SCHOOL OF PUBLIC HEALTH

COLLEGE OF HEALTH SCIENCES

UNIVERSITY OF GHANA

ANALYSIS OF METAL CONCENTRATIONS IN SURFACE AND GROUNDWATERS IN TWO MINING COMMUNITIES IN THE ATIWA DISTRICTS OF GHANA.

BY

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This dissertation is submitted to the University of Ghana, Legon in partial fulfillment of the requirement for the award of **MASTER OF PUBLIC HEALTH Degree.**

OCTOBER, 2022

DECLARATION

1, Yobo Mireku, hereby declare that apart from references to other peoples' work, which have been duly acknowledged, this dissertation has been written independently by me and has not been submitted for the award of any degree in any institution.

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DEDICATION

I dedicate this work to my lovely wife, Dr. Gifty Asante and my children Ewurama, Owuraku and Barima for their support, prayers and encouragement. God richly bless them.

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ABSTRACT

Introduction: In Ghana, mining of minerals such as gold, diamonds, bauxite and other minerals have played a significant role in the socio-economic development of the nation by reducing unemployment and generated billions of dollars for the country over the years. In recent times however, artisanal mining of gold, popularly known as galamsey has resulted in unwarranted pollution of the environment, especially rivers with mercury and other chemicals. Thus, the quality of most rivers in Ghana has been affected.

Objective: The aim of the study was to determine the extent of metal pollution in ground and surface water in two mining communities in the Atiwa districts of Ghana.

Methods: Water samples from groundwater (wells and bore holes), surface water (rivers) and tap water sources were analyzed for their physicochemical properties such as pH, turbidity, electrical conductivity, salinity and total dissolved solids as well as metal concentrations. Metals concentrations were measured using an Atomic Absorption Spectrophotometer whiles physicochemical parameters were measured with EDZO 7200 multimeter.

Results: The mean levels of physicochemical parameters of the samples were as follows: pH: tap water-6.2±0.2, bore hole-6.8±0.26, well-7.5±0.2, river- 7.6±0.2. EC: river-76.9±15.9, tap water-104.7±54.6, bore hole-105.4±52.6, well-131.2±86.7. Salinity: river-36.9±7.3, bore hole-52.4±25.7, well-61.9±41.2, tap water-122±255. Turbidity: tap water-2.6±3.0, bore hole-4.2±9.9, well-4.8±5.9, river-134.4±276. TDS: river-52±10.7, bore hole-73±34.8, tapwater74.8±32.0, well-86.2±57.2.The mean concentration of metals were as follows: bore hole samples: Hg-0.0002 ±0.0001, As-0.004±0.002, Pb-0.009±0.005, Cd-0.013±0.018, Fe-0.095±0.131. Well samples: Hg-0.0006±0.0005, As-0.003±0.002, Cd-0.015±0.011, Pb-0.049±0.063, Fe-0.884±0.353. Tap water: Hg-0.0001±0.000, As-0.001±0.001, Pb-0.003±0.002, Cd-0.003±0.004, Fe-0.066±0.154 and finally the mean concentrations for river samples were: Hg-0.0249±0.0171, Cd-0.128±0.08, Pb-0.164±0.088, As-0.233±0.938 and Fe-6.238±1.274.

Conclusion: The concentrations of metals in all the tap water supplied by GWCL were within the acceptable limits set by WHO and therefore safe for consumption with regards to the metals that were analysed. The rivers that were sampled contained metal concentrations that were above WHO permissible limit for drinking water for all the metals that were analysed hence ingestion of water from these sources either directly or indirectly could pose a long term adverse health effect to the consumer.

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LIST OF ABBREVIATIONS

As	Arsenic
ASGM	Artisanal and Small-scale Gold Mining
Cd	Cadmium
EC	Electrical Conductivity
FAAS	atomic absorption spectrophotometer
Fe	Iron
FIAS-AAS	Flow Injection Analysis System – Atomic Absorption Spectrophotometer
GPS	Global Positioning System
GSA	Ghana Standard Authority
GSS	Ghana Statistical Service
GWCL	Ghana Water Company Limited
Hg	Mercury
HIV/AIDs	Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome
IARC	International Agency for Research on Cancer
ISE	Ion selective Electrode
LOD	Limit Of Detection
NTU	Nephelometric Turbidity Unit
Pb	Lead
TDS	Total dissolved Solids
UN	United Nations
UNEP	United Nation Environmental Protection
USAID	United States Agency for International Development
USEPA	United State Environmental Protection Agency
WEPAL	Wageningen Evaluating Programs for Analytical Laboratories

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Water is life and without water, the existence of man and all other living things will be impossible. Access to adequate, good, and clean quality water is an essential element in ensuring good hygiene and sanitation which directly or indirectly improves human health by reducing morbidity and mortality, decreasing pre-natal and post-natal risk, as well as preventing vector and water-borne diseases. (Funari et al., 2011). Girl child enrolment and retention in school are also improved when there is access to adequate and clean sources of water. Lack of access to potable sources of water and drought exposes more especially the vulnerable in the society including women and children to sanitation and water-related diseases. (United Nations, 2018).

Water is gradually becoming a scarce commodity with compromised quality due to increasing population size, rapid industrialization, and increase urbanisation thus putting much stress on water resources as a result of an increase in individual and collective demands.(Faye, 2021). Water resources are under threat from pollution due to anthropogenic activities such as improper disposal of domestic, municipal, and industrial solid waste, agricultural and irrigation activities, direct disposal of industrial effluent into drainages without prior treatment, small and large scale gold mining activities (Ministry Of Water Resources, Works And Housing, 2007).

Using such contaminated water for domestic purposes including drinking, cooking, and personal hygiene exposes individuals particularly women because of their domestic roles to all forms of water-related diseases such as cholera, typhoid fever, trachoma, scabies, and the rest. (United Nations, 2018).

Heavy metals are elements with high atomic weight, and can be toxic to living organisms even at low concentrations and also have the potential to bioaccumulate in the food chain (EPA 2000). Examples include metals such as mercury, chromium, cadmium, lead, silver, nickel, and metalloids such as arsenic and selenium.

Heavy metals are of a major public health concern due to their adverse health impact and effect on humans and on the environment. They are non-biodegradable with the potential to bioaccumulate in the ecosystem whiles others have the capacity to undergo biomagnification. In Europe thirteen of these heavy metals are of greatest concern. Four of these thirteen elements are among WHO's top ten chemicals of major public health concern. These are mercury, lead, arsenic and cadmium (WHO, 2011).

Fossil fuel and gasoline combustion, incineration of waste, foundries, small and large scale mining activities, smelting, industrial and agricultural activities are the major means through which heavy metals are released into the environment (Norwegian Meteorological Institute, 2004). Human exposure to harmful heavy metals can occur in many ways, ranging from the consumption of contaminated food, exposure to air-borne particles, and contact or consumption of contaminated water (Jaishankar et al., 2014). Although small-scale mining has contributed enormously to the economy of Ghana over the years, it has also negatively impacted the environment and human health. The major environmental impact associated with mining is the persistent release of harmful and toxic substances such as mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), among others (Emmanuel et al., 2018).Numerous studies have associated the contamination of surface and groundwater bodies with heavy metals in Ghana to gold mining activities (Armah et al., 2010; Ato et al., 2010; Cobbina, S. J, Myilla, M., and Michael, 2013; Cobbina et al., 2015; Emmanuel et al., 2018; Kpan et al., 2014; Appoh et al., 2011; Oppong Afum, 2016).

1.2 Problem Statement

Globally, one out of three people don't have access to potable and clean drinking water (WHO, 2019) whiles those who have access don't often get the needed quantities that meet their basic daily requirements. Availability of clean, potable, and reliable sources of drinking water is crucial in improving the livelihood of both humans and animals and for improving the educational and economic status of women and girls thereby bridging the gender inequality gap (United States Agency for International Development (USAID), 2020); United Nations, 2018). Our water bodies and resources must be effectively managed to ensure continuous access to quality, reliable, and affordable drinking water and proper sanitation services as changes in the weather as a result of global warming, increase in ambient temperature, and rising sea level threatens the availability and access to clean water (United Nations, 2018).

Groundwater has been a major source of water supply for domestic use in Ghana in the past. The situation is not different in the Atiwa districts of Ghana where the majority of households, as well as public and private institutions such as schools and health facilities rely on mechanised boreholes and hand dug-wells for cooking, drinking, washing, bathing, general cleaning, and for other purposes.

Also, surface water bodies in the form of rivers and streams in the Atiwa districts are the main sources of water for irrigation farming, drinking water for farm and domestic animals as well as for domestic use by rural farming communities in some remote parts of the districts.

In recent times, these water bodies are continually being subjected to pollution as a result of artisanal illegal mining activities, also known as 'galamsey' which is on the increase in the Atiwa enclave, coupled with an increase in other anthropogenic activities such as farming etc.

Although mining plays a significant role in improving the economic status and living standards of mining communities and ensuring poverty alleviation, there are also numerous social and environmental problems associated with it. It is seen as a major means of polluting the environment with heavy metals. For example, artisanal and small-scale gold mining is seen as the major source of mercury pollution to the environment worldwide (UNEP, 2012).

Water resources, both surface and ground waters in the Atiwa mining districts are not exempt from pollution or contamination with heavy metals. Rivers and other water bodies in the districts have been destroyed through bad and unregulated mining practices and river Birim which hitherto was clean and drinkable has now become clayey and undrinkable. Long-term exposure to toxic heavy metals either through direct or indirect consumption of these contaminated water sources can lead to cancers and physical, muscular, neurological degenerative processes that cause Alzheimer's disease, Parkinson's disease, muscular dystrophy and multiple sclerosis (Karcioglu & Arslan, 2019). Data on the level of contamination with Pb, As, Hg, Cd and Fe of the various water bodies in the Atiwa districts are absent. The study is to provide a baseline data on the level of contamination of both ground and surface water sources (river/stream, boreholes, wells and tap water) with these metals and the physicochemical parameters of these water sources in the districts.

