Water Quality of the Kpong Headpond

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DECLARATION

This thesis is the result of research work undertaken by ESTHER AMA ANKU in the Environmental Science Program, University of Ghana, under the supervision of Prof. Chris Gordon (Principal supervisor) and Dr. Charles Biney.

Sign.....

(Esther Ama Anku)

Sign.....

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Sign.....

(Dr. Charles Biney)

DEDICATION

I dedicate this thesis to my children Ewoenam, Emefa, Akpene and Senanu.

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ABSTRACT

The Kpong Headpond was formed in 1982 when the Lower Volta River was dammed at Akuse. The main uses of the water in the Headpond are for hydroelectric power generation, domestic and industrial use and for irrigation. Several activities however, tend to put this body of water at risk of pollution. These include poor waste disposal, poor farming practices and extensive human and animal contact with the water. An eight-month field study was undertaken to monitor the water quality of the Kpong Headpond and the impact of the surrounding lakeside communities on the water quality. The study involved physicochemical and bacteriological analysis as well as macroinvertebrate analysis and social surveys. The study identified two potential point sources of pollution to the Kpong Headpond. These are the Akosombo Textiles Limited (ATL) effluent discharge and the Akosombo Sewage Treatment Plant (ASTP) effluent discharge. The general water quality in terms of physicochemistry was satisfactory. With the exception of one site (which received ATL effluent), the parameters measured at all the other sites fluctuated within the limits expected in similar freshwater bodies. ATL effluent had a drastic impact on the water quality at the site of discharge, which include low oxygen levels, high nutrient concentrations, high alkalinity, high conductivity and high turbidity values. The ASTP outfall was also identified to be a major source of nutrients and coliform bacteria to the Headpond. All the sites were contaminated with feacal coliform, an indication of the probable presence of pathogens. The social survey of the lakeside communities revealed that most of the settlements lacked basic sanitation facilities like toilets and appropriate refuse disposal sites.

1 INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL BACKGROUND

Water symbolizes life and all living things need water for survival. The value of water as a resource lies in Man's ability to use it for a wide diversity of desirable purposes. It is so vital to life that we cannot live more than four days without it (Naar, 1990).

Water covers three-quarters of the earth's surface, but more than 97 % of the earth's water is saltwater in the oceans, and less than 3 % is fresh water. Of the latter, 77 % is frozen in polar ice caps and glaciers, 22 % is groundwater, and the remaining small fraction is in lakes, rivers, streams, plants and animals (World Resources Institute and International Institute for Environment and Development, 1988).

Through history, the world's surface waters, i.e., lakes, streams and rivers have provided important resources and services, including water for drinking, washing, agriculture, energy production, transportation, recreation, and waste disposal.

One limitation that most people do not fully appreciate, care about, or even know about is water quality. Human activities are threatening the sustainable use of freshwater resources around the globe. Data compiled by World Resources Institute and International Institute for Environment and Development (1988) indicate that the world's lakes and rivers receive enormous quantities of municipal sewage, industrial discharges, and surface runoff from agricultural areas on a continuous basis. If the discharge of pollutants into our groundwater and surface waters is not stopped, the survival of future generations is at risk.

1.2 SPECIFIC BACKGROUND

In recent years, dams or impounding reservoirs have been constructed in various parts of Ghana to satisfy the growing demand for water for domestic, agricultural, industrial and hydroelectric power generation purposes. These impoundments include Kwanyaku (Central Region), Barekese and Owabi (Ashanti Region) and the Volta Lake, which spans the Eastern, Brong Ahafo, Volta and Northern Regions. When these reservoirs are formed, eutrophication of the water-bodies is accelerated due to the combined effect of periodic stratifications, which tend to circulate the nutrients (WRI, 1975).

The Kpong Headpond was formed in 1982 by damming the Lower Volta River at Akuse, about 25 km below the Akosombo dam. The dominant water use of the Kpong Headpond is for hydroelectric power generation of 160 MW to augment the 912 MW produced at Akosombo. It uses virtually all the water discharged through the penstocks of the Akosombo dam for power generation. A substantial part of the water in the Headpond is also abstracted for domestic, agricultural and industrial purposes. At present, a 180 million litres per day capacity plant situated at Kpong provides Tema and the eastern part of Accra with its municipal water needs (Larmie, 1993). Water demand of the Lower Volta River for irrigation use has been calculated to be in the order of 135 m^3/s (Nathan Consortium, 1970). Several small village communities along the Headpond rely on it in its raw form for their domestic needs as well as for cottage activities. Akosombo Textile Limited (ATL) and the Juapong Textiles Limited (JTL) also depend on the Headpond for their water supply.

Unfortunately, this important water resource is being polluted by both industrial and domestic wastes (Larmie 1993). If this pollution is not checked, it could lead to a further deterioration of the water quality of the Headpond.

1.3 JUSTIFICATION FOR STUDY.

The Kpong Headpond is a very important source of water supply for communities along the Headpond and other areas including the Accra-Tema Metropolitan area. This source of water however risks getting polluted by several activities that occur within the lakeshore areas of the Headpond. These include poor waste disposal, bad farming practices and extensive human and animal contact with the Headpond. To control pollution of the Headpond, it is necessary for these sources of pollution to be investigated and also to assess the effects of the pollution on the quality of water.

The study therefore sought to provide more information about the causes and impacts of pollution in the Headpond, by investigating the sources and effects of pollution.

The results and recommendations stemming from this research are expected to be of great benefit to the Asuogyaman and the Manya District Assemblies as well as the Volta River Authority in the control and management of pollution in the Kpong Headpond and its environs. The results and recommendations are also expected to enhance the sustainable management of natural resources in the Volta River Basin.

1.4 AIMS OF RESEARCH

The main aims of the research were to:

- Identify and investigate the main sources of pollution in the Kpong Headpond
- Assess the effects of the pollutants on the quality of water for various uses

Some recommendations were also to be made on how best to control pollution in the Headpond to enhance its water quality.

1.5 OBJECTIVES OF STUDY

The objectives of the study were as follows:

- To identify the main sources and effluent inflows of pollutants into the Kpong Headpond.
- To determine the mode of treatment and efficiency of treatment of pollutants, where they exist, at identified sources of pollution.
- To determine water supply and sanitation facilities available in selected lakeside communities including Fodzoku, Kpong, Atimpoku, South Senchi, Senchi ferry, Ghanakpe, New Powmu, Mangoase, Kokontekpedzi and "Small London"
- To determine the perception of people about the quality of water in the Headpond.
- To identify any health related issues of the pollutants on the Lakeside communities of the Kpong Headpond
- To recommend to the Volta River Authority and the Asuogyaman and Manya Krobo District Assemblies, ways to mitigate or reduce the introduction of pollutants into the Kpong Headpond as a means of improving the water quality.

1.6 NATURE OF WATER POLLUTION

The word pollution implies undesirable quality, but different individuals may interpret it in various ways. Lamb (1985) attributes this partly to emotional reactions and to subjective differences about our goals in using water resources and quality characteristics desired or needed to meet these goals.

Water pollution, has been defined by Lamb (1985) as: "the presence of materials in water that interfere unreasonably with one or more beneficial uses of it". Cunningham and Saigo (1990) similarly defined water pollution as 'anything physical, biological or chemical change in water quality that adversely affects living organisms or makes water unsuitable for desired uses'. These definitions relate pollution to specific quality problems as summed up in the definition GESAMP (1988) which defines water pollution as 'the introduction by man, directly or indirectly, of substances or energy which results in such deleterious effects as i) harm to living resources, ii) hazards to human health, iii) hindrance to aquatic activities including fishing, iv) impairment of water quality with respect to its use in agricultural, industrial and often economic activities and v) reduction of amenities.' For example, if a municipal or industrial wastewater discharge, either alone or in combination with others, actually interferes with a beneficial use that otherwise would be desirable and reasonable, then the recipient watercourse is 'polluted' On the other hand, if that discharge would not create or threaten an identifiable water quality problem, it would not constitute pollution. These definitions are at odds with what is favoured by some individuals and groups who feel that any change in water quality from the natural state should be considered as pollution (Lamb, 1985).

1.6.1 Sources Of Pollution

Sources of aquatic pollution are normally classified as point or non-point:

1.6.1.1 Point Sources

Moran *et al.*, (1986) defined a point source as a source that discharges effluent, such as wastewater from sewage treatment and industrial plants. Chapman (1992) also defined a point source as a pollution input that can be related to a single outlet. The major point sources of pollution to freshwaters originate from the collection and discharge of domestic wastewater, industrial wastes or certain agricultural activities, such as animal husbandry. As noted by Chapman (1992), the disposal of sewage, both untreated or inadequately treated is probably still the major point source of pollution to the world's waters. Other important sources include mine and industrial effluents.

1.6.1.2 Diffuse Sources

Diffuse sources are also known as non-point sources. Examples of non-point sources include runoff from agricultural fields, cleared forest areas, construction sites and roads (Miller, 1988) [cited in Spellman, 1996]. Of particular interest to environmentalists in recent years have been agricultural effluents. For example, Mason (1990) reported that farm effluent has been estimated to be more than 200 times as potent (in terms of BOD) as treated sewage. Chapman (1992) noted that an important difference between a point source and a diffuse source is that a point source may be collected, treated or controlled by conventional means whereas diffuse sources may not.

1.7 DESCRIPTION OF PARAMETERS

1.7.1 pH

pH is a term used to indicate the alkalinity or acidity of a substance as ranked on a scale from 1.0 to 14.0 (Spellman and Drinan, 2000). The pH of water is a measure of the concentration of hydrogen ions [H^+]. Mathematically, pH could be defined as follows:

$pH = -\log_{10}(a_H)$ where (a_H) is the activity of the hydrogen ion.

As [H^+] increases, so pH decreases and the solution becomes more acidic and as [H^+] decreases, pH increases and the solution becomes more alkaline. Davies and Day (1998) observed that the pH of natural waters is determined by geological influences and biotic activities. Most freshwaters are relatively well buffered and more or less neutral with pH values ranging between 6 and 8.

One of the main ways in which pH affects aquatic ecosystems is by determining the chemical species of elements, and thus the availability and the potential toxicity of many heavy metals and other substances. Changing the pH of water changes the concentration of both hydrogen and hydroxyl ions, which in turn affects the ionic balance of aquatic organisms. Aquatic organisms are sensitive to pH changes (Pierce *et al.*, 1998) hence a proper pH balance is critical to healthy cellular functioning (Cunningham and Saigo, 1990). Relatively small changes in pH are not normally lethal, although growth rates may be impaired and fecundity reduced as a result of increased physiological stress placed on the organism outside its optimal pH range (Davies and Day, 1998). Spellman (1996) also reported that a sharp change in pH in a natural stream might cause the death of most

organisms in the stream. Haslam (1990) pointed out that values of pH from 5 to 9 are harmless to most fish. However since toxicity of ammonia, cyanide and many others varies with pH, variations within the 5-9 ranges may be lethal by altering the toxicity of such compounds.

1.7.2 Temperature

Heat input into aquatic systems and the resultant temperature change can significantly affect biological communities and the beneficial use of the water resource system. Altering or removing vegetative cover as well as discharging heated water (e.g., cooling water) directly into water bodies, could cause thermal pollution of water bodies.

When a natural stream is heated by thermal pollution to a point above its normal water temperature, the stream's health is affected. Such thermal pollution has caused many complex aquatic problems (Miller, 1988). Mason (1990) noted that an increase in temperature alters the physical environment, in terms of both a reduction in the density of the water and the amount of oxygen present in the water. Jeffries and Mills (1990) also noted that since all aquatic organisms have thermal tolerance limits, a discharge may be lethal if beyond the threshold for a species. Thus direct heat may cause the death of aquatic animals. Lamb (1985) similarly noted that as stream temperature rises, the death rates of some fish are increased significantly. This effect begins with the most sensitive types of fish, but a sufficient temperature increase may eliminate all types. Fish are able to detect differences in temperature as small as 0.05°C (Haslam, 1995).

Increase in temperature has an adverse impact on the dissolved oxygen resources in streams. Oxygen solubility in water decreases as temperatures increase, so that species requiring high oxygen levels are adversely affected by warming water (Cunningham and Saigo, 1992). Furthermore, higher temperature usually decreases the rate at which oxygen is transferred from the atmosphere into the water to replenish the oxygen consumed by chemical reactions. Rates of biochemical reactions in streams are accelerated with the rise in temperature. Thus the impact of discharges with high BOD into a stream usually is increased substantially by temperature rise.

1.7.3 Total Dissolved Solids And Conductivity

The total amount of material dissolved in a water sample is commonly measured as Total dissolved solids (TDS), conductivity or as salinity (Davies and Day, 1998). TDS represents the total quantity of dissolved material, organic and inorganic, ionized and unionized in a sample of water. TDS associated with freshwater systems often consist of inorganic salts, small amounts of organic matter and dissolved materials (Larmie, 1993). In stream water, dissolved solids consist of calcium, magnesium, carbonate, chloride, nitrate, phosphate, iron, sulphate and other ions or particles that will pass through a filter with pores of 0.45μm in size (Spellman and Drinan, 2000). The TDS concentration of natural waters varies widely. Rainwater has a TDS concentration of < 10 mg/L; runoff from wet, well-drained regions can have a TDS concentration as little as 25 mg/L while seawater has approximately 35,000 mg/L (McCutcheon *et al.*, 1990).

TDS is an important indicator of water quality. Dissolved solids affect ionic strength, which has an impact on the mobility and transformation of metals and ionisable chemicals (McCutcheon *et al.*, 1990). TDS is also an important indicator of the suitability of water for drinking, irrigation and industrial use. Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes and higher costs because of corrosion of pipes and the necessity for additional treatment.

In natural aquatic ecosystems, TDS is determined by the degree of weathering and the chemical composition of rocks and by the relative influences of evaporation and rainfall in the catchment. TDS and conductivity are usually closely correlated for a particular type of water (Lamb, 1985). The ions that form the bulk of TDS are the sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations and the chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) anions, which are collectively known as the major ions. The normal ionic dominance pattern for freshwater is $Ca^{2+} > Mg^{2+} > Na^+ > K^+ : HCO^{3-} > SO_4^{2-} > Cl^-$ (Burton 1976).

Certain human activities increase the Total Dissolved Solids of water such as the disposal of large effluent loads into waterbodies. In South Africa for example, the concentration of TDS in the Vaal Dam is reported to be increasing at an alarming rate of 2.5 mg/l every year (Davies and Day, 1998). This increases the cost of purification of the water for industrial and domestic use. Spellman and Drinan (2000) have also documented that the concentration of Total Dissolved Solids affects the water balance in the cells of aquatic organisms. This in turn affects the organism's ability to maintain the proper cell density,

making keeping its position in the water column difficult. It might float up or sink down to a depth to which it is not adapted and it might not survive. It is desirable to remove these excess dissolved minerals, gases and organic constituents because they may cause physiological effects and produce aesthetically displeasing colour, taste and odours.

Conductivity is a measure of the ability of a sample of water to conduct an electrical current and is therefore a measure of the number of ions (charged particles) in solution (Davies and Day, 1998).

1.7.4 Suspended Solids, Turbidity and Colour

Suspended matter is material with a particle size larger than 2 μm (Lamb, 1985). Suspended solids include tiny particles of silts and clays, living organisms (zooplankton, phytoplankton and bacterioplankton) and dead particulate organic matter, (POM). The size of particles that remain in suspension depends largely on current speed. When water moves very slowly, or not at all, most of the particles settle out of suspension and are deposited in the bottoms of rivers, lakes or wetlands.

Suspended solids have both physical and chemical effects on aquatic systems. Lamb (1985) observed that organic matter lighter than water might float and form a scum that is unsightly and interferes with passage of light and oxygen through the surface of the water. Large numbers of small particles suspended in water give rise to increased turbidity and reduce light penetration through the water column. When light penetration is reduced, photosynthesis is also reduced. Less food is available to organisms lower in the food chain. High suspended solids in a stream or river can have adverse effects on the

biota in many ways. Suspended solids may contain organic matter, hence putrefaction may occur and stream may be devoid of dissolved oxygen. Mineral and organic suspended matter can lead to silting thereby blanketing the streambed and rendering the stream bed unsuitable for flora and fauna life.

Spellman and Drinan (2000), defined turbidity as a unit of measurement quantifying the degree to which light travelling through a water column is scattered by the suspended organic and inorganic particles. The scattering of light increases with greater suspended loads. Severe turbidity will also make it difficult for predators that search visually for their prey to find food. Davies and Day (1998) noted that because of their small sizes, suspended solids may have a considerable surface area and many of them carry an electrical charge. As a result, a variety of dissolved substances, e.g., phosphate and heavy metal ions, become adsorbed onto the surfaces of the particles.

Sediment and suspended solids make up the largest volume of water pollutants in the US and other parts of the world. Cunningham and Saigo (1992) reported that erosion and runoff from croplands contributed about 25 billion tons of soil, sediment and suspended solids to world surface waters each year while forests, grazing lands, urban construction sites and other sources of erosion and runoff added at least 50 billion tons.

In many instances, the suspended matter in streams and lakes is carried through runoff from farmlands and urban areas, or it may be discharged in municipal and industrial wastewater. The amount of suspended matter entering watercourses in land runoff may be increased substantially when the water passes over land developed for agriculture,

because of vegetation clearing and cultivation of the soil especially where land management practices are poor.

The colour and turbidity of water determine the depth to which light is transmitted which in turn controls the amount of primary productivity. Colour has no direct chemical significance but is a qualitative indication of the chemical state of water. It is usually related to organic matter in water. Natural minerals such as ferric hydroxide and organic substances such as humic acids give true colour to water (Manahan, 1991). Apparent colour is caused by coloured particulates and the refraction and reflection of light on suspended particles. Polluted water may therefore, have a strong apparent colour.

Different species of phyto and zooplankton can also give water an apparent colour. A dark blue-green colour for example may be caused by blue-green algae (Straskraba and Tundisi, 1999).

1.7.5 Nutrients

Nutrients are those chemicals required for plants to grow. In freshwater ecosystems, plant growth is usually encouraged by the addition of phosphorus in the form of the phosphate ion PO_4^{3-} and nitrogen, mostly in the form of nitrate ion (NO_3^-) and ammonium ion (NH_4^+) (Davies and Day, 1998). When the levels of nutrients build up to a point where the growth of algae and rooted plants becomes noticeably enhanced, the water becomes more and more eutrophic. Large amounts of nutrients may enter aquatic ecosystems in effluents from industry but as Davies and Day (1998) observed, the greatest proportion of

nutrients comes from sewage and agricultural activities. They also observed that except in the most efficient treatment plants such as reed beds, purified sewage effluent is very rich in nutrients especially, nitrogen and phosphorus.

1.7.5.1 Nitrogen

Nitrogen occurs in many forms in the environment and takes part in many biochemical reactions. It is commonly found as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) ions. Major sources of nitrogen include runoff from animal feedlots, fertilizer runoff from agricultural fields, municipal wastewater discharges and certain bacteria and blue-green algae that obtain nitrogen directly from the atmosphere (Spellman and Drinan, 2000).

Nitrate is seldom abundant in natural surface waters because it is incorporated into cells or chemically reduced by microbes and converted into atmospheric nitrogen. Natural levels may be enhanced by municipal and industrial wastewaters, including leachates from waste disposal sites and landfills. In lakes, levels of nitrate in excess of 0.2 mg/L NO_3-N tend to stimulate algal growth and indicate possible eutrophic conditions (Chapman, 1992). Nitrate concentrations exceeding 10 mg/L present a potentially serious public health problem. Concentrations of 11 to 40 mg/L may cause methaemoglobinemia (blue babies) in infants less than six months of age (Krenkel and Novotny, 1980). The bacteria commonly found in the intestinal tract of infants can convert NO_3 to highly toxic nitrites. Nitrites can replace oxygen in the bloodstream and results in oxygen starvation that causes a bluish discolouration of the infant i.e., methaemoglobinemia.

Nitrites are an intermediate stage of nitrification and are readily oxidized to nitrates. The process of nitrification is the conversion by bacteria of ammoniacal nitrogen to nitrites and eventually nitrates. Denitrification is the reverse of this process. Nitrites are toxic to aquatic organisms even at low concentrations.

