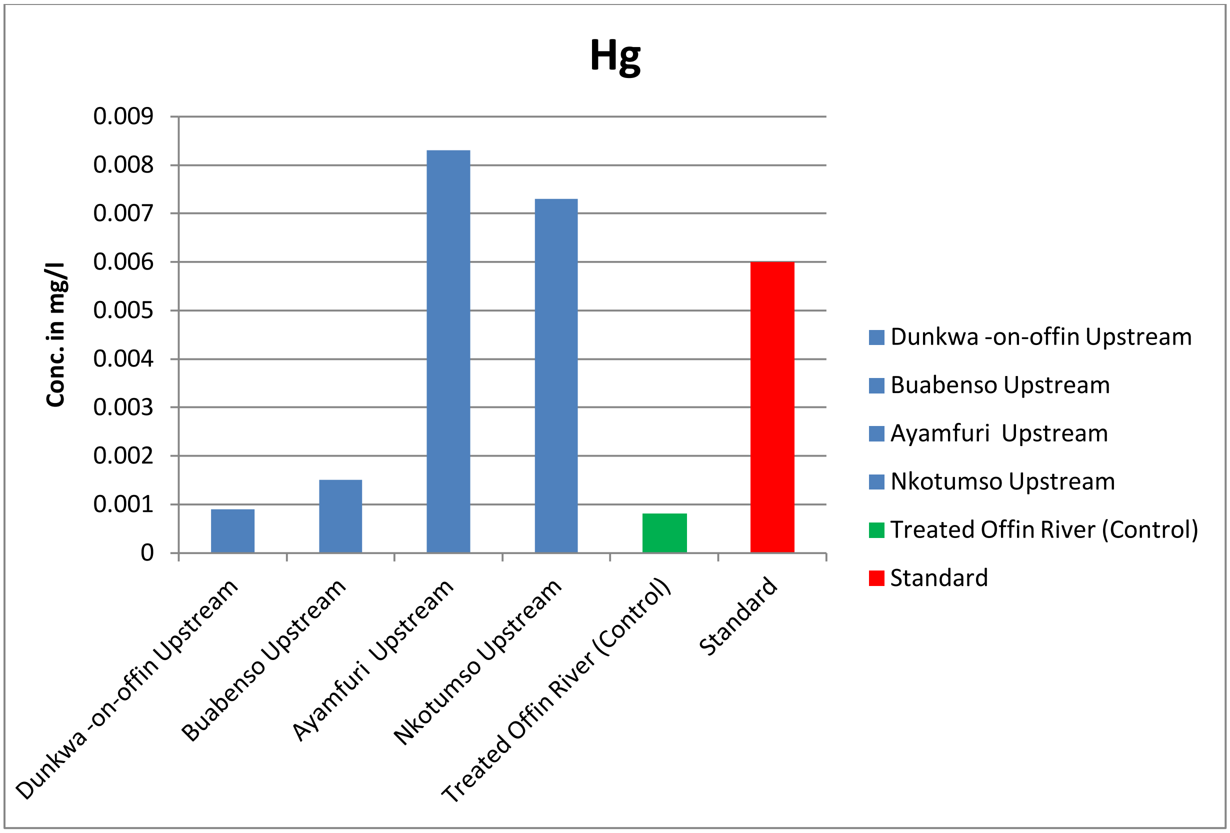


Figure 14: Upstream concentrations of Hg compared with control and standard

4.2.3 Mercury

From the graph above, concentrations from the upstream of Dunkwa-on-Offin, Buabenso and the treated Offin River recorded less concentration as compared to concentrations recorded at Ayanfuri and Nkotumso given the permissible limit set by the WHO to be 0.006mg/l.

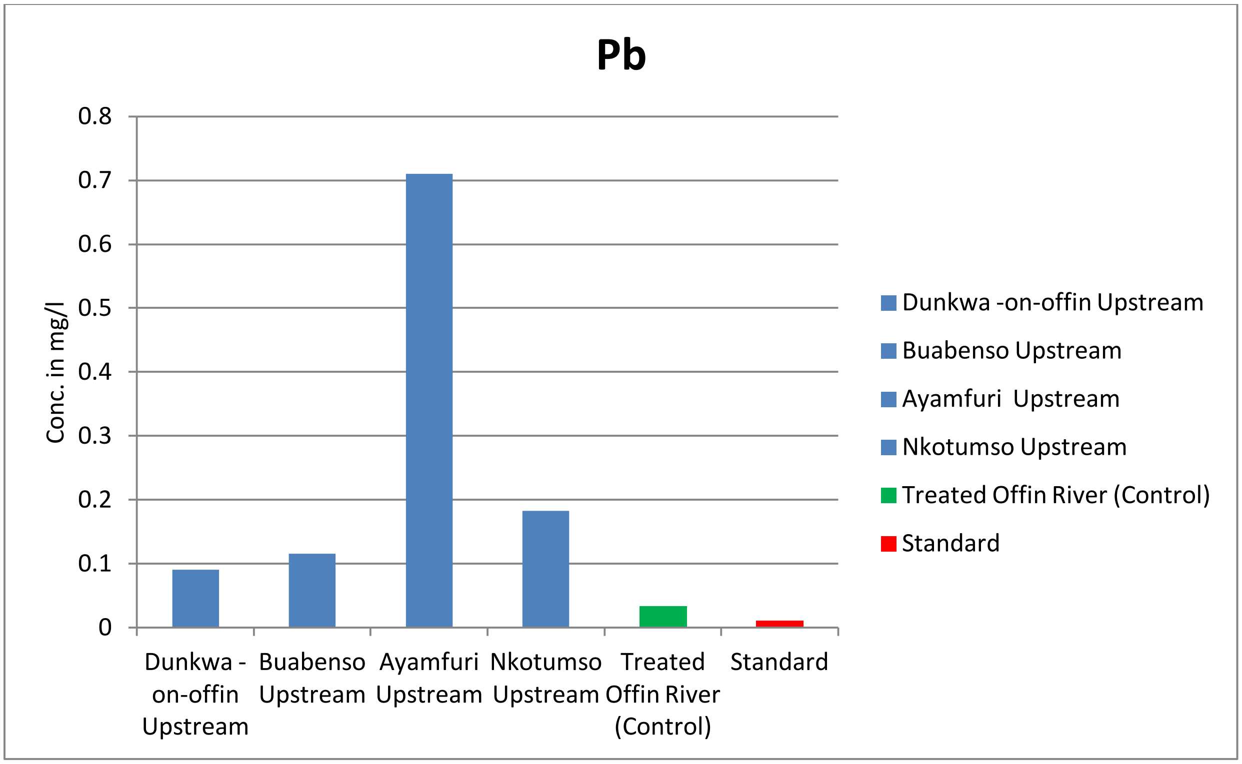


Figure 15: Upstream concentrations of Pb compared with control and standard

4.2.4 Lead

All concentrations for lead were higher than the permissible standard set by WHO to be 0.01mg/l.

4.3 Downstream Concentrations

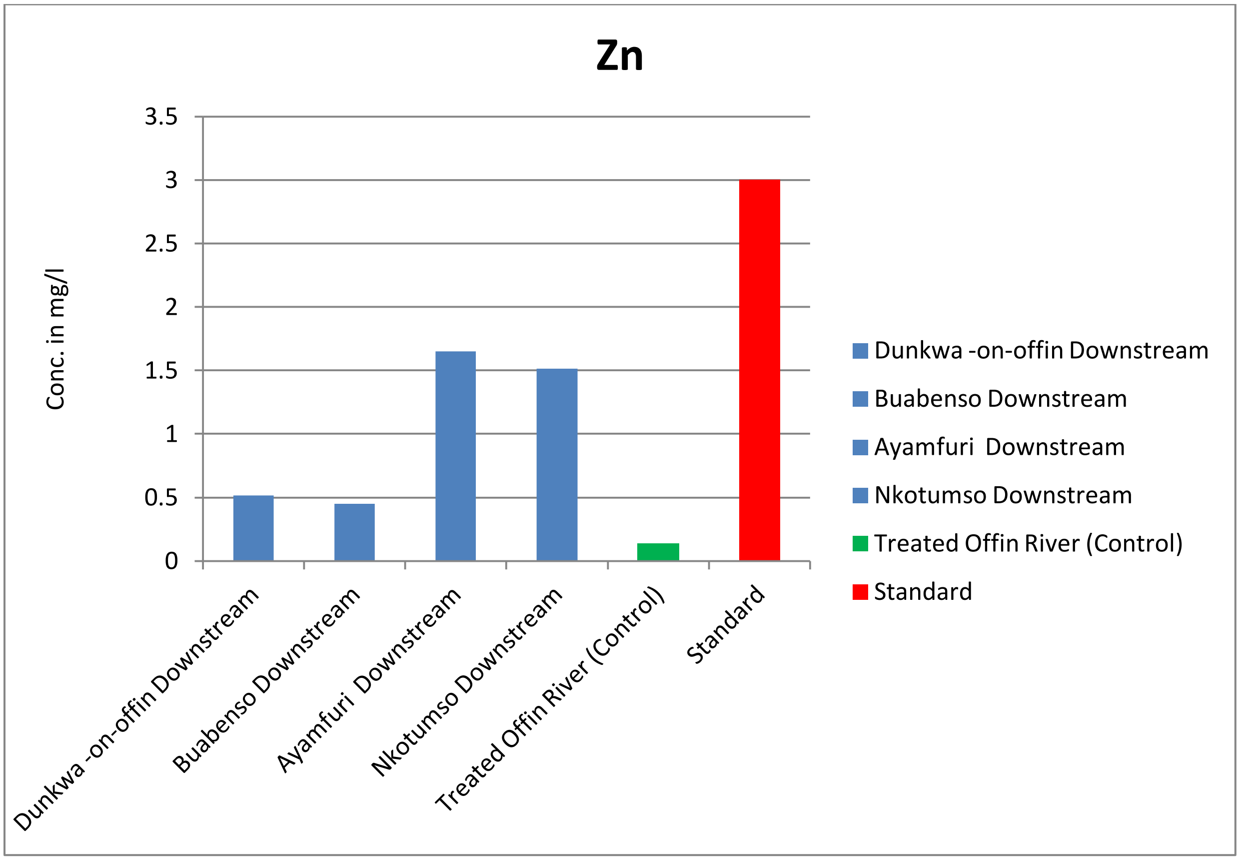


Figure 16: Downstream concentrations of Zn compared with control and standard

4.3.1 Zinc

From the graph above the concentrations taken up the downstream points were also all below the standard set by WHO to be 3.0mg/l. This implies that, the concentrations of Zinc were not higher or in a state that will cause for public attention.

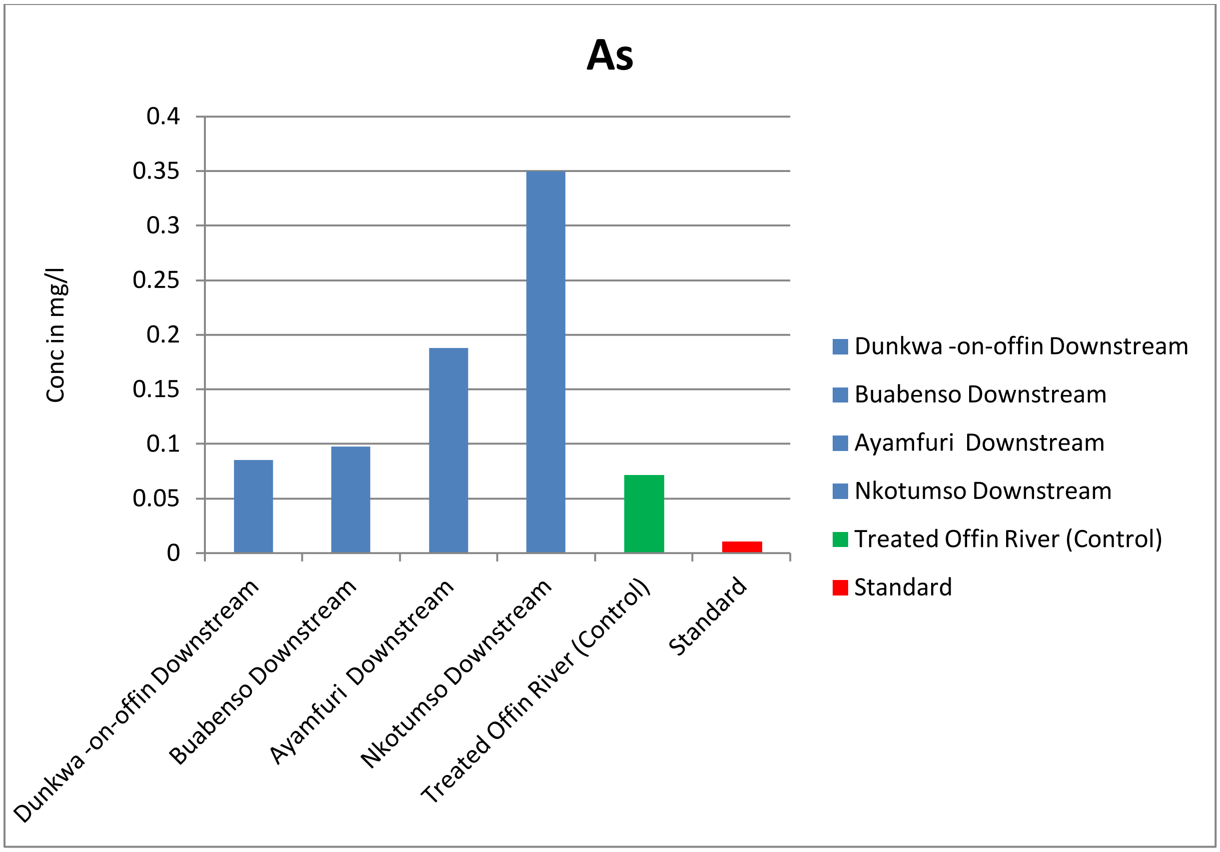


Figure 17: Downstream concentrations of As compared with control and standard

4.3.2 Arsenic

From the table above, it was clear that, concentrations of Arsenic for samples taken at the downstream points of Dunkwa-on-Offin, Buabenso, Ayanfuri and Nkotumso were all also higher than the standard values assigned by WHO. Even the treated Offin River recorded values higher than the 0.01mg/l assigned by WHO as the permissible limit in drinking water.