1.3 Narrative of Conceptual Framework

Pollution of our water bodies with heavy metals and other pollutants are either through anthropogenic activities or through natural means. Example of these man-made activities and processes include mining activities, direct and indirect disposal of industrial effluent and solid waste, municipal and domestic waste into water bodies or runways, incineration of waste, leaching from non-engineered landfills and agricultural application of manure, fertilizers, and pesticides on farmlands. Pollution is enhanced through heavy rains and runoff. These pollutants including heavy metals are passed to humans through direct ingestion of these drinking water sources and also in the preparation of food and beverages and personal cleansing. Indirectly, human get exposure by consuming fruits and vegetables, livestock and poultry products that have also come into contact with these polluted drinking water sources by means of irrigation farming and livestock watering.

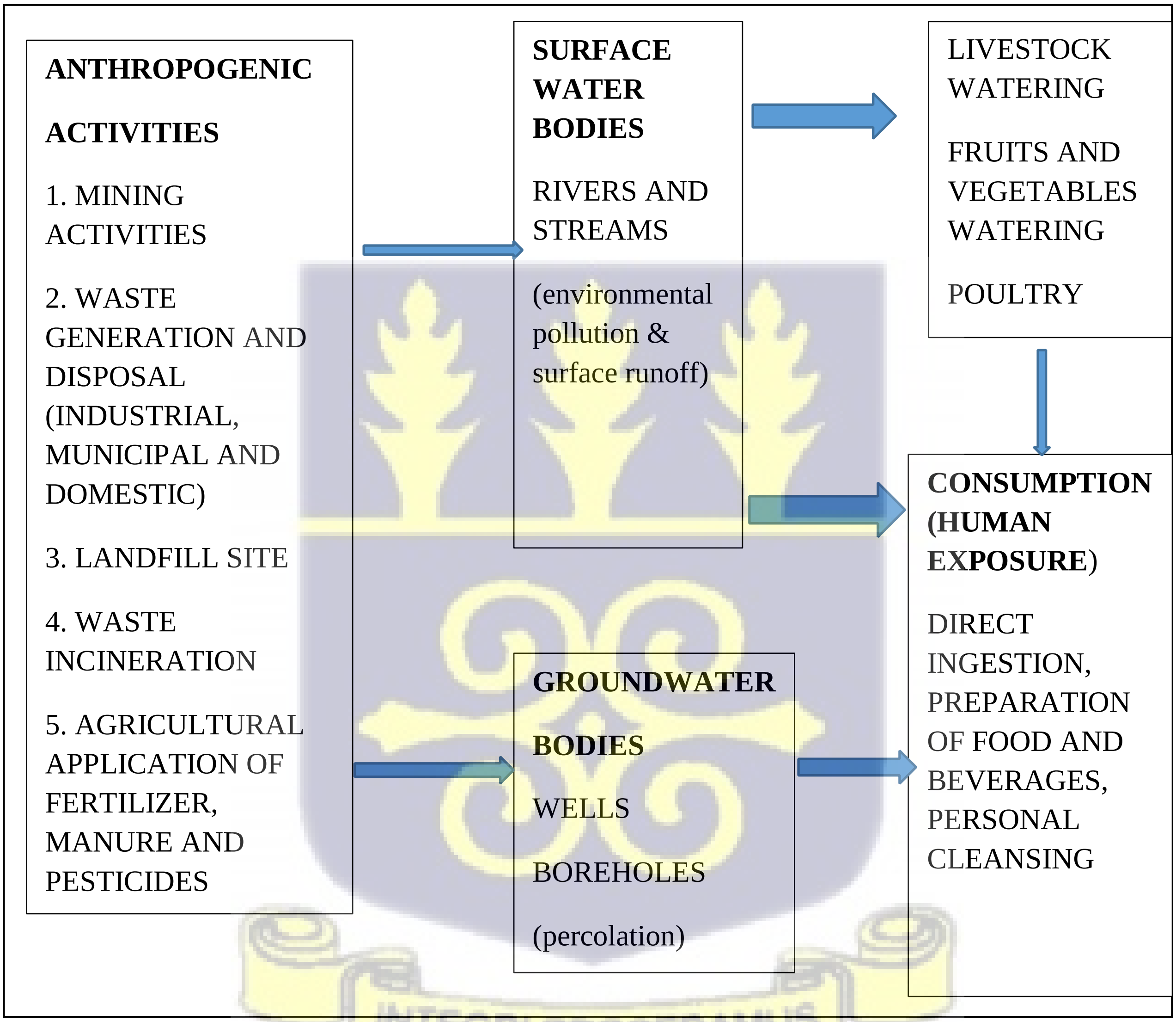


Figure 1. 1: Conceptual Framework

1.4 Justification

Anyinam and Kwabeng are the two district capitals of Atiwa East and Atiwa West respectively. The area over the years has seen an increase in mining activities precisely smallscale mining known as galamsey. This has, therefore, attracted several people into the area to engage in mining activities. The growing population and the increased commercial activities in the two areas have resulted in human activities that have raised the levels of chemical pollution in the various sources of water in the area. Most households in these two communities depend on hand-dug wells in their homes or community boreholes for domestic and drinking purposes due to pollution of surface water sources as a result of the mining activities as well as the decrease in quality and quantity of water being supplied from Ghana Water Company Limited (GWCL). Although there is a surge in mining activities in the Atiwa districts which has led to increased pollution of the water bodies, the extent of pollution or contamination of the water sources with heavy metals in the districts has not been determined to know if people in the Atiwa districts are at risk of contamination with heavy metals. Due to the long latency period of heavy metals it is imperative that the concentration levels of these heavy metals in drinking water sources are periodically assessed and to know whether they are within acceptable limit for use and also to ensure that the health of the people in Atiwa is safeguarded in the long term.

Therefore, this current study seeks to determine the extent of metal pollution of water sources in the Atiwa districts.

1.5 Research Question

1. Do sources of water in Anyinam and Kwabeng have high levels of Zn, Pb, Hg, As and Fe, due to increased illegal mining activities?

2. How do levels of metals compare with WHO acceptable limits?

1.6 OBJECTIVES

1.6.1 General Objective:

Determine the levels of metals contamination in surface and groundwater in Anyinam and Kwabeng in Atiwa districts.

1.6.2 Specific Objectives:

1. Determine the physico-chemical parameters of surface and ground water in Atiwa and compare to WHO acceptable threshold limits.

2. Measure concentrations of metals Cadmium (Cd), Lead (Pb), Mercury (Hg), Arsenic (As), and Iron (Fe) in surface and ground water in Atiwa and compare to WHO acceptable threshold limits.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sources of Heavy Metal Contamination

Contamination of drinking water sources could come from naturally occurring sources or anthropogenic sources. Naturally occurring heavy metals could be in the organic or inorganic form. The former is a result of the eutrophication process as well as by the action of certain microorganisms that inhabits the water bodies and the latter from rocks and soil through the water percolate and also through geological setting and climatic effect (WHO, 2017). Contamination from anthropogenic sources include sources from industrial and domestic areas through direct disposal of effluent from processing industries into sewage systems without prior treatment, disposal of domestic and municipal waste, urban runoffs, leakages of fuel, incineration, leaching from un-engineered landfill sites, and mining activities. Other man-made sources include agricultural and farming activities such as manure, pesticide, and fertilizer applications. Drinking water sources also get contaminated with heavy metals through the material that comes into contact with the water in the distribution system such as DBPs, the piping materials and its corrosion, and coagulants used in the treatment process (WHO, 2017).

2.2 Mining and Heavy Metal Pollution of Water Sources

Mining has recently become unpopular because it has been seen as a major source of heavy metal pollution of our water bodies and the environment throughout the various stages in the mining process including mineral exploitation, transportation of ore, smelting, and refining, amalgamation, and wastewater and tailings disposal (Ato et al., 2010). Heavy metal pollution in Ghanaian mining towns and communities has been widely investigated. A study conducted in the northern parts of Ashanti Gold Belt of Ghana to investigate the level of trace metal contamination in boreholes, wells and streams due to mining found out that all the wells and streams that were investigated had one or more trace metal level outside the acceptable limit set by WHO and only three out of the sixty-seven boreholes samples were safe for human consumption (Tay & Momade, 2009). (Cobbina, S. J, Myilla, M., and Michael, 2013) in a study conducted in the Datuku in the Talensi-Nabdam district of Ghana to assess the effect of small scale gold mining on the quality of drinking water in the community found the mean levels of cadmium, total iron, arsenic and turbidity to be above WHO recommended threshold for drinking water. In a similar study titled 'heavy metal pollution in the Birim river of Ghana' also concluded that the Birim river was heavily polluted with heavy metals and the samples with high metal concentrations were located in areas where small scale mining was dominant (Oppong Afum, 2016). Mercury levels in boreholes, streams and river samples analysed within the Birim North district of Ghana had concentrations above WHO acceptable limit (Appoh et al., 2011). Jerome, Boadu and Anukwah also determined the level of Hg, Pb and Cu in water and soil samples in Dunkwa-on-Offin in the Central Region of Ghana where illegal small scale mining practices were on the increase. They found the mean concentrations of the metals in the water samples to be 190.27mg/l, 75.92mg/l and 211.31mg/l respectively for Pb, Cu and Hg. These levels were far above acceptable limits (Kpan et al., 2014).

