KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF ENGINEERING

DEPARTMENT OF MATERIALS ENGINEERING

An Assessment of the Water Quality Status of the Lake Amponsah in the Bibiani-Anhwiaso-Bekwai District, Ghana

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Ernest Kumi-Aboagye

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CHAPTER ONE

INTRODUCTION

1.1 Background

Water is a very important natural resource that is harnessed by society for several unsubstitutable purposes. It is used fundamentally for purposes including domestic (drinking, cooking and sanitation), industrial (manufacturing, agriculture, transportation and recreation) as well as the ecosystem sustainability on which all living organisms depend (UNESCO, 2005). Different levels of quality are required for water to meet these demands. Global water is not evenly distributed. There has been evidence of acute water shortage in some areas resulting in the occurrence of health-related disorders and in some cases loss of life. On the contrary, other areas may experience abundance of water and in extreme cases, flooding ensues. These situations have anthropogenic undertones. In spite of these benefits offered by water, humans continuously contaminate water bodies by excessive abstraction, changing the landcover, using the resource as convenient sinks for the indiscriminate disposal of domestic, industrial and agricultural waste thereby liberating pollutants.

The long-term environmental well being of a reservoir may depend on the types and volumes of economic activities which take place in the catchment of the reservoir. For example, pollutants may be from agricultural land and forest runoff loaded with excesses of applied herbicides, fungicides and pesticides and overused fertilizers or manure; nitrogen and phosphorus percolation; storm-water drainage from lawns, parking lots and streets; radioactive dust and acid deposition. Maponga and Ngorima (2003) report that the overreliance on water by humans results in accelerated evaporation of surface water, drainage of wetlands, erosion and the siltation of rivers and reservoirs. Small-scale mining activity can change the landscape (Chidumayo, 1997).

Another example of the anthropogenic disturbances is mining most of which, in Ghana are of the small-scale kind. Small-scale mining, in Ghana is defined to include both the exploitation of mineral deposits using fairly rudimentary implements and/or at low levels of production with minimal capital investment. Makoni *et al.* (2004) showed a strong link in water resource use, economic activity (especially rain fed farming) and resource exploitation. According to the World Bank Group, small-scale mining is largely a poverty-driven activity, typically practiced in the poorest and most remote rural areas of a country by a largely itinerant, poorly educated populace with few employment alternatives (Aryee *et al.,* 2002).

Small-scale resource exploitation can have effect on water resources by changing the land use locally as well as landscape. Four key areas of impact that mining may have on water systems are: release of metals, acid mine drainage (AMD), siltation and water use. Ashton *et al.* (2001) observed that small-scale miners put up unplanned mining compounds sited close to water courses, with attendant poor sanitary facilities, resulting in considerable pollution from human waste. Some small-scale miners use cyanide and mercury in their gold concentration and amalgamation. The mercury-based amalgamation process, with catastrophic results for the environment and human health, is the preferred gold recovery method employed by almost all small-scale gold miners because it is a very simple, inexpensive and an easier - to - use technique. The mercury released into the atmosphere in the form of vapour or enters aquatic systems.

Small-scale mining is commonly associated with informal, unregulated, under-capitalized and under-equipped mining operations, where technical and management skills are lacking. The technology used by small-scale miners in many developing countries has hardly changed over centuries and may be characterized by wastage of non-renewable resources and also impact negatively on human and environmental health. Many small-scale miners extract gold using primitive techniques. Gold in the ore sludge is mixed with mercury into an amalgam, which is then separated by heating into mercury vapour and gold. An estimated two grams of mercury are released into the environment for each gram of gold recovered. The extensive use of mercury in gold extraction has become a source of anxiety and worry and mass extinction of some biological species including both plants and animals (Amegbey *et al.*, 1997).

In Ghana, the main environmental problems associated with pollution of water bodies in towns are citing of small-scale industries mainly garages, extraction industries (e.g. gold, palm oil, and palm kernel oil) and waste dumps. In the case of artisanal gold mining the environmental problems include Hg pollution (Amegbey *et. al*., 1997; Hilson, 2002). Improper use and handling of mercury can also lead to potential health hazards to miners and others who may be exposed to the metal through the food chain (Lacerda and Salomons, 1998). In the vicinity of Lake Amponsah in the Bibiani are some human activities including small-scale mining and palm kernel oil extraction and deposition of domestic waste. This leads to indiscriminate discharge of effluents into the lake, perhaps due to lack of understanding of the effects of such actions. The lake is used for domestic water purposes as well as a source of supply of fish. Apparently, these activities in the lake vicinity exert a profound influence on the quality of the lake resources.

1.2 Problem Statement and Justification

The overall impacts of small-scale industries on water bodies are severe, but until recently they have not been subjected to thorough scientific investigation. Some small-scale industries' operations occur close to, and are supported by Lake Amponsah.

Plate 1.1 A section of Lake Amponsah in Bibiani
Source: Field Survey (2011)

The lake (Plate 1.1) is used by the industries for all their activities. Effluents from the activities of small-scale industries are discharged into the lake indiscriminately. This practice poses a serious threat to the health of the lake ecosystem and that of the communities that depend on the lake for domestic and economic activities. The exact water quality status of the lake and the aquatic environmental awareness gap between sound practices and the communities' understanding with respect to the dangers posed by their activities to human and environmental health is uncertain.

Generally, anthropogenic activities around Lake Amponsah are rampant. The continuous degradation of the lake is believed by some members of the community to have resulted in drastic reduction of aquatic organisms and siltation of the lake and its associated reduction in storage capacity making some areas of communities around the lake prone to flooding. Anthropogenic activities including setting up of small-scale industries around the lake and citing of a refuse dump site at the input point of the lake are perceived to be responsible for this situation. This can lead to water scarcity or water stress within the community, a sure precursor of conflict among neighbouring communities.

The impact of anthropogenic activities on the lake water quality has either been ignored or not thoroughly examined. Unfortunately, majority of the populace, particularly those engaged in these activities are, perhaps, unaware of the dangers posed by their activities.

It is therefore important to conduct a scientific study on the water quality of the lake for the necessary remedial action to be taken to avert any possible human health deterioration and subsequent death of the lake.

1.3 Aim and Objectives of the Study

The main objective of the study was to determine the water quality status of the Lake Amponsah.

The specific objectives of the study were:

1. To assess the quality of the water of Lake Amponsah for domestic purposes.
2. To assess the quality of the water of Lake Amponsah for aquatic life.
3. To assess the level of understanding of the communities along Lake Amponsah on the causes and effects of water quality deterioration.

CHAPTER TWO

LITERATURE REVIEW

2.1.1 Importance of water

Water, one of nature's most important gifts to mankind is essential for biological (including the health of living organisms and the environment) and economic activities. Water is used for domestic, industrial and environmental sustainability. It is important to the mechanics of the human body flushing out toxins, keeping the organs hydrated, preventing fatigue and boosting energy as well as helping a host of other disorders. In fact, all the cell and organ functions that make up the entire anatomy and physiology of living organisms depend on water for their functioning. It forms a drought management system within the bodies of living organisms. Water makes up more than two thirds of human body weight. Dirmeyer and Brubaker (2006) noted that the human brain is made up of 95% water, blood is 82% and lungs 90% and a mere 2% drop in our body's water supply can trigger signs of dehydration: fuzzy short-term memory, trouble with basic math, and difficulty focusing on smaller print, such as a computer screen. Mild dehydration is also one of the most common causes of daytime fatigue. Water also plays a key role in the prevention of disease.

Although water might be everywhere, one must never take it for granted. The issue of water, in the context of availability, remains a global concern. Since water is of such tremendous importance in the physiology and anatomy of living things and also sustainability of the environment, it would be very necessary that the quality of water be just as important as the quantity (Hallock, 2001).

Environmental water needs that describes the level of the minimum incoming and outgoing flows to be maintained in the water system so as to preserve minimum water quality is also an issue of great concern. Deterioration of the environment and pollution of water resources by anthropogenic activities, with varying extents depending on the locality is of greater global importance. The principal threats weighing on the environment may be as follows (Cude, 2001);

- Abusive uptake of surface water cuts down on downstream flow from watering places (reduced water quantities, modification of the physical conditions of riverbeds), while uptake from water tables impacts the tables themselves, and on resurgence.

i. The release of industrial and household wastewater either partially or completely untreated, the filtration of pesticides and residue of fertilizers, as well as navigation are often factors affecting the quality of water.

ii. Poorly adopted agricultural practices and clearing in watersheds all accelerate the speed of water and charge it with solids that increases the intensity of floods and reduce the water storage capacity in dams.

iii. The many sources of pollution by agriculture owing to the uncontrolled use of chemical fertilizer and phytosanitary product affect the flow of gullies and on underground tables. The long-term effects thereof can be extremely detrimental.

iv. The overexploitation of natural resources (non-irrigated agriculture in certain regions, the lack of planning for land use, the depletion of nutrients, demographic growth), the loss of marshlands and forest, and the proliferation of illnesses carried by water (irrigated areas).

v. The change and variability in the climate: exacerbation of floods and droughts (poverty, displacement of populations). However, cyclical droughts in the region, along with the advance of desertification and the chronic scarcity of water resulting from weakens even more insufficiently irrigated land, with low yield performance.

vi. The onslaught in waterways of sedimentation and aquatic plants, the proliferation of aquatic plants is an indicator of the modification in the natural equilibrium of waterways, in some regions entailing a reduction in the intensity of light penetrating into the water and modification in the physical and chemical quality of the water that causes the disappearance of certain fish species and the appearance of new ones.

- Sustainable development requires an increase in water availability to meet the various socio-economic needs while fighting pollution and wastage. Again there should be filling of the ever-increasing gap between limited water resources and rising demand – a consequence of development in various economic sectors, therefore constitutes one of the major challenges the water sector has to face. Water policies should try to comply with progressive and sustainable socio-economic development. This entails two opposing factors in the water system:

i. supply and cost relative to availability or the increase thereof. Inside, the pressures are their effects weigh heavily on resources and ecosystems.

ii. use and demand, the equilibrium of which with regard to supply, limits increase.

The mobilization and judicious use of water resources therefore requires integrated management to ensure the sustainability of water and the environment. To do so, the different countries are also led, in addition to traditional information, to use satellite earth observation images serving as a tool of analysis for identification of the potential and evolution of underground water (Soldan, 2003). These are operational applications that can support the strategic decisions for water management. The use thereof is going to become increasingly generalized with the development of information and communication technologies.

2.1.2 Water contamination and pollution

Water consists of two hydrogen atoms and an oxygen atom. Its chemical formula is H_2O. The hydrogen bond in water gives it its ability to dissolve many substances - a universal solvency (Kambole, 2003). Sometimes the characteristics of water may change due to the addition of foreign substances. In such instances water would not be able to exhibit properties that enable it to perform certain functions efficiently. This is the stage of water described as contamination. In its advanced form, water would not be able to perform the functions at all. This advanced stage of contaminated water is termed polluted water (Peirce *et al.*, 1997).

2.2 Water quality

The term 'water quality' describes the physical, chemical, biological and aesthetic properties of water which determine its fitness for a variety of uses and for protecting the health and integrity of aquatic ecosystems. Many of these properties are controlled by constituents which are either dissolved or suspended in water (DWAF, 1996).

Poor water quality can be the result of natural processes but is more often associated with human activities and is closely linked to industrial development. Although substances that can be harmful to life can have natural or human-made sources, the contribution of some human-produced chemicals to the natural environment far overshadows natural sources (UNEP GEMS, 2006). Thus, the quality of any body of surface or ground water is a function of either or both natural influences and human activities. Without human influences, water quality would be determined by weathering of bedrock minerals, by atmospheric processes of evapotranspiration and the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soil, by hydrological factors that lead to runoff, and by biological processes within the aquatic environment that can alter the physical and chemical composition of water. As a result, water in the natural environment contains many dissolved substances and non-dissolved particulate matter. According to Stark *et al*. (2000), dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of the organisms that rely on this ecosystem service.

The quality of water required to maintain ecosystem health is largely a function of natural background conditions. Some aquatic ecosystems are able to resist large changes in water quality without any detectable effects on ecosystem composition and function, whereas other ecosystems are sensitive to small changes in the physical and chemical makeup of a body of water and this can lead to degradation of ecosystem services and loss of biological diversity. The degradation of water quality by humans is often gradual, and subtle adaptations of aquatic ecosystems to these changes may not always be readily detected until a dramatic shift in ecosystem condition occurs (UNEP GEMS, 2006).
Water quality is variable in both time and space and requires routine monitoring to detect spatial patterns and changes over time. There is a range of chemical, physical, and biological components that affect water quality and hundreds of variables could be examined and measured. Some variables provide a general indication of water pollution, whereas others enable the direct tracking of pollution sources (UNEP GEMS, 2006). A wide range of measurable characteristics, compounds or constituents can potentially be found in water and affect its quality (ADWG, 1996). They fall into several categories, namely: physical, microbiological, chemical (including inorganic chemicals, organic compounds and pesticides) and radiological.

2.2.1 Domestic Water

The use of water in the domestic environment is common to all consumers and probably provides the widest direct experience of the effects of water quality. According to Department of Water Affairs and Forestry (DWAF, 1996), the term "domestic water", refers to water which is used in the domestic environment and refers to all uses water can be put to in this environment. This includes water for:

- drinking
- food and beverage preparation
- hot water systems
- bathing and personal hygiene
- washing, for example, dishes
- laundry
- gardening which may include water for fish ponds

Drinking water is often assumed to be the water use with the most stringent quality requirements but other domestic uses such as laundry can dominate quality requirements in some instances (DWAF, 1996).

Domestic water users can experience a range of impacts as a result of changes in water quality. These may be categorized as health impacts (short term and long term), aesthetic impacts (which can include changes in water taste, odour or colour and staining of laundry or household fittings and fixtures) and economic impacts, which may include increased cost of treatment, increased cost of distribution (due to scaling, corrosion or deposition of sediments in the distributing system) as well as scaling or corrosion of household pipes, fittings and appliances (DWAF, 1996).

2.2.2 Aquatic Ecosystems

Aquatic ecosystems include numerous species, habitats and processes, all of which are interlinked and interdependent, and which require protection if healthy ecosystem structure and functioning are to be maintained. The effects of changes in water quality on specific components of ecosystems are often indirect due to the complex and interlinked nature of aquatic ecosystems. The complexity of determining the effects of changes in water quality on aquatic ecosystems is compounded by the fact that many of the cause-effect relationships are poorly understood or completely unknown. It is therefore often difficult to separate the effects of changes in water quality from other effects such as changes in flow regime or climatic changes. The effects of a water quality constituent on aquatic ecosystems can sometimes be modified significantly by interactions with other constituents in the water, e.g. antagonistic or synergistic effects (DWAF, 1996). For instance oxygen is a vital feature of any water body because it greatly influences the solubility of metals and is essential for all forms of biological life. (Chapman, 1996)

2.2.3 Physical quality of drinking water

Drinking water should be safe to use and aesthetically pleasing. Ideally, it should be clear, colourless and well aerated, with no unpalatable taste or odour, and it should contain no suspended matter, harmful chemical substances or pathogenic micro-organisms. Appearance and taste and odour are generally the characteristics by which the public judges water quality, and are therefore useful indicators of water quality. However, water which is turbid or coloured or has an objectionable taste or odour may not be safe to drink. On the contrary, the absence of any unpleasant qualities does not guarantee water's safety. The sense of taste and smell tend to vary, so acceptability of the same water can vary from person to person, and from day to day for the same person. Similarly, one individual within a group may be more or less sensitive to a particular substance than the group as a whole. The safety of water in public health terms is determined by its microbiological, physical, chemical and radiological quality. Of these, microbiological quality is the most important (ADWG, 1996).