Ammonium occurs in low concentrations in natural waters and is also a common pollutant associated with sewage and industrial effluents (Davies and Day, 1998). Unpolluted waters contain small amounts of ammonia and ammonium compounds, usually less than 0.1 mg/L as nitrogen (Chapman, 1992). Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer runoff. In regions where organic loads are high, hydrolysis of urea may generate odorous ammonia and ammonium compounds.

1.7.5.2 Phosphorus

In aquatic environments, phosphorus is found in the form of Phosphate (PO_4) and is often a limiting nutrient. Major sources of phosphorus to aquatic environments include fertilizer runoff, domestic wastes, sewage and industrial treatment plants (Manahan, 1991). Chapman (1992) reported that in most natural surface waters, phosphorus ranges from 0.005 to 0.02 mg/L PO_4-P. Pierce *et al.* (1998) also observed that phosphate concentrations between 0.01 mg/L and 0.1 mg/L appear to be enough to accelerate eutrophication.

de-Graft Johnson (1981) defined eutrophication broadly as the increase in supply of plant nutrients to waters due to human activities in catchment areas which results in an

increased production of algae and higher aquatic plants. Eutrophication is a natural process that occurs in virtually all bodies of water. The gradual accumulation of nutrients and organic biomass, accompanied by increased levels of production and a decrease in the average depth of the water column caused by sediment accumulation constitute the natural eutrophication process (Laws, 1993). Natural eutrophication may take thousands of years. If however enough nutrients are introduced into a lake system, as may happen as a result of human activity, the eutrophication process may be shortened to as little as a decade (Laws, 1993).

Species associated with eutrophic systems are sometimes less desirable than species characteristic of oligotrophic systems. Laws (1993) indicated that the diversity of organisms in eutrophied waters are often much lower than in oligotrophic waters. This is sometimes due to competition for resources and predation pressure. Oxygen concentrations in highly eutrophic systems generally fluctuate over a wide range. Since it is impossible for some organisms to function efficiently unless the oxygen concentration in the water is near saturation, such organisms are often absent from eutrophied waters.

Cyanobacteria, which are frequently associated with organic nutrient enrichment, are a class of organisms frequently associated with undesirable water quality conditions. Some cyanobacteria are toxic to organisms and humans (Straskraba and Tundisi, 1999). Davies and Day (1998) also observed that some of these cyanobacteria are known to be powerful carcinogens even in minute doses.

Excessive amounts of phytoplankton and macroscopic plants in the water create aesthetic problems and reduce the value of the body of water as a recreational source.

1.7.6 Dissolved Oxygen

The amount of oxygen dissolved in water is a good indicator of water quality and of the kinds of life it can support (Cunningham and Saigo, 1990). It can be an indicator of the healthiness of a stream and its ability to support a balanced aquatic system (Spellman, 1996). Davies and Day (1998) similarly noted that the concentration of dissolved oxygen is probably one of the most important abiotic determinants of the survival of most aquatic organisms. Water with oxygen content above 8 mg/L will support fish and other desirable forms of aquatic life whereas water with less than 2 mg/L oxygen will be detrimental to such aquatic organisms. Only pollution tolerant species like some worms, bacteria, fungi and other decomposers can survive such conditions (Cunningham and Saigo, 1992).

In water, oxygen is rapidly consumed by the oxidation of organic matter (Manahan, 1991). In addition to the microorganism–mediated oxidation of organic matter, oxygen in water may be consumed by the bio-oxidation of nitrogenous material, and by the chemical or biochemical oxidation of chemical reducing agents. All these processes contribute to the deoxygenation of water. Anaerobic conditions also occur naturally in stagnant water such as swamps and at the bottom of deep lakes (Baird, 1995). Straskraba and Tundisi (1999) reported that absence of oxygen (anoxia) near the bottom is one of the most serious phenomena that affect reservoir or lake water quality. Under anoxic conditions, some substances including phosphorus, iron and manganese are rapidly released from bottom sediments. Sulphides such as hydrogen sulphide also develop giving an obnoxious odour to the water. Hydrogen sulphide is a product of the anaerobic decay of organic matter containing sulphur. It is also produced in the anaerobic reduction

of sulphate by microorganisms. Wastes from chemical plants, textile mills, etc may also contain sulphates.

Oxygen is added to water by diffusion from the air, especially when turbulence and mixing rates are high, and by photosynthesis of green plants, algae and cyanobacteria. Oxygen is removed from water by respiration and chemical processes that consume oxygen (Cunningham and Saigo, 1992). Under natural conditions, the concentration of dissolved oxygen fluctuates diurnally, depending on the relative rates of photosynthesis and respiration. It is usually lowest at dawn, increasing during the day and peaking in the afternoon and decreasing at night (Davies and Day, 1998). Manahan (1991) noted that the amount of oxygen that can be dissolved in water depends on the rate of aeration from the atmosphere, temperature, air pressure and salinity while the actual amount in a given body of water depends on the relative rates of respiration by all organisms, and of photosynthesis by plants.

1.7.7 Biochemical Oxygen Demand (BOD)

The addition of certain organic materials such as sewage and food processing wastes to water stimulates oxygen consumption by decomposers. Pierce *et al.* (1998) reported that such oxygen-demanding substances decompose in the waterbody and can deplete the water's oxygen and create anaerobic conditions. BOD is a standard test of the amount of dissolved oxygen utilized by aquatic microorganisms over a 5-day period (Cunningham and Saigo, 1990). Manahan (1991) defined BOD as the degree of oxygen consumption by microbially mediated oxidation of contaminants in water. Unpolluted waters typically

have BOD values of 2 mg/L oxygen or less, whereas those receiving wastewaters may have values up to 10 mg/L or more (Chapman, 1992).

The effects of oxygen-demanding wastes on rivers depend to a great extent on the volume, flows and temperature of the river water. The addition of oxidizable pollutants to streams produces a typical oxygen sag curve. Initially, a well-aerated, unpolluted stream is relatively free of oxidizable material; the oxygen level is high; and the bacterial population is relatively low. With the addition of oxidizable pollutant, the oxygen level drops because re-aeration cannot keep up with oxygen consumption. In the decomposition zone, the bacterial population rises. A high bacterial population and very low oxygen levels characterize the septic zone. The septic zone terminates when the oxidizable pollutant is exhausted, and then the recovery zone begins. In the recovery zone, the bacterial population decreases and the dissolved oxygen level increases until the water regains its original condition. Aeration occurs readily in a turbulent, rapidly flowing river, and, therefore is able to recover more quickly from oxygen-depleting processes than a slow running river.

1.7.8 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is the amount of oxygen consumed when the substances in the water are oxidized by a strong chemical oxidant and can be measured by refluxing the water sample in a mixture of chromic and sulphuric acid for a period of 2 hours (Laws, 1993). The COD method is faster than the BOD test but normally gives much higher results because it oxidizes compounds not ordinarily metabolized by bacteria. Straskraba and Tundisi (1999) documented that high COD is often associated with increased colour

and the high colour can result in an increase of up to ten fold in treatment costs. Chapman (1992) reported that the concentrations of COD observed in surface waters range from 20 mg/L oxygen or less in unpolluted waters to greater than 200 mg/L oxygen in waters receiving effluents. Industrial wastewaters may have COD levels from 100 to 60,000 mg/L oxygen.

1.7.9 Coliform Bacteria

The most serious water pollutants in terms of human health worldwide are pathogenic organisms. A wide variety of human pathogens may be found in human excrement as well as from other animals. Most of these pathogens can be classified as viruses, protozoan, helminthes (i.e., intestinal worms) and bacteria. Laws (1993) observed that both raw sanitary sewage and land runoff contain pathogenic organisms, and virtually every sizable body of water contains some pathogens. Cunningham and Saigo (1990) similarly noted that the main source of these pathogens is from untreated or improperly treated human wastes. Animal wastes from feedlots of fields near waterways and food-processing factories with inadequate waste treatment facilities also are sources of disease-causing organisms. Pathogens found in human excrement, whether urine or feacal material, come from persons who are carriers of the disease causing organisms (Laws, 1993).

Coliform bacteria are used to evaluate the microbiological quality of water and the number present is interpreted as an indicator of the extent to which that water has been contaminated recently by feacal discharges (Lamb, 1985). Pierce *et al.* (1998) similarly noted that if a large number of coliforms are present, there is a good chance of recent

pollution by wastes from warm-blooded animals and therefore the water may contain pathogenic organisms.

Faecal coliform bacteria are a subset of the total coliform group and are viewed as being more accurately related to organisms originating in human wastes (Lamb, 1985). Some coliforms are capable of causing disease, but most are not regarded as pathogenic; however the number present does provide a measure of the probability that waterborne pathogens might be present.

Chapman (1992) observed that contamination of waterbodies by animal or human excrement introduces the risk of infection to those who use the water for drinking, food preparation, personal hygiene and even recreation. To avoid human infection, the World Health Organisation (WHO) recommended concentration for drinking water as zero organisms per 100 mL. The WHO limits for primary contact is 1000 cfu/100 mL for total coliforms and 200 cfu/100 mL for feacal coliforms while the secondary contact limits are 10,000 cfu/100 mL for total coliform and 500 cfu/100 mL for feacal coliform (WHO, 1993).

1.8 SELF-PURIFICATION OF POLLUTED WATER BODIES

Fresh water systems are able to compensate for small amounts of wastes they receive since nature has a way of fighting back pollution (Spellman, 1996). Any water body is capable of assimilating a certain amount of pollution without serious effects because of the dilution and self-purification factors. Wastewater may give rise to certain undesirable changes in the quality of receiving waters particularly as regards downstream abstraction. Depending on the degree of dilution available, there may be significant increases in

dissolved solids, organic content, as well as nitrogen and phosphorus, colour and turbidity. There could also be the creation of dissolved oxygen deficits. Each stream, due to a limited amount of dissolved oxygen (DO), has a limited capacity for aerobic decomposition of organic matter without becoming anaerobic. High concentrations of organic substances encourage the growth of decomposers such as bacteria and fungi, which convert the biodegradable organic substances in the stream into their cells and into basic substances like carbon dioxide, nitrates, sulphates and phosphates (Moran *et al.*, 1986). If the organic load received is above the capacity of the stream, it becomes unfit for normal aquatic life and unable to support organisms sensitive to oxygen depletion (Smith, 1974). The suitability of the water for various uses may also be impaired.

Haslam (1995) has observed that, pollutants entering streams may either move downstream with the water or be deposited on the bed, accumulating particularly in silt. Within the river, chemical (e.g. oxygenation) and biological (e.g. microbial) agents may render the pollutants harmless. However some substances are resistant to such processes even when in very low concentrations. Other substances are decomposed slowly so downstream purification is ineffective if concentrations are high or if further impurities are constantly added downstream, for example from a series of sewage works.

Grimaldi and Simonds (1989) cautioned that the days when natural methods in streams (e.g., the self-purification process) automatically compensated for increase in anthropogenic pollution are over. It is therefore essential that effluent discharged into a watercourse is of high quality and the degree of pollution is such that the self-purifying capacity of the river is not overloaded.

1.9 POLLUTION OF WATER BODIES IN GHANA

Pollution of waterbodies is a major problem facing Ghana as well as many other developing and developed countries. Ghana is experiencing a high level of pollution in her waterbodies particularly where they are located near human settlements, industrial (including mining) estates and agricultural undertakings. Based on previous experience with environmental problems, Akuffo (1998), Straskraba and Tundisi (1999) noted a strong relationship between the degree of pollution and density of population in both poor and rich countries. The following three are major input sources to watersheds and thus, drive this relationship: Urbanisation, Industrialisation and large-scale agricultural development.

1.9.1 Effect of Urbanisation and Industrialisation on Water Quality

Biney (1990) in a study of Ghanaian freshwater and coastal ecosystems concluded that the Korle lagoon located in the center of the capital, Accra was the most polluted water body in Ghana. This is because the Odaw river/ Korle lagoon/ Chemu catchment is the most industrialized and most populated in the Greater Accra region, which has resulted in uncontrolled increases in the quantity and diversity of discharges that reach the lagoon. Before the explosion of urban and industrial activities in the Chemu /Odaw/ Korle catchment, the Korle lagoon was clean enough to support a thriving fishery of mainly tilapias and mullets. However the gross pollution of the catchment over the years has led to a complete loss of fishery. Biney (1996) indicated that substances which contribute to increases in Biochemical Oxygen Demand (BOD), originating from domestic sewage, industrial effluents and land runoff are the most important sources of pollution in all the

catchments. Of the calculated total daily BOD of 140 x 10^3 kg in 1990, 68 % was estimated to have been received by the Odaw/ Korle/ Chemu 1 catchment, 16 % by the Sakumo II and 5 % by the Kpeshie/ Osu Klorte catchment.

Amuzu and Leitmann (1991) undertook an Environmental Profile of Accra and reported that most surface waters in the Greater Accra region were seriously polluted as a result of the uncontrolled discharge of untreated domestic and industrial effluents into the waterbodies. They also pointed out that acute pollution is confined mostly to waters in urban and industrial areas.

Nana- Amankwah *et al.* (1995) in a study of the impact of development and urbanization on the Nima Creek in Accra observed that, the middle and lower sections of the creek were heavily polluted with human faecal waste. This condition was attributed to high population densities and poor standard of living in the area.

Industrial wastes as well as domestic wastes are polluting several other water bodies in Ghana. Mensah (1976) in a survey of water quality and pollution of inland and coastal waters of Ghana, observed that most industries in Ghana pollute inland waters and make them unfit for several purposes. For example, some diamond-mining companies at Akwatia, Kade and Edubiase discharged mine wastes containing considerable amounts of suspended solids; mostly silt, about 18,000 mg/L into the Birim River. The resultant turbidity of the river downstream of the mines could be as high as 800 NTU. Dadzie-Mensah (1999) similarly reported that the Ankobra River is significantly polluted due to mining activities in the Prestea area. Chemicals such as arsenic, cyanide and mercuric compounds from the extraction of gold are washed directly into the river, polluting it to

such an extent that areas downstream no longer benefit from the rich resources of the river.

1.9.1.1 Sanitation

Water pollution control depends to a very large extent on the efficiency with which sanitation problems are handled (Akuffo, 1998). This is especially so in a developing country where most of the pollution loads comes from domestic rather than industrial sources. Akuffo (1998) cautions that, the neglect of sanitation makes it almost impossible to control pollution because waste has to be effectively collected and treated before it is discharged to avoid pollution. Noi-Nortey (1990) stated that the sanitation sector, is one of the least developed in Ghana. Amuzu and Leitmann (1991) reported that the average volume of sewage in the Accra Metropolitan Area (AMA) is 0.74 m^3/ capita / day in high-income areas and 0.19 m^3/ capita/ day in other areas. The most common forms of human waste disposal were reported to be pit latrines, pan/ bucket latrines and open defeacation. Open defeacation was common in the slum and peri-urban areas. People used open space, beaches and watercourses in areas where there was no public place of convenience. Table 1.1 shows the proportion of the national population who had access to flush toilets, pit latrines, bucket latrines and no toilet facilities in a sanitation service survey conducted in 1987.

Table 1.1 Sanitation Service Coverage in Ghana (1987)

Type of facility	Urban (%)	Rural (%)	National (%)
Flush toilet	13.4	0.8	5.6
Pit/ public latrine	49.5	61.5	69.1
Pan/ Bucket latrine	28.6	6.0	3.3
No facility	8.6	24.2	18.1

*Source: Ghana Living Standards Survey (1987)

In Ghana many rivers flowing through towns and villages, serve not only as a source of water supply for the inhabitants but also as sewers for these towns and villages. The Densu river drains Koforidua (population about 80,000), Nsawam (Population about 39,000) and numerous other small towns and villages. These towns and villages have neither waste treatment facilities nor facilities for waste diversion (Akuffo, 1998). Amuzu (1985) [cited in Akuffo, 1998] recorded sediment load as high as 128 tonnes per day in the river Densu as well as nitrate-N and orthophosphate concentrations of 5.1 and 1.2 mg/L respectively, at Nsawam. In the Weija Lake itself, near the raw water intake point of the Ghana Water Company Limited (GWCL), total nitrogen concentration of 5.3 mg/L has been recorded (Akuffo, 1998).

1.9.2 Effect of Agriculture on Water Quality

Agricultural pollutants come mainly form the use of agrochemicals such as fertilizers, pesticides and herbicides. When lands are deforested through bushfires, lumbering, etc, leaching of soil nutrients takes place and the nutrients find their way into waterbodies to impair the water quality. In a water resources management study undertaken by the Ministry of Works and Housing (1998), it was reported that the Densu River was the most polluted river in Ghana. This was due to human, industrial and agricultural waste discharges.

Many lakes in the world are becoming less attractive to live on because of the rapid destruction of these lakes as a result of eutrophication. Through man's activities, excess nutrients enter into lakes, streams and estuaries etc, which accelerate the process of cultural eutrophication. In Ghana, the problem of eutrophication occurs in two man-made

lakes: Weija lake (closed in 1975) and Barekese lake (closed in 1969), as reported by Akuffo (1998). Upstream the Weija dam, two large urban centres, Nsawam and Koforidua, discharge untreated wastes into the Densu River. There are also some villages and diverse farming activities upstream the Barekese Lake on the Offin River. Organic wastes, whether treated or untreated contain high levels of plant nutrients and when these are available in aquatic systems they cause eutrophication.

Other Ghanaian lakes and water supply reservoirs are also very much vulnerable to eutrophication. Nana-Amankwah (1993), holds the view that eutrophication associated with weed problems in Ghana is of varying degrees and exists in almost all of the man-made lakes like the Volta and Kpong Headpond, water supply reservoirs like Barekese, Owabi and Weija; and streams like the Odaw in Accra.

In the Volta Lake and water supply reservoirs such as Weija and Owabi, there is successive invasion of weed species such as *Pistia stratiotes*, *Ceratophyllum demersum* and *Utricalaria inflexa* that develop into thick floating materials called 'sudds' which climaxes the weed infestation (Nana-Amankwah, 1993).

Ariel *et al.* (1995) observed that macrophyte abundance, while in part related to sediment type and composition and to nutrient factors, is most often determined by light availability. They argued that it is a common misconception that nutrient enrichment of lakes causes nuisance macrophyte growth. Cooke *et al.* (1993) suggest that high nutrient concentrations in the water column trigger algal blooms, decreasing light penetration and limiting macrophyte growth. Clear lakes with nutrient–rich littoral areas can display

excessive macrophyte growth as evidenced by abundant growth of water hyacinths in Lake Chad and Lake Victoria.

1.9.3.Effect of Water Pollution on Aquatic Organisms

Each species thrives optimally in water with particular combinations of physical or chemical attributes. Alterations in the water quality will therefore affect different species to a greater or lesser extent.

Davies and Day (1998) have listed the following as effects of altered water quality on aquatic communities:

- A shift in the physical position of a community of riverine organisms
- The introduction or loss of key species
- Reduction in diversity as a result of very small increases in the concentration of toxins such as trace metals
- Reduction in, and ultimately loss of, decomposers and thus of nutrient cycling in streams.

According to Lamb (1985), the types of substrates present and the environmental conditions determine which species of organisms are favoured, and the amounts of necessary chemicals available to them dictate the extent of growth for each type.

Water bodies have physical and chemical characteristics that greatly influence the aquatic environment and affects types and numbers of organisms that develop. The biological impacts that result from adding potential pollutant to a stream or lake vary depending on the life present in the watercourse, types of materials, amounts added, dilution available, temperature, other chemicals in the water and many other factors.

The ecological system in a clean water body usually includes many species of organisms, but relatively few of any one type. According to Lamb (1985), this diversity is viewed as a stable and desirable system.

Pollution impacts in aquatic biology may be divided into 2 broad categories:

1. The generation of excessive growths in water body and
2. The elimination, or major reduction of some life forms

The first category sometimes results after the addition of large quantities of certain materials that can be used by some species to produce objectionable growths. Different species vary in their sensitivities to potential toxic chemicals.

1.10 PREVIOUS STUDIES ON THE VOLTA RIVER AND LAKESIDE COMMUNITIES

1.10.1 Water Quality

Mensah (1976) noted that untreated effluents from two textile industries were discharged into the Lower Volta River. These factories are Akosombo and Juapong Textile factories. Akosombo Textiles Limited (ATL) was reported to discharge 118,650,000 litres of untreated effluents per month in to the Volta River. The effluents contained salts and were of a higher temperature. She observed that despite the large volume of river water that diluted the effluents, the water was deeply coloured with dyestuffs and the temperature was high. High pH,ammonia and BOD values were also recorded in the river, which indicated incidence of pollution. Fauna at the point of discharge were greatly affected when compared with those found upstream and downstream of the point of discharge of the effluents.

