CHAPTER ONE

1.0 Introduction:

Gold mining has played a pivotal role in the socio – economic development of Ghana for the past 200 years. According to Tenkorang (2001), the foreign exchange earnings from the export of gold rose from $107.2 million dollars to $744.2 million dollars in 1989 to 1999. From 1983 to 2002, foreign direct investment (FDI) inflow to the sector amounted to over US $6 billion dollars. Akabzaa *et al* (2004) has noted that there is a growing dissension over the net benefits of these investments to the country as a whole, and to the communities directly impacted by mining in particular. This has resulted in increasing incidence of conflicts between affected communities and mining companies.

However, gold mining in Ghana in recent times has become unpopular as result of the environmental damages the country has experienced from that sector of the economy (Kwarteng, 2003). This is due to cyanide spillages into community water bodies and other impacts of mining such as noise and air pollution.

Water availability is one of several current and future critical issues facing Africa. Recent Intergovernmental Panel on Climate Change (IPCC) fourth assessment report states that twelve countries would be limited to 1,000 to 1,700 m^3/person/year, and the population at risk could be up to 460 million mainly in West Africa. The estimate was based only on population growth rates and did not take into account the variation in water resources due to climate change. Ghana is one of the twelve countries that would face water scarcity.

Mining operations in the study area have affected negatively on surface and underground water in a number of ways:

- The mining process exposes heavy metals and sulphur compounds that were previously locked away in the earth. Rainwater leaches these compounds out of the exposed earth, resulting in "acid mine drainage" and heavy metal pollution that continues long after the mining operations have ceased.

- Similarly, the action of rainwater on piles of mining waste (tailings) transfers pollution to freshwater supplies.
- In the case of gold mining, cyanide is intentionally poured on piles of mined rock (a leach heap) to chemically extract the gold from the ore. Some of the cyanide ultimately finds its way into nearby water body.
- Huge pools of mining waste "tailings" are often stored behind containment dams. Most tailings impoundments leak at some point in the mine's life. In the event like this, water pollution is guaranteed as shown in fig. 1.0 below.

Mining companies in developing countries sometimes dump mining waste directly into rivers or other bodies of water as a method of disposal. Developed countries are not immune from such irresponsible way of disposing of mine waste.

Water supplies in the study area are from rivers, streams and rainfall and are characterised by their natural geographical distribution and accessibility, and unsustainable water use. Water is life. Water is livelihood. Water is health. It is for this reason that this study was conducted to determine the levels of heavy metals in water bodies in the Tarkwa mining area.

Fig. 1.0 Abandoned tailings dam at Binsere - Obuasi area (picture taken on 14th June 2008)

1.1 Mining and water pollution

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. Water is essential for growing food; for household water uses, including drinking, cooking and sanitation; as a critical input into industry; for tourism and cultural purposes; and for its role in sustaining the earth's ecosystems. However, this essential resource is under threat. Growing national, regional and seasonal water scarcities in much of the world pose severe challenges for national governments and international development and environmental communities. The challenges of growing water scarcity are heightened by the increasing costs of developing new water treatment systems, degradation of soil in irrigated areas, depletion of groundwater, water pollution and degradation of water-related ecosystems, and wasteful use of already developed water supplies, often encouraged by the subsidies and distorted incentives that influence water use. An overarching picture on the water–livelihoods–environment nexus is required to reduce uncertainties about management and investment decisions that will meet environmental security objectives.

Mining affects fresh water through heavy use of water in processing ore and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which we all depend. Water has been called “mining’s most common casualty” (James Lyon, interview, Mineral Policy Centre, Washington DC). There is growing awareness of the environmental legacy of mining activities that have been undertaken with little concern for the environment. The price we have paid for our everyday use of minerals has sometimes been very high. Mining by its nature consumes, diverts and can seriously pollute water resources.

Negative impacts can vary from the sedimentation caused by poorly built roads during exploration through to the sediment, and disturbance of water during mine construction. Water pollution from mine waste rock and tailings may need to be managed for decades, if not centuries, after closure. These impacts depend on a variety of factors, such as the sensitivity of local terrain, the composition of minerals being mined, the type of technology employed, the skill, knowledge and environmental commitment of the company, and finally, our ability to monitor and enforce compliance with environmental regulations. There are four main ways in which mining impact on water quality negatively. These are:

- Acid Mine Drainage (AMD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid Mine Drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing sulphide minerals are excavated from an open pit or opened up in an underground mine, it reacts with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity, a naturally occurring type of bacteria called Thiobacillus ferroxidans may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out – a process that can last hundreds, even thousands of years. Acid is carried off the mine site by rainwater or surface drainage and deposited into nearby streams, rivers, lakes and groundwater. AMD severely degrades water quality, and can kill aquatic life and make water virtually unusable.
- Heavy metal pollution is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream as water washes over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is particularly accelerated in the low pH conditions such as are created by Acid Mine Drainage.
- Processing chemicals pollution occurs when chemical agents (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to humans and wildlife.
- Erosion and sedimentation of rivers and streams in mining communities occurs during mineral development. Soil and rock are disturbed in the course of constructing and maintaining roads, open pits and waste impoundments. In the absence of adequate

prevention and control strategies, erosion of the exposed earth may carry substantial amounts of sediment into streams, rivers and lakes. Excessive sediment can clog riverbeds and smother watershed vegetation, wildlife habitat and aquatic organisms.

In addition to the above four ways in which mining operations affect water quality, gold mining can deplete surface and groundwater supplies. Groundwater withdrawals may damage or destroy streamside habitat many miles from the actual mine site. For example, in Nevada, the driest state in the United States of America, the Humboldt River is being drained to benefit gold mining operations along the Carlin Trend. Mines in the north eastern Nevada desert pumped out more than 580 billion gallons of water between 1986 and 2001 – enough to feed New York City's taps for more than a year. Groundwater withdrawn from the Santa Cruz River Basin in Southern Arizona for use at a nearby copper mine is lowering the water table and drying up the river (Environmental Mining Council of British Columbia, 2000).

For the sake of current and future generations, we need to safeguard the purity and quantity of our water against irresponsible mineral development. We need to ensure the best pollution prevention strategies are employed in cases where the risks can be managed. However, we also need to recognise that in some places mining should not be allowed to proceed because the identified risks to other resources are too great.

1.2 Rationale for the project:

In Ghana, most communities are established along rivers, forest and places where they could have access to water bodies because of the nature of income generating activities of these communities. Many communities in Ghana are named after rivers. Examples of such communities are Huniso, Subriso, Praso, etc.

Community people have good reasons to live along rivers/streams especially in developing economy such as Ghana, where provision of potable water is an illusion even for many urban communities not to talk about the mining communities, which are rural and remote. For this reason, rivers and streams are revered in most Ghanaian communities, as they perceive the rivers/streams to protect them in times of calamities. Rivers and streams provide communities with water for cooking, drinking, farming, building, recreation and aesthetic.

The Environmental Protection Council (EPC, 1991) of Ghana estimated that freshwater resource in Ghana amounted to 40 million acre – feet from rainfall, rivers, streams, spring and creeks, natural lakes impoundments and ground water from various aquifers. Availability of potable water to the population is an indicator of social and economic well – being.

The Ghanaian Chronicle issue of July 25 2003 carried a story attributed to the Regional Programmes Officers of EPA (Environmental Protection Agency) that Ghana is listed among countries in Africa that would experience water stress of 1700 cubic metres or less per a person annually by 2025. This is due to the pollution of water bodies.

Water pollution can be defined as anything human beings do to cause harmful effects to water bodies. This occurs because of the introduction of toxic chemicals from the effluents of mining operations, industries and sewage from hotel, domestic wastes and municipal wastes; run- off of agricultural wastes.

Mining is an activity classified as most polluting as well as draining the dwindling water resources in the world. A study conducted by Economic Commission for Africa (ECA) in 1999 on the water situation in African countries specifically cited Ghana as being one of the most water – stressed countries. In Ghana, the effects of the activities of mining companies on our water bodies through dewatering, ground water pollution, the virtually free use of water for mining operations, pollution of streams through cyanide and other waste spillages, are affecting the health status of residents of mining communities. A study by CHRAJ confirms the above assertion. A similar study by Duker et al (2005) has shown a positive relationship between exposure to arsenic in contaminated water bodies, soil and food crops to the occurrence of Buruli Ulcer disease by residents of Amansie East district of Ashanti Region.

Ghana has recorded about 11 cyanide spillages between 1989 and 2004, which officially were made public. Notably among them are:

- In 1989, there was a cyanide spillage by Obenemase Mine, near Konongo, which contaminated a tributary of River Oweri (Obiri, 2005).
- In June 1996, a large quantity of cyanide solution was released into Agonaben stream, a tributary of River Bonsa by Teberebie Goldfields causing harm to both aquatic lives and human beings (Obiri, 2005).
- Ashanti Goldfields Company Limited – AGC now AngloGold Ashanti – Obuasi Gold Mine spilled large volumes in 1998 and many communities were affected. The affected communities include Dokyiwa, Hia and Fenaso, just to mention a few. Low compensation was paid to the affected farmers whose farmlands and source of drinking water were destroyed by the spillage (Adimado and Amegbey, 2003).
- Bogoso Goldfields Limited (BGL) operates an open pit mine at Bogoso and had a major cyanide spillage in 1994, which polluted River Anikoko, which flows into River Bodwire. Many farmers were forced to abandon their farms to resettle in other communities. The company constructed boreholes for some affected communities but in places where boreholes were no available, the farmers were compelled to drink the polluted streams thus, posing health hazard to them. Affected villages include Brakwaline, Nakaba and Anikoko. Residents of Anikoko voluntarily had to abandon their village due to pollution from BGL's roaster, which emitted gases that destroyed farms and caused illnesses among the populace (Obiri, 2005).
- Abosso Goldfields Limited (AGL) now Goldfields Ghana limited – Damang Gold Mine spilled large volumes of cyanide solutions to streams/rivers in its immediate environment in November 1997. The spillage occurred because of leakage from the tailings pipeline as well as the failure of the tailings pump to pump back decanted cyanide solution to the plant for reuse.
- In 2001, Goldfields Ghana Limited – Tarkwa Mine spilled large volumes of cyanide solution into river Asuman in Abekoase. Water from an abandoned underground mine within the mining concession of Goldfields Ghana Ltd. has seeped into the Asuman River in the Wassa West District of the Western Region, sparking fears of contamination and a worsening health situation for area communities. The May 20th 2003 edition of the Peoples' Daily Graphic reports of an incidence of cyanide spillage into river Asuman in the Wassa area of the Western region by Goldfields Ghana Limited – Tarkwa Mine. This

incidence precipitated unhealthy relations between the mining companies and the community.

- In October 2004, Bogoso Gold Limited spilled large volumes of cyanide solutions into River Aprepre in Dumase. River Aprepre flows into rivers such as Manse, Ankobra, Egya Nsiah. communities affected; include Juaben, Goloto and Brakwaline. Again, in 2006, a cyanide spillage occurred in the communities. Some community members suffered in various ways following the spillage in 2004 and 2006 into river Apepre. This river serves as the source of water, which the village use for all household chores as well as drinking.

Water pollution has been a major issue at the Obuasi mine operated by AngloGold in Ghana, which is one of the world's leading sources of gold. Ashanti Goldfields Corp., which AngloGold acquired in 2004, first produced gold at Obuasi in the late 19th Century, when Ghana was known as Gold Coast. While some of the environmental problems are attributed by the company to careless behaviour on the part of the "illegal" individual miners known as *galamseys*, the operations of AngloGold also creates huge problems.

For example, in October 2006, the human rights group ActionAid International published a critical report on the Obuasi mine that included information on pollution issues. The report describes conditions in a 2,500-person village where runoff from a nearby waste rock pile repeatedly floods the community during heavy rain storms. ActionAid quotes a farmer Thomas Antwi as saying: "Whenever it rains heavily, the rainstorm washes most of the debris [from the waste dump] downstream, and then those who are at the furthest end of town get affected and they cannot stay there until the water subsides." Residents call the village "Ahansonyewodea" (which the reports says roughly translates as "This place is not your territory") as a form of protest against the mines (ActionAid, 2006).

In its environmental reports, AngloGold has acknowledged numerous spills at Obuasi, including an incident in 2006 in which rock dump material eroded because of heavy rain, resulting in flooding of the community of Ahansonyewodea, and another that year in which slurry spillage occurred at Aboagyekrom, a suburb of Obuasi.

The above reported incidences as well as many others which have not been made public call for thorough scientific assessment of levels of heavy metals in water bodies in the study areas and to inform governmental agencies and other stakeholders involved in the maintenance of sound environmental practices as well as those who are involved in the use of these chemicals in their operations.

