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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

ARTISANAL ACTIVITIES AT THE "SUAME MAGAZINE" INDUSTRIAL AREA AND ITS EFFECT OF HEAVY METAL LEVELS ON THE AREA'S WATER RESOURCES

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, COLLEGE OF SCIENCE KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE.

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DECLARATION

I hereby declare that this submission is my own work towards the award of the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

I dedicate this work to the Almighty God and to my sweet and ever-loving aunt and husband, Mr and Mrs. Fori Dwumah and to my dear parents, Mr. and Mrs. Onyina Antwi.

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ABSTRACT

Industrial discharges from artisanal activities are known to adversely affect natural resources and human health. Water samples collected from an area with a high artisanal population in the Kumasi municipality were monitored for temperature, pH, turbidity, conductivity and heavy metals (Lead, Iron, Cadmium, Chromium) from hand-dug wells, hand-pump wells, pipe- borne water and surface waters. Physicochemical parameters were determined using standard procedures whilst heavy metals were determined by Atomic Absorption Spectrometry method. From the results temperature ranged between 26.33 ± 0.31 and 29.22 ± 0.51˚C. Mean pH ranged between 4.24 and 6.40 which were below the WHO acceptable limit of 6.5 in all the water sources. Turbidity values were within the WHO limit of <5NTU with the exception of surface waters which recorded turbidity values of 50.89NTU. Conductivity was within the acceptable limit in all the water sources. Mean levels of heavy metals were 0.18-1.06 for Pb and 0.23-11.49 for Fe in all the different water sources. Cd levels were below detection limits in all the water samples from the study area. However, Cd level in surface water from the study site exceeded levels from the control site. Cr levels in all the water sources, with the exception of surface waters, were below detection limit in both the study and control sites. Sanitation survey of the study site indicated that most hand-dug and hand-pump wells were shallow and sited close to metallurgical shops with no proper drainage and sewerage systems. Data from this study could help advice the Community Water and Sanitation Agency on the need to adopt an integrated approach in minimizing heavy metal pollution of water sources within the "Suame Magazine" and its environs.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	-	Atomic Absorption spectrometry
ANOVA	-	Analysis of Variance
BDL	-	Below detection limit
Cd	-	Cadmium
Cr	-	Chromium
CWSA	-	Community Water and Sanitation Agency
E.C	-	Electrical Conductivity
Fe	-	Iron
KCl	-	Potassium Chloride

LSD	-	Least Significance Difference
MCL	-	Maximum Contaminant Limit
Mg/l	-	Milligram per litre
Ml	-	Milliliter
NTU	-	Nephelometric Turbidity Unit
^{O}C	-	Degree Celcius
Pb	-	Lead
S.D	-	Standard Deviation
SPSS	-	Statistical Package for Social Scientist
WHO	-	World Health Organization
X	-	Mean
µS/cm	-	Microsecond per centimeter
µm	-	Micro meter

CHAPTER ONE

1.0 INTRODUCTION

Globally, about 900 billion people still remain without access to improved sources of water. Similarly, about 2.6 billion have no access to any form of improved sanitation services (WHO/ UNICEF, 2010). The majority of these persons are in Asia (20%) and sub-Saharan Africa (42%) (WHO/UNICEF, 2000). Consequently, people in developing countries especially children below five years die every year from diseases associated with lack of access to safe drinking-water, inadequate sanitation and poor hygiene (WHO 2000).

Urban water supply coverage is only 70% of the total water requirements in the urban areas of Ghana. Out of the 70% only 40% can boast of regular water supply (CWSD, 1999). The use of groundwater as the main source of potable water supply is increasing worldwide and in Ghana, 62-71% of people in peri-urban and rural communities rely on groundwater (Obiri- Danso *et al*., 2009) as their main source of drinking water. However, in many developing countries, groundwater sources have been contaminated as a result of the indiscriminate dumping of untreated industrial wastes into receiving waters which eventually pollute water supplies (World Water Day, 2010). Secondly, there is direct contamination of surface waters with metals in discharges from mining, smelting, leachates from municipal wastes, hazardous E-waste, agrochemicals, accidental oil spillages and industrial manufacturing (Asamoah-Boateng, 2009; Adetunji and Odetokun, 2011).

Poor water supply and inadequate sanitation results in diarrhoeal diseases such as cholera, dysentery and chronic and long term ill effects due to heavy metal poisoning and accumulation. Heavy metal poisoning is evident in Bangladesh, where 20% of its well water naturally contains high levels of arsenic (WHO/UNICEF, 2000). The incidence of high fluoride and arsenic in groundwater of Karbi Angling and Nagaon district of Assan, India and its manifestation in the form of fluorosis has also been reported (Sabhapandit *et al.*, 2010).

Industrial waste has been a problem since the industrial revolution. Industrial waste may be toxic, ignitable, corrosive or reactive. If improperly managed, this waste can pose dangerous health and environmental consequences. Further work done in Shush and Andimeshek plain in Iran with high agricultural activities indicated high levels of cadmium (0.005 mg/l) in groundwater samples which exceeded WHO Maximum Contaminant Limit(MCL) (0.003 mg/l) (Nouri *et al.*, 2006).

Again, heavy metals present in groundwater has also been reported in India, indicating that areas which were near to industries have metal polluted water (Yadav *et al.*, 2011)

1.1 STATEMENT OF PROBLEM

The "Suame Magazine", located in the Suame sub-metro in the north-eastern part of the Kumasi metropolis has over 200,000 workers grouped under approximately 12,000 independent enterprises involved in Manufacturing, Vehicle Repair & Maintenance, Metal working, Sale of engineering materials and automobile spare- parts(Adeya,2001).

Various waste including waste oil, metal scraps, used batteries and effluents among others, which often contain heavy metals are indiscriminately discarded by the artisans and end up in the general environment. Alarmingly, many semi rural holdings exist within the magazine which serves as both residence and metallurgical shop for most artisans and other individuals in such polluted environment. Due to the metropolitan authority's inability to extend potable water supply to the entire area owing to lack of maintenance or increased population, groundwater consumption has become a common practice with many homes having resorted to the use of hand-dug and hand-pump wells for domestic purposes.

Considering the high water table and the depth of hand- dug wells (approximately 3 to 15 meters), the suitability of groundwater for drinking in the area has raised some concerns due to the possibility of contamination of the underlying ground water by heavy metals.

1.2 MAIN OBJECTIVE

- The purpose of the study is to determine the concentration of some physico-chemical parameters and heavy metals (Cadmium, Chromium, Iron, and Lead) of water sources (hand-pump wells, hand-dug wells, surface waters, pipe- borne water) in the "Suame Magazine" industrial area of Kumasi.

1.2.1 Specific objectives

- To determine the physico-chemical parameters (pH, temperature, electrical conductivity, total dissolved solids) of hand-pump wells, hand dug wells, pipe borne water and surface waters.
- To determine the concentration of cadmium, chromium, iron and lead in the Hand-pump wells, hand dug wells, pipe borne water and surface waters.

1.3 JUSTIFICATION OF STUDY

The consumption of water worldwide increases yearly while most of the world's water resources continue to dwindle due to improper environmental management practices (UNEP, 2000). Globally, more than twenty five thousand people die daily as a result of water related diseases (WHO, 2002). The increasing dependence on ground water as a source of potable water supply has spurred efforts to protect the quality of this limited resource.

Heavy metals are priority toxic pollutants that severely limit the beneficial use of water for domestic or industrial application (Nagendrappa *et al.,* 2010). Pollution due to artisanal activities, threatened to increase the heavy metal concentration in both soil and water sources of "Suame Magazine" and its environs. Whilst different studies in auto repair workshops have been carried out by different authors on soil contamination, little is known on the effect of artisanal activities on water sources, especially in the study area.

The research would;

- Help determine whether heavy metals contamination of water sources at the "Suame Magazine" is significant enough to warrant public health concern.
- Provide baseline information on heavy metal contamination of water sources in the "Suame Magazine" area.
- Provide a basis for planning management strategy to achieve better environment quality and substantial development of the "Suame Magazine"

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sources of Water

Water is one of the essentials that supports all forms of plant and animal life (Vanloon and Duffy, 2005) and it is generally obtained from two principal natural sources; Surface water such as fresh water lakes, rivers, streams, etc. and Ground water such as borehole water and well water (McMurray and Fay, 2004; Mendie, 2005). Water has unique chemical properties due to its polarity and hydrogen bonds which means it is able to dissolve, absorb, adsorb or suspend many different compounds (WHO, 2007), thus, in nature, water is not pure as it acquires contaminants from its surrounding and those arising from humans and animals as well as other biological activities (Mendie, 2005). (Momodou and Anyankorah, 2010)

2.1.1 Groundwater

Groundwater is underground or subsurface water. Groundwater comes from surface water percolating through overlying soils and it resides in the pore spaces between particles of soil and other geologic materials. Formations that have all the pore spaced saturated with water are called saturated zones or aquifers. The top of the aquifer is called the water table. Aquifers typically consist of gravel, sand, sandstone, or fractured rock, like limestone. These materials are permeable because they have large connected spaces that allow water to flow through. The amount of ground water and the speed at which groundwater flows depends on the size of the spaces in the soil or rock and how well the spaces are connected (USGS, 2009).

Groundwater is located in an underground, saturated zone but can intercept surface water. Water wells extend into aquifers to allow water to be collected and pumped to the surface. Groundwater does not (generally) exist as underground rivers or pools – instead it is captured between particles above an impermeable layer that restricts water movement further downward. The quality of ground water is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring and varies from place to place and with the depth of the water table (Jain *et al.*, 1995)

With sufficient water infilteration, soil contaminants such as heavy metals can leach to underlying groundwater. Unconfined aquifers are especially vulnerable to various contaminants (Nouri *et al.*, 2006) and sediment loads (including microscopic bacteria, viruses and protozoa)

2.1.2 Surface Water

Municipal areas draw heavily on surface water for their drinking water supplies. Precipitation that does not evaporate or infiltrate into the ground runs as surface water, which may accumulate to form streams, and streams join to form rivers. Lakes are inland depressions that hold standing freshwater. Ponds are generally considered to be small temporary or permanent bodies of water shallow enough for rooted plants to grow over and at the bottom. While lakes contain nearly one hundred times as much water as all rivers and streams combined, they are still a major component of total world water supply (Mallard, 1982).

Because of the interconnectedness of groundwater and surface water, these contaminants may be shared between the two sources. Neither water source can ever be entirely free from water contaminants. Due to the cycle of water (hydrology), the two sources of drinking water feed each other, sharing contaminants.

2.2 WATER POLLUTION

Water is a unique substance, because it can naturally renew and cleanse itself, by allowing pollutants to settle out (through the process of sedimentation) or break down, or by diluting the pollutants to a point where they are not in harmful concentrations. However, this natural process takes time, and is difficult when excessive quantities of harmful contaminants are added to the water. Water pollution includes all of the waste materials that cannot be naturally broken down by water.

Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans and groundwater). Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds. Water pollution affects plants and organisms living in these bodies of water. In almost all cases the effect is damaging not only to individual species and populations, but also to the natural biological communities.

It has been suggested that water pollution is the leading worldwide cause of deaths and disease and that it accounts for the deaths of more than 14,000 people daily (Larry, 2006). An estimated 700 million Indians have no access to a proper toilet, and 1,000 Indian children die of diarrhoeal sickness every day Some 90% of China's cities suffer from some degree of water pollution, and nearly 500 million people lack access to safe drinking water(A special report on India, 2008). In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well. In the most recent national report on water quality in the United States, 45 percent of assessed stream miles, 47 percent of assessed lake acres, and 32 percent of assessed bay and estuarine square miles were classified as polluted (USEPA, 2007)

Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support human use, such as drinking water, and/or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish. Natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water.

2.3. SOURCES OF WATER POLLUTION

Surface water and groundwater have often been studied and managed as separate resources, although they are interrelated (United States Geological Survey (USGS), 1998). Surface water seeps through the soil and becomes groundwater. Conversely, groundwater can also feed surface water sources. Sources of surface water pollution are generally grouped into two categories based on their origin.

2.3.1 Point Sources

Point source water pollution refers to contaminants that enter a waterway from a single, identifiable source, such as a pipe or ditch. Examples of sources in this category include discharges from a sewage treatment plant, a factory, or a city storm drain. The U.S. Clean Water Act (CWA) defines point source for regulatory enforcement purposes. The CWA definition of point source was amended in 1987 to include municipal storm sewer systems, as well as industrial storm water, such as from construction sites.