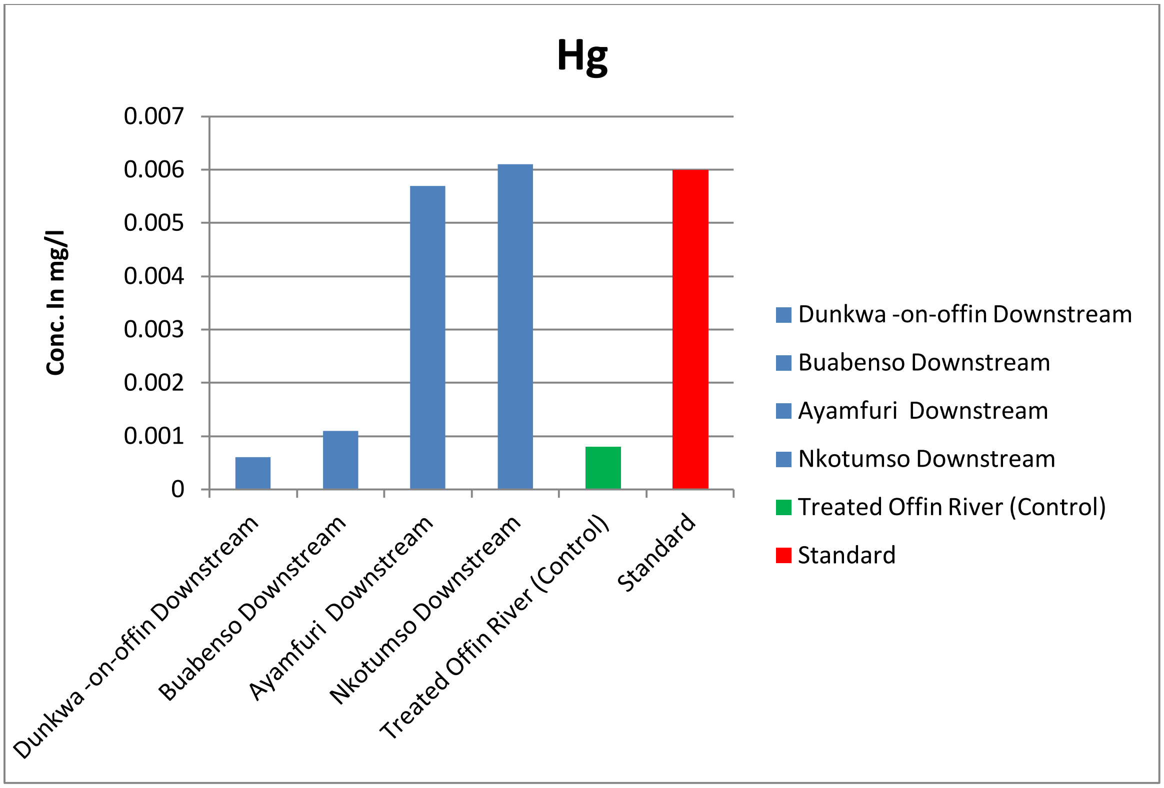


Figure 18: Downstream concentrations of Hg compared with control and standard

4.3.3 Mercury

From the graph above, concentrations from the downstream of Dunkwa-on-Offin, Buabenso, Ayanfuri and the treated Offin River recorded less concentration as compared to concentrations recorded at Nkotumso given the permissible limit set by WHO to be 0.006mg/l. Here only Nkotumso downstream recorded values higher than the permissible standard for drinking water quality.

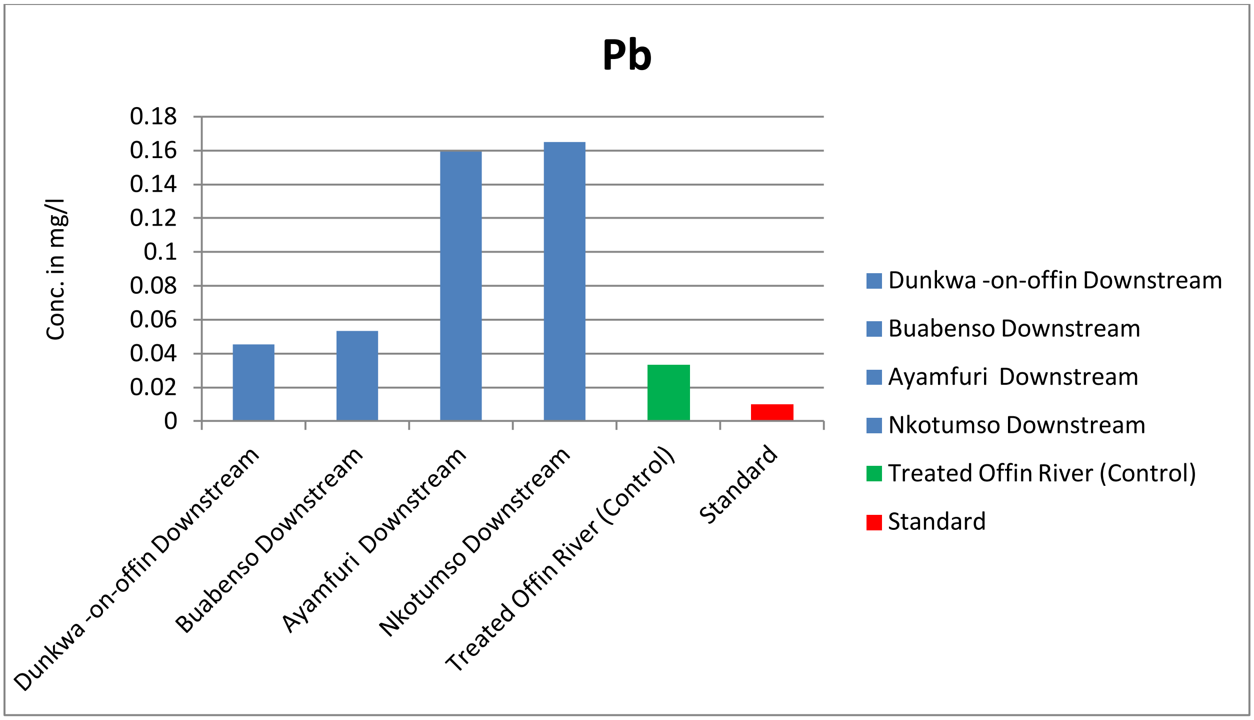


Figure 19: Downstream concentrations of Pb compared with control and standard

4.3.4 Lead

All values recorded here also showed higher concentrations above standard.

4.4 Reasons for higher concentration of Arsenic and Lead for control sample in some cases

From the concentrations recorded in some upstream and downstream sampling points, the Arsenic and Lead concentrations at the control point was even above the permissible limit. This is solely because, recently, the already treated Offin River at Dunkwa has started seeing some levels of pollution. Some miners have started discharging mining waste into the river without knowledge of authorities. This information was made available to me by someone I interviewed during my stay at Dunkwa.

4.5 Mean Concentration of Heavy Metals

		Metals			
Sample	Community	Zn (Mg/l)	As (Mg/l)	Hg (Mg/l)	Pb (Mg/l)
1	Dunkwa -On-Offin	1.12815	0.0916	0.00075	0.0682
2	Buabenso	0.73405	0.1332	0.0013	0.0845
3	Ayanfuri	1.615	0.18655	0.007	0.4346
4	Nkotumso	1.42815	0.33755	0.0067	0.1737
	Control	0.1393	0.0714	0.0008	0.03345
	WHO permissible Standard	3	0.01	0.006	0.01

Table 6: Mean concentrations of heavy metals from the various sampling points in Mg/l

From the table above, it can be noticed that the town with the highest concentration of these metals in its water is Ayanfuri followed by Nkotumso with the town with the least concentrations being Dunkwa-On-Offin. This is mainly so because most efforts to curtail illegal mining activities have been maximized most in Dunkwa. Arsenic and Lead showed higher concentrations than Mercury and Zinc throughout the study.

This might have contributed to it being the town with the least concentrations here.

Dunkwa < Buabenso < Nkotumso < Ayamfuri.

4.6 Interpretations of Elevated Concentrations

4.6.1 Interpretation of the Impact of Higher Arsenic Concentrations for Humans

1. Acute intoxification to people who drinks from such contaminated waters.

2. Abdominal pains can also be other side effects that can be associated with cooking or drinking with water sources from these areas.
3. Nausea is possible with drinking from water collected from these areas
4. Continual bathing or swimming in these water sources can later lead to skin cancer over the years.
5. Bladder and lung cancer is another effect to worry about when drinking from here.
6. Muscular cramps are also possible for people who drink from here without knowledge of the Arsenic concentration in these water sources.

4.6.2 Interpretation of the Impact of Higher Arsenic Concentrations for Irrigation

1. Use of arsenic-contaminated irrigation water decreased seed germination and rice yield, reduced plant height and affected development of root growth (Abedin et al., 2002).

4.6.3 Interpretation of the Impact of Higher Mercury Concentrations for Humans

1. Mercury will cause severe disruption of any tissue with which it comes into contact with. However, the two main effects of mercury poisoning are neurological and renal disturbances (WHO, 2005).
2. Hearing Impairment can result from continuous accumulation of mercury in the human body and later result in memory problems.
3. Can also affect developing fetus of pregnant women
4. Kidney damage

4.6.4 Interpretation of the Impact of Higher Arsenic Concentrations for Irrigation

1. Continual usage of water containing mercury for irrigation may lead to the eventual build up of toxic mercury in agricultural soils which when taken by plants can be harmful to man and animals that consume the end products.

4.6.5 Interpretation of the Impact of Higher Lead Concentrations on Humans

1. Reproductive toxicity, embryo toxicity, and teratogenicity: Effects on sperm counts and on the testicles (testicular atrophy) in male rats and on estrous cycles in female rats (Rice and Karpinski, 1988).
2. Effects on cardiovascular functioning in humans (Vaziri, 2002
3. Effect on renal functioning (Gonick, 2002).
4. Headache and restlessness are also common symptoms (Beattie et al. 1972).
5. Effect on kidney, lungs and may lead to brain cancer with time (Steenland and Boffetta, 2000)
6. All effects of lead are of health concern for human however, children are at most risk during early childhood (P.de Voigt (ed), 2016).

4.6.6 Interpretation of the Impact of Higher Lead Concentrations for Irrigation

Can inhibit plant cell growth at very high concentrations of 5.00mg/l but though concentrations are higher isn't so high to cause serious problems in irrigation waters. [10]

[10] www.fao.org/docrep/003/t0234e/t0234e06.htm accessed on 18-06-2018

4.7 Correlation of Mean Concentrations

		Metals			
Sample	**Community**	**Zn (Mg/l)**	**As (Mg/l)**	**Hg (Mg/l)**	**Pb (Mg/l)**
1	Dunkwa -On-Offin	1.12815	0.0916	0.00075	0.0682
2	Buabenso	0.73405	0.1332	0.0013	0.0845
3	Ayanfuri	1.615	0.18655	0.007	0.4346
4	Nkotumso	1.42815	0.33755	0.0067	0.1737
5	Treated Offin River (Control)	0.1393	0.0714	0.0008	0.03345

Table 7: Correlations of mean metal concentrations

	Zn	**As**		**Hg**		**Pb**	
			R^2		R^2		R^2
Zn	-	0.66	0.44	0.8	0.64	0.76	0.58
As	-	-	-	0.83	0.70	0.42	0.18
Hg	-	-	-	-	-	0.83	0.70
Pb	-	-	-	-	-	-	-

Table 8: Correlation table of metals with R^2 values

From the table above, the correlation of Zinc and Arsenic shows a value of 0.66 indicating that there is a higher positive linear correlation between the two metals. Zinc and Mercury also gives a correlation of 0.80 which also suggests a higher positive correlation as Zinc and Lead which gives a correlation value of 0.76.

Arsenic and Mercury also gives a higher positive correlation of 0.83 but Arsenic and Lead however gives a lower correlation of 0.42. However mercury and lead gives a higher positive linear correlation of 0.83.