Biney (1977) in pre-impoundment chemical studies of the Lower Volta found that differences with respect to chemical constituents of water samples from different sites were not very significant with the exception of the sample from ATL which recorded high concentrations of parameters measured. He reported that the alkalinity had been increasing since September 1976. The recovery capacity of the river was generally good since for most constituents, the concentrations below the ATL discharge point were not

very different from upstream the point of discharge (Biney 1977). He therefore concluded that the level of pollution of the Lower Volta was low since most of the parameters, which indicate the presence of pollution, occurred in low quantities. Amoah (1989) also reported that effluents from ATL had lowered the dissolved oxygen of the river and increased suspended solids, the latter making the water more turbid. Effluents from the Akosombo Sewage Treatment Plant encouraged the growth and multiplication of indicator bacteria when discharged into the river (Amoah 1989)

Larmie (1993) undertook an assessment of the water quality characteristics of the Lower Volta River. He observed two important sources of pollution within the Lower Volta Basin as textile and domestic sewage effluent releases at Akosombo. Contrary to Mensah's (1976) report on the high temperature conditions of the river after the discharge of the ATL effluents, Larmie (1993) reported that the effluents from the ATL industries did not seem to have any impact on the temperature conditions of the Lower Volta River. Larmie (1993) also observed that the river water was generally alkaline in character. He recorded pH values ranging from 6.7 to 7.6 in 1990 and 1991 respectively. He also observed that the effect of the textile effluent on the dissolved oxygen (DO) content of the river was more pronounced in the dry season than in the wet. The range of the DO values was between 5.0 and 7.5 mg/L. He recommended the use of the Lower Volta River as a raw water source for domestic water supply as far as from the Akosombo dam to Agordome.

In a comparative study of the nutrient status of the Weija Lake and the Kpong reservoir in Southeast Ghana, Ansa- Asare and Asante (1998) recorded a mean temperature range of

28.9-30.8 °C for the Kpong reservoir. Over the 5-year study period, temperatures were more or less constant. The pH was also about neutral with a range of 6.7-7.0 and alkalinity values ranged from 40.3 – 52.0 mg/L as $CaCO_3$. Low suspended solids concentrations with a mean value of 4.32 mg/L were also recorded.

Ansa-Asare and Asante (1998) also observed that the yearly average orthophosphate levels were mostly moderate in relation to natural levels (0.02 mg/L, Ansa-Asare, 1996). The yearly mean values ranged between a minimum of 0 mg/L to a maximum of 0.08 mg/L. Nitrate-nitrogen concentrations ranged from a yearly mean of 0.2 to 0.5 mg/L while ammonia-nitrogen recorded yearly mean values ranging from 0 mg/L to 0.4 mg/L. The distribution of ammonia concentration showed a gradual increase over the 5- year period at both Weija and Kpong. Ansa-Asare and Asante (1998) however observed that on the average, there was complete nitrification of ammonia to nitrate over the 5-year period.

The Kpong reservoir recorded moderate dissolved oxygen concentrations. The five year monthly means ranged from 4.6 mg/L in January to 9.0 mg/L in September. BOD values recorded were comparatively lower than the Weija. The 5-year monthly mean concentrations ranged from 2.2 mg/L in May to 4.22 mg/L in March.

1.10.2 Problem with Weeds

The Volta dams were built to produce hydro-energy to enhance socio-economic development and bring prosperity to the peoples of Ghana. However one of the major environmental problems has been the invasion, development and spread of aquatic plants causing nuisance in the lakes created and rivers upstream and downstream of the lakes

(de-Graft Johnson, 1999). These weeds have negative effects on water transport, power generation, health, irrigated agriculture and fisheries. de-Graft Johnson (1999) also reported that the clarity of the water in the Headpond with its general shallowness encouraged the development of submerged weeds (*Potamogeton, Vallisneria Ceratophyllum*), free-floating weeds (*Pistia, Azolla, Lemna*) and emergent macrophytes (*Typha, Echinochloa, Enyfra, Mariscus, Phragmites*). 'Sudd' formers such as *Vossia, Leersia, Cyclosorus* and *Scirpus* were also abundant.

Gyimah-Amoako (1988) estimated the vascular macrophytes weed cover to be between 20– 25 % of the Headpond surface area (Plates 1 and 2). A survey carried out by consultants from the University of Ghana, indicated that aquatic weeds particularly the submerged weed *Ceratophyllum* species were spreading very fast (VRA, 1998). An estimated 240 tonnes of shoreline weed within the Headpond and Lower Volta areas were removed in 1998 as against 136 tonnes in 1997, an increase of 76.5 % (Plate 2). de-Graft Johnson (1999) reported that, in spite of the application of mechanical and manual control, about 35 % of the Headpond was still infested with aquatic weeds. Areas cleared were re-infested at a fast rate (i.e. 6-8 weeks after clearing).

Plate 1 Aquatic Weeds in the Kpong Headpond

Plate 2 Manual Weed Clearance from the Headpond

The effect of the weeds in the Kpong Headpond on the socio-economy, environment and health of especially the lakeshore communities has been catastrophic (de-Graft Johnson, 1999). The aquatic macrophytes especially the floating types such as *P.stratiotes* may increase water loss in the lake through transpiration. The weeds are also noted to cause

considerable water quality problems. For instance, their decayed remnants are observed to depress dissolved oxygen and increase BOD and nutrient levels in water bodies (Nana-Amankwah *et al.*, 1995). They can also trap silt leading to a reduction in the retention capacity of the dam. Odei (1975) showed some link between colonies of some forms of aquatic plant and snail vectors of schistosomiasis. He found that an area of 9.35 m^2 covered with *Althernanthera sessilis* in the Volta Lake contained 148 *Bulinus truncates*, while a much wider adjacent area, without weeds, produced only four snails.

These aquatic weeds also have the capability of interfering with power generation. de-Graft Johnson (1999) reported that, there were instances where some generating units at the Kpong generation station had to be shut down in order to remove weeds that had drifted into them. Laryea (2001) also reported that, within a span of two days in May 2001,the Kpong generating station had to flush out debris (actually aquatic weeds) on four occasions through the spillway.

Some emergent and floating weed colonies have developed in the Volta Lake and the Kpong Headpond. *Ceratophyllum* beds growing in front of some fishing villages have sometimes become difficult to penetrate even with light outboard motors (Abrokwah-Ampadu, 1984).

1.10.3 Fisheries in the Kpong Headpond

Before the Kpong Headpond was constructed in 1981, 50 fish species had been recorded from the area (Ayensu *et al.*, 1996). However, since the impoundment only 39 belonging to 30 genera and 16 families have been encountered. Most of the species, which were identified to be absent, were estuarine. This could be attributed to the fact that no facility

was created to allow fishes to move upstream beyond the dam. Moreover as noted by Odei (1983), ecological conditions created below the two dams have resulted in permanent freshwater, silt free waters and the growth of aquatic weeds, which are unfavourable for estuarine or brackish water fishes.

Standard fishing methods are used on the Headpond. Gordon (1999) reported that two of such methods are the use of mosquito netting and the 'wangara' method. The mosquito netting is used to catch the small clupeids (popularly known as 'one man thousand').

Fish catch from the Kpong Headpond has been estimated by Futa (1993) to be between 300 and 600 tons per year i.e., about 80 to 160 kg/ ha/ yr. In 1982, the reservoir produced between 463 to 618 metric tons of fish (Vanderpuye, 1982).

1.10.4 Public Health

Another negative impact associated with the formation of man-made lakes in tropical countries is the propagation of water-borne diseases. Odei (1979) recorded an increasing trend in the incidence of Schistosome infection in some river basins and impoundments in Ghana. He observed that the Weija Lake showed an increase of 83 % between 1968 (when the new dam had not been built) and 1979 (when the new dam was built).

The epidemiological survey in 1960-61, before the construction of the Akosombo dam, showed that the prevalence of schistosomiasis in school children in the lake area was 5 %. In the period 1964-67 after the construction of the dam, it had gone up to 90 % (Derban, 1975)

Surveys undertaken along the Kpong Headpond before impoundment (VRA, 1977) showed a high incidence of communicable diseases particularly malaria, gastrointestinal infections, pulmonary tuberculosis, urinary schistosomiasis and onchocerciasis. Worm infestations, particularly roundworm, hookworm and strongiloides were also common particularly among children. Other conditions found less frequently were infectious hepatitis, yaws, dental carries and dermatitis. Further studies undertaken near the headpond prior to impoundment indicated a high prevalence of onchocerciasis, which ranged between 14.35 and 68.8 % with a mean prevalence of 39 %. This high incidence was due to the proximity of the Senchi and Kpong rapids, which were a major breeding site for the Simulium fly. The prevalence of schistosomiasis in the area also ranged between 7 % and 20 % with and overall incidence of about 15 % (VRA, 1977).

With the inundation of the two rapids after the construction of the Kpong dam in 1982, the Simulium fly in the flooded area was eliminated and this has led to an eradication of the disease in the vicinity (Yeboah, 1999). The impoundment however provided habitat for the spread of schistosomiasis. The main intermediate hosts of schistosomiasis in the Volta Basin are *Bulinus truncatus rohfsi* (for *S.haematobium*) and *Biomphalaria pfeifferi* (for *S.mansoni*). Gordon (1999) observed that the construction of the two dams on the Volta River at Akosombo and Kpong created ecological changes favouring the proliferation of these snails in the lake area, on the Headpond and in the Lower Volta. He reported that the prevalence rates of urinary Bilharzia have since ranged between 70 % and 75 % in some lakeside communities and in some cases almost 100 % have been recorded among school children in the Lower Volta.

2 DESCRIPTION OF STUDY AREA

2.1 LOCATION

The study was undertaken on the Kpong Headpond and immediate lakeshore areas. The Kpong Headpond is located in the Lower Volta Basin below the Akosombo dam. It lies within the coordinates of 6° 08′ to 6° 17′ N and 0° 03′ to 0° 07′ E, and at 14.17 m above sea level (Fig 2.1).

2.2 THE KPONG HEADPOND

The Kpong Headpond (Fig 2.1) was created when the Kpong dam was constructed in the Lower Volta River in 1981. The lake or the Headpond as it is called, extends from the Kpong dam itself, which is just on the outskirts of Akuse, as far as to the Akosombo Dam, 25 km to the North (Moxon, 1984). The area covered by the Headpond is relatively small compared to lake Volta. It covers an area of about 36 km^2 and has a maximum depth of about 15 m near the dam, with an average depth of about 5 m (VRA, 1981). The eastern shoreline has a length of 29 km while the western shoreline is 39 km. The dykes and dams have a total length of 7 km (source, VRA engineering dept.). Before the construction of the dam, the Kpong area was well populated and cultivated. The construction of the dam therefore had a significant impact on the existing communities and agriculture and agro industries that existed in the area. 68 villages, 1,494 structures,

1,084 households and 5,462 people were affected by the formation of the Headpond (VRA, 1984).

The Headpond is shallow at Kpong and the water velocity is slow enough to favour the growth of aquatic weeds. Intense growth of aquatic weeds could be observed at this vicinity. The Headpond has also completely submerged the Kpong and Senchi rapids however some islands and rocks protrude through the Headpond surface especially at Kpong (VRA, 1981). The Headpond functions as a slow moving river and it is fed by the flow through the penstocks of the Akosombo dam and the Akosombo gorge. Kalitsi (1999) noted that the Kpong Scheme is essentially a run-of-the-river type since it utilizes the discharge from the upstream plant at Akosombo for power generation. It has no long-term storage function, but acts only as a reservoir for daily fluctuations. The Kpong turbines act in tandem with the Akosombo units, essentially taking all the flows passing through the Akosombo station (see appendix A for discharge rates). The velocity of the water averages 0.05 m/s through the main width of the Headpond, but there are backwater areas on the fringes of the Headpond with lower velocities. The mean annual flow of water through the reservoir is 1,183 m^3/ s (Ansa-Asare and Asante, 1998). The turnover period for the headwater has been estimated to be about 5 days (VRA, 1981).

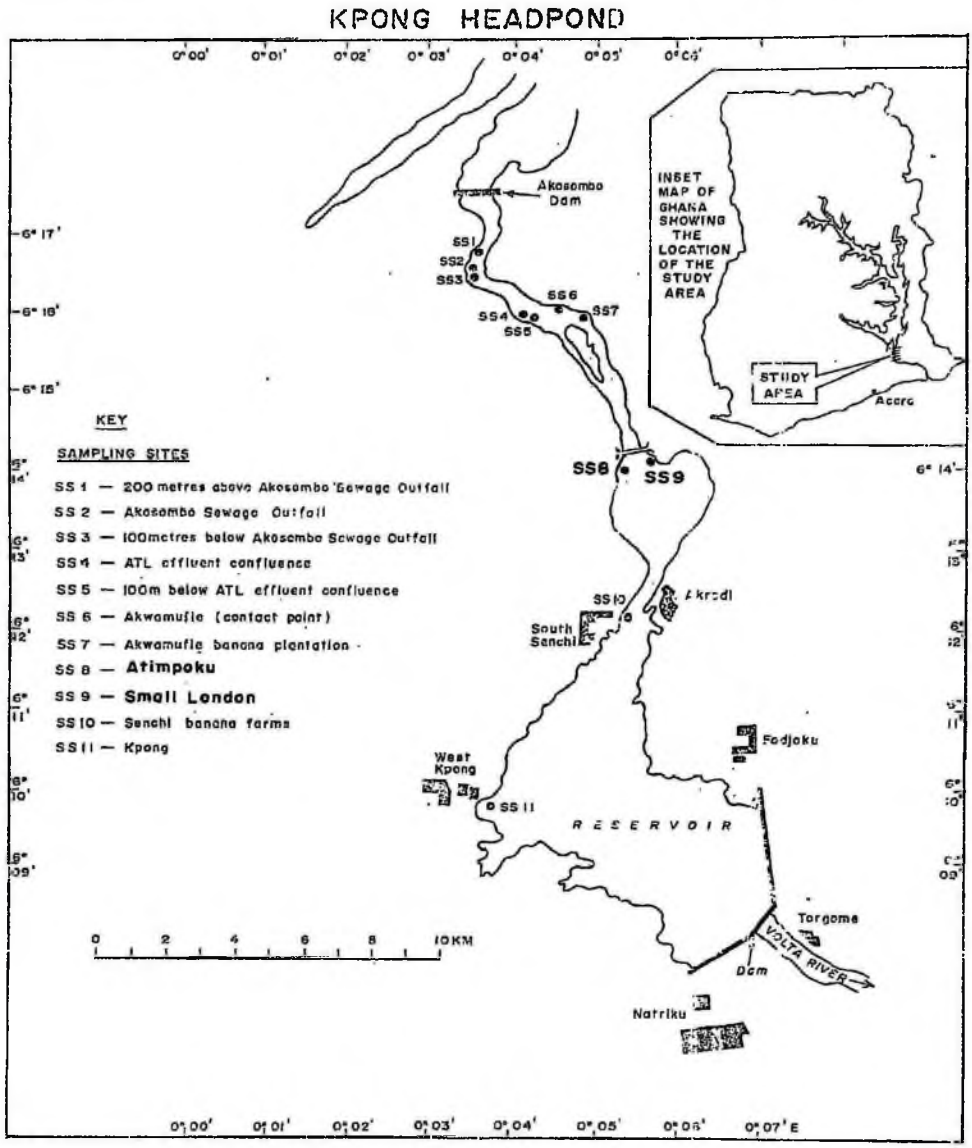

Figure 2.1 Map Showing Study Area and Water Sampling Sites

2.3 CLIMATE

The climate is a tropical forest-savanna transition type with two rainfall peaks (Kankam-Yeboah and Mensah, 1997). Figures 2.2a to 2.2g show a summary of climatic data at Akuse from 1995 to 2000 (Source, Meteorological Services, Akuse).

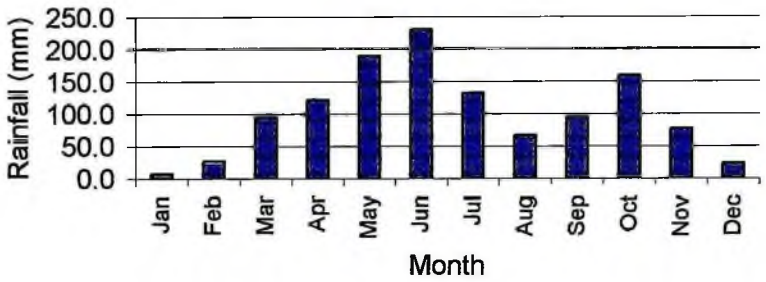

Figure 2.2a Mean Monthly Rainfall (mm) at Akuse.

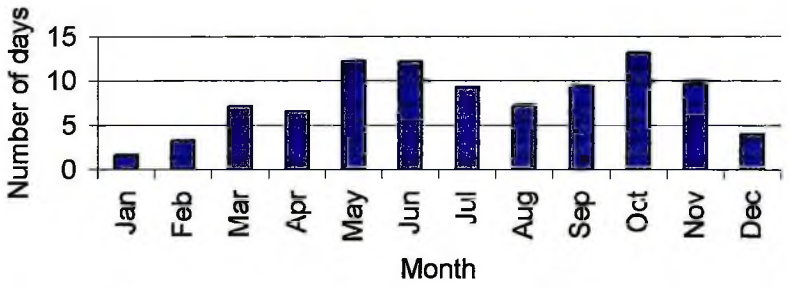

Figure 2.2b Mean Monthly Total Rainy Days at Akuse.

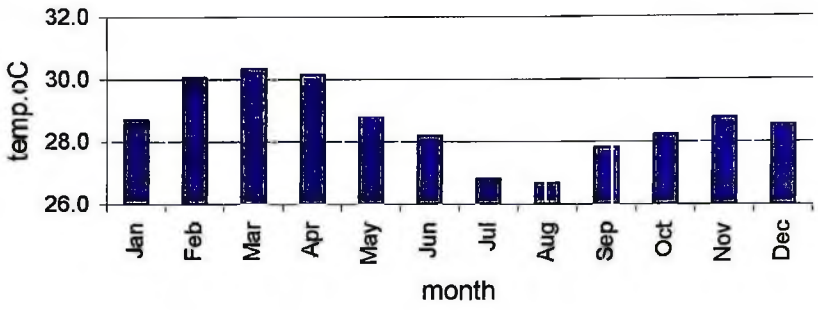

Figure 2.2c Mean Monthly Temperature (°C) at Akuse.

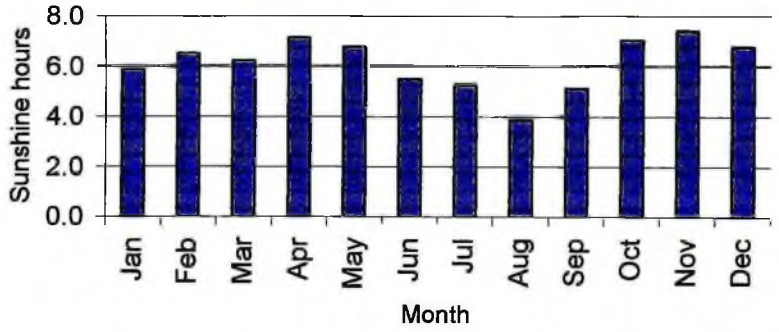

Figure 2.2d Mean Monthly Sunshine Duration (hours) at Akuse.

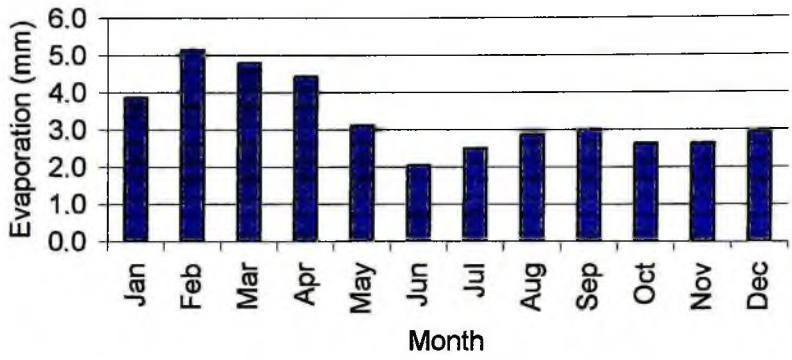

Figure 2.2e Mean Monthly Evaporation (mm) at Akuse.