2.2.3.2 **An overview of physical characteristics of water**

The appearance, taste, odour and "feel" of water determine what people experience when they drink or use the water and how they rate its quality, while other physical characteristics suggest whether corrosion or encrustation are likely to be significant problems in pipes or fittings. According to Australian drinking water guideline ADWG (1996), the measurable physical characteristics which determine these largely subjective qualities are true colour (that is, the colour which remains after any suspended particles have been removed), turbidity (the cloudiness caused by fine suspended matter in the water), hardness (the reduced ability to get a lather using soap), total dissolved solids (TDS), pH, temperature, taste and odour, as well as dissolved oxygen (DO). Colour and turbidity influence the appearance of water. Taste can be influenced by temperature, total dissolved solids, and pH and the "feel" by pH, temperature, and hardness. pH, temperature, hardness, total dissolved solids, and dissolved oxygen affect rates of corrosion and encrustation (scale build-up) of pipes and fittings (ADWG, 1996).

2.2.3.1.1 Temperature

Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic inhabitants. It is important in aquatic systems because it can cause mortality and it can influence the solubility of dissolved oxygen (DO) and other materials in the water column (e.g. ammonia). Water temperatures fluctuate naturally both daily and seasonally (UNEP GEMS, 2006).

Aquatic organisms often have narrow temperature tolerances. Thus, although water bodies have the ability to buffer against atmospheric temperature extremes, even moderate changes in water temperatures can have serious impacts on aquatic life, such as bacteria, algae, invertebrates and fish. Thermal pollution comes in the form of direct impacts, such as the discharge of industrial wastes into aquatic receiving bodies, or indirectly through human activities such as the removal of shading stream bank vegetation or the construction of impoundments.

Temperature is very important to living organisms as it affects some of the basic physical and chemical processes necessary for life. For example, temperature affects the movement of molecules, fluid dynamics, and saturation concentrations of dissolved gasses in water, and the metabolic rate of organisms. Aquatic ecosystems experience diel (daily) and annual fluctuations in temperatures. This thermal regimen is crucial for aquatic fauna, as many life history traits, such as reproduction and growth, are regulated by temperature. Therefore, changes in temperatures can eliminate species that are adapted to the natural cycle of water temperatures found in free-flowing systems. Increases in temperature will also affect the levels of dissolved oxygen in the water column, which is inversely proportional to temperature, reducing the survivorship of oxygen sensitive species (Carron and Rajaram, 2001; Hauer and Hill, 1996).

2.2.3.1.2 pH

pH is a measure of the hydrogen ion concentration of water. It is measured on a logarithmic scale from 0 to 14. The pH of a solution is the negative logarithm to the base ten of the hydrogen ion concentration, expressed mathematically as:

$$pH = -\log_{10} [H^+]$$

where $[H^+]$ is the concentration of hydrogen ion.

In water, a small number of water (H_2O) molecules dissociate and form hydrogen (H^+) and hydroxyl (OH^-) ions. If the relative proportion of the hydrogen ions is greater than the hydroxyl ions, then the water is defined as being acidic. If the hydroxyl ions dominate, then the water is defined as being alkaline. The relative proportion of hydrogen and hydroxyl ions is measured on a negative logarithmic scale from 1 (acidic) to 14 (alkaline) with 7 being neutral (US EPA, 1997; Friedl *et al*., 2004). Thus, a pH value of 7 is neutral, greater than 7 is alkaline, and less than 7 is acidic. The pH of water does not have direct health consequences except at extremes. The selection of raw water as a drinking water source is never based solely on pH. Danger to health would result primarily from the presence of metal ions, which are more likely to influence selection than the pH value (DWAF, 2006). The adverse effects of pH result from the solubilisation of toxic heavy metals and the protonation or deprotonation of other ions. The pH of natural waters is influenced by various factors and processes, including temperature, discharge of effluents, acid mine drainage, acidic precipitation, runoff, microbial activity and decay processes (DWAF, 2006). The pH of an aquatic ecosystem is important due to its close link to biological productivity. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 (DWAF, 2006) usually indicate good water quality and this range is typical of most major drainage basins of the world.

2.2.1.1.3 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) is a measure of the amount of various inorganic salts dissolved in water. According to ADWG (1996), total dissolved solids (TDS) consist of inorganic salts and small amounts of organic matter that are dissolved in water. Clay particles and colloidal iron and manganese oxides and silica fine enough to pass through a 0.45 micrometer filter membrane can also contribute to total dissolved solids. Total dissolved solids comprise sodium, potassium, calcium, magnesium, chloride, sulphate, bicarbonate, carbonate, silica, organic matter, fluoride, iron, manganese, nitrate (and nitrite) and phosphate. TDS concentration is directly proportional to the electrical conductivity (EC) of water. Since electrical conductivity is much easier to measure than TDS, it is normally used as an estimate of the TDS concentration (DWAF, 2006). The electrical conductivity of water, measured in EC units, increases with the concentration of dissolved solids. Electrical conductivity can be used as a measure of TDS, but the factor used to convert EC into TDS will depend on the type of dissolved solids present in the water (ADWG, 1996).

2.2.3.1.4 Turbidity and suspended solids

Turbidity is a measure of the light-scattering ability of water and is indicative of the concentration of suspended matter in water. ADWG (1996) observe that the degree of scattering is dependent on the amount, size and composition of the suspended matter. The turbidity of water is also related to clarity, a measure of the transparency of water and settleable material, which refers to suspended matter which settles after a defined time period as opposed to that which remains in suspension (DWAF, 2006). It is often expressed as total suspended solids (TSS). The greater the amount of suspended solids in the water, the murkier it appears, and the higher the measured turbidity (UNEP GEMS, 2006). Turbidity is sometimes used as a surrogate characteristic for suspended solids. It is not possible to establish general relationship between turbidity and suspended solids, as natural waters usually contain heterogeneous mixtures of suspended material of variable composition; however specific relationships can be developed for particular water bodies (ADWG, 1996). Turbidity in water is caused by the presence of suspended matter which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter. The latter can be both living matter such as microorganisms and non-living matter such as dead algal cells. According to UNEP GEMS (2006) the major source of turbidity in the open water zone of most lakes is typically phytoplankton, but closer to shore, particulates may also include clays and silts from shoreline erosion, re-suspended bottom sediments, and organic detritus from stream and/or water discharges. Suspended solids in streams are often the result of sediments carried by the water. US EPA (1997) notes the source of these sediments includes natural and anthropogenic activities in the watershed, such as natural or excessive soil erosion from agriculture, forestry or construction, urban runoff, industrial effluents, or excess phytoplankton growth.

2.2.3.1.5 Salinity and specific conductance

Salinity is an indication of the concentration of dissolved salts in a body of water. The ions responsible for salinity include the major cations (calcium, Ca^{2+}; magnesium, Mg^{2+}, sodium, Na^{+} and potassium, K^{+}) and the major anions (carbonates, CO_3^{2-} and bicarbonate HCO_3^{2-}, sulphate, SO_4^{2-}, and chloride, Cl^{-}). The level of salinity in aquatic systems is important to aquatic plants and animals as species can survive only within certain salinity ranges (Friedl *et al.,* 2004). Although some species are well-adapted to surviving in saline environments, growth and reproduction of many species can be hindered by increases in salinity.

Salinity is measured by comparing the dissolved solids in a water sample with a standardized solution. The dissolved solids can be estimated using total dissolved solids or by measuring the specific conductance. Specific conductance, or conductivity, measures how well the water conducts an electrical current, a property that is proportional to the concentration of ions in solution. Conductivity is often used as an alternate of salinity measurements. The specific conductance of a body of surface or ground water can also be used to detect pollution sources (Stoddard *et al*., 1999).

2.2.3.1.6 Dissolved Oxygen

Drinking water will generally contain adequate concentration of dissolved oxygen; however under some circumstances the oxygen concentration may be reduced. This may occur, for instance, where water has been drawn from deep storages, where there is considerable growth of microorganisms in a distribution system, or following prolonged periods of high water temperature. Low oxygen concentrations or anoxic conditions enable nuisance anaerobic microorganisms to grow, producing by-products which affect the aesthetic quality of the water and increase corrosion of pipes and fittings (ADWG, 1996). Oxygen that is dissolved in the water column is one of the most important components of aquatic systems. Oxygen is required for the metabolism of aerobic organisms, and it influences inorganic chemical reactions. Oxygen is often used as an indicator of water quality, such that high concentrations of oxygen usually indicate good water quality. Oxygen enters water through diffusion across the water's surface, by rapid movement such as waterfalls or riffles in streams (aeration), or as a by-product of photosynthesis.

The amount of dissolved oxygen gas depends highly on temperature and somewhat on atmospheric pressure. Salinity also influences dissolved oxygen concentrations, such that oxygen is low in highly saline waters and vice versa. The amount of any gas, including oxygen, dissolved in water is inversely proportional to the temperature of the water, that is, as temperature increases, the amount of dissolved oxygen decreases (UNEP GEMS, 2006). High algal production in surface waters can lead to depleted oxygen concentrations at high depths as cells die and settle to the bottom of the lake, where they are decomposed by bacteria. The decomposition process consumes oxygen from the water through bacterial respiration.

2.2.3.1.7 Alkalinity

Alkalinity is not a contaminant. It is the total measure of the substances in water that have "acid-neutralizing" capability. Alkalinity should not be confused with pH. pH measures the strength of an acid or base whilst alkalinity signifies a solution's power to react with acid and neutralize it (US EPA, 2006). According to State Water Resources Control Board of California

(SWRCBC), 2005, the main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates may also contribute to alkalinity of water.

2.2.3 Chemical quality of drinking water

A number of chemicals, both organic and inorganic, and including some pesticides, are of concern in drinking water from the health perspective because some are toxic to humans and some are suspected of causing cancer. Some can also affect the aesthetic quality of water (ADWG, 1996). Inorganic chemicals in drinking water usually occur as dissolved salts such as carbonates, chlorides etc., attached to suspended material such as clay particles, or as complexes with naturally occurring organic compounds. Organic compounds are usually present in drinking water in very low concentrations, and may occur either naturally or as a result of human activities. By-products of disinfection are the most commonly found organic contaminants in drinking water.

2.2.4.1 Inorganic chemicals in drinking water

The ionic composition of surface and ground waters is governed by exchanges with the underlying geology of the drainage basin and with atmospheric deposition. Human activities within the drainage basin also influence the ionic composition, by altering discharge regimes and transport of particulate matter across the landscape, and by changing the chemical composition of surface runoff and atmospheric deposition of solutes through wet and dry precipitation (UNEP GEMS, 2006).

Metals occur naturally and become integrated into aquatic organisms through food and water. Trace metals such as mercury, copper, selenium, and zinc are essential metabolic components in low concentrations. However, metals tend to bioaccumulate in tissues and prolonged exposure or exposure at higher concentrations can lead to illness. Elevated concentrations of trace metals can have negative consequences for both wildlife and humans. Human activities such as mining and heavy industry can result in higher concentrations than those that would be found naturally (UNEP GEMS, 2006). Metals tend to be strongly associated with sediments in rivers, lakes, and reservoirs and their release to the surrounding water is largely a function of pH, oxidation-reduction state, and organic matter content of the water (and the same is also true for nutrient and organic compounds). Metals in water can pose serious threats to human health. Mohan and Kumar (1998) note metal toxicity can cause reduced survivorship in fish through chronic stress, which impairs health and decreases the affected individuals' ability to secure food, shelter, or reproductive partners. Trace metals can be harmful to aquatic organisms. Effects include reduced growth rates, impaired reproduction, and sometimes death. Acute or chronic toxicity will influence species numbers and diversity, altering community structure and function. Bioconcentration and bioaccumulation of these substances in the food chain can put terrestrial consumers, including humans, at risk.

The ionic composition of surface waters is usually considered to be relatively stable and insensitive to biological processes occurring within a body of water. Magnesium, sodium and potassium concentrations tend not to be heavily influenced by metabolic activities of aquatic organisms, whereas calcium can exhibit noticeable seasonal and spatial dynamics as a result of biological activity. Chloride concentrations are not heavily influenced by biological activity, while sulphate and inorganic carbon (carbonate and bicarbonate) concentrations can be driven by production and respiration cycles of the aquatic biota (Wetzel, 2001). External forces such as climatic events that govern evaporation and discharge regimes and anthropogenic inputs can also drive patterns in ionic concentrations. Such forces are probably most responsible for long-term changes in the ionic composition of lakes and rivers.

2.2.4.2 Mercury

Mercury is a metal found naturally in the environment but human activities have greatly increased its atmospheric concentration, accounting for about 75% of worldwide emissions. It is present in the inorganic form in surface water and groundwater at concentrations usually below 0.5 µg/l, although local mineral deposits may produce higher levels in groundwater (WHO, 2008). Anthropogenic sources of mercury in the environment include incinerators (municipal waste), coal-burning facilities (electrical generation), industrial processes (older methods for producing chlorine and caustic soda), and some consumer products (e.g., batteries, fluorescent lights, thermometers). The form of mercury of most concern from a water quality perspective is Hg^{2+} because it dissolves quickly in water and is consequently the form most often found in aquatic ecosystems. Mercury in water is usually measured in its total or dissolved forms (UNEP GEMS, 2006). Methyl mercury can easily enter the food chain as a consequence of rapid diffusion and tight binding to proteins. Environmental levels of methyl mercury depend on the balance between bacterial methylation and demethylation. Naturally occurring levels of mercury in groundwater and surface water are less than 0.5 µg/l. The WHO guideline value for total mercury is 0.001 mg/l.

When mercury is found in water some of the microorganisms present transform it into methyl mercury, which is very toxic. Methyl mercury tends to remain dissolved in water and does not travel far in the atmosphere. Conversely, it can be converted back into elemental mercury and re-emitted to the atmosphere. Mercury is of concern because it accumulates in the tissues of wildlife and humans, sometimes at tens of thousands of times the concentration found in the water source, causing reproductive and neurological problems (UNEP GEMS, 2006). In humans, prenatal exposure to high mercury levels, particularly in fish-eating populations, has been associated with developmental problems related to the central nervous system (WHO, 2004).

Aesthetic effects associated with mercury are not significant for domestic water use. Mercury poisoning takes the form of neurological (organic mercury) and renal (inorganic mercury) disturbances. Both the organic and inorganic forms are toxic although the organic is about one order of magnitude more toxic because it is able to cross biological membranes more readily (DWAF, 2006). . This is attributable to the greater lipid solubility conferred to mercury by the associated organic groups. Depending on the dosage, effects associated with the ingestion of mercury are either chronic or acute (DWAF, 2006).

2.2.4.3 Arsenic

Arsenic is fairly widespread in the environment, the average concentration in the earth's crust being approximately 2 mg/kg (DWAF, 1996). It is found as arsenates, with sulphides and in association with many other metallic ores, and occasionally in the elemental form. Arsenic levels in natural waters generally range between 1 and 2 µg/l, although concentrations may be elevated (up to 12 µg/l) in areas containing natural sources (WHO, 2008). It is a greyish semi-metallic element which occurs naturally in some surface and ground water sources, may lead to development of skin lesions and cancer in people exposed to excess concentrations through drinking water, bathing water or food.