2.3.2 Non–point Sources

Non–point source pollution refers to diffuse contamination that does not originate from a single discrete source. NPS pollution is often the cumulative effect of small amounts of contaminants gathered from a large area. Contaminated storm water washed off of parking lots, roads and highways, called urban runoff, is sometimes included under the category of NPS pollution. However, this runoff is typically channeled into storm drain systems and discharged through pipes to local surface waters, and is a point source. However where such water is not channeled and drains directly to ground it is a non-point source.

2.4.0. METALLURGIC HISTORY AND INDUSTRIAL ACTIVITIES OF "SUAME MAGAZINE" INDUSTRIAL AREA

"Suame magazine" is one of the industrial areas and enterprise cluster (Adeya, 2001, 2006) located in Kumasi, Ghana, and possibly one of Africa's largest light- industrial clusters. The site once housed a military magazine, hence the term "Suame Magazine" which was coined when the cluster was established at former armories. The site was created when the entrepreneurs also known as "fitters" were removed from Kumasi city centre in the 1950s and 1960s. Prior to this small and medium scale enterprises had started clustering at former armories in Kumasi as early as 1935.

The site where Suame cluster is located is zoned for administrative purposes but plots within the zones are not well demarcated, owing to the haphazard construction of temporary workshops and residential shacks by 'squatter artisans' at the industrial area.

In 1984, over 40,000 people were working in Suame and as at the year 2000, there were about 80,000 people (Adeya, 2001).currently there are over 200,000 people who work and live in the magazine area.

Other non-vehicular activities embarked on within the area include; banking, sale of building and hardware materials, and sale of food, amongst others, constituting about 40,000 professionals.

Suame cluster is dominated by micro and small enterprises (MSEs). On average the enterprises have 5 workers, but the relatively more sophisticated manufacturing workshops have 7-10 workers on average. The major metallurgic activities can be categorized under manufacturing, vehicle repair, metalworking, and sale of engineering materials, sale of automobile spare-parts and sale of food. Communication centers are increasingly playing an important role in enhancing the activities of the clusters.

2.5 HEAVY METALS

Advancement in technology had led to high level of industrialization leading to discharge of heavy metals into our environment. (Abidemi, 2011).Heavy metals are natural components of the Earth's crust. They cannot be degraded or destroyed (Lenntech, 2005).

The most frequently reported heavy metals with regards to potential hazards and the occurrence in contaminated soils are Cd, Cr, Pb, Zn, Fe and Cu (Alloway, 1995). The concentration of these toxic elements in soils may be derived from various sources, including anthropogenic pollution, weathering of natural high background rocks and metal deposits (Akoto *et al*., 2008)

Heavy metals is a general collective term which applies to the group of metals and metalloids with atomic density greater than 4 g/cm3 or 5 times or more, greater than water. Their pollution of the environment, even at low levels and the resulting long – term cumulative health effects are among the leading health concerns all over the world (Yahaya *et al.,* 2010). Heavy metals normally occurring in nature are not harmful to our environment, because they are only present in very small amounts. However, if the levels of these metals are higher than the levels of healthy life, the roles of these metals change to a negative dimension. This is evident in

Bangladesh where high levels of arsenic in groundwater were evident. Drinking water is also an important source for heavy metals for humans (Tuzen and. Soylak, 2006).

2.5.1 Beneficial Heavy Metals

In small quantities, certain heavy metals are nutritionally essential for a healthy life. Some of these are referred to as the trace elements (e.g., iron, copper, manganese, and zinc). These elements, or some form of them, are commonly found naturally in foodstuffs, in fruits and vegetables, and in commercially available multivitamin products. Diagnostic medical applications include direct injection of gallium during radiological procedures, dosing with chromium in parenteral nutrition mixtures, and the use of lead as a radiation shield around x-ray equipment. Heavy metals are also entered into the environment through industrial applications such as in the manufacture of pesticides, batteries, alloys, electroplated metal parts, textile dyes, steel, and so forth. Many of these products are in our homes and actually add to our quality of life when properly used. (Life Extention Information Centre, 2011)

2.5.2 Toxic Heavy Metals

Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and in manufacturing, pharmaceutical, industrial, or residential settings. Heavy metal poisoning could result, for instance, from drinking-water contamination (e.g. lead pipes), high ambient air concentrations near emission sources, or intake via the food chain. (Lenntech, 2005)

Some heavy metals like Ar, Cd and Pb have been reported to have no known bio-importance in human biochemistry and physiology and consumption even at very low concentrations can be toxic (Yahaya *et al.*, 2010).

Industrial exposure accounts for a common route of exposure for adults. Ingestion is the most common route of exposure in children. Children may develop toxic levels from the normal hand-to-mouth activity of small children who come in contact with contaminated soil or by actually eating objects that are not food (dirt or paint chips). Less common routes of exposure are during a radiological procedure, from inappropriate dosing or monitoring during intravenous (parenteral) nutrition, from a broken thermometer, or from a suicide or homicide attempt.(Life Extension Information Centre,2011)

Heavy metals can enter a water supply by industrial and consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater (Lenntech, 2005).

2.6.0 FACTORS AFFECTING THE MOBILITY OF HEAVY METALS IN THE ENVIRONMENT

Besides the metals man have created through nuclear reactions the rest have been on earth since the planet was formed. The metals exist naturally in the bedrock and are released through weathering. In water, metals exist in different forms, both dissolved and suspended, depending on a number of different parameters. The solubility, transportation and toxicity differ between different metal species. The transportation of metals with groundwater is normally affected by sorption to solid aquifer material. The most important chemical retention mechanisms are sorption processes and precipitation. (Asklund and Eldvall, 2005)

Other chemical processes of importance are redox reactions and complexation. An increased aqueous complexation often makes an element more soluble, but the form is often less toxic. The redox status decides the speciation of some redox-sensitive elements.

Different redox species have different retention capacity and the redox status is important for transport. These mechanisms and the mobility of metals are affected by a number of different parameters e.g. the oxidation state of the metal ion, pH and Eh.

2.7.0 EFFECTS OF HEAVY METALS IN THE ENVIRONMENT

Food chain contamination by heavy metals has become a burning issue in recent years because of their potential accumulation in biosystems through contaminated water, soil and air. Metals are persistent pollutants that can be biomagnified in the food chains, becoming increasingly dangerous to human beings and wildlife .Heavy metals enter into the environment mainly via three routes namely: (i) deposition of atmospheric particulate, (ii) disposal of metal enriched sewage sludge and sewage effluents and (iii) by-products from metal mining process. Soil is one of the repositories for anthropogenic wastes. Biochemical processes can mobilize them to pollute water supplies and impact food chains. Heavy metals such as Cu, Cr, Cd, Ni, and Pb are potential soil and water pollutants. (Adelekan and Abegunde, 2011)

2.7.1 Soil Heavy Metal Pollution

Soil is one of the repositories for anthropogenic wastes. Heavy metal contamination in the soils is a major concern because of their toxicity and threat to human life and the environment. (Yahaya *et a*l., 2010). Heavy metal contaminants in the environment are eventually deposited in soils in some form of a low solubility compound, such as pyrite. (Adelekan and Abegunde, 2011) Research carried out by Kodom *et al*. (2009**)** aimed to investigate the extent of heavy metal pollution in the surface soils at "Suame-Magazine" industrial area of Kumasi, and to verify any significant industrial impact. It indicated extremely high values of Zn, Pb and Cr above their respective threshold limit values in all the investigated zones of high industrial impact due to the chemical and metallurgical activities highly embarked on at the area. This was attributed to the indiscriminate disposal of industrial waste as well as anthropogenic point source contamination and is terribly alarming in terms of environmental pollution.

2.7.2 Heavy Metals in Groundwater

With sufficient surface water infiltration, soil contaminants such as heavy metals can leach to underlying groundwater. Occurrence of heavy metals in groundwater is directly related to soil characteristics that determine the rate of water movement. (Nagendrappa *et al.,* 2010*).*

The quality of ground water varies from place to place and with the depth of the water table. (Shyamala *et al.*, 2008).

Previous work carried out in Ilaro and Aiyetero, Ogun State in Nigeria indicated levels of Pb with mean concentration of 0.262 and 0.195, 1.28 and 0.704(Fe), 0.0015 and 0.019(Cd) respectively.(Ufoegbune *et al.*,2011)

Unconfined aquifers with shallow water tables overlain by permeable soils are especially vulnerable to various contaminants. (USEPA, 2002)

2.8.0 NATURAL SOURCES OF HEAVY METALS IN GROUNDWATER

Ground water — its depth from the surface, quality for drinking water, and chance of being polluted — varies from place to place. Generally, the deeper the well, the better the ground water. The amount of new water flowing into the area also affects ground water quality (USEPA, 2002)

The basic natural processes contributing in trace elements to water are chemical and physical weathering of rock and soil leaching (USEPA, 2002). Ground water may contain some natural impurities or contaminants, even with no human activity or pollution. Natural contaminants can come from many conditions in the watershed or in the ground. The types and concentrations of natural impurities depends on the nature of the geological materials through which the groundwater moves and the quality of the recharge water. (USEPA, 2002)

This is highlighted recently in Bangladesh where natural levels of arsenic in groundwater were found to be causing harmful effects on the population (Anawara *et al.,* 2002).

Water moving through underground rocks and soils may pick up magnesium, calcium and chlorides. Some ground water naturally contains dissolved elements such as arsenic, fluoride, boron, selenium, or radon, a gas formed by the natural breakdown of radioactive uranium in soil. (USEPA, 2002)

The incidence of high fluoride and arsenic in groundwater of Karbi Angling and Nagaon district of Assan, India and its manifestation in the form of fluorosis has been reported. (Sabhapandit *et* *al.*, 2010). Whether these natural contaminants are health problems depends on the amount of the substance present. The effect of these natural sources of contamination of ground water quality depends on the type of contaminants and its concentration (USEPA, 2002)

2.9.0 ANTHROPOGENIC SOURCES OF HEAVY METALS IN GROUNDWATER

There are many sources to ground water pollution. The most polluting of them are the city sewage, agricultural and industrial waste discharged into the surface waters.

Waste resulting from manufacturing or other industrial processes may be categorized as hazardous waste and may include lead-acid batteries, paints, solder, and scrap metal among others. These wastes contain heavy metals which find its way into surface waters due to surface run-off and direct percolation into groundwater. Industrial waste has been a problem since the industrial revolution. Industrial waste may be toxic, ignitable, corrosive or reactive. If improperly managed, this waste can pose dangerous health and environmental consequences

Studies conducted by Adelekan and Abegunde in 2011,regarding heavy metal groundwater pollution at automobile mechanic villages in Ibadan, Nigeria showed that all heavy metals(Cd, Pb, Cr, Ni) except cu measured in hand-dug wells were lower than the limits set by WHO guideline for drinking water (Adelekan and Abegunde, 2011).

Further work done in Shush and Andimeshek plain in Iran with high agricultural activities indicated high levels of cadmium (0.005 mg/l) in groundwater samples which exceeded WHO MCL. (0.003 mg/l) with high levels recorded in shallow wells than deeper wells.(Nouri *et al.*,2006) Again, heavy metals in groundwater in adjoining villages of Bhiwari industrial area, India showed that areas which were near to industries have polluted water (Yadav *et al.*, 2011)

2.10.0 HEAVY METALS IN DRINKING WATER AND THEIR IMPACT ON HUMAN HEALTH AND THE ENVIRONMENT

2.10.1 Iron

Iron (Fe) is a metallic element that makes up about 5 percent of the Earth's crust. It occurs mainly in Fe^{2+} (ferrous iron) and Fe^{3+} (ferric iron) (Colter and Mahler, 2006).

Usually, iron occurring in ground water is in the form of ferric hydroxide, in concentrations less than 500 μg/L (Oyeku and Eludoyin, 2010). In its pure form, iron is a dark-gray metal, but it is exclusively found in combination with other elements called ores. Most common iron-containing ores are hematite, magnetite, and taconite. When in the presence of oxygen, iron is a reactive element that oxidizes (rusts) very easily. The red, orange, and yellow colors visible in many soils and rocks all over the world are usually iron-oxides. Ferric iron deposits within corroded pipes can break free and generate rusty tap water. (Colter and Mahler, 2006).