Residents of mining communities in and around the concession of AngloGold Ashanti – Obuasi Gold Mine claim that mining operations of the company has contributed to the pollution of water bodies in their communities. A baseline study conducted by Wassa Association of Communities Affected by Mining (WACAM) on communities' perception of pollution of water bodies in the Obuasi area revealed that out of the 160 streams and rivers in the concession of AngloGold Ashanti – Obuasi Gold Mine, 145 of the streams/rivers are perceived to have been polluted by mining operations of the company and by small – scale mining operators. That is, only 15 of the rivers/streams are perceived not to be polluted.

A similar baseline study conducted by Wassa Association of Communities Affected by Mining (WACAM) have also revealed that all the 117 rivers/streams listed in the Tarkwa and its surrounding communities are perceived to have been polluted by the operations of mining companies as well as artisanal mining operations (WACAM, 2008).

Residents of the communities based their assertion on the fact that the mining company has erected metal sign posts with warning inscription such as "don't drink, don't swim and don't fish'' as a prove of the pollution of water bodies in the concession of the company as shown in fig. 2.0 below. Similarly, the communities rely on physical characteristics of the rivers such as colour, taste, odour and presence of aquatic organisms in assessing whether their rivers/streams are polluted or not.

Fig. 2.0. A caution sign post placed in front of one of the polluted streams/rivers (picture taken on 29th October 2008 at Dokyiwaa – Obuasi)

It is against this background that a study of this nature is important to determine the extent of pollution by heavy metals in water bodies in the study areas and compare them with WHO and GEPA permissible guidelines in other to ascertain whether indeed the communities' perception of pollution of their water bodies is justifiable.

1.3 The study areas:

1.3.1 Tarkwa area

The Wassa West district occupies the mid-southern part of the Western region of Ghana with Tarkwa as its administrative capital. The population of the district is approximately 236,000 and is mainly composed of not only the indigenous Wassa ethnic group but also all ethnic groups in Ghana. Subsistence farming is the main occupation of the people although rubber, oil palm and cocoa are also produced. Mining is the main industrial activity in the area (Avotri *et al.*, 2002). The area lies within the main gold belt of Ghana that stretches from Axim in the southwest, to Konongo in the northeast (Kortatsi 2004). Location of the Wassa West district and the study area is shown in figure 3.0 below. Wassa West district has been split into two districts namely Tarkwa - Nsuaem Municipality and Prestea – Bogoso district. The administrative headquarters for Tarkwa – Nsuaem municipality is still Tarkwa whilst that of Prestea Bogoso is Bogoso. The two districts are regarded as the gold mining hub of Ghana with about 8 mining companies and many small – scale miners (legal and illegal). Examples of some of the mining companies are; Golden Star Resources, Goldfields Ghana Limited (Tarkwa and Damang Mines), AngloGold Ashanti Iduapriem Mine, Sankofa Goldfields.

1.3.2 Climate of Tarkwa area

Wassa west district is situated on the border of two climatic regions. The southern part belongs to the south western equatorial climatic region and the northern part has a wet semi equatorial climate. Generally, the rainfall pattern follows the northward advance and the southward retreat of the inter-tropical convergence zone that separates dry air from Sahara and the moisture-monsoon air from the Atlantic Ocean. The north air mass, locally called the Harmattan, brings in hot and dry weather during December to February (Dickson & Benneh 1980). The area is characterised by double rainfall maxima. The first and largest peak occurs in June, whilst the second and smaller peak occurs in October. Around 53% of rainfall in the region falls between March and July. The mean annual rainfall is approximately 1874mm with max and min values of 1449mm and 2608, respectively. The mean pH of the rain water in the area during 2000-2001 was 6.07 (Kortatsi, 2004). The area is very humid and warm with temperatures between 26-30C° (Dickson and Benneh, 1980).

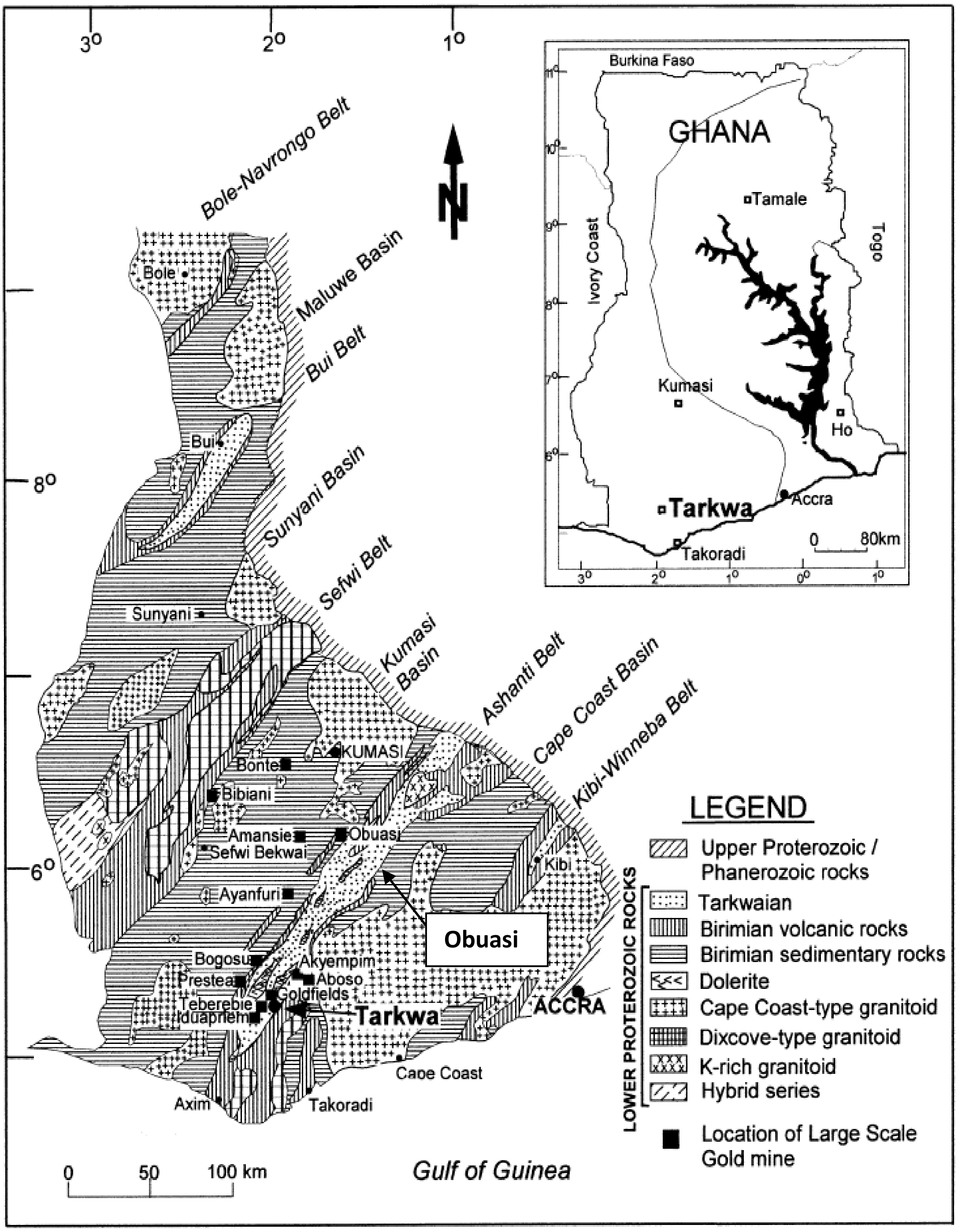

Fig. 3.0 Map of Ghana showing the study areas.

1.3.3 Obuasi area

Obuasi Municipality is one of the 21 districts of the Ashanti Region located at the southern part of Ashanti region. It is bounded to the east by Adansi South, west by Amansie Central and to the north by Adansi North, to the south by Upper Denkyira district in the Central Region. The town is the administrative headquarters of Ashanti Goldfields Company, now AngloGold Ashanti – Obuasi Mine. The headquarters of this new company is in South Africa. It is located in the south -western sector of the Ashanti Region of the Republic of Ghana. The town is located on latitude 6^o15 and on longitude 1^o40. The town can be found in a valley and is surrounded by hills, mountains made up of igneous and sedimentary rocks. The rocks are rich in the gold ore. It is located in the tropical evergreen rain forest belt. As such, the soil is very good for producing food and cash crops such as cocoa, coffee, etc. Because of the high rainfall values and the rich mineral content of the soil from weathering of the rocks, it has concentration of gold ore and the area is very good for farming (AGC, 2001; Anamuah-Mensah, 2000).

1.3.4 Climate of Obuasi area

The climate of the area is characterised by seasonal weather patterns. This involves a double wet season in April to June and October to November and the main dry season between from December to March. However, due to changes in the local climate as well as global climate change, this year’s rains started in the mid of May and peaked up from June to August with daily temperatures of 22 to 30˚C during the wet season and 31 to 34˚C during the dry season. Relative humidity ranges from 70 to 90%. The average rainfall value between May to August 2008 is 150 - 250mm (Ghana Meteorological Agency)

1.4 Gold deposits in the study areas

1.4.1 Gold deposits and gold mining at Obuasi area

The gold bearing quartz rocks contains the ore. The ore is obtained from underground and surface or open pit mining.

The ores are classified as:

- Underground ore: This consists predominantly of sulphides – pyrites (FeS_2) and arsenopyrites (FeAsS).
- Surface ore: This consists of
  - (a) Oxides – mainly as iron oxides – haematite (α- Fe_2O_3) and magnetite (Fe_3O_4).
  - (b) Sulphides – mainly as pyrites and arsenopyrites.
  - (c) Transition ore – partially oxidized sulphide forms a transition between the above two types of surface ore.
- Old tailings – these are low-grade ores, which consist of dumped tailings from processing of gold.

In all these, the gold is found trapped or entangled in the crystal structure of the sulphides and the oxides (Williams and Burson, 1985). AngloGold Ashanti – Obuasi Mine (AGA) engages in both surface and underground mining. The company employs the two main forms of underground mining namely:

(a) Those that require some form of support such as pillars. These include open stopping, and cut and fill.

(b) Those that require no support. These include long wall mining, sub level caving and block caving mining.

In all these, the gold bearing ore is transported to the surface of the earth for processing. The surface mining involves the development of physical structures to provide access to the mineralized zone. The liberation of the ore from the gold bearing rock involves blasting of the gold bearing rocks or open pit mining (Williams and Burson, 1985). The liberated ore is then hauled to processing plants for processing.

1.4.2 Gold deposit and gold mining at Tarkwa area

The gold bearing ores obtained from Birimian and Tarkwain rock systems are found in the area. The ores consists of (Knight and Scott, 2001):

- Oxides mainly as iron oxides – haemetite (α- Fe_2O_3) and magnetite (Fe_3O_4)
- Sulphides – mainly as pyrites and arsenopyrites.

- Transition ore – partially oxidized sulphide forms a transition between the above two types of ores.

In all these raw materials, the gold is found trapped or entangled in the crystal structure of the sulphides and the oxides bearing rocks. Blasting of the gold bearing rock is the most common method of assessing the ore. The company engages in surface mining. The gold ores are hauled to the processing plant where the gold is extracted from the ore. The company approximately mines about 152,000 ounces of gold every year.

1.5 Small scale mining (galamsey)

'Galamsey' is the name given to the activity of non-professional small-scale miners in Ghana. The galamsey operations are normally carried out at the gold and diamond mining areas. In the gold mining areas, the gold bearing ores are dug from the ground or sometimes the tailing from the gold treatment plants are washed several times with clean water in a bucket or a pan to remove the slime. Usually, an inclined table is then set up and the surface is covered with an old jute sack or even a piece of carpet or any woollen material that can hold heavy particles. The gold bearing material in the pan is then poured onto the covered table and further washed to remove the light material. The heavy materials are trapped in the sack covering the table. This operation is continued until the sack is saturated with the concentrate and the initial material is reduced to a very small quantity very rich in gold. The gold on the piece of sack/ cloth is then washed off into a pan. The water is decanted and mercury is added to the very small volume of concentrate obtained. The mercury is rubbed hard into the concentrate until an amalgam (Au/Hg) a solution of gold is formed leaving behind the gangue. The Au/Hg is put in a clean white handkerchief and tied. The mercury is then squeezed out of the gold amalgam. The gold amalgam, which is white in colour because of mercury contamination, is then roasted in an open fire; the mercury is vaporized to the atmosphere leaving behind the impure gold. The crude gold is either refined in hot concentrated nitric acid solution or sold to buyers called 'dealers'. The mercury contaminated water is discharged into nearby water bodies and vegetation.