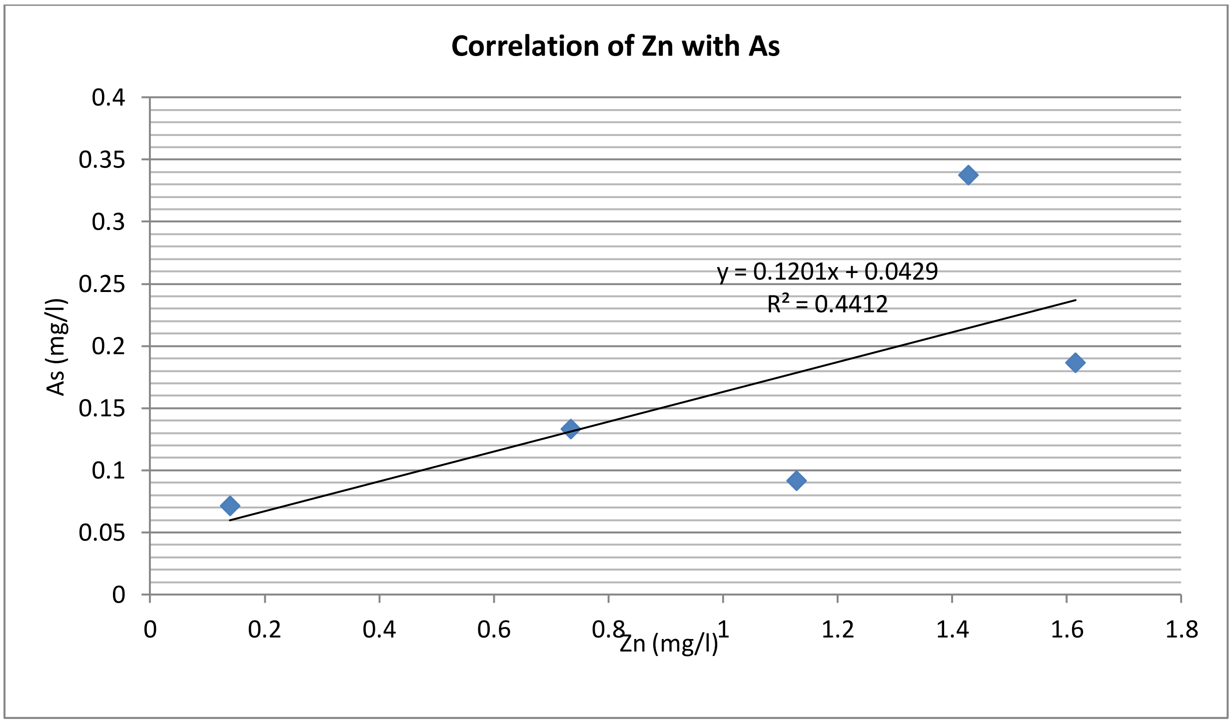


Figure 20: Correlation of Zinc with Arsenic

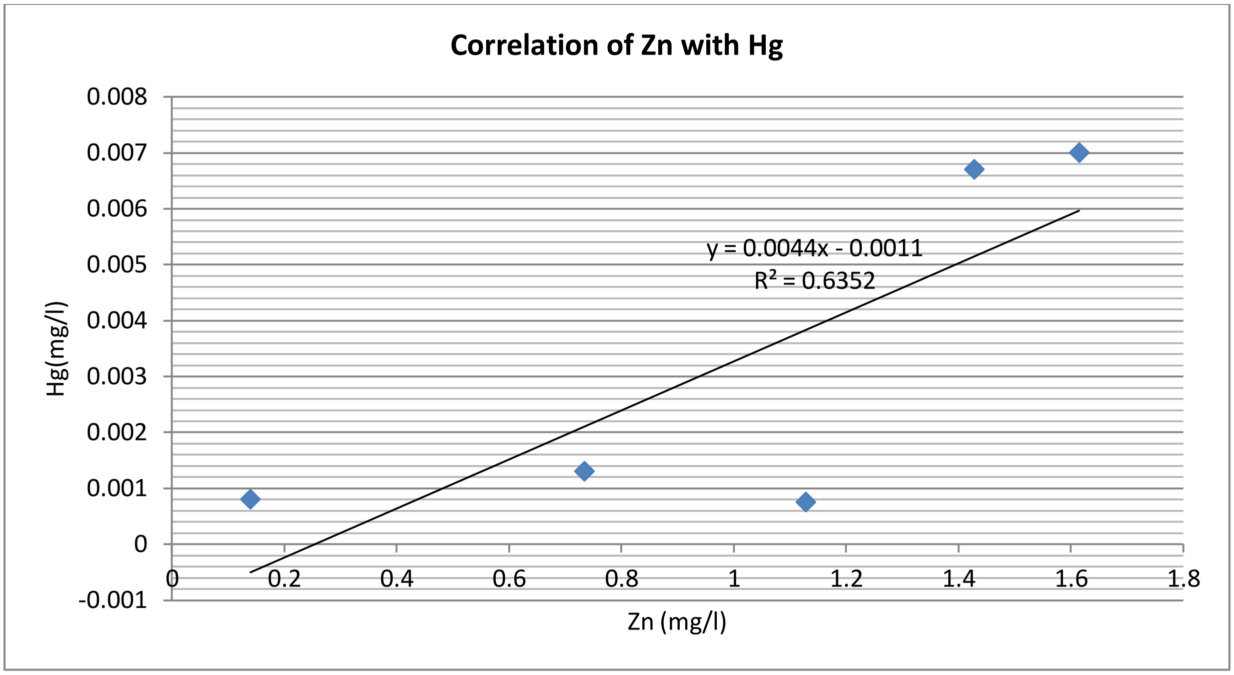


Figure 21: Correlation of Zinc with Mercury

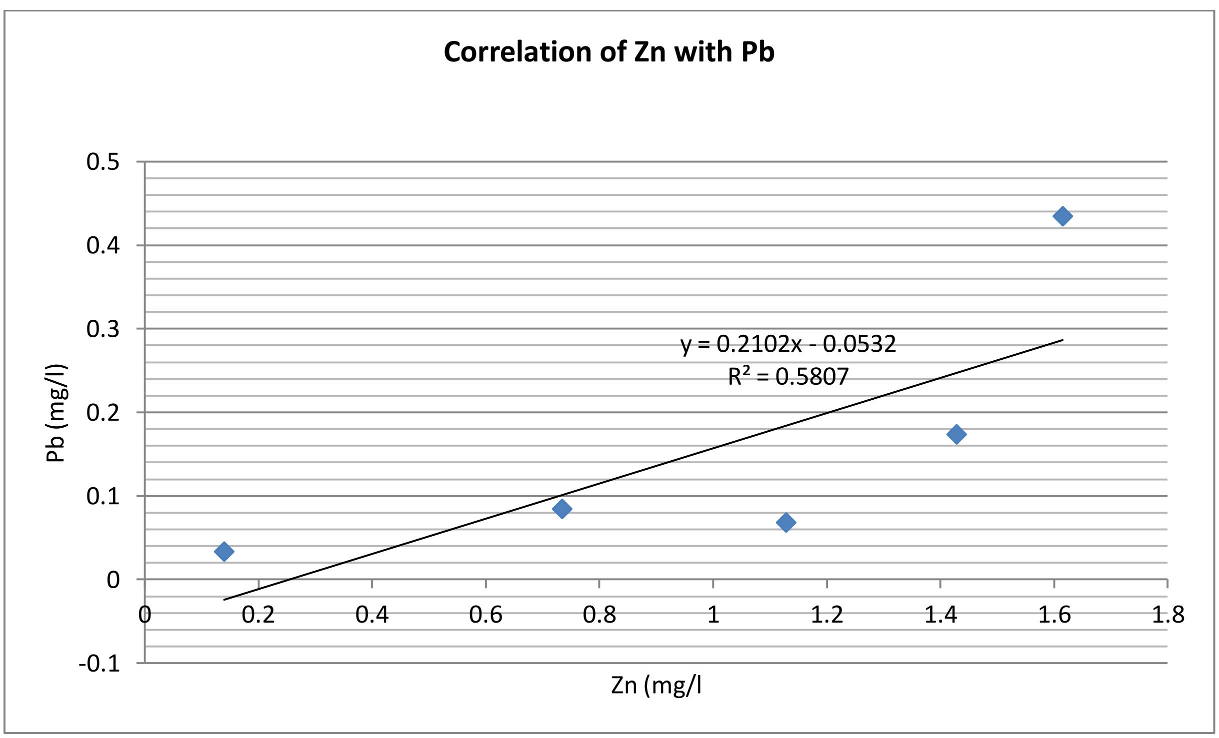


Figure 22: Correlation of Zinc and Lead

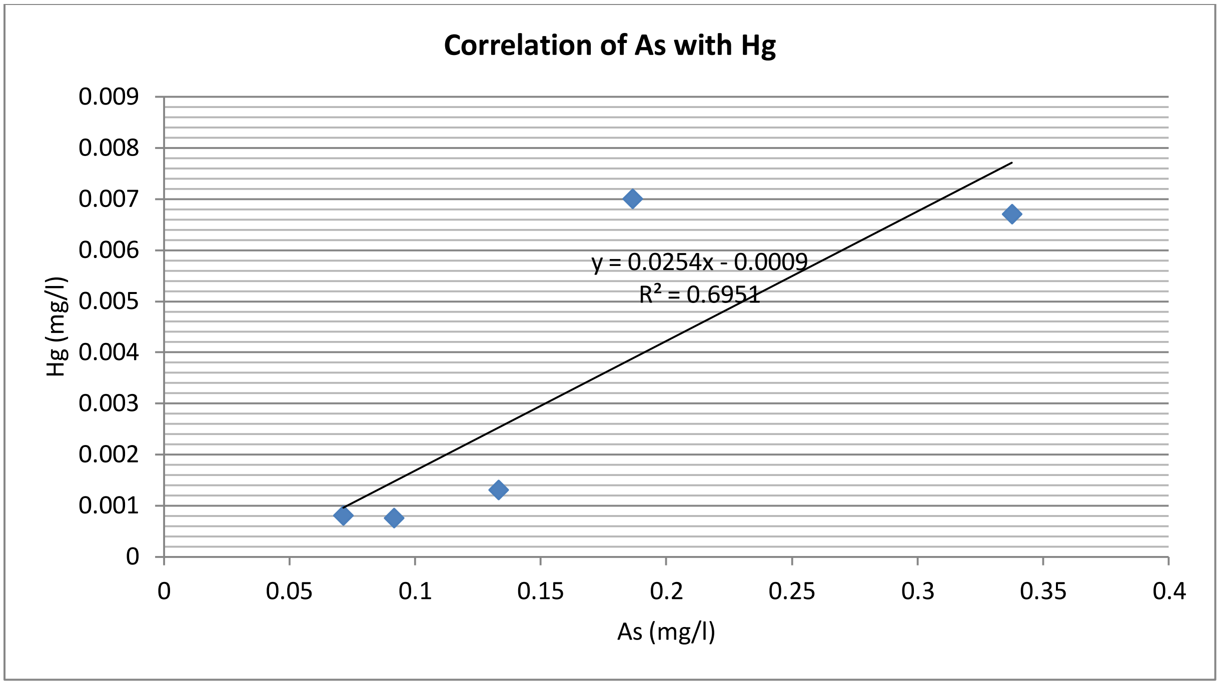


Figure 23: Correlation of Arsenic with Mercury

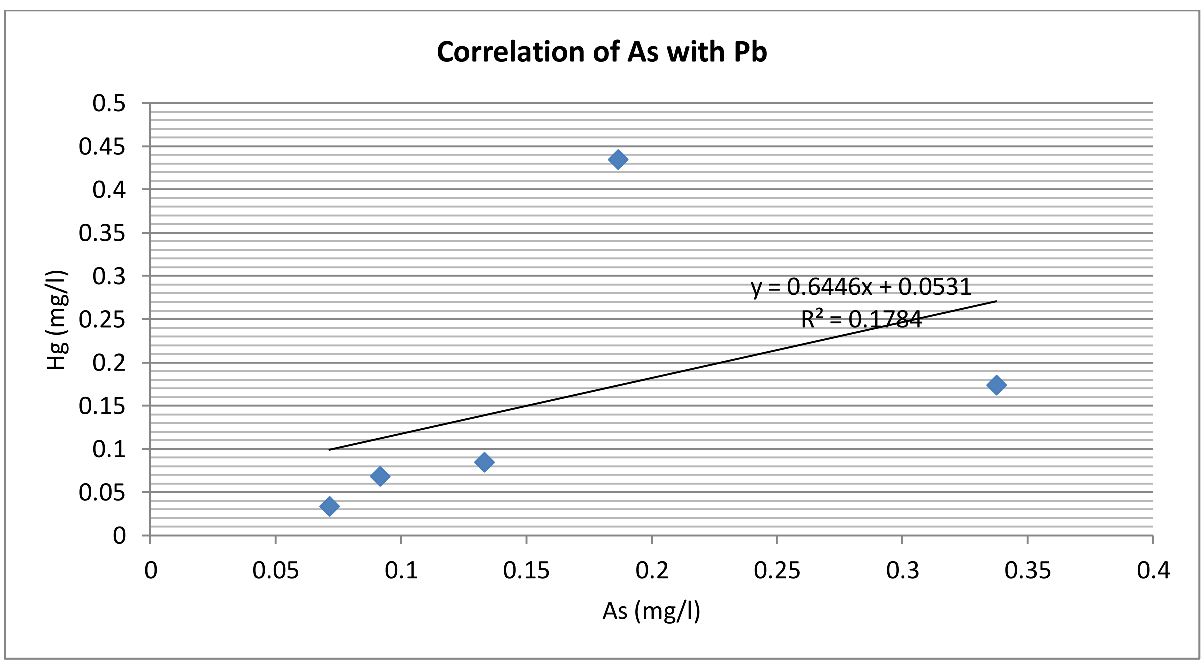


Figure 24: Correlation of Arsenic with Lead

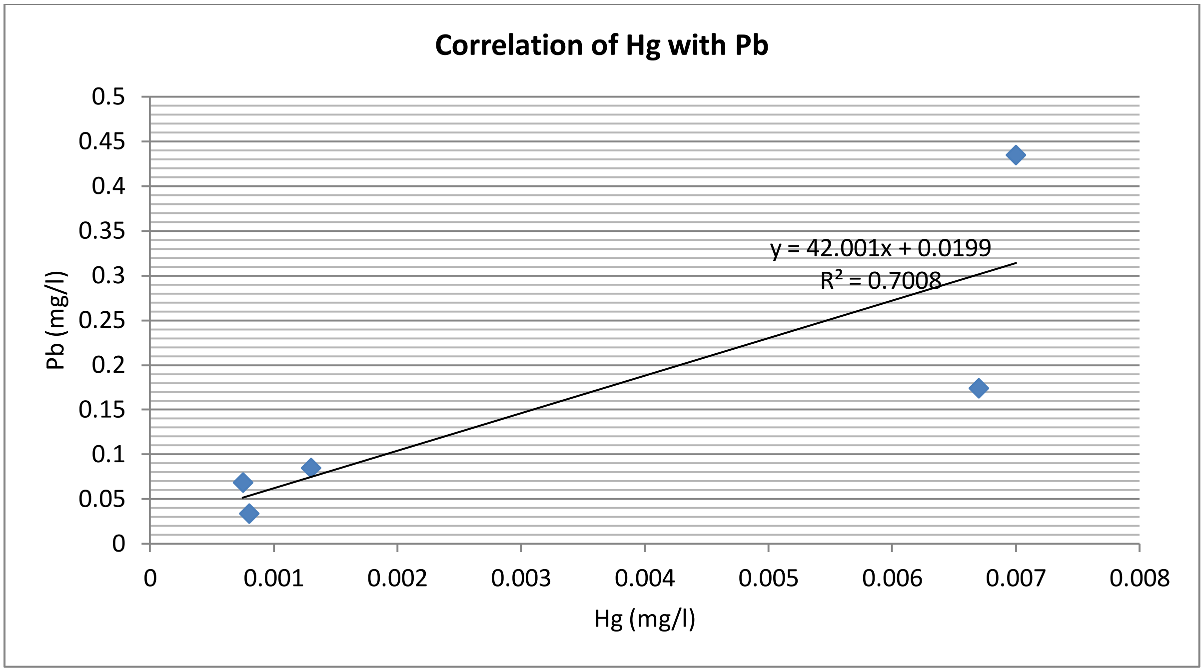


Figure 25: Correlation of Mercury with Lead

4.8 Findings from Questionnaires

As explained earlier in chapter three, when it comes to issue of illegal mining, few people are willing to freely open up. This situation made it difficult first to reach a larger number of people with regards to interviews and questionnaire answering. However, with the very few that were able to own up, data collected were described in tables, graphs and charts and described in the sections below. It is very important to know that, all figures given here mainly represent that from the sampling (respondents) and not from the entire population.