2.10.1.1 Adverse Human Impacts:

The shortage of iron causes disease called "anemia''. Although iron is an essential mineral, prolonged consumption of drinking water with high concentration of iron may lead to liver disease called Haermosiderosis (Rajappa *et al.*, 2010; Nagendrappa *et al.*, 2010). Diseases of aging such as Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis, diabetes mellitus, and others have been linked to excess iron intake. (Brewer, 2009). High concentrations of dissolved iron can result in poor tasting, unattractive water that stains both plumbing fixtures and clothing. (Colter and Mahler, 2006).

Previous studies conducted in an industrial area Sialkot, Pakistan, shown high levels of Fe which varied between 0.004 and 0.828 mg/l, well above WHO MCL of 0.3 mg/l. (Ullah *et al*., 2009).

In Mebrahatu and Zerabuk's work (2011), iron content varies from 97 µg/L in sample taken from Mekelle to 1872 µg/L from Zalambessa, Ethiopia. About 62.69% of the samples were within the desirable concentration of iron in drinking water (300ug/L) set by WHO (2008), whereas 37.31% of the samples have shown iron concentration above the limit.

2.10.1.2 Adverse Impacts on the Environment:

Iron can also cause algae blooms, which create biological oxygen demand, can kill fish, smother aquatic plants and produce potent neurotoxins. Even low concentrations of iron (0.1-1.0 mg/L) may cause nuisance algae species to replace inoffensive species. (StormwaterRXLLC, 2010). Water collects iron in several ways. Even as it falls through the air, water acquires small amounts of the oxides of iron found in the atmospheric dust. Water rich in carbon dioxide, readily dissolves iron from the earth's plentiful deposits as it leaches these in its underground flow. Elevated levels of iron in storm water can be caused by rusting steel in constant contact with water

2.11. Lead

Lead is the most significant of all the heavy metals because it is toxic, very common (Gregoriadou *et al*., 2001) and harmful even in small amounts. Lead is a toxic metal whose high potency makes it a dangerous environmental threat to human health

2.11.1. Adverse Human Impact

People are exposed to lead through the air they breathe, through water and through food/ ingestion. Most of the lead we take is removed from our bodies in urine; however, as exposure to lead is cumulative over time, there is still risk of buildup, particularly in children (Salem *et al.*, 2000). A recent report suggests that even a blood level of 10 micrograms per deciliter can have harmful effects on children's learning and behavior. People can be exposed to lead contamination from the motor vehicle exhaust of leaded gasoline, as well as from industrial sources such as smelters and lead manufacturing and recycling industries, from cottage industry uses and waste sites (e.g. contaminated landfills) (WHO, 2012) and through inhalation of lead paints in dust.

Exposure to lead through water is generally low in comparison with exposure through air or food. Lead from natural sources is present in tap water to some extent, but analysis of both surface and ground water suggests that lead concentration is fairly low. The main source of lead in drinking water is (old) lead piping and lead-combining solders. (WHO, 2012)

Studies on lead are numerous because of its hazardous effects .Lead is a metal with no known biological benefit to humans. Too much lead can damage various systems of the body including the nervous and reproductive systems and the kidneys, and it can cause high blood pressure and anemia. Lead accumulates in the bones and lead poisoning may be diagnosed from a blue line around the gums. Lead is especially harmful to the developing brains of foetuses and young children and to pregnant women. Lead interferes with the metabolism of calcium and Vitamin D. High blood lead levels in children can cause consequences which may be irreversible including learning disabilities, behavioral problems, and mental retardation. At very high levels, lead can cause convulsions, coma and death (WHO, 2012)

Studies conducted in some of the Great Cairo Cities, Egypt aimed to determine the relationship between the contaminant drinking water and its impact on human health. It was revealed that Patients who suffer from renal failure were related to contaminant drinking water mainly with lead and cadmium *(*Salem *et al.*, 2000). Previous studies conducted in an industrial area Sialkot, Pakistan, shown high levels of Pb with maximum mean concentration of 0.81 mg/l, well above WHO MCL of 0.01 mg/l. (Ullah *et al*., 2009) Also, Studies conducted by Adelekan and Abegunde in 2011,regarding heavy metal groundwater pollution at automobile mechanic villages in Ibadan, Nigeria showed that , Pb concentration measured in hand-dug wells was lower than the limits set by WHO guideline for drinking water (Adelekan and Abegunde, 2011).

A maximum level of Pb (1347 μg/L) was found in drinking water sampled from Indasilase in Ethiopia. More than 70.15% of the samples analyzed contain lead concentration within the WHO (2008) MAL of lead in drinking water (10 μg/L). (Mebrahatu and Zerabuk, 2011)

Not only does lead poisoning stunt a child's growth, damage the nervous system, and cause learning disabilities, but also it is now linked to crime and anti-social behavior in children (U.S. General Accounting Office Report, 2000)

2.11.2. Adverse Impact on the Environment

Lead (Pb) is the most common environmental contaminant found in soils. Unlike other metals, Pb has no biological role, and is potentially toxic to microorganisms (Sobolev and Begonia, 2008). Its excessive accumulation in living organisms is always detrimental.

Nwoko and Egunjobi (2002) found Pb concentrations which were described as being highly elevated in soil and vegetation in an abandoned battery factory site.

Lead is found in trace amounts in various foods, notably in fish, which are heavily subjected to industrial pollution. Some old homes may have lead water pipes, which can then contaminate drinking water.

The highest lead concentration was reported from Heliopolice and El-Salam areas in Cairo, Egypt with 0.90 ppm and 0.70 ppm respectively. All areas have exceeded the standard limit (0.1 ppm) in most of the drinking water samples (tap water). (Salem *et al.*,2000) .

In the analysis of the some wells and boreholes water samples collected, 36.73% of the total contained Lead in levels above the Maximum Contaminant Level (0.01 mg/L) with maximum concentration of 0.024 mg/L, in a study conducted by Momodu and Anyankora (2010). Lead has been recognized for centuries as a cumulative general metabolic poison (Adepouju-Bello and Alabi, 2005; Momodu and Anyankora, 2010).

2.12. Cadmium

Cadmium is produced as an inevitable by-product of zinc (or occasionally lead) refining, since these metals occur naturally within the raw ore. However, once collected the cadmium is relatively easy to recycle.

The major sources of cadmium in drinking water are corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints.

Cadmium compounds are used as stabilizers in PVC products, color pigment, several alloys and, now most commonly, in re-chargeable nickel– cadmium batteries. Metallic cadmium has mostly been used as an anticorrosion agent (Cadmiation). Cadmium is also present as a pollutant in phosphate fertilizer. Natural as well as anthropogenic sources of cadmium, including industrial emissions and the application of fertilizer and sewage sludge to farm land, may lead to contamination of soils, and to increased cadmium uptake by crops and vegetables, grown for human consumption. The uptake process of soil cadmium by plants is enhanced at low pH. (Department of Epidemiology and Public Health, Imperial College, London, UK, 2012).

Cadmium derives its toxicological properties from its chemical similarity to zinc an essential micronutrient for plants, animals and humans. Cadmium is biopersistent and, once absorbed by an organism, remains resident for many years (over decades for humans) although it is eventually excreted.

Studies conducted by Adelekan and Abegunde in 2011,regarding heavy metal groundwater pollution at automobile mechanic villages in Ibadan, Nigeria showed that all Cd, measured in hand-dug wells were lower than the limits set by WHO guideline for drinking water.

2.12.1 Adverse Human Impact

In humans, long-term exposure is associated with renal dysfunction. High exposure can lead to obstructive lung disease and has been linked to lung cancer, although data concerning the latter are difficult to interpret due to compounding factors. Cadmium exposure may cause kidney damage. Long-term high cadmium exposure may also produce bone defects (Osteomalacia, osteoporosis) in humans and animals. In addition, the metal can be linked to increased blood pressure and effects on the myocardium in animals, although most human data do not support these findings.

The average daily intake for humans is estimated as 0.15µg from air and 1µg from water. Smoking a packet of 20 cigarettes can lead to the inhalation of around 2-4µg of cadmium, but levels may vary widely.

In general, non-smoking population the major exposure pathway is through food, via the addition of cadmium to agricultural soil from various sources (atmospheric deposition and fertilizer application) and uptake by food and fodder crops. Additional exposure to humans arises through cadmium in ambient air and drinking water. (Department of Epidemiology and Public Health, Imperial College, London, UK, 2012*)*

2.12.2. Adverse Impact on the Environment.

Cadmium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of Cadmium.

2.13.0 Chromium

Chromium is found in drinking water sources and the environment in two principal forms: trivalent chromium (chromium 3) and hexavalent chromium (chromium 6). Chromium 3 is found naturally in foods at low levels and is an essential human dietary nutrient. Chromium 6 is the more-toxic form of chromium. Chromium can transform from its hexavalent form to its trivalent form, and vice versa.

Hexavalent chromium, also known as chromium 6, is a heavy metal that is commonly found at low levels in drinking water. (California Environmental Protection Agency Fact Sheet, 2009)

2.13 .1 Adverse Human Impact.

Chromium 6 is known to be a potent carcinogen when inhaled. It was recently found to also cause cancer in laboratory mice and rats that were exposed through drinking water. Low-level exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage to circulatory and nerve tissue.

2.13.2 Adverse Impact on the Environment

When an industrial facility emits chromium 6 into the environment, it is sometimes deposited into the soil and often is converted to chromium 3 with some remaining traces of chromium 6. Chromium 6 can occur naturally but can also enter drinking water sources by historic leaks from industrial plants' hazardous waste sites. Various other sources also contribute to the amount of hexavalent chromium in groundwater. Chromium is used in metal alloys and pigments for paints, cement, paper, rubber, and other materials. Chromium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of chromium (California Environmental Protection Agency Fact Sheet, 2009)

Studies conducted by Adelekan and Abegunde in 2011,regarding heavy metal groundwater pollution at automobile mechanic villages in Ibadan, Nigeria showed that, Cr, measured in hand-dug wells were lower than the limits set by WHO guideline for drinking water.

2.14.0 CHEMICAL AND PHYSICAL POLLUTION

2.14.1 Temperature.

Water Temperature is a controlling factor for aquatic life: it controls the rate of metabolic activities, reproductive activities and therefore, life cycles. If stream temperatures increase, decrease or fluctuate too widely, metabolic activities may speed up, slow down, malfunction, or stop altogether.

There are many factors that can influence the stream temperature. Water temperatures can fluctuate seasonally, daily, and even hourly, especially in smaller sized streams. Spring discharges and overhanging canopy of stream vegetation provides shade and helps buffer the effects of temperature changes. Water temperature is also influenced by the quantity and velocity of stream flow and the temperature of effluents dumped into the water. When people dump heated effluents into waterways, the effluents raise the temperature of the water. The sun has much less effect in warming the waters of streams with greater and swifter flows than of streams with smaller, slower flows. Temperature affects the concentration of dissolved oxygen in a water body. Oxygen is more easily dissolved in cold water. (Missouri Department of Natural Resource, accessed on May 9th, 2012).

Adefemi and Awukuni(2010) have reported the temperature of Ona river in Itaogbolu area of Ondo State- Nigeria a farming village, to be higher than those obtained from wells. Temperature of the samples was in the range 25.10- 27.10˚C. Studies conducted in a petrochemical area in Ubeji community in Nigeria have shown a stream temperature mean of 27.5 to be higher. (Ogunjala and Ogunlaja(2007).