Fig. 4.0 'Galamsey site near river Asasre in Himan (picture taken on 23rd May 2008)

1.6 Aims and objectives:

The overall aim of the study is to assess the quality of rivers and streams in the Obuasi and Tarkwa mining areas. The specific objectives of the study are to:

- Determine the levels of heavy metals in streams and rivers in the Obuasi and Tarkwa mining areas.
- Determine the levels of heavy metals in alternate source of drinking that has been provided for communities whose source of drinking have been impacted upon negatively by mining activities in the study areas.
- Compare the levels of heavy metals in the water bodies in the study areas with permissible levels of GEPA (Ghana Environmental Protection Agency), USEPA (US Environmental Protection Agency) and WHO (World Health Organisation).
- To recommend to government and other stakeholders the need to provide alternate potable water for the inhabitants should mining operations in the area cease.

1.7 Justification for the study:

To reiterate, water is life. Water is wealth and finally water is health. It is in this regard that this study aims at assessing the levels of heavy metals such as As, Cd, Hg, Pb, Mn, Zn, Fe and Cu in rivers/streams and other water bodies in the Obuasi and Tarkwa mining areas respectively. The results of this study would provide evidence whether mining operations of large scale mining companies as well as small scale (galamsey operators) miners have negative effect on surface water and other water bodies in the study areas.

The study would ascertain the quality of alternate water that has been provided by the company for some communities within their concession. Water borne diseases are linked with drinking polluted water. It is very important that the alternate water being supplied to the communities by the company is assessed independently, because residents of mining communities claim that in some cases they do not know the source of the alternate water that is being supplied to them.

The leaching and seepage of metals, spillage of cyanide solutions and other toxic chemicals from tailings dam, ore stockpiles and waste dumps have contaminated most water bodies in the study area (Obiri *et al*., 2007; Adimado and Amegbey, 2003).

Cyanide poisoning occurs when one ingests lethal dose of cyanide through the mouth, which then causes cytotoxic hypoxia. Cytotoxic hypoxia results from an interference of the utilisation of oxygen during cell metabolism in the presence of adequate oxygen supply and blood flow. Cyanide inhibition of cytochrome oxidase halts electron transport, oxidative phosphorylation and aerobic glucose metabolism. This results in lactic acidemia and high concentrations of HbO_2 in the venous return (thereby bringing flush to skin that could be confused with HbCO) (Smith, 1980).

The U.S. National Research Council has recently concluded, based on epidemiologic studies that the evidence is now sufficient to include lung and bladder cancer, along with the skin cancers, as being caused by ingestion of inorganic arsenic (NRC, 2001). They further concluded that there is some indication that arsenic may induce cancers in other organs, although the evidence is not as strong. Chronic arsenic exposure has been implicated in several noncancerous conditions, in particular, skin disease, diabetes mellitus, hypertension and cardiovascular disease, perturbed porphyrin metabolism, and irreversible noncirrhotic portal hypertension (NRC, 2001). It has been long known that arsenic exposure is associated with skin pathology, including hyperpigmentation, hyperkeratosis, and skin cancers. In the majority of cases in which an internal cancer has been ascribed to arsenic exposure, a dermatologic hallmark of arsenic poisoning was also identified (Tsai et al., 1999). Effects of arsenic on the liver have been suggested in a few case reports, although the pathology has not been well described. In addition to noncirrhotic portal hypertension (Nevens, et al., 1990), other liver pathology has been described, including hepatic enlargement, hepatocellular carcinoma (Centeno et al., 2000), and liver angiosarcoma (Neshiwat et al., 1992). Epidemiologic studies have not confirmed the association between arsenic exposure and hepatocellular carcinoma and liver angiosarcomas. In this article, we present two cases of liver cancer that appear to be associated with arsenic exposure, one involving a hepatocellular carcinoma and the other a liver angiosarcoma.

Similarly, exposure to mercury (II) fumes or ions in water body contaminated with both inorganic and organic mercury causes respiratory damage, damage to the brain and may result in death after long period of exposure. Other symptoms include (ASTDR, 2000):

- Irritation of upper respiratory tract.
- Metallic taste in the mouth
- Cough
- Skin irritation
- Chest pains.

The above symptoms are common in the study areas. Hence, there is the need to assess the risk posed by cadmium, mercury, iron, manganese and zinc to the inhabitants in the catchment areas of this study. The other heavy metals such as arsenic, lead and mercury were selected for this work because they are very toxic and present in the environment. The hazards associated with these toxic or hazardous metals are only felt if the metal concerned is present in the sample being analysed not as a free metal but in its speciated form or as a salt.

The three major routes of entry of toxic chemicals into the human body are: inhalation, skin absorption and ingestion. The oral route (or ingestion) is usually thought to be a minor pathway for workplace exposure but since most of the effluents from the mines contaminate surface and underground water bodies, in this case, ingestion becomes a significant route by which toxic chemicals from the mines enter the body of residents in the study area.

The communities claim that the diseases they suffer are caused by the bad quality of water supplied to them by mining companies after their rivers and streams had been destroyed by large scale surface mining operations of the mining companies. For instance, the people of Abekoase in the Western region complained of episodes of cyanide spillage, which polluted their main source of water and contaminated fish in the river. They further alleged that those who ate the contaminated fish suffered stomach disorders.

Fig. 5.0 Resident fishing from River Jimi perceived to be polluted from the mining operations of AngloGold Ashanti – Obuasi Mine (picture taken on 3rd May 2008).

This study is very crucial because mines generally have short life span, hence pollution of water bodies in their concession will have serious consequences for inhabitants of mining communities in the event of mine closure. The question most people living in mining communities have been asking is who will provide them with potable water when the mining company closes down. They also have little or no idea as to the source of the drinking water being supplied to them by the management of AGA – Obuasi Mine. Residents in communities within the concessions of AGA – Obuasi claims that their source of drinking water is pumped from the plant area of the company.

Fig. 6.0 AGA – Obuasi mine Jimi pump station that pumps water from the Jimi dam to the plant area (picture 3rd May 2008).

CHAPTER TWO

LITERATURE REVIEW

2.0. Toxicity of toxic chemicals

A toxic chemical is one that poses unreasonable risk to health, safety and property (George, 1982). It may do so either through an alteration of normal function or the destruction of life of an organism. The US Federal Agency in charge of Occupational Health defines a toxic chemical as "...any substance whose presence presents an imminent danger to public health or welfare or the environment, when discharged into the waters of USA..." (USEPA, 1999c).

The definition of a toxic chemical varies from one country to another. One of the most widely accepted definition is stated in the US Resource Conservation and Recovery Act of 1976 (RCRA) which states that "...a chemical is said to be toxic or hazardous if it can cause or contribute significantly to an increase in mortality or an increase in serious irreversible or incapacitating reversible, illness or pose a substantial hazard to human health or the environment..." (Williams and Burson, 1985). The fundamental question of any risk assessment of toxic chemicals is whether the chemicals will reach a target (e.g., a person, animal, etc) in a concentration large enough to cause damage. The extent of damage is an indication of the chemical's toxicity at a specified concentration, i.e. the toxicity of the chemical in question.

Toxicity of a chemical is a relative term generally used in comparing the harmful effect of one chemical on some biological mechanism with the effect of another chemical. Toxicity of a chemical, "...is the likelihood of a chemical to cause harm to living organisms when ingested, or inhaled or absorbed through the skin..." (Eldon and Bradley, 2004). The toxicity of a substance describes the nature, the degree and the extent of its undesirable effects. It is the basic property of a chemical and reflects its inherent ability to produce injury to human health or other organisms. In general, the toxicity of any chemical depends on its **a**bsorption, **d**istribution, **m**etabolism and **e**xcretion (A.D.M.E.) (Alloway and Ayers, 1993).

Absorption is defined as the movement of a toxic chemical from the site of initial contact with the biologic system across a biological barrier and into either the bloodstream or the lymphatic system. A toxicant exterior to the body is absorbed into the body and then into the bloodstream. From the bloodstream, it is both eliminated and distributed to various tissues, including the target tissue. A target tissue is one on which the toxicant or the toxic chemical exerts its effect. The target tissue could be either the blood cells or any other organ of the body. For example, the red blood cell is the target tissue for carbon monoxide as well as arsine gas. However, certain toxic chemicals produce adverse effects without being absorbed into the human body while for most toxic chemicals their effects are only felt after they have been absorbed into the human body. For example, an acid can cause serious damage to the skin even though it is not absorbed through the skin (O'Flaherty 1981, 1985).

Absorption of toxic chemicals into the body takes place across the epithelium membrane. The principal routes for absorption of toxic chemicals into the body are:

- Ingestion
- Inhalation
- Skin (Dermal) contact

Most toxic chemicals may be present in food or in drinking water. For such chemicals, ingestion is the only source by which these chemicals are absorbed into the gastrointestinal tract. If they have been inhaled but are relatively large metallic particulates, they will be collected in the nasopharyngeal area of the respiratory tract and mucociliary clearance of the respiratory tract introduces these toxic chemicals into the gastrointestinal tract. A very important route for the absorption of toxicants into the body is through the gastrointestinal tract. Metals such as lead, arsenic, cadmium, etc are absorbed into the cells lining the intestinal tract by

- Passive or facilitated diffusion.
- Specific transport processes.
- Active transport (Guidotti, 1976).

The gastrointestinal absorption of toxic metals varies widely. Metal salts of lead, tin and cadmium are poorly absorbed (< 10%) while the salts of arsenic and thallium are almost completely absorbed (>90%). The absorption of toxic metals depends on many factors, including:

- The solubility of the metal salt in fluids of the intestinal tract.
- The chemical form of the metal (the lipid – soluble methyl mercury is completely absorbed, whereas inorganic mercury is poorly absorbed).

- The presence and composition of other materials in the intestinal tract (these can affect passage of contents through the alimentary tract).
- The competition for absorption sites between similar metals (e.g., zinc and cadmium, or calcium and lead)
- The physiological state of the person who has been exposed to the toxic metal (high vitamin D enhances the absorption of lead).

Inhalation is the second major pathway for the absorption of toxic chemicals into the body. The lung is a very important route. Gases and vapours such as hydrogen cyanide, sulphur dioxide and any other toxic gas are absorbed through the lungs.

Liquid or particulate aerosols, such as lead, mercury, cadmium and arsenic dust are deposited and / or absorbed in the lung. The rate of absorption of these particulates depends on the size of the particulates. The size of the particulate matter is expressed as the diffusion mean equivalent diameter (DMED). DMED is a measure of particle diameter; the amount deposited is calculated as the difference between the amount of the toxic chemical inhaled and the amount exhaled. For a standard man, with a breathing cycle of about 4cycles/sec, lung deposition of lead varied from about 24% for particles with a DMED of 0.09µm to 68% for very small particles with a DMED of 0.02µm. Particulate size is inversely proportional to the magnitude of particle deposited in the lung. Particulate may be dissolved and absorbed into the bloodstream or may reach the systemic circulation directly. If they are not readily soluble, they may be phagocytized by alveolar macrophages and then either transferred directly to the lymphatic system, where they may remain for a considerable period or are moved together with the macrophage to the mucociliary escalator for clearance by that route.

The third major pathway for absorption of toxic chemicals into the body is by the skin contact. The skin is a very effective barrier to absorption, primarily because of the outermost keratinized layer of thick – walled epidermal cells, the stratum corneum, which in general is not permeable to toxicant, although its permeability varies from location to location. However, there may be slight absorption through the sweat glands or the hair follicles. For example, certain metals such as mercury, zinc, arsenic and copper are deposited in the hair follicle.

All toxic chemicals that penetrate the skin appear to do so by passive diffusion. The permeability of toxic chemicals is an important factor in evaluating (the health effects) dermal exposure to toxic chemicals. The permeability of toxic chemicals through the skin can be increased by abrasion. Abrasion damages or removes the stratum corneum, and increases the permeability of toxicants through the damaged area. It can also be increased by the solubility of the chemical in the fatty tissues of the skin. Once a toxic chemical is absorbed into the bloodstream, it is either eliminated or distributed to various tissues including the target tissue. Distribution of toxic chemicals in the body is similar to excretion of toxic chemicals and they occur at the same time.

Disposition of toxic chemicals in the body includes both distribution and elimination of the toxic chemical which occur simultaneously. Kinetic models are used to explain the rate of disposition of toxic chemicals in an organism. The rate of distribution of a toxic chemical in the body is related to the kinetic distribution constant.

The most basic kinetic model used to explain how a given toxicant distributes itself in the body is the one – compartment open model. The model assumes that the toxicant introduced instantaneously into the body is distributed instantaneously and homogeneously, and eliminated at a rate that is at all times directly proportional to the amount left in the body at a first order rate. The constant of proportionality between the rate of elimination and the amount present in the body is the distribution constant.

$$C\ (t) \rightarrow Ke$$

Where:

C (t) = the concentration of the toxicant which is a function of time.

Ke = the distribution constant.

From this model, the logarithm of concentration of the chemical in question in the blood is a linear function of time (Hodgson and Guthrine, 1980).