4.9 Dunkwa-On-Offin

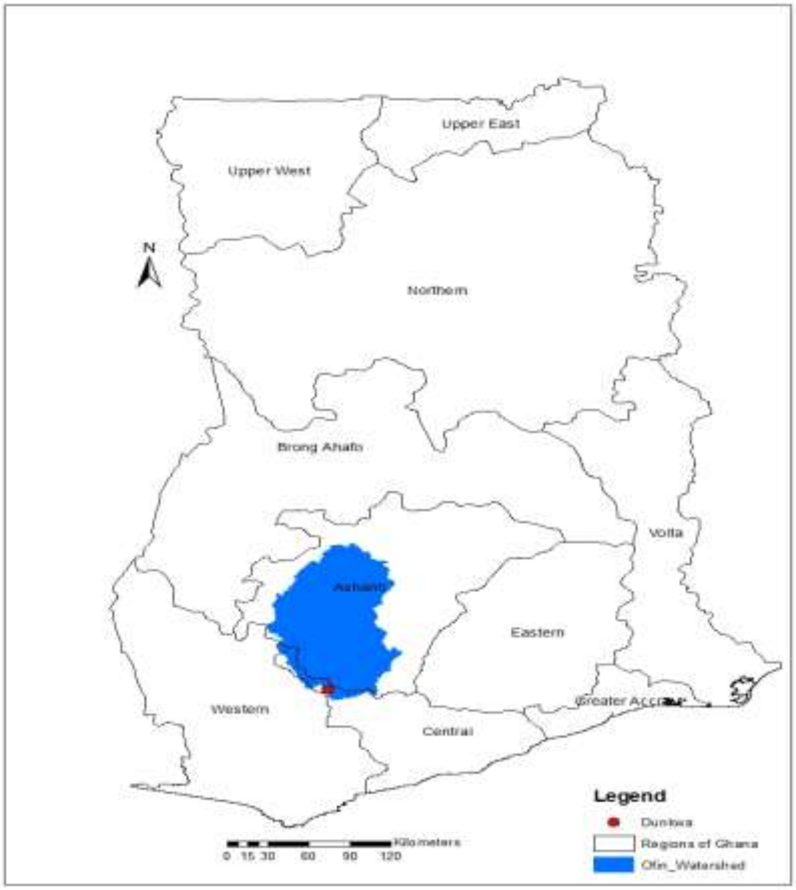


Figure 26: A map of Ghana showing location of Dunkwa

Dunkwa-On-Offin is a town in the central region of Ghana. It's mostly called Dunkwa and it's currently the capital of the Upper Denkyira East Municipal District. From the 2013 settlement population statistics, it has a population of around 33, 379 people.[11] Located on the Offin River, the town rises 117 metres above sea level.[12] The major occupation for the people of Dunkwa is Farming, mining and trading. Its geographical cordinates are 5.969812º N, -1.783097º W.

---

[11] www.wikiwand.com/en/Dunkwa-on-Offin .Accessed on 23-09-18
[12] www.wikiwand.com/en/Dunkwa-on-Offin .Accessed on 23-09-18

With regards to questionnaire distribution, only 30 people responded and information about these 30 respondents is as described in tables and charts below. 7 out of the 30 were farmers, 4 were students, and 14 of them were into gold mining, 3 government workers and 2 admitted to not being employed. However, the gold miners couldn't tell me if their activity were that of the illegal mining or legal.

Profession	**Frequency**	**Percentage**
Farmers	7	23%
Students	4	13%
Gold Miners	14	47%
Government workers	3	10%
Not employed	2	7%
Total	**30**	**100%**

Table 9: Population structure of Dunkwa – on-Offin showing frequency and percentage from questionnaire

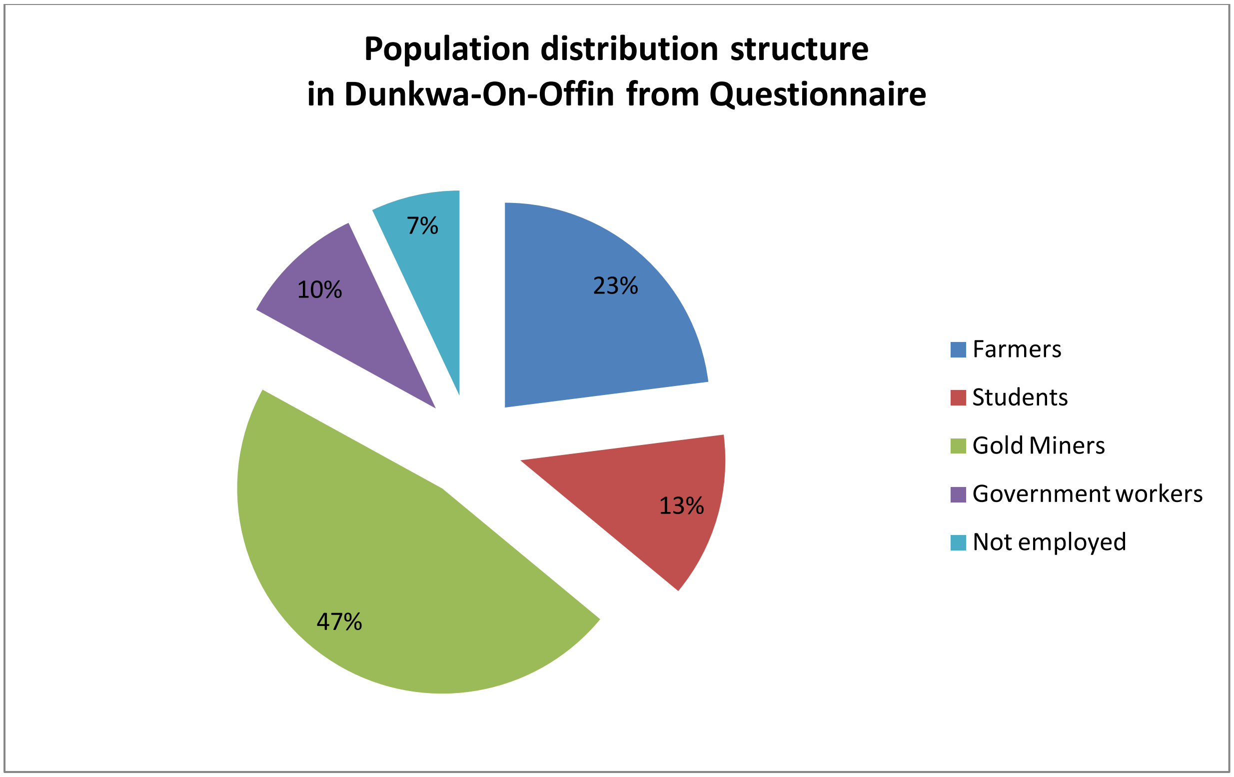


Figure 27: Population distribution structure in Dunkwa – on – Offin from Questionnaire

Item	**Frequency**	**Percentage**
Number of people involved in the small scale mining	14	47%
People who believed in the continuation of the "Galamsey" activities	22	73%
Number of people who don't believe in continuation of activity	8	27%
Number of complain to destruction to farmlands	20	67%
Number of people who agreed to using Mercury	8	27%
Number of people having knowledge of the effects of mercury on water bodies and health of animals	21	70%

Table 10: Other findings from questionnaire distribution in Dunkwa – on – Offin

4.9.1 Interpretation of findings

From the questionnaire, it is quite clear that majority of people living within Dunkwa are mostly Gold miners or are people who are into gold mining whether legal or illegal with the second largest distribution structure being farmers. It is also evident that, much people have greater knowledge of the effects of mercury. As much as few people only responded positive to using mercury in gold recovery, observations from the field indicated that, it is widely used in the business of gold mining within the region but few were willing to freely own up to using it. Complain to farmlands were noticed as a result of illegal gold mining activities within the community and several people have in the past noticed mercury and other chemical spills within their farmlands and rivers.

4.10 Buabenso

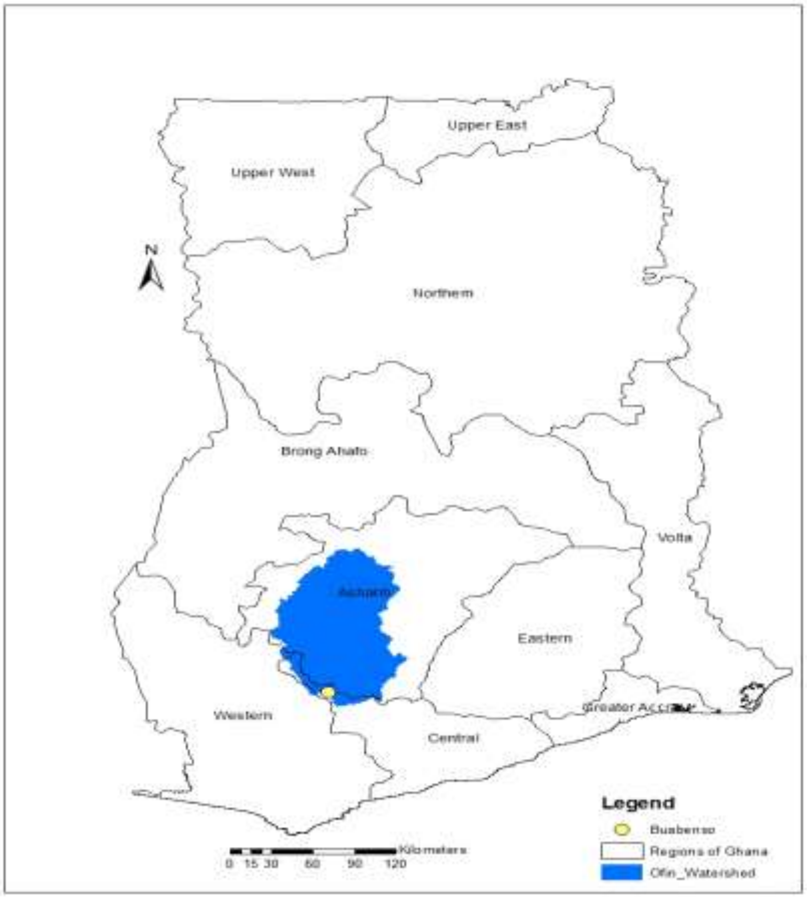


Figure 28: Map of Ghana showing location of Buabenso

Buabenso is located in the north west of the central region of Ghana with geographical cordinates of 5.955425º N, -1.738065º W. The major occupation within this community is farming and mining. With regards to questionnaire distribution, only 40 people responded and information about these 40 respondents is as described in tables and charts below.

Profession	**Frequency**	**Percentage**
Farmers	16	40%

Students	6	15%
Gold Miners	12	30%
Government workers	2	5%
Not employed	4	10%
Total	**40**	**100%**

Table 11: Population structure of Buabenso showing frequency and percentage from questionnaire

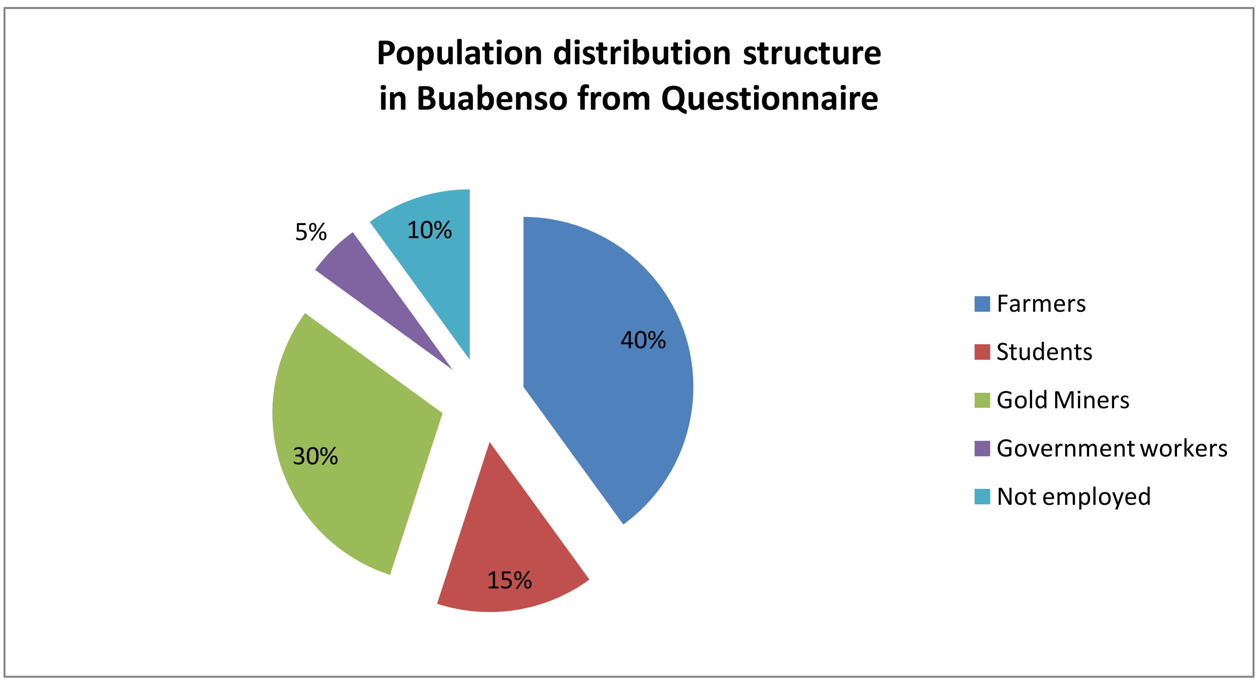


Figure 29: Population distribution structure in Buabenso from Questionnaire

Item	Frequency	Percentage
Number of people involved in the small scale mining	16	40%
People who believed in the continuation of the "Galamsey" activities	18	45%
Number of people who don't believe in continuation of activity	22	55%
Number of complain to destruction to farmlands	12	30%
Number of people who agreed to using Mercury	7	17.5%
Number of people having knowledge of the effects of mercury on water bodies and health of animals	31	77.5%

Table 12: Other findings from questionnaire distribution in Buabenso

4.10.1 Interpretations of findings

Per the outcome of the questionnaire distribution, it is evident that, majority of people living within Buabenso are farmers with the second largest group being gold miners both legal and illegal miners. As much as a larger percentage of the population structure know the negative effects of mercury on water bodies and health of plants and animals, the devastating effects of illegal mining to the environment, it is still quite surprising when other people still believe in the continuation of illegal mining within the community. Also, the destruction of farmlands clearly explains that illegal mining does more harm than good to the community and even though they would love to have a way to overcome this effect, only few people have the financial and technical means to overcome the effects.