2.14.2 pH

The balance of positive hydrogen ions (H^+) and negative hydroxide ions (OH^-) in water determines how acidic or basic the water is. pH is expressed in a scale with ranges from 1 to 14. A solution with a pH less than 7 has more H+ activity than OH-, and is considered acidic. A solution with a pH value greater than 7 has more OH- activity than H+, and is considered basic. In pure water, the concentration of positive hydrogen ions is in equilibrium with the concentration of negative hydroxide ions, and the pH measures exactly 7.

pH is an important limiting chemical factor for aquatic life. If the water in a stream is too acidic or basic, the H+ or OH- ion activity may disrupt aquatic organisms biochemical reactions by either harming or killing the stream organisms. Streams generally have pH values ranging between 6 and 9, depending upon the presence of dissolved substances that come from bedrock, soils and other materials in the watershed. (http://www.h2ou.com/h2wtrqual.htm/, assessed on April 10, 2012)

In a lake or pond, the water's pH is affected by its age and the chemicals discharged by communities and industries. Most lakes are basic (alkaline) when they are first formed and become more acidic with time due to the build-up of organic materials. Studies conducted in a petrochemical area in Ubeji community in Nigeria have shown mean pH range of 4.66 and 6.85 (Ogunlaja and Ogunlaja(2007).

pH will produce a synergistic effect when acid waters (waters with low pH values) come into contact with certain chemicals and metals, they often make them more toxic than normal. (http://www.h2ou.com/h2wtrqual.htm/, assessed on April 10, 2012)

2.14.3 Turbidity

Turbidity is the term given to anything that is suspended in a water supply. It is most common in surface waters and usually non-existent in ground water except in shallow wells and springs after heavy rains. Turbidity gives the water a cloudy appearance or shows as dirty sediments. Turbidity may be caused when light is blocked by large amounts of un-dissolved materials such as sand, clay, silt or suspended irons, microorganisms, and coal dust.

The most frequent causes of turbidity in lakes and rivers are plankton and soil erosion.

Moderately low levels of turbidity may indicate a healthy, well-functioning ecosystem, with moderate amounts of plankton present to fuel the food chain. However, higher levels of turbidity pose several problems for stream systems. Turbidity blocks out the light needed by submerged aquatic vegetation. It also can raise surface water temperatures above normal because suspended particles near the surface facilitate the absorption of heat from sunlight. Turbid waters may also be low in dissolved oxygen. High turbidity may result from sediment bearing runoff, or nutrients inputs that cause plankton blooms. Turbidity can cause the staining of sinks and fixtures as well as the discoloring of fabrics. Turbidity is measured in NTU (Nephelometric Turbidity Units) (Missouri Department of Natural Resource, accessed on May 9th, 2012)

2.14.4 Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius (25 ˚C). (Missouri Department of Natural Resource, accessed on may 9th, 2012).

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through.

Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate;

an oil spill would lower the conductivity. The basic unit of measurement of conductivity is the mho or siemens. Conductivity is measured in micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µS/cm). (Missouri Department of Natural Resource, accessed on May 9th, 2012)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

The study area, "Suame magazine" is an industrial cluster located in Suame, a suburb of Kumasi in the Ashanti Region. The total land area is approximately 1.8 km long and 0.3 km wide (Adeya, 2001; 2006). Geographically, it lies on latitude 6° 43' 00'' North and longitude 1° 38' 00''West.

The "Suame Magazine" is probably one of Africa's largest light- industrial clusters with an approximately 12,000 independent micro, small, and medium sized enterprises and workshops and over 200,000 people who work and live in the area. The main activities can be categorized under manufacturing, vehicle repair, metal working, sale of engineering material and automobile spare parts. On the average, an enterprise may have about 5 workers, but the relatively more sophisticated manufacturing workshop has between 7 and10 workers. Communication centers are increasingly playing an important role in enhancing the activities of the clusters (Adeya, 2001; 2006).

3.1.1 Geology

Geologically, the study area is underlain by the Birimian formations (lower and upper). Essentially, rock types comprises of the greywacke, phyllite, biotite, staurolite, kyanite and schist (CWSA, 2009, Kortatsi, 2006). The greywackes vary from fine grained to medium grained and all have been metamorphosed and recrystalined. Near the contacts with the granite batholite, metamorphism has produced biotite, staurolite, garnet, kyanite and schist. The rocks are deeply weathered and fresh outcrops of phyllite are never seen; good sections of the phyllites are exposed. Quartz veins are found in all the country rocks but are most common in the phyllites and slates where definite veins may grade into silicified banding which is quite common.

3.1.2. Hydrogeology

The hydrogeology of the area is controlled by the presence of fracture zones in the bedrock and a thick weathered zone. Where there are well-developed fracture zones, the bedrock has a high secondary permeability. The successful boreholes have intercepted some of such fractured zones. The weathered zone represents the main storage capacity of the aquifer, as this is where the rocks have been leached by weathering processes, resulting in an enhanced porosity where infiltrating water can be stored. Due to permeability contrast between bedrock and overburden there usually is some groundwater occurrence at the interphase (CSWA, 2009). The recharge to the aquifer is mainly by vertical infiltration from precipitation excess, where surface water bodies such as stream are in hydraulic continuity with the aquifer, induce recharge can occur (CSWA, 2009).

3.1.3 Soil Type

The major soil type of the Kumasi metropolis is the Forest Oxysol (ghanadistricts.com, Kortatsi, 2006). Forest Oxysol is endowed with the nutrient mostly needed to sustain the cultivation of foodstuff such as vegetables, plantain and cassava. The presence of this type of soil has sustained the cultivation of food crops notably at the periphery of the Metropolis.

Generally, soils in Kumasi belong to the Bekwai, Nzema, Kokofu and Oda series (ghanadistricts.com). They are generally well drained except the Oda series, which is poorly drained and is usually found in the low-lying areas or valley bottom. The soils are clayey or silt-loam and are described as forest Oxysols because of their ‘sharp’ or acidic nature (Kortatsi, 2006, ghanadistricts.com).

3.1.4 `Climatic Condition

The study area which is located in the Ashanti region lies within three different climatic zones. In the south- east, the climate is the dry equatorial type whilst the eastern and the northern portions are influenced by the tropical continental type. The climate in the remaining portion is the semi-equatorial type.

The dry equatorial type has rainfall occurring in two seasons with mean annual rainfall varying between 740 mm and 890 mm. the major rainy season occurs in May/June whilst the minor occurs in October.

The tropical continental or savannah has mean annual rainfall varying between 1150 mm and 1250 mm and occurs in two seasons. Relative humidity is very high and varies from 75 to 97%. The wet semi-equatorial type is characterized by double rainfall maxima of varying intensity, followed by a prolonged dry season. Mean annual rainfall is between 1250mm and 2000mm.The highest monthly temperature of about 30º occurs in March/April and the lowest of about 24º in august (CWSA, 2009).

3.1.5 Topography

The study area falls in the district which has high topography and lies in range of 152.4 meters and 609.6 meters above sea level (CWSA, 2009).

3.1.6 Vegetation

The study area lie in the forest zone and the natural vegetation was originally semi-deciduous type with thin undergrowth. However, in certain sections, most importantly the study area, the activities of man with high industrial activity in vehicular repair works and allied artisans coupled with high human population density, has over the years influenced the forest to the appearance of grass, grading gradually to savannah trees with isolated patches of thickets. The tall trees in the forest areas exhibit deciduous characteristics during the dry season (Nov. to March) with young trees remaining evergreen during the period (CWSA, 2009).

3.2.0 SELECTION OF SAMPLING SITES

Water Samples were collected from that part of the area where most artisanal activities occur. Metallurgical activities that go on at the "Suame Magazine" can be categorized into five major groups. Table 3.1 delineates the product groupings and services in Suame cluster.

Table 3.1: Product Groupings and Services in Suame Cluster.

Major Sectors	Product Group and Services
Manufacturing	Food processing equipment and farm implements; cook stoves; utensils and foundry products.
Vehicle Repair & Maintenance	Engine overhauling; auto electrical works;

	vehicle interior upholstery; auto body straightening and spraying.
Metal working	Metal fabrication and plant construction, angle irons, channel irons, bars and so on.
Sale of engineering materials & accessories	Sheet metals, bars, iron rods, steel sections. Hand tools, fasteners, electric motors, pumps and so on.
Sale of automobile spare-parts	Second-hand engines and parts, car decorating materials and so on.
Sale of food	All types of food and drinks.
Communication and Business Centres	Telephone and fax services, photocopying, computer typesetting, Internet and e-mail services, sale of mobile phone cards, videocassettes and barbering

Source: Adeya, UNU-INTECH Field survey, 2001

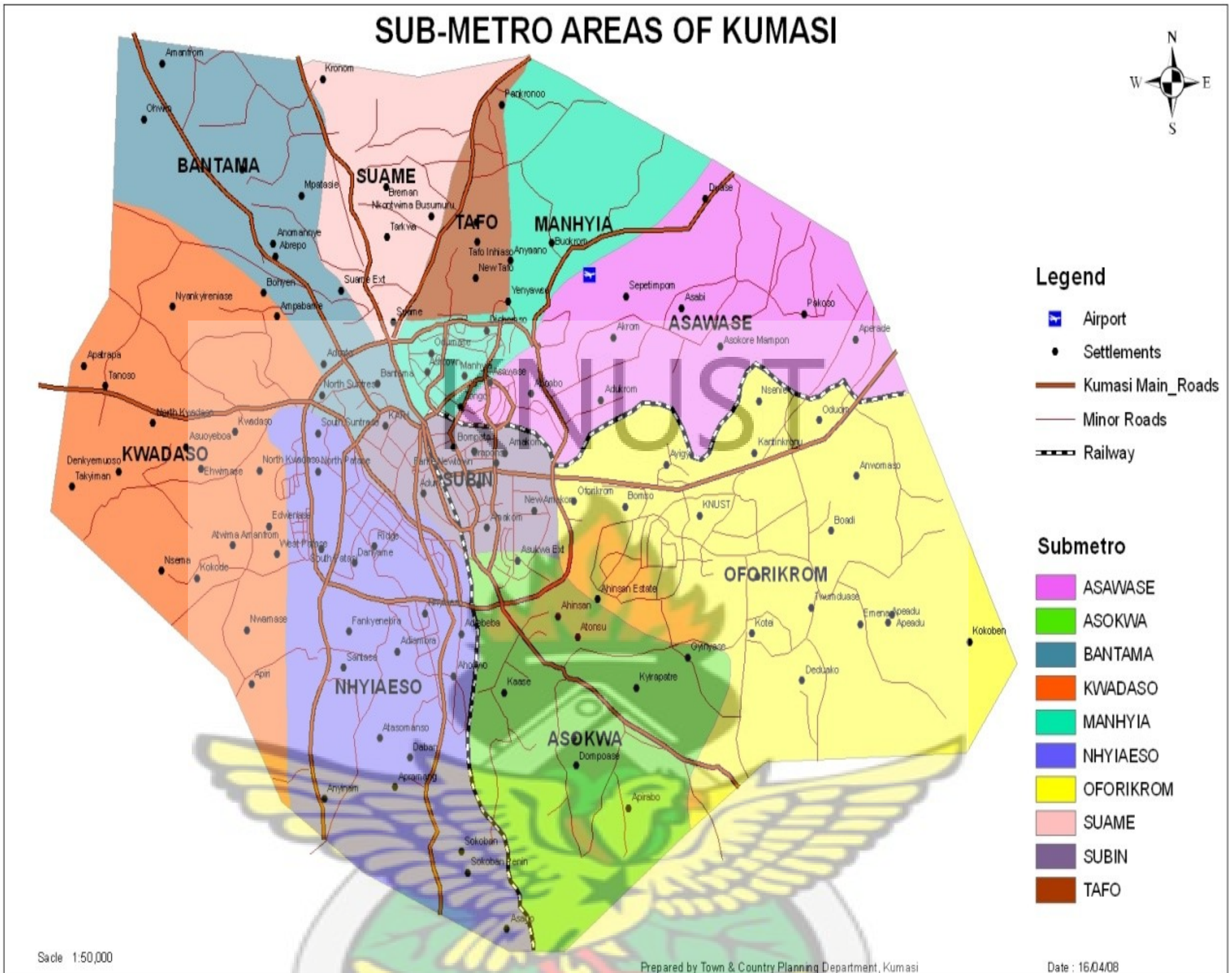

Figure 3.1: Administrative Map of Kumasi Metropolitan Assembly

(Source: Town and Country Planning Department)