Arsenic occurs in three oxidation states, namely, (0), (III) and (V). In solution arsenic can exist as arsenite, As (III); arsenate, As (V); and as various organic complexes. Inorganic arsenates form arsenate salts with cations of calcium or iron. Soluble arsenic compounds are readily taken up by living organisms and at elevated concentrations can exert toxic effects. Once absorbed by living organisms, arsenic is excreted slowly, and hence accumulation easily occurs in the body. Therefore a single, once-off exposure to a high concentration of arsenic can have serious effects. Ingestion of arsenic in drinking water is most likely to lead to chronic effects, principally different types of skin lesions (DWAF, 1996).

Soluble arsenic salts are readily absorbed by the gastro-intestinal tract. After absorption inorganic arsenic binds to haemoglobin, and is deposited in the liver, kidney, lungs, spleen, and skin. Inorganic arsenic does not appear to cross the blood-brain barrier but can cross the placenta (ADWG, 1996).

2.2.4.4 Lead

Lead is used principally in the production of lead-acid batteries, solder and alloys. The Organolead compounds tetraethyl and tetramethyl lead have also been used extensively as antiknock and lubricating agents in petrol, although their use for these in many countries is being phased out. Due to the decreasing use of lead-containing additives in petrol and of lead-containing solder in the food processing industry, concentrations in air and food are declining, and intake from drinking water constitutes a greater proportion of total intake. Lead is rarely present in tap water as a result of its dissolution from natural sources; rather, its presence is primarily from household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes. The amount of lead dissolved from the plumbing system depends on several factors, including pH, temperature, water hardness and standing time of the water. Lead concentrations in drinking water are generally below 5µg/l, although much higher concentrations (above 100µg/l) have been measured where lead fittings are present (WHO, 2008). It is a toxicant that accumulates in the skeleton. Infants, children up to 6 years of age and pregnant women are most susceptible to its adverse health effects. Lead also interferes with calcium metabolism, both directly and by interfering with vitamin D metabolism. It is toxic to both the central and peripheral nervous systems, inducing subencephalopathic neurological and behavioural effects (WHO, 2008).

Results from prospective (longitudinal) epidemiological studies suggest that prenatal exposure to lead may have early effects on mental development. Evidence from studies in humans indicates adverse neurotoxic effects other than cancer may occur at very low concentrations of lead (WHO, 2008). Lead is a cumulative poison that can severely affect the central nervous system. According to South African Department of Water Affairs and Forestry (1996), exposure to lead, particularly of young children, should be minimized as far as possible. At relatively low concentrations, particularly with continuous exposure, lead can cause neurological impairment in foetuses and young children (ADWG, 1996; DWAF, 1996). This can lead to behavioural changes and impaired performance in intelligence quotient tests (DWAF, 1996; WHO, 2008). The effects are slight at low or intermittent exposure to lead, but become more pronounced as the exposure to lead increases. In adults the neurological effects are much less pronounced and the effects of exposure to toxic concentrations of lead take the form of anaemia and lead colic, that is, acute episodes of abdominal pain (DWAF, 1996).

2.2.4.5 Iron

Iron is one of the most abundant metals in the Earth's crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/l. Iron may also be present in water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution (WHO, 2008). It is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day (WHO, 2008). Iron poisoning is rare since excessively high concentrations do not occur naturally in water. The extreme unpalatability of such water would probably prevent consumption (DWAF, 1996). The effects of iron are predominantly aesthetic, such as the staining of enamelled surfaces of baths, hand basins and lavatory cisterns/bowls and laundry. Iron causes discolouration of water supplies when present at low concentrations in association with aluminium.

2.2.4.6 Copper

Copper is both an essential element and a drinking water contaminant. It has many commercial uses. It is used to make pipes, valves and fittings and is present in alloys and coatings. Copper sulphate pentahydrate is sometimes added to surface water for the control of algae. Copper concentrations in drinking water vary widely; usually range from ≤0.005 to >30 mg/l, primarily as a result of the corrosion of interior copper plumbing (WHO, 2008). Copper levels in running or fully flushed water tend to be low, whereas those in standing or partially flushed water samples are more variable and can be considerably higher. Copper concentrations in treated water often increase during distribution, especially in systems with an acid pH or high-carbonate waters with an alkaline pH. The primary sources of copper exposure in developed countries are food and water (WHO, 2008). Ingestion of high concentrations of copper results in gastrointestinal disturbances and possible liver, kidney and red blood cell damage (DWAF, 1996). However, due to the enormously disagreeable taste of water with high concentrations of copper, it is unlikely that such water would be consumed.

2.2.4.7 Cadmium

Cadmium is released to the environment in wastewater, and diffuse pollution is caused by contamination from fertilizers and local air pollution. Contamination in drinking water may also be caused by impurities in the zinc of galvanized pipes and solders and some metal fittings. Food is the main source of daily exposure to cadmium. Smoking is a significant additional source of cadmium exposure (WHO, 2008). According to World Health Organization, cadmium levels in drinking water are usually less than 1µg/l and consequently set a guideline value for cadmium as 0.003 mg/l drinking water (WHO, 2008). Furthermore, ADWG (1996) notes that based on health considerations, the concentration of cadmium in drinking water should not exceed 0.002 mg/l.

Absorption of cadmium compounds is dependent on the solubility of the compounds. Cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of several decades (WHO, 2008; DWAF, 2006; ADWG, 1996). There is evidence that cadmium is carcinogenic by the inhalation route. However, there is no evidence of carcinogenicity by the oral route and no clear evidence for the genotoxicity of cadmium. The kidney is the main target organ for cadmium toxicity (WHO, 2008). At high concentrations cadmium is acutely toxic and can cause severe renal damage with renal failure. Cadmium also causes acute gastroenteritis. This closely mimics the gastroenteritis caused by microorganisms. Cadmium poisoning is very difficult to treat due to rapid and irreversible uptake by the kidneys (DWAF, 2006).

2.2.4.8 Zinc

Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. The principal source of zinc is normally diet. Although levels of zinc in surface water and groundwater normally do not exceed 0.01 and 0.05 mg/l, respectively, concentrations in tap water can be much higher as a result of dissolution of zinc from pipes (WHO, 2008). The stable oxidation states of zinc are the metal (0) and the +II oxidation state, which is the form found in nature. The carbonate, hydroxide and oxide forms of zinc are relatively resistant to corrosion and therefore zinc has many applications. The presence of zinc in domestic water arises mainly from the leaching of galvanized plumbing and fittings. Zinc is an essential nutritional trace element for plants and animals. Humans have a high tolerance level to elevated zinc concentrations, whereas fish are highly susceptible to poisoning (DWAF, 1996).

Sulphide (sphalerite) is the most common mineral form of zinc. Zinc is also found as a carbonate, oxide or silicate and may occur in association with many other metal ores such as copper and arsenic. The chloride, sulphate and nitrate salts of zinc are highly soluble in water, but at neutral and alkaline pH they hydrolyze to form relatively insoluble hydroxides which tend to be associated with sediments. On acidification of the water, the insoluble hydroxides are released back into solution. If the water is acidic, zinc leaching caused by dissolution of the protective zinc hydroxide layer of galvanized piping can give rise to relatively high concentrations of zinc in solution (DWAF, 1996).

2.2.4.9 Hardness

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium. It is usually expressed as the equivalent quantity of calcium carbonate. Depending on pH and alkalinity, hardness above about 200 mg/l can result in scale deposition, particularly on heating. Soft waters with a hardness of less than about 100 mg/l have a low buffering capacity and may be more corrosive to water pipes (WHO, 2008). According to World Health Organization, WHO (2008), a number of ecological and analytical epidemiological studies have shown a statistically significant inverse relationship between hardness of drinking water and cardiovascular disease.

Soft water requires less soap than hard water to obtain lather. Hard water can also cause scale to form on hot water pipes and fittings. Hardness is due basically to the presence of calcium and magnesium ions, although other cations such as strontium, iron, manganese and barium can also contribute. Total hardness is the sum of the concentrations of Ca^{2+} and Mg^{2+} ions expressed as a calcium carbonate equivalent. Hardness may also be classified as carbonate (temporary) or non-carbonate (permanent) hardness. Carbonate hardness is the total alkalinity expressed as calcium carbonate, where alkalinity is the sum of the carbonate, bicarbonate and hydroxide content. Non-carbonate hardness is the difference between the total and carbonate hardness (ADWG, 1996).

2.2.4.10 Nickel

In aqueous solution, nickel occurs mostly as the green hexa-aquanickel (II) ion, $Ni(H_2O)_6^{2+}$. The nickel ion content of ground water may increase as a result of the oxidation of natural nickel containing ferrous sulphate deposits (WHO, 1996). Oxidation can occur if the ground water table is lowered or if nitrate has leached from the soil. Nickel concentrations in ground water around the world are normally < 20 mg/l, although levels up to several hundred micrograms per litre in ground water and drinking water have been reported (WHO, 1996).

2.2.4.11 Nitrogen and Phosphorus

Nutrients are generally not toxic, but which stimulate eutrophication if present in excess. The constituents of nutrients include inorganic nitrogen (nitrate, nitrite, ammonium) and inorganic phosphorus (ortho-phosphates) (DWAF, 1998). Compounds of nitrogen (N) and phosphorus (P) are major cellular components of organisms. Since the availability of these elements is often less than biological demand, environmental sources can regulate or limit the productivity of organisms in aquatic ecosystems (UNEP GEMS, 2006). Productivity of aquatic ecosystems can, therefore, be managed by regulating direct or indirect inputs of nitrogen and phosphorus with the aim of either reducing or increasing primary production. Phosphorus is present in natural waters primarily as phosphates, which can be separated into inorganic and organic phosphates. Phosphates can enter aquatic environments from the natural weathering of minerals in the drainage basin, from biological decomposition, and as runoff from human activities in urban and agricultural areas. Inorganic phosphorus, as orthophosphate (PO_4^{3-}), is biologically available to primary producers that rely on phosphorus for production and has been demonstrated to be an important nutrient limiting maximum biomass of these organisms in many inland systems. Phosphorus in water is usually measured as total phosphorus, total dissolved phosphorus (i.e., all P that passes through a 0.45μm pore-size filter), and soluble reactive or orthophosphorus (UNEP GEMS, 2006).

Nitrogen occurs in water in a variety of inorganic and organic forms and the concentration of each form is primarily mediated by biological activity. Nitrogen-fixation, performed by cyanobacteria (blue-green algae) and certain bacteria, converts dissolved molecular N_2 to ammonium (NH_4^+). Aerobic bacteria convert NH_4^+ to nitrate (NO_3^-) and nitrite (NO_2^-) through nitrification, and anaerobic and facultative bacteria convert NO_3^- and NO_2^- to N_2 gas through denitrification. Primary producers assimilate inorganic N as NH_4^+ and NO_3^-, and organic N is returned to the inorganic nutrient pool through bacterial decomposition and excretion of NH_4^+ and amino acids by living organisms (UNEP GEMS, 2006). Nitrogen in water is usually measured as total nitrogen, ammonium, nitrate, nitrite, total nitrogen (= organic nitrogen + NH_4^+), or as a combination of these parameters to estimate inorganic or organic nitrogen concentrations (UNEP GEMS, 2006).

Phosphorus and nitrogen are considered to be the primary causes of eutrophication of aquatic ecosystems, where increased nutrient concentrations lead to increased primary productivity. Some systems are naturally eutrophic, whereas others have become eutrophic due to human activities such as runoff from agricultural lands and the discharge of municipal waste into rivers and lakes. Aquatic ecosystems can be classified into trophic state, which provides an indication of a system's potential for biomass growth of primary producers. Trophic states are usually defined as oligotrophic (low productivity), mesotrophic (intermediate productivity), and eutrophic (high productivity). Ultraoligotrophic and hypereutrophic states represent opposite extremes in the trophic status classifications of aquatic environments. Dodds *et al*., (1998), note that whilst there are many methods for classifying systems into trophic state, a common approach looks at concentrations of nutrients across many systems and separates systems according to their rank in the range of nutrient concentrations.

2.2.4.12 Sulphate

Sulphate is the oxy-anion of sulphur in the +VI oxidation state and forms salts with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium. Sulphate is a common constituent of water and arises from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals. Sulphates are discharged from acid mine wastes and many other industrial processes such as tanneries, textile mills and processes using sulphuric acid or sulphates. Sulphates can be removed or added to water by ion exchange processes, and microbiological reduction or oxidation can interconvert sulphur and sulphate (DWAF, 1996). Consumption of excessive amounts of sulphate in drinking water typically results in diarrhoea. Sulphate imparts a bitter or salty taste to water, and is associated with varying degrees of unpalatability (DWAF, 1996). The presence of sulphate in drinking water may also cause noticeable taste at concentrations above 250 mg/l and may contribute to the corrosion of distribution systems (WHO, 2008).

2.2.5 Microorganisms in drinking water

Microbial communities of bacteria, viruses, protists and fungi are omnipresent in aquatic environments, but it is only in recent years that the importance of their contribution to aquatic ecosystem functioning have been recognized (UNEP GEMS, 2006). The majority of microbes inhabiting aquatic ecosystems are completely benign to humans and have important roles in aquatic ecosystem functioning. However, microbial contamination of surface and ground waters by pathogenic or disease-causing organisms such as coliform bacteria is probably the most important water quality issue in the developing world, where access to safe, clean water for drinking, bathing and irrigation is often unavailable. The most common and widespread health risk associated with drinking water is contamination, either directly or indirectly, by human or animal excreta, and with the microorganisms contained in faeces (ADWG, 1996). Drinking contaminated water or using it in food preparation may cause infection. Those at greatest risk of infection are infants and young children, people whose immune system is suppressed, the sick, and the elderly. The World Health Organization identifies the greatest human health risk of microbial contamination as being through the consumption of water contaminated by human or animal faeces (WHO, 2004).

ADWG (1996) noted that pathogenic (disease-causing) organisms of concern include bacteria, viruses and protozoa. These organisms cause diseases which vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhoea, dysentery, hepatitis, cholera, or typhoid fever.

Infection is the main, but not the only problem associated with microorganisms in drinking water. Certain algae and bacteria, for instance, can produce toxins which affect humans, and which may remain in the water even when the organisms responsible have been removed (ADWG, 1996). Other nuisance organisms can cause problems of taste, odour or colour, as well as promoting deposition and corrosion problems.

Most microbes are heterotrophic organisms, meaning they require organic carbon to kindle their metabolism. Bacteria and fungi are important decomposers of organic matter in aquatic ecosystems, releasing nutrients and minerals to the water column that can be used to fuel metabolism of other organisms. Wommack and Colwell (2000), note that although the study of aquatic viruses is still in its infancy, these viruses appear to infect primarily bacterial and single-celled algae and have important roles in regulating production and diversity of the microbial food web.

Surface and ground water can be infected with a variety of pathogens. Monitoring microbes in surface or ground waters is used to detect the presence of pathogenic organisms in order to prevent disease. There are a number of broad classes of such microbes including bacteria, protozoa, parasitic worms, fungi, and viruses. Indicator microorganisms are used to suggest the presence of pathogens. The organisms most often used are faecal indicators: organisms that indicate the presence of faecal contamination from animal or human wastes. Tests used to indicate the presence of pathogenic organisms include those for total coliforms, faecal coliforms, or for Escherichia coli (E. coli) specifically (Ashbolt *et al.*, 2001).

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes the issues relating to the study area and the data collected. On the study area, the focus was on the vicinity of Lake Amponsah, the project environment with regards to its geographic location. Data-related issues highlight the source and type of data collected, sampling techniques and the methods of analysis.

3.1 Study area

Lake Amponsah is a shallow lake in Bibiani Old Town. Bibiani town is located at approximately 6°27' latitude north and 2°17' longitude west in the Western Region of Ghana (Figure 3.1).