2.3 Heavy Metals

2.3.1 Mercury

Mercury has a long-range atmospheric transport once released into the environment. It persists and bio-accumulate leading to contamination of water bodies, mammals, fish, plants, and the food chain. It is a global concern due to its impact on the environment and on health. It is a powerful neurotoxin with a negative health impact on young children and unborn babies in the womb causing limb deformities, hydrocephalus, and brain damage (UN, 2017). It is extensively used in mining to recover gold particles. Improper handling of mercury in mining activities leads to it being released into the atmosphere, soil, and water bodies. People living in Artisanal and Small-scale Gold Mining (ASGM) communities especially miners, children, and women both pregnant and non-pregnant are at risk of exposure to mercury (UNEP, 2012).

Acute mercury exposure can cause tremors, memory loss, and death. Chronic exposure may lead to kidney failure, movement disorders such as Parkinson's disease and Alzheimer's as well as cognitive impairment. Disposal of tailings into water bodies in mining communities may lead to the formation of methyl mercury which is a highly toxic form of mercury. Methyl mercury accumulates in fish, crustaceans, and other seafood. Consumption of such contaminated seafood may be poisonous and fatal with other serious health problems such as nerve, brain, and kidney damage. Consumption of rice and other crops and vegetables irrigated with mercury-contaminated water may also lead to similar health effects (Esdaile & Chalker, 2018).

2.3.2 Arsenic

Arsenic in the elemental form is a naturally occurring solid metalloid found in rocks, soil, and groundwater. Other sources include the combustion of fossil fuels and as a by-product from the smelting of zinc, lead, and copper. Its use includes glass manufacturing, computer chips that are silicon-based, preservation of wood, pesticides, and drug manufacture, to mention a few. Its use however is declining due to its toxicity. Inorganic arsenic is more toxic compared to organic arsenic with the most toxic form being the colourless and non-irritant arsine gas. Death occurs within 30 minutes at a concentration of 25-50ppm. Exposure to arsenic is mainly through the consumption of contaminated food and water and also through inhalation (WHO, 2011). The largest poisoning of a population in history is the consumption of groundwater contaminated with naturally occurring inorganic arsenic in Bangladesh (Khan et al., 1997; Dhar et al., 1998).

Naturally occurring arsenic has contaminated ground waters and has subsequently led to mass poisoning of humans in various parts of the world such as Mexico, the United States, Argentina, India, China, and Thailand (Smith et al., 2000). Arsenic has a long latency period with a window period of between 10 to 20 years or even more. Chronic or long-term exposure could lead to cancers of the skin, bladder, kidney, and lungs. Other long-term health effects include hypertension, diabetes mellitus, peripheral neuropathy, and neurological defects (Smith et al., 2000). At a high concentration, acute symptoms such as abdominal pain and diarrhoea may occur (WHO, 1996). The risk of dying from lung, liver, or bladder cancer over a lifetime from drinking one litre per day of water containing arsenic at a concentration of 50ug/l is 13 per 1000 people (Smith et al. 1992).

2.3.3 Cadmium

Cadmium is a heavy metal widely used in batteries manufacturing and other steel and plastic industries. Its pollution to the environment is from wastewater and fertilizers. Human exposure to cadmium is mostly through food and cigarette smoking. Cadmium is a probable carcinogen to humans per IARC classification. It accumulates mainly in the kidneys with a long half-life of 10-35 years in humans. The World Health Organization's acceptable limit is 3ug/L however values found in drinking water sources are mostly below 1ug/L (WHO, 2008).

2.3.4 Lead

Lead and lead compounds are mainly used to produce leaded-acid batteries, solder, alloys, leaded paints, and petrol. Their use for such purposes is being phased out by many countries. They are found in pipes, solder, or fitting of the plumbing systems in households. Lead is found in tap water due to corrosion of the plumbing system while the water stays in the pipes.

Concentrations found in pipe water are usually below 5ug/L but concentrations above 100ug/L have been found where there are lead service connections and fittings in the plumbing system of the buildings (WHO, 20II). Lead is very toxic and human exposure to lead is associated with adverse health effects such as hypertension, poor pregnancy outcomes, fertility problems, impaired kidney function, neurodevelopmental impairment in children, and mortality.

2.4 Iron

Iron is an essential element that is abundant in the earth's crust. It occurs naturally in fresh waters at concentrations between 0.5 to 50ug/L. The minimum daily quantity required by the human body ranges from 10 to 50mg/kg depending on the physiological status, age, sex and bioavailability of the individual. There is no established WHO guideline value because concentrations found in drinking water sources are not of health concern.

2.5 Physicochemical Properties of Water

The composition of both ground and surface waters is dependent and affected by a variety of natural and human factors. Notable among the natural factors are hydrological, geological, topographical, meteorological, climatic, and biological influences. Water quality and composition also differ partly due to seasonal variations in water levels, run-off volumes, and weather conditions. Mining, disposal of domestic, industrial, and urban liquid and solid waste into waterways, construction of dams, diversion of water flow among others contribute significantly to the composition and physical and chemical qualities of water bodies (UNEP/WHO, 1996).

2.4.1 pH

pH is a unit of measurement that determines the degree of acidity or alkalinity of a medium or solution. The importance of maintaining an optimum pH range for biological processes, agriculture, industry, and the aquatic environment cannot be overstated. The pH of water is mostly affected by a variety of chemical and biological processes happening within it. A significant amount of sulphide minerals primarily pyrite can be found in open-pit rocks. When atmospheric oxygen comes into contact with the pyrite in the rocks the pH condition reduces.

During mining activities, rocks that contain sulphide minerals are extracted or exposed in underground mining. Sulphuric acid is produced when water and oxygen come into contact with these rocks. The pH of water bodies is subsequently reduced when water that passes over these rocks find their ways into these water bodies (Banunle, Fei-Baffoe, and Otchere, 2018). pH can also be elevated to 9.5 by an algal bloom (Queensland Government, 2018).

2.4.2 Total Dissolved Solids (TDS)

Inorganic salt mainly sodium, potassium, magnesium, calcium, bicarbonate, sulfates, and chlorides and minor quantities of organic materials dissolved in water make up TDS. Industrial effluent, urban runoff, sewage, and other natural sources contribute to TDS in drinking water. Due to differences in the mineral solubilities, TDS levels differ significantly at different geological locations. Although no guideline value has been established by WHO because concentrations found in drinking water sources do not have any adverse health implications, high levels of TDS in drinking water may be undesirable and objectionable to consumers (WHO, 2008).

2.4.3 Turbidity

Turbidity of water is the measure of the colloidal, soluble, and suspended particles that obstruct the passage of light through the water. It can affect the growth of phytoplanktons and other plants in the water by interfering with the rate of photosynthesis. It is measured in Nephelometric Turbidity Unit (NTU) using a probe (Queensland Government, 2018).

2.4.4 Electrical Conductivity (EC)

Electrical conductivity measures water's ability to carry electrical current as a result of the presence of dissolved salts. Thus, EC determines the salinity of the water and the dissolved salt concentration. The unit of measurement is siemens per metre (S/m), microsiemens per centimetre (us/cm), or millisiemens per centimetre (mS/cm) depending on the type of water being measured (Queensland Government, 2018).

2.4.5 Salinity

Salinity is the measure of the concentration of salt in water and land. It occurs through natural means (primary salinity) or human activities (secondary salinity). Primary salinity occurs in salt lakes or when there is naturally occurring large deposits of salt deep in the soil or deposited at the surface as a result of weathering of rocks or the salts being deposited by the action of wind or rain over so many years. Secondary salinity is a result of industrial processes such as mining whereby salt deposits are mobilised towards the surface of the soil or into waterways. It also occurs due to changes in land use such as vegetation clearing and excessive irrigation which consequently results in the rising of water tables. Also, an increase in industrial, sewage, and agricultural run-off containing salt, fertilizers and other organic matter could lead to secondary salinity (Liddicoat et al., 2004).

High salinity is detrimental to both aquatic and terrestrial life. Optimum salinity is required for aquatic flora and fauna to maintain the ecosystem as salt concentration higher than normal to the living things could lead to stress and even death of the organisms. Additionally, high salinity leads to corrosion of machinery, fences, bridges, and roads. It also reduces crop yield as it affects the quantity of nutrient that is available to plants roots (Fipps, n.d.).

CHAPTER THREE

3.0 METHODS

3.1 Study Design

The study adopted an analytical cross-sectional design to analyse four heavy metals (Pb, Hg, As, Cd) and Fe in groundwater (wells and boreholes), surface water (rivers), and tap water in Atiwa.

3.2. Study Area

The study was conducted in two towns, Anyinam and Kwabeng which are the district capitals for Atiwa East and Atiwa West districts respectively.

The Atiwa district which is located in the Eastern region of Ghana was split into Atiwa East and Atiwa West by a legislative instrument LI 2344 and LI 2345 respectively in 2017. The Atiwa district was made up of six sub-districts namely Kadewaso, New Jejeti, Anyinam, which are now under Atiwa east and Abomosu, Kwabeng,and Awenare which are now under Atiwa west. (Fig 3.2). The Atiwa East district covers an area of 625.78 sq. km and has a population of 64, 647 according to the 2021 population and housing census (Ghana Statistical Service (GSS), 2021). Agriculture is the main economic activity which engages about 60% of the working force (Atiwa East District Assembly, 2020). Small-scale mining activities take place in most of the towns within the district. Anyinam is the district capital, and it is the main commercial town in the district with different small-scale mining companies operating in most of its communities. It currently has five sub-districts namely Kadewaso, New Jejeti, Anyinam, Enyiresi and Akyem Sekyere. (Fig 3.1 and 3.2). Atiwa west has a population of 61,219 with Kwabeng as the district capital. Most of the communities are rural communities with Agriculture being the main economic activity. Mining is also common in most of the communities with the capital not being an exception (Atiwa West District Assembly, 2019).