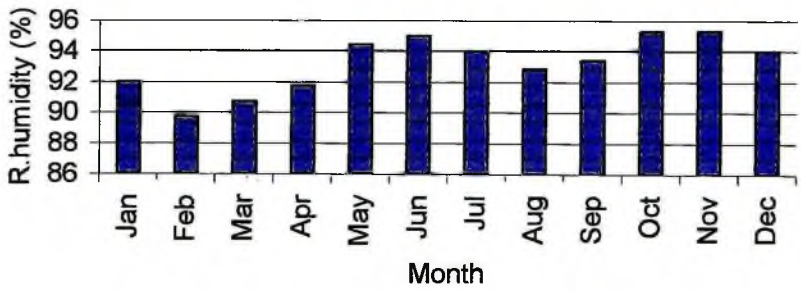

Figure 2.2f Mean Monthly Relative Humidity (%) at 06 Hours

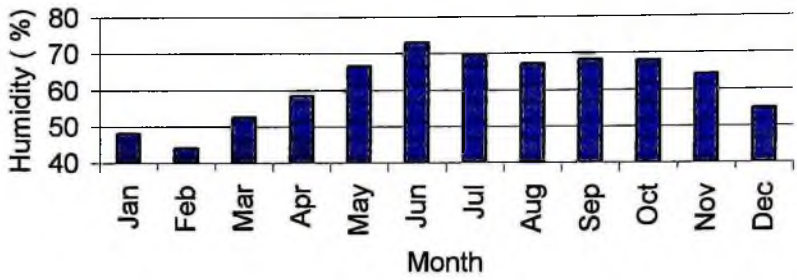

Figure 2.2g Mean Monthly Relative Humidity (%) at 15 Hours

2.3.1 Rainfall

There are two rainy seasons. The major rainy season occurs from April to June / July and the minor season from September to October, with a dry spell in July and August. Rain is rarely prolonged over any part of Ghana and the average duration is 2 or 3 hours.

2.3.2 Temperature

The average annual temperature for the area is 27.4 °C with little variation year to year. The average daily temperatures are highest in March, prior to the start of the rainy season, decreasing to a minimum in August.

2.3.3 Relative Humidity

The average morning (0600 hrs) relative humidity ranges from 89 % in February to 95 % in November while the afternoon (1500 hrs) values range from 45 % in February to 72 % in June. The average evening and early morning relative humidity are generally over 90

% while the afternoon minimum is 75 % with a seasonal variation of about 15 to 20 % (VRA, 1984).

2.3.4 Surface Wind Speeds

Surface wind speeds are generally low with inland speeds averaging about 8 km/hr. Wind speeds are lowest at night and during early morning, rising to a maximum during the middle of the afternoon when average values range from 8 to 15 km/hr. The highest wind speeds occur as gusts associated with thunderstorm and line squalls. Winds are generally, west-south westerly or southwesterly throughout the year.

2.4 HYDROLOGY

Prior to the completion of the Akosombo dam in 1966, the Volta river was a natural flow regime with discharges varying at the Kpong area from about 6 m^3/s to a maximum of 11,000 m^3/s (VRA, 1984). However, following construction of the Akosombo dam, discharges of Kpong were effectively fully regulated. Due to the insignificant live headpond storage; the Kpong reservoir contributes little to flow regulation. The long-term average discharge from Akosombo is 1,183 m^3/s, (Ansa- Asare and Asante, 1998). Data available at Senchi Halcrow gave a runoff of $34.2 \times 10^9 m^3$.

2.5 TOPOGRAPHY

The area is low-lying with topographic elevation of about 15 m above mean sea level, but rises steadily to the northwest on to the Akwapim-Togo ranges (Benneh and Dickson, 1980).

The Volta River emerges from the rugged topography of the Akwapim-Togo range of Hills to flow across the Accra Plains. Both alluvial and residual soils were present before the construction of the Kpong dam and the Volta River had excavated its bed in these soils, leaving steep banks in many places.

2.6 GEOLOGY

Rocks of the Precambrian Dahomeyan formation underlie the area and close to the contact zone with the Togo series, which overlies the Dahomeyan rocks (Kesse, 1985). The rocks encountered are of the garnetiferous hornblende gneiss consisting of light to dark, green hornblende, oligoclase, quartz and red garnets (VRA, 1984).

2.6.1 Soils

The soils of the area are the tropical black earths, commonly called the Akuse series. When wet, they become heavy and sticky but when dry, they become hard and compact and develop wide cracks. Towards the northern part of the area around Akwamufie, the soil can be classified as the forest ochrosol type. These are generally alkaline and contain considerable amounts of nutrients.

Before the construction of the Kpong dam, both banks of the Volta River at the site had been blanketed with soil cover, the deposition of which had been attributed mainly to floodplain conditions. The soil was made up of two main strata: an upper relatively impervious silty clay layer and a lower pervious, silty sand layer, which generally lies directly on the bedrock.

The upper alluvium, which varied in thickness, was brown and mottled with a fine-grained fraction (less than 2microns in size) varying from 5-55 %. The lower strata which is predominantly reddish brown although some parts are multicoloured, consist of clean, uniform, medium to coarse quartz particles up to 40 μm in size. The lower strata are locally absent where bedrock is at high elevations. In the exposed riverbanks, the silty alluvium had become weathered, hardened and desiccated and the sand was weakly cemented.

2.7 VEGETATION

In the past, the vegetation of the area was forest type (Kankam-Yeboah and Mensah, 1997). However human activity has modified this. At present, most of the vegetation consists of a mosaic of secondary forests, thickets, grassland and numerous cultivated clearing. The secondary forest consists of climbers, shrubs and soft woody trees like the silk cotton *Ceiba pentradra*, (Ghana Investments Centre, 1989).

2.8 POPULATION AND SOCIO-ECONOMIC ACTIVITIES

The Headpond is located within two districts, which are Asuogyaman and Manya-Krobo districts with populations of 74,142 and 143,950 respectively (GSS, 2000). Major towns in the area include Akuse, Kpong, Akrade, Atimpoku and Akosombo. Their populations are shown in Table 2.1 below:

Table 2.1 Population Estimates for Major Towns in the Volta Basin.

Town	Population (1984)*	Estimated Population (2000) **
Akuse	2838	4233
Kpong	7435	11,093
New Akrade	1177	1756
Atimpoku	1652	2465
Akwamufie	1454	2169
Akosombo	9820	14,651

- * Source (Statistical service, 1989)
- **Calculation based on 2.5 % growth rate (Ghana Statistical Service, 2000)

The Akwamus and settlers from the Tongu and other Anlo areas mainly inhabit the lakeside communities. They are predominantly fishermen and subsistent farmers. The principal crops cultivated are maize, cassava, rice and vegetables. Rice is mostly cultivated on the flat plains under fold conditions by peasant farmers. Antwi and Ofori-Danson (1993) reported that about 5,650 ha of agricultural land are currently irrigated for large-scale vegetable and rice cultivation. The Kpong Farms and the University of Ghana Agricultural Research Station at Kpong also grow rice commercially under irrigation. The Volta River Estates Limited (VREL) has also cultivated three plantations of banana at Senchi, Mangoase and Akwamufie. A few of the youth in the area are employed in these farms.

There are also a number of recreational activities on and along the Kpong Headpond. These include Riverside resorts (Plate3) and occasional regattas organized by the Akosombo Textiles Limited and the Volta River Estates Limited. Other recreational activities include boat cruising by tourists and swimming by the inhabitants along the Headpond.

Plate 3 A Hotel and Riverside Resort Situated Along the Headpond at Atimpoku.

3 MATERIALS AND METHODS

3.1 SELECTION OF SAMPLING STATIONS

The research began with a reconnaissance survey around the Kpong Headpond to identify the major forms of activities within the area and also to identify potential sources of pollution. Areas visited included Kpong, Atimpoku, Volta River Estates Limited (Akrade), Akosombo and Akuse. This was followed with another reconnaissance survey on the Kpong Headpond by boat to select the sampling stations. This was done beginning from Akuse (i.e., the Kpong dam) to Akosombo (close to the dam) and back over a period of two days.

Sampling stations were selected based on the intensity of activities observed at the various localities visited along the Headpond. These included activities such as fetching water for domestic use, bathing at the banks, farming and other industrial activities. Point sources of potential pollutants were also surveyed.

At the end of the preliminary survey, 11 sites were selected (Fig 2.1). A Global Positioning System (GPS) was used to record the coordinates of all the selected sampling stations. The coordinates of the selected sites are presented in Table 3.1 below.

Table 3.1 Coordinates of Sampling Sites

SAMPLING SITES	COORDINATES	
SS1	N 06° 17′ 13.7″	E 00° 03′ 35.3″
SS2	N 06° 16′ 40.5″	E 00° 03′ 47.3″
SS3	N 06° 16′ 45.0″	E 00° 03′ 36.9″
SS4	N 06° 16′ 16.8″	E 00° 04′ 14.8″
SS5	N 06° 16′ 09.5″	E 00° 04′ 29.7″
SS6	N 06° 16′ 27.0″	E 00° 04′ 39.6″
SS7	N 06° 16′ 19.6″	E 00° 05′ 04.2″
SS8	N 06° 14′ 01.5″	E 00° 05′ 35.0″
SS9	N 06° 14′ 13.4″	E 00° 05′ 54.3″
SS10	N 06° 11′ 50.9″	E 00° 05′ 33.6″
SS11	N 06° 09′ 17.9″	E 00° 03′ 50.0″

3.2 DESCRIPTION OF SAMPLING STATIONS

3.2.1 Sampling Station 1 (SS1)

This site was located 200 m above the Akosombo sewage outfall at the right bank. The site was sheltered with terrestrial plants some of which overhang the Headpond. No settlements were visible at the site although a maize farm was located close by in the month of May.

3.2.2 Sampling Station 2 (SS2)

The site was located about 10 m downstream of the Akosombo sewage treatment plant (ASTP) outfall at the right bank. There was a fishy odour at the site and this may be attributed to the activities of fishermen and fishmongers who fish and dry their Clupeids (one-man-thousand) in the area.

The outfall actually comprised treated wastewater from the Akosombo sewage plant, which empties into a large storm water drain before entering the Headpond.

3.2.3 Sampling Station 3 (SS3)

The sampling station was located 100 m below the Akosombo sewage outfall. No settlements were immediately visible at the area but further downstream about some 200m, was located a small community called Abume which had the Headpond as its only source of water.

3.2.4 Sampling Station 4 (SS4)

This sampling station was located at the site where the Akosombo Textiles Limited (ATL) effluent enters the Headpond at the right bank. A very pungent odour was observed at the site. The discolouration of the water at this site was also clearly visible. The vegetation along the banks at the site was quite thick and only few aquatic plants were visible in the area. Some of the vegetation in the water and the surrounding area had coated leaves and stems apparently due to the highly coloured and turbid water at the site.

3.2.5 Sampling Station 5 (SS5)

This sampling station was 100 m below where the (ATL) effluent was sampled. The site was well sheltered with shrubs. Not much human activity was observed.

3.2.6 Sampling Station 6 (SS6)

Site SS6 was located at a canoe-landing site at Akwamufie at the left bank. The main activities observed at the area included people joining and disembarking canoes. At certain periods of sampling, people were seen fetching water for domestic use or swimming in the Headpond. The site was also very close to a one-storey building at the bank.

3.2.7 Sampling Station 7 (SS7)

This sampling station is located at the Akwamufie banana plantation about 500 m below site SS6. The farms are rather close to the Headpond with about 5 – 10 m of vegetation separating them. There is no human settlement immediately around the sampling site.

3.2.8 Sampling Station 8 (SS8)

The site was located at Atimpoku, downstream the slaughterhouse and about some 500 m below the Adomi Bridge. There was a basket-weaving site very close to the site the wastes from which were dumped in the water. Some houses were very close to the Headpond and their bathhouses were located at the banks with the wastewater entering the Headpond directly.

3.2.9 Sampling Station 9 (SS9)

This site was at the left bank near a small community called 'small London'. It was observed that some of the settlements were quite close to the Headpond with a lot of human contact. At the various times of sampling, people (especially men) were observed

to be bathing and swimming while some women had also come to fetch water for domestic use.

3.2.10 Sampling Station 10 (SS10)

This site is located near the Senchi Banana Plantation, which was about 10 m from the shoreline. No human settlements were immediately visible from the Headpond to this site although a footpath was located about 300 m downstream the sampling station. Thick aquatic vegetation was observed along the edges of the shoreline.

3.2.11 Sampling Station 11 (SS11)

This sampling site was located at the right bank at Kpong, near the fish market where most people could be seen either buying or selling fish. This is a popular spot for travelers along the Kpong –Accra road to buy fish from the Headpond, especially fresh tilapia. Several activities were observed in the vicinity and immediately upstream the station. These included people joining and disembarking canoes, people bathing at the banks and some people either washing or fetching water for domestic purposes. Human contact with the water was observed to be quite heavy.

Another observable feature at this site was the presence of a lot of aquatic plants especially the submerged *Ceratophyllum* species. A lot of floating weeds such as *Pistia* and *Azola* were also observed floating on the surface of some sections of the Headpond.

3.3 SAMPLING AND PHYSICOCHEMICAL ANALYSIS

Water samples for physicochemical analysis were obtained from the eleven strategically chosen sampling sites (Fig. 2.1) in October 2000, December 2000, February 2001 and May 2001. An outboard-motored Aluminium boat was used to reach the sampling sites.

At each sampling site, a clean plastic bucket was used to fetch water by hand from a depth of about 10 cm for *in-situ* measurements. 2 litre bottles were also filled for other chemical analysis in the laboratory. Water samples were placed on ice soon after collection and transported to the laboratory within 24 hours of collection. In the laboratory, the water samples were stored in a refrigerator at 4 °C. The chemical analyses were performed within seven days after collection.

Water chemistry parameters were measured at Volta Basin Research Project (VBRP), Legon and at the Water Research Institute (WRI) laboratories. At the VBRP, Legon, the following analyses were performed: Total Suspended Solids, Turbidity and Apparent Colour determinations using the Hach DREL 2000 spectrophotometer. DO, BOD, COD, NO_3-N, PO_4-P, and NH_3-N determinations were carried out at the WRI using methods according to (APHA, 1998).

3.3.1 pH, Temperature, Total dissolved solids and Conductivity

The parameters pH, temperature, total dissolved solids and conductivity were measured *in-situ* using the Horiba Digital Water Quality Checker (model V.10). pH was measured in pH units while temperature, total dissolved solids and conductivity were measured in °C, mg/L and $\mu S\ cm^{-1}$ respectively.

3.3.2 Dissolved Oxygen (DO)

The Azide modification of the Winkler method was used to determine the amount of dissolved oxygen in each sample. Water samples were collected in 300 mL glass-stoppered bottles carefully to avoid the formation of air bubbles. The DO in the water samples were fixed in the field by adding 2 mL of manganous chloride solution (Winkler I) followed by 2 mL of alkaline- iodide-azide reagent (Winkler II). The bottles were inverted several times to ensure adequate mixing.

In the laboratory, the samples were acidified with 2 mL of concentrated tetraoxo-sulphate (VI) acid. The DO was determined immediately after acidification by titration with standard sodium thiosulphate solution. A 100 mL aliquot of the acidified sample was titrated against M/80 sodium thiosulphate solution to a straw yellow colour. About 1 mL of starch indicator was added forming an intense blue-black colour. Titration was continued until a colourless end-point was reached. The amount of DO in the sample was then calculated as follows:

$$\text{Mg/L } O_2 = \frac{\text{Volume of M/80 thiosulphate}}{\text{Volume of sample used}}$$

3.3.3 Biochemical Oxygen Demand (BOD)

The azide modification of the Winkler method (APHA, 1998) was used in the determination of BOD. 300 mL bottles with wide flared mouth, which had previously been painted black with bitumen and covered with aluminium foil, were used to fetch the sample. This was to prevent the possibility of photosynthetic production of oxygen. The

bottles were filled carefully to avoid the formation of air bubbles and stoppered carefully. They were then incubated in the dark at 20 °C for five days.

The DO concentration was measured before and after incubation and BOD calculated from the difference between the initial and final dissolved oxygen.

For samples that had low DO values, the dilution method for BOD determination was used since it was expected that no DO would be left in the original sample after the 5-day incubation period. This was particularly the case with samples from ATL and Akosombo Sewage effluents.

Dilution Method (BOD)

The water sample was diluted by adding specially prepared dilution water. The dilution water was prepared as follows:

5 L of distilled water was placed in a large plastic bottle. 1 mL each of the following solutions was added per litre of water: i) Phosphate buffer ii) $MgSO_4$ iii) $CaCl_2$ and iv) $FeCl_3$. The dilution water was then saturated with oxygen by bubbling air through it for at least 24hours and used as soon as possible.

600 mL of the diluted sample was prepared with a dilution factor that could yield a residual DO of at least 1 mg/L and a DO uptake of at least 2 mg/L after 5-day incubation This range yields the most reliable results (APHA, 1998). Two 300 mL BOD bottles were then filled with the diluted sample. One of the two bottles was then incubated in the dark at 20 °C for a period of 5 days. The other bottle was fixed with 2 mL $MnSO_4$ followed by 2 mL alkaline-iodide-azide and corked carefully to exclude air bubbles. It was then

shaken thoroughly by inverting several times and then the precipitate was allowed to settle at the bottom to the sample. After the precipitate had settled, 2 mL conc H_2SO_4 was added, corked and the bottle again inverted several times to dissolve the precipitate giving an intense yellow colour.

100 mL of the sample was then titrated with m/80 sodium thiosulphate to a pale yellow colour and 1 mL starch solution added as indicator. Titration was continued to the first disappearance of the blue colour. The same procedure was followed for the incubated sample at the end of the 5 days to ascertain the difference in DO for the calculation of the BOD.

BOD_5, mg/L = (D_1-D_2) /p

D_1 = DO of diluted sample immediately after preparation

D_2 = DO of diluted sample after 5 day incubation at 20 °C

P = decimal volume fraction of sample used

3.3.4 Chemical Oxygen Demand

The closed tube reflux method was used in the analysis.

5 mL of the water sample or a diluted aliquot was placed into a culture tube. 3 mL of potassium dichromate solution was added followed by 7 mL H_2SO_4 reagent (i.e. silver sulphate in sulphuric acid). The tube was then capped tightly and shaken to mix completely. The tubes were then placed in a digester and refluxed for 2 hours. After 2 hours the samples were cooled to room temperature and 1 to 2 drops of ferroin indicator added.

The sample was then titrated against Standard Ferrous Ammonium Sulphate (FAS) solution. The colour change observed was from blue-green to a reddish brown precipitate.

A blank, containing the reagents and a volume of deionised water equal to that of the sample, was also refluxed and titrated in the same manner.

The COD in mg/L O_2 was then calculated for the sample as follows:

$$\text{COD mg}O_2\text{/l} = \frac{(A-B) \times M \times 8000}{\text{mL sample}}$$

Where A = mL of FAS used for blank
B = mL of FAS used for sample
M = molarity of FAS and
8000 = milliequivalent weight of oxygen X 1000 mL/1

3.3.5 Nitrate-Nitrogen (NO_3-N)

The hydrazine reduction method (APHA, 1998) was used in the analysis. 10 mL of the sample was pipetted into a test-tube and 1.0 mL of 0.3 M NaOH added and mixed gently. 1 mL of reducing mixture (20 mL Copper Sulphate, 16 mL hydrazine sulphate and 20 mL 0.3 M sodium hydroxide) was added and mixed.

The sample was then heated at 60 °C for 10 minutes in a water bath. It was then cooled to room temperature and 1.0 mL of colour developing reagent added and shaken.

The absorbance was read at 520 nm using a UV-VIS spectrophotometer (Ultrospec II model). A calibrated curve prepared for standard solutions was used to compute sample concentration.

3.3.6 Ammonia-Nitrogen

The Direct-Nesslerization method as specified by the APHA Standard Methods was used. The method is based on the colourimetric determination of ammonia after the addition of Nessler's reagent. The yellow to brown colour produced by the Nessler-ammonia reaction absorbs strongly in the range of 400 – 425 nm when a 1 cm light path is used.