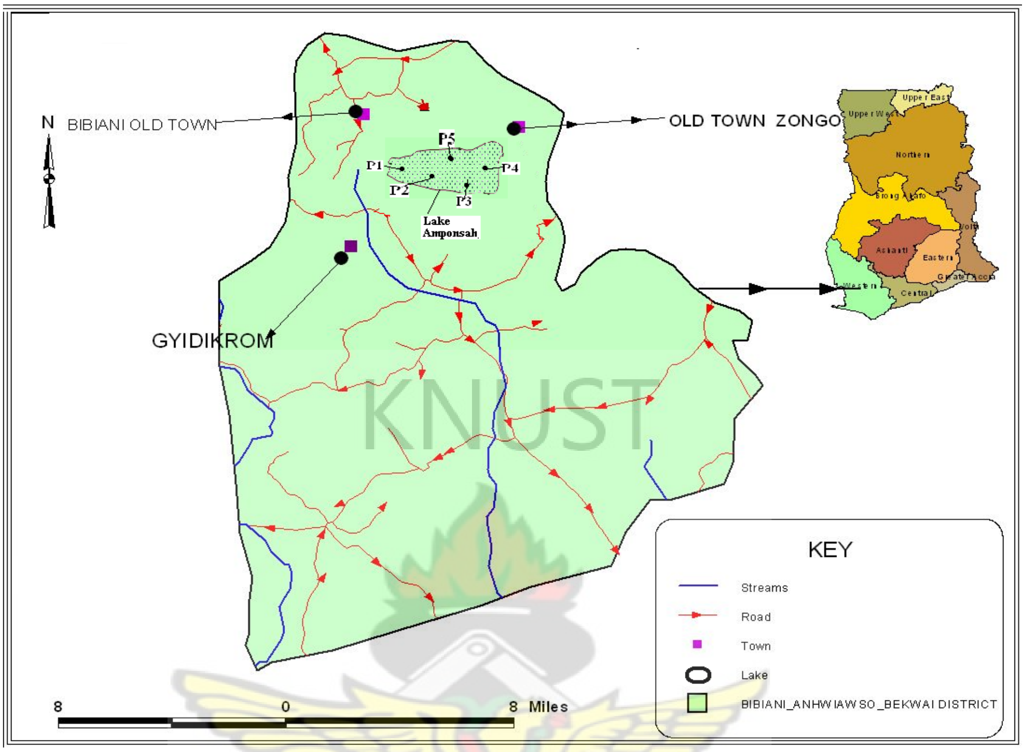

Figure 3.1: Map of the Bibiani Showing Lake Amponsah and the Sampling Points (P_1, P_2, P_3, P_4 and P_5) of the Study

The principal and most practicable accesses to the area are from the east through the Kumasi road, Mim in Brong Ahafo and Sefwi Bekwai. Lake Amponsah is a man-made reservoir built by the State Gold Mining for domestic water use. Its mean depth of the lake is approximately 4.00m, with the greatest depth up to 5.79m (19ft). The lake covers an area of 0.051 km^2 (51,156.67m^2) and has a storage capacity of about 168,205.40 cubic meters (37 million gallons) of water and it also receives storm runoff from within its immediate catchment. The lake is fed by the Amponsah stream from the community. However, at the time of the survey, its inlet had been silted preventing any possible inflow. There are small-scale mining activities including illegal gold mining popularly termed 'galamsey' and a palm kernel oil extraction industry around the lake.

3.2 Method of data collection

Two broad classes of data (quantitative and qualitative) were collected for the study. These in turn consisted of familiarization visit and reconnaissance survey, analysis of secondary information and primary field research.

Familiarization visit and reconnaissance survey

Familiarization visit and reconnaissance survey were undertaken in the community of the study and also in the project site. The period was also used to identify and establish the needed contacts and rapports and protocols with a range of stakeholders namely; the chiefs, district assembly, opinion leaders, key informants and for further communication.

It was also used to mobilize logistical resources.

Analysis of secondary data

Relevant reports and published literature on the quality of water for human use and aquatic life, general environmental degradation and communities' understanding of it and illegal mining were reviewed. These formed the bases for the choice of methods and protocols for data collection as well as discussion of results.

Primary field research

This entailed;

- measurement of the levels of physical (temperature, total dissolved solids (TDS), pH, turbidity, conductivity); chemical (DO, PO_4^{3-} and SO_4^{2-}), heavy metals (As, Fe, Cu, Pb, Zn, Cd, Ni and Hg), bacteriological (total and faecal coliforms) water quality parameters to determine the water quality status of the lake

- administration of questionnaire to assess the level of understanding of small-scale industrialists and the communities on the causes and effects of water quality deterioration.

3.3 Sampling Procedure

3.3.1 Water samples

Sampling was the single grab type and was taken away from the edges of the reservoir, where possible. Sampling was done at five sections of the lake. These were the P_1, P_2, P_3, PS_4 and P_5 (Figure 3.1). Samples were collected across each section of the lake per month at each location for three months (January-March, 2011).

A total of 15 water samples were taken from the lake. Water samples for physico-chemical analyses were collected at depth 20-30cm in the lake directly into 1-litre plastic bottles (high density polyethylene containers), previously washed with quality HNO_3 and rinsed afterwards with distilled water. Each sampling bottle was then rinsed three times with the lake water prior to sampling. Temperature, pH, turbidity, total dissolved solids (TDS), and conductivity were measured *in situ* (Plate 3.1), using a temperature probe, portable pH meter, 2100P turbidimeter and *Sension 5* conductivity meter respectively. Dissolved oxygen (DO) was measured directly using a DO meter

Plate 3.1 Measurement of dissolved oxygen in Lake Amponsah in Bibiani
Source: Field Survey (2011)

Samples for bacteriological analyses were collected into sterilized plain glass bottles. A Garmin GPS map 60CSx was used to determine the coordinates of the sampling sites (Table 3.1). The pH-meter was calibrated in the morning and also during field studies if unusual measures were made. The 2100P turbidimeter and *Sension 5* conductivity-meter were calibrated in the mornings before sampling. All samples were stored in an icebox and transported to the laboratory for analyses. The collection, preservation, storage and preparation protocols of water samples followed those outlined in APHA *et al.* (1998).

Table 3.1: Sampling Points and their Geographical Locations

Sampling Point and Code	GPS Reading
P_1	N: 07.14359, E: 05.75365
P_2	N: 07.14279, E: 05.75423
P_3	N: 07.14242, E: 05.75648
P_4	N: 07.14295, E: 05.75696
P_5	N: 07.14417, E: 05.75573

3.3.2 Sediment samples

Sediment samples were collected with an Eckman grab sampler (Plate 3.2) into clean polyethylene bags and kept at ambient temperature in the field. In the laboratory, samples were dried at 30^{o}C, sieved through a 100µm mesh and stored in polyethylene bags at -10^{o}C. They were analyzed for pH, PO_4^{3-} and the following metals: As, Fe, Cu, Pb, Zn, Cd, Ni and Hg. All the analyses were based on standard methods as appropriate to each parameter, as prescribed in the APHA *et al*., (1998).

Plate 3.2 Sampling of sediments from Lake Amponsah for laboratory analysis

Source: Field Survey (2011)

3.4 Laboratory analyses

Analyses of samples for levels of water quality parameters were performed at the Environmental Laboratory of the AngloGold Ashanti, Obuasi Mine (Plate 3.3).

Plate 3.3 Laboratory analyses of samples from Lake Amponsah for levels of water quality parameters

3.5 Administration of questionnaire

Two types of structured questionnaires were administered. The first set of 50 was to the community members (Plate 3.4) three of who were palm kernel oil extractors (Plate 3.5) to seek their views about the impact of anthropogenic activities on the health of the lake as well as humans. The other type (25) was administered to small-scale miners to solicit their views on awareness of consequences of their activities and lake pollution.

Plate 3.4 Interview with members of the communities around Lake Amponsah

Plate 3.5 Interview with palm kernel oil extractors along the inlet stream of Lake Amponsah

3.6 Data analysis

The data obtained were analyzed using Statistical Package for Social Scientists (SPSS.v16) and Microsoft Excel 2007 and output presented in tables, charts and graphs to visually display respondents' expressed views.

CHAPTER FOUR

RESULTS

In this chapter results of the physico- chemical and bacteriological water quality analysis as well as the questionnaire administration are presented in tables and charts. The first part considers the water quality while the second part is of socio-economic nature. The later is, in turn, made up of two sections. The first section focuses on the demographic characteristics of respondents e.g. gender and age distributions, marital status, educational background and occupation. The second section is related to assessment of respondents' understanding of the causes and effects of pollution of water bodies.

4.1 Water Quality Parameters

4.1.1 Physico-Chemical and Bacteriological Parameters

Some statistics namely; the means, medians and standard deviations of the various levels of physico-chemical and bacteriological characteristics of water sampled from Lake Amponsah are presented in Table 4.1. The soundness of the physico-chemical and biological characteristics of water is a very important condition for healthy wellbeing of society including humans and the environment. Therefore the WHO Guideline values, one of the categories of benchmarks for the determination of the suitability of water for the numerous purposes are also presented. The correlations of water quality parameters are also displayed in this section (Table 4.2).

Table 4.1: Mean Values of Physico-chemical and Bacteriological Parameters of Water Sampled from Lake Amponsah (unless otherwise stated, levels of water samples are measured in mg/l)

Parameter	Mean	Median	STD Dev	Min	Max	Guideline value (WHO)
Physical						
Temperature (°C)	27.927	28.000	0.938	26.000	29.000	
pH	8.256	8.290	0.288	7.600	8.770	6.5-8.5
True Colour (TCU)	447.467	455.000	232.543	172.000	847.700	150.000
Conductivity (µS/cm)	571.267	454.000	211.428	434.000	1013.000	1500.000
Total Alkalinity	165.333	160.000	14.075	140.000	180.000	
Total Hardness	145.333	140.000	27.740	100.000	180.000	400.000
TSS	120.067	99.000	48.257	82.000	221.000	
TDS	262.647	203.000	120.470	188.000	500.000	1000.000
Turbidity (NTU)	64.800	66.200	15.141	40.000	89.100	5.000
Chemical						
Dissolved Oxygen	2.887	3.000	0.990	1.200	4.200	
BOD	1.320	1.400	0.243	0.900	1.700	

Fe	2.264	1.902	0.949	1.257	4.210	0.3
F	< 0.010	< 0.010	0.000	< 0.010	< 0.010	1.5
Cu	0.033	0.021	0.021	0.014	0.075	2.000
Ni	0.010	0.010	0.000	< 0.010	0.010	0.07
Zn	<0.010	< 0.010	0.000	< 0.010	0.010	3.0
Pb	0.170	0.097	0.205	0.009	0.880	0.01
Cd	0.044	0.046	0.006	0.031	0.052	0.003
Hg	0.007	0.007	0.002	0.004	0.009	0.001
As	0.285	0.168	0.257	0.104	0.818	0.010
PO_4^{3-}	0.975	0.100	1.800	0.100	4.750	
SO_4^{2-}	14.133	14.000	1.506	11.000	17.000	500.00
Bacteriological						
Total coliform (cfc/100ml)	1834.933	1812.000	91.857	1699.000	1986.000	0.00
Faecal coliform (cfc/100ml)	1153.933	1162.000	57.116	1076.000	1257.000	0.00

Table 4.2: Correlations of Water Quality Parameters

	pH	Fe	Cu	Ni	Pb	Cd	Hg	As	PO_4^{3-}	SO_4^{2-}
pH	1.00	0.10	0.73	0.00	0.18	-0.10	0.05	0.11	0.15	-0.41
Fe		1.00	-0.46	0.00	0.08	-0.53	0.31	0.96	0.95	0.15
Cu			1.00	0.00	0.29	0.31	-0.14	-0.52	-0.45	-0.71
Ni				1.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb					1.00	-0.07	-0.01	-0.05	-0.04	-0.18
Cd						1.00	0.27	-0.53	-0.52	0.07
Hg							1.00	0.33	0.28	0.05
As								1.00	0.98	0.20
PO_4^{3-}									1.00	0.05
SO_4^{2-}										1.00

The pH of Amponsah reservoir varied between 7.60 and 8.77, with a mean value of 8.26. The level of TDS was in the range of 188.0 mg/l to 500.0 mg/l with an average value of 262.6 mg/l. The average electrical conductivity was 571.3µS/cm (varying from 434.0 to 1013.0 µS/cm). Water temperatures ranged from 26.0 to 29.0^{o}C with an average value of 27.927^{o}C. The mean of turbidity was 64.8 NTU and ranged from 40.0 to 89.1 NTU. Colour, with a mean of 447.47. TCU varied between 172.0–847.7 TCU.

The mean of DO was mean value of 2.887 mg/l and varied between 1.200 and 4.200 mg/l. BOD ranged from 0.900 to 1.700 mg/l with an average of 1.320 mg/l. Total Alkalinity ranged had a mean of 165.333 mg/l. Total Hardness recorded a mean of 145.333 mg/l, and ranged from 100.000 to 180.000 mg/l. TSS ranged from 82.000 to 221.000 mg/l with an average value of 120.067 mg/l. Trace metals studied included Ni, Cu, Hg, Pb, As, Fe, Zn, Cd and F. Results (Table 4.1) of the trace metal level for water samples showed that Ni level ranged from < 0.01 to 0.010 mg/l. Cu level ranged from 0.014 to 0.075 mg/l with mean of 0.033 mg/l. Hg had a mean conc. of 0.007 mg/l and ranged from 0.004 to 0.009 mg/l. Pb level had a mean value of 0.170 mg/l.

The mean value of As was 0.285 mg/l and ranged from 0.104 to 0.818 mg/l. Fe level ranged from 1.257 to 4.210 mg/l with a mean value of 2.264 mg/l. Zn concentration ranged from < 0.010 to 0.010 mg/l. The average concentration of Cd was 0.044 and ranged from 0.031 to 0.052 mg/l. F concentration was <0.010 mg/l throughout the study. PO_4^{3-} concentration ranged from 0.010 to 4.750 mg/l with a mean value of 0.975. SO_4^{2-} value ranged from 11.000 to 17.000 mg/l with an average concentration of 14.133 mg/l.

Total coliform varied from 1699 to 1986 cfc/100ml and had a mean value of 1834.9 cfc/100ml. Faecal coliform had a mean value of 1153.9 cfc/100ml and ranged from 1076 to 1257 cfc/100ml.

4.1.2 Sediment quality

Table 4.3: Mean Values of pH and Heavy Metals Concentration of Sediment Samples

Parameter	Mean	Median	Std Dev	Min	Max
pH	6.36	6.01	0.81	5.39	7.67
As (mg/kg)	3.558	3.562	0.515	3.050	4.446
Fe (mg/kg)	562.278	551.947	73.214	459.447	676.896
Cu (mg/kg)	0.428	0.465	0.082	0.316	0.518

Pb (mg/kg)	0.487	0.335	0.259	0.255	0.809
Zn (mg/kg)	1.311	0.695	1.443	0.444	4.123
Cd (mg/kg)	0.043	0.029	0.055	0.019	0.240
Ni (mg/kg)	0.332	0.364	0.084	0.221	0.448
Hg (mg/kg)	0.026	0.024	0.017	0.005	0.053

Mean levels of heavy metals in the sediments are listed in Tables 4.3. The mean were: Fe, 562.278 mg/kg (dry weight); Pb, 0.487 mg/kg; Cd, 0.043 mg/kg; As, 3.558 mg/kg; Cu, 0.428 mg/kg; Ni 0.332 mg/kg; Zn, 1.311 mg/kg and Hg, 0.026 mg/kg (Table 4.3).