Toxic effects of toxic chemicals do only occur after the toxicant had entered the bloodstream following absorption through the gut, the lungs or the skin. Once in the bloodstream, the chemicals are circulated around the body and undergo metabolism, usually in the liver, or stored in various organs. Some of the products of this metabolism may be excreted via the kidneys as urine, the digestive tract as faeces, lungs as exhaled air (Rodricks, 1992). In human beings, metabolic conversion of compounds not essential for normal biological functions takes place mainly in the liver but some metabolism can also occur in the lungs, intestines, kidneys and the skin.

Enzymes usually catalyse these conversions but possession of the right enzymes depends on the similarity of the pollutant to commonly encountered substances or evolutionary adaptations. New chemicals may remain in the bloodstream unaltered or are metabolised slowly due to lack of previous exposure to the chemicals. Metabolism of toxic chemicals reduces the toxicity of that chemical. For example, toluene, a neurotoxin that is absorbed through the lungs, is converted to a less toxic chemical (benzoic acid) which is easily excreted than toluene (Rodricks, 1992).

Excretion is the next major factor that determines the toxicity of chemicals especially toxic metals. The important route for excretion of most toxic chemicals is renal elimination. For example, most toxic metals in the blood plasma are bound to plasma and amino acids. Metals bound to low – molecular – weight proteins and amino acids are filtered in the glomerulous into the fluid of the renal tubule. Some metals such as zinc and cadmium are effectively resorbed by the tubular epithelia before they reach the urinary bladder where very little resorption occurs. Tubular resorption of a given metal in the kidney depends on the urinary pH, the amount and kind of amino acids and proteins associated with the metal and the presence of or absence of other metals competing for resorption. Again, any toxic metal or chemical that poisons renal tubular epithelia will reduce the resorption and thereby increase the urinary excretion of metals (Guthrine and Perry, 1980).

Other ways by which toxic chemicals are eliminated from the body are through:

- Biotransformation
- Gastrointestinal tract
- Enterohepatic circulation
- Minor pathways such as excretion through loss of hair, nails, saliva lactation, etc.

2.1. Acute and chronic toxicity

The toxicity of a chemical is commonly categorised based on the duration of exposure, i.e., acute, chronic and sub – chronic.

Acute toxicity is caused by a relatively large dose of a chemical over a short period. It is caused by fast poisons, which include both synthetic and naturally occurring compounds.

The duration of time from the exposure to the toxic chemical to the onset of the clinical signs and symptoms is usually short and the intensity of the effects is often higher than with chronic toxicity. Frequently, the organs and tissues affected are those involved in absorption or elimination of the chemical.

Chronic toxicity is caused by long or repeated exposure to relatively small doses of chemicals. The time duration from initial exposure to the onset of the signs and symptoms of toxicity may be months or even years. The development of symptoms for chronic exposure to toxic chemicals is often gradual and the intensity of the symptoms is often less severe (but not always) than with acute toxicity. Diagnosis of chronic metal intoxication is more difficult than the diagnosis of acute intoxication because of the longer duration between onset of exposure and the development of symptoms. The chronic exposure to toxic chemicals such as lead, cadmium, arsenic and zinc is often more serious than the acute exposure to these toxic chemicals. This is because of the longer duration between onset of exposure and the development of symptoms. Organ systems not involved in absorption or elimination of the toxic chemical such as hematopoietic or immune system may be affected by chronic exposure to the toxic chemical. It is against this background that, a study of this nature is needed to establish scientifically the levels of lead, arsenic, mercury, copper, manganese, cadmium, zinc and iron in water bodies in the Obuasi mining area, which has a long history of mining. A recent report issued by CHRAJ (Commission on Human Rights and Administrative Justice, 2008), reveals that most water bodies in the Obuasi mining area has been polluted with toxic chemicals such as lead, mercury, cadmium, zinc, arsenic, iron and that these chemicals have bio - accumulated in the water bodies as a result of the fact that they are being continually released into the environment. The report further revealed that, residents of communities within the Obuasi mining area have suffered certain diseases because of their continual use of water bodies loaded with heavy metals.

Sub – chronic toxicity of chemicals are determined by investigating the biochemical and other changes which take place over a period of months. Sub – chronic toxicity is dosing over a shorter time – fraction of a lifetime, such as one eighth of an experimental rodent's lifetime.

2.2. Source and toxicities of As, Cd, Mn, Hg, Zn, Cu, Fe And Pb in the study area

2.2.1. Source of arsenic and toxicity of arsenic

Arsenic is a naturally occurring element in the earth's crust. Arsenic is found in the deep bedrock materials as well as the shallow glacial materials in the study areas. They are also found alongside the gold ores such arsenopyrites (FeAsS) (Coakley, 1996). Arsenic is usually present in the environment in inorganic form. The inorganic arsenic easily dissolves and enters underground and surface waters. The presence of arsenic in the environment may be attributed to one of the following sources: residual arsenic from former pesticidal use, smelter emission from ores of gold such as arsenopyrites from the sulphur treatment plant. Arsenic in the study areas, especially Obuasi, is very high in the soil/sediment and river water (Obiri, 2005).

Franblau and Lillis (1989), reported two cases of sub – chronic (2 months) arsenic intoxication resulting from ingestion of contaminated well water (9 – 10.9mg/L), sporadically (once or twice a week) for about two months. Acute gastrointestinal symptoms, central and peripheral neuropathy, bone marrow suppression, hepatic toxicity and mild mucous membrane and cutaneous changes were observed. The calculated dose was between 0.03 – 0.08mg/Kg/day based on a body weight of 65kg and ingestion of arsenic from 238 to 475ml water/day. The effects observed for the short –term arsenic exposure (appearance of edema, gastrointestinal or upper respiratory symptoms), differ from those for long – term arsenic exposure (skin disorders and damages to the nervous system). Symptoms such as peripheral neuropathy appeared in some of the subjects or individuals even after cessation of the arsenic intake (USEPA, 1988). According to Tseng, et al., (1968), chronic dermal exposure to arsenic causes skin cancer. The prevalence of skin cancer is very high in areas where chronic exposure to inorganic arsenic is very high. Tseng noted that, hyperpigmentation, keratosis and possible vascular complications were seen at LOAEL = 0.17mg/L (0.014mg/kg/day). The NOAEL = 0.009mg/L of water (0.0008mg/kg/day).

According to (IARC, 1980), inorganic form of arsenic is classified as a class A Carcinogen (Human Carcinogen). This classification is based on sufficient evidence from human data. That is, increased lung cancer mortality was observed in multiple populations exposed to arsenic primarily through drinking of arsenic contaminated water. Again, an increased mortality from multiple internal cancers (liver, kidney, lung and bladder) and an increased incidence of skin cancer had been observed in populations consuming drinking water with high inorganic arsenic concentration.

2.2.2. Source of mercury and toxicity of mercury

Elemental mercury is a silvery metallic liquid that is volatile at room temperature. Mercury is found in soil and rocks typically as an ore known as cinnabar, consisting of insoluble mercuric sulphide. In Ghana, the presence of mercury in the environment may be attributed to the use of mercury in gold recovery processes where the inorganic form of the metal either is washed into rivers or is vaporized readily into the atmosphere (Obiri, 2005; Essumang *et al*., 2007). Mercury compounds are also used as germicides and fungicides, and as industrial catalyst in the manufacture of plastics, pulp paper, paints, cosmetics, batteries, etc.

Mercury is a non essential element, a neurontoxin and has tertogenic effects. It also affects the renal system, nervous system, gastrointestinal tract and the respiratory system. It is responsible for the death of 52 people in Minamata, Japan in 1952 through eating of contaminated fish (Lee, 1994). Mercury has been shown to be toxic to human populations because of occupational exposure and accidental ingestion of mercury-contaminated food. The nature of mercury toxicity depends on its chemical form. For example, methylmercury (MeHg) is very toxic as compared to inorganic mercury. The methylmercury is of special concern because of its enhanced lipohilicity, bioaccumulation and volatility as compared with the inorganic mercury. For this reason, it is able to cross biological membranes more easily and enters the brain, spinal cord, the peripheral nerves and the placenta. The foetus in the uterus may show symptoms of cerebral palsy through mercury intoxication, even though the mother may not show symptoms of mercury poisoning (Kpekata, 1974; W.H.O., 1990). Accidental ingestion exposure to high levels of organic mercury compounds has produced developmental toxicity in humans. Aryl mercury compounds are even more dangerous and cause brain damage giving numbness, loss of vision, deafness, madness and death (W.H.O., 1990). The USEPA has classified both mercuric chloride and methylmercury as possible human carcinogens (Group C), based on the absence of data in humans and limited evidence of carcinogenicity in animals, whereas elemental mercury is in Group D, i.e., not classifiable due to inadequate data (Barregard, 1990).

2.2.3. Source of zinc and toxicity of zinc

Zinc is an element of moderate abundance in the earth crust. It occurs in rocks as chalcophile and sphalarite, ZnS (referred to as zinc in Europe). The natural zinc content of soils is estimated to be 1 – 300mg/kg. The presence of zinc in the environment is associated with mining and smelting which pollutes the air, water and soil with fine particles, which ultimately undergo oxidation to release Zn^{2+}. Zinc is used in a wide variety of industrial, agricultural, and consumer products. It is found in all human tissues and all body fluids and is essential for growth, development and reproduction. Zinc is usually present in tap water at concentrations less than 0.2 mg/L, although drinking water in galvanized pipes can contain up to 2 to 5 mg/L. Typically, concentrations are much less than 5 mg/L, which is based on the threshold for metallic taste in water.

Zinc is an essential trace element for all bacteria, plants and animals including human beings. It has many biochemical functions (catalytic, regulatory and structural). The catalytic role of zinc is understood in terms of the fact that it forms part of the specialized enzymes and proteins. Although zinc is an essential element to plants, animals and man, very high concentrations of zinc is very toxic, hence harmful to the body. The toxicity of zinc is due to having cadmium as an impurity. It causes phytotoxicity. Zinc therefore affects many functions of the body such as reproduction, skin health, sense of smell and taste, brain functions and growth.

However, low blood levels of zinc are also associated with hypogeusia, in which there is loss of sense of taste. Gastrointestinal distress is a common symptom following acute oral exposure to zinc compounds. The USEPA has given zinc a carcinogenicity weight-of-evidence classification of D (not classifiable as to human carcinogenicity), based on inadequate evidence in humans and laboratory animals.

2.2.4. Source of cadmium and toxicity of cadmium

Cadmium is a soft, ductile metal which is obtained as a by – product from the smelting of lead and zinc ores. It is also found in chalophile as a mineral called greenockite, CdS. Volcanic eruption is also another source of cadmium in the environment. Naturally, cadmium levels in the atmosphere are thought to be about $2ng/m^3$ though high values are found near zinc smelters. Cadmium in the study area may come from the mining and processing of zinc and other chalophilic metals. The anthropogenic sources of cadmium in the environment poses serious threat because of its surface input to soil system making the metal more accessible for plant and animal uptake. Cadmium is obtained mainly as a by-product during the processing of zinc-bearing ores and from the refining of lead and copper from sulphide ores. Cadmium is used primarily for the production of nickel-cadmium batteries, in metal plating, and for the production of pigments, plastics, synthetics and metallic alloys.

Cadmium has been shown to be toxic to human populations from occupational inhalation exposure and accidental ingestion of cadmium contaminated food. Inhalation of cadmium dust in certain occupational settings may be associated with an increased incidence of lung cancer. Other symptoms include; irritation of upper respiratory tract, metallic taste in the mouth, cough and chest pains (Foulkes, 1986). Ingestion of elevated levels of cadmium has resulted in toxicity to the kidney and skeletal system and may be associated with an elevated incidence of hypertension and cardiovascular disease.

2.2.5. Sources of iron and manganese and toxicities of iron and manganese

Iron in the study area is associated with the Birimian and Tarkwanian rock system. The Birimian and the Tarkwanian rock systems contains high amount of iron and other toxic chemicals such as manganese. The high concentration of iron in the study area is from the weathering of the Birimian and Tarkwanian rock system. Other sources of iron in the study area is the occasional discharge of mining waste, acid mine drainage which may increase iron levels in the surface water. Iron is one of the major constituent in the lithosphere (i.e. soil or rock) soil as oxides or hydroxides. Manganese is also used in the alloying of iron to produce stainless steel and other products of iron (AGC, 2001).

Manganese is one of the most abundant metals in soils, where it occurs as oxides and hydroxides, and it cycles through its various oxidation states. Manganese occurs principally as pyrolusite (MnO_2), and to a lesser extent as rhodochrosite ($MnCO_3$). More than 25 million tonnes are mined every year, representing 5 million tons of the metal, and reserves are estimated to exceed 3 billion tonnes of the metal. The main mining areas for manganese ores are South Africa, Russia, Ukraine, Georgia, Gabon and Australia. Manganese is an essential element for all species. Some organisms, such as diatoms, molluscs and sponges, accumulate manganese. Fish can have up to 5 ppm and mammals up to 3 ppm in their tissue, although normally they have around 1 ppm. However, in Ghana, manganese in mining communities is due to leaching of manganese from waste rocks.