10 mL of the sample was pipetted into a test tube and one drop of Rochelle salt added. This was mixed well and then 0.4 mL of Nessler's reagent was added. A blank was similarly prepared using deionised water as the sample. The samples were then allowed to stand for 10 minutes for colour development after which their absorbance were determined using a UV-VIS Spectrophotometer at a wavelength of 410 nm using a 1 cm light path cuvette. The spectrophotometer was set to zero using the blank solution.

A calibration curve was prepared and used to determine the concentration of ammonia-nitrogen in the unknown samples.

3.3.7 Orthophosphate.

The Stannous Chloride method (APHA, 1998) was used in the determination. 10 mL of the sample (free from colour and turbidity) was pipetted into a test tube. 0.4 mL Molybdate reagent I and 0.05 mL (1 drop) stannous chloride reagent were then added with thorough mixing after each addition. After 10 minutes, but before 12 minutes, the absorbance was measured at a wavelength of 690 nm on the UV-VIS spectrophotometer.

The sample concentration was then determined from a calibration curve that was prepared.

3.3.8 Apparent Colour

The Platinum-Cobalt Standard method was used. About 50 mL of the sample was poured into a sample cell. Another sample cell was filled with filtered deionised water and used as blank. The sample was then read at a wavelength of 455 nm in Pt Co units on DREL 2000 Spectrophotometer.

3.3.9 Turbidity

The absorptometric method was used. 25 mL of the sample was poured into a sample cell and another sample cell filled with 25 mL of deionised water as blank. The sample was then read at a wavelength of 450 nm in Nephelometric Turbidity Units (NTU).

3.3.10 Suspended Solids

The Photometric method was used. 500 mL of the sample was blended at high speed in a commercial blender for exactly 2 minutes. It was then poured into a 600 mL beaker. The sample was stirred and 25 mL of the blended sample immediately poured into a sample cell. Another sample cell was filled with 25 mL of demineralised water and used as blank.

The prepared sample cell was swirled to remove any gas bubbles and uniformly suspend any residue. It was then read at a wavelength of 810 nm in mg/L Suspended Solids.

3.4 BACTERIOLOGICAL ANALYSIS

At each of the sampling sites, a sterilized 300 mL bottle was filled with the water sample for microbiological analysis in the laboratory. To avoid contamination of the bottle, the base of the bottle was held rather than the neck to fetch the water. The bacteriological analyses were carried out at the Volta River Authority (VRA), Public Health laboratory using the ELE Paqualab.

The membrane filter technique was used to enumerate the total and feacal coliforms present. The media used for growth was Lauryl Sulphate broth. 2 mL of sterilized Lauryl sulphate broth was poured on an absorptive pad placed in a small petri dish.

50 mL of the sample was filtered through a membrane filter system, which had previously been sterilized. The filter paper was lifted from the system with a sterilized forceps and carefully placed on the soaked pad. The petri dish was then covered and inverted for incubation. For each sample, a duplicate was prepared. The sample for enumeration of Total Coliforms was incubated at 37 °C while that for Feacal Coliform was incubated at 44 °C in an ELE paqualab for a period of 18 hours.

After the incubation period, the growths on the media were identified and counted in coliform forming units (cfu /100 mL).

3.5 MACRO INVERTEBRATES ANALYSIS

At sampling stations where there was some aquatic vegetation, a sweep net was used to disturb the vegetation for one minute so as to collect any fauna (Gordon, 1995). In general 1-2 m sections of the bank were sampled in one sweep. The contents of the nets were emptied onto white sorting trays and any organisms found were collected. The sorted invertebrates were then preserved with 10 % formalin stained with Rose Bengal Stain and sent to the Laboratory. Identification and counting of Macroinvertebrates was done at the VBRP laboratory at Legon. At the laboratory, identification keys were used to identify the organisms to the taxa or family levels with the aid of a hand lens and bright illumination.

3.6 INTERVIEWS AND QUESTIONNAIRE SURVEY.

The data for the study were obtained from two sources. Primary data were obtained from field interviews that were conducted and this was complemented with others obtained form questionnaires sent to some selected institutions.

3.6.1 Field Survey

The field survey was conducted in two phases. The first phase was used to carry out reconnaissance visits to selected lakeside communities and other project areas, which in one way or another, depended on the water in the Headpond as a source of water supply. The second phase was for interviewing selected household members in some selected communities.

3.6.1.1 Reconnaissance Visits

Reconnaissance visits were made to a number of project sites, their immediate environs and other selected lakeside communities whose activities were thought to have an impact on the quality of water in the Headpond. The purpose of the reconnaissance visits was to obtain familiarity with the study area and gain some insights into the general as well as some specific impacts of activities in the lakeside areas on the quality of the water. It was also used to assess the feasibility of a formal survey.

The companies visited were the Akosombo Textiles Limited (ATL), Volta River Estates Limited (VREL), Kpong water works, Senchi River resort, Alos bay resort, Kpong irrigation Canal. Some of the lakeside communities that were visited were Kpong (Ayipala, Anlokodzi, Wharf), Atimpoku, New Senchi, Senchi ferry, Akrade, New Powmu, Ghanakpe, Small London, Abume and Kokontekpedzi.

3.6.1.2 Formal Interviewing

A total of 95 people were interviewed from 10 settlements along the Headpond. In all the communities, respondents were questioned, among other things, about their sources of water, incidence of diseases and the condition of the physical environment.

The interview was conducted in either Ewe or Akan depending on the local language spoken by the interviewee. One criterion was that, a respondent should live in the community in which the interview was conducted. Only one respondent was interviewed per household.

3.7 STATISTICAL ANALYSIS

3.7.1 Water Quality

A completely randomized design (CRD) was used for the experiment. The analysis of variance was used to test significance (Steele and Torrie, 1980) while Least Significant Difference (LSD) was used to compare the individual treatment means where significant differences were observed.

3.7.2 Macroinvertebrates

To analyse community structure, the following parameters were examined: diversity measured by the Shannon Wiener Index (H'), Evenness (J) also known as equitability and Species Richness (D) also known as Margalef's index (Gordon, 1995).

i) Shannon's $H' = -\sum_{i=1}^{s} \frac{n_i}{n} \ln \frac{n_i}{n}$

ii) Evenness Index $J' = \frac{H'}{Log_2 s}$

iii) Species Richness $d = \frac{(s-1)}{\ln N}$

Where: n= the number of individuals in a sample from a population

n_i= the number of individuals in a species I of a population or community

s = number of species in the sample

N = number of individuals in the sample

3.7.3 Social Survey

SPSS software was used to generate descriptive statistics and Chi square analysis of the data collected. For purposes of illustration, statistical diagrams such as bar graphs and Pie charts were employed wherever appropriate.

4 RESULTS

4.1 PHYSICAL CHARACTERISTICS OF THE WATER

4.1.1 Hydrogen Ion Concentration, pH at the Sampling Sites

The pH values of water from the various sites are presented in Appendix A1. The values ranged from a minimum of 6.83 (at site SS1) to a maximum of 11.2 at (site SS4). Ten of the sites recorded near neutral pH values throughout the study period while one site (SS4) consistently recorded alkaline values ranging from 10.3 to 11.2 in Figure 4.1.

Table 4.1 shows an ANOVA table comparing the mean values of pH at the various sites. The mean pH value recorded at site SS4 was significantly different ($p<0.05$) from that at the ten other sites while there was no significant difference ($p >0.05$) between these ten sites.

The ANOVA table also indicated that, temporal variations in pH were also highly significant ($p<0.05$). Mean pH values obtained in May were significantly ($p<0.05$) higher than that recorded in October, December and February. However there was no significant ($p>0.05$) difference between the mean values recorded in October, December and February.

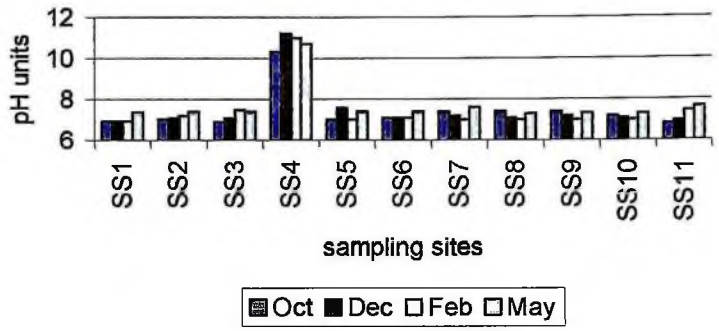

Figure 4.1 Spatial and Temporal Variations in pH

Table 4.1 Statistical ANOVA Table for pH at the sampling sites

Source of Variation	SS	df	MS	F	P-value	F crit
Sites	47.34351	10	4.734351	89.17468	1.67E-19	2.16458
Time	0.592827	3	0.197609	3.7221	0.021842	2.922278
Error	1.592723	30	0.053091			
Total	49.52906	43				

4.1.2 Temperature

The results obtained are presented in Appendix A2. The readings varied between a minimum of 27.7 °C to a maximum of 31.4 °C. There were slight variations in the water temperatures recorded at the various sites during the study period as shown by their standard deviations. For the months of October, December and February, site SS4 recorded the highest temperature values while in May; the highest temperature was recorded at site SS11. Figure 4.2 shows the temperature variations at the sites over the study period. The differences in the temperature values at the various sites were significant ($p<0.05$) as shown in Table 4.2.

Appendix A2 also shows those sites, which were either significantly ($p< 0.05$) different from each other or not significantly different ($p>0.05$). Seasonal variations observed in the water temperature were also significant ($p<0.05$) as shown in the ANOVA table (Table 4.2.). There was a gradual and consistent increase in the water temperature recorded from October to May. This is illustrated in Figure 4.2.

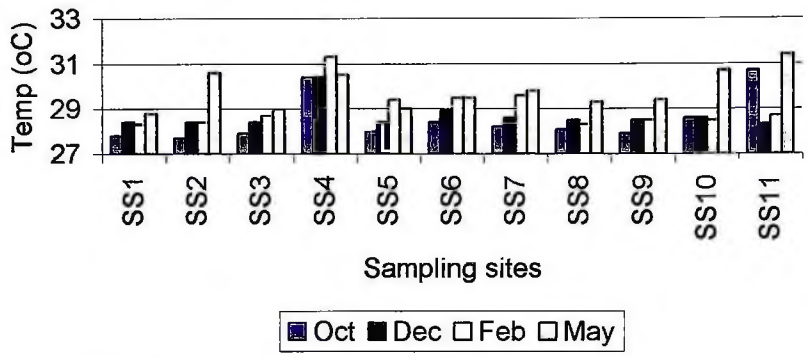

Figure 4.2 Spatial and Temporal Variations in Temperature

Table 4.2 Statistical ANOVA Table for Temperature at the sampling sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	18.38409	10	1.838409	4.796039	0.000392	2.16458
Time	10.93545	3	3.645152	9.509467	0.000143	2.922278
Error	11.49955	30	0.383318			
Total	40.81909	43				

4.1 3 Conductivity

Conductivity values obtained in the study are presented in Appendix A3. Figure 4.3 illustrates the variations in conductivity values during the study. The values recorded

ranged from 51 µS/cm to 1590 µS/cm. All the sites, with the exception of site SS4 recorded moderate values. Site SS4 recorded a highly variable conductivity values ranging from 383 to 1590 µS/cm during the study (Fig. 4.3).

Table 4.3 is an ANOVA table that compares the means of conductivity values obtained in the study. The conductivity values obtained at site SS4 were significantly ($p < 0.05$) higher than the conductivity values obtained at the other sites. There were however no significant ($p>0.05$) differences within the other sites.

Table 4.3 shows that the differences in the mean conductivity values were not significantly ($p>0.05$) different. Although there was a marked increase in the conductivity values obtained at site SS2 in May, this was not statistically significant ($p> 0.05$).

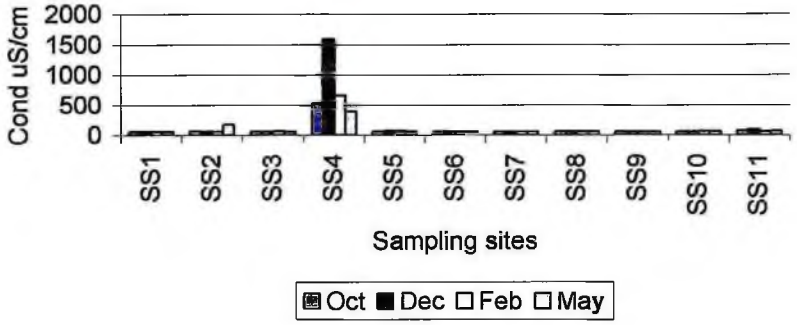

Figure 4.3 Spatial and Temporal Variations in Conductivity

Table 4.3 Statistical ANOVA Table for Conductivity at the sampling sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	1941510	10	194151	7.044792	1.4E-05	2.16458
Time	77064.27	3	25688.09	0.932095	0.43732	2.922278
Error	826785.2	30	27559.51			
Total	2845360	43				

4.1 4 Total Dissolved Solids (TDS)

Results for TDS measured over the period are shown in Appendix A4. The values ranged from a minimum of 26.9 mg/L at site SS1 to a maximum of 194.4 at site SS4. Apart from site SS4, all the other sites had moderate Total Dissolved Solids concentrations (Fig 4.4).

Table 4.4 shows an ANOVA table comparing the means of TDS values obtained in the study. Site SS4 recorded TDS values that were significantly ($p<0.05$) higher than the other ten sites while there were no significant differences between the other sites.

Table 4.4 also showed that there were no significant ($p > 0.05$) seasonal variations in the TDS concentrations. However, as indicated by the relatively higher standard deviation of 31.0 at site SS2, there was a marked increase in the concentration of TDS at site SS2 in May (Fig. 4.4.). TDS concentrations measured at site SS4 was also highly variable with a standard deviation of 286.21.

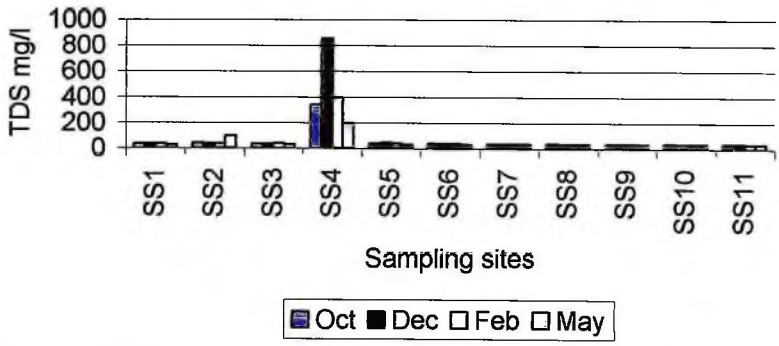

Figure 4.4 Spacial and Temporal Variations in TDS Concentrations

Table 4.4 Statistical ANOVA Table for TDS at the sampling sites

Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	613389.7	10	61338.97	8.096804	3.64E-06	2.16458
Time	21728.72	3	7242.908	0.956071	0.42615	2.922278
Error	227271.1	30	7575.702			
Total	862389.5	43				

4.1 5 Suspended Solids (SS)

Appendix A5 shows the concentrations of Suspended solids measured during the study. Apart from site SS4, the SS concentrations measured at all the other sites were quite low with mean values ranging from 3.3 mg/L at site SS1 to 10.8 mg/L at site SS2. Site SS4 however, recorded higher concentrations of suspended solids with an average value of 203.3 mg/L. Figure 4.5 illustrates the spatial and temporal variations of suspended solids. Table 4.5 also shows an ANOVA table comparing the mean concentrations of suspended solids measured over the study period. Site SS4 had a mean concentration of Suspended solids that was significantly ($p<0.05$) higher than what was observed at the other sites. The ten other sites however did not show any significant differences ($p>0.05$) between them.

Table 4.5 shows that there was no significant ($p>0.05$) seasonal variation in the suspended solids concentrations.

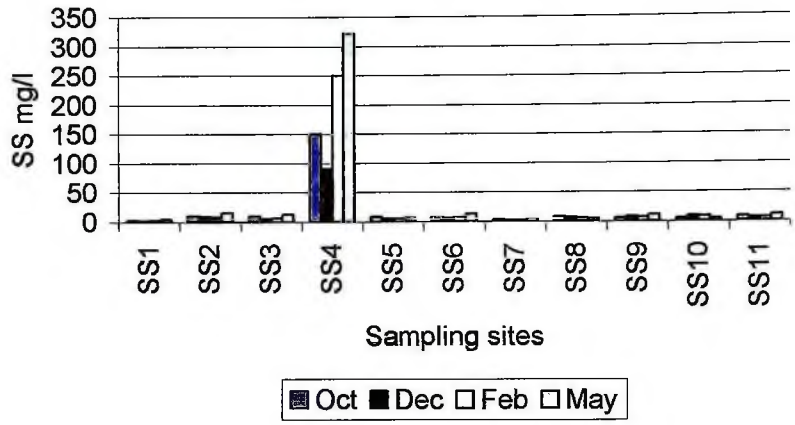

Figure 4.5 Spatial and Temporal Variations in Suspended Solids Concentrations

Table 4.5 Statistical ANOVA Table for Suspended Solids at the sampling sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	140004.5	10	14000.45	14.81365	4.85E-09	2.16458
Time	3530.364	3	1176.788	1.24514	0.310807	2.922278
Error	28353.14	30	945.1045			
Total	171888	43				

4.1 6 Turbidity

Appendix A6 shows turbidity values obtained. The values were generally low ranging from a mean value of 4.0 NTU at site SS2 to a maximum of 134.5 NTU at site SS4. Figure 4.6 shows the turbidity values recorded at the various sites. Site SS4 recorded the highest turbidity value followed by Site SS2. The other nine sites had similar mean turbidity readings.

Table 4.6 is an ANOVA table comparing the mean values for turbidity. Turbidity at Site SS4 was significantly ($p<0.05$) higher than the other sites. Site SS2 was also significantly

($p<0.05$) more turbid than the others. However there was no significant difference ($p>0.05$) between the other nine sites as shown in Fig. 4.6.

There were no significant ($p>0.05$) temporal variations in turbidity values obtained during the study as indicated by Table 4.6.

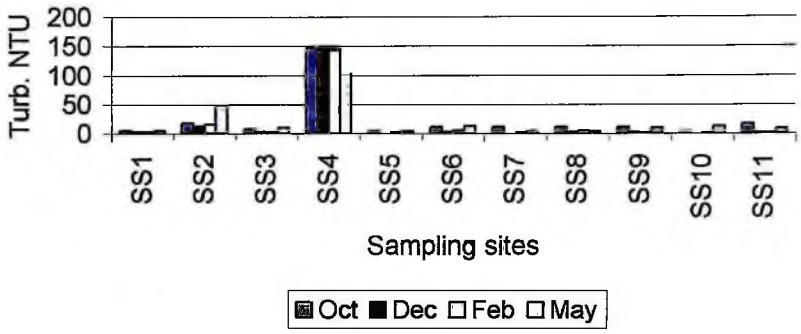

Figure 4.6 Spatial and Temporal Variations in Turbidity

Table 4.6 Statistical ANOVA Table for Turbidity at the sampling sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	60184.5	10	6018.45	74.24491	2.31E-18	2.16458
Time	343.8864	3	114.6288	1.414086	0.257987	2.922278
Error	2431.864	30	81.06212			
Total	62960.25	43				

4.1 7 Apparent Colour

The results obtained are shown in Appendix A7. The values ranged from a minimum value of 5.0 ptCo to a maximum value of 552 ptCo. Figure 4.7 shows the variations of apparent colour at the various sites during the study. With the exception of Sites SS2 and

SS4, which recorded remarkably higher levels, the other sites recorded generally low levels of apparent colour.

Table 4.7 Statistical ANOVA Table for Apparent Co lour at the sampling sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	482138.7	10	48213.87	16.01193	1.91E-09	2.16458
Time	9589.364	3	3196.455	1.06155	0.38005	2.922278
Error	90333.64	30	3011.121			
Total	582061.7	43				

Plate 4 Colour of water sampled at site SS4 in October 2000.

Table 4.7 shows an ANOVA table comparing the means of apparent colour obtained in the study. Site SS4 had a significantly ($p<0.05$) higher apparent colour (Plate 4) than all the other sites. Although Site SS2 also showed some considerable level of apparent colour, this was not significantly different from the nine other sites.