It currently has six sub-districts namely Abomosu, Awenare, Kwabeng, Akrofufu Akropong and Ekorso. (Fig 3.1 and 3.2).

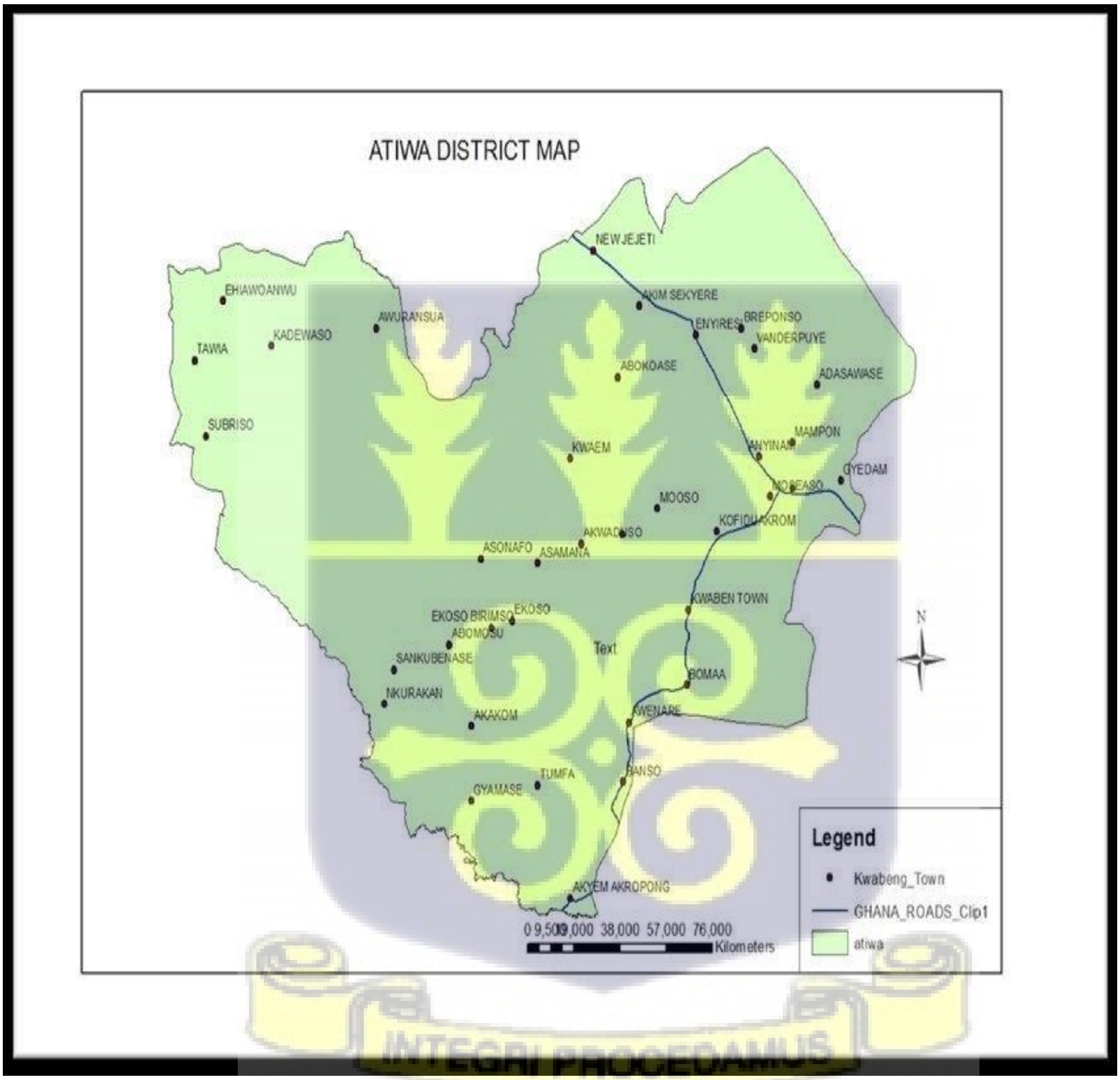
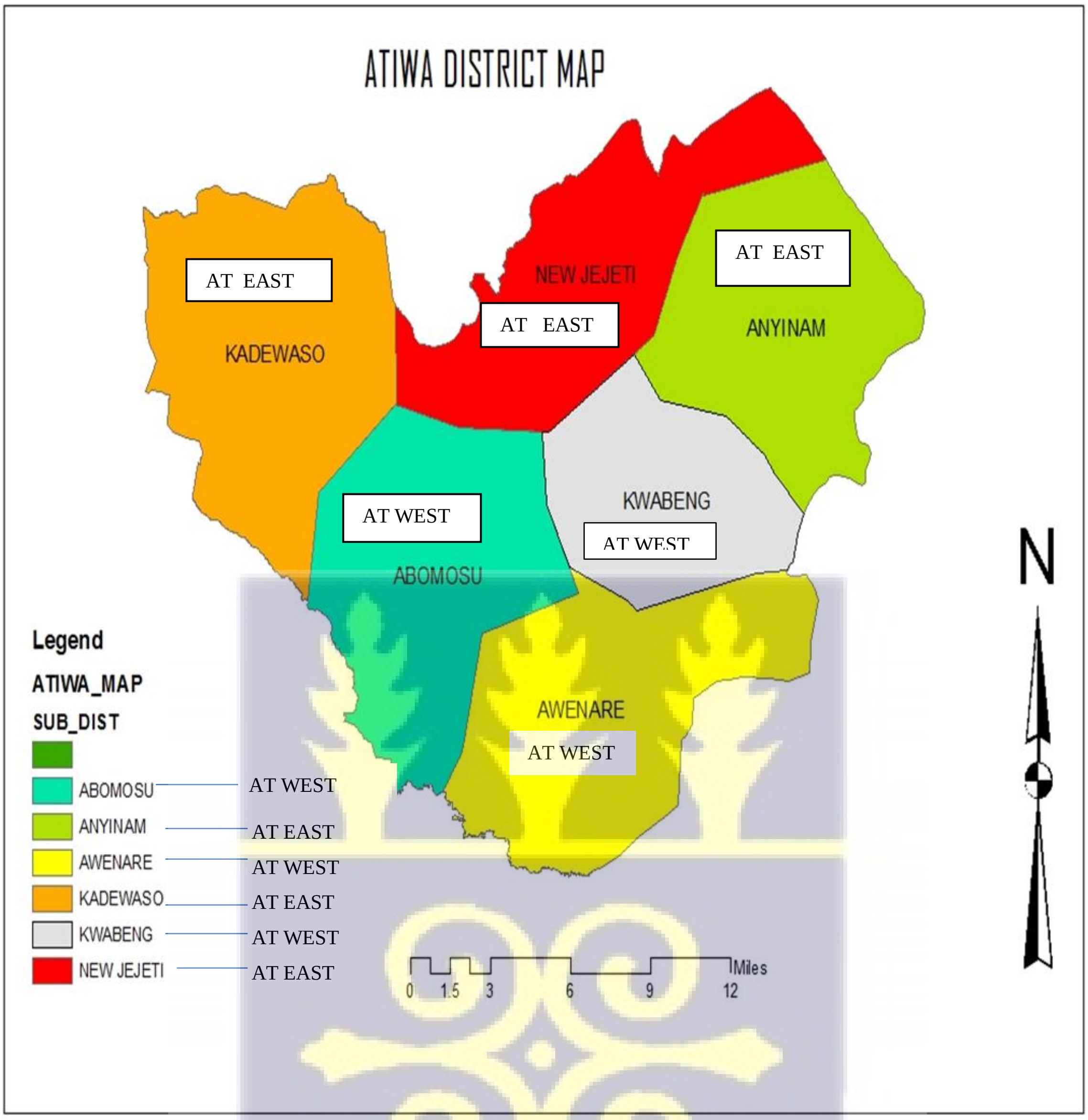


Figure 3. 1: Map of Atiwa District showing the various communities



AT=ATIWA
Figure 3. 2: Map of Atiwa District showing sub-districts.

3.3 Study Samples

Surface water samples from river Birim and other streams as well as Tap water from Ghana Water Company Limited were sampled. Groundwater sources from hand-dug wells (HDW) and boreholes both mechanised (MBH) and non-mechanised boreholes (NMBH) were also sampled.

3.4 Inclusion and Exclusion Criteria

Boreholes and Wells that were not functional and not being used by community members were excluded from the study. Priority was given to bore holes and Wells that were being patronised by the majority of community members. The stream and rivers being used as the main source of water used by GWCL to serve community members were included. Streams and rivers used for mining activities in the study area were included and those that were not used were excluded.

3.5 Sample Collection

Samples were collected from 64 different sampling points. Sampling was done in triplicate at each sampling point from the same source.

3.5.1 Sample Collection in Kwabeng Town

Of the 64 sampling points, 28 were from Kwabeng Township and 36 were from Anyinam Township. Samples collected in Kwabeng included water from 14 Boreholes, water from 9 Taps supplied by Ghana Water Company Limited (GWCL), and 5 water samples from 2 different rivers (3 different sampling points from river A and 2 different sampling points from river B). No sample was collected from wells because no well was found in the Kwabeng town during the sampling period. (Table 3.1).