The toxicity of iron is governed by absorption. That is, the more you take in the more you are at risk. The iron is absorbed in the ferrous state by cells of the intestinal mucous. There are many health problems associated with ingestion of high amounts of iron in drinking water, these include: anorexia, oligura, diarrhoea, hypothermia, metabolic acidosis to some extent death.

The toxicity of manganese is also governed by absorption. That is the more you take in the more you are at risk. Manganese is a neurotoxin. High levels of manganese is associated with the following symptoms; tremors, weakness in the legs, staggering gait, behavioural disorders, etc. children exposed to high levels of manganese exhibit low IQs. There is clear evidence from studies of humans exposed to manganese dusts in mines and factories that inhalation of high levels of manganese can lead to a series of serious and ultimately disabling neurological effects in humans. This disease, termed manganism, typically begins with feelings of weakness and lethargy. As the disease progresses, a number of other neurological signs may become manifest. Although not all individuals develop identical signs, the most common are a slow and clumsy gait, speech disturbances, a masklike face and tremors. The neurological symptoms may improve when exposure ceases; however, in most cases, the symptoms are found to persist for many years post-exposure. In addition, a syndrome of psychological disturbances (hallucination, psychosis) frequently emerges, although such symptoms are sometimes absent.

2.2.6. Sources of lead and copper and toxicities of lead and copper

The presence of lead and copper in the study, area is due to weathering and leaching of these two metals from waste rocks dumps (AGC, 2001). Other sources of lead and copper are the weathering of the Birimain and Tarkwanian rocks, which contains high levels of lead and copper. Similarly, improper disposal of lead – acid batteries and copper wire also accounts for high levels of lead and copper in the study area. Copper can be released into the environment by both natural sources and human activities. Examples of natural sources are wind-blown dust, decaying vegetation, forest fires and sea spray. A few examples of human activities that contribute to copper release have already been named. Other examples are mining, metal production, wood production and phosphate fertilizer production.

Because copper is released both naturally and through human activity, it is very widespread in the environment. Copper is often found near mines, industrial settings, landfills and waste disposals.

Most copper compounds will settle and be bound to either water sediment or soil particles. Soluble copper compounds form the largest threat to human health. Usually water-soluble copper compounds occur in the environment after release through application in agriculture.

Lead is a neurotoxin metal. It affects the central nervous system. Children exposed to high levels of lead contaminated water have low IQs. Other symptoms associated with exposure to lead are behavioural disorders, tremors, etc.

Copper can be found in many kinds of food, in drinking water and in air. Because of that, we absorb eminent quantities of copper each day by eating, drinking and breathing. The absorption of copper is necessary, because copper is a trace element that is essential for human health. Although humans can handle proportionally large concentrations of copper, too much copper can still cause eminent health problems.

Copper concentrations in air are usually quite low, so that exposure to copper through breathing is negligible. However, people that live near smelters that process copper ore into metal do experience this kind of exposure. People that live in houses that still have copper plumbing are exposed to higher levels of copper than most people, because copper is released into their drinking water through corrosion of pipes.

Occupational exposure to copper often occurs. In the work place environment, copper contagion can lead to a flu-like condition known as metal fever. This condition will pass after two days and is caused by over sensitivity.

Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomach aches, dizziness, vomiting and diarrhoea. Intentionally high uptakes of copper may cause liver and kidney damage and even death. There are scientific articles that indicate a link between long-term exposure to high concentrations of copper and a decline in intelligence with young adolescents. Whether this should be of concern is a topic for further investigation. Industrial exposure to copper fumes, dusts or mists may result in metal fume fever with atrophic changes in nasal mucous membranes. Chronic copper poisoning results in Wilson’s disease, characterised by a hepatic cirrhosis, brain damage, demyelination, renal disease and copper deposition in the cornea.

CHAPTER THREE

METHODOLOGY

3.0. Sampling technique:

The sampling methods were based on those recommended by the US EPA (citation), but were modified to suit the field situations and available resources. The methods employed maintained the primary features of the EPA methods (USEPA, 1991). The samples investigated in this work were water samples from rivers/streams and alternate source of water provided for affected communities in the study areas. The rivers and streams were selected from the list of 160 streams and rivers in the Obuasi area. Random sampling techniques were adopted to select 41 streams/rivers perceived to be polluted including 6 rivers/streams perceived not to be polluted by residents of the mining communities within the concession of the company. The study also collected water samples from 3 alternate sources of water that have been provided for the various communities. These water bodies were selected using simple random sampling techniques[1]. List of water bodies selected and the communities where it can be found as well as members of the community's perceptions about the quality of the water body for Obuasi area have been shown in Table 1.0 below.

Similarly, random sampling techniques were adopted to select 43 streams/rivers perceived to be polluted in the Tarkwa area as well as 7 alternate water bodies provided for the communities involved. Table 2.0 below shows the list of the selected rivers/streams and other water bodies sampled in the Tarkwa area.

The samples were collected between May and September 2008. In all, 400 samples were collected, that is, 200 samples were collected from Obuasi and 200 from Tarkwa areas. Each sample was analysed separately for the following toxic chemicals; As, Mn, Fe, Pb, Cd, Hg, Cu and Zn. Physico – chemical parameters such as pH, conductivity, turbidity and total

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[1] Random sampling techniques – list of rivers, streams and other water bodies in Obuasi and Tarkwa were written and put into separate boxes. The respective boxes were well shaken, after which the names of rivers, streams and other water bodies in the boxes were drawn without replacement and looking into the respective boxes. The boxes were shaken thoroughly after each draw.

dissolved solids were also measured using standard methods of analysis as prescribed by American Association of Water Works (AWWA, 1998).

Table 1.0 List and state of rivers/streams/ alternative source of water sampled in the Obuasi area.

S/No.	Name of River/Stream	Name of Community	Community Perception about the state of the River/Stream
1.	Nyam	Badukrom and other villages	Polluted
2.	Asuakoo	Suhyenso and other villages	Polluted
3.	Suhyen	Suhyenso and other villages	Polluted
4.	Akotosua	Suhyenso and other villages	Polluted
5.	Abebesua	Suhyenso and other villages	Polluted
6.	Awurabena	Anyinam	Polluted
7.	Roro	Tweapease	Polluted
8.	Amoateng	Adinkra	Polluted
9.	Saah	Sansu	“
10.	Asutia	“	“
11.	Totonyaa	“	“
12..	Afiafi	“	“
13.	Nsuofufuo	Sansu Anwoma	“
14.	Apitiso	Hia, Ntonsua, Apitiso, etc	“
15.	Sonusua	Apitiso	“
16.	Mampo	Nyamebekyere	“
17.	Dadiesua	Mamiriwa I	“
18.	Abomesu		“
19.	Subiri	Brobbeyakuraa, Akwesiadeakuraa, etc	“
20.	Agyenu		“
21.	Fenanan	Mamiriwa I, Mamiriwa II	“
22.	Gyapomaa	Mamiriwa I	“
23.	Dokyiwaa	Dokyiwaa, Binsere	“
24.	Akwesibadusu	Mamiriwa II	“
25.	Bankyeasua	Mamiriwa II	“
26.	Asuafu	Kronko, Nkroapem, etc	“
27.	Jimi	Wamase, Ampuyase, etc	“
28.	Abenaso	Odumasi	“
29.	Danyame	Krodua	“
30.	Kwabrafo	Obuasi	“
31.	Akapori	Odumasi	“
32.	Pompo	Obuasi	“
33.	Borehole at Odumasi	Odumasi	Alternate water supplied

34.	Tap water at Odumasi	Odumasi	“
35.	Broniwaa	“	Polluted
36.	Kaw	“	“
38.	Krodua	Krodua	“
39.	Ayanta	Ankaako, Mile 14, etc	Not Polluted
40.	Anikoko	Mile 14	“
41.	Nankansu	Boete, Diawuoso, etc	“
42.	Kyerabodwese	Sampsonkrom	“
43.	Bowdie	Tweapease	“
44.	Mennam	Apitiso	“
45.	Supu	Dokyiwa, Hia, etc	Polluted
46.	Kobi	Dokyiwa	“
47.	Amenfu	Tweapease	Polluted
48.	Tap water at Obuasi	Obuasi	Alternate water supplied
49.	Akyenawe	Sansu, Nyamebekyere, etc	Polluted
50.	Akyerempe		“

Table 2.0 List and state of rivers/streams/alternate source of water sampled in the Tarkwa area.

S/No.	Name of River/Stream	Name of Community	Community Perception about the state of the River/Stream
1.	Huni	Huniso, Tebe and others	Polluted
2.	Subri	Kwameanimpah, Densu, etc	Polluted
3.	Nana Boat	Koduakrom	Polluted
4.	Asuman	Abekoase, Tebe	Polluted
5.	Borehole	Koduakrom	Alternate water supplied
6.	Well	Koduakrom	“
7.	Nana Panipa	Damang, Sumani	Polluted
8.	Ben	Koduakrom, Kyekyewere, etc	Polluted
9.	Asasre	Himan, Prestea	“
10.	Amenkuman	Prestea	“
11.	Anikoko	Prestea, Himan	“
12..	Apsamadi	Prestea	“
13.	Number two	Prestea	“
14.	Abodweseh	Prestea	“
15.	Achofe	Mile 8, Adisakrom, etc	“
16.	Betinyere	Teberebie, etc	“
17.	Ahomabruen	Mile 8, Adisakrom, etc	“
18.	Ateberebe	Teberebie	“

19.	Aboponi	Aboponiso, Mile 10, etc	“
20.	Awora	Teberebie	“
21.	Apakyii	Tarkwa, Affuanta, etc	“
22.	Peepe	Tarkwa, Atuabo, etc	“
23.	Agonaben	Mile 8, Adisakrom	“
24	Bonsa	Bonsa, Wassa Nkran, etc	“
25.	Aprepre	Dumase, Koloto, etc	“
26.	Wurawura	Dumase	“
27.	Benyan	Dumase	“
28.	Achesua	Dumase	“
29.	Nsuabena	Dumase	“
30.	Donyame	Twiagya	“
31.	Kwakronkron	Twiagya	“
32.	Twiagya	Twiagya	“
33.	Borehole	Twiagya	Alternate water supplied
34.	Borehole	Dumase	“
35.	Nongoro	Twiagya	Polluted
36.	Bodwire	Brakwaline, Anikoko, etc	“
38.	Anikoko	Brakwaline, Anikoko, etc	“
39.	Ankobra	Prestea	Polluted
40.	Bonsawire	Aboso, Nsuaem, etc	“
41.	Dinyame	Himan	“
42.	Bediabewo	Agona, Bonsa No.2, etc	“
43.	Aboyensu	Teberebie	“
44.	Borehole	Abekoase	Alternate water supplied
45.	Aworadofo	Akyempim	Polluted
46.	Adahaso	Akyempim, Subri	“
47.	Ahumabro	Wangrakrom	Polluted
48.	Water supplied in polytank	Dumase	Alternate water supplied
49.	Manse	Kwameanimpah	Polluted
50.	Borehole	Prestea	Alternate water supplied

3.1. Sample collection, preparation and storage:

The water samples were collected from the rivers/streams into plastic bottles that has been pre – washed with detergent and tap water, and later rinsed with 1:1 conc. nitric acid and distilled water. The sampling bottles were rinsed three times with the water samples from the streams/rivers after which 1.5L of the water samples were collected from the following sampling points.

Two samples were collected from each sampling point. One was acidified with 10% nitric acid for the analysis of heavy metals whilst the other was used for the physicochemical analysis. Identification labels were fixed on each water sample collected. The samples stored in an ice – chest 4°C and later conveyed to the laboratory for analysis. In the laboratory, the acidified samples were filtered using Whatman's no. 0.45µm filter paper. The 0.45µm membrane filter paper was used because the analyte of interest in this work is the total dissolved metals. The filtered samples and the unfiltered samples were stored in the refrigerator at 4°C for further analysis (APHA – AWWA, 1998).

3.2.0. Digestion of samples for the analysis of As, Fe, Mn, Cu, Pb, Cd and Zn

One hundred millilitres of the well – acidified water sample was mixed with 5ml conc. HNO_3 and 5ml conc. H_2SO_4. This mixture was then heated until the volume was reduced to about 15 – 20ml. The digested sample was allowed to cool to room temperature. It was then filtered through Whatman's 0.45µm filter paper. The final volume was adjusted to 100ml with double distilled water and stored for analysis (APHA – AWWA, 1998).