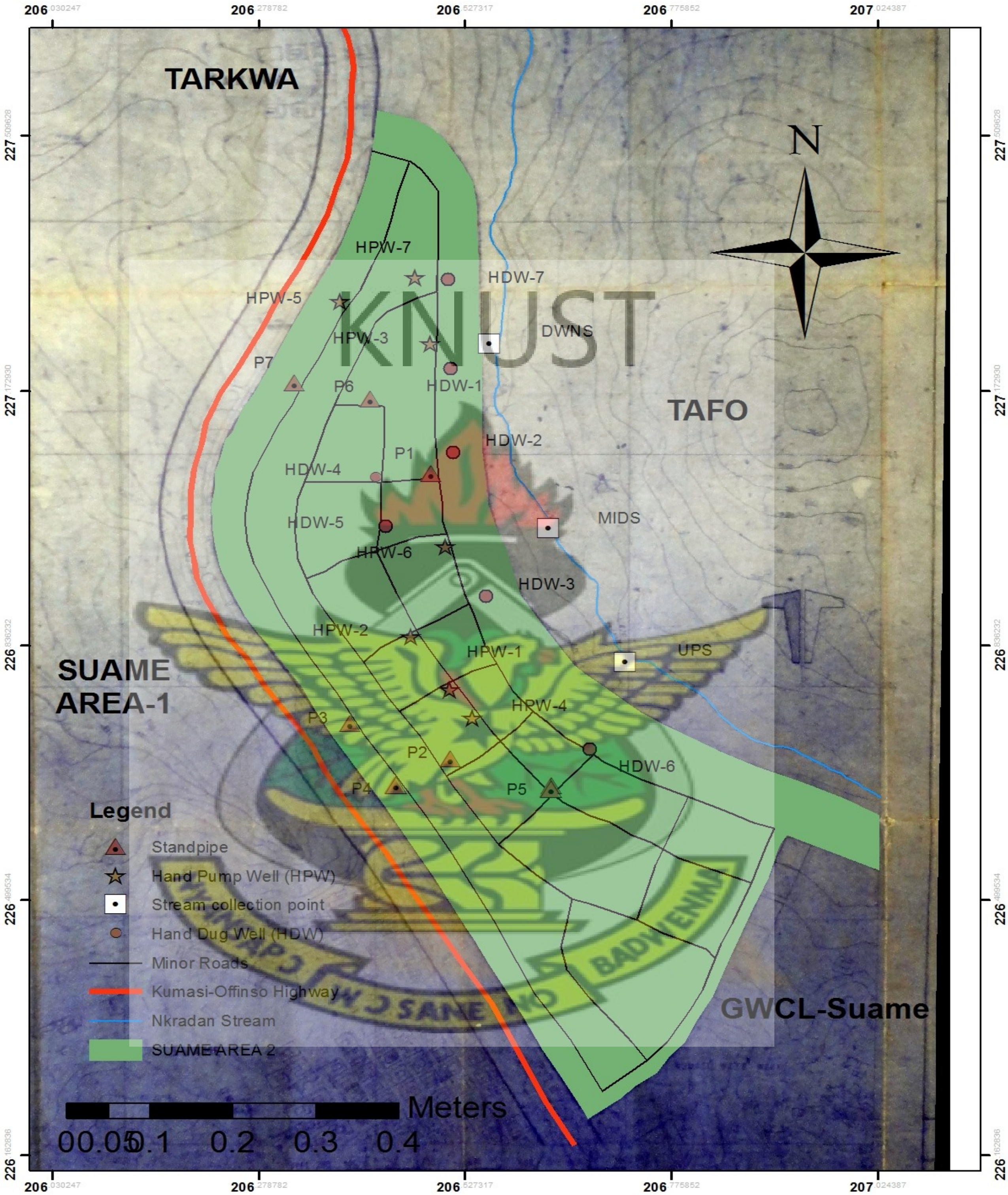

Figure 3.2. A Map of the "Suame Magazine" Area Showing Sampling Sites.

Plate 1: A section of soldering activities in "Suame Magazine"

Plate 2: A section of scrap metals disposed close to a hand-dug well.

Plate 3: Disposal of junk spare parts and oil spillage on bare ground

Plate 4: A shallow hand-dug well covered with a typical wooden cover slab.

Plate5: A hand-dug well with fissured concrete lining.

Plate 6: A section of the polluted “Nkradan” stream

3.2.1 Sampling

Global Positioning System was used to take the coordinates of the sampling locations.

A total of 144 samples from 22 water sources (7 pipes, 7 hand-dug wells, 7 Hand-pump wells, and a stream) were collected from the sampling site (Figure 3.2). Samples from the "Nkradan" stream were taken from upstream, midstream and downstream (Figure 3.2). The control (background) samples were obtained from Boadi New Site, a residential community that has no industrial impact. Since activities affecting the stream at Boadi (Control site) is not known, natural background values of surface water will be used as control.

Water samples were collected using sterilized 500ml plastic bottles. Water was pumped out of the boreholes at a very fast rate to cool the metal pipe in order to eliminate the influence of the water temperature with that of the metal pipe. The pumping was sustained for at least five minutes. Tap water was also allowed to run out for some time. All samples were taken in triplicate, placed in an 'ice chest' in ice packs and transported to the laboratory.

To every 500ml of sample for metal analysis, 5 ml of Conc. HNO_3 was added. This treatment was used to minimize adsorption of metals on the container walls. All the wells were between 3 and 15 meters in depth. The environmental sanitation condition and the human activities around the water sources were noted.

Table 3.2 Sampled Water Sources, Location and GPS Points

Sample Identification	Water Source	GPS Point
P-1	Pipe 1	6°43’086” N 1°38’ 706”W
P-2	Pipe 2	6°43’092” N 1°38’ 655”W
P-3	Pipe 3	6°43’147”N 1°38’ 699”W
P-4	Pipe 4	6°43’ 215”N 1°38’ 800”W
P-5	Pipe 5	6°43’ 231”N 1°38’ 811”W
P-6	Pipe 6	6°43’ 355”N 1°38’ 838”W
P-7	Pipe 7	6°43’ 598”N 1°38’ 812”W
HDW-1	Hand-dug well 1	6°43’ 287”N 1°38’ 773”W
HDW-2	Hand-dug well 2	6°43’3 39”N 1°38’ 843”W
HDW-3	Hand-dug well 3	6°43’ 339”N 1°38’ 794”W
HDW-4	Hand-dug well 4	6°43’ 440”N 1°38’ 801”W
HDW-5	Hand-dug well 5	6°43’ 654”N 1°38’ 784”W
HDW-6	Hand-dug well 6	6°43’ 439”N 1°38’ 818”W
HDW-7	Hand-dug well 7	6°43’ 277”N 1°38’775”W
HPW-1	Hand-pump well 1	6°43’ 196”N 1°38’ 690”W
HPW-2	Hand-pump well 2	6°43’ 278”N 1°38’ 780”W
HPW-3	Hand-pump well 3	6°43’ 222”N 1°38’ 743”W
HPW-4	Hand-pump well 4	6°43’ 280”N 1°38’ 832”W
HPW-5	Hand-pump well 5	6°43’ 589”N 1°38’ 864”W
HPW-6	Hand-pump well 6	6°43’ 312”N 1°38’ 786”W
HPW-7	Hand-pump well 7	6°43’ 277”N 1°38’ 776”W
UPS	Upstream	6°43’ 215”N 1°38’622”W
MIDS	Midstream	6°43’437”N 1°38’786”W
DWNS	Downstream	6°43’”N 648 1°38’647”W

3.3 DETERMINATION OF PHYSICO-CHEMICAL PARAMETERS

3.3.1 Temperature Determination

This was determined on site at the time of sampling. A standardized pocket thermometer was immersed in the water sample and the reading recorded.

3.3.2 Measurement of pH

pH was measured using a pH meter HANNA HI 83141, (degree of accuracy 0.01) equipped with a temperature probe. The pH meter was initially calibrated by placing the pH electrode into a buffer solution of known pH (pH 4) and the asymmetric potential control of the instrument adjusted until the meter reads the known pH value of the buffer solution. The standard electrode after rinsing with distilled water was further immersed in a second buffer solution (pH 9) and the instrument adjusted to read the pH value of this buffer solution. This procedure was used to standardize the readings of the instrument before performing the actual test. With the pH meter calibrated, the electrode was then rinsed three times with some of the water sample to be analyzed before it was immersed in the water sample, allowed to stabilize and the pH value read from the instrument. The beaker and the electrode were washed in between samples with deionised water in order to prevent contamination by other samples. Duplicate pH values were taken.

3.3.3 Measurement of Electrical Conductivity (EC)

A high powered microcomputer conductivity meter HANNA HI 9828 with a degree of accuracy of 0.01 was used to measure the conductivity of the water samples in the laboratory within two hours of collection. The instrument was initially calibrated by rinsing with 3 portions of 0.01 m

KCl solution. The conductivity of this standard is known to be 1413 μS/cm. The adjusting knob on the conductivity meter was adjusted to ensure that the readout corresponds with this value. After calibration, 3 portions of each sample was used to rinse the electrode and then immersed in the sample for the actual measurement. Duplicate values were taken and units were in micro Siemens per centimeter.

3.3.4 Measurement of Turbidity

Turbidity of the water samples was measured with a microprocessor turbidity meter WAGTECH 7100 after samples were brought to the laboratory on ice and analyzed within two hours of collection. The instrument was first calibrated by dipping the probe into standard solution with turbidity values of 0.01 and 10.00 Nephelometric Turbidity Unit (NTU).

The curette was filled with the sample after shaking the sample vigorously; making sure that there is no air bubbles trapped in the sample. The curette was cleaned with a tissue paper and placed in the sample container of the turbidity meter and covered with a black container to prevent any external light. The turbidity was read from the scale in units of Nephelometric Turbidity Unit (NTU). This was done three times and the mean value taken.

3.4 DETERMINATION OF METALS (Fe, Pb, Cd, and Cr)

3.4.1 Digestion of Samples

Standard procedure of open digestion set by the APHA (2009) was employed for the digestion of water samples. 50 mL well-mixed, acid preserved sample was measured and transferred into a beaker. 5 mL of concentrated HNO_3 was added to 50 mL of the water sample. The mixture was heated slowly to evaporate to a volume of about 15 – 20 mL on a hot plate. Continues heating and adding of concentrated HNO_3 as necessary was employed until digestion was complete as shown by a light- colored, clear solution. The walls of the beaker was washed down with double distilled water and then filtered with a 0.45 µm pore filter paper. The filtrate was transferred to a 50 mL volumetric flask and topped to the mark. The digested samples were used to measure the individual metal concentrations in the water using an atomic absorption spectrometer (AAS) (Spectra 220). Blanks were also made going through the same procedure but without the samples.

3.3.0 STATISTICAL ANALYSIS

The Statistical Package for Social Scientists (SPPS) version 16.0 for windows was used for analyzing data. Analysis of variance was performed using a One-way ANOVA and the Least Significance Difference (LSD) to test if significance difference existed between mean concentrations of heavy metals of the different water sources. Significant difference was tested at 95% confidence level ($P<0.05$)

CHAPTER FOUR

4.0 RESULTS

4.1 PHYSICO-CHEMICAL PARAMETERS

4.1.1 Temperature

Temperature measured for all samples of water sources within the 'Suame Magazine' is presented in Table 4.1a. Mean temperature in all the different sources of water ranged between 26.33 ± 0.31 to 29.22 ± 0.51˚C (Table 4.1b) with surface waters recording the highest mean temperature value of 29.22 ± 0.51˚C and the lowest in hand-pump wells (Table 4.1b). Differences in temperature for all the different water sources were not statistically significant ($P<0.05$) except for surface waters.

Temperature measured for samples of water sources collected from control site is shown in Appendix C. Average temperatures of water samples from the control site ranged between 29.58 ± 0.37 to 32.67 ± 0.02 (Table 4.1c) and all these exceeded mean total temperatures recorded from the study site.