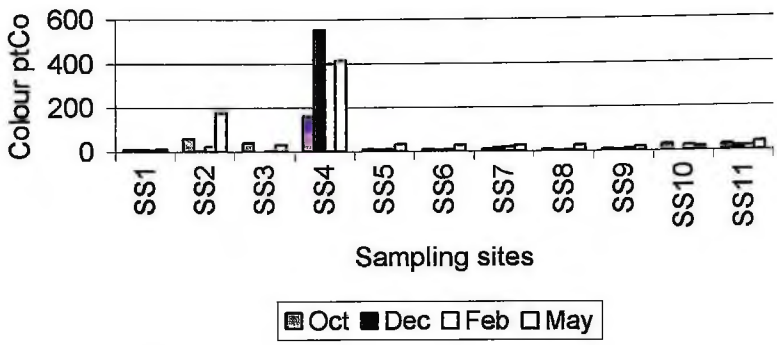

Figure 4.7 Spatial and Temporal Variations in Apparent Colour

4.2 CHEMICAL CHARACTERISTICS OF THE WATER

4.2.1 Ammonia-Nitrogen Concentration

Results obtained for ammonia concentrations during the study are presented in Appendix A8. The values obtained ranged from a minimum value of <0.01 mg/L to a maximum mean value of 0.9 mg/L. Most of the sites did not have measurable quantities of Ammonia-Nitrogen in the water since their concentrations were less than 0.01 mg/L. Only two of the eleven sites had appreciable quantities of ammonia to be measured as shown in Figure 4.8.

Table 4.8 is an ANOVA table comparing the means of Ammonia-Nitrogen concentrations obtained in the study. The ammonia–nitrogen concentration at site SS4 was significantly ($p<0.05$) higher than all the other ten sites. There were however no significant differences ($p>0.05$) between the other ten sites although site SS2 recorded some appreciable amount of ammonia.

Table 4.8.also showed that there were no significant ($p>0.05$) seasonal variations in the concentrations of Ammonia-Nitrogen recorded over the study period.

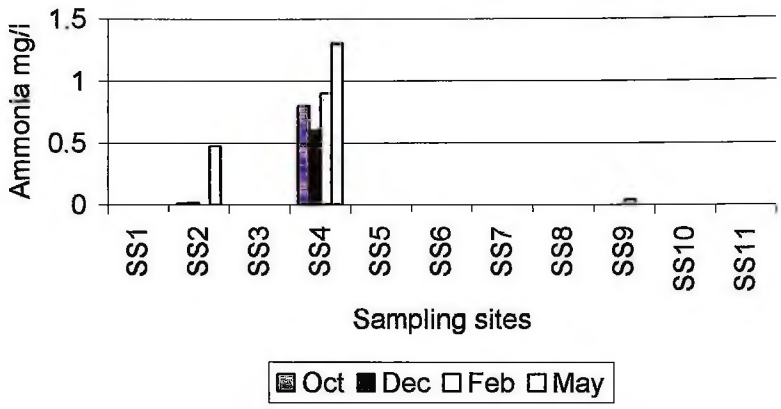

Figure 4.8 Spatial and Temporal Variations in Ammonia Concentration

Table 4.8 Statistical ANOVA Table for Ammonia-Nitrogen at the sampling sites.

Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	2.913364	10	0.291336	24.97818	7.23E-12	2.16458
Time	0.070191	3	0.023397	2.005976	0.134317	2.922278
Error	0.349909	30	0.011664			
Total	3.333464	43				

4.2.2 Nitrate-Nitrogen Concentration

Nitrate- nitrogen results obtained in the water the study are presented in Appendix A9. The values ranged from a minimum of <0.01 mg/L to a maximum of 0.43 mg/L at site SS4. Site SS4 recorded the highest level of 0.43 mg/L while the least value of <0.01 mg/L was recorded at nine sites in May.

Figure 4.9 illustrates the variability in concentrations of NO_3-N obtained in the study. There was no clear trend in the concentrations obtained at the various sites. Sites SS2 and SS4 however, recorded higher concentrations than the other nine sites.

The ANOVA(Table 4.9) for nitrate concentrations indicate that site SS4 was significantly different from the other ten sites. Site SS2 also had a mean concentration of nitrate nitrogen that was significantly ($p<0.05$) higher than the nine other sites as shown in Appendix 4.9. However, there were no significant ($p>0.05$) differences between these nine other sites. Table 4.9 also showed that there were no significant ($p>0.05$) differences in NO_3-N concentration obtained during the various sampling periods.

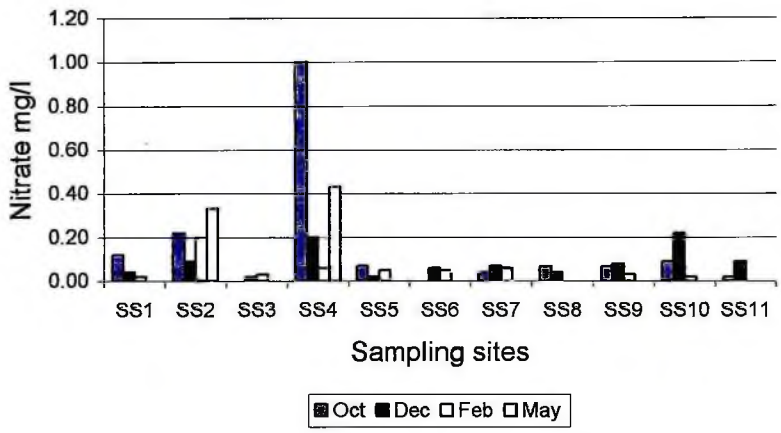

Figure4.9 Spatial and Temporal Variations in Nitrate-Nitrogen Concentrations

Table 4.9 Statistical ANOVA Table for Nitrate-Nitrogen

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	0.608641	10	0.060864	3.423839	0.004308	2.16458
Time	0.070464	3	0.023488	1.321296	0.285802	2.922278
Error	0.533297	30	0.017777			
Total	1.212402	43				

4.2.3 Ortho Phosphate Concentration

Results obtained are presented in Appendix A10. The values were generally low but their mean values were slightly above the natural background levels of freshwater bodies (i.e. 0.02 mg/L). The values recorded ranged from a minimum of <0.01 mg/L to a maximum of 0.75 mg/L. The highest value was recorded at site SS2 in December whereas the lowest concentration was recorded at 8 sites in May. Figure 4.10 shows the variations in concentrations of orthophosphate recorded during the study. There was no clear pattern in the levels of orthophosphate in time and space. However sites SS2 and SS4 had remarkably higher levels than the other nine sites.

Table 4.10 shows an ANOVA table comparing the mean values of Orthophosphate. Site SS2 had significantly ($p<0.05$) higher concentration of Orthophosphate than the ten other sites whereas Site SS4 also had a significantly ($p<0.05$) higher concentration than nine other sites. There were however no significant ($p>0.05$) differences in orthophosphate concentrations between the nine sites (Appendix A10).

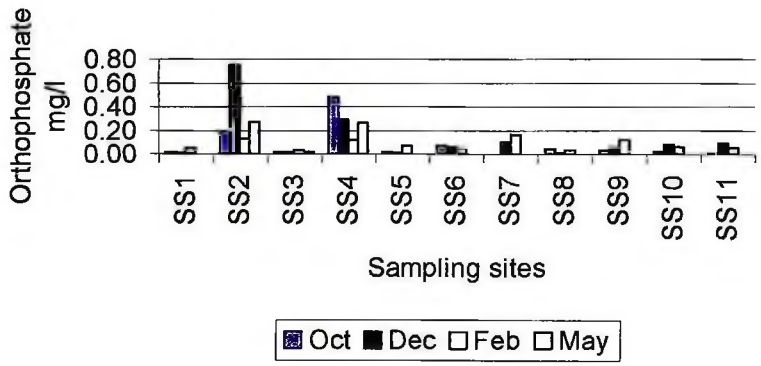

Figure 4.10 Spatial and Temporal Variations in Orthophosphate Concentrations

Table 4.10 Statistical ANOVA Table for Orthophosphate concentrations at the sampling sites.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	0.507118	10	0.050712	4.932911	0.000314	2.16458
Time	0.040891	3	0.01363	1.325866	0.284366	2.922278
Error	0.308409	30	0.01028			
Total	0.856418	43				

4.2.4 Dissolved Oxygen Concentration

Results obtained for dissolved oxygen concentrations over the study period are shown in Appendix A11. The mean values of DO recorded varied from a minimum 0.2 mg/L at siteSS4 to a maximum of 6.5 mg/L at site SS11.Generally, the DO values recorded were moderate ranging from 51 % to 80 % saturation except at site SS4 which recorded only 1.88 % (Figure 4.11).

Table 4.11 is an ANOVA table comparing the mean DO values obtained.. Site SS4 had a dissolved oxygen concentration that was significantly ($P<0.05$) less than the DO recorded at all the other sites. Appendix A11 shows sites, which had significantly ($p<0.05$) different concentration of DO and those that were not statistically different. Table 4.11 also showed that there were significant ($p<0.05$) seasonal variations in the DO recorded during the study. Mean DO values obtained in October, December and May were not significantly ($p>0.05$) different. However DO values obtained in February were significantly ($P<0.05$) lower than what was recorded at the other sampling periods.

Table 4.11 Statistical ANOVA Table for DO at the sampling sites.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	105.2073	10	10.52073	29.31802	8.82E-13	2.16458
Columns	7.494545	3	2.498182	6.961662	0.001082	2.922278
Error	10.76545	30	0.358848			
Total	123.4673	43				

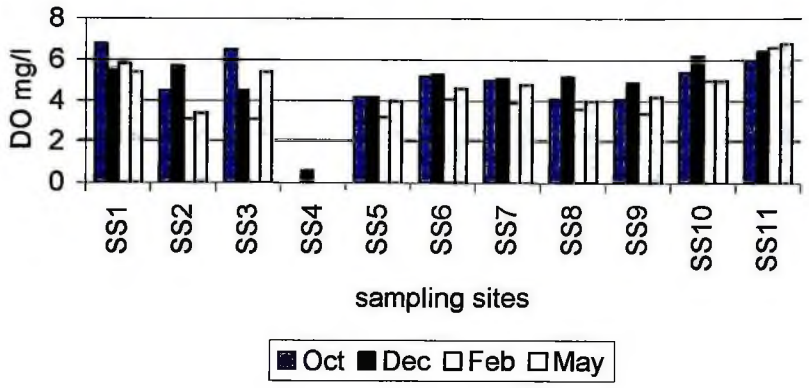

Figure 4.11 Spatial and Temporal Variations in DO Concentrations

4.2.5 Biochemical Oxygen Demand

The results obtained are as shown in Appendix A12. The values obtained ranged from, a mean minimum of 1.0 mg/L at site SS1 to a maximum of 87.5 mg/L at site SS4.Ten out of the eleven sites recorded very low BOD values as shown in Figure 4.12 whereas Site SS4 recorded high values.

Table 4.12 shows an ANOVA table comparing the mean values of BOD obtained over the study period. Site SS4 had a significantly ($p<0.01$) higher BOD value as compared to the ten other sites. There was however no significant ($p>0.05$) difference between the ten other sites.

There was no significant seasonal variation in the BOD concentrations measured over the period despite the high variations observed at site SS4 with a standard deviation of 33.0 (Appendix A12).

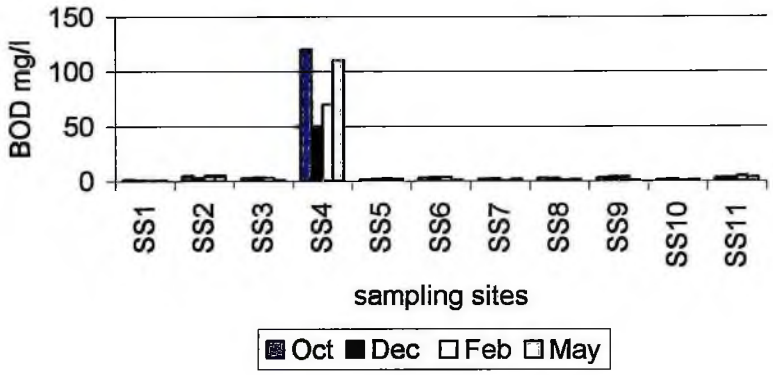

Figure 4.12 Spatial and Temporal Variations in BOD

Table 4.12 Statistical ANOVA Table for BOD at the sampling sites.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	26338.52	10	2633.852	25.99003	4.31E-12	2.16458
Columns	263.477	3	87.82568	0.866637	0.469166	2.922278
Error	3040.225	30	101.3408			
Total	29642.22	43				

4.2.6 Chemical Oxygen Demand

Chemical Oxygen Demand was analysed only in February and May. The results obtained are presented in Appendix A13. The values ranged from 7.2 mg/L to 316.8 mg/L. The highest COD concentrations were recorded at Site SS4 while the minimum value was recorded at Site SS1. With the exception of Sites SS2 and SS4, all the other sites had their mean concentrations of COD falling within the natural background levels. Figure 4.13 shows the variations in COD at the various sites. Table 4.13 also shows an ANOVA table comparing the means of COD values obtained. There were significant differences ($p<0.05$) between the sites. Site SS4 had a significantly ($p<0.05$) higher concentration of COD than the remaining ten sites. Site SS1 also recorded a significantly ($p<0.05$) lower value than the other sites (Table 4.13.1). However there were no significant ($p>0.05$) differences between the other nine sites (Appendix A 13). Table 4.13 also showed that there were no significant differences ($p>0.05$) within the various sampling periods.

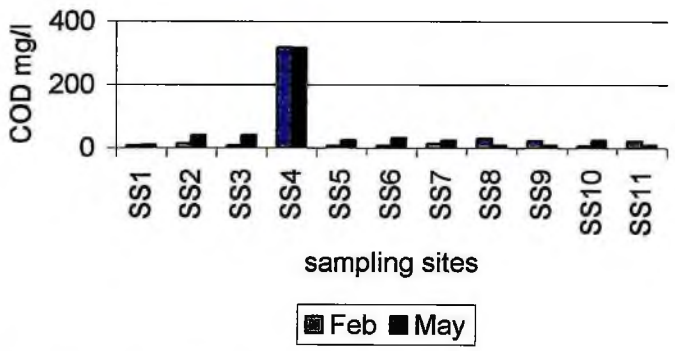

Figure 4.13 Spatial and Temporal Variations in COD

Table 4.13 Statistical ANOVA Table for COD at the sampling sites.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sites	162371.1	10	16237.11	101.6929	1.07E-08	2.97824
Time	248.9091	1	248.9091	1.558916	0.240263	4.964591
Error	1596.681	10	159.6681			
Total	164216.7	21				

4.3 MICROBIOLOGICAL QUALITY OF THE WATER FROM THE INDICATED SITES.

4.3.1 Total Coliform

The values obtained for total coliform counts (cfu /100 mL) in the water are shown in Appendix A14. All the various sites recorded the presence of total coliforms with mean values ranging from a minimum of 35 cfu/ 100 mL at SS4 to a maximum of 720 cfu/ 100 mL at Site SS2. Figure 4.14 shows the distribution of total coliform counts at the sites. High numbers were recorded at Sites SS2, SS8, SS10 and SS11 whereas the other sites had less counts. Table 4.14 shows an ANOVA table comparing the means of total coliform. There were no significant ($p>0.05$) differences between sites SS2, SS8 and SS11. These sites had significantly ($p<0.05$) higher total coliform counts than the other sites. However all the other sites were not significantly ($p<0.05$) different from one another.

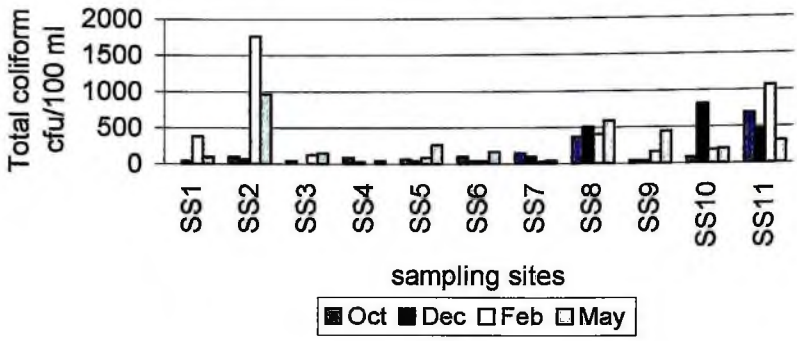

Figure 4.14 Spatial and Temporal Variations in Total Coliform

There were no significant ($p>0.05$) seasonal variations in the counts of total coliform over the study period despite the slight variations observed as shown by the appreciable standard deviation values (Appendix A 14).

Table 4.14 Statistical ANOVA Table for Total Coliforms at the sampling sites.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2338891	10	233889.1	2.757476	0.015381	2.16458
Columns	352800	3	117600	1.386465	0.265976	2.922278
Error	2544600	30	84820			
Total	5236291	43				

4.3.2 Feacal Coliform

Feacal coliform counts obtained at the sites during the study are shown in Appendix A15. All the sites recorded the presence of feacal coliform ranging from a mean minimum value of 10 cfu/100 mL at site SS4 to a maximum of 205 cfu/100 mL at site SS2.

Table 4.15 shows an ANOVA table comparing the mean feacal coliform counts obtained. Despite the variations observed in figure 4.15, there were no significant ($p>0.05$) differences between the sites in terms of the feacal coliform countsobtined from the water at different sampling times.

There were no significant ($p>0.05$) seasonal variations in the feacal coliform counts recorded during the study (Table 4.15).

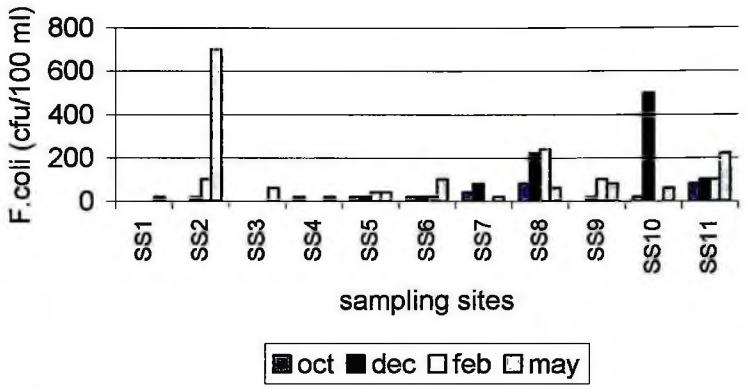

Figure 4.15 Spatial and Temporal Variations in Feacal Coliform

Table 4.15 Statistical ANOVA Table for Feacal Coliforms at the sampling sites.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	192418.2	10	19241.82	1.159866	0.354455	2.16458
Columns	61709.09	3	20569.7	1.239908	0.312601	2.922278
Error	497690.9	30	16589.7			
Total	751818.2	43				

4.4 MACRO-INVERTEBRATES

4.4.1 Occurrence and Abundance

A list of all the macro invertebrates found during the study period is presented in Appendix A 16a. A total of 14 species were recorded from the 11 sites during the study including *molluscs*, *hydracarina*, *crustacean* and *insecta* species. The sites recorded a significant population of aquatic insects, which were mainly associated with floating or submerged aquatic weeds.

The occurrence of the various taxa is shown in Appendix A 16f.The taxa/ species that occurred most was *Insecta*. All the 11 sites recorded the presence of an *Insecta* species at one time or another. *Hydracarina* occurred in 10 out of 11 sites while *Mollusca* occurred at 9 out of eleven sites. *Tubifera* species had the least occurrence. It was only recorded at site SS2. *Oligochaetes* also occurred at only 2 sites while fish and *Hirudinea* occurred at 3 sites respectively. There were significant differences in species composition and relative abundance between the sites. Figure 4.16a shows the distribution of major faunal groups in the Kpong Headpond during the study period while Figures 4.16b and 4.16c illustrate the spatial and temporal changes in abundance and composition of macroinvertebrates.

At site SS1, 6 species were recorded during the period with *Coleoptera* dominant followed by *Ephemeroptera* and *Odonata* species. A total of 58 individuals were collected.

Site SS2 recorded 7 different species with gastropods and *Hydracarina* dominating. *Tubifera* species, which are commonly found at sewage outfalls, was found at the site in May. A total of 23 individuals were collected during the study.

Site SS3 similarly recorded 7 different species dominated by *Odonata*. The number of individuals present during the period was 23.