3.2.1. Digestion of samples for the analysis of mercury (Hg).

100mL of the water sample was transferred into a 150mL beaker. 5mL of conc. sulphuric acid was added. Additional 2.5mL of conc. nitric acid was also added and mixed thoroughly after each addition. 15mL of 5%w/w potassium permanganate was added to the mixture. The solution was shaken and additional portions of potassium permanganate added until the purple colour persisted for at least 15mins. 8mL of 5% w/w potassium per sulphate was then added and the solution heated for 2hours on a water bath at 95°C. It was cooled and 6mL of 12% w/v hydroxylamine hydrochloride was added to the resulting solution to reduce the excess permanganate. The digested solution was stored for analysis (American Water Works Association, 1998).

3.3.0. Analysis of samples for As, Fe, Cu, Mn, Cd, Pb and Zn

The method for the analysis of the water samples in this work was based on standard methods for analysis of heavy metals adopted by the US Environmental Protection Agency and American Water Works Association. The determination of the heavy metals in the samples was carried out by the Heavy Metals Laboratory of the Water Research Institute (WRI) of Council for Scientific and Industrial Research (CSIR). The concentrations of Fe, Cu, Mn, Cd, Pb and Zn were determined using flame AAS (Atomic Absorption Spectrophotometer) Perkin Elmer model 520 after double distilled water has been used to zero the instrument, the concentrations of Fe, Cu, Cd, Pb, Mn and Zn in the blank were also measured and then followed by the determination of the concentrations of Fe, Cu, Mn, Cd, Pb and Zn in the digested samples. The concentration of arsenic in the water samples were determined using flame AAS Perkin Elmer model 520 coupled with arsine gas generator. In the determination of arsenic concentrations in the water samples, 5ml of 0.5% $NaBH_4$ and 5ml of 0.5M HCl were added to each of the digested sample to reduce all the arsenic in the samples to an arsine gas, in the arsine generator, which was coupled to the flame Perkin Elmer model 520.

3.3.1. Analysis of samples for mercury (Hg)

A double distilled water was first used to zero the instrument, the concentration of mercury in the blank was determined as follows:

- A carrier solution containing 3% v/v HCl and a reducing agent 1.1% m/v $SnCl_2$ in 3%v/v HCl were automatically sucked into a mixing chamber to reduce the mercury in the +2 state to its elemental state as, the concentration of mercury in water samples digested were taken through the same process.
- The mercury vapour generated was directed to the cold vapour cell mounted on the AAS, the mercury concentration in the blank was measured automatically.

3.4.0. Analysis of physico-chemical parameters

The physico-chemical parameters including pH, turbidity, conductivity and total dissolved solids were also determined by the Potable Laboratory section of Water Research Institute of CSIR. The pHs of the samples were determined using Jennway pH meter model 3510, after the meter has been calibrated with pH buffer solutions of 4, 7 and 10.

The turbidity of the samples were also determined using Hach Turbidimeter model 2100P whilst the electrical conductivities and the total dissolved solids of the samples were also determined with Jennway Conductivity meter model 4520.

3.5.0. Recovery and reproducibility studies

To check the sensitivity and efficiency of the method used in the chemical analysis, recovery and reproducibility studies were conducted. In the recovery studies, known concentrations of manganese, cadmium, iron, mercury, arsenic, lead, copper and zinc were determined using the Perkin – Elmer flame AAS and in the case of mercury, the cold vapour Perkin – Elmer AAS was used. Table 2.0 shows the results of arsenic, cadmium, iron, lead, manganese, copper, mercury and zinc in the recovery studies.

Table 3.0 Results of arsenic, cadmium, iron, manganese, copper, mercury, and zinc in the recovery studies.

Concentration mg/l	Amount recovered (mg/l)			Percentage Recovered	Standard Deviation
	1	2	Mean		
0.20	0.19	0.19	0.19	95.0	0.00
0.40	0.41	0.38	0.40	100.0	0.02
0.60	0.58	0.61	0.60	100.0	0.02
0.80	0.81	0.77	0.79	98.8	0.02
1.00	0.98	0.98	0.98	100.0	0.00

From Table 3.0, the percentage of arsenic, cadmium, manganese, iron, lead, copper, mercury and zinc recovered from double distilled water is between 95 to 100% and a standard error of 0.001. It was realized that the method used for the chemical analysis was very efficient.

To check the reproducibility of the method used, reproducibility studies were also conducted. In the reproducibility studies, double distilled water containing 1.0mg/l of arsenic, cadmium, copper, iron, lead, manganese, mercury and zinc solutions respectively were determined using Perkin – Elmer flame and cold vapour AAS model 520. The results obtained have been presented in Table 4.0 below.

Table 4.0 Reproducibility studies of 1.0mg/l solution of arsenic, cadmium, manganese, copper, iron, lead, mercury and zinc in double distilled water.

Replicates	Amount recovered from 1.0 mg/l							
	As	Zn	Cd	Mn	Fe	Hg	Pb	Cu
1	0.974	0.930	0.991	0.992	0.978	1.003	0.930	0.991
2	0.969	0.980	0.995	0.979	0.990	1.000	0.958	0.990
3	1.014	0.960	0.994	0.984	0.992	0.985	0.986	0.985
4	1.010	1.010	0.983	1.002	0.963	0.968	0.975	0.985
5	1.002	0.990	0.976	0.995	0.974	0.988	0.993	0.994
6	0.988	0.960	0.977	0.988	0.990	0.996	0.990	0.993
7	0.991	0.990	0.984	0.974	0.996	0.990	0.978	0.956
8	0.994	1.020	0.990	0.969	0.983	0.995	0.996	0.999
9	0.995	1.030	0.979	0.990	0.974	0.989	0.977	0.998
10	1.021	0.990	0.982	0.981	0.969	0.979	0.969	0.995
Mean	0.996	0.986	0.985	0.985	0.981	0.989	0.975	0.989
Percent recovered	99.6	98.6	98.5	98.5	98.1	98.9	97.5	98.9
Standard deviation	0.017	0.030	0.007	0.010	0.011	0.010	0.019	0.012
Percent coefficient of variation	1.706	3.043	0.711	0.014	1.121	1.011	1.948	1.214
Standard error	0.005	0.009	0.002	0.003	0.003	0.003	0.006	0.004

From Table 4.0, the percentage of the metals recovered in the reproducibility studies varies from 97.5% for lead with a standard error of 0.004 to 99.6% for arsenic also with a standard error of 0.005. The standard error is less than 1, this suggests that the method employed for the chemical determination of arsenic, manganese, iron, cadmium, copper, mercury, lead and zinc is reproducible.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0. Levels of arsenic, manganese, copper, iron, lead, cadmium, mercury and zinc in the water bodies in the Obuasi area

The results of mean levels of arsenic, manganese, copper, iron, lead, cadmium, mercury and zinc in the selected rivers/streams and other water bodies in the Obuasi mining area have been presented in Table 5.0 below.

Table 5.0 Results of mean levels of arsenic, manganese, copper, cadmium, lead, iron, mercury and zinc

Rivers/streams/ Other water bodies	Concentrations in mg/L for Cu, Mn, As, Fe, Cd, Zn and Pb							
	Cu	Mn	Cd	Fe	Pb	As	Hg ppb)	Zn
Nyam	16.34	96.95	53.7	66.9	0.118	13.56	4.21	22.48
Asuakoo	24.00	22.72	17.1	20.51	0.033	3.73	3.32	16.05
Suhyen	41.16	76.05	39.9	40.0	0.038	5.72	4.76	10.92
Akotosua	10.23	10.72	50.1	181.9	0.047	5.21	3.73	31.40
Abebesua	32.89	21.68	52.8	45.6	0.004	4.30	2.52	51.03
Awurabena	83.11	23.06	17.4	68.0	0.048	10.30	11.37	21.73
Roro	63.50	74.20	42.8	86.7	0.021	14.21	10.78	34.15
Twepease	23.63	40.20	35.1	29.7	0.434	11.70	25.30	8.585
Saah	22.35	21.03	0.916	23.6	0.888	7.34	13.10	6.403
Asutia	10.82	5.54	4.13	9.08	0.046	13.62	9.38	0.129
Totonyaa	2.140	2.39	6.62	6.65	1.113	4.63	7.87	1.323
Afiafi	7.978	3.49	4.70	3.69	0.356	12.87	7.56	5.297
Nsuofufuo	5.190	2.91	5.03	3.69	0.535	12.54	14.21	0.001
Apitiso	3.798	1.78	4.43	2.73	0.069	7.56	4.68	0.001
Sonusua	3.070	4.08	6.36	3.53	0.775	12.81	3.52	5.855
Mampo	5.230	8.64	7.75	7.76	0.026	13.82	6.71	4.459

Dadiesua	4.605	4.08	3.33	6.25	2.220	5.56	10.31	3.413
Abomesu	14.05	9.20	8.23	10.07	5.88	6.89	5.72	6.667
Subiri	12.77	13.50	22.58	9.08	2.581	4.35	4.35	6.520
Agyenu	18.96	14.30	22.11	8.72	0.001	9.78	8.78	5.399
Fenanan	0.243	0.111	2.69	0.029	0.226	3.56	3.64	0.007
Gyapomaa	10.70	5.76	9.14	1.142	0.288	4.78	7.83	2.112
Dokyiwaa	3.978	7.38	4.34	3.067	3.055	17.32	5.65	8.648
Akwesibadusu	11.97	13.2	8.39	8.43	0.512	14.65	3.78	10.935
Bankyeasua	6.103	6.40	6.76	8.39	1.124	7.34	4.82	6.673
Asuafu	3.05	5.90	3.32	5.32	0.416	3.89	2.72	1.453
Jimi	21.58	19.3	4.76	8.09	1.05	3.45	0.054	0.260
Abenaso	10.61	3.8	3.73	2.34	3.38	2.92	0.02	0.034
Danyame	11.52	18.7	2.52	13.8	1.73	1.99	0.054	0.107
Kwabrafo	68.69	15.9	11.37	12.7	15.2	34.6	0.02	13.2
Akapori	24.09	39.3	10.78	13.6	2.27	0.692	0.020	0.029
Pompo	83.11	48.1	25.30	0.046	13.3	23.67	0.020	3.345
Borehole at Odumasi	3.07	2.73	3.12	4.36	0.12	0.048	0.020	0.110
Tap water at Odumasi	0.243	7.90	3.81	1.346	0.044	0.025	0.054	0.025
Broniwaa	1.56	23.8	7.87	9.02	0.805	0.33	0.02	0.045
Kaw	5.96	9.89	7.56	10.2	2.47	2.20	0.02	0.005
Krodua	6.17	4.576	14.21	7.45	2.91	2.46	0.02	0.005
Ayanta	1.057	5.76	4.68	4.78	1.62	0.068	0.013	0.078
Anikoko	2.25	9.89	3.52	8.98	0.673	0.019	0.023	0.005
Nankansu	0.24	4.576	6.71	1.56	0.916	0.260	0.005	0.004
Kyerabodwese	0.043	5.76	10.31	0.014	0.713	0.674	0.014	0.089
Bowdie	0.002	4.63	5.72	3.34	1.244	0.112	0.045	0.062
Mennam	0.002	2.56	4.35	2.67	0.163	0.36	0.064	0.020
Supu	3.05	5.76	8.78	1.80	2.27	4.32	0.894	0.028
Kobi	1.56	12.7	3.64	1.67	1.62	1.65	0.061	0.012

Amenfu	3.07	6.45	7.83	1.50	0.068	0.805	0.692	0.33
Tap water at Obuasi	0.043	0.081	0.045	0.48	0.021	0.005	0.001	0.005
Akyenawe	5.28	23.7	3.78	4.82	2.47	1.26	0.028	0.765
Akyerempe	4.605	21.8	4.82	1.43	0.059	2.91	0.982	3.762

From Table 5.0, the mean concentration of copper in the water samples ranges from 0.002 mg/l to 83.11mg/l. The standard deviation ranges from 0.000 to 3.626. The high levels of copper in the water bodies could be attributed to occasional accidental cyanide spillages as well as leaching of toxic metals from waste rocks, which are dumped very close to some of these water bodies.

High levels of copper in the water bodies would pose significant health hazards to residents of Obuasi and its surrounding areas. Residents in the study area are likely to exhibit symptoms associated with copper intoxication including irritation of the nose, mouth and eyes and it causes headaches, stomach aches, dizziness, vomiting and diarrhoea. High uptakes of copper may cause liver and kidney damage and even death. There are scientific articles that indicate a link between long-term exposure to high concentrations of copper and a decline in intelligence with young adolescents (ATSDR, 2001).

High levels of arsenic, iron, lead, cadmium, mercury and zinc were recorded in water samples in the study area, which pose significant health hazard to them. For example, exposure to high levels of iron in drinking water can result in iron storage disease where the liver becomes cirrhotic. Hepatoma, the primary cancer of the liver has become the most common death among patients with hemochromatosis.

A comparison of the heavy metal concentration in water samples from the study area with background values from Ghana Environmental Protection Agency (GEPA) permissible guideline values and the World Health Organisation (WHO) values also presented in Table 5.0 revealed that most of the parameters analysed in this study were above the recommended values.