4.11 Ayanfuri

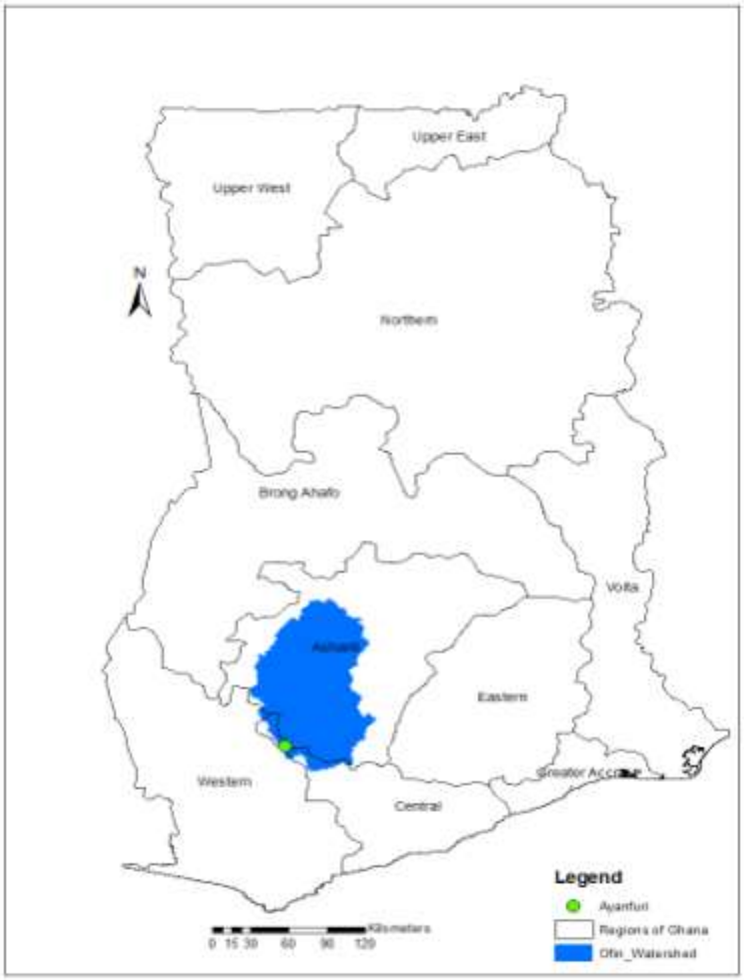


Figure 30: Map of Ghana showing location of Ayanfuri

Ayanfuri is one of the mining towns within the central region of Ghana with an elevation of 76m.[13] It is located in the Upper Denkyira West district and has geographical cordinates 5.964156º N, and -1.895271º W. The Upper Denkyira West district has a population of 31,300 of which 3,935 of the population lives in Ayanfuri (Amponsah et. al, 2015). The major occupation of the people of Ayanfuri includes farming, trading and mining. With regards to questionnaire

[13] https://en.wikipedia.ord/wiki/Ayanfuri Accessed on 23-09-18

distribution, only 47 people responded and information about these 40 respondents is as described in tables and charts below.

Profession	**Frequency**	**Percentage**
Farmers	19	40.42%
Students	4	8.51%
Gold Miners	18	38.30%
Government workers	5	10.64%
Not employed	1	2.13%
Total	**47**	100%

Table 13: Population structure of Ayanfuri showing frequency and percentage from Questionnaire

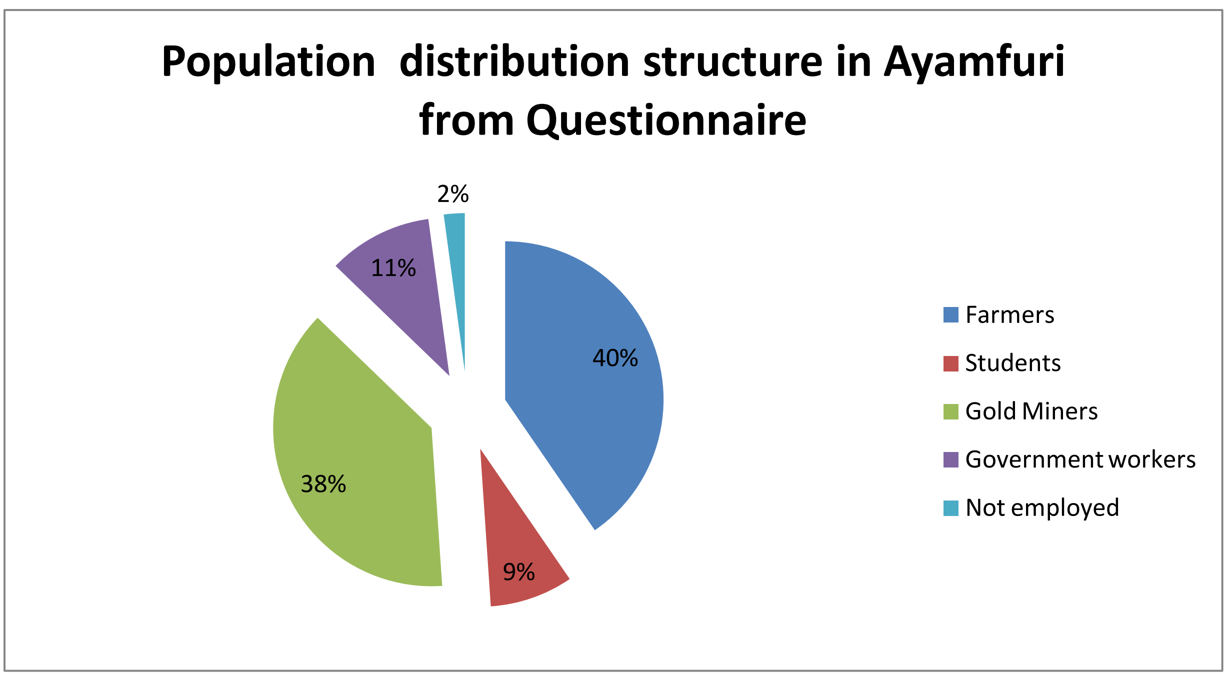


Figure 31: Population distribution structure in Ayanfuri from Questionnaire

Item	**Frequency**	**Percentage**
Number of people involved in the small scale mining	22	47%
People who believed in the continuation of the “Galamsey” activities	15	32%
Number of people who don’t believe in continuation of activity	5	11%
Number of complain to destruction to farmlands	8	17%
Number of people who agreed to using Mercury	15	32%
Number of people having knowledge of the effects of mercury on water bodies and health of animals	14	30%

Table 14: Other findings from questionnaire distribution in Ayanfuri

4.11.1 Interpretations from Findings

From the questionnaire, it is quite clear that majority of people living within Ayanfuri are mostly farmers and miners. It is clear that only few people here are unemployed. This is due to the busy nature of the community as a mining town. Here, it also seems that as much as numerous effects of mercury are known, the inhabitants are still more interested in small scale mining.

4.12 Nkotumso

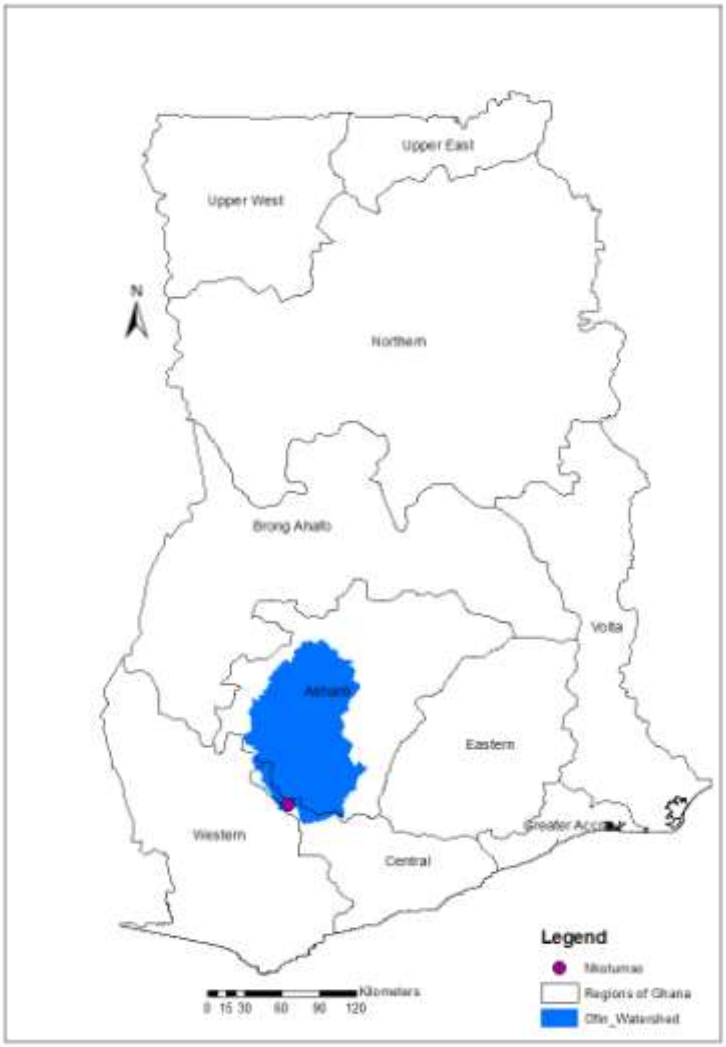


Figure 32: A map of Ghana showing Nkotumso

Nkotumso is located in the central region of Ghana with geographical cordinates of 5.999747º N, -1.918473º W. The major occupation within this community is farming and mining. With regards to questionnaire distribution, only 43 people responded and information about these 40 respondents is as described in tables and charts below.

Profession	**Frequency**	**Percentage**
Farmers	16	37.2%
Students	4	9.3%
Gold Miners	16	37.2%
Government workers	5	11.6
Not employed	2	4.7
Total	**43**	**100%**

Table 15: Population structure of Nkotumso showing frequency and percentage from questionnaire distribution

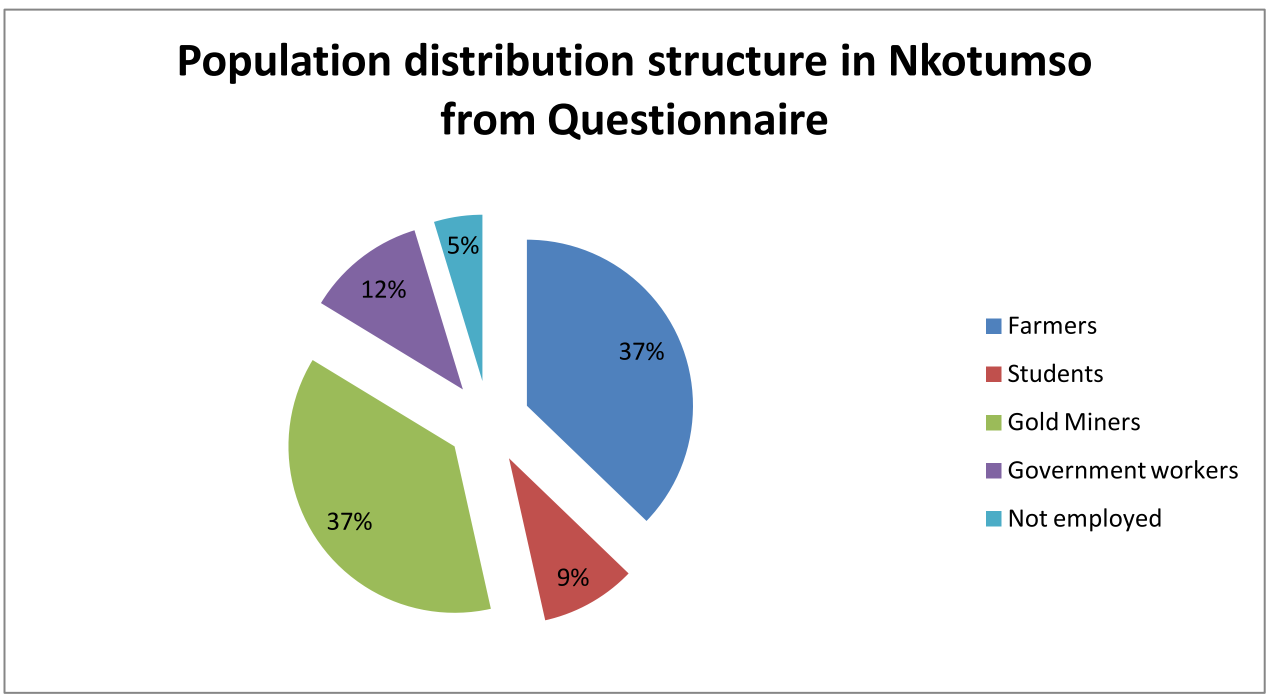


Figure 33: Population distribution structure in Nkotumso from questionnaire

Item	Frequency	Percentage
Number of people involved in the small scale mining	18	42%
People who believed in the continuation of the “Galamsey” activities	31	72%
Number of people who don’t believe in continuation of activity	12	28%
Number of complain to destruction to farmlands	17	40%
Number of people who agreed to using Mercury	3	7%
Number of people having knowledge of the effects of mercury on water bodies and health of animals	21	45%

Table 16: Other findings from questionnaire distribution in Nkotumso

4.13 Fertilizer Usage among Communities

During the field observation, 58 farms were visited in all four communities. 7 of these farms were in Dunkwa, 16 were in Buabenso, 19 were in Ayamfuri and 16 farms were also visited in Nkotumso. Most of the farmers were cocoa farmers with the cultivation of other crops as maize, tomatoes, yam, cassava and sorghum. Fertilizers noticed for use by the farmers were identified as NPK 15:15:15, NPK 23:10:05, urea and ammonium sulfate. Few farmers were also seen using other locally manufactured fertilizers and other organic fertilizers and green manures. However, data gathered from field visitations in this regard is described below.

		Fertilizer application farms		No fertilizers application	
Communities	Number of farms visited	Number of farms	Percentage	Number of farms	Percentage
Dunkwa-on-Offin	7	3	43%	4	57%
Buabenso	16	7	44%	9	56%
Ayanfuri	19	10	53%	9	47%
Nkotumso	16	12	75%	4	25%

Table 17: Tables showing fertilizer usage among communities

4.14 Relationship between the fertilizer application within communities and heavy metal concentration

Very large concentrations of chemicals are mostly spread on agricultural soils as fertilizers. According to a study conducted on fertilizer application and soils, fertilizers tend to increase metals particularly Cadmium, Lead and Arsenic (Atafar et.al, 2010). From the field observation, there seem to be a positive relationship between fertilizer application and heavy metal concentrations. This is because, concentrations recorded for Ayanfuri and Nkotumso were always very high as compared to concentrations recorded in Dunkwa and Buabenso. Also Arsenic and Lead seemed to record higher values throughout all sampling locations. Though the smelting process in the gold extraction could be the core factor, there is the indication that fertilizer application had an influence in the higher concentrations recorded.

4.15 The 'Galamsey' process as observed

The illegal gold mining mostly referred to as the "Galamsey" activities normally begins by excavating deep down the earth crust to about 50 feet deep down the earth crust. Mostly this excavation is aimed at extracting rocks suspected to contain gold, gold concentrates or precious minerals. This rocks are the broken down into smaller rock particles a little smaller or at times very much smaller than the original so as to enable easy washing.

The second stage involves passing these broken down rocks into a washing plant. This machine is designed in such a way that water is being directed towards the smaller rocks particles as they move along it.

Figure 34: Washing plant used to wash rock particles suspected to be containing gold concentrates

The reason is to wash the smaller rock particles of dirt that may be trapped within the rocks. On another side of the water plant are laid blankets. These blankets are placed to trap any gold particle that is being washed away.