4.2 UNDERSTANDING OF MEMBERS OF THE COMMUNITIES AROUND LAKE AMPONSAH ON THE CAUSES AND EFFECTS OF WATER QUALITY DEGRADATION

In order to set the study in the right context, it was important to understand some demographic characteristics of the respondents. The rationale was to identify those characteristics that may help explain the anthropogenic activities in the vicinity of the lake. The characteristics considered were gender, age, marital status, occupation, length of stay in community, period in the occupation, education and household size.

Respondents included both males and females. They consisted of the married, unmarried and widowed who, with the exception of 33.3%, had Basic Certificate, Middle School Leaving Certificate and Ordinary and Advanced Level General Certificates. They also had 1 to 10 years of experience in farming, small-scale mining and public service.

Table 4.4 Socioeconomic Characteristics of Respondents in the Communities along Lake Amponsah

Demographic Variable	Characteristics/ Groupings	Number (*n* = 75)	%
Gender	Male	50	66.7
	Female	25	33.3
Age Group (years)	< 18	3	4.0
	18 - 30	27	36.0
	31 - 40	18	24.0
	41 – 50	16	21.3
	51 – 60	9	12.0
	> 60	2	2.7
Marital Status	Single	22	29.3
	Married	45	60.0
	Divorced	5	6.7
	Widowed	3	4.0
Occupation	Farming	30	40.0
	Mining	25	33.3
	Public servant	5	6.7
	Traders	9	12.0
	Hospitality	3	4.0
	Palm kernel oil extractors	3	4.0
No. of Years of Stay in Community	1 - 10	10	13.3
	11 - 20	8	10.7
	21 - 30	11	14.7
	3 1 - 40	15	20.0
	41 - 50	20	26.7
	51 - 60	4	5.3
	> 60	7	9.3
No. of Years in Small-Scale Industry	< 1	1	4.0
	1 - 5	9	36.0
	6 - 10	6	24.0
	> 10	9	36.0
Palm kernel oil extraction (*n* = 3)	1 – 5	2	66.7
	6-10	1	33.3
Educational Attainment	No. formal education	25	33.3
	MSLC	3	4.0
	BECE	23	30.7

	SSSCE	13	17.3
	O/A Level	8	10.7
	Tertiary	3	4.0
Household Size	3 - 5	41	54.7
	6 - 8	18	24.0
	9 - 11	14	18.7
	12 -14	1	1.3
	15 - 17	1	1.3

4.2.1 Age of respondents

The age group of respondents ranged from <18 to > 60 years. Those who were 18 – 30 years formed the majority (36%), those below 18 years (4%) minority, with those in the age ranges 31 – 40 and 41 – 50 having 24.0% and 21.3% respectively. Only a few (2.7%) of respondents were over 60 years (Figure 4.1).

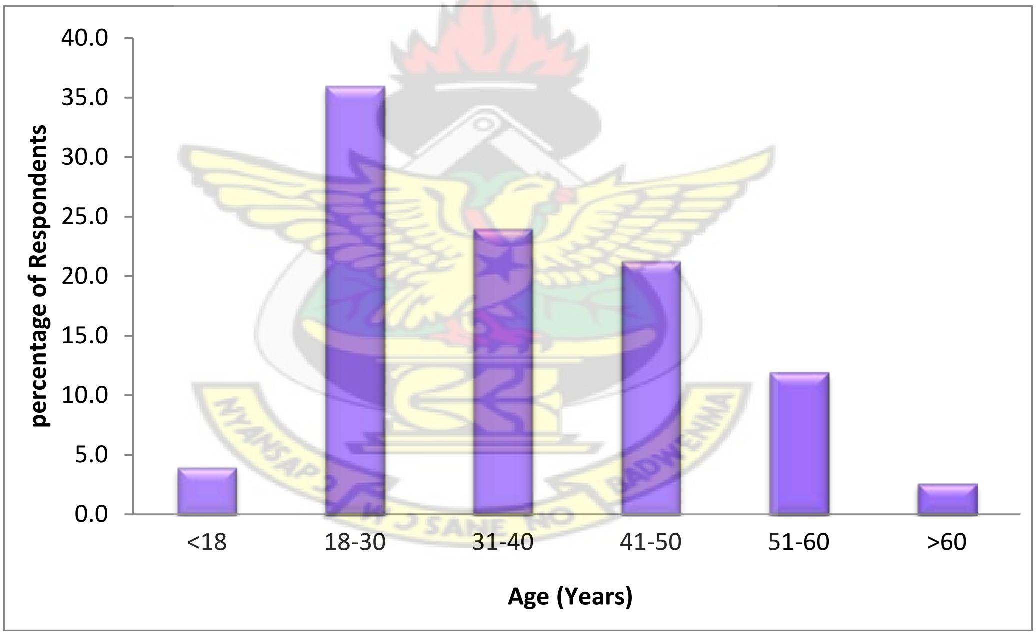

Figure 4.1 Age Distribution of respondents around Lake Amponsah

4.2.2 Marital statuses of respondents

Majority of espondents were either married (60.0%) or single (29.3%). The divorced and widowed formed the minority (Figure 4.2).

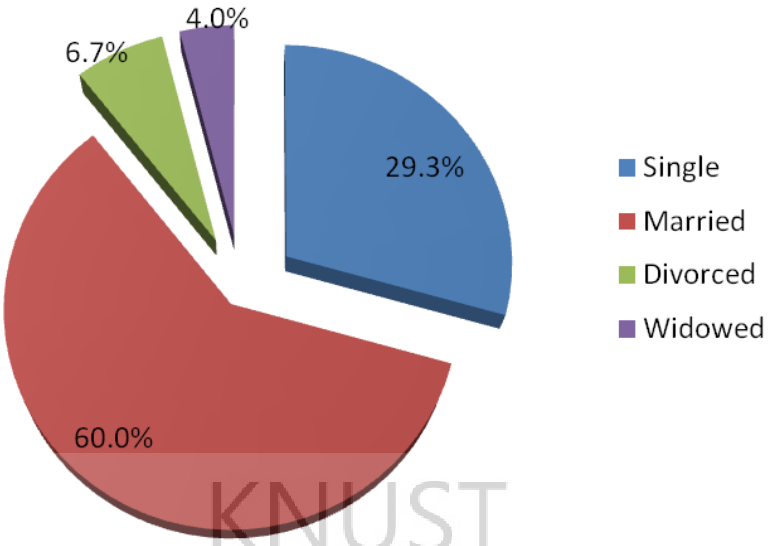

Figure 4.2 Distribution of marital statuses of respondents around Lake Amponsah

4.2.3 Occupations of respondents

Respondents were mainly farmers (40.0%) and small-scale miners (33.3%) (Figure 4.3). Palm kernel oil extractors and those in the hospitality industry were quite few with equal percentages (4.0%).

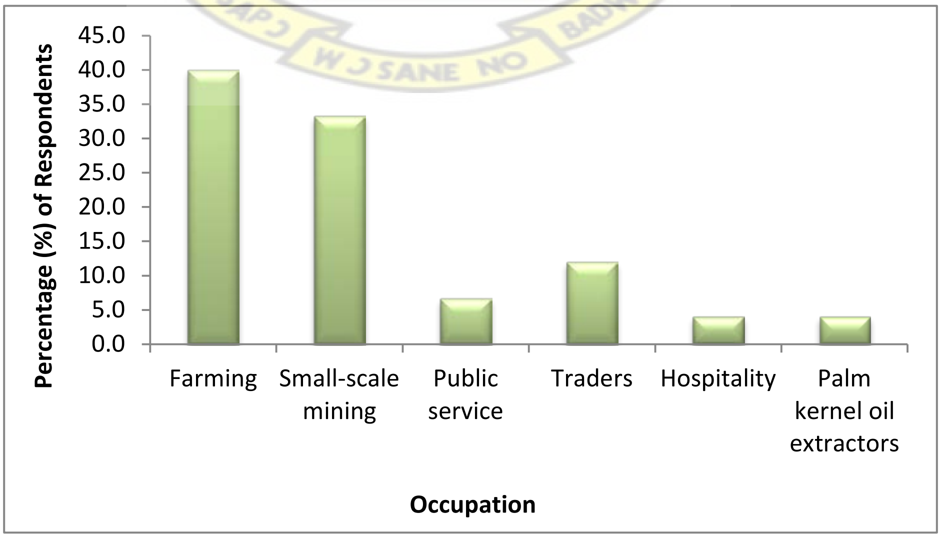

Figure 4.3 Distribution of occupation of respondents around Lake Amponsah

4.2.4 Length of stay in the community

Respondents had lived in the community for periods ranging from one year to sixty years. Those who had lived in the community for 41 to 50 years formed the majority (26.7%). This was followed by those in the range 31 – 40 (20%) and 21 – 30 (14.7%) in that order. Less than 10% had lived in the community for over 60 years (Figure 4.4).

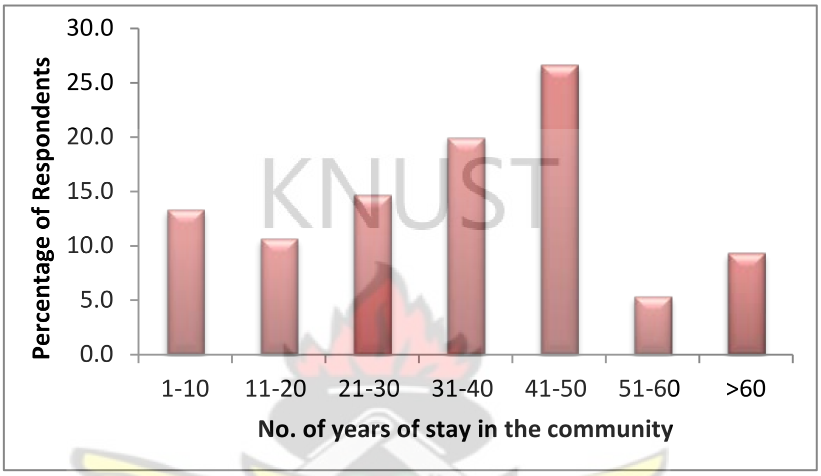

Figure 4.4 Distribution of respondents' length of period of stay around Lake Amponsah

4.2.5 Length of stay in the smale-scale industries along Lake Amponsah

For over ten years, 36% of respondents have been carrying out small-scale mining operations along the Lake Amponsah. Twenty-four percent have been in the occupation for a period between 6 and 10 years. One respondent (representing 4%) is a new entrant (Figure 4.5). Sixty-seven percent of palm kernel oil extractors are relatively newer in the occupation as compared to the 33% that had been in the business for 6 to 10 years.

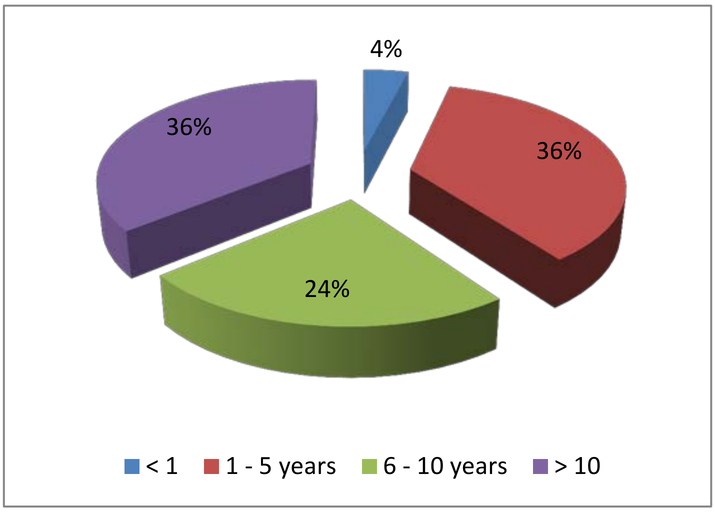

Figure 4.5 Number of years of stay in the small-scale mining industry around Lake Amponsah

4.2.6 Educational attainment by respondents

Twenty-five (25) of respondents, representing (33.3%) had no formal education. Of the educated, 46% had Basic education, 42% Senior Secondary School/Senior High School or General Certificate (Ordinary or Advance Level) education while equal percentage (6%) had Middle School and Tertiary education (Figure 4.6).

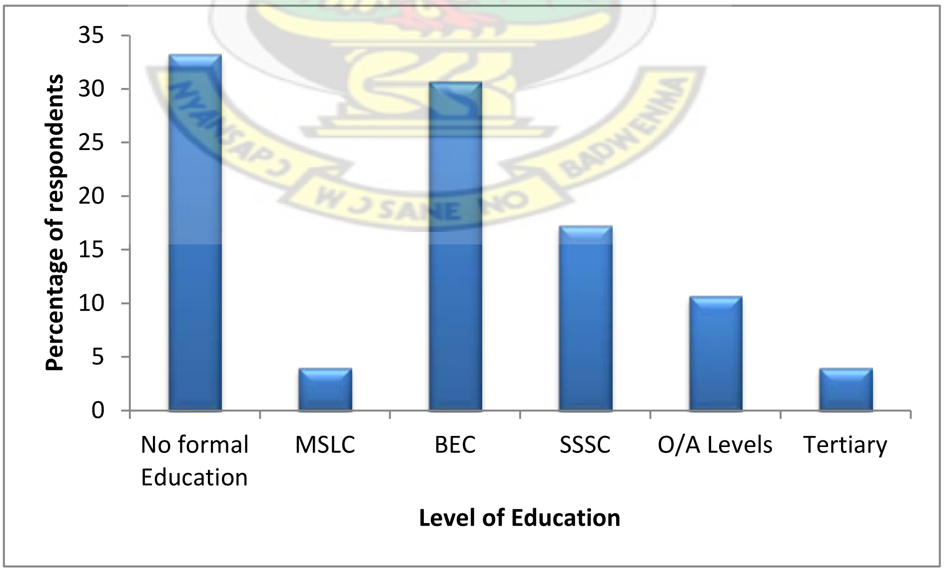

Figure 4.6 Distribution of level of education of respondents

4.2.7 Distribution of household of respondents

The sizes of respondents' households varied and ranged from 3 to 17 people. The commonest class of household size among respondents was 3 – 5 (54.7%). Large household sizes 15 – 17 and 12 – 14 people were the least (2) among respondents, and represented 2.6% (Figure 4.7).

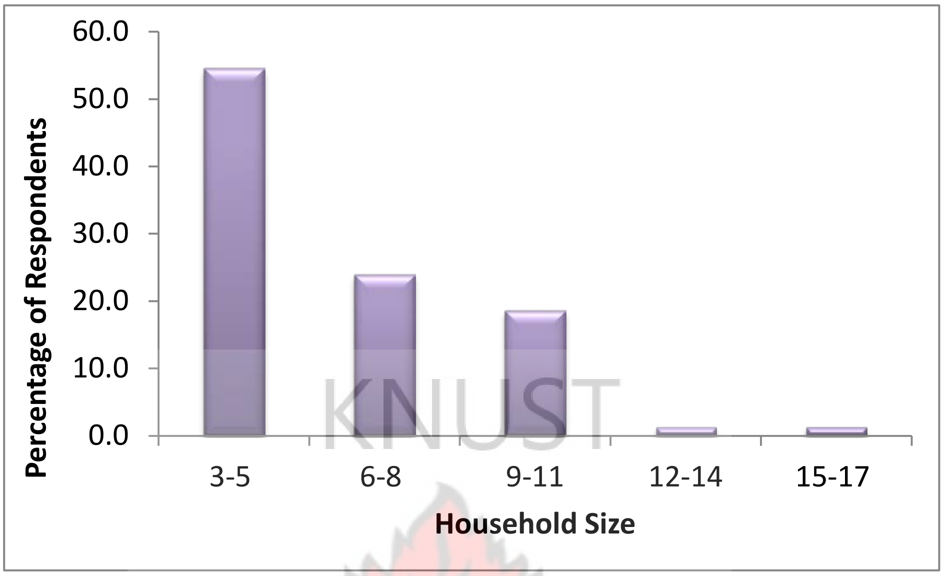

Figure 4.7 Distribution of level of household sizes of respondents around Lake Amponsah

4.2.8 Community's knowledge of environmental degradation

Respondents did not know much about the causes and effects of environmental degradation on humans and the environment itself as well as the anthropogenic contribution to the degradation; fourteen percent (14%) of respondents knew of human factor as a contributor to general environmental degradation and 17% to water pollution in particular. The remaining 69% did not have any knowledge attributed their occurrences of water pollution to curses from the gods.