3.5.2 Sample Collection in Anyinam Town

Thirty-six samples were collected from Anyinam as follows: fourteen water samples from 14 different boreholes, 15 well samples, 4 tap water supplied by GWCL. Three water samples collected at 3 different sampling points from River Birim which is the only river in the town. (Table 3.1).

3.6 Geographical Location of Samples

The Global Positioning System (GPS) address was taken at all the 64 sampling points with a smartphone using the GhanaPostGPS application and recorded. (Appendices 1 and 2).

Table 3. 1: Types and Number of Samples Collected in Kwabeng and Anyinam

SAMPLE TYPE	ANYINAM	KWABENG	TOTAL
BORE HOLES	14	14	28
WELLS	15	0	15
TAP WATER	4	9	13
RIVERS	3	5	8

3.7 Water Sampling and Treatment

Water samples were collected from the various sampling points. In the case of boreholes, tap water, and Wells, the samples were randomly collected in all directions of the towns making sure that a distance of at least 300m was left between samples from the same source. For example, if a well is sampled the next well to be sampled must be at least 300m away. At each sampling point, water samples were collected into a 500mL plastic bottle which was prewashed with detergents, soaked and washed in 10% nitric acid for 24 hours, rinsed with double distilled water, and oven-dried overnight (APHA, 2005; Boadi *et al*., (2011). The samples collected for metal analysis were filtered through 0.45 µm filter onsite and acidified with 5 mL of nitric acid (HNO_3) to a pH below 2.0 according to EPA Method 3005. Water quality parameters such as pH, electrical conductivity, salinity, total dissolved solids, and turbidity were measured in situ using EZDO 7200 multi meter. The electrode of the meter was dipped into the water samples whiles the values were read and recorded. The electrode of the meter was rinsed with distilled water after each sample measurement. All samples collected were well labelled, stored in an ice chest at 4 °C, and sent to the laboratory for analysis within 48 hours of sampling. Samples were kept in the refrigerator at 4 °C for 48 hours in the laboratory before heavy metal analysis were done.

3.8 Determination of Metal Concentrations

The samples were aspirated directly into the atomic absorption spectrophotometer to determine the metal content. The concentrations of heavy metals were measured using PINAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer. Cadmium (Cd) and lead (Pb) were determined using a flame atomic absorption spectrophotometer (FAAS). Arsenic (As) was determined using flow injection analysis system – atomic absorption spectrophotometer (FIAS-AAS) (Hydride Generation Technique) while mercury (Hg) was determined using flow injection analysis system – atomic absorption spectrophotometer (FIAS-AAS) (Cold Vapour Technique). Airacetylene gas was used as the source of fuel for Fe, Pb, and Cd while argon gas was used for As and Hg.

Table 3. 2: Instrument Analytical Condition of Investigated Metal Ion

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

3.9 Quality Control

All the reagents used were of analytical grade. Plastic and glassware were soaked in 10% HNO_3 for 24 hours, rinsed with distilled water and oven-dried overnight. A blank was run for each digestion procedure to correct the measurement. Each sample was analyzed in triplicates and two standards were tested after every 10 samples to check for interference and cross-contamination. The percent recovery of the metals analyzed is presented in Table 4. In order to guarantee the accuracy of the data, standard reference material ISE Sample 999 of moist clay from Liteta/Ivory Coast, WEPAL (Wageningen Evaluating Programs for Analytical Laboratories) was included in every batch of the sample digestion and analysis as part of the quality control protocol. To calculate mean concentration, it was assumed that the values below the limit of detection (LOD) were equal to half the LOD. For several samples, the concentration of metals was below the limit of detection (LOD) or quantification.

Table 3. 3: Certified and measured concentration of Fe, Pb, Cd, As, and Hg in ISE sample 999 of moist clay from Liteta/Ivory Coast, WEPAL

Analyte	Certified value (mg/kg	Measured value (mg/kg)	% Recoveries
Fe	62800 ± 61.0	63016 ± 57.7	98.1
Pb	4.710 ± 1.157	4.907 ± 0.235	98.7
Cd	0.040 ± 0.020	0.048 ± 0.031	99.6
As	0.772 ± 0.344	0.852 ± 0.223	95.3
Hg	0.0102 ± 0.00127	0.0122 ± 0.00118	97.2

3.10 Data Analysis

The analysis of the samples was done in triplicates and the values entered into Microsoft Excel version 2016 to find the averages. The data were then exported into STATA version 16 for descriptive summary statistics. Kruskal Wallis test was conducted to establish whether the difference noticed between the levels of the metals concentrations as well as the physico chemical parameters of the different water sources were statistically significant. Mann Whitney U test was also conducted with the same STATA version 16 to establish whether there were statistically significant differences between the two locations in relation to the levels of the metals and their physicochemical parameters.

3.11 Ethical Review

Ethical clearance was not sought since the study did not involve human or animal subjects. However, oral permission was sought from owners of the Wells, Boreholes and Tap waters before sampling was carried out.

CHAPTER FOUR

4.0 RESULTS

4.1 Concentrations of Metals and Physicochemical Parameters of Samples

The concentrations of metals analysed and the physicochemical parameters of all the 64 individual water samples are represented in appendix 3. The metals that were analysed are iron (Fe), lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg). The physicochemical parameters were pH, electrical conductivity (EC), salinity, turbidity, and total dissolved solids. Analysis was done for 8 river samples represented by ID 1-8, 13 tap water samples represented by ID 9-21, 15 well samples represented by ID 22-36 and 28 borehole samples represented by ID 37-64.

Table 4. 1: Metals Concentrations and Physicochemical Properties Levels of River Samples

	Variable	**Obs**	**Mean**	**Std. Dev**	**Min**	**Max**	**WHO Limit**
METALS/(mg/L)	Fe	8	6.24	1.27	4.33	8.31	NA
	Pb	8	0.16	0.09	0.03	0.28	0.01
	Cd	8	0.13	0.08	0.02	0.19	0.003
	As	8	0.23	0.09	0.04	0.32	0.01
	Hg	8	0.025	0.02	0.01	0.07	0.006
PHYSICOCHEMICAL PARAMETERS	pH	8	7.6	0.2	7.3	7.9	6.5-8.5
	EC(µScm)	8	76.8	15.9	45	103	
	Salinity(mg/L)	8	36.8	7.3	22	48	
	Turbidity(NTU)	8	159	271	14	809	<5
	TDS(mg/L)	8	52	10.7	30	69	600

EC=electrical conductivity, TDS=total dissolved solids

4.2 Concentration of Metals and Physicochemical Parameters of River Samples

The minimum, maximum, mean and the standard deviations of the levels of metals and the physicochemical parameters of the 8 river samples is represented in table 4.1. From the table, the concentration of Hg in the river samples ranged from 0.01 to 0.07mg/L with a mean of 0.025mg/L, Pb was from 0.03 to 0.28mg/L, that of Cd ranged between 0.02 to 0.19 with a mean value of 0.13mg/L and As was from 0.04 to 0.32mg/L. The concentrations of all these four heavy metals in all the river samples were higher than the WHO acceptable limit in drinking water of 0.01, 0.003,0.01 and 0.006mg/L for Pb, Cd, As and Hg respectively. Fe had a mean value of 6.24±1.27.The pH level of the river samples were within the WHO permissible limit of 6.5 to 8.5. The value ranged from 7.3 to 7.9. The turbidity was far above WHO limit of < 5NTU ranging from 14 to 809NTU with a mean value of 159NTU. The mean levels of the other physicochemical properties were electrical conductivity- 76.8±15.9, salinity-36.8±7.3 and TDS-52±10.7.

4.3 Concentration of Metals and Physicochemical Parameters of Tap Water Samples

From table 4.2, the concentration of Hg in the tap water samples ranged from 0.0001 to 0.0002 which is far below WHO permissible limit in drinking water sources of 0.006mg/L. The level of As was 0.0001 to 0.002mg/L which is also below WHO limit of 0.01mg/L. The mean values of the other metals were Fe-0.066±0.15; Pb-0.003±0.001 and Cd-0.003±0.004. The mean pH value of 6.2±0.2 was outside the WHO range of 6.5-8.5. The levels of the other parameters were electrical conductivity-104.7+54.6, salinity-122+255, turbidity-2.56±3.04 and finally TDS-74.8±32. Some of the samples had turbidity values above WHO acceptable limit.

Table 4. 2: Metals Concentrations and Physicochemical Properties Levels of Tap Water Samples

	Variable	**Obs**	**Mean**	**Std Dev**	**Min**	**Max**	**WHO Limit**
METALS	Fe	13	0.066	0.15	0.001	0.55	**NA**
	Pb	13	0.003	0.002	0.001	0.01	**0.01**
	Cd	13	0.003	0.004	0.001	0.015	**0.003**
	As	13	0.0003	0.001	0.0001	0.002	**0.01**
	Hg	13	0.0001	0.0000	0.0001	0.0002	**0.006**
PHYSICOCHEMICAL PARAMETERS	pH	13	6.2	0.2	5.9	6.6	**6.5-8.5**
	EC(μScm)	13	104.7	54.6	7.7	210	
	Salinity(mg/L)	13	122	255	36	968	
	Turbidity(NTU)	13	2.56	3.04	0.01	8.4	**<5**
	TDS(mg/L)	13	74.8	32.0	52	144	**600**

4.4 Concentration of Metals and Physicochemical Parameters of Borehole Samples

Results for all the 28 borehole samples are summarised in table 4.3.The mean concentration of Hg was 0.0002 with a range of 0.0001 to 0.0005mg/L, that of As was 0.0037 with a range of 0.001 to 0.008mg/L. All the samples had Hg and As concentrations that were below the WHO permissible limit in drinking water sources. The minimum concentration obtained for Pb was 0.001 and the maximum was 0.019mg/L with a mean of 0.017mg/L which is above the WHO limit of 0.01mg/L. The mean concentration of Cd was 0.013mg/L which is also above WHO permissible limit of Cd in drinking water sources. The mean values for the rest of the parameters were pH-6.7±0.2, EC-105±52.6, salinity-52.4±25.7, turbidity-4.2±9.9 and TDS-73±34.8. The pH and TDS values for all the 28 borehole samples were within the acceptable limit of WHO. However, the turbidity of some of the borehole water samples was above WHO limit of <5NTU.