Figure 35: Blankets used for trapping gold particles

The waste water is normally disposed off into pits dug by these miners or river bodies.

The next process involves removing the blankets onto another structure designed by the illegal miners. Here, the blankets are washed again into a bowl containing mercury. The purpose of this mercury is to trap the gold particles.

Figure 36: The last stage of gold trapping for refinery process

When washed into this bowl, they are visible here but trapped together with the mercury. They are finally being molded together with a rag into shapes, normally round. They are passed through hot fire to take away the mercury and bring out its golden brittle colour.

The dangerous thing here however is that, this waste water containing mercury are left on the ground untreated. The effect is made more serious when there is rainfall and it’s washed into flowing water bodies nearby. Sometimes, these washings are even done inside already polluted water bodies.

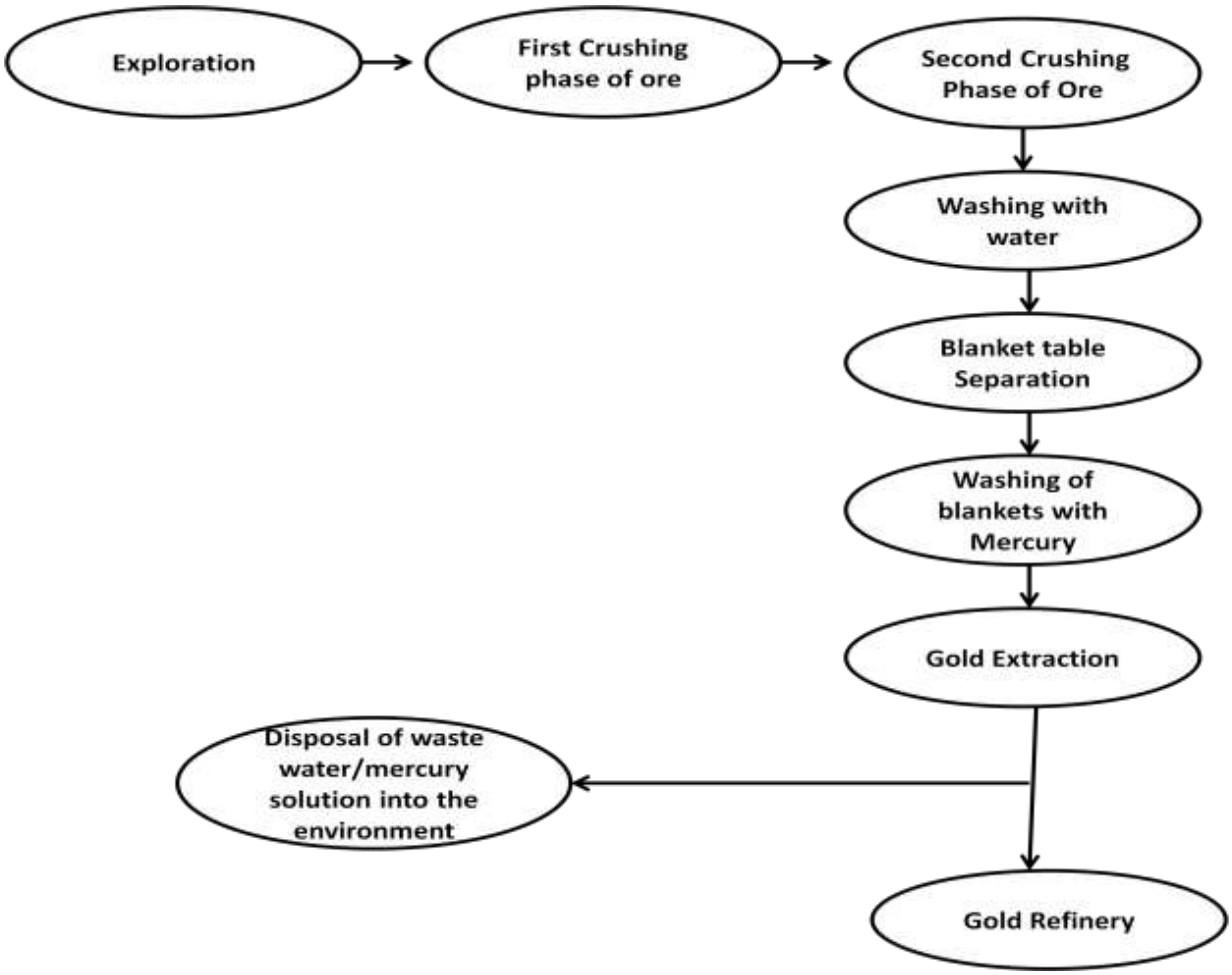
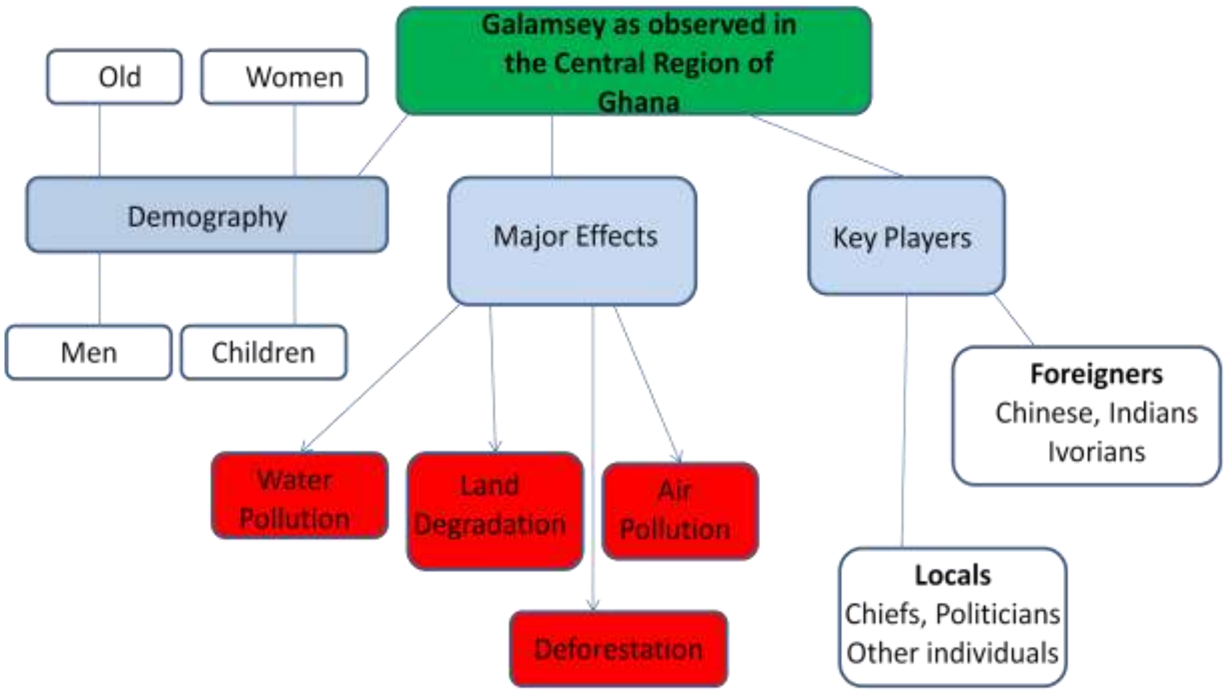


Figure 37: Diagrammatic Description of the “Galamsey” Process

What happens is that, after the gold is extracted for refinery, the waste water or solution containing mercury and or other chemicals are disposed off into the soil or the water bodies in which the washing plants are situated. These chemicals are later spread into the larger adjoining water bodies or leach into ground waters below. Those left on the soil also have the tendency to be washed into streams and other water bodies closer to them.

Illegal mining popularly termed as ‘Galamsey’ was also seen to be undertaken by both the old, men, women and children with two (2) major key players identified to be influencing the activity. The key players were composed of Foreigners with Chinese dominating and some major locals (Chiefs, unidentified politicians and few other locals) also behind the activity.



**Demography involves men, women, children and the old
Major Effects of "Galamsey" leads to water Pollution, land degradation, Deforestation and water pollution
Key Players are seen to be Foreigners and Locals**

Figure 38: Galamsey as observed in the central region of Ghana

4.16 RELEVEANT INSTITUTIONS AND POLICIES

According to the minerals and mining policy of Ghana 2014, several institutions have been identified as having a stake in mining issues in Ghana. However, the few institutions identified and considered to have relevant stake in the issues of illegal gold mining and water quality issues include; the minerals commission, ministry of Environment science and technology, the

Environmental protection Agency, Forestry Commission, lands commission and the water resources commission[14].

Minerals Commission

The minerals commission has a responsibility for awareness raising, regulating and managing all mineral resources belonging to the country and to cordinates all policies with regards to mineral resources. It has a department called the Inspectorate Division which is responsible for undertaking safety inspections regularly at mining sites to ensure that all mining companies comply with already established policies.

The Environmental Protection Agency

The Environmental Protection Agency is responsible for setting guidelines for the compliance of environmentally permissible mining activities.

Forestry Commission

The Forestry Commission of Ghana is the institution charged with the sustainanable management of the country's forest resources. It maintains a joint effort with the Minerals commission to ensure that all activities of mining are carried out with strict adherence to the laws and regulations governing the forestry department of Ghana.

[14] Minerals and mining policy of Ghana 2014. Accessed from https://www.extractiveshub.org/servefile/getFile/id/798 on 24-09-18

Water Resources Commission

The water Resources Commission is the institution charged with sustainable use of the country's water resources. It also has other equally important role of finding alternate uses of water that determines the important qualities of water as both economical and social good.

Lands Commission

This commission is charged with management of land uses in Ghana. It has an evaluation division, it determines the amount of compensation to individuals who might have been affected or lost their lands through mining activities. It has a survey and mapping division with responsibilities of demarcating, mapping and certifying land boundaries

Office of the Administrator of Stool Lands

This office has a responsibility of receiving payments of parts of royalties and rents for surface rights accruing to mining communities which are later to be giving to bonafide beneficiaries who might have suffered one way or the other from mining activities on their lands.

4.17 Minerals and Mining Act, 2006 of the Republic of Ghana

With regards to issue of mining in Ghana, the country is guided by the "Minerals and Mining Act, 2006"[15]. These Acts clearly specify everything about mining from acquiring license to mine, land available for application of mining rights, water rights, issues concerning forestry and environmental protection and all penalties in the issue of mining in the country. These Acts are specified in the "Seven hundred and third Act" of the republic of Ghana entitled "The Minerals

[15] http://extwprlegs1.fao.org/docs/pdf/gha85046.pdf Accessed on 27-09-2018

and Mining Act, 2006" enacted by the president and parliament of Ghana. Few notable and relevant chapters are explained below.

Mineral rights

Section nine (9) which talks about mineral rights clearly states in sub –section one (1) that, despite a right which any individual may hold to any land which may contain any minerals, the person or individual may however not conduct any activities with regards to the exploration or mining of minerals unless that individual have attained the necessary rights to mine in line with this Act.

Application for mineral rights

Section eleven (11) also talks about applying for mineral rights. Under this section, all applications for mining must be submitted to the Minerals Commission in writing with documents proving the individual or groups available financial and technical resources, overall budget on the mining project, proposal and schedule indicating how the supposed project will benefit the citizens of the country.

Water right

Water rights are discussed in section seventeen (17) of the Minerals and Mining Act, 2006. In this section, it is noted that subject to having the necessary permission under Act 552 of the Water Resources Commission Act 1996, one (the person/group/institution) may for the purposes of mining acquire, redirect, redirect, convey and make use of water from all water bodies available, however, this shouldn't destroy the water body.

Forestry and environmental protection

Issues regarding Forestry and Environmental Protection are also discussed in section 18 of the Mining Act. In this section, even after getting the necessary mining right, individuals, groups or institutions may once again obtain permission and permits from the Forestry Commission and the Environmental Protection Agency in the country. This is geared towards the sustainability of the natural resources, maintaining public health and ensuring the survival of the environment. It is with this regard, that one could be penalized when the mining operation destroys natural resources and becomes a threat to public health and the environment.

Small scale mining

Application for license to small scale mining

Issues regarding small scale mining are discussed under section 82 of the Minerals and Mining Act 2006. Under this section, the government of Ghana gives rights to small scale mining; however, this section makes it clear that, unless the Minister for Mines or an officer authorized by the minister has issued a license, no individual, group or institution may involve in any small scale mining activity.

Purchase of mercury

Purchase of mercury is spelt out in section 96. In this section, the government of Ghana gives recognition for the use of mercury for mining operations. However, he may obtain them from approved dealers in reasonable quantities suitable for the small scale mining activity.

Offences and penalties

Offenses and penalties concerning small scale illegal mining are spelt out in section 99 of the Minerals and mining Act 2006. Here, any individual, group or institution who involves in small scale mining without a license issued by the Minister does so illegally. Such person, group or institution commits an offense and is liable to a fine of a thousand penalty units as defined by the state or to imprisonment of a term of three years or even both. The state court that defines the penalty may also in addition, seize for the state from the individual, group or institution the mineral of which offense was made.

4.18 Where lies the Missing Gap

From the Minerals and Mining Act of 2006, enacted by the president and the parliament of the republic of Ghana, it is evident that, there are clearly distinct policies governing mining, water and forest resources conservation and the use of mercury in mineral exploration. Again the responsibilities of the several institutions that also have a stake in mining have also be discussed in the chapters above. The question therefore remains what the missing gap is or what is possibly going wrong? In field observation, interviews and from responses received from questionnaire distribution, few of such reasons include; weaker institutional capacities, revenues paid to the government by mining groups or institutions are too high and so people like to carry on their activities without knowledge of the state; thus illegal mining, insufficient institutional collaboration or coordinating mechanisms to sufficiently manage mining issues. Others also believe that, the monies they pay to the government is not properly used for the development of their communities so they would rather not pay any monies to the government; thus lack of transparency in managing mineral revenues.

Another observation I made was that, most of these mining sites were clearly owned by Chinese nationals and these were the very sites that payed little attention to sustaining the environment or doing any reclamation works after mining

4.19 Key findings

From the results and discussion, it was found that Ayamfuri recorded highest concentration throughout the study followed by Nkotumso, Buabenso and Dunkwa in that order. Higher concentrations of Arsenic, Lead and mercury in the water samples was attributed to improper discharge of mining waste which tends to find themselves in surrounding water bodies. Again the Ghana Minerals and mining Act of 2006 looked into policies regarding water rights, mercury usage, sustainability of natural resources and offenses when there is default in stated policies. Conclusions were that, it isn't that there aren't any policies regarding mining issues in Ghana, however, there seemed to be insufficient institutional coordination, lack of transparency in the management of mineral revenues and sheer greed by some individuals to enrich themselves with little concern for the environment.