Table 6.0 Permissible background heavy metals concentrations, pH, turbidity, electrical conductivity and total dissolved solids in water bodies.

Parameter	GEPA	WHO	USEPA
Manganese (mg/l)	-	0.4	0.05
Lead (mg/l)	0.1	0.01	0.015
Copper (mg/l)	-	2.0	1.0
Arsenic (mg/l)	1.0	0.01	0.01
Zinc (mg/l)	10	3.0	5.0
Mercury (ppb)	0.2	0.01	0.001
Iron (mg/l)	-	0.3	0.3
Cadmium (mg/l)	-	0.003	0.005
pH	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5
Turbidity (NTU)	5	5	-
Electrical Conductivity (µS/cm)	-	-	500
Colour	15	15	-
Total dissolved solids (mg/l)	1000	1000	-

Comparing the results obtained in this study with the permissible levels of heavy metals in drinking water as set by GEPA and WHO, it is clear that, the concentrations of arsenic, iron, manganese, lead, copper, zinc, cadmium and mercury in the most the water samples exceeded both GEPA and WHO recommended values. For example, arsenic concentration in the River Nyam is 1,356 times higher than the WHO value and 13.56 times higher than GEPA value.

A comparison of levels of arsenic, cadmium, mercury, copper, lead, manganese, iron and zinc with GEPA and WHO permissible guidelines values show that concentrations of arsenic, mercury, lead, manganese, copper, cadmium, zinc and iron are higher than GEPA and WHO values.

The USEPA has classified inorganic arsenic as a class ‘A’ human carcinogen. This classification is based on evidence from animal and epidemiological studies, which suggest that exposure to arsenic, causes cancer. Franblau and Lillis (1989) reported two cases of sub-chronic arsenic intoxication resulting from ingestion of contaminated well water, sporadically (once or twice a week) for about 2 months. Acute gastrointestinal symptoms, central and peripheral neuropathy, bone marrow depression, hepatic toxicity, skin pigmentation occurred when the calculated dose was between 0.03 and 0.08 mg/kg/day based on a body weight of 65 kg and ingestion of arsenic from 238 ml to 475 ml water/day. Comparing the calculated arsenic dose ingested in the Franblau and Lillis (1989) study to the calculated arsenic concentration obtained in this study, which residents in Odumasi, Obuasi and its surrounding areas ingest daily from drinking streams/rivers (they perceived not be polluted), borehole and tap water (alternate drinking water provided for them), it was found out that the calculated arsenic concentration in water bodies in the study area is higher than the estimated arsenic dose used in Franblau and Lillis (1989) study. Hence, symptoms associated with arsenic intoxication would be higher for residents in the study area.

Similar reasoning can be applied to other toxic chemicals measured in this study. For example, cadmium concentrations in rivers Anikoko, Ayanta, Nankansu, Kyerabodwese, Bowdie and Mennam are highly contaminated with cadmium ions, which are above WHO acceptable limits. Cadmium has been shown to be toxic to human populations from ingested food and drinking water. Ingestion of elevated levels of cadmium results in kidney and skeletal system toxicity, increased hypertension and cardiovascular diseases.

Most mining communities attribute a variety of health problems prevalent in their environment to mining activities. At Obuasi, medical officers at the Bryant Mission and Obuasi Government medical facilities acknowledged that some of the diseases prevalent in communities in the periphery of the mine are in part attributable to mining. A recent investigative report issued by CHRAJ into activities of mining operations in mining communities reveals that, some of the commonest diseases reported to health facilities are skin diseases, chest diseases including TB, diarrhoea and malaria, as well as typhoid. Communities located very close to centres of mining activities like Anyinam claim air pollution makes them experience dizziness and headache (CHRAJ, 2008).

The above diseases are similar to symptoms associated with exposure to elevated levels of cadmium, arsenic, copper, zinc, manganese, iron, lead and mercury in drinking water. Hence, there seems to be a positive correlation between exposure to elevated levels of toxic chemicals in drinking water and symptoms of diseases attributed to mining operations. However, this assertion has not been examined scientifically.

This suggests heavy pollution of As, Hg, Cu, Fe, Pb, Mn, Zn and CD metals in water bodies in the study area. This poses significant health hazard to residents in the study area who use water from the water bodies.

4.1. Results of physic-chemical parameters

The results of the physico-chemical parameters of the water bodies in the study area have been presented in Table 7.0 below.

Table 7.0 Mean results of pH, conductivity, turbidity and total dissolved solids in the water bodies.

Rivers/streams/other water bodies	pH	Conductivity	Turbidity	Total Dissolved Solids
Nyam	7.20	124	31	124
Asuakoo	6.27	31.2	34	17.2
Suhyen	5.74	98.0	6.0	53.9
Akotosua	5.56	32.5	18	17.9
Abebesua	6.90	105	20	57.8
Awurabena	7.37	105	20	629
Roro	6.33	34.3	41	18.9
Twepease	7.03	542	23	298
Saah	6.93	68.9	12	6.6
Asutia	6.80	51.9	36	29.5
Totonyaa	5.75	33.1	11	18.2
Afiafi	6.58	100	24	55.0
Nsuofufuo	5.91	191	97	105
Apitiso	6.50	73.7	8	40.5
Sonusua	6.87	105	14	57.8
Mampo	7.07	411	13	226
Dadiesua	6.62	62.1	29	34.2
Abomesu	7.08	318	10	175
Subiri	6.58	58.8	30	323
Agyenu	6.52	52.1	35	287
Fenanan	7.20	124	31	124
Gyapomaa	6.27	31.2	34	17.2
Dokyiwaa	5.74	98.0	6.0	53.9
Akwesibadusu	5.56	32.5	18	17.9
Bankyeasua	6.90	105	20	57.8
Asuafu	7.37	105	20	629
Jimi	6.33	34.3	41	18.9
Abenaso	7.03	542	23	298
Danyame	6.93	68.9	12	6.6
Kwabrafo	4.80	51.9	36	29.5
Akapori	5.75	33.1	11	18.2
Pompo	4.58	100	24	55.0
Borehole at Odumasi	5.91	191	19	105
Tap water at Odumasi	6.50	73.7	10	40.5

Broniwaa	6.87	105	14	57.8
Kaw	7.07	411	13	226
Krodua	6.62	62.1	29	34.2
Ayanta	7.08	318	10	29.5
Anikoko	6.58	58.8	30	18.2
Nankansu	6.52	52.1	35	55.0
Kyerabodwese	6.50	34.3	97	105
Bowdie	6.87	542	34	40.5
Mennam	7.07	68.9	30	57.8
Supu	6.62	51.9	35	226
Kobi	7.08	33.1	97	34.2
Amenfu	6.58	100	34	567
Tap water at Obuasi	6.98	191	4	175
Akyenawe	6.33	73.7	97	676
Akyerempe	6.20	105	34	654

From Table 7.0, the pH of the water samples ranges from 4.58 to 7.37, the conductivity of the samples were also between 31.2 to 411µS/cm, the turbidity also ranges from 4.0 to 97 NTU and the amount of total dissolved solids in the water samples were between 17.2 to 105 mg/l.

It can be seen from Table 6.0 that, water samples from rivers Akyerempe, Akyenawe, Suhyen, Akotosua, Totonyaa, Nsuofufuo, Dokyiwaa, Akwesibediasu, Jimi, Kwabrafo, Akapori and Pompo as well as the borehole at Odumasi recorded low pHs (i.e., pHs in the acidic region). Comparing the pH of water from these water bodies with GEPA and WHO permissible values indicates that, these water bodies are not fit for human consumption.

In the same vein, the turbidity of all the water bodies sampled in this study except tap water from Obuasi township were above GEPA and WHO recommended guideline value of 5 NTU. This is an indication of some level of pollution, which means that these water bodies cannot be used for drinking. However, total dissolved solids in the water bodies sampled in this study were below WHO and GEPA guideline value of 1000mg/l.

4.2. Mean levels of As, Cd, Fe, Hg, Mn, Cu, Pb and Zn in water bodies in Tarkwa area

The results of mean levels of As, Cd, Fe, Hg, Mn, Cu, Pb and Zn in water bodies in Tarkwa area have been presented in table 8.0 below.

Table 8.0 Results of mean levels of arsenic, manganese, copper, cadmium, lead, iron, mercury and zinc

Rivers/streams/ Other water bodies	Concentrations in mg/L for Cu, Mn, As, Fe, Cd, Zn and Pb							
	Cu	Mn	Cd	Fe	Pb	As	Hg (ppb)	Zn
Huni	0.605	1.513	0.007	8.43	0.669	2.451	0.402	0.448
Subri	0.857	0.125	0.017	8.39	0.045	1.689	0.415	0.124
Nana Boat	<0.002	1.057	<0.002	5.32	0.250	1.754	0.618	0.040
Asuman	0.987	0.175	0.018	8.09	0.011	3.332	1.523	0.389
Borehole – Koduakrom	0.330	1.057	0.018	2.34	0.001	0.752	0.305	0.389
Well – Koduakrom	0.389	0.620	0.011	13.8	0.067	0.426	0.210	0.154
Nana Panipa	2.031	0.086	0.007	12.7	2.603	2.896	1.723	0.123
Ben	2.051	0.126	0.006	13.6	0.009	1.523	0.303	0.354
Asasre	0.220	0.356	0.013	24.60	0.008	1.345	0.287	0.140
Amenkuma	0.162	0.323	0.018	34.36	0.001	1.041	0.452	0.118
Anikoko	1.026	0.084	0.012	1.346	0.069	3.464	0.305	0.154
Apsamadi	0.020	0.425	0.012	9.02	0.775	3.412	0.285	0.494
Number two	<0.002	0.157	0.157	10.2	0.026	2.956	0.312	0.051
Abodweseh	1.246	0.490	0.113	7.45	2.220	1.569	0.212	0.432
Achofe	1.023	0.279	0.028	4.78	5.88	2.856	0.353	0.186
Betinyere	1.765	0.425	<0.002	8.98	2.581	3.697	0.425	0.102
Ahomabruen	1.365	0.569	<0.002	1.56	0.001	2.106	0.405	0.239
Ateberebe	2.451	0.031	<0.002	14.3	0.226	2.698	0.381	0.083
Aboponi	0.657	0.052	0.019	3.34	0.288	6.879	0.376	0.105
Awora	0.548	0.032	0.003	2.67	3.055	2.125	0.328	0.135
Apakyii	0.469	0.063	0.006	1.80	0.512	1.563	0.693	0.300
Peepe	0.789	0.041	0.010	1.67	1.124	1.236	0.367	0.321
Agonaben	0.985	0.063	0.010	4.50	0.416	6.451	0.045	0.134
Bonsa	1.652	<0.002	<0.002	5.03	0.005	4.126	0.146	0.157
Aprepre	1.984	0.276	<0.002	4.82	1.250	1.235	1.371	0.188
Wurawura	1.365	0.235	<0.002	5.43	0.530	1.572	0.054	0.110
Benyan	1.015	0.109	0.003	4.70	1.110	5.298	0.026	0.785
Achesua	4.358	0.027	0.200	4.08	0.030	0.935	<0.020	<0.005
Nsuabena	3.256	0.112	1.170	8.591	0.285	1.95	<0.020	<0.005

Donyame	0.995	0.268	0.860	1.46	0.120	2.65	0.082	0.333
Kwakronkron	1.025	0.028	1.130	2.84	0.445	2.18	0.025	0.008
Twiagya	4.563	2.98	0.560	14.5	0.003	4.30	<0.020	0.014
Borehole – Dumase	0.048	0.032	0.005	13.2	0.105	1.89	<0.020	0.012
Borehole - Twiagya	<0.020	0.127	0.025	12.4	0.267	0.259	<0.020	0.457
Nongoro	<0.020	0.318	0.005	23.5	0.978	1.07	<0.020	1.453
Bodwire	0.220	0.958	0.014	2.04	0.035	9.22	<0.020	0.260
Anikoko	<0.020	0.283	0.045	4.75	0.105	0.605	0.054	0.034
Ankobra	<0.020	0.943	0.064	49.2	0.786	0.832	1.731	0.107
Bonsawire	<0.020	0.062	0.894	3.66	0.052	23.2	0.146	1.321
Dinyame	0.057	0.224	0.061	8.672	0.188	19.2	0.045	0.029
Bediabewo	<0.020	0.046	0.692	3.08	0.043	3.02	0.381	3.345
Aboyensu	<0.020	0.140	0.001	5.90	0.600	0.436	1.342	0.110
Borehole – Abekoase	<0.020	0.107	0.028	4.24	0.070	0.137	<0.020	0.025
Aworadofo	<0.020	0.043	0.982	9.935	0.040	9.15	0.254	0.045
Adahaso	<0.020	0.600	0.007	1.95	0.345	12.5	0.330	<0.005
Ahumabro	<0.020	0.070	0.125	2.65	0.129	25.9	0.019	<0.005
Water supplied in polytank at Dumase	<0.020	0.040	0.006	2.18	0.092	2.44	<0.020	0.078
Manse	<0.020	0.345	0.067	4.30	0.051	2.634	0.367	<0.005
Borehole – Prestea	<0.020	0.129	0.045	1.89	0.031	4.343	3.675	0.897

From Table 8.0, it can be seen that the mean concentration of arsenic in the water samples ranges from 0.259 – 25.2 mg/l with a standard deviation of 0.021 to 1.256, whereas the mean concentration of iron also ranged from 1.346 to 34.60 mg/l. High concentration of iron and arsenic in the water bodies in Tarkwa area is due to leaching of arsenic and iron from waste rocks and uncontrolled cyanide spillages in the area.