CHAPTER FIVE

DISCUSSION

5.1 WATER QUALITY CHARACTERISTICS

5.1.1 PHYSICO-CHEMICAL CHARACTERISTICS OF WATER

5.1.1 pH

The pH value is a measure of the hydrogen ion activity in a water sample. The lake water exhibited a slight alkalinity with pH values of 8.256 (Table 4.1). This was within the safe limit (6.5–8.5) for drinking according to WHO Guidelines for drinking water 2011. Based on these guidelines, the pH of the lake water poses no adverse human health hazards. Although pH usually has no direct impact on domestic consumption, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection (WHO, 2011).

According to the WHO (2011) pH of surface water, values typically range between 4 and 11. pH may affect the availability and toxicity of trace metals, non-metallic and some essential elements e. g. selenium. Small changes in pH often cause large changes in the concentration of available metallic complexes and can lead to significant increases in the availability and toxicity of most metals. The observed alkalinity may be attributed to the possible high rates of photosynthesis due to coverage of a section of the lake by aquatic plants (Plate 5.1), which occurs with consumption of high amount of CO_2, a critical factor for increased acidity in water (Canadian Water Quality Guidelines, 2002).

Plate 5.1: A Section of Lake Amponsah with partly covered aquatic weeds

This drives the equilibrium toward alkalinity and hence increases the pH. This is one of the reasons why the practice of dumping wastes including those of phosphorus origin into the lake needs to be checked.

Although aquatic organisms generally have well developed mechanisms for maintaining ionic and osmotic balance, extreme changes in pH may cause negative health effect. According to Ikuta *et al*. (1999) greater energy expenditure, with subsequent effects such as slow growth and reduced fecundity are some of the effects. In some instances, gradual reductions in pH may result in a change in community structure, with acid-tolerant organisms replacing less tolerant ones. pH strongly influences corrosion and scaling processes which may cause considerable damage to industrial equipment and structures. Schorr and Valdez (2006) noted that at pH 6.5 - 8.0 few problems in this regard occur but at levels on either side of this range, corrosion or scaling occurs. This

could affect metallic equipment including those used for small-scale mining.

5.1.2 Turbidity

Turbidity is a measure of the light-scattering ability of water and it indicates of the level of suspended matter in water. It is also related to clarity, a measure of the transparency of water and suspended matter which settles after a defined time period as opposed to that which remains suspended. The mean turbidity (64.8 NTU) was 1296% > 5 NTU, the WHO permissible value. Turbidity is strongly associated with taste and colour of water. It can have a significant effect on the microbiological quality of water. DWAF (1998) reiterated that high turbidity can protect microorganisms from the effects of disinfection and stimulate the growth of bacteria. The turbidity in natural waters is caused by suspended matter which usually consists of a mixture of inorganic matter, e. g. clay and soil particles and organic matter UNEP GEMS (2006). The turbidity of raw water can range from < 1 NTU in very clear water, to >1000 NTU in turbid, muddy water. Discharge of sewage and other wastes were observed around the lake (Plates 5.2). This could be the cause of the high turbidity recorded in this study.

Plate 5.2: Wastes dumping site cited at the bank of Lake Amponsah

The consumption of turbid water *per se* does not have any direct health effects, but the associated effects due to microbial contamination or the ingestion of substances bound to particulate matter, do. However, US EPA (2003) indicated nausea, cramps, diarrhoea, and headaches as symptoms associated with intake of turbid water.

Substances such as clay, silt and finely divided organic material that cause turbidity may scatter light while coloured organic (fulvic, humic and tannic acids), inorganic matter, plankton and other microscopic organisms may absorb light. This may result in decrease in water temperature which may affect temperature-sensitive aquatic organisms.

5.1.3 Temperature

Temperature is a parameter that determines the transfer of heat to, or from, other bodies. It affects other water quality parameters. For instance as temperature increases viscosity, surface tension, compressibility, specific heat, ionization constant and the latent heat of vaporization decrease, whereas thermal conductivity and vapour pressure increase. The solubilities of H, N_2, CO_2 and O decrease with increasing temperature hence decreasing their availability to aquatic organisms. Also elevated water temperatures increase metabolic rates, including respiration and thus oxygen demand of aquatic organisms. Oxygen demand therefore would increase and may lead to a decrease in dissolved oxygen supply. This may induce intensified vulnerability of the aquatic organisms to suppression of normal activities as water temperature increases.

The mean temperature of lake water recorded was 27.9°C (Table 4.1). This is within the natural background levels of 22–29°C for waters in the tropics as noted by (Stumm and Morgan, 1981). However, in the present situation there is indiscriminate discharge of domestic and industrial waste into the lake which may increase organic loads to cause oxygen depletion a situation that needs to be prevented for healthy growth of aquatic organisms. Microbial activity which takes place at higher water temperatures could also be accelerated. Therefore, unless measures are put in place to curb this current trend of anthropogenic perturbations, including riparian vegetation cover removal and disposal of industrial and domestic wastes into the water body by the community and small-scale industries, the possibility of the level soaring above the guideline limit in the near future cannot be ruled out.

Temperature plays an important role in water by affecting the rates of chemical reactions and therefore the metabolic rates of organisms. According to the Environmental Protection Division (2001), the effect of temperature changes on aquatic organisms depends on the extent, duration and timing of these changes. Relatively small temperature changes, if maintained for a period of time, may lead to alterations in community composition, as a result of the differential optimal temperatures of the respective organisms. Large, rapid shifts in temperature are lethal to aquatic organisms. It is therefore one of the major factors controlling the distribution of aquatic organisms. Again, clearance of vegetation could promote higher rate of evapotranspiration from the lake surface. This in turn could lead to decrease in lake water volume and hence increase the concentration of pollutants to worsen the effect of pollution on aquatic organisms.

5.1.4 Dissolved solids

Dissolved solids, comprise total dissolved solids (TDS) and total suspended solids (TSS) and are the respective measures of the quantity of all compounds that are dissolved and suspended. DS value recorded 120.06mg/l and 262.647 mg/l (Table 4.1) respectively were below the WHO recommended limit of 1000 mg/l for drinking water (WHO, 1996). According to McCutheon *et al.* (1983) the palatability of water with a TDS level less than 600 mg/l is generally considered to be good whereas water with TDS greater than 1200 mg/l becomes increasingly unpalatable. However the Environmental Protection Division (2001) posited that for aesthetic objective, TDS should not be higher than 500 mg/l. This indicates that based on the latter, the lake is aesthetically unpolluted.

TDS concentration is directly proportional to the electrical conductivity (EC) of water which is a measure of the ability of water to conduct an electrical current (DWAF, 2006). The level (571.267 µS/cm) of electrical conductivity (EC) of the lake water was within the World Health Organization (WHO) drinking water permissible limit of 1500µs/cm. Plants and animals possess a wide range of physiological mechanisms and adaptations to maintain the necessary balance of water and dissolved ions in cells and tissues. This however has a threshold beyond which they would be adversely affected. The characteristics of the geological formations are strong factors that affect TDS concentrations of natural waters (DWAF, 2006).

Natural waters contain varying quantities of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material. Temperature and rainfall are other factors. Increases in total suspended solids may also result from anthropogenic sources, including, discharges of domestic sewage and industrial effluents (e. g. pulp and paper mill, clay, brick and pottery industries) and discharge from mining operations DWAF (1996). Mining activities at the bank of the lake characterized by removal of vegetation and discharge of mine waste together with inflow of domestic and other industrial waste could be the source of the TDS level recorded. This confirms the observation by the DWAF (1996), that land use practices such as overgrazing, and removal of riparian vegetation accelerate erosion and result in increased loads of suspended solids in rivers.

5.1.5 Colour (True Colour)

The true colour of water is the visual attribute of water resulting from the light it emit, transmits or reflects. It is the colour after the water has been filtered through a 0.45 micron filter. It may also result from the contamination of the water source with industrial effluents. Most people can detect colour above 15 true colour units (TCU) in a glass of water. In natural waters, colour is due mainly to the presence of dissolved organic matter originating from soil and decaying vegetable matter (Smith and Davie-Colley, 1992). The citing of industries (palm kernel oil extraction and small-scale mining) as well as refuse dump in the vicinity of the lake could be the source of the higher degree of coloration (172.0 and 847.7 TCU) reported in the study (Table 4.1) than the WHO level of 150 TCU. This indicates that even the minimum level of coloration in this study was beyond the acceptable level. Although there is no health based guideline limit for colour, an aesthetic objective or limit of ≤ 15 TCU has been set to minimize consumer concern.

The colour of samples reported in this study varied between 172.0 and 847.7 TUC (Table 4.1). The WHO level of colour is 150 TCU. Colour is an important physical property of water because of its implications for water supply, and the need to reduce it to acceptable levels by water treatment is highly recommended (Tõnno *et al*., 2003). Increase in the colour of water in a lake may lead to increases in treatment cost. Colour is also known to modify the toxicity of certain contaminants, such as metals. For instance, the toxicities of aluminum, copper, and zinc are reduced in coloured waters because they form complexes with humic substances that render these metals unavailable. Conversely, mercury availability, bioaccumulation in fish and hence toxicity increase as water colour increases. This is also true for other metals and these may play a significant role in determining toxicity of contaminants in waters that are naturally highly coloured (Scheren *et al*., 2000).

5.1.6 Alkalinity and Total Hardness

Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of the organisms that rely on this ecosystem service (Stark *et al*., 2000). The presence of these minerals imparts alkalinity and hardness to water. Calcium and magnesium ions are two critical mineral ions that excel in this respect. The means levels of both alkalinity (160.333 mg/l and total hardness 145.333 mg/l) recorded in this study were all within the WHO recommended limit for drinking water of 400 mg/l (Table 4.1).

Public acceptability of the degree of hardness of water may vary considerably from one community to another. The taste threshold for the calcium ion is in the range of 100–300 mg/l, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium (WHO, 2004). A range of 75 mg/l to more than 300 mg/l has also been set by the Guidelines for Canadian Drinking Water Quality (2004). The US EPA (1986) indicated that alkalinity level of 100-200 ppm or its equivalent 99.89 -199.78 mg/l will stabilize the pH level in an aquatic environment. Buffering materials in aquatic environments are produced by leaching minerals, through rocks, soil and other waste. The geological formation together with the activities of small-sale miners and disposal of wastes could account for the observed moderate buffering capacity of the lake water and could have offset any possible rise in hardness above the recommended limit. Calcium and magnesium are needed to support calcification of larval skeletal structures; support newly fertilized freshwater fish eggs and mitigate the toxicity of some metals to gill-breathing organisms (Burton Jr. and Pitt, 2002). Timmons *et al*. (2002) observed that alkalinity and hardness are related through common ions formed in aquatic systems. Specifically, the counter-ions associated with the bicarbonate and carbonate fraction of alkalinity are the principal ions responsible for hardness (usually Ca^{2+} and Mg^{2+}).

5.1.7 Dissolved Oxygen (DO)

Many aquatic ecosystems rely heavily on external subsidies of organic matter to sustain production. However, excess inputs of organic matter from the drainage basin, can upset the production balance of an aquatic system and lead to excessive bacterial production and consumption of dissolved oxygen that could compromise the integrity of the ecosystem and lead to favourable conditions. Therefore maintenance of adequate DO concentrations is critical for the survival and functioning of the aquatic biota because it is required for the respiration of all aerobic organisms. It provides a useful measure of the health of an aquatic ecosystem. High amount of dissolved oxygen has often been used as an indicator of good water quality (DFID, 1999).

In unpolluted surface waters, dissolved oxygen concentrations are usually close to saturation. 60 % is Sub lethal while 40% is lethal. Violation of these minimum values is likely to cause acute toxic effects on aquatic biota (DWAF, 1996). Also according to (DFID, 1999), DO concentrations of 8.0–10.0 mg/l at 25^{o}C is good but below 5.0 mg/l adversely affect aquatic life. Prolonged exposure of aquatic communities to dissolved oxygen concentrations less than 50 % of saturation can cause significant changes in community composition, as more tolerant species are favoured. Also, the US Department of Ecology (2010) set a minimum DO concentration of > 8.0 mg/l at natural conditions for rearing/spawning.

DO level of the lake water varied between 1.2 and 4.2 mg/l with a mean of 2.887 mg/l (Table 4.1). The lower level of DO may be caused by suspension of anoxic sediments resulting from river floods or mining activities, oxidizable organic matter of natural origin (detritus) or from the discharged wastes. It may also change the sensitivity of the aquatic fish and invertebrates at eggs, larvae and adult stages, feeding and reproduction behaviours and may exhibit little ability to reverse toxic effects.

5.1.8 Biochemical Oxygen Demand (BOD)

BOD measures the amount of biodegradable organic content in water, A ranged between 0.9 mg/l and 1.7 mg/l was recorded in this study (Table 4.1). The mean value of 1.32 mg/l recorded fell within the WHO recommended value of < 3.0. The discharge of refuse may be source of the BOD recorded in this study. According to APHA *et al.* (1998), natural waters with BOD value of 4 mg/l are considered to be slightly polluted with organic matter but safe for drinking. Relatively healthy streams will have a 5-day BOD reading of less than 2 mg/l, whereas polluted streams may approach 10 mg/l (Dallas and Day, 1993). Although these observations may suggest that there is a low quantity of effluents in Lake Amponsah and that the low is not threatened with respect to BOD level (DWAF, 1996), the present rate of expansion of the observed anthropogenic impact could impose higher restrictions on the suitability of the lake for aquatic life.

5.1.9 Fluoride (F)

Fluoride, a highly reactive halogen rarely exist as free fluorine gas in nature, but occurs either as the fluoride ion or in combination with calcium, potassium and phosphates. DWAF (1996) noted that traces of fluoride (< 1 mg/l) occur in many aquatic ecosystems. Low concentrations of fluoride (< 1000 μg/l) strengthen tooth enamel and bones in mammals. The guideline values of the WHO and European Union for F concentration is 1.5 mg/l and 2mg/l and 0.8 mg /l for US and Japan respectively according to (WHO, 2008). Water samples analyzed for fluoride in the study was consistently < 0.01 mg/l suggesting that the lake water is of good quality in terms of fluoride. Epidemiological evidence exists that concentrations above this value carry an increasing risk of dental fluorosis and that progressively higher concentrations lead to increasing risks of skeletal fluorosis (Camargo, 2003). Dubey (2009) stated that it would be useful to consider setting a standard or local guideline at a concentration lower than 1.5 mg/l, a recommended level for artificial fluoridation of water supplies set by Rodgher *et al*. (2011). Fluoride toxicity can seriously affect aquatic life. For instance, it has been reported by Mishra *et al*., (2009) that at fluoride concentration > 60 mg /l and at high temperatures there is a higher reduction in the growth of aquatic floating plant (50%) than at low temperatures. Therefore in Lake Amponsah where temperature elevation has been observed a rise in fluoride levels could adversely affect aquatic flora and hence productivity.