CHAPTER FIVE

5.0 Conclusion

From this research, observations were that Ayanfuri came out as the community with the highest concentrations of Arsenic, Lead, Mercury and Zinc in its water samples followed by Nkotumso and Buabenso with Dunkwa-on-Offin recording the lowest concentrations. The less concentration of heavy metals at Dunkwa indicates that obvious efforts are being made by the government to halt illegal mining in the region. However, there are more to be done since certain remote areas still have the ‘Galamsey’ activities being undertaken at night and during certain odd hours when no eye is watching. Also field observations revealed that even the Offin River at Dunkwa that is under treatment has started seeing some amount of pollution from illegal miners. As much as the Minerals and Mining Act of 2006 and the relevant stakeholders are doing their best to bring down the issue of illegal mining in the country, more still need to be done. Suggested institutional policies after the study are discussed in the sub chapter below.

5.1 Institutional Recommendations

The Government of Ghana has understood and has therefore given recognition to small scale mining activities undertaken by Ghanaians for reasons as; offering job opportunities to people and the generation of foreign exchange, however, concerns are that, small scale miners are being advised to seek required mining permits and to operate or carry out their operations in a proper technical, economical and environmentally friendly manner. This is to protect human and animal life, ensure survival and well being of the environment and the protection of forest and water bodies. Major Key institutions identified to enable government make this agenda come true to protect plant and animal life and ensure survival of the environment include; Ministry of lands and Natural resources, Ministry of Environment, Science and Technology (MEST), Minerals Commission of Ghana (MCG), Environmental Protection Agency (EPA), The Forestry Commission (FC) and the Water Resources Commission (WRC). Specific recommended roles are specified below.

Institution	Recommended Roles
Ministry of lands and Natural Resources	1. Raising Public awareness to participate in sustainable forest, wildlife and land use management 2. Promote and developing mining sector support programs such as Environmental Impact Assessment programs to measure the effect of past, current and future consequences of mining operations in order to find desired solutions to problems of today and the future resulting from illegal and small scale mining. 3. Initiating control programs such as mercury and other harmful chemicals abatement Projects to find alternate gold processing methods for small scale miners to eliminate the use of mercury. This will eliminate dangers that small scale miners, soils and water bodies are mostly subjected to. 4. Undertaking of Reclamation activities in conjunction with the Minerals Commission in mined out areas to prove to communities that, mined out lands can be reclaimed.
Ministry of Environment, Science and Technology (MEST)	1. Initiate and coordinate research including the review of policies, laws and regulations in the environment, science, technology and innovation sector in the mining industry. This would ensure higher and safe mining standards for small scale miners. 2. Ensure supervision, monitoring and evaluation

	of activities of science, technology and environment of small scale miners in collaboration with the Environmental Protection Agencies
The Minerals Commission of Ghana (MCG)	1. The primary mission of the minerals commission in Ghana is to ensure the efficient and effective regulation of Ghana mineral resources, however, certain specific recommended policies for this study include; a. Encouraging mine workers to go for regular health check up to ensure that they are not being exposed to dangerous chemicals eg. Mercury, Cyanide, etc b. Conducting regular safety inspection to ensure pits are reclaimed after mining. c. Conducting regular inspection on mining permits of miners and mining companies and ensuring that renewal of license is done in the right process. d. Ensuring education on illegal mining and their dangers to the environment.
Environmental Protection Agency (EPA)	1. One of the core responsibilities of the EPA in Ghana has always been to set guidelines that will ensure environmentally friendly atmosphere in mining activities, however in collaboration with the minerals commission;

	they can team up to make sure that all mining operations are in line with the country's mining standards. 2. The EPA must ensure that individuals or agencies interested in mining produces some amount of money that may be kept in the coffers of either the EPA or Minerals commission which might be used for reclamation and rehabilitation in case individuals/mining companies fail to do so after mining.
Forestry Commission (FC)	1. The Forestry commission being a bigger institution can also ensure that the country's forest covers are properly marked to prevent destruction due to mining. This can be done in collaboration with the minerals commission and the EPA. The primary reason is that, before mining can be done on any forest reserve, permit must have been given from the Minerals Commission and endorsed by the Forestry commission and EPA before the activity can be carried out.
Water Resources Commission (WRC)	1. The water resources commission of Ghana is responsible for ensuring that the country's water resources are used sustainably, however very specific policy directives under this study include; a. Inspecting water bodies around mining communities and

	conducting regular monitoring to ensure that they conform to acceptable water quality standards. b. Prosecuting culprits found to be contaminating/polluting water bodies from their activities. This could be easy with community collaboration. c. With collaboration with the EPA, Ministry of science, Environment and Technology and Minerals commission, they can conduct educational programs for small scale miners to ensure that groundwater is also not altered or disturbed

Table 18: Recommended policy roles

If all these institutions mentioned above could follow these recommended policy actions, it is believed that, water quality in mining communities would improve. Also, forest covers would be efficiently sustained and improved and land management would also improve whilst land degradation resulting from illegal and small scale mining becomes a thing of the past.

.

References

Abedin, M.J., J. Cotter-Howells and A.A. Meharg, (2002). Arsenic uptake and accumulation in rice (*Oryza sativa* L.) irrigated with contaminated water. Plant Soil, 240: 311-319.

Agarwal SK, Tiwari SC, Dash SC (1993). Spectrum of poisoning requiring hemodialysis in a tertiary care hospital in India. *International Journal of Artificial Organs*, 16(1):20–22.

Akabzaa, T., & Darimani, A. (2001). „Impact of Mining Sector Investment in Ghana: A Study of the Tarkwa Mining Region", Draft Report Prepared for SAPRI.

Amegbey N. A., and Eshun P. A., (2003). Mercury use and occupational exposure in the Ghanaian small scale gold mining industry; Ghana Mining Journal 7: 54-61

Amponsah N., Bakobie, N., Cobbina J.S., and Duwiejuah, B.A. (2015). Assessment of Rainwater Quality in Ayanfuri, Ghana. American Chemical Science Journal. 6. 172-182. 10.9734/ACSJ/2015/15881.

Amponsah –Tawiah K., and Dartey-Baah K., (2011). The Mining Industry in Ghana: A Blessing or a Curse; International Journal of Business and Social Science Vol. 2 No. 12; July 2011, Centre for Promoting Ideas, USA.

Aragón, F. M., and Rud J. P., (2015). "Polluting Industries and Agricultural Productivity: Evidence from Mining in Ghana." Economic Journal. doi.10.1111/ecoj.12244

Atafar Z., Mesdaghinia A, Nouri J., Homaee M., Yunesian M., Ahmadimoghaddam M., and Mahvi A.H., (2010). Effect of fertilizer application on soil heavy metal concentration. Environ Monit Assess. 2010 Jan: 160(1-4):83-9. Doi: 10.1007/s10661-008-0659-x

ATSDR (2002). Toxicological profile for copper (draft for public comment). Atlanta, GA, US

Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (Subcontract No. ATSDR-205-1999-00024).

Beattie A.D, Moore M.R., and Goldberg A.,(1972). Tetraethyl –lead poisoning. Lancet 300:12-15

Bernhoft R.A., (2011). *Review Article;* Mercury Toxicity and Treatment: A Review of the Literature. Hindawi Publishing Corporation Journal of Environmental and Public Health. Volume 2012, Article ID 460508, 10 pages, doi:10.1155/2012/460508.

Bidstrup F.L., (1964). *Toxicity of mercury and its compounds*. Amsterdam, Elsevier.

Chatham House, (2015). The The Impact of Mining on Forests: Information Needs for Effective Policy Responses. Accessed from www.chathamhouse.org/sites/default/files/events/special/Mining_workshop_summary_final.pdf on 31st July, 2018

Coakley G. J., (1999). The Mineral Industry of Ghana, Minerals yearbook, volume III. John Hopkins University Press, Baltimore

Down, C.G., & Stocks, J. (1977). Environmental Impact of Mining. London: Applied Science Publishers

Eggert, R. G. (2001). "Mining and economic sustainability: National economies and local Communities". Background study prepared for the Mining, Minerals, and Sustainable Development Project, London.

Eisler R. and Wiemeye S.N., (2004). Cyanide Hazards to plants and Animals from Gold mining and related water Issues. Rev Environ Contam Toxicol 183:21-54

Gajigo, O., Mutambatsere E., and Mdiaye G.. (2012). "Gold Mining in Africa: Maximizing Economic Returns for Countries." African Development Bank, Abidjan, Côte d'Ivoire.

Garvin T., McGee T. K., Smoyer-Tomic K. E., and Aubynn E. A., (2009). "Community--company relations in gold mining in Ghana". Journal of Environmental Management.

Grinspan D.,„and Biagini R. (1985). [Chronic regional hydroarsenicism. The manifestations of arsenic poisoning caused by drinking water] Medicinea Cutanea Ibero-Latino-Americana, 13:85-109

Gonick H.C.,(2002). Lead, renal and hypertension. Am J Kidney Dis. 2002 Jul 40(1): 202-204

Hassan Z.H., (2010). Underground mining methods. DOI: 10.13140/RG.2.1.2881.1124

Hilson G. (2001). A contextual review of the Ghanaian small scale mining industry

Hilson. G. 2002. "Harvesting mineral riches: 1000 years of gold mining in Ghana." Resources **Policy, Elsevier, 2002, 28, 13-26**

ICMM, (2015). A report of the Ghana Chamber of mines. Accessed from www.tabforestmines.com/wp-content/uploads/2015/10/Ghana-Chamber-of-Mines-report.pdf on 17-06-2018

Ilyin I., Berg T., Dutchak S. and Pacyna J., (2004). EMEP Assessment Report – Part I; assessed from http://www.emep.int/publ/reports/2004/assessment/Part1_117-138_07-Metals.pdf on 03-01-2018.

IPCS (1990). *Methylmercury*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 101).

Kumari N.A., Diarra M., Roxan Y.A., Kanga K.G.O., (2017). A review on technical aspects in mining exploration and exploitation; International journal of advanced research in science and engineering; Volume no.6, Issue no. 10. ISBN: 2319-8354

Laura M.P, Lothar R. and Hajo H., (2010). The Essential Toxin: Impact of zinc on human health. International Journal of Environmental Research and Public Health 2010, 7, 1342-1365; DOI: 10.3390/ijerph70041342

Mantey J., Owusu- Nimo F., Nyarko K. B. and Aubynn A., (2016). Operational dynamics of "Galamsey" within eleven selected districts of western region of Ghana. Journal of Mining & Environment, Published online: 23 May 2016. DOI: 10.22044/jme.2016.62

Moore MR et al., (N.D). Maternal lead levels after alterations to water supply. *Lancet*, 1981, 2:203-204.

Neilsen-Kudsk F., (1972). Absorption of mercury vapour from the respiratory tract in man. *Acta Pharmacologica*, 23:250.

Noulas C., Tziouvalekas M., and Karyotic T., (2018). Zinc in soils, water and food crops. Journal of Trace elements in medicine and Biology; Vol 49;doi.org/10.1016/j.jtemb.2018.02.009

Ramani R.V., (2012). Surface Mining Technology: Progress and Prospects; 1st International Symposium on Innovation and Technology in the Phosphate Industry [SYMPHOS 2011]. Procedia Engineering 46 (2012) 9 – 21; DOI: 10.1016/j.proeng.2012.09.440 Accessed from www.researchgate.net/publication/257725809_Surface_Mining_Technology_Progress_and_Prospects on 30th July 2018.

Rashmi V., and Dwivedi P., (2013). Heavy metal water pollution-A case study. Accessed from: https://www.researchgate.net/publication/303152384_Heavy_metal_water_pollution-A_case_study on 6th August, 2018].

Ochieng G.M., Seanego E.S.,and Nkwonta O.I., (2010). Impacts of Mining on water resources in South Africa: A review. Scientific Research and Essays Vol. 5(22), pp. 3351-3357

Olias M., and Nieto J.M., (2015). Background Conditions and Mining Pollution throughout history in the Río Tinto (SW Spain). Environments 2015,2,295-316;doi:10.3390/environments 2030295

P. de Voigt (ed). (2016). Reviews of Environmental Contamination and Toxicology. Volume 238; DOI 10.1007/398_2015_5003

Punam C., Dabalen A. L., and Land B.C., (2017). Mining in Africa: Are Local Communities Better Off? Africa Development Forum series. Washington, DC: World Bank. doi:10.1596/978-1-4648-0819-7. License: Creative Commons Attribution CC BY 3.0 IGO

Rice D.C, Karpinski K.F., (1988). Lifetime low-level lead exposure produces deficits in delayed alternation in adult monkeys. *Neurotoxicology and teratology*, 1988, 10:207-214.

Sherlock J.C. et al. (1984) Reduction in exposure to lead from drinking water and its effect on blood lead concentrations. *Human toxicology*, 1984, 3:383-392.

Simate G.S., and Ndlovu S., (2014). Acid mine drainage: Challenges and opportunities. *J. Environ. Chem. Eng.* 2014, *2*, 1785–1803.

Standing, A., and G. Hilson. 2013. "Distributing mining wealth to communities in Ghana: Addressing problems of elite capture and political corruption." *U4* issue 2013 (5).

Steenland K. and Boffetta P., (2000). Lead and cancer in humans; where are we now? Am J Ind Med 38:295-299

Teisinger J, Fiserova-Bergerova V., (1965). Pulmonary retention and excretion of mercury vapours in man. *Industrial Medicine and Surgery*, 34:580.

Tetteh F., (2015). Mining in the Forest Reserve. Journal of Energy and Natural Resource Law; Vol. 22:2, 241-242, DOI: 10.1080/02646811.2004.11433369

Tiwali S., Tripathi I.P., and Tiwari H.P., (2013). Effects of Lead on Environment. International Journal of Emerging Research in Management &Technology ISSN: 2278-9359 (Volume-2, Issue-6).

Tsikata F. S., (1997).The Vicissitudes of Mineral Policy in Ghana, Resource Policy, Elsevier Publishing Technology, Amsterdam. Resource Policy 23, 9-14

Umweltbundesamtes (1990–1992). *Umwelt-Survey*. Band V. *Trinkwasser* [*Environmental survey*. Vol. V. *Drinking-water*.] Berlin, Institut für Wasser-, Boden- und Lufthygiene des Umweltbundesamtes (WaBoLu-Heft 5/97).

Vasantha E., (2013). Formulate a Hit Item Replacement and Propose Cluster Ensembling (CE) Algorithm for Data Compression; International Journal of Engineering Sciences & Research Technology. ISSN: 2277-9655. Accessed from www.ijesrt.com/issues%20pdf%20file/Archives%202013/november-2013/36.pdf on 30th July 2018.