Comparing the levels of As, Cd, Cu, Zn, Hg, Mn, Pb and Fe in Table 8.0 with Table 6.0, it is clear that the levels of arsenic, cadmium, lead, iron, mercury, copper, zinc and manganese in most of the water sampled in the Tarkwa area were found to exceed GEPA and WHO permissible guidelines. This poses serious health problems for residents in the Tarkwa area whose streams and rivers have been polluted from prolonged mining operations. In some cases, alternate water provided for residents of Dumase, Twigyaa, Prestea and Abekoase have high levels of iron, arsenic and manganese in the boreholes drilled for the aforementioned communities.

Comparing the levels of heavy metals in water bodies in Obuasi area to that of Tarkwa area, it can be seen that the levels of As, Mn, Cu, Cd, Pb, Zn, Fe and Hg in the water bodies in Obuasi area were generally higher than that of Tarkwa area. This calls for a concerted effort by all stakeholders to ensure that these communities are provided with clean and potable water.

The results of the study revealed that level of heavy metals in the alternate provided for some the communities such as Abekoase, Dumase, Twiagya, Koduakrom, Odumasi and Obuasi have high levels of iron and manganese. It can also be observed that alternate water provided for Odumasi and Obuasi in the Obuasi areas have high levels of cadmium, lead and manganese than Abekoase, Dumase, Twigyaa, Prestea and Koduakrom as shown in fig. 7.0 below

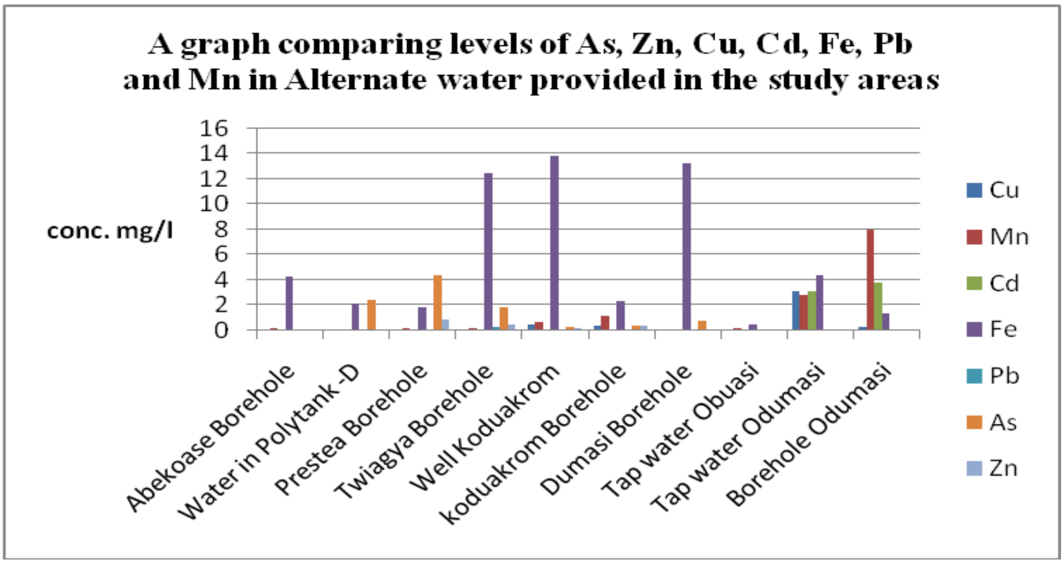

Fig. 7.0 A graph comparing the levels of heavy metals in the alternate water provided some communities in the study areas.

4.3. Results of physicochemical parameters

The mean results of pH, conductivity, turbidity and total dissolved solids of water samples collected from the Tarkwa area has been presented in Table 9.0 below.

Table 9.0 Mean results of pH, conductivity, turbidity and total dissolved solids of the water samples in Tarkwa area

Rivers/streams/other water bodies	pH	Conductivity	Turbidity	Total Dissolved Solids
Huni	7.20	124	31	124
Subri	6.27	31.2	34	17.2
Nana Boat	5.74	98.0	6.0	53.9
Asuman	5.56	32.5	18	17.9
Borehole – Koduakrom	6.90	105	20	57.8
Well – Koduakrom	7.37	105	20	629
Nana Panipa	6.33	34.3	41	18.9
Ben	7.03	542	23	298
Asasre	6.93	68.9	12	6.6
Amenkuma	6.80	51.9	36	29.5

Anikoko	5.75	33.1	11	18.2
Apsamadi	6.58	100	24	55.0
Number two	5.91	191	97	105
Abodweseh	6.50	73.7	8	40.5
Achofe	6.87	105	14	57.8
Betinyere	7.07	411	13	226
Ahomabruen	6.62	62.1	29	34.2
Ateberebe	7.08	318	10	175
Aboponi	6.58	58.8	30	323
Awora	6.52	52.1	35	287
Apakyii	4.63	124	31	124
Peepe	6.27	31.2	34	17.2
Agonaben	5.74	98.0	6.0	53.9
Bonsa	5.56	32.5	18	17.9
Aprepre	6.90	105	20	57.8
Wurawura	7.37	105	20	629
Benyan	6.33	34.3	41	18.9
Achesua	7.03	542	23	298
Nsuabena	6.93	68.9	12	6.6
Donyame	4.80	51.9	36	29.5
Kwakronkron	5.75	33.1	11	18.2
Twiagya	4.58	100	24	55.0
Borehole – Dumase	5.91	191	19	105
Borehole - Twiagya	6.50	73.7	10	40.5
Nongoro	6.87	105	14	57.8
Bodwire	7.07	411	13	226
Anikoko	6.62	62.1	29	34.2
Ankobra	7.08	318	10	29.5
Bonsawire	6.58	58.8	30	18.2
Dinyame	6.52	52.1	35	55.0
Bediabewo	6.50	34.3	97	105
Aboyensu	5.56	542	34	40.5
Borehole – Abekoase	7.07	68.9	30	57.8
Aworadofo	6.62	51.9	35	226
Adahaso	7.08	33.1	97	34.2
Ahumabro	6.58	100	34	567
Water supplied in polytank at Dumase	6.98	191	4	175
Manse	6.33	73.7	97	676
Borehole – Prestea	6.20	105	34	654

From Table 9.0, it can been seen that the pH of the following water bodies in the Tarkwa area were found to be below GEPA and WHO recommended pH for drinking water value of 6.5 – 8.5, they are; rivers Subri, Nanaboat, Asuman, Anikoko, Number two, Aboponi, Apakyii, Peepe, Agonaben, Bonsa, Donyame, Kwakronkron, Twiagya, Aboyensu, Manse and Banyan.

The results of the pH measurement also revealed that the pH of water samples from boreholes in Dumase and Prestea have very low pHs. This suggests that water from the boreholes in Dumase and Prestea are not suitable for human consumption. This poses serious health challenges for residents in Dumase and Prestea. This is because most of the streams in the two communities have been polluted as a result of mining operations of mining companies and artisanal mining.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0. Conclusion

Water is life. Water is wealth. Water is health. Water plays significant role in the day to day activities of humankind. This is because blood plasma is made up of 90% water. Water transport dissolved nutrients as well as toxic materials to various organs of the body. It is in this regard that this study was conducted to determine the levels of heavy metals in water bodies in the study, which serve as source of drinking to residents in the study area.

The study is a follow up of a baseline survey, which was undertaken by WACAM. The study listed 160 streams/rivers in the Obuasi area and 117 streams/rivers in the Tarkwa area. Out of the 160 rivers/streams listed in the Obuasi area, 6 of the streams/rivers were perceived by residents of the mining communities in that area as not polluted. The remaining 154 rivers/streams were perceived to be polluted. Residents in the study based their assertion on the use of their sense of taste, smell and colour and in some cases sign post placed against certain river/streams in the study area cautioning them not to swim, fish or drink those water bodies. However, all the 117 streams/rivers listed in the Tarkwa were perceived to be polluted by residents in Tarkwa area.

There was therefore the need for an independent scientific investigation to ascertain the levels of pollution or otherwise of the water bodies in the study area. It was against this background that this was undertaken.

This study aims among other things to:

- Determine the levels of heavy metals in streams and rivers in the Obuasi and Tarkwa mining areas.
- Determine the levels of heavy metals in alternate source of drinking that has been provided for communities whose source of drinking have been impacted upon negatively by mining activities in the study areas.
- Compare the levels of heavy metals in streams and rivers within the concession of the company with permissible levels of GEPA (Ghana Environmental Protection Agency), USEPA (US Environmental Protection Agency) and WHO (World Health Organisation).

The results of the study show that most water bodies in the study areas are polluted. The mean level of arsenic ranges from 0.005 to 35.4mg/l. In some cases, the levels of arsenic recorded in some of the water bodies in Obuasi area perceived not to be polluted were extremely very high. This is attributed to the presence of large amounts of arsenic in the environment due to the operations of the then PTP plant as well as blasting and haulage of arsenopyrite ores. Arsenic is carcinogenic hence large amounts of arsenic is likely to cause cancer related cases.

Manganese, lead and mercury are neurotoxic metals. Hence, exposure to high levels of these neurotoxins in drinking poses significant health hazard to residents. It affects the intelligence quotient of children. Hence, resident children in the study area are likely to perform poorly in academic exercises as a result of exposure to high levels of neurotoxins in their drinking water.

It was noted that the pH, conductivity, turbidity and the mean levels of the heavy metals in the alternate water provided for some affected communities are above GEPA and WHO guideline limits. This raises serious concern about the quality of drinking water being offered to residents in the study area. It is important for residents in the study area to be provided with potable water.

The average life expectancy figures for Ghanaian males and females are 55.4 years and 57.6 years respectively. Average life expectancy is the number of years a Ghanaian child can live. Exposure to elevated levels of heavy metals and low pH of some water samples in the study area would further decrease the life expectancy figures for residents in the study areas (GLSS, 2003).

5.1. Recommendations

From the results of this study, it is recommended that;

- There should be regular follow-up studies to measure the levels of heavy metals and other toxic chemicals in water bodies in the study areas. This is necessary to further substantiate this study, document improvements and degradation, etc.
- Since mercury, arsenic, cadmium, manganese, iron, lead and zinc dusts are carried in the air, a study should be conducted to determine levels of these chemicals in the air in the study areas.

- A similar study can be conducted in different regions or mining communities to assess the health impacts of toxic chemicals used by the mining companies and those used by the galamsey operators.
- The body fluids and other tissues such as finger nails, hairs, etc of the miners and the inhabitants should be sampled for mercury, arsenic, cyanide, cadmium and zinc to determine the body's burden of these toxic chemicals.
- A collaborative research should be conducted by the Department of Science Education, Primary Education Department (University of Education Winneba), Nugouchi Memorial Institute for Medical Research and Centre for Environmental Impact Analysis to sample body fluids of school children in basic schools and the samples analysed for the presence of toxic chemicals such as lead, mercury, etc, which affects the pupils' intelligence quotient.
- Fishes and other food crops sold in the market should be sampled and analysed for the presence of toxic chemicals, the health risk of such toxic chemicals should also be determined.
- Crops grown on mine reclaimed land should be analyzed for the above COC's and their human health risk also evaluated.
- A study should be conducted to determine the concentrations and speciation of the COC's in the study areas including the characterisation of the health risk associated with each form of the COC's in the study areas. For example, methylmercury, arylmercury, etc are more toxic than their corresponding inorganic mercury.
- A similar study should be conducted to determine the levels of persisted organic pollutants (POPs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in the study area as most of the mining activities in the study area require the use of machines that runs on fossil fuel.
- It is important for all stakeholders to supply polluted free drinking water to residents in the study area, since most of the source of drinking water has been impacted upon negatively.
- Mining companies, Government, Minerals Commission, Water Resources Commission, Ghana Water Company Limited and the District Assemblies should adopt method or technology that removes high levels of toxic chemicals from the

water bodies in the study area. This should be taken seriously in the light of global climate change, which the 4th IPCC (Intergovernmental Panel on Climate Change) report states that Ghana will experience water stress by the year 2015.

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