5.1.10 Sulphate (SO_4^{2-})

The range of sulphate (SO_4^{2-}) in the samples was 11.0 to 17.0 mg/l and had a mean concentration of 14.13 mg/l. This was below the WHO permissible limit for drinking water and therefore is not likely to cause adverse human health effects. However, according to DWAF (1996), usually, the concentration of sulphate in surface water is 5 mg/l and may reach several 100 mg/l where dissolution of sulphate minerals or discharge of sulphate rich effluents from acid mine drainage takes place.

Leaching of materials of sulphate origin from the disposed waste and also mining activities around the lake could be a source of the higher concentration of sulphate recorded in the study. Sulphates are discharged into the aquatic environment in wastes from industries that use sulphates and sulphuric acid (e.g. mining and smelting operations). Atmospheric sulphur dioxide may also contribute to the sulphate content of surface waters (Eisler and Wiemeyer, 2004). Sulphate is one of the least toxic anions, ingestion of large quantities of which may result in major physiological effects including gastrointestinal irritation. This effect is enhanced when sulphate is consumed in combination with magnesium. Water containing magnesium sulphate at levels above 1000 mg/l acts as a purgative in human adults. Lower concentrations may affect new users and children. Ingestion of water containing magnesium sulphate at concentrations in excess of 600 mg/l can cause diarrhoea in children. Generally taste threshold concentrations for various sulphate salts appear to be at or above 500 mg/l (WHO, 2008).

5.1.11 Copper (Cu)

Copper is a common metallic element in the rocks and minerals of the earth's crust, and is commonly found as an impurity in mineral ores. Average copper concentration in the lake water sample was 0.033 mg/l which was below the limit of 2.0 mg/l permitted by WHO in drinking water. Also levels in sediments with variation from 0.316 mg/kg to 0.518 mg/kg and a mean of 0.428 mg/kg (Table 4.3) were recorded in this study. The occurrence of natural sources of copper in the aquatic environment is due to weathering processes or from dissolution of copper minerals and native copper. Metallic copper is insoluble in water. Anthropogenic sources account for 33 - 60 % of the total annual global input of copper to the aquatic environment (Das and Notling, 1993).

Cu has been shown to cause acute gastrointestinal discomfort and nausea at concentrations above 3 mg/l. Even at lower concentrations in water dissolved copper causes brain damage in mammals (Das and Notling, 1993). The extreme toxicity of dissolved copper, calls for the adoption of a precautionary approach. The duration of exposure and the life stage of the organism are some of the factors that influence the effect of copper concentrations on aquatic organisms. Higher concentrations can alter species richness and species composition of invertebrate communities (WHO, 2004). Copper is easily adsorbed and precipitated in sediments at alkaline pH. Less than 1 % of total copper exists in the free ionic form in natural waters. It is therefore not surprising that Cu concentration in sediment was higher than in water (0.428 mg/kg and 0.033mg/l respectively). The toxicity of copper increases with a decrease in dissolved oxygen. The low level of dissolved oxygen in the study could therefore contribute to the high concentration of copper.

5.1.12 Iron (Fe)

Iron concentration in natural waters depends on the geology of the area as well as the properties of other chemicals present in the water body. The form (ferrous, Fe^{2+}) or (ferric, Fe^{3+}) in which it occurs determines its oxygen availability. In waters of good oxygen concentration, the ferric form is insoluble while the ferrous form is more soluble in reducing waters. The colour imparted to drinking water may be a source of concern to consumers at levels above 0.3 mg/l (WHO, 2004). The mean concentration of Fe recorded in the study 2.26 mg/l (Table 4.1) and the levels varied between 1.257 and 4.210 mg/l were above the maximum limits WHO (2004) guideline value of 0.3 mg/l for drinking water. The natural source of iron in waters includes weathering of rocks. However iron is also released into the lake by leaching from sandstone, anthropogenic sources such as discharge of acid mine drainage, mineral processing and sewage and landfill leachates. These activities are not uncommon in the vicinity of the lake and could account for the high levels of iron recorded.

Iron is an essential trace element for both plants and animals. It is required by most organisms for essential growth and development. Its deficiency could cause adverse biological effects. The toxicity of iron depends on whether it is in the ferrous or ferric state, and in suspension or solution. It may act as inhibitors to various enzymes. Water Stewardship Division (2008) notes that the concentration should not exceed 1.0 mg/l total iron and 0.35 mg/l dissolved iron to protect freshwater aquatic life from adverse effects of iron. An acute toxicity to aquatic insects at iron concentrations ranging from 0.320 mg/l to 16.000 mg/l has been reported (Warnick and Bell 1969).

Iron (Fe) has frequently been used as an indication of natural changes in the trace metal carrying capacity of sediments (Rule, 1986), and its concentration has been related to the abundance of metal reactive compounds supposedly not significantly affected by man's action (Luoma, 1990). GESAMP (1982) and Salomons and Froster (1984) also noted that the recommended values of unpolluted sediments is 41000.000 mg/kg. This suggests that Fe levels in sediment from the lake which varied from 459.447 to 676.896 mg/kg and had a mean concentration of 562.278 ± 73.214 mg/kg is unpolluted. Effect of anthropogenic activities which constantly lead to agitation of the water could restrict settlement of the sediment but encourage its availability in the water to cause increased concentration in the later.

5.1.13 Arsenic

Arsenic (As) is one of the chemicals of greatest health concern in some natural waters. Mance (1987) stated that apart from occupational exposure, the most important routes of exposure are through food and drinking water, including beverages that are made from drinking water. Arsenic levels in Lake Amponsah was in the range 0.104-0.818 mg/l and exhibited a mean of 0.285 mg/l, values which are in excess of the WHO guideline limit of 0.010 mg/l (WHO, 1993 and WHO, 2008). The WHO (2008), observed that arsenic levels in natural waters generally range between 0.001 and 0.002 mg/l, although levels may be elevated (up to 0.012 mg/l) in areas containing natural sources. Environmental Protection Division (2001) prescribed an interim guideline maximum arsenic concentration of 0.025 for drinking water sources and 0.005 for freshwater aquatic life and none for recreation and aesthetics.

The ADWG (1996) noted that soluble arsenic salts are readily absorbed by the gastro-intestinal tract. After absorption inorganic arsenic binds to haemoglobin, and is deposited in the liver, kidney, lungs, spleen, and skin. According to the US EPA (2002) arsenic is classified as "very toxic and relatively accessible" to aquatic organisms. It has a variety of adverse effects on both vertebrate and invertebrate aquatic organisms, the type and severity of adverse effects being dependent on the life stages of the organisms concerned. Exposure to arsenic results in reduced growth and reproduction in both fish and invertebrate populations. Arsenic also causes behavioural changes such as reduced migration in fish (DWAF, 1996**)**.

Arsenic results from weathering of arsenic-containing rocks and volcanic activity. Its distribution in sediments is spatially heterogeneous (Mandal and Suzuki, 2002). Its level in the sediments in this study ranged between 3.050 and 4.446 mg/kg with an average value of 3.558 mg/kg. In the sediments, arsenic, together with phosphate ($PO4^{3-}$), appears to be primarily adsorbed on amorphous Fe oxyhydroxides (FAO, 2006). Its ease of adsorption onto sediments and suspended solids enhances its high concentrations in water bodies subjected to industrial pollution, or activities such as mining, leaching of fertilizers and detergents (WHO, 2008), which are common activities that occur around Lake Amponsah.

5.1.14 Zinc

Zinc is a trace metal and also an essential micronutrient in all organisms. It is an essential micronutrient for all organisms as it forms the active site in various metalloenzymes. Zn is one of the earliest known trace metals and a common environmental pollutant. It is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. A mean concentration of < 0.010mg/l (Table 4.1) of Zn was recorded in this study, with a range < 0.010 and 0.010 mg/l. This fell below the threshold value (3 mg/l) acceptable to consumers WHO (2008). Drinking water containing zinc at levels below levels as occurred in this study indicates absence of detrimental effect when the water is used for domestic purposes. However, prolonged consumption of considerably large doses can result in some health complications such as fatigue, dizziness and neutropenia (Hess and Schmidt, 2002). In the case of sediment, it was 1.311 mg/kg (Table 4.3), a value below the recommended maximum concentration (95 mg/kg) which should not be exceeded to prevent specified detrimental effects from occurring (Salomons and Foster, 1984).

In aquatic ecosystems zinc is toxic to fish and aquatic organisms at relatively low concentrations. The requirement for trace elements frequently varies substantially between species, but the optimal concentration range is generally narrow. According to Alabaster and Lloyd (1980), Zn could be toxic to some aquatic organisms such as fish. Severe imbalances can cause death, whereas marginal imbalances contribute to reduced fitness. The lethal effect of zinc on fish is thought to be from the formation of insoluble compounds in the mucus covering the gills.

Zinc occurs in rocks and ores and can enter aquatic ecosystems through both natural processes such as weathering and erosion, and through industrial activity. The greatest dissolved zinc concentrations will occur in water with low pH, low alkalinity and high ionic strength (Goss *et al*., 2002). Possible sources of Zn in sediment from the lake include industrial effluents from the small-scale mining, urban storm water runoff and domestic effluents. Although these activities occur around the lake, the high pH and low alkalinity could have restricted its dissolution in the lake water and also its availability in the sediments.

5.1.15 Lead

Lead is defined by the US EPA as potentially hazardous to most forms of life including terrestrial and aquatic habitats. Its toxicity and accessibility are described by the US EPA as considerable. In raw drinking water, with and without treatment, the total lead concentration should not exceed 50 µg/l at any time (Environmental Protection Division, 2001). However the WHO gave a guideline value of 0.01 mg/l for Pb in domestic water supply (WHO, 2008). In freshwater the maximum level as set by the Environmental Protection Division (2001) are water 3 µg/l for (hardness ≤ 8 mg/l) and 3.31 µg/l for (hardness > 8 mg/l) while 50 µg/l is recommended for recreation and aesthetics. It is principally released into the aquatic environment through weathering of sulphide ores. It enters the aquatic ecosystems via direct deposition or surface runoff and occurs as by-products of lead photolysis. The concentration of lead recorded in the lake water varied between 0.009 and 0.880 mg/l with a mean of 0.170 mg/l (Table 4.1).

Sediments from the lake had a mean lead concentration of 0.487 mg/kg and varied from 0.255 to 0.809 mg/kg (Table 4.3) which was below the recommended values (19.00 mg/kg) of unpolluted sediments (Salomons and Froster, 1984). According to the WHO (2008), the major sources of lead in the aquatic environment are anthropogenic; these include fallout of lead dust and runoff associated with lead emissions from gasoline-powered motor vehicles, industrial and municipal wastewater discharge and mining. Small-scale mining activities around the lake could contribute to lead deposition through the use of gasoline-powered motors. Since these occur also around the lake, the lower concentration of Pb in sediment of the lake is quite surprising. Other factors that affect dissolution and availability of lead could have exerted their influence at the expense of those sources. DWAF (1996) notes that, lead exerts chronic and acute toxic effects on aquatic organisms through interference with haemoglobin synthesis, displacement of calcium at functional sites and inhibition of some enzymes involved in energy metabolism. When absorbed by vertebrate it is deposited in the bony skeleton, where it forms mucous to cause suffocation.

5.1.16 Nickel

Nickel is one of the most common of the metals occurring in surface waters. It is not unequivocally considered essential to aquatic organisms, mainly because nickel requirements of many species have not been studied (Gray *et al*., 2001). Natural sources of nickel include weathering of rocks, inflow of particulate matter, and precipitation (McGeer *et al*., 2003). The mean Ni level recorded in the lake water was 0 .010 mg/l. Values ranged between < 0.01mg/l and 0.010 mg/l. These values were below the WHO guideline value of 0.07 mg/l for drinking water (WHO, 2008). Also the mean level of nickel in the sediments in this study was 0.332 mg/kg and varied from 0.221 to 0.448 mg/kg and was below the US EPA guideline value of 51.6 mg/kg. This metal normally occurs in surface waters at low concentrations. Anthropogenic sources of nickel include the burning of coal and other fossil fuels, and discharges from such industries as electroplating and smelting (US EPA, 1995). These anthropogenic activities are rare in the vicinity and may explain the low concentrations of nickel recorded in the study.

According to the WHO (2005), the concentration of nickel in drinking water is normally less than 0.02 mg/l, although in special cases of release from natural or industrial nickel deposits in the ground, nickel concentrations in drinking water may be higher. It can be toxic to aquatic life. The US EPA (1986) observed respiratory effects and dermatitis in aquatic life. The toxicity appears to decrease with increasing hardness. Aquatic organisms including fish may show variation of tolerance to nickel concentrations.

5.1.17 Cadmium

Cadmium is a metal element which is highly toxic to marine and fresh water aquatic life. It is insoluble in water although many of its organic and inorganic salts are highly soluble. It is among the elements defined by the US EPA as potentially hazardous to most forms of life, and is considered to be toxic and relatively accessible to aquatic organisms. Cadmium concentrations in unpolluted natural waters are usually below 0.001 mg/l WHO (2011). The lake water recorded a higher mean Cd value (0.044 mg/l) exceeding the WHO guideline value of 0.003 mg/l (WHO, 2008). It is chemically similar to Zn and occurs naturally with Zn and Pb in sulphide ores (e.g. ZnS and PbS). The mean Cd level detected in sediments from the Lake Amponsah was 0.043 mg/kg and varied from 0.019 to 0.240 mg/kg (Table 4.3). This was lower than the guideline value (0.11 mg/kg) of unpolluted marine sediments (GESAMP, 1982; Salomons and Froster, 1984; IAEA, 1989).

Cadmium is present in the earth's crust at an average concentration of 0.2 mg/kg. Due to its abundance, large quantities of cadmium enter the global environment annually as a result of natural weathering processes. Anthropogenic activities that release cadmium into the environment include wastewater, and diffuse pollution from fertilizers and local air pollution. In fresh waters Cd is found at trace concentrations mostly as a result of industrial activities through emission from mining, fertilizers and pesticides application in agriculture and deterioration of galvanized materials and cadmium-plated containers. The higher concentration of cadmium in this study may have resulted from mining activities and the dumped waste which may include cadmium-based containers. Cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of 10–35 years (DWAF, 1996). There is evidence that cadmium is carcinogenic by the inhalation route, but not by the oral route. It is known to inhibit bone repair mechanisms. It is accumulated by macrophytes, phytoplankton, zooplankton, invertebrates and fish.

5.1.18 Mercury

Mercury is a heavy metal that occurs at very low levels in the natural environment. It may occur at concentrations < 0.5 µg/l in natural waters. A mean value of 0.007 mg/l was recorded in water sample in this study (Table 4.1), which is higher than the WHO guideline value of 0.001 mg/l for mercury probably due to the discharge of mercury compounds into the lake by small-scale mining activities. It may however occur at high levels in water bodies subject to industrial pollution, or in the vicinity of industrial activities that utilize or discharge mercury or compounds thereof. Naturally occurring levels of Hg in surface and ground water is < 0.5 µg/l. Sediment levels of Hg recorded in this study ranged from 0.005 to 0.053 mg/kg at a mean of 0.026 mg/kg (Table 4.3). This was below the set guideline value of 0.20 mg/kg for sediment in mercury by the US EPA. Mercury has a strong affinity for sediments and suspended solids.