Table 4.1a: Measured Temperature (˚C) of Sampled Water Sources within "Suame Magazine"

No. of Sampled Water source	1	2	3	4	5	6	7

Pipe-borne water	26.33	26.17	26.67	26.17	26.50	26.67	27.8
Hand-dug wells	26.83	26.50	26.67	26.83	26.33	26.33	26.55
Hand-pump wells	26.17	26.50	26.67	25.33	26.67	26.83	26.17
	upstream	midstream	Downstream	-	-	-	-
Surface water	29.67	28.67	29.33				

Table 4.1b.Mean S.D and Range of Temperature Levels of Water Sources within "Suame Magazine"

Sample ID	X ± S.D (˚C)	Range(˚C)
Pipe-borne water	26.62 ± 0.56 [a]	26.17 - 27.83
Hand-dug well	26.55 ± 0.23 [a]	26.33 – 26.83
Hand-pump well	26.33 ± 0.31 [a]	25.83– 26.67
Surface water	29.22 ± 0.51 [b]	28.67 – 29.67

Same letter along each column is not significantly different
a=Not Significant b= Significant Difference
X= Mean, S.D=Standard Deviation

Table 4.1c.Mean S.D and Range of Temperature Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D (˚C)	Range(˚C)
Pipe-borne water	31.00 ± 0.20	31.00 – 31.50
Hand-dug well	29.58 ± 0.37	29.00 – 30.01
Hand-pump well	32.67 ± 0.02	32.65– 32.70

X= Mean, S.D=Standard Deviation

4.1.2 pH

pH of all sampled water sources within "Suame Magazine" is presented below (Table 4.1d)

Mean pH levels of all the water sources within the "Suame Magazine" industrial area ranged between 4.56 ± 0.24 to 6.08 ± 0.19 (Table 4.1e), with pipe borne water recording the highest mean pH values of 6.08 ± 0.19 and the lowest was recorded in the surface water samples (Table 4.1e). These differences in pH for all the water sources were statistically significant at ($P<0.05$) (Table 4.1e). pH measured for samples of water sources collected from control site is shown in (Appendix C). The mean pH of control samples ranged between7.13 ± 0.03 to 7.44 ± 0.05 and was neutral.

Generally, the mean pH values of water samples from control site were within the WHO guideline value of 6.50 - 8.50 (WHO, 2008). However, samples from the study site were below the WHO guideline values.

Table 4.1d. Measured pH of Sampled Water Sources within "Suame Magazine"

No. of sampled water sources	1	2	3	4	5	6	7
Pipe-borne water	5.98	6.21	6.16	6.15	6.17	6.20	5.68
Hand-dug wells	5.61	5.62	5.54	5.33	5.67	5.49	5.59
Hand-pump wells	6.18	5.86	5.90	5.76	5.51	6.40	5.54
	upstream	midstream	Downstream	-	-	-	-
Surface water	4.84	4.42	4.43				

Table 4.1e: Mean S.D and Range of pH Levels of Water Sources within "Suame Magazine"

Sample ID	X ± S.D	Range
Pipe-borne water	6.08 ± 0.19 [a]	5.68 – 6.21
Hand-dug well	5.56 ± 0.11 [b]	5.33 – 5.67
Hand-pump well	5.88 ± 0.32 [c]	5.51– 6.40
Surface water	4.56 ± 0.24 [d]	4.24 – 4.84

a, b, c, d =Significant Difference at ($P<0.05$)
X= Mean, S.D=Standard Deviation

Table 4.1f.Mean S.D and Range of pH Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D	Range
Pipe-borne water	7.44 ± 0.05	7.37 – 7.46
Hand-dug well	7.13 ± 0.03	7.08 – 7.17
Hand-pump well	7.27 ± 0.01	7.25– 7.28

X= Mean, S.D=Standard Deviation

4.1.3 Turbidity

Measured turbidity values of all sampled water sources measured within “Suame Magazine” is presented below (Table 4.1g)

Turbidity levels of the water samples in the study site ranged between 3.02 ± 1.65 to 50.89 ± 8.86 NTU with surface water samples recording the highest mean values whilst the lowest was recorded in water from hand-pump wells (Table 4.1h). Differences in turbidity levels between the different water sources were not statistically significant when tested at (P<0.05) (Table 4.1h) but showed significant difference to surface water samples.

Mean turbidity levels for control samples ranged between 1.83 ± 0.41 to 3.83 ± 0.75 (Table 4.1i).

Turbidity values from the “Suame Magazine” site marginally exceeded values for the control samples in pipe and hand-dug well (Table 4.1i). However, the hand-pump wells in control site had a mean value (Table 4.1i) which was higher than that of the study site. Mean values in water samples from the “Suame magazine” and control site were well within the WHO guidelines (<5 NTU) (WHO, 2008) for drinking water quality except for surface waters from the study site.

Table 4.1g.Measured Turbidity (NTU) of Sampled Water Sources within “Suame Magazine”

No. of water sources samples	1	2	3	4	5	6	7

Pipe-borne water	1.83	2.00	5.83	4.33	1.67	3.83	1.67
Hand-dug wells	2.17	1.67	2.33	3.00	4.33	6.67	7.00
Hand-pump wells	2.00	1.17	0.33	3.50	1.67	1.50	3.33
	upstream	midstream	Downstream	-	-	-	-
Surface water	56.50	40.67	55.50				

Table 4.1h: Mean S.D and Range of Turbidity Levels of Water Sources within "Suame Magazine"

Sample ID	X ± S.D (NTU)	Range(NTU)
Pipe-borne water	3.02 ± 1.65 [a]	1.67 – 5.80
Hand-dug well	3.88 ± 2.19 [a]	1.67 – 7.00

Hand-pump well	1.93 ± 1.14 [a]	0.33– 3.50
Surface water	50.89 ± 8.86 [b]	40.67 – 56.50

Same letter along each column is not significantly different
a= Not Significant, b= Significant Difference
X= Mean, S.D=Standard Deviation

Table 4.1.i.Mean S.D and Range of Turbidity Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D (NTU)	Range(NTU)
Pipe-borne water	3.00 ± 0.89	2.00 – 4.00
Hand-dug well	1.83 ± 0.41	1.00 – 2.00
Hand-pump well	3.83 ± 0.75	3.00– 5.00

X= Mean, S.D=Standard Deviation

4.1.4 Electrical Conductivity

Conductivity of all sampled water sources within "Suame Magazine" is shown in Table 4.1j. Conductivity levels of the different water samples in the study site ranged from 144.22 ± 16.09 to 423.56 ± 52.12 μS/cm with surface water samples recording the highest value, whilst the lowest was recorded in pipe borne water samples (Table 4.1k). The differences in conductivity values of the different water samples were not statistically significant (Table 4.1k), but were significantly different to surface waters ($P<0.05$).

Even though conductivity values from "Suame Magazine" exceeded values for control samples in the range 17.67 ± 0.52 to 155.00 ± 118.98 (Table 4.1l) , mean values recorded at both sites were well within the WHO guidelines for drinking water quality of 1500 μS/cm .

Table 4.1j.Measured Conductivity (μS/cm) of Sampled Water Sources within "Suame Magazine"

No. of sampled water sources s	1	2	3	4	5	6	7
Pipe-borne water	163.53	138.30	142.50	132.62	133.00	139.80	162.62
Hand-dug wells	150.52	149.37	152.30	202.40	157.50	157.15	163.10
Hand-pump wells	146.00	156.47	143.70	137.52	155.00	112.15	158.72
	upstream	midstream	Downstream	-	-	-	-

Surface water	405.88	482.22	382.58

Table 4.1k: Mean S.D and Range of Conductivity Levels of Water Sources within "Suame Magazine"

Sample ID	X ± S.D (µS/cm)	Range(µS/cm)
Pipe-borne water	144.62 ± 13.09 [a]	132.62 – 163.55
Hand-dug well	161.76 ± 18.54 [a]	149.37 – 202.40
Hand-pump well	144.22 ± 16.09 [a]	112.15– 158.72
Surface water	423.56 ± 52.12 [b]	382.58 – 482.22

Same letter along each column is not significantly different
a=Not Significant, b= Significant Difference
X= Mean, S.D=Standard Deviation

Table 4.1l.Mean S.D and Range of Conductivity Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D (µS/cm)	Range(µS/cm)
Pipe-borne water	93.17 ± 8.08	91.00 – 109.00
Hand-dug well	155.00 ± 118.98	97.00 – 136.00

Hand-pump well	17.67 ± 0.52	17.00– 18.00

X= Mean, S.D=Standard Deviation

4.2 HEAVY METAL CONCENTRATION

4.2.1 Lead (Pb) Concentration

Lead concentrations in all the water sources; pipe borne, hand-dug wells, hand pump wells, surface waters, from the "Suame Magazine" ranged from 0.42 ± 0.18 to 0.86 ± 0.31 mg/l. Lead concentrations in the individual samples of water sources are shown in Figure 4.1, 4.2, 4.3 and 4.4, and table of results (Appendix 3). The highest concentration was recorded in upstream surface waters and the lowest in hand-pump water samples (Table 4.2a). However, the differences in lead levels between the different water samples were not statistically significant, but showed significant difference ($P< 0.05$) to surface waters at ($P=0.000$, $P=0.002$, $P=0.000$) for pipe, hand-dug and hand-pump wells respectively.

Lead concentration in control samples ranged from 0.28 ± 0.04 to 0.33 ± 0.16 mg/l. Comparing the results to that of control samples, mean lead levels in samples from "Suame Magazine" exceeded the percent Pb recovery in control samples for pipe (33.0%), hand-dug well (28.0%), and hand-pump well (31.0%) (Table 4.2b). Generally, mean levels of lead in all water sources from the study site and control site were far above the WHO maximum contaminant limit (MCL) of 0.01 mg/l (WHO, 2008)

Table 4.2a.Mean S.D and Range of Lead (Pb) in Different Sources of Water from "Suame Magazine"

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	0.48 ± 0.06 [a]	0.41- 0.58
Hand-dug well	0.54 ± 0.14 [a]	0.26- 0.71
Hand-pump well	0.42 ± 0.18 [a]	0.18 – 0.62
Surface water	0.86 ± 0.31 [b]	0.52 – 1.06

Same letter along each column are not significantly different.
a= Not Significant
b=Significant Difference
X= Mean, S.D=Standard Deviation

Table 4.2b.Mean S.D and Range of Pb Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	0.33 ± 0.16	0.17 – 0.63
Hand-dug well	0.28 ± 0.04	0.22 – 0.34
Hand-pump well	0.31 ± 0.07	0.22– 0.38

X= Mean, S.D=Standard Deviation

Fig.4.1: Concentration of (Pb) in Pipe-borne Water Samples from "Suame Magazine" showing WHO Standard.

Fig.4.2: Concentration of Pb in Hand-dug Well Water Samples from "Suame Magazine" showing WHO Standard

Fig. 4.3: Concentration of Pl WHO Limit=Pb **Samples from "Suame Magazine" showing WHO Standard**

WHO Limit=Pb

Fig.4.4: Concentration of Pb in Surface Water Samples from "Suame Magazine" showing WHO Standard

4.2.2 Iron (Fe) Concentration

Concentration of iron in all the different sources of water from the "Suame Magazine" ranged from 0.48 ± 0.21 to 9.31 ± 2.25 mg/l, with the highest concentration occurring in downstream surface water samples and the lowest in pipe-borne water (Table 4.2c). Iron concentrations in the individual samples of water sources are shown in Figure 4.5, 4.6, 4.7, 4.8 and table of results in Appendix 3. The differences in iron levels between the different water sources were not statistically significant at ($P< 0.05$) but showed significant difference to surface waters at ($P=0.000$, $P=0.000$, $P=0.000$) in pipe, hand-dug and hand-pump wells respectively.

Mean Iron concentration in the control samples ranged from 1.59 ± 0.16 to 1.84 ± 0.36 mg/l. Comparing the results to that of the control samples, recovery levels of iron in control samples; pipe-borne (159%), hand-dug well (161%), and hand-pump well (184%) (Table 4.2d), far exceeded mean iron concentrations of water sources from the study site except surface water. Iron concentrations in the individual samples of water sources from control site are shown in Appendix C. Generally, mean levels of iron in all water sources from the study site (Table 4.2c) and was far above WHO maximum contaminant limit (MCL) of 0.3 mg/l. (WHO, 2008).