Site SS4 recorded the least number of macro invertebrates during the period. Only one *Coleopteran* species was collected in the month of December with the other three months recording nothing.

At site SS5, a total of 9 species were recorded dominated by the *Odonata zygoptera* and *Coleopteran* species. A total of 60 individuals were recorded during the period.

Site SS6 recorded a total of 82 individuals belonging to 10 different taxa / species. They were dominated by *Hydracarina* and *Ephemeroptera* species. Site SS7 had a similar composition and species richness as SS6. A total of 95 individuals from 10 different taxa were collected.

Site SS8 recorded a total of 44 individuals, which were dominated by *Hemiptera geridinae*.

At site SS9 a total of 44 individuals from 9 different taxa or species were recorded. It was dominated by the *insecta* species like *Ephemeroptera* and *Odonata*. A total of 44 individuals were collected during the period.

te SS8 recorded the highest number of individuals totaling 238 from 11 different taxa. owever it had the least evenness index since the composition was very dissimilar. The *phemeroptera* species highly dominated the isolated species followed by the rustaceans.

Only 3 different species were recorded at site SS11 during the study period with an abundance of only 21. Most of these were isolated from submerged weeds at the sampling site since vegetation at the banks was almost non- existent.

Table 4.16a List of Aquatic Invertebrates in the Kpong Headpond.

Insecta
Ephemeroptera
Diptera (Chironomid)
Coleoptera
Hemiptera geridinae
Hemiptera ranatridae
Odonata zygoptera
Odonata anisoptera
Crustacea (prawns)
Mollusca
Hydracarina
Hirudinae
fish
oligochaete
Tubifera syrphidae

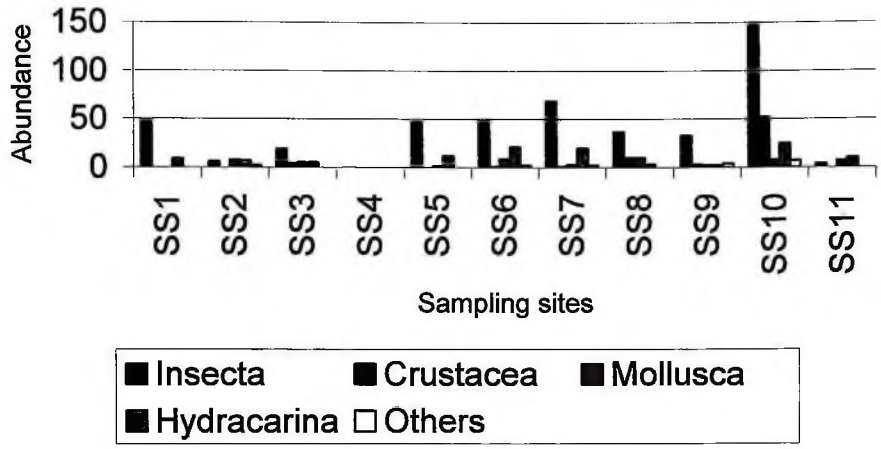

Figure 4.16a Distribution of Major Faunal Groups in the Kpong Headpond

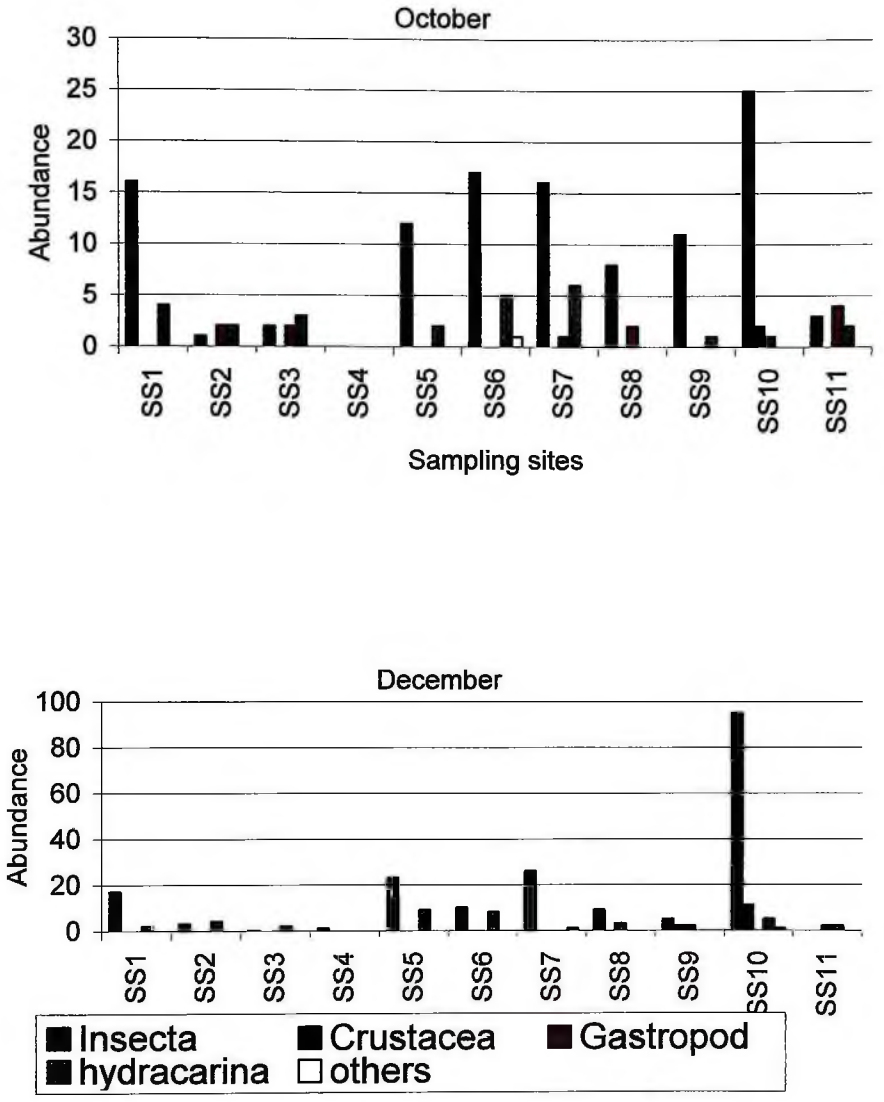

Figure 4.16b Monthly Changes in Macroinvertebrates Composition and Abundance

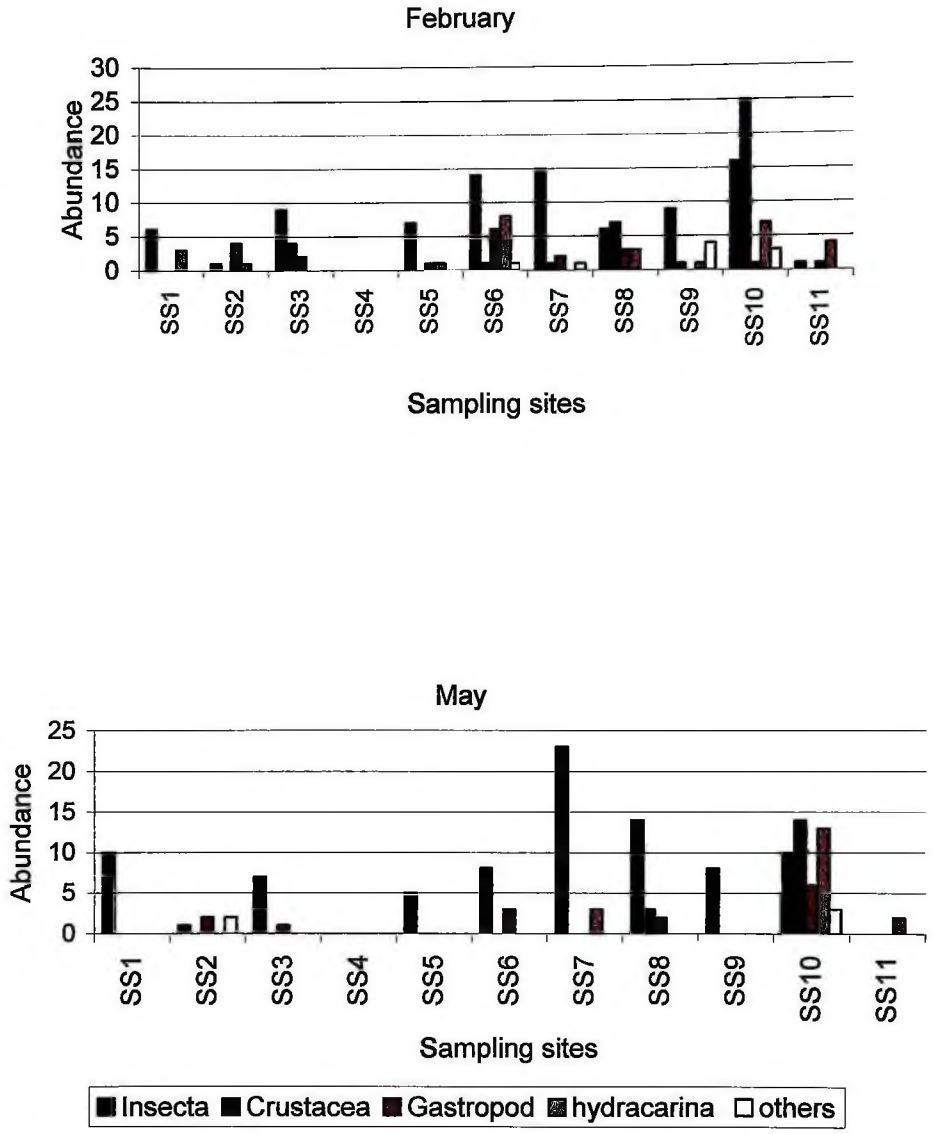

Figure 4.16c Monthly Changes in Macroinvertebrate Abundance and Composition

4.4.2. Diversity Indices

4.4.2.1 Shannon –Weiner Index

Appendix A 16b shows a summary of Shannon-Wiener Index calculated for the sites. The values ranged from a minimum of 0 to a maximum of 1.77.

Site SS4 recorded an index of 0 throughout the study. Figure 4.16d shows the spatial and temporal changes of the Shannon-Wiener Index. The indices varied widely between the sites.

Table 4.16b shows an ANOVA table for the Shannon Index. The table indicated that there were significant ($p<0.05$) differences between the sampling sites but no significant ($p> 0.05$) temporal differences in the Shannon Index calculated. Further analysis of the ANOVA table indicated that apart from sites SS4 and SS11, there were no significant ($p > 0.05$) differences between the nine other sites. Site SS4 had significantly ($p<0.05$) lower values of Shannon index than all the other sites. Site SS11 also recorded a significantly ($p<0.05$) lower Shannon Index compared to nine other sites as shown in Appendix A 16b.

4.4.2.2 Evenness

Results calculated for evenness at the various sites are summarized in Appendix A 16c. The values ranged from a minimum of 0 to a maximum of 1. Site SS4 recorded 0 throughout the study period.

Table 4.16c shows an ANOVA table comparing the means of evenness values calculated. There were significant ($p<0.05$) differences between the sites but no significant ($p> 0.05$) temporal differences.

Site SS4 had a significantly ($p<0.05$) less evenness compared to the other sites. Table 4.16c shows the sites that had similar ($p>0.05$) evenness and those that were significantly different ($p >0.05$) from each other.

4.4.2.3 Species Richness.

Appendix A 16d shows a summary of species richness of the eleven sites over the four sampling periods. Values recorded ranged from a minimum of 0 at site SS4 to a maximum of 2.3 at site SS5. Figure 4.16e shows the spatial and temporal changes of species richness. It showed that there were marked differences in species richness between the sites and over the sampling period.

Table 4. 16d is an ANOVA table comparing the species richness at the various sites. Nine of the eleven sites had species richness that was not significantly ($p>0.05$) different from each other. However sites SS4 and SS11 were significantly ($p<0.05$) different from each

other and the other nine sites. Site SS4 recorded significantly ($p<0.05$) lower species richness compared to the other sites (Table 4.16d).

Table 4. 16d also showed that there were significant differences between the sampling periods. Further analysis of the table showed that species richness in December was significantly ($p<0.05$) higher than in the other months. However there were no significant ($p>0.05$) differences between the species richness in October, February and May.

Table 4.16b ANOVA Table for Shannon Index

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	6.705423	10	0.670542	6.17611	4.69E-05	2.16458
Columns	0.779757	3	0.259919	2.394016	0.08799	2.922278
Error	3.25711	30	0.10857			
Total	10.74229	43				

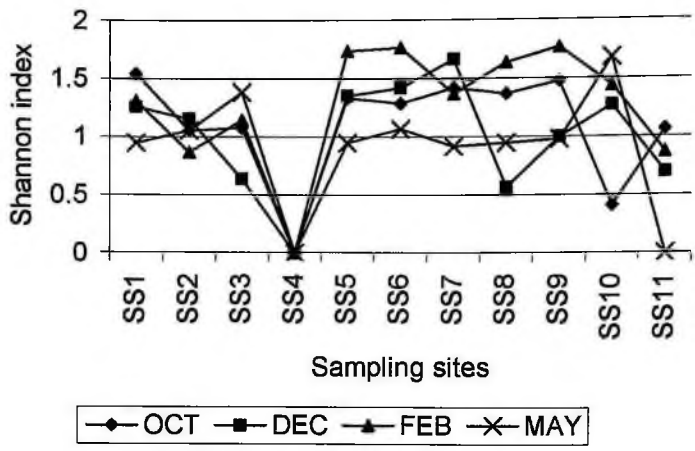

Figure 4.16d Spatial and Temporal Variations of Shannon- Wiener Index.

Table 4.16c ANOVA Table for Evenness

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.881137	10	0.288114	10.33463	2.88E-07	2.16458
Columns	0.069182	3	0.023061	0.827183	0.489335	2.922278
Error	0.836354	30	0.027878			
Total	3.786672	43				

Table 4.16d ANOVA Table for Species Richness

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7.484997	10	0.7485	4.573625	0.000566	2.16458
Columns	1.759739	3	0.58658	3.58423	0.025131	2.922278
Error	4.90967	30	0.163656			
Total	14.15441	43				

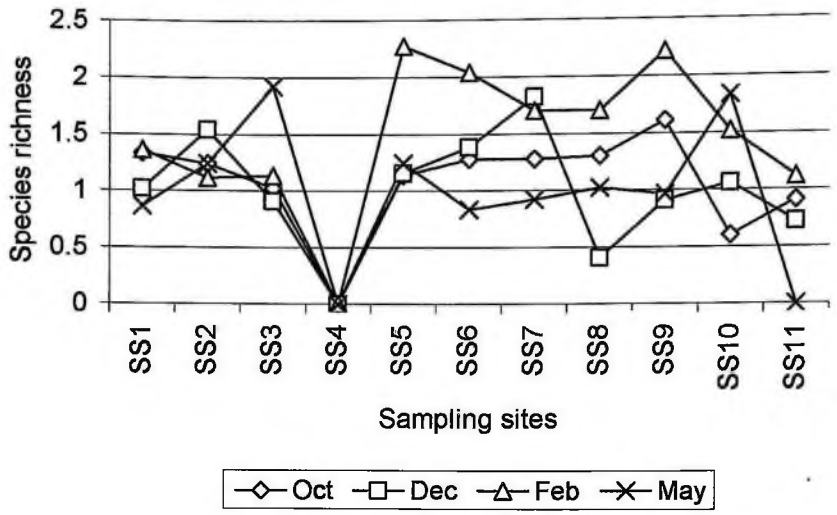

Figure 4.16e Spatial and Temporal Variations in Species Richness

4.5 SOCIAL SURVEY

A social survey was conducted to assess the water supply and sanitation status in the lakeside communities. 95 people from ten selected communities responded to the interview. Table 4.17.1 shows the settlements and the number of respondents. The ages of the respondents are shown in Figure 4.17.1. 53 % of the respondents were male while 47 % were female.

Table 4.17.1 Respondents to the interview conducted at the indicated settlements along the lakeside of the Lower Volta Basin.

Settlements	Frequency	Percent
Kpong	12	12.6
Atimpoku	12	12.6
New Powmu	10	10.5
Mangoase	10	10.5
Kokontekpedzi	10	10.5
Fodzoku	10	10.5
Ghanakpe	8	8.4
Senchi Ferry	8	8.4
Small London	8	8.4
South Senchi	7	7.4
Total	95	100.0

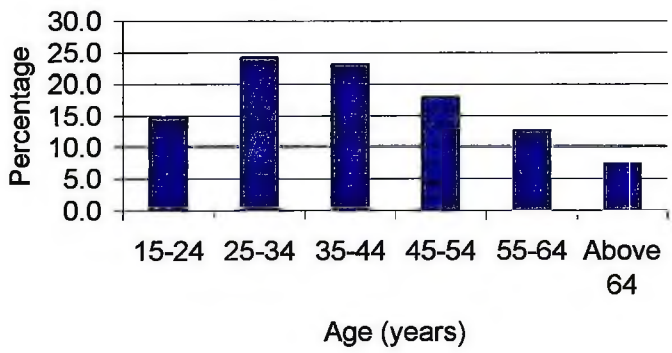

Figure 4.17.1 Graph Showing Ages of Respondents to the administered questionnaire.

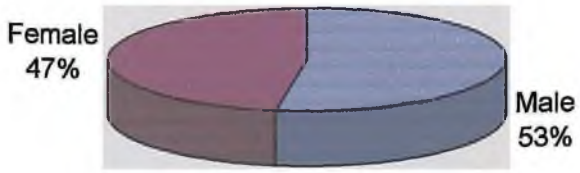

Figure 4.17.2 Pie Chart Showing Sex of Respondents to the questionnaire.

4.5.1 Water supply

Three primary sources of water were identified in the study area, namely: pipe-borne, raw water from the Headpond and well. Table 4.17.2 and figure 4.17.3 showed that there were significant differences in the sources of water for the households in the various communities.

Table 4.17.2 Pearson Chi-Square for Sources of Water

	Value	df	Asymp.Sig.(2-Sided)
Pearson Chi- Square	90.918	27	.000

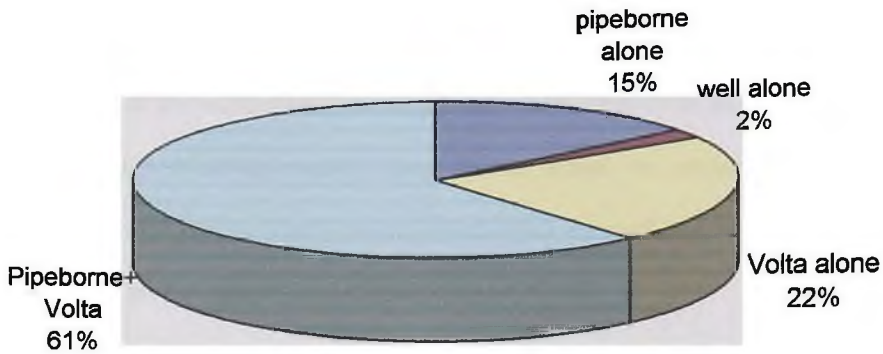

Figure 4.17.3 Pie Chart Showing Sources of Water for Households in selected settlements along the Lower Volta Basin.

Most of the respondents used pipe-borne water for drinking and cooking purposes while they use water in the Headpond for washing, bathing and other domestic uses. About 83 % of the respondents therefore depended on the Headpond in one way or another for water supply.

34 % of the respondents were satisfied with their source of water while 65.2 % expressed dissatisfaction. Reasons such as non-potability of water from the Headpond and inadequate and unreliable supply of potable water were cited for their dissatisfaction. 69.5 % of the respondents indicated that they had periodic shortages of water while 30.5 % said they never experienced water shortage. These were mainly those who depended solely on the Headpond as their source of water for household use. During water shortage, 87.9 % of the respondents depended on the Headpond while 12.2 % walked long distances for water mainly for drinking purposes. Only 29.7 % of the respondents boiled or treated water from the Headpond before drinking. 70.3 % drank the water raw.

4.5.2 Sanitation

A field survey of the communities revealed that wastewater from kitchens, bathrooms, etc, was just poured indiscriminately about or into drains. No constructed drains were located in the communities. Earth drains, which often emptied into the Headpond, were common site in all the communities (Plate 5).