(Vaziri N.D., 2002). Pathogenesis of lead induced hypertension: role of oxidative stress. J Hypertens suppl. 2002 S15 – S20

World Health Organization, (1989). *Lead—environmental aspects*. Geneva, (Environmental Health Criteria, No. 85).

(WHO, 2003). Zinc in Drinking-water. Background document for development of WHO *Guidelines for Drinking-water Quality*. WHO/SDE/WSH/03.04/17

WHO, (2004). Copper in Drinking-water: Background document for development of WHO *Guidelines for Drinking-water Quality*. WHO/SDE/WSH/03.04/88

WHO, (2005). Mercury in Drinking-water; Background document for development of WHO *Guidelines for Drinking-water Quality*. WHO/SDE/WSH/05.08/10

WHO, 2007. Exposure to Mercury; A major public concern. Geneva Switzerland. Accessed on www.who.int/ipcs/features/mercury.pdf on 10th May, 2018.

WHO, 2008. Guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda,Vol.1,Recommendations.– 3rd ed. ISBN 978 92 4 154761 1 (WEB version) (NLM classification: WA 675). Accessed on http://www.who.int/water_sanitation_health/dwq/fulltext.pdf on 6th August 2018

WHO (2011). Guidelinesfor drinking water quality. Fourth edition; World Health Organization; Geneva, Switzerland; 2011. ISBN: 978 92 4 154815 1

WHO, (2011). Lead in Drinking-water. Background document for development of WHO *Guidelines for Drinking-water Quality*. WHO/SDE/WSH/03.04/09/Rev/1

Younger P.L., (2001). Passive treatment of ferruginous mine water using high surface area media. Elsevier science limited, Britain.

Appendix 1

QUESTIONNAIRE

RICHARD BOAMAH ADU

MSc NATURAL RESOURCE MANAGEMENT AND DEVELOPMENT

TH Köln

Thank you for being part of this research on the topic: illegal gold mining and water quality; a case study of the Offin River in the central region of Ghana

1. What is your name? (Optional)

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

2. Gender

   [a] Male

   [b] Female

3. Nationality: Please specify

   [a] Ghanaian

   [b] Other

4. If other, please state it……………………………………………………………………..

5. How old are you?

   [a] 18 – 20

   [b] 21 – 30

   [c] 31 – 40

   [d] 41 – 50

[e] Above 50

6. Occupation/professional status

   [a] Student

   [b] Civil servant

   [c] Farmer

   [d] Mine worker

   [e] Unemployed

   [F] Other

7. If other state it…………………………………………………………………………..

8. What is your marital status, please specify

   [a] Single, never married

   [b] Married

   [c] Widowed

   [d] Divorced

   [e] Separated

9. Do you live here?

   [a] Yes

   [b] No

10. If not, how often do you visit here

    [a] Regularly

    [b] Once a week

    [b] Once a Month

    [d] Not often

11. What is mining in your own ideas?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

12. Have u ever been involved in mining?

[a] Yes

[b] No

13. What is Galamsey in your own ideas?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

14. Do you believe it ought to be legalized?

[a] Yes

[b] No

15. If yes, why so?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

16. Do you have any family member or friend involved in mining?

[a] Yes

[b] No

17. If yes, how many?

    [a] 1

    [b] 2

    [c] 3

    [d] More than 3

18. Do they use in their operations; water bodies in the communities or their own constructed source of water or tap water?

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

19. How does the water look like after the end of their operations

    [a] Polluted

    [b] Unpolluted

20. Have you heard of farmers complaining of Galamsey affecting their yield?

    [a] Yes

    [b] No

21. Do they mention any chemical as the cause of this low yield?

    [a] Yes

    [b] No

22. If Yes, what chemical do they normally refer to? State/list

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

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

23. Do you think Galamsey operators use chemicals

    [a] Yes

[b] No

24. If you are a farmer, do you use any fertilizers in farming?

    [a] Yes

    [b] No

25. Can you list them? Optional

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

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

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

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

26. Do u believe these chemicals might affect agricultural production

    [a] Yes

    [b] No

27. Does illegal mining or Galamsey lead to deforestation in your opinion?

    [a] Yes

    [b] No

28. Do you believe it is dangerous to drink water around mining or Galamsey sites?

    [a] Yes

    [b] No

    [c] No idea

29. What are some of the diseases that you face from drinking polluted waters here in this community? List them

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

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

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

………………………………………………………………………………………………

………………………………………………………………………………………………

30. Do you experience any other effects not mentioned from illegal mining apart from the ones mentioned here?

    [a] Yes

    [b] No

31. If yes, list them

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

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

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

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

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

32. Are farmlands located on/along mining sites/lands?

    [a] Yes

    [b] No

    [c] No idea

33. If these farmlands are destroyed, do farmers receive any compensation?

    [a] Yes

    [b] No

    [c] No idea

34. If yes, in what form? State

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

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

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

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

35. Are farmers satisfied with the compensation?

[a] Yes

[b] No

[c] No idea

36. Do the community elders or chiefs know about the existence of this illegal mining?

[a] Yes

[b] No

[c] No idea

37. If yes, have you noticed any attempts from them to stop it?

[a] Yes

[b] No

[c] No idea

THANK YOU VERY MUCH FOR PARTICIPATING IN THIS VERY IMPORTANT GROUP DISCUSSION

Appendix 2

Drinking Water Quality Standard

Chemicals of Health Significance as described by World Health Organization Guidelines (WHO) for Drinking-water Quality in third edition (2008) and fourth edition (2011)

Parameter	**Unit**	**WHO 3rd Edition (2008) GuidelineValue**	**Parameter**	**Unit**	**WHO 4th edition (2011) Guideline Value**
Acrylamide	µg/L	0.5	Acrylamide	µg/L	0.5
Alachlor	µg/L	20	Alachlor	µg/L	20
Aldicarb	µg/L	10	Aldicarb	µg/L	10
Aldrin and Dieldrin	µg/L	0.03	Aldrin and Dieldrin	µg/L	0.03
Antimony	mg/L	0.02	Antimony	mg/L	0.02
Arsenic	mg/L	0.01 (P)	Arsenic	mg/L	0.01 (A,T)
Atrazine	µg/L	2	Atrazine and its chloro-s-triazine metabolites	µg/L	100
Barium	mg/L	0.7	Barium	mg/L	0.7
Benzene	µg/L	10	Benzene	µg/L	10
Benzo[a]pyrene	µg/L	0.7	Benzo[a]pyrene	µg/L	0.7
Boron	mg/L	0.5 (T)	Boron	mg/L	2.4
Bromate	µg/L	10 (A,T)	Bromate	µg/L	10 (A,T)
Bromodichloromethane	µg/L	60	Bromodichloromethane	µg/L	60
Bromoform	µg/L	100	Bromoform	µg/L	100
Cadmium	mg/L	0.003	Cadmium	mg/L	0.003
Carbofuran	µg/L	7	Carbofuran	µg/L	7
Carbon tetrachloride	µg/L	4	Carbon tetrachloride	µg/L	4
Chlorate	µg/L	700 (D)	Chlorate	µg/L	700 (D)
Chlordane	µg/L	0.2	Chlordane	µg/L	0.2
Chlorine	mg/L	5 (C)	Chlorine	mg/L	5 (C)
Chlorite	µg/L	700 (D)	Chlorite	µg/L	700 (D)
Chloroform	µg/L	300	Chloroform	µg/L	300
Chlorotoluron	µg/L	30	Chlorotoluron	µg/L	30
Chlorpyrifos	µg/L	30	Chlorpyrifos	µg/L	30

Chromium	mg/L	0.05 (P)	Chromium	mg/L	0.05 (P)
Copper	mg/L	2	Copper	mg/L	2
Cyanazine	µg/L	0.6	Cyanazine	µg/L	0.6
Cyanide	mg/L	0.07	-	-	-
Cyanogen chloride	mg/L	0.07	-	-	-
2,4-D (2,4-dichlorophenoxyacetic acid)	µg/L	30	2,4 – D(2,4 -dichlorophenoxyaceticacid)	µg/L	30
2,4-DB(2,4-dichlorophenoxybutyricacid)	µg/L	90	2,4 –DB (2,4-dichlorophenoxybutyric acid)	µg/L	90
DDT (Dichlorodiphenyltrichlorethane) and metabolites	µg/L	1	DDT (Dichlorodiphenyltrichlorethane) and metabolites	µg/L	1
Di(2-ethylhexyl)phthalate	µg/L	8	Di(2-ethylhexyl)phthalate	µg/L	8
Dibromoacetonitrile	µg/L	70	Dibromoacetonitrile	µg/L	70
Dibromochloromethane	µg/L	100	Dibromochloromethane	µg/L	100
1,2-Dibromo-3- µg/L chloropropane	1	1,2-Dibromo-3-Chloropropane	µg/L	1	
1,2-Dibromoethane	µg/L	0.4 (P)	1,2-Dibromoethane	µg/L	0.4 (P)
Dichloroacetate	µg/L	50 (T,D)	Dichloroacetate	µg/L	50 (D)
Dichloroacetonitrile	µg/L	20 (P)	Dichloroacetonitrile	µg/L	20 (P)
1,2-Dichlorobenzene	µg/L	1000 (C)	1,2-Dichlorobenzene	µg/L	1000 (C)
1,4-Dichlorobenzene	µg/L	300 (C)	1,4-Dichlorobenzene	µg/L	300 ©
1,2-Dichloroethane	µg/L	30	1,2-Dichloroethane	µg/L	30
1,2-Dichloroethene	µg/L	50	1,2-Dichloroethene	µg/L	50

Dichloromethane	µg/L	20	Dichloromethane	µg/L	20
1,2-Dichloropropane	µg/L	40 (P)	1,2-Dichloropropane	µg/L	40 (P)
1,3-Dichloropropene	µg/L	20	1,3-Dichloropropene	µg/L	20
Dichlorprop	µg/L	100	Dichlorprop	µg/L	100
Dimethoate	µg/L	6	Dimethoate	µg/L	6
1,4-Dioxane	µg/L	50	1,4-Dioxane	µg/L	50
Edetic acid (EDTA)	µg/L	600	Edetic acid	µg/L	600
Endrin	µg/L	0.6	Endrin	µg/L	0.6
Epichlorohydrin	µg/L	0.4 (P)	Epichlorohydrin	µg/L	0.4 (P)
Ethylbenzene	µg/L	300 (C)	Ethylbenzene	µg/L	300 (C)
Fenoprop	µg/L	9	Fenoprop	µg/L	9
Fluoride	mg/L	1.5	Fluoride	mg/L	1.5
Hexachlorobutadiene	µg/L	0.6	Hexachlorobutadiene	µg/L	0.6
-	-	-	Hydroxyatrazine	µg/L	200
Isoproturon	µg/L	9	Isoproturon	µg/L	9
Lead	mg/L	0.01	Lead	mg/L	0.01 (A,T)
Lindane	µg/L	2	Lindane	µg/L	2
Manganese	mg/L	0.4 (C)	-	-	-
MCPA (4-(2-Methyl-4-chlorophenoxy) acetic acid)	µg/L	2	MCPA (4-(2-Methyl-4-chlorophenoxy) acetic acid)	µg/L	2
Mecoprop	µg/L	10	Mecoprop	µg/L	10
Mercury	mg/L	0.006	Mercury	mg/L	0.006
Methoxychlor	µg/L	20	Methoxychlor	µg/L	20
Metolachlor	µg/L	10	Metolachlor	µg/L	10
Microcystin-LR	µg/L	1 (P)	Microcystin-LR	µg/L	1 (P)
Molinate	µg/L	6	Molinate	µg/L	6
Molybdenum	mg/L	0.07	-	-	-
Monochloramine	mg/L	3	Monochloramine	mg/L	3

Monochloroacetate	µg/L	20	Monochloroacetate	µg/L	20
Nickel	mg/L	0.07	Nickel	mg/L	0.07
Nitrate (as NO_3^-)	mg/L	50	Nitrate (as NO_3^-)	mg/L	50
Nitrilotriacetic acid (NTA)	µg/L	200	Nitrilotriacetic acid	µg/L	200
Nitrite (as NO_2^-)	mg/L	3	Nitrite (as NO_2^-)	mg/L	3
N-Nitrosodimethylamine (NDMA)	µg/L	100	*N*-Nitrosodimethylamine	µg/L	0.1
Pendimethalin	µg/L	20	Pendimethalin	µg/L	20
Pentachlorophenol	µg/L	9 (P)	Pentachlorophenol	µg/L	9 (P)
Permethrin	µg/L	300	-	-	-
Pyriproxyfen	µg/L	300	-	-	-
Selenium	mg/L	0.01	Selenium	mg/L	0.04 (P)
Simazine	µg/L	2	Simazine	µg/L	2
Sodium dichloroisocyanurate (as cyanuric acid)	mg/L	40	Sodium dichloroisocyanurate (as cyanuric acid)	mg/L	40
Styrene	µg/L	20 (C)	Styrene	µg/L	20 (C)
2,4,5-T	µg/L	9	2,4,5-T (2,4,5-trichlorophenoxy acetic acid)	µg/L	9
Terbuthylazine	µg/L	7	Terbuthylazine	µg/L	7
Tetrachloroethene	µg/L	40	Tetrachloroethene	µg/L	40
Toluene	µg/L	700 (C)	Toluene	µg/L	700 (C)
Trichloroacetate	µg/L	200	Trichloroacetate	µg/L	200
Trichloroethene	µg/L	20 (P)	Trichloroethene	µg/L	20 (P)
2,4,6-Trichlorophenol	µg/L	200 (C)	2,4,6-Trichlorophenol	µg/L	200 (C)

Trifluralin	µg/L	20	Trifluralin	µg/L	20
Trihalomethanes	-	The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1	Trihalomethanes		The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Uranium	mg/L	0.015 (P,T)	Uranium	mg/L	0.03 (P)
Vinyl chloride	µg/L	0.3	Vinyl chloride	µg/L	0.3
Xylenes	µg/L	500 (C)	Xylenes	µg/L	500 (C)

Note:

1. According to WHO Drinking-water Quality 3rd edition (2008):

P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited;

T = provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc;

A = provisional guideline value because calculated guideline value is below the achievable quantification level;

D = provisional guideline value because disinfection is likely to result in the guideline value being exceeded;

C = concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odor of the water, leading to consumer complaints.

2. According to the WHO Drinking water Quality 4th edition (2011):

A = provisional guideline value because calculated guideline value is below the achievable quantification level.

C = concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odor of the water, leading to consumer complaints.

D = provisional guideline value because disinfection is likely to result in the guideline value being exceeded

P = provisional guideline value because of uncertainties in the health database;

T= Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.