According to the DWAF (1996), mercury serves no known beneficial physiological function in humans. The kidneys are the main route of excretion of inorganic mercury. In humans, acute oral poisoning results primarily in haemorrhagic gastritis and colitis; the ultimate damage being to the kidney. Dissolved mercury salts are also easily absorbed by aquatic organisms and can be bio-accumulated which in turn increases the risk of mercury toxicity to aquatic and terrestrial organisms in the food chain. Mercury is present in the inorganic form in surface water and groundwater at concentrations usually below 0.5 µg/l although local mineral deposits may produce higher levels in groundwater. Inorganic mercury can also cause nausea, vomiting, pain, ulceration and diarrhoea (WHO, 1980). These toxicity effects of mercury therefore suggest health risk for both humans and aquatic life forms.

5.1.19 Correlation among water quality parameters

The correlation of the parameters did not follow a particular trend embracing all (negative, zero and positive trends) making their effects on each other generally quite uncertain. Except for a strong positive correlation with Cu, pH did not show any significant correlation with any of the other parameters. pH characteristically influenced adsorption. Maximum adsorption occurred at pH 2 and 12 whereas minimum adsorption occurred at pH 6-8 (Igwe *et al.*, 2005). Also Hodi *et al.* (1995) observed a slower adsorption of cadmium at higher pH values. The correlation of As with PO_4^{3-} was very significantly positive. Similarly, Fe exhibited very significant positive correlation with As and PO_4^{3-}. As is strongly adsorbed on the surface of iron hydroxide through the formation of inner-sphere complexes (Bang and Meng, 2004). Again, As and PO_4^{3-} indicated a negative correlation with Cd. Also Cu showed negative correlation with Hg (weak), PO_4^{3-} (moderate) and As (strong). Ni did not generally correlate with any of the parameters. Pb negatively correlated with all of the parameters. Cd did not generally show any significant correlation with the other parameters except moderate correlation

with PO_4^{3-} and As. The correlated of Hg with the parameters were not significant.

5.1.2 Bacteriological characteristics of samples

5.1.2.1 Bacteriological characteristics of water

Given the importance of quality water, bacteriological pollution should be considered since it also affects the ability of resident and non-resident organisms to use resources provided by the ecosystem and to maintain ecological services. Coliform count is the microbiological test used to detect the level of pollutions caused by living things especially human beings. According to Wommack and Colwell (2000), securing the microbial safety of drinking water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination including entry and growth of pathogens to levels not injurious to health. It is for this reason, that it is not only the end product that matters. Total coliforms and faecal coliforms specifically are tests used to indicate the presence of pathogenic organisms in water (Ashbolt *et al.*, 2001).

The results (Table 4.1) obtained for the bacteriological analysis of the lake water indicate that the microbial water quality of Lake Amponsah was poor. According to WHO (1993), coliform bacteria must not be detectable in any 100 ml (i.e. 0/100 ml) of all water intended for drinking. The mean total coliform was 1835 cfc/100 ml while the faecal coliform was 1154 cfc /100 ml. The results suggest that the general microbial qualities of the lake water are unacceptable. This may be attributed to faecal pollution of the lake resulting from the discharge of agricultural wastes as well as domestic including human excreta into the lake. Apart from serving as a source of domestic water supply, the lake is used for other purposes such as recreation including swimming and small-scale mining. Pollution of lake would therefore imply a possible serious health risk through outbreak of water-related diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996), a development which calls for urgent measure to curb the menace.

5.2 COMMUNITIES UNDERSTANDING OF CAUSES AND EFFECTS OF WATER QUALITY DETERIORATION

5.2.1 Gender

The small-scale industries which directly impacted Lake Amponsah, by virtue of proximity, were the small-scale mining operation (Plate 5.3) and the palm kernel extraction industry (Plate 5.4).

Plate 5.3: A site for gold recovery (using mercury) at the bank of Lake Amponsah

Plate 5.4: Palm kernel oil extraction industry with kernel wastes discharged into the drain that enters the Lake Amponsah

Women's involvement in these activities was relatively minimal. The illegal mining operations had a larger number of people (55) who were all men and 25 of whom were interviewed while the kernel extraction industry had 5 all of who were females and 3 interviewed. According to FAO Women and Population Division (1996), women have considerable knowledge about water resources, including water quality and reliability and are key to the success of water resources development and protection. The inclusion of 33.3% of women around the lake in the study could therefore generate vital information that would help in the conservation of the lake.

5.2.2 Age Distribution of Respondents

The economically active population comprises all persons of either sex, and above a certain age, who furnish the supply of labour for the productive activities (falling in the production boundary of the system), during a specified time-reference period. It includes all persons who fulfill the requirements for inclusion among the employed (employees or self employed) or the unemployed (European System of National and Regional Accounts, 1995). Majority (85.3%) of respondents were of ages ranging between 18 and 50 (Figure 4.1) and was dominated by those in the range 18 to 30 years (36%). Respondents who formed majority of this age group were the most energetic and active and were engaged in the illegal mining operations suggesting that the intensity of their activities could be very high and exerts a proportionally high impact on the lake.

The most-active population in China, India, Europe and the United States of America is the age group 20-34 years (United Nations, Department of Economic and Social Affairs, 2011). Ihake (2008) recounted that age is negatively related to output and that negative relation indicates that in advanced age, output decreases due to decline in the ability to do manual work. About 88% of the interviewees (small-scale miners) were in the age class of 18-50 years who are involved in small-scale mining activities.

5.2.3 Respondents' Occupation

The predominant occupation in the community is farming (40.0%). This is followed by small-scale mining (33.3%) (Figure 4.3). However during the dry season when agricultural activities are not brisk, some farmers undertake small-scale mining thereby increasing the number of small-scale miners over that of the raining season. This promotes also the occurrence of illegal mining. The small-scale miners are both natives and foreigners. Macro-level models predicts that labour will flow from 'labour-abundant' regions to 'labour-scarce' ones in order to secure higher wages on offer (Nyame and Grant, 2007).

Plate 5.5: Excavated earth heaped around Lake Amponsah due to small-scale mining

Farming does not occur around the lake due to the occurrence of small-scale mining activities. Among the activities of respondents, small-scale mining and palm kernel extraction exert direct effect on the lake. Several key environmental issues are associated with small-scale mining. They include those related to siltation and destruction of riparian vegetation (Plate 5.5) (International Resources Group, 2009).

Plates 5.6: Interview with some small-scale miniers

5.2.4 Number of years in the business

Sixty percent (60%) of the total respondents sampled have been in the small-scale mining for a period over 6 years and (36%) over 10 years. This may suggest that there has been continuous subjection of the lake to the effect of these mining operations for quite some time. Again the occurrence of the palm kernel oil extraction activities for 1 – 5 years by two respondents and 6 -10 by another respondent may indicate an expansion of attraction to the industry with its attendant impact on the lake water quality. Ajewole (2010) noted that with a greater number of years of experience, people become more risk-averse when judging new technology. Holding all other factors constant, higher number of years in an occupation implies more experience. This in turn encourages the individual to remain. In this study, this promotes the degradation of the lake unless the effects of the activities are very well understood or are directly felt by the offender.

5.2.5 Educational attainment

Although majority 50 (representing 66.7%) of respondents had formal education, it is only 48% of the educated that had attained levels beyond the basic education. In the general sense sixty-eight percent (68%) of total respondents either have no formal education or have only basic education (Figure 4.6). Education may increase ability of individuals and groups to adjust disequilibrium and the propensity to successfully adopt innovations (Weir, 1999).

People can be a major asset in reversing a trend towards degradation. However, they need to be educated as subsistence agriculture, poverty and illiteracy can be important root causes of environmental degradation. For instance it may be difficult for illiterates to perceive what some environmental changes are, e. g. what sulphur dioxide or dissolved oxygen means in terms of water quality (Eswaran *et al.*, 2001). Abdin and Gaafar (2009) reiterated that water stress conditions are bound to such factors as conscious behaviuor of the users. This derives from the level of education, accessibility and availability of information and cultural patterns.

5.2.6 Households

Results show generally large household sizes, ranging from 3 to 17. Over forty-five percent of respondents (45.3%) had household sizes of 6 and above (Figure 4.7). In a community where natural resources are negatively impacted by anthropogenic activities large household sizes play important role. Bolaane and Ali (2004) noted some correlation between waste generation and household. Again households with more members use more of their home labour to enhance their activities (Hoang and Yabe, 2012). The tendency is for inhabitants to make adjustments and also seek for alternatives whenever possible. Ghimire and Mohai (2005) observed that the adjustments people make in their tastes, preferences and ultimately in their behaviour, have profound implications for the delicate relationships that human beings have with their environment.

5.2.7 Knowledge on pollution of water bodies

The generally low level of environmental degradation awareness (14%) and water pollution in particular (17%) noted is a matter of great concern. This might have culminated in the range of environmental degradation such as excessive land clearing, disposal of industrial wastes in the lake or steeply sloped pits observed in the study. The effects of these include blockage of waterways and damage to water bodies.

Small-scale miners in this study did not have reclamation schemes thereby leaving the environment to its own fate. There is cumulative siltation, interference with water flow and subsequent damage to ecosystems and people who depend on these for livelihoods. The use of mercury by small-scale miners to process ore as occurs in Lake Amponsah is a worrisome practice and corroborates the finding of Tschakert, (2009) that the use of mercury by artisanal small-scale miners constitutes a point source of contamination.

Information about health effect, handling, disposal and other important guidelines of chemicals normally embodied in material safety data sheets (MSDS), including labels on chemical containers and educational campaign leaflets if any, are usually transmitted in written form and so the ability to read and understand such information is very essential for the small-scale miners to appreciate the consequences of poor environmental management.

Besides, formal education generally sensitizes people on environmental hygiene and the dangers of improper waste disposal. The low educational attainment level could contribute to the less regard for environmental consciousness and might have promoted degradation of the lake. The continuous disposal of domestic waste into the lake together with discharge of mine waste also share these attribute. This affirms the observation made by Baabereyir **(**2009) that the current poor waste disposal attitude of the Ghanaian public can largely be attributed to the low literacy rate and educational attainment in the country which adversely affects the environmental attitudes of the population.

Plates 5.7: Interviews with some members of the community

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The physico-chemical and bacteriological characteristics of Lake Amponsah assessed were below expectation when viewed against available guideline values mainly those prescribed by the WHO, US EPA and the DWAF for both domestic purposes and aquatic life. Anthropogenic activities particularly discharge of effluents from small-scale industries cited in the vicinity of the lake together with indiscriminate discharge of domestic and effluents into the lake are the potential cause.

The causes and effects of factors that lead to water quality deterioration and the general degradation of the environment have not been well understood by the community. This has manifested in the extent to which the lake water has been negatively impacted. The study therefore concludes that the physico-chemical and bacteriological characteristics of the Lake Amponsah have been compromised pointing to a polluted status.

6.2 Recommendations

The human and ecosystem health risk posed by the current state of water quality of Lake Amponsah as a result of anthropogenic impact calls for immediate measures in order to avert any health hazard in the community. It is therefore recommended that;

- There should be intensified education of the community on human and ecological dangers associated with polluted water bodies. A collaboration of organizations namely the Water Resources Commission, EPA-Ghana, Bibiani-Anhwiaso-Bekwai District Assembly, Water and Sanitation Development Board and other water related NGOs would be very helpful in achieving the goal.

- Water management interventions including frequent and periodic monitoring of the lake water quality and its surrounding environment should be put in place by the Water Resources Commission in collaboration with EPA-Ghana, Water and Sanitation Development Board and Bibiani-Anhwiaso Bekwai District.

- There should be stricter enforcement of environmental laws by the Ghana-EPA to avert any further deterioration of the quality of the lake.

- Indigenous knowledge such as taboo day could be improved to promote conservation of the lake.

- There should be greater involvement of industries and companies in the provision of waste and sanitary management facilities of greater capacities to deal with waste generated by the community in order to enhance prevention of waste disposal into the lake and its surrounding.

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APPENDICES

APPENDIX: A

SAMPLES OF QUESTIONNAIRE

Interview with Small-Scale Miners at Bibiani

1. How old are you (years): Under 18 [ ] 18-30 [ ] 31-40 [ ] 41-50 [ ] 51-60 [ ] 61^{+}[ ]
2. What is your educational level? No formal education [ ] MSLC [ ] BECE [ ] SSCE [ ] O-L/A-L [ ] Tertiary [ ]

3. How long have you worked as a small-scale miner? Less than 1 [ ] 1-5 [ ] 6-10 [ ] 10+ [ ]

4. What motivated you to go into the small-scale mining business?……………….……

5. What equipment/tools do you work with?……………………………………………..

6. What chemical(s) do you use: (i)………………………….. (ii)………………………

7. What do you know about this or these chemical(s)?..

   ………………………………………………………………………………………

8. Do you know the effect of using this chemical?..

9. Do you anticipate any health effect in the long term?..

10. Where do you get the information concerning the Chemical?......................................

11. Do you have any bad experience with this chemical? Yes [ ] No [ ]

12. If answer to the above question (Q11) is yes, then what is it? ………………………

13. What exactly do you do? (e.g. milling, washing, digging/excavating)……………...

14. What is your average daily production…………………………...……………………

15. Are you aware of any environmental problem (s) associated with your activities?

    • Yes [ ] what are these problems? …………………………… No [ ]

16. Who manages the site? ………………………………………………………………..

17. Is the processing site approved by the EPA?

    Yes it is [ ] No it isn't [ ] Don't know [ ]

18. Are you a native of this town? Yes [ ] No [ ] (i) where do you originally come from?……………….... (ii) How long have you lived in this community? ....

19. Do you have anything else to say about your work or a question to ask with regard to this discussion?………………………………………………………………………

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

Thank you for your time and assistance

Interview with Residents of Household around Vicinity of Lake Amponsah

1. House number: …………………………………………….

2. How long have you lived in this neighbourhood? ....

3. What is your educational level? No formal education [ ] MSLC [ ] BCE [ ] SSCE [ ] O-L/A-L [ ] Tertiary [ ]

4. What is your occupation? ………………………….……….. ……...............................

5 How many adults live in your house?……………..…………………………..

6. How many occupants are small-scale miners? ……………………..………………

7. What is your source of domestic water supply? ………………………………………

8. Do you have any comment about the source of domestic water supply? • Yes [ ] what is it? ……………………………………………………………….... ..• No [ ]

9. What do you know about small-scale mining?………………………………………..

10. Can you name the type(s) of chemical(s) used for small-scale mining?
 (i)……………….…………………….. (ii)……………………………...................
 (iii)………………………….………….

11. What do you know about this or these chemical(s)?...
 ………………………………………………………………………………………

12. Do you know the effect of this or these chemical(s) on human health?
 • Yes [ ] what is it?........... ………………………………….. …. • No [ ]

13. Do you know of any environmental problem (s) associated with the small-scale mining activities? • Yes [ ] what are these problems?…………… No [ ]

14. Do you suffer any nuisance associated with the small-scale mining? • Yes [ ] what do you suffer from?... • No [ ]

15. Does small-scale mining pose any nuisance to the residents of this community?
 • Yes [ ] what nuisance(s) does it cause? ………………No [ ]

16. How does the nuisance(s) affect the community?…………………………………….
……………………………………………………………………………………………

17. As residents, have you collectively complained about conditions of small-scale mining to the district authorities or the Minerals Commission? •Yes [ ] •No[ ] why?.............…………………………………………………………………………

18. What was the complaint about?……………………………………………………….

19. How did the authorities respond to your concerns?..

20. Do you have anything else to say or a question to ask with regard to this discussion?.............…………………………………………………………………………………
………………………………………………………………………………………

Thank you for your time and assistance

APPENDIX B

Plate 5.8: Wastes dumping site cited at the bank of Lake Amponsah