Table 4. 3: Metals Concentrations and Physicochemical Properties Levels of Borehole Samples

	Variable	**Obs**	**Mean**	**Std. Dev**	**Min**	**Max**	**WHO Limit**
METALS	Fe	28	0.0946	0.13	0.0016	0.418	**NA**
	Pb	28	0.017	0.005	0.001	0.019	**0.01**
	Cd	28	0.013	0.018	0.001	0.078	**0.003**
	As	28	0.0037	0.0022	0.001	0.0077	**0.01**
	Hg	28	0.0002	0.0001	0.0001	0.0005	**0.006**
PHYSICO-CHEMICAL PARAMETERS	pH	28	6.7	0.2	6.2	7.4	**6.5-8.5**
	EC(µS/cm)	28	105	52.6	27	206	
	Salinity(mg/L)	28	52.4	25.7	12	104	
	Turbidity(NTU)	28	4.2	9.9	0.01	52.5	**<5**
	TDS(mg/L)	28	73	34.8	18	146	**600**

4.5 Concentration of Metals and Physicochemical Parameters of Well Samples

Table 4.4 gives the summary results for water samples from the 15 wells. The concentration of Pb ranged from 0.014 to 0.226mg/L with a mean of 0.049mg/L, meaning that all the 15 wells had their Hg levels above the WHO permissible limit of 0.01mg/L. The range for Cd was from 0.002 to 0.032 with a mean of 0.015mg/L, that of Hg was 0.0002 to 0.0016mg/L and As also ranged from 0.001 to 0.008mg/L. The mean level of Fe was 0.883±0.35. All the wells had As and Hg levels below WHO acceptable limit for drinking water. The mean value for pH and TDS were 7.5±0.2 and 86.2±57.3 respectively which are all within WHO permissible limit. Other values obtained were 131.2±86.7, 61.9±41.2 and 4.85±5.9 which represent mean values for EC, salinity and turbidity respectively.

Table 4. 4: Metals Concentrations and Physicochemical Properties Levels of Well Samples

	Variable	**Obs**	**Mean**	**Std. Dev**	**Min**	**Max**	**WHO Limit**
METALS	Fe	15	0.883	0.35	0.064	1.225	**NA**
	Pb	15	0.049	0.06	0.014	0.226	**0.01**
	Cd	15	0.015	0.11	0.002	0.032	**0.003**
	As	15	0.003	0.002	0.001	0.008	**0.01**
	Hg	15	0.0006	0.0001	0.0002	0.0016	**0.006**
PHYSICO-CHEMICAL PARAMETERS	pH	15	7.5	0.2	7.2	7.9	**6.5-8.5**
	EC(µScm)	15	131.2	86.7	38	310	
	Salinity(mg/L)	15	61.9	41.2	18	150	
	Turbidity(NTU)	15	4.85	5.9	0.1	21.4	**<5**
	TDS(mg/L)	15	86.2	57.3	26	209	**600**

4.6 Comparison of Metal Concentrations and Physicochemical Parameters of Surface and ground waters to WHO Permissible Limits

Table 4.5 shows a comparison between the metal concentrations and the physicochemical parameters of the ground water sources (boreholes and wells) and the surface water sources (rivers and tap waters) to WHO permissible limits in drinking water sources. From the table, the mean level of Hg and As in the rivers was 0.025mg/L and 0.23mg/L respectively. These values are higher than the WHO values of 0.006mg/L and 0.01mg/L respectively for Hg and As. The rest of the water sources had Hg and As levels below the WHO limit. The mean concentrations of Cd were in the ascending order of 0.003, 0.013, 0.015 and 0.13mg/L for TW, BH, Well and Rivers respectively. Apart from TW, the rest of the water sources had higher Cd levels than the WHO level of 0.003mg/L. Again, the mean levels of Pb were in similar ascending order of 0.003, 0.017, 0.049 and 0.16mg/L respectively for TW, BH, Well and Rivers. All the levels were higher than the WHO permissible limit of 0.01mg/L for Pb except that of TW. Fe levels were as follows: River-6.24, Well-0.88, BH-0.09, and TW-0.07mg/L. The river samples had the highest pH of 7.6 followed by well samples with 7.5 and borehole samples with a value of 6.7. All were within WHO range of 6.5 to 8.5. Tap water had the least pH of 6.2 and was outside the acceptable range. The mean turbidity of the river samples was 159NTU which was very high and above the permissible limit of <5NTUset by WHO. The turbidity of the rest were 4.85 for wells, 4.2 for boreholes and 2.56NTU for tap waters. The TDS values of all the samples were far below WHO limit of 600mg/L. The values were: well-86.2, tap water -74.8, borehole-73 and river- 52mg/L. The salinity levels were as follows: tap water-122, well-61.9, borehole-52.4, and river-36.8.

4.7 KRUSKAL-WALLIS ANALYSIS

Kruskal-Wallis test was done to find out if there exist a significant difference in the concentrations of each metal and the physicochemical parameters across all the four water sources: river (n = 8); TW (n = 13); BH (n = 28); and well (n = 15). The test showed that there was a statistically significant difference in the levels of Fe across the four different water sources, $X^2(3) = 45.839$, $p<0.001$. The rest of the metals also had a statistically significant difference in their levels across the water sources at $X^2(3) = 48.874$, $p<0.001$ for Pb; $X^2(3) = 27.917$, $p<0.001$ for Cd; $X^2(3) = 41.175$, $p<0.001$ for As and $X^2(3) = 45.078$, $p<0.001$ for Hg. With regards to the physicochemical parameters, Kruskal-Wallis analysis revealed that the differences in the mean pH and turbidity observed across the four water sources as depicted in table 4.5 was statistically significant,$X^2(3) = 50.626$, $p<0.001$ for pH and $X^2(3) = 13.030$, $p<0.05$ for turbidity. The differences in the EC, salinity and TDS levels across the four different water sources as shown in table 4.5 was however not statistically significant, $X^2(3) = 3.368$, $p > 0.10$ for EC; $X^2(3) = 3.817$, $p>0.10$ for salinity and $X^2(3) = 3.831$, $p>0.10$ for TDS.

Table 4. 5: Mean Metal Concentrations and Physicochemical Parameters of River, Tapwater, Borehole and Well Samples

		SAMPLE SOURCES				
		RIVER	**TW**	**BH**	**WELL**	**WHO**
	Fe	6.24	0.066	0.0946	0.883	**NA**
METALS	Pb	0.16	0.003	0.017	0.049	**0.01**
	Cd	0.13	0.003	0.013	0.015	**0.003**
	As	0.23	0.0003	0.0037	0.003	**0.01**
	Hg	0.025	0.0001	0.0002	0.0006	**0.006**
PHYSICO-CHEMICAL PARAMETERS	pH	7.6	6.2	6.7	7.5	**6.5-8.5**
	EC(µScm)	76.8	104.7	105	131.2	
	Sal(mg/L)	36.8	122	52.4	61.9	
	Tur(NTU)	159	2.56	4.2	4.85	<5
	TDS(mg/L	52	74.8	73	86.2	**600**

TW=tap water, BH=borehole, Sal=salinity, EC=electrical conductivity, Tur=turbidity

4.8 Comparison of Metals Levels and Physicochemical Parameters of the water samples between Kwabeng and Anyinam Towns (Mann-Whitney U Test)

Mann-Whitney U test was carried out to compare the levels of the metals and the physicochemical parameters of the water samples between the two towns (Kwabeng and Anyinam) (Table 4.6). From the analysis, there was a significant difference in the levels of Fe in the water sources between Kwabeng and Anyinam ($z=-3.404$, $p<0.001$). Anyinam water samples contained higher levels of Fe than Kwabeng water samples. The concentrations of Pb, Hg, Cd and As were all higher in Anyinam water samples than in Kwabeng water samples but the differences were not significant. With regards to the physicochemical parameters, significant differences were found between the two towns in the levels of: pH (z= -3.046, p<0.005); TDS (z=-1.977, p<0.05); and salinity (z=-2.133, p<0.05) of the water samples. Levels in Anyinam samples were higher than in Kwabeng samples for all the 3 parameters. Turbidity and EC levels were non-significantly higher in Anyinam compared to Kwabeng water samples.

Table 4. 6: Comparison of Metals Levels and Physicochemical Parameters of the water samples between Kwabeng and Anyinam Towns (Mann-Whitney U Test)

	TOWNS					
	KWABENG (n=28)		ANYINAM (n=36)			
	median	Rank sum	median	Rank sum	z-value	p-value
Hg	.0001667	830.5	.0002167	1249.5	-1.086	0.2773
Pb	.0091667	821.5	.0141667	1258.5	-1.199	0.2306
Fe	.0223333	658.5	.4163333	1421.5	-3.404	0.0007
Cd	.0026667	824	.014	1256	-1.167	0.2433
As	.0026667	935.5	.0028333	1144.5	0.347	0.7287
pH	6.65	685.5	7.2	1394.5	-3.046	0.0023
TDS(mg/L	58	764	72	1316	-1.977	0.0480
EC(µScm)	85	777	92	1303	-1.801	0.0718
Tur(NTU)	1.4	871	2.65	1209	-0.528	0.5972
Sal(mg/L)	40.5	752.5	52.5	1327.5	-2.133	0.0330

CHAPTER FIVE

5.0 DISCUSSION

5.1 Metals Concentrations and Physicochemical Parameters of River Samples

The surface water that were analysed in this study were river samples specifically river Birim and other rivers as well as Tap water from GWCL. The concentration of all the metals that were analysed specifically Hg, Cd, As, Fe, and Pb in all the river samples were far above the maximum permissible limit established by both WHO and Ghana Standards Authority (GSA). A similar study conducted by Armah et al. (2010) in Obuasi mining area in Ghana involving stream and rivers also had similar findings whereby all metals had higher levels above the WHO acceptable limit. A study by Appoh et al. (2011) conducted in the Birim North District recorded very low Hg levels in rivers and streams that were inconsistent with the mercury level recorded in this study.