Table 4.2c. Mean S.D and Range of Iron (Fe) levels in different Water Sources from "Suame Magazine"

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	0.48 ± 0.21 [a]	0.23- 0.83

Hand-dug well	0.66 ± 0.37 ^{a}	0.30 – 1.29
Hand-pump well	0.90 ± 0.39 ^{a}	0.27 – 1.56
Surface water	9.31 ± 2.25 ^{b}	8.87 – 11.49

Same letter along each column are not significantly different
a = Not Significant
b = Significant Difference
X= Mean, S.D=Standard Deviation

Table 4.2d. Mean S.D and Range of Fe Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	1.59 ± 0.16	1.29 – 1.76
Hand-dug well	1.61 ± 0.28	1.23 – 2.07
Hand-pump well	1.84 ± 0.36	1.20– 2.27

X= Mean, S.D=Standard Deviation

Fig 4.5: Concentration of Fe in Pipe borne Water Samples from "Suame Magazine" showing WHO Standard

Fig. 4.6: Concentration of Iron in Hand-dug Well Water Samples from "Suame Magazine" showing WHO Standard

Fig. 4.7: Concentration of Iron in Hand-pump Well Water Samples from "Suame Magazine" showing WHO Standard

Fig. 4.8: Concentration of Iron in Surface Water Samples from "Suame Magazine" showing WHO Standard

4.2.3 Concentration of Cadmium (Cd)

Cadmium concentrations in all the different water sources within the "Suame Magazine" were below the detection limit (BDL) of 0.03 mg/l (Table 4.2e) except in surface waters which had mean value of 0.34 ± 0.28 mg/ l with the highest concentration recorded downstream and lowest upstream (Fig. 4.9) (Appendix 3). Equally high cadmium levels were recorded in control samples, in the range 0.04 ± 0.01 to 0.07 ± 0.01 mg/l (Table 4.2f) which was all higher than that of the study site except for surface waters. Control samples also exceeded WHO limit of 0.003 mg/l.

Table 4.2e: Mean S.D and Range of Cadmium (Cd) Levels in the Different Water Sources from "Suame Magazine"

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	BDL	BDL

Hand-dug well	BDL	BDL
Hand-pump well	BDL	BDL
Surface water	0.34 ± 0.28	0.04 – 0.59

WHO Maximum Contaminant Limit: 0.003 mg/l (WHO, 2008)
AAS Detection Limit: 0.03
BDL: Below Detection Limit
X= Mean, S.D=Standard Deviation

Table 4.2f. Mean S.D and Range of Cd Levels of Water Sources from Control Site (Boadi)

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	0.07 ± 0.01	0.05 – 0.07
Hand-dug well	0.05 ± 0.02	0.02 – 0.06
Hand-pump well	0.04 ± 0.01	0.02– 0.06

X= Mean, S.D=Standard Deviation

Fig.4.9: Concentration of Cadmium in Surface Water Samples from “Suame Magazine” showing WHO Standard

4.2.4 Chromium (Cr) Concentration

Chromium concentrations in all the different water sources from study site (Table 4.2g) and control site were below the detection limit (BDL) of 0.006 mg/l except in the surface water samples from the study site (Table 4.2d) which recorded a mean of 0.04 ± 0.02 mg/l, slightly above WHO limit of 0.05 mg/l (Figure 4.10).

Fig 4.11 shows the relationship between the total Mean Concentration of Heavy Metals of Water Sources within "Suame Magazine" and their Control Samples.

Table 4.2g: Mean S.D and Range of Cr Levels in the Different Water Sources from "Suame Magazine".

Sample ID	X ± S.D (mg/l)	Range(mg/l)
Pipe-borne water	BDL	BDL
Hand-dug well	BDL	BDL
Hand-pump well	BDL	BDL
Surface water	0.04 ± 0.02	0.04-0.05

WHO Maximum Contaminant Limit: 0.05 mg/l (WHO, 2008)
AAS Detection Limit: 0.006
BDL: Below Detection Limit
X= Mean, S.D=Standard Deviation

Fig.4.10: Concentration of Cr in Surface Water Sample from "Suame Magazine" indicating WHO Standard.

Fig.4.11: Total Mean Concentration of Heavy Metals of Water Sources within "Suame Magazine" and their Control Sample.

4.3 SURVEY OF SANITARY CONDITIONS WITHIN THE "SUAME MAGAZINE"

During the survey it was discovered that hand-dug wells were shallow, approximately 3 to 15 m in depth and hand pump wells were up to 50m and sited close to metallurgical workshops. These wells are often covered with dirty wooden slabs and rusted iron sheathing with no proper concrete aprons raised above ground level to prevent contamination from run-off water. All kinds of receptacles including dirty buckets and containers used for bathing and workshop activities were used in fetching water from the wells. It was further noted that most wells had its concrete lining fissured which contributed to large volumes of silt and clay particles in the water.

Most PVC piping used for pipe water distribution had breakages and leakages which might possibly introduce dirt and leachates from industrial activities into water.

No proper drainage and sewer system existed within the magazine. Waste water from houses and masses of toxic waste from lead-acid batteries, used oil, junk spare parts, soldering among others from metallurgic activities were disposed off haphazardly into open drainage canals or straight onto the ground which often drained back into the streams. The growing levels of pollution in the stream caused by industrial effluents pose great health risk to the inhabitants of the area. Although the stream is not used for drinking, domestic animals such as goats, sheep, ducks and fowls drink from the polluted stream, and for growing of crops such as sugarcane and cocoyam which enters the food chain and ends up in man. The stream was also used for defecation as there were only few toilet facilities (KVIP).

It was further observed that, KVIPs and refuse dumps were sited very close to hand-dug wells and hand-pump wells.

CHAPTER FIVE

5.0 DISCUSSION

5.1 PHYSICO-CHEMICAL PARAMETERS

This study has shown that the mean temperature of all the different water sources; hand-dug wells, hand-pump wells, pipe- borne water and surface waters ranged between 26.33 ± 0.31 and 29.22 ± 0.51 ˚C (Table 4.1a). The highest (29.22 ˚C) was recorded in surface waters and the lowest (26.33 ˚C) in hand-pump wells (Table 4.1a). Similar temperatures differences between surface water and well waters have been reported by Adefemi and Awukuni (2010) and Ogunlaja and Ogunlaja (2007). The relatively low temperatures of water in pipe-borne water, hand-dug and hand-pump wells to that of surface water could be due to increase in rate of chemical reaction and nature of biological activities as a result of effluent discharge from the magazine into the stream, since temperature is one of the factors that govern the assimilative capacity of aquatic system. (Adefemi and Awukuni, (2010), Ogunlaja and Ogunlaja (2007)). Temperature of drinking water is often not of a major concern to consumers as it depends on individual taste and preference. It is noted that high water temperature enhances the growth of microorganisms and may increase taste, odor, color and corrosion problems.

Mean pH levels of all the water sources within the "Suame Magazine" industrial area were in the acidic region and varied between 4.56 ± 0.24 and 6.08 ± 0.19 (Table 4.1b). These pH values were very low compared to the WHO standard for drinking water (6.5-8.5) (WHO 2008) thereby making it unfit for drinking. Effluent release from industrial activities into streams and direct seepage into groundwater may contribute to the acidic nature of water sources in the magazine area (Mesner and Geiger, 2010). Streams that directly receive effluents from petrochemical areas have been reported to be more acidic (Ogunlaja and Ogunlaja 2007.). pH below 6.5, causes corrosion of metal pipes and dissolution of inorganic materials from the bedrock, resulting in the release of toxic metals such as Pb, Cd, Iron etc. into water. pH of control samples were neutral.

The mean turbidity was generally low and within WHO guideline limit of <5 NTU in all the water sources within the magazine except in the surface waters which recorded much higher mean turbidity value. The relatively higher turbidity values in the hand-dug wells (3.88 NTU) may be due to the fact that some wells had their concrete lining fissured which introduced silt and clay particles in the water and the direct seepage of suspended particulate matter into wells. Turbidity in pipe borne water may be due to sloughing of biofilm within the distribution system which can protect microorganisms from the effects of disinfection thereby stimulating bacterial growth. The high turbidity in the stream – a measure of undissolved materials was undoubtedly high as a result of sediment bearing runoff, suspended irons, and microorganisms amongst others from industrial activity which has caused large amounts of algal blooms in the streams (Akoto and Adiyiah, 2007). Control samples were within WHO acceptable limits.

Conductivity levels of the water samples in the study site varied between 144.22 ±16.09 and 423.56 ± 52.12 µS/cm with samples from surface waters recording the highest mean value whilst the lowest was recorded for hand-pump wells (Table 4.1d). Conductivity levels were relatively low compared to WHO guideline limit of 1500 µS/cm. However, comparing this to that of the control sites which recorded much lower levels, it is evident that, there is an influence from anthropogenic sources despite the low conductivity levels in the water sources (Ullah *et al.*, 2009; Nkansah *et al.*, 2011; Adefemi and Awokuni, 2010). Discharges from streams are known to change its conductivity depending on their make-up. An oil spill does not conduct electrical current very well and therefore have a low conductivity when in water (USEPA, 2012).

5.2 HEAVY METAL LEVELS IN WATER SOURCES AT “SUAME MAGAZINE” INDUSTRIAL AREA.

The most prevalent metallic pollutant in the water sources of the “Suame Magazine” industrial area was Fe. The highest mean Fe concentration was recorded in surface water upstream (9.95 mg/l) (Table 4.2b), and the lowest recorded in pipe- borne water (0.48 mg/l) (Table 4.2b).

Hand-pump wells recorded (0.90 mg/l) and hand-pump wells (0.66 mg/l) which all exceeded the maximum contaminant limit value of 0.03 mg/l.

Surface waters recorded the highest Fe concentration (Table 4.2b), which can be associated with the indiscriminate disposal of scrap metals, smelting of iron ores and abandoned waste dump which contain debris of ironic materials. Similarly, iron metal particulates, effluents from smelting and leachates from waste dumps are also released through surface runoff into streams (Obiri-Danso *et al.*, 2009; Espeby and Gustafsson, 2001).

Hand-pump wells recorded the second highest Fe concentration (Table4.2b) which may be due to corrosion of the fitted hand pumps which appear rusty and old and its subsequent release of iron into water. Iron presence in pipe borne water could be attributed to breakages of PVC distribution channels which allow inflow of leachates into pipe water.

Ironically, iron levels in the control samples were higher than at the study site which may be due to natural occurrence in the soil (USEPA, 20002). Geologically, soils in Kumasi are underlain by the Birimian formations, which have a higher content of heavy metals (Kortatsi, 2006; Espeby and Gustafsson, 2001).

Notwithstanding, the levels of iron recorded in all the water sources from the study site, anthropogenic activities within the "Suame Magazine", could also be contributing to the high iron levels. Although iron is an essential mineral, prolonged consumption of drinking water with high concentrations of iron may lead to a liver disease called Haermosiderosis (Rajappa *et al.*, 2010; Nagendrappa *et al.*, 2010), diabetes mellitus, and others. High concentrations of dissolved iron can also result in poor tasting, unattractive water that stains both plumbing fixtures and clothing (Colter and Mahler, 2006; Ullah *et al*., 2009).

Lead concentrations in the study area were highest in the “Nkradan” stream (0.86 mg/l), followed by the hand-dug wells, pipe borne water and hand-pump wells in descending order (Table 4.2a).

Source of lead in the water sources could be from the indiscriminate disposal of waste from lead-acid batteries, lead-based solder; metallic alloy, lead-based paints, used oil, waste incineration, scrap and junk auto part (Nkansah *et a.l*, 2011). These parts may be coated with oil or grease, which may contain lead residues that create harmful storm water runoff endangering aquatic life, and public drinking water supplies. Also leachates from these wastes via storm water run-off are released directly into the streams. Additionally, motor vehicle exhaust of leaded gasoline gets adsorbed onto soil surfaces are washed into the streams during rainfall. Lead in hand-dug wells could be attributed to the fact that most of the hand-dug wells were very shallow with depths as low as 3 to 15 meters. This makes them more prone to contaminants due to easy in-flow and seepage of industrial effluent into wells within the “Suame Magazine” area. Unconfined aquifers are known to be vulnerable to various contaminants (Nouri *et al*., 2006) and sediment loads (including microscopic bacteria, viruses and protozoa). Seepage and infiltrations of pollutants from surface water will also affect the quality of groundwater, accounting for the lead levels in hand-pump wells. Lead in pipe borne water sources can be linked to breakages and leakages in PVC piping that allowed lead-containing leachate into pipe borne water within the magazine (Salem *et al*. 2000). Nonetheless, PVC pipes may contain high levels of lead that can deteriorate from the effects of heat and sun lead which releases dangerously high levels of lead dust into the water running through PVC pipes .Also due to interaction of metal species with the pipe material(http//www.ehow.com/info_8364828_health-concerns-pvc-pipe.html**) (**Lead Action News, 2010) .However, there is not enough data on PVC pipes containing Pb material which has generated much controversy to its contamination of pipe water. Lead is of no known biological benefit to human as lead can damage various systems of the body including the nervous and reproductive systems and the kidneys, and it can cause high blood pressure and anemia (WHO, 2012). Lead levels in control samples might be of natural origin since there is no known industrial activity at the control site.

Cadmium concentrations in all the water sources from the study site were in trace quantities and below the detection limit. However, samples from the stream recorded high levels (0.36 mg/l) of cadmium which was above maximum contaminant limit of 0.003 mg/l. This might be as a result of industrial effluents arising from the disposal of waste containing cadmium such as metal plating and coating operations, including, machinery and baking enamels, waste batteries and paints. Absence of cadmium in hand dug wells and hand pump wells might be due to sorption processes that might have occurred in solid (soil) surfaces (Kodom *et al*., 2009; Espeby and Gustafsson, 2001). Cd levels in control samples of hand-dug wells, hand-pump wells and pipe –borne water exceeded that from the study area which might be of natural origin of the bedrock. However, surface water from "Suame Magazine" recorded high cadmium levels than from the control site. In humans, long-term exposure is associated with renal dysfunction, kidney damage, and lung cancer and bone defects. Cadmium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of Cadmium (Adelekan and Abegunde, 2011).

Concentrations of Chromium (Cr) in all the water sources from the "Suame Magazine" were below the detection limit. However, samples from the stream recorded a concentration of 0.04 mg/l which was below the maximum contaminant limit of 0.05 mg/l. Generally chromium content of surface waters reflects the extent of industrial activity but did not constitute a major problem as it was within the acceptable limit (Adelekan and Abegunde, 2011; Yadav *et al.*, 2011).

CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

This study brings to the fore the need for increased water quality from the different water sources within the "Suame Magazine" area. The water sources were high in iron (Fe) and lead (Pb) which was far above WHO Maximum Contaminant Limit. Cadmium (Cd) and chromium (Cr) concentrations were low in all the water sources and Below Detection Limit (BDL) except in surface waters. pH levels in all the water sources were below the range of WHO MCL of 6.5-8.5 thereby making them too acidic for drinking.

Temperature, turbidity and conductivity levels in all water sources were within WHO MCL except surface water which had high turbidity value.

6.2. RECOMMENDATIONS

Based on the outcome of the study the following is recommended;

1. It is recommended that water quality analysis be carried out on all hand-dug and hand-pump wells and be disinfected at least once in a year by the appropriate authorized bodies such as the CWSA. PVC pipes that have breakages and leakages needs to be replaced to reduce the iron and lead content found in pipe water.
2. Proper drainage and sewer systems should be constructed in the magazine to ensure proper disposal of hazardous liquid waste, thereby preventing seepage into groundwater and surface water.
3. There should be comprehensive waste management plan for the inhabitants to follow on daily waste disposal and education on the dangers of drinking polluted water.
4. The provision of regulatory guidance and recommended pollution prevention opportunities to help mechanics to handle their waste in cost-effective and environmentally sound ways is ideal. this may include;
    - Mechanics been made aware it is their responsibility to be able to realize hazardous waste streams from their operations and the practice of good-housekeeping that will reduce spills and waste and to conserve natural resources.
    - Adopt the strategy of reuse and recycling of materials such as used oil and brake fluids.

- Substitute less hazardous materials to do their job.

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APPENDIX A:

ANOVA FOR PHYSICO-CHEMICAL PARAMETERS:

A1: TEMPERATURE

Report

Water Source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe (Suame)	26.6157	7	.56285	.21274
Pipe (Control)	31.0833	6	.20412	.08333
Hand dug well(Suame)	26.5457	7	.23050	.08712
Hand-dug well (Control)	29.5833	6	.20412	.08333
Hand-pump well(Suame)	26.3343	7	.30582	.11559
Hand-pump well(Control)	32.6667	6	.60553	.24721
Surface water(Suame)	29.2233	3	.50846	.29356
Surface water (Control)	34.5833	3	.36364	.20995
Total	29.0642	45	2.77877	.41423

ANOVA

Temperature

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	333.935	7	47.705	303.684	.000
Within Groups	5.812	37	.157		
Total	339.748	44			

A2: pH

Report

Water Source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe (Suame)	6.0786	7	.19178	.07249
Pipe (Control)	7.4350	6	.04764	.01945
Hand dug well(Suame)	5.5643	7	.11043	.04174
Hand-dug well (Control)	7.1283	6	.06585	.02688
Hand-pump well(Suame)	5.8786	7	.32354	.12229
Hand-pump well(Control)	7.2700	6	.03742	.01528
Surface water(Suame)	4.5633	3	.23965	.13836
Surface water (Control)	8.0550	3	.10970	.06333
Total	6.4779	45	.96333	.14360

ANOVA

pH

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39.731	7	5.676	190.758	.000
Within Groups	1.101	37	.030		
Total	40.832	44			

A3: TURBIDITY

Report

Water Source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe (Suame)	3.0229	7	1.65175	.62430
Pipe (Control)	3.0000	6	.89443	.36515
Hand dug well2(Suame)	3.8814	7	2.18732	.82673
Hand-dug well 4 (Control)	1.8333	6	.40825	.16667
Hand-pump well(Suame)	1.9286	7	1.14163	.43149
Hand-pump well(Control)	3.8333	6	.75277	.30732
Surface water(Suame)	50.8900	3	8.86489	5.11815
Surface water (Control)	49.7460	3	16.57699	9.57073
Total	9.2386	45	16.83992	2.51035

ANOVA

Turbidity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11710.322	7	1672.903	80.666	.000
Within Groups	767.328	37	20.739		
Total	12477.651	44			

A4: CONDUCTIVITY

Report

Water Source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe (Suame)	1.4462E2	7	13.09123	4.94802
Pipe (Control)	93.1667	6	8.08497	3.30067
Hand dug well(Suame)	1.6176E2	7	18.53891	7.00705
Hand-dug well (Control)	1.5500E2	6	118.97899	48.57297
Hand-pump well(Suame)	1.4422E2	7	16.09003	6.08146
Hand-pump well(Control)	17.6667	6	.51640	.21082
Surface water(Suame)	4.2356E2	3	52.11976	30.09136
Surface water (Control)	1.6978E2	3	12.32920	7.11827
Total	1.4510E2	45	99.09733	14.77256

ANOVA

conductivity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	350603.431	7	50086.204	22.742	.000
Within Groups	81488.886	37	2202.402		
Total	432092.317	44			

APPENDIX B:

ANOVA FOR HEAVY METALS

B1: LEAD (Pb)

Report

water_source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe 1(Suame)	.4786	7	.06094	.02304
Pipe 2 (Control)	.3333	6	.15996	.06530
Hand-dug well (Suame)	.5400	7	.14434	.05455
Hand-dug well(Control)	.2817	6	.04309	.01759
Hand-pump well (Suame)	.4229	7	.17500	.06614
Hand-pump (Control)	.3067	6	.06683	.02728
Surface water(Suame)	.8567	3	.30989	.17892
Surface water(Control)	.1533	3	.03055	.01764
Total	.4144	45	.20396	.03040

ANOVA

Lead

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.146	7	.164	8.848	.000
Within Groups	.685	37	.019		
Total	1.830	44			

B2: IRON (Fe)

Report

Water Source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe (Suame)	.4843	7	.21023	.07946
Pipe (Control)	1.5967	6	.16008	.06535
Hand-dug well (Suame)	.6571	7	.36641	.13849
Hand-dug well (Control)	1.6050	6	.27812	.11354
Hand-pump well (Suame)	.8986	7	.38732	.14639
Hand-pump well (Control)	1.8350	6	.35647	.14553
Surface water(Suame)	9.3133	3	2.24812	1.29795
Surface water(Control)	4.4200	3	.48867	.28213
Total	1.9044	45	2.28926	.34126

ANOVA

Iron

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	216.885	7	30.984	83.637	.000
Within Groups	13.707	37	.370		
Total	230.592	44			

B3: CADMIUM (Cd)

Report

Water Source	Mean	N	Std. Deviation	Std. Error of Mean
Pipe (Control)	.0650	6	.00837	.00342
Hand-dug well (Control)	.0450	6	.01517	.00619
Hand -pump well(Control)	.0417	6	.01472	.00601
Surface water(Suame)	.3400	3	.27839	.16073
Surface water(Control)	.0433	3	.01155	.00667
Total	.0858	24	.12877	.02629

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.224	4	.056	6.727	.002
Within Groups	.158	19	.008		
Total	.381	23			

APPENDIX C:

MEASURED PHYSICO-CHEMICAL PARAMETERS OF SAMPLES

C.1a: Measured Temperature Levels of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	31.00	31.50	31.00	31.00	31.00	31.00
Hand-dug wells	29.00	29.50	29.51	29.50	29.95	30.01
Hand-pump wells	32.70	32.70	32.68	32.65	32.65	32.66

C1b: Measured pH Levels of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	7.46	7.39	7.37	7.50	7.44	7.45
Hand-dug wells	7.12	7.17	7.13	7.08	7.12	7.16
Hand-pump	7.27	7.28	7.25	7.26	7.27	7.27

wells						

C1c: Measured Turbidity Levels of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	2.00	3.00	2.00	4.00	3.00	4.00
Hand-dug wells	2.00	2.00	2.00	1.00	2.00	2.00
Hand-pump wells	4.00	3.00	3.00	4.00	4.00	5.00

C1d: Measured Conductivity Levels of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	88.00	89.00	91.00	88.00	109.00	94.00

Hand-dug wells	396.00	136.00	101.00	102.00	98.00	97.00	
Hand-pump wells	18.00	18.00	17.00	18.00	17.00	18.00	

APPENDIX C2

MEASURED HEAVY METAL CONCENTRATION OF SAMPLES

C2a:Measured Pb concentration of Sampled Water Sources within "Suame Magazine"

No. of Sampled Water source	1	2	3	4	5	6	7
Pipe-borne water	0.43	0.44	0.50	0.46	0.58	0.53	0.41
Hand-dug wells	0.64	0.50	0.57	0.50	0.26	0.71	0.60
Hand-pu	0.62	0.44	0.49	0.18	0.50	0.18	0.55

mp wells							
	upstream	midstream	Downstream	-	-	-	-
Surface water	1.06	0.52	1.01				

C2b: Measured Pb concentration of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	0.22	0.34	0.63	0.32	0.32	0.17
Hand-dug wells	0.26	0.22	0.30	0.31	0.34	0.26
Hand-pump wells	0.24	0.29	0.38	0.36	0.35	0.22

C2c: Measured Fe Concentration of Sampled Water Sources within "Suame Magazine"

No. of	1	2	3	4	5	6	7

Sampled Water source							
Pipe-borne water	0.46	0.54	0.83	0.25	0.45	0.63	0.23
Hand-dug wells	0.55	0.44	0.35	1.01	1.29	0.66	0.30
Hand-pump wells	0.27	0.73	0.81	1.07	0.91	1.56	0.94
	upstream	midstream	Downstream	-	-	-	-
Surface water	8.87	9.45	11.49				

C2d: Measured Fe concentration of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	1.65	1.62	1.60	1.29	1.76	1.6o

Hand-dug wells	1.44	1.23	2.07	1.65	1.61	1.63	
Hand-pump wells	1.93	1.96	1.73	1.92	2.27	1.20	

C2e: Measured Cd Concentration of Sampled Water Sources within "Suame Magazine"

No. of Sampled Water source	1	2	3	4	5	6	7
Pipe-borne water	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Hand-dug wells	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Hand-pump wells	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	upstream	midstream	Downstream	-	-	-	-
Surface water	0.04	0.39	0.59				

C2f: Measured Cd Concentration of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	0.07	0.07	0.07	0.07	0.06	0.05
Hand-dug wells	0.04	0.02	0.05	0.04	0.06	0.06
Hand-pump wells	0.06	0.05	0.05	0.04	0.03	0.02

C2g: Measured Cr Concentration of Sampled Water Sources within "Suame Magazine"

No. of Sampled Water source	1	2	3	4	5	6	7
Pipe-borne water	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Hand-dug wells	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Hand-pump wells	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	upstream	midstream	Downstream	-	-	-	-
Surface water	0.04	0.04	0.05				

C2h: Measured Cr Concentration of Sampled Water Sources from Control Site (Boadi)

No. of Sampled Water source	1	2	3	4	5	6
Pipe-borne water	BDL	BDL	BDL	BDL	BDL	BDL
Hand-dug wells	BDL	BDL	BDL	BDL	BDL	BDL
Hand-pump wells	BDL	BDL	BDL	BDL	BDL	BDL