The pH recorded in this study for these samples were consistent with the study of Armah et al. (2010). However, the turbidity of the river samples in this study was inconsistent with the same study. A value of 134.4NTU obtained in this study was far above what was obtained in the study of Armah et al even though both values were above the acceptable limit of 5NTU. The high turbidity value as well as high levels of metals obtained in this study area indicates a high degree of pollution of the surface water bodies in the study area which is once again consistent with a study conducted by Oppong Afum (2016). The high pollution may be attributed to the increase in mining activities in the area as these are the main water sources used in the mining activities. The very high turbidity coupled with high levels of metals in the rivers is worrying as these are the main sources of water used by the GWCL. High pollution of these water bodies will lead to increase cost in the water treatment process by GWCL which will subsequently be shifted to the final consumer who will then have to pay more to get access to potable water.

High levels of heavy metals in the river are likely to bioaccumulate in livestock that drink directly from these water bodies and these metals are finally passed on to human through the food chain with the attending numerous adverse health outcomes (Addo et al., 2012).

5.2 Metal Concentrations and Physicochemical Parameters of Borehole Samples

The concentration of As and Hg recorded in all the borehole samples were below the WHO and GSA acceptable limit for drinking water. In the case of Pb and Cd some of the samples had concentrations above WHO and GSA acceptable limit whereas others were below the limit. This result is consistent with a study conducted by Cobbina, S. J, Myilla, M., and Michael (2013). The high level of Pb and Cd in some of the boreholes could be attributed to the depth of these individual boreholes as well as ingress of leachate from waste and landfill sites containing plumbing materials, paints, plastics, batteries and other Pb and Cd containing materials. The mean Fe concentration of 0.155mg/L found in the borehole samples was below GSA acceptable limit of 0.3mg/L in drinking water sources which is consistent with the study of Tay & Momade (2009). Four boreholes specifically samples BH15, BH16, BH18 and BH26 had Fe concentrations that were above the limit and this could be due to their abundance in the soil in the sampling point since the major source of Fe in drinking water sources are naturally occurring Fe in the earth crust. These four boreholes were not in close proximity to mining sites.

The level of pH, electrical conductivity, salinity, turbidity and total dissolved solids of the boreholes that were sampled were within the acceptable limit. The pH range obtained was not outside the range of 6.5 to 8.5 to be able to cause corrosion in the distribution system of households that depend on mechanised boreholes.

5.3 Metal Concentrations and Physicochemical Parameters of Well Samples

The concentration of Hg and As in all the wells were within WHO and GSA acceptable limit in drinking water. This is at variance with the levels obtained by Cobbina et al. (2015) for these two metals. However the concentrations of Pb in all the wells that were sampled were above the acceptable WHO value of 0.01 mg/L. This again agrees with the study of Cobbina et al. (2015) but inconsistent with a study conducted in the Ashanti gold belt of Ghana by Tay & Momade (2009) which had Pb concentrations in all well samples below the WHO limit. The high level of Pb recorded in this study may be due to the depth of these Wells as well as erosions of natural deposit. Direct and indirect consumption of these wells which have high levels of Pb could be associated with the increase number of people with hypertension in the locality. Chronic exposure to lead can also lead to neurodevelopmental impairment in utero. Also, only 5 samples out of the 15 wells namely samples W5, W6, W7, W8 and W9 had Cd levels below the acceptable level of 0.003mg/L. It is worth mentioning that these 5 wells were all on slightly hilly grounds and far away from mining sites hence the possibility of runoff from waste composed of Cd containing materials such as batteries, paints and erosion from natural deposit cannot be overlooked as a possible source of the high level of Cd in the other 10 wells. Also, 2 wells had Fe values below GSA standard. These two wells were in close proximity to mining sites hence the other wells with Fe values higher above the standard is likely to be due to the natural occurrence of Fe in the soil and the soil type in those sampling points. The concentration of Cd and Fe obtained in this study was consistent with the study of Tay & Momade (2009). The mean levels of pH, electrical conductivity, salinity, turbidity and total dissolved solids in the well samples were within the acceptable limit.

5.4 Metal Concentrations and Physicochemical Parameters of Tap Water Samples

The concentrations of Cadmium and Arsenic in all the tap water that were sampled were within the acceptable required limit set by WHO and GSA. Of the 13 tap water samples, only one specifically sample TW13 had the concentration of both Fe and Pb to be above the acceptable limit. This tap water had been newly installed less than one month before sampling hence the high level of Pb is likely to be from the pipes, Pb solders and fittings in the plumbing work since these are possible sources of Pb in tap waters as stated in WHO's report (WHO, 2011). The rest of the samples had Fe and Pb levels below the acceptable limit. Sample TW7 also had its Cd concentration to be 0.015mg/L which is above the acceptable limit of 0.003mg/L. The rest of the samples had Cd values below this limit. The high level of Cd found in sample TW7 cannot be from the source where the water is pumped since others from the same source had lower levels and therefore it is likely to be from corroded galvanised pipelines as indicated in USEPA (2011) report or likely to be due to random error. The level of salinity, electrical conductivity, turbidity and total dissolved solids were within the acceptable limit of both GSA and WHO. However, the mean pH of the tap water samples of 6.2 obtained in the study can cause corrosion in the treatment plant and the distribution system. Corrosion of the treatment plant will lead to frequent servicing of these plants thereby increasing the cost of the entire water treatment process. This cost will finally be shifted to the consumer hence the consumer will have to pay more to get access to potable and clean water. This has adverse health implication on the consumer because there will be an attempt to conserve and economise water which could lead to improper hygiene and for that matter all forms of water related diseases. The quality and quantity of food consumed by the family will also be affected because expenses on water will increase which could affect the expenses on food leading to undernutrition especially on the side of children.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In conclusion, tap water supplied by GWCL had metal concentrations and physicochemical parameters that were within WHO acceptable limit for drinking water and therefore safe for human consumption with respect to the parameters that were analysed in this study. Majority of the boreholes and wells also contained safer levels of metals.

On the other hand, the concentration of metals in river Birim and the other rivers that were sampled were above the acceptable limits set by both WHO. Community members who therefore directly or indirectly depend on these sources of water may likely suffer from the effect of the long term exposure to these metals such as skin lesions and skin cancer, kidney cancer, neurological effects, hypertension and cardiovascular disease, peripheral vascular disease and diabetes mellitus.

6.2 Recommendations

1. The Environmental Health Department of the district assemblies of Atiwa East and West should periodically assess the level of metals especially those included in WHO list of chemicals of health concern (Lead, Cadmium, Mercury and Arsenic) in boreholes, wells, rivers and streams especially within mining communities and towns.
2. The District Chief Executives of Atiwa east and Atiwa west districts together with the districts Police Commanders, Chiefs and Elders and religious leaders must come together to stop illegal mining in the locality by: 1. Forming patrol team with the sole mandate of patrolling forest reserves and illegal mining sites during both day and night; 2. Confiscating gadgets and equipment used by these miners; 3. Enacting a by-

law that prohibits land owners from giving out their lands for mining activities; and 4. Criminalising illegal mining in the districts through the incarceration of perpetrators.

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APPENDICES

APPENDIX 1: Geographical locations of Kwabeng Samples

SAMPLE TYPE	CODE	DESCRIPTION	GEOGRAPHICAL LOCATION	
BORE HOLE SAMPLES			LATITUDE	LONGITUDE
	BH1	Bore Hole 1	6.309700	-0.588778
	BH2	Bore Hole 2	6.310239	-0.590979
	BH3	Bore Hole 3	6.319537	-0.590395
	BH4	Bore Hole 4	6.320390	-0.596773
	BH5	Bore Hole 5	6.325151	-0.586712
	BH6	Bore Hole 6	6.324927	-0.585275
	BH7	Bore Hole 7	6.324567	-0.584826
	BH8	Bore Hole 8	6.320435	-0.582670
	BH9	Bore Hole 9	6.321558	-0.582759
	BH10	Bore Hole 10	6.326499	-0.586667
	BH11	Bore Hole 11	6.314012	-0.584331
	BH12	Bore Hole 12	6.314371	-0.580783
	BH13	Bore Hole 13	6.321962	-0.591473
	BH14	Bore Hole 14	6.323085	-0.588733
TAP WATER SAMPLES	TW1	Tap Water 1	6.314686	-0.589632
	TW2	Tap Water 2	6.319537	-0.590395
	TW3	Tap Water 3	6.325690	-0.586173
	TW4	Tap Water 4	6.318504	-0.588060
	TW5	Tap Water 5	6.316842	-0.587341
	TW6	Tap Water 6	6.316033	-0.586308
	TW7	Tap Water 7	6.321064	-0.590710

RIVER SAMPLES	TW8	Tap Water 8	6.315988	-0.589542
	TW9	Tap Water 9	6.320166	-0.587925
	RA1	River A point 1	6.323265	-0.587565
	RA2	River A point 2	6.326364	-0.590215
	RA3	River A point 3	6.319896	-0.585365
	RB1	River B point 1	6.314461	-0.590350
	RB2	River B point 2	6.319267	-0.597402

APPENDIX 2: Geographical Locations of Anyinam Samples

SAMPLE TYPE	CODE	DESCRIPTION	GEOGRAPHICAL LOCATION	
			LATITUDE	LONGITUDE
BORE HOLE SAMPLES	BH15	Bore hole 15	6.370023	-0.544671
	BH 16	Bore hole 16	6.367822	-0.544087
	BH 17	Bore Hole 17	6.372224	-0.540943
	BH 18	Bore Hole 18	6.373661	-0.546917
	BH 19	Bore Hole 19	6.373796	-0.545884
	BH 20	Bore Hole 20	6.375093	-0.541841
	BH21	Bore Hole 21	6.377793	-0.554058
	BH22	Bore Hole 22	6.378512	-0.555361
	BH23	Bore Hole 23	6.381342	-0.551049
	BH24	Bore Hole 24	6.383049	-0.552396
	BH25	Bore Hole 25	6.387585	-0.562368
	BH26	Bore Hole 26	6.388304	-0.561963
	BH27	Bore Hole 27	6.388753	-0.558505

	BH 28	Bore Hole 28	6.381162	-0.547725
WELL SAMPLES	W1	Well 1	6.373930	-0.545704
	W2	Well 2	6.374290	-0.544401
	W3	Well 3	6.371235	-0.544087
	W4	Well 4	6.371819	-0.543683
	W5	Well 5	6.371730	-0.546288
	W6	Well 6	6.374964	-.0541257
	W7	Well 7	6.375503	-0.539910
	W8	Well 8	6.375612	-0.538710
	W9	Well 9	6.376131	-0.548174
	W10	Well 10	6.377299	-0.549118
	W11	Well 11	6.374739	-0.553205
	W12	Well 12	6.384711	-0.553968
	W13	Well 13	6.388124	-0.562143
	W14	Well 14	6.388529	-0.560346
	W15	Well 15	6.388214	-0.556798
TAP WATER SAMPLES	TW 10	Tap Water 10	6.374135	-0.545020
	TW11	Tap Water 11	6.374290	-0.541167
	TW12	Tap Water 12	6.375503	-0.553205
	TW 13	Tap Water 13	6.380488	-0.546692
RIVER SAMPLES	RC1	River C Point 1	6.386283	-0.552621
	RC2	River C Point 2	6.387900	-0.556798
	RC3	River C Point 3	6.386058	-0.553474

APPENDIX 3: Concentrations of Metals and Physicochemical levels of Individual Samples

ID	CODE	Fe	Pb	Cd	As	Hg	pH	EC	Sal	Turb	TDS
1	RA1	5.925	0.221	0.188	0.291	0.017	7.3	83	39	21.8	56
2	RB1	4.328	0.192	0.174	0.186	0.014	7.4	76	36	14	51
3	RB2	4.941	0.219	0.194	0.248	0.0217	7.4	74	35	17.6	50
4	RA2	6.043	0.201	0.179	0.281	0.0216	7.3	103	48	42.8	69
5	RA3	8.311	0.281	0.194	0.316	0.0178	7.7	45	22	24.2	30
6	RC1	6.748	0.065	0.041	0.044	0.0178	7.7	76	37	145.4	52
7	RC2	6.212	0.110	0.029	0.175	0.0667	7.9	76	37	809	52
8	RC3	7.396	0.025	0.025	0.319	0.0219	7.8	82	41	200	56
9	TW1	0.025	0.005	0.001	0.002	0.000	6	88	40	0.1	61
10	TW2	0.001	0.001	0.003	0.000	0.0001	6.4	77	39	8	54
11	TW3	0.014	0.001	0.003	0.000	0.0001	5.9	88	42	0.2	60
12	TW4	0.004	0.001	0.003	0.000	0.0001	6	89	42	0.8	60
13	TW5	0.001	0.001	0.002	0.000	0.0001	6.4	92	43	1.1	61
14	TW6	0.024	0.002	0.002	0.000	0.0001	6.5	7.7	38	4.1	52
15	TW7	0.012	0.001	0.015	0.000	0.0001	6	82	41	1.3	58
16	TW8	0.013	0.005	0.001	0.000	0.0001	6.5	76	36	0.5	52
17	TW9	0.015	0.001	0.001	0.000	0.0001	6	93	43	0.01	61
18	TW 10	0.015	0.002	0.001	0.000	0.0001	6.1	210	102	1.1	144
19	TW11	0.011	0.004	0.001	0.000	0.0001	6.5	109	53	1.6	73
20	TW12	0.165	0.002	0.002	0.000	0.0001	6	142	968	8.4	97
21	TW 13	0.559	0.006	0.002	0.000	0.0001	6.6	208	99	6.1	140
22	W1	1.217	0.025	0.021	0.006	0.0016	7.6	254	123	6.9	173
23	W2	1.040	0.024	0.018	0.002	0.0012	7.4	141	67	1.5	95
24	W3	0.989	0.016	0.032	0.002	0.0014	7.9	46	22	3.2	31

25	W4	0.936	0.019	0.027	0.005	0.0002	7.6	65	31	14.2	44
26	W5	1.064	0.178	0.002	0.005	0.0002	7.2	161	77	0.9	108
27	W6	0.889	0.028	0.003	0.004	0.0003	7.5	200	80	2.9	99
28	W7	0.957	0.016	0.003	0.003	0.0011	7.2	257	123	0.6	173
29	W8	0.829	0.015	0.002	0.001	0.0003	7.3	93	43	0.9	62
30	W9	1.078	0.015	0.003	0.001	0.0010	7.6	64	30	0.1	42
31	W10	1.115	0.023	0.004	0.002	0.0002	7.6	115	56	0.6	79
32	W11	1.225	0.217	0.028	0.002	0.0002	7.6	89	43	21.4	61
33	W12	0.065	0.021	0.015	0.002	0.0002	7.5	310	150	5.6	209
34	W13	0.678	0.014	0.029	0.004	0.0002	7.7	38	18	2.4	26
35	W14	0.109	0.054	0.016	0.008	0.0004	7.3	58	28	8.2	39
36	W15	1.063	0.070	0.023	0.005	0.0004	7.2	77	37	3.3	52
37	BH1	0.019	0.009	0.013	0.007	0.000	6.6	70	26	2.4	46
38	BH2	0.019	0.005	0.013	0.002	0.0002	6.4	53	25	52.5	36
39	BH3	0.012	0.003	0.019	0.005	0.0003	6.9	101	49	4.1	69
40	BH4	0.022	0.016	0.017	0.007	0.0002	6.6	196	93	0.01	131
ID	**CODE**	**Fe**	**Pb**	**Cd**	**As**	**Hg**	**pH**	**EC**	**Sal**	**Turb**	**TDS**
41	BH5	0.022	0.014	0.003	0.007	0.0005	6.7	201	94	1.2	130
42	BH6	0.032	0.016	0.003	0.003	0.0002	6.8	70	33	1.1	47
43	BH7	0.109	0.009	0.002	0.008	0.0003	7.1	206	104	4.7	146
44	BH8	0.114	0.019	0.002	0.006	0.0002	6.8	54	25	1.5	36
45	BH9	0.033	0.003	0.002	0.002	0.0001	6.6	47	22	1	31
46	BH10	0.031	0.016	0.002	0.002	0.0002	6.9	124	62	2.4	87
47	BH11	0.022	0.015	0.017	0.002	0.0001	6.7	36	18	0.1	25
48	BH12	0.022	0.017	0.001	0.003	0.0001	6.8	87	41	0.1	58
49	BH13	0.002	0.009	0.002	0.008	0.0002	6.6	100	47	0.1	67
50	BH14	0.026	0.014	0.001	0.001	0.0001	6.9	103	49	3.1	70
51	BH15	0.414	0.009	0.001	0.002	0.0002	6.9	27	12	0.01	18

52	BH16	0.364	0.007	0.002	0.003	0.0001	6.8	105	50	0.1	71
53	BH17	0.294	0.001	0.009	0.001	0.0001	6.6	126	61	4.2	85
54	BH18	0.311	0.015	0.001	0.003	0.0001	7.1	84	26	6.6	37
55	BH 19	0.025	0.009	0.002	0.001	0.0001	6.9	138	68	3.6	95
56	BH20	0.032	0.005	0.014	0.005	0.0002	6.8	52	72	0.01	102
57	BH21	0.046	0.008	0.078	0.003	0.0001	7.4	81	40	6.2	56
58	BH22	0.094	0.011	0.014	0.002	0.0002	6.6	187	91	1.7	120
59	BH23	0.022	0.010	0.007	0.003	0.0002	7.1	91	43	1.3	61
60	BH24	0.025	0.008	0.015	0.003	0.0002	6.9	192	88	0.7	122
61	BH25	0.026	0.004	0.002	0.003	0.0002	6.3	90	64	13.5	76
62	BH26	0.419	0.011	0.029	0.002	0.0001	6.9	162	75	1.9	101
63	BH27	0.024	0.007	0.019	0.005	0.0002	6.4	76	36	0.1	50
64	BH 28	0.070	0.002	0.063	0.003	0.0002	6.2	91	52	3.6	71

BH=Borehole, TW=Tap Water, W=Well Samples, RA=River A, RB=River B, RC=River C Turb=Turbidity, Sal=Salinity, EC=Electrical Conductivity, TDS=Total Dissolved Solids