Plate 5 Sullage Entering the Headpond at Atimpoku

4.5.2.1 Toilet Facilities

The proportion of respondents who had access to private toilet facilities is shown in Figure 4.17.4. The main types of toilets were pit latrines. Only few people (about 2 %) used pan latrines. Table 4.17.3 shows a Pearson Chi-Square table comparing access to private toilet facilities. More than 80 % of residents in the lakeside communities depended on public toilets or used open defeacation. About 62 % of the respondents said they depended on Public toilets while 20 % said they depended on open defeacation.

Table 4.17.3 Pearson Chi-Square for Access to Private Toilets

	Value	df	Asymp.sig. (2- sided)
Pearson Chi-Square	14.616	9	.102

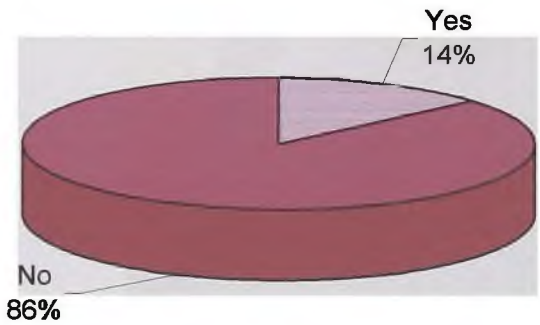

Figure 4.17.4 Pie Chart Showing Access to Private Toilet Facilities in the selected settlements.

20 % of the respondents indicated they were satisfied with their toilet facilities while about 80 % were dissatisfied. Reasons given for their dissatisfaction included the unhygienic nature of the public toilets, lack of maintenance and inadequate toilets for the communities. Visits to some of the public toilets in the communities revealed the gross insanitary conditions (see plate 6).

Plate 6 Entrance to a Female Public Toilet at New Powmu (Note the filth).

Some of the toilets were full and needed to be dislodged or abandoned. Some of the communities had KVIPS while others had to do with pit latrines dug by the communities. In some of the communities, the unhygienic nature of the toilets left the inhabitants with no choice than to resort to open defeacation leading subsequently to the pollution of water of the Kpong Headpond.

On how to improve the toilet facilities of the communities, about 77.8 % of the respondents indicated that the district assemblies should provide them with greater number of and modern toilets while 16.7 % said the existing toilet facilities should be well maintained; 5 % of the respondents indicated that provision of more toilets and adequate maintenance will improve sanitation facilities in the area.

4.5.2.2 Refuse Disposal

There were significant differences ($p<0.05$) in the mode of disposal of refuse in the communities as shown in Table 4.17.4. 51.6 % of the respondents kept their refuse in their homes or backyards and controlled them by burning. 31.9 % dumped refuse at designated points while 16.5 % of the respondents did not have any specified place for disposal. The refuse dumps in the localities were not properly maintained and posed a health problem for the inhabitants. Some were located either too close to settlements and the Headpond (Plate 7 and 8). While some used the refuse to check erosion, others just dumped them about indiscriminately. Only 28.9 % of the respondents were satisfied with waste disposal facilities in their communities while 71.1 % were dissatisfied. The respondents had some suggestions on how to improve refuse disposal in their communities. These included provision of community refuse containers and officially designated refuse disposal sites.

Plate 7 Refuse Dump at Dzidzorkope. Note the proximity to the settlements and the Headpond.

Plate 8 Dumping of Refuse Close to the Headpond at Atimpoku.

Table 4.17.4 Pearson Chi-Square for Refuse Disposal

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	79.451	18	0.000

4.5.3 Public Health

Diseases, which mainly affected the inhabitants in the lakeside communities, include bilharzia, malaria, diarrhoeal diseases, skin itching/rashes and eye diseases. Appendix E shows secondary data collected from the VRA hospital (Akosombo) and the MOH Asuogyaman Clinic at Atimpoku on reported cases. At the Asuogyaman MOH Clinic, a total of 47,362 malaria cases were reported from 1998 to 2000. An average of 1,000

diarrhoeal cases were also reported per year. The VRA hospital similarly recorded an average of 10,000 and 500 cases per year for malaria and diarrhoea respectively. There was a decline in the reported cases of bilharzia at both the Asuogyaman MOH Clinic and the VRA hospital. At the MOH Clinic, the bilharzia cases reported were 114, 99 and 51 in 1998, 1999 and 2000 respectively. The VRA hospital similarly recorded 104, 82 and 57 in 1998, 1999 and 2000 respectively. Data collected from the Lakeside unit of the VRA (Akosombo) also indicated a decreasing trend in the disease from 1997 to 1999.

4.5.3.1 Bilharzia

In all the settlements visited, the inhabitants complained of bilharzia. Table 4.17.5 shows that there were significant differences ($p<0.05$) in the number of people who suffered from bilharzia in the communities. The lowest prevalence of the disease was recorded at New Powmu whereas Atimpoku, Kpong and Fodzoku had the highest prevalence. Figure 4.17.5 shows the proportion of respondents or members of their households who suffered from Bilharzia. The most vulnerable group was the fishermen and children who often swam in the water. Figure 4.17.6 showed the mode of treatment for those afflicted with bilharzia. Over half the number (53.4 %) sought medical attention. 20.7 % percent self medicated while 25.9 % did not apply any form of treatment at all.

Table 4.17.5 Pearson Chi-Square for Bilharzia Prevalence in Communities

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.922	9	0.018

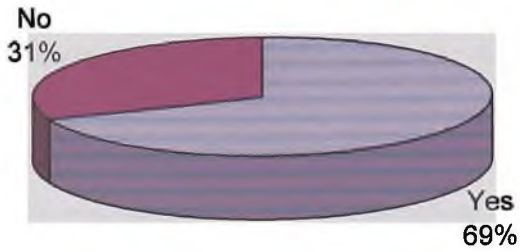

Figure 4.17.5 Pie Chart Showing Proportion of Bilharzia Patients

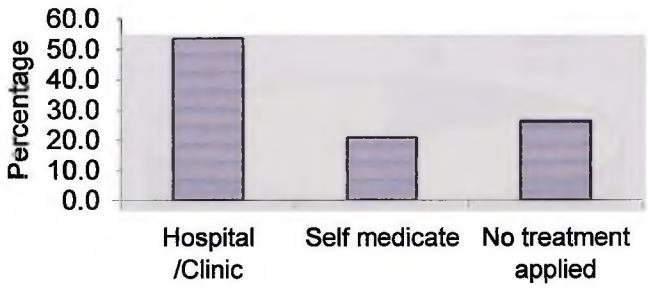

Figure 4.17.6 Graph Showing Mode of Treatment of Bilharzia Patients

4.5.4 Perception of Water Quality

Figure 4.17.7 shows the perception of the respondents on the quality of water in the Headpond. 85 % of the respondents perceived the water to be of poor quality. Several reasons were cited as being responsible for the bad quality of the water. These included such activities like bathing, swimming, washing, defeacation and dumping of refuse in the Headpond. Other reasons cited included the increasing growth of aquatic weeds and the discharge of Akosombo Textiles Limited and Akosombo Sewage Treatment Plant

effluent into the Headpond. Other respondents cited the frequent drowning of people and the subsequent decomposition of their bodies as affecting the water quality.

The respondents had some suggestions on ways to enhance the water quality of the Volta. While 50 % of the respondents suggested an intensification of environmental education 35.9 % suggested that the Volta River Authority should clear the weeds in and around the Headpond. 6.3 % also suggested enactment of bye-laws by the district assemblies to curb certain pollution practices.

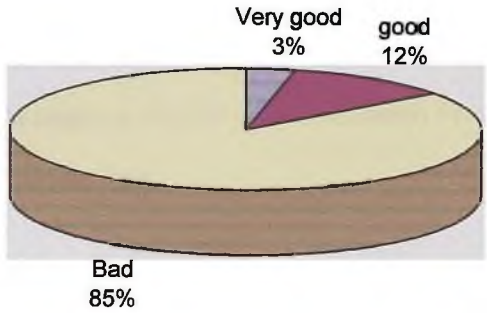

Figure 4.17.7 Pie Chart Showing Perception of Respondents on Quality of Water

5 DISCUSSION

5.1 WATER QUALITY

5.1.1 Physico-chemical Characteristics

In general, there was no regular pattern of increase or decreases in most of the physico-chemical parameters surveyed from upstream to the downstream waters.

The concentration of some parameters such as conductivity, BOD, COD and suspended solids, tended to be higher at site SS4 where Akosombo Textiles Limited (ATL) effluents were discharged into the water.

5.1.1.1 pH

The range of pH values recorded was from 6.8 to 11.2. With the exception of Site SS4, all the other sites recorded near neutral to slightly basic pH values. Site SS4 however, consistently recorded highly alkaline values, which ranged from 10.3 to 11.2. Biney (1990) and Ansa-Asare (1998) recorded neutral values for the same waterbody while Larmie (1993) recorded generally basic conditions (i.e. pH > 7). WRI (1999) also recorded pH values ranging from 7.5 to 8.1 during the dry season and 6.8 to 7.1 during the rainy season. pH of freshwaters in Ghana are normally slightly acidic but turn slightly alkaline at their lower reaches (Biney, 1985). Davies and Day (1998) noted that the pH of natural waters is determined by geological influences and biotic activities. The geology of the area could therefore account for the generally neutral to slightly basic pH

conditions noted of the water. The intense photosynthetic activities within the Headpond could also account for the slightly basic conditions observed (Symoens *et al.*, 1981). Photosynthetic activities remove CO_2 from solution with a corresponding increase in pH. Submerged aquatic plants e.g., *Ceratophyllum demersum* were observed in the Headpond.

The high pH values recorded at site SS4 is directly attributable to the highly alkaline nature of the ATL effluent, which are regularly discharged into the Headpond. This is as a result of the various dyestuffs and caustic soda used by ATL in the production of fabrics. Larmie (1993), Amoah (1989) and Mensah (1976) made similar observations at the same site. It could therefore be inferred that the water quality at this site has not changed much over two decades due to the impact of ATL activities. It was however observed that, 100 m below the site, the pH of the water returned to normal. This could be attributed to dilution effects of the large volume of water present. Pierce *et al.* (1998) and Spellman (1996) documented that aquatic organisms are sensitive to pH changes. It was therefore expected that the high pH values recorded at this site could affect the composition of the aquatic community at the site.

5.1.1.2 Water Temperature

Water temperatures ranged from 27.7 °C to a maximum of 31.4 °C during the study. This reflected the generally high tropical ambient temperatures. The gradual increase in termperature from October to May was thus due to increasing ambient air temperature during the sampling period. Larmie (1993) similarly recorded a peak in water temperature of the Headpond in May with the lowest in August.

The highest mean temperature value recorded at site SS4 can be attributed to the higher temperature of the ATL effluent discharged into the Headpond. The temperature was always about 2 °C above the ambient at this site. Mensah (1976) also observed that the water temperature at the point of discharge was higher than that of the other parts of the waterbody. Cunningham and Saigo (1992) reported that increase in temperature has an adverse impact on dissolved oxygen resources in a stream since oxygen solubility in water decreases as temperature increase. Increases in water temperature are also expected to affect aquatic organisms since all aquatic organisms have thermal tolerance limits (Jeffries and Mills, 1990).

5.1.1.3 Conductivity and Total Dissolved Solids

All the sites (with the exception of SS4) recorded moderate total dissolved solids (TDS) and conductivity values, which were within the natural background levels (50-300 µS/cm).

TDS and conductivity values are usually closely correlated for a particular type of water (Davies and Day, 1998). This is because the specific conductivity of water or its ability to conduct an electric current, is related to the total dissolved ionic solids.

Site SS4 recorded high concentrations of TDS and conductivity. These high values were due to the high concentrations of dissolved dyestuffs and salts in the ATL effluent. The possible harmful effects of such high values include increasing the hardness of water and making it unsuitable for many industrial processes. A high increase in TDS affects the water balance in cells of aquatic organisms (Spellman and Drinan, 2000). This could

make the organism float or sink to depth to which it is not adapted and might therefore not survive. Other consequences of high TDS and conductivity values include causing physiological effects and producing aesthetically displeasing colour, taste and odour. This is confirmed by the pungent odour observed at the site.

5.1.1.4 Dissolved Oxygen, Biochemical Oxygen demand and Chemical Oxygen Demand

Dissolved oxygen concentrations over the study period were generally moderate. With the exception of site SS4, which recorded almost no oxygen, all the sites recorded saturation values ranging from 51 % to 80 %. Previous studies (WRI 1999, Ansa-Asare 1998 and Larmie 1993) indicated that the Kpong Headpond is well oxygenated. Biney (1990) observed that the stagnant nature of lacustrine environments encourages the growth of both micro and macrophytes, which oxygenate the waters by their photosynthetic activities. The moderate levels of dissolved oxygen could therefore be attributed to the high photosynthetic activities in the Kpong Headpond, especially at the Kpong area due to the presence of submerged macrophytes. The low levels of organic matter present in the water as indicated by the BOD and COD values were also supportive of the high oxygenation of the Headpond. This is because higher BOD and COD tend to deplete dissolved oxygen in a body of water. Surface mixing due to action of winds and traffic on the Headpond are also possible sources of oxygenation of the Headpond.

Site SS4 recorded the least concentration of dissolved oxygen. High mean concentration of 87.5 mg/L and 315.9 mg/L were measured for BOD and COD respectively at the site.

These were respectively 25 and 15 times higher than the natural background levels of 1-3 mg/L for BOD (Ansa-Asare, 1996) and 20 mg/L for COD (Chapman 1992). The very high COD concentrations indicated that a high proportion of the oxygen demand imposed on the water was due to the presence of inorganic substances in the ATL effluent. Dissolved oxygen was virtually depleted at the site throughout the study. Amoah (1989), Biney (1977) and Mensah (1976), also made similar observations. The very low level of oxygen recorded consistently at the site indicates a high level of pollution.

The amount of dissolved oxygen is a good indicator of water quality and of the kinds of life it can support (Cunningham and Saigo, 1990). Spellman (1996) similarly noted that the amount of oxygen dissolved in a water body could be an indicator of the "healthiness" of a stream and its ability to support a balanced aquatic system. Concentrations of 5.0 mg/L and above are recommended for maintaining good fish populations (Sherbini *et al.*, 1992).

Due to the low levels of Oxygen at Site SS4, the water here is not expected to support any aquatic organisms (Lamb, 1985). The other sites, however, had enough oxygen to support aquatic life. Although the BOD values at sites SS2 and SS11 were slightly above the natural background levels, there was no significant effect on the dissolved oxygen content to affect the survival of organisms.

5.1.1.5 Total Suspended Solids and Turbidity

Total suspended solids and turbidity values measured during the study were generally low compared to other freshwater bodies in Ghana like the River Densu. Apart from Site SS4, which consistently recorded values above natural background levels, all the sites

recorded low values. The high values recorded were due to the presence of dyestuffs, starch, detergents and other chemicals used by ATL, in the effluent discharged. Mensah (1976) similarly recorded highly turbid water at this site, which suggests that the quality of water at the site has not improved in the last two decades. Site SS2 recorded an appreciable level of suspended solids in May. This could be due to an increase in the quantity of effluent discharged as a result of an increase in runoff through the storm water drains.

Studies by Biney (1985) showed that the Kpong Headpond was clear with a Secchi disc transparency of about 180 cm. This was attributed to the fact that silts and other solid matter settled out of suspension as the water was retained behind the Akosombo dam before being released into the Headpond. The construction of the Kpong dam is also likely to have increased the transparency of the water since more solid particles settled out of the water. The Kpong water works has since 1984 stopped using coagulants due to the clarity of the water (Cudjoe, Pers com). This led to a drop in their cost of water treatment. The clarity of the water however has led to an increase in the growth of aquatic weeds in the Headpond. Nana-Amankwah (1993) reported that eutrophication associated with weed problems in Ghana is of varying degrees and exists in almost all of the man-made lakes like the Volta and the Kpong Headpond. Ariel *et al.* (1995) observed that macrophyte abundance, while in part related to sediment type and compositon and to nutrient factors, is most often determined by light availability. Cooke *et al.* (1993) also suggested that clear lakes with nutrient- rich littoral areas could display excessive macrophyte growth as evidenced by abundant growth of water hyacinths in Lake Chad

and Lake Victoria. Increasing concentrations of nutrients in the Headpond will therefore aggravate the weed menace.

5.1.1.6 Nutrients

Nitrate-nitrogen

The nitrate values obtained during the study were generally low compared to the WHO guidelines limit of 10 mg/L. The values recorded ranged from a minimum of <0.01 mg/L to a maximum of 0.43 mg/L. However, the mean values recorded at the various sites were higher than the natural background levels of 0.23 mg/L (Chapman, 1992). The highest level was found at site SS4 as a result of the discharge of the ATL effluent. Site SS2 also recorded significantly ($p<0.05$) high values due to the sewage outfall.

Nitrate is toxic when present in excessive amounts in drinking water and in some cases may cause methemoglobinemia in infants. The health effects of nitrate are the consequences of its ready conversion to nitrite in the body (Straskraba and Tundisi, 1999). The low levels of nitrates in the water therefore pose no risks to human health. Ansa- Asare (1998) recorded yearly mean nitrate values ranging from 0.2 to 0.5 mg/L within the Kpong Headpond. WRI (1999), recorded values that ranged from 0.06 to 0.9 mg/L. These indicate that there are seasonal variations in the concentration of nitrate-nitrogen in the Headpond, sometimes with concentrations higher than natural background levels. Berg *et al. (1958),* [cited in Akuffo (1998)], observed that lakes have the ability to add to their own nutrient status by trapping and recycling nutrients. It is therefore probable that the Headpond has been recycling the nutrients borne by the aquatic weeds within the water. Another possible source of nutrients could be from farming activities,

especially the banana plantations and livestock rearing (Plate 9) around the Headpond. Inorganic fertilizer and organic manure are used to maintain the fertility of the soil (Blay, pers com) and these could leach into the Headpond especially at areas very close to the shoreline. High levels of nitrate were measured along the shorelines of these plantations at certain times of the study, which was probably due to the use of fertilizers.

Plate 9 Pig Sty and Farm near the Headpond at Kokontekpedzi.

Orthophosphate

The orthophosphate concentrations recorded were generally low ranging from 0.00 to 0.75 mg/L. Site SS2 recorded the highest concentrations of orthophosphate. This is due to the discharge of effluent from the Akosombo sewage treatment plant. Phosphates are normally released from the oxidation of organic matter in sewage effluents, (Akuffo, 1998) hence this could account for the high concentration measured. Site SS4 also recorded appreciable concentrations of orthophosphate. This is probably due to the use of

detergents and other chemicals in the production of fabrics by ATL, which are discharged in the effluent. Values recorded at the other sites were within the natural background levels of 0.02 mg/L (Chapman, 1992). Yearly mean concentrations of orthophosphate recorded by Ansa-Asare and Asante (1998) ranged from 0.02 to a maximum of 0.08 mg/L. Thomas (1970), noted that phosphates become strongly bound to soil and do not easily find their way into water bodies. In lakes and reservoirs, phosphates are released into the epilimnion from the decay of littoral vegetation and from anthropogenic sources (Nana- Amankwah *et al.*, 1995). Phosphates are essential nutrients for plant growth. Pierce *et al.* (1998) observed that phosphate concentration between 0.01 and 0.1 mg/L appeared to be enough to accelerate eutrophication. McCutcheon *et al.* (1990) similarly reported that critical levels of phosphorus causing excessive algae growth could be as low as 0.01 to 0.005 mg/L. It is therefore possible that the level of phosphates in the Headpond is contributing to the fast and intense growth of aquatic weed, which is a sign of eutrophication (de-Graft Johnson, 1981).

Ammonia

Apart from sites SS2 and SS4, ammonia nitrogen was not detected at the other sites during the period of study. This is in contrast to levels recorded by Ansa-Asare and Asante (1998). The high levels measured at the two sites were due to the presence of sewage and industrial effluents. Davies and Day (1998) observed that ammonia is a common pollutant associated with sewage and industrial effluents. Chapman (1992) also noted that unpolluted waters contain small amounts of ammonia and ammonia compounds usually less than 0.1 mg/L. Natural background levels are less than 0.02

mg/L (Straskraba and Tundisi, 1999). Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer runoff. McCutcheon *et al.* (1990) observed that concentrations higher than 0.05 mg/L tend to cause significant toxicity to fish and other organisms.

5.1.2 Microbiological Characteristics

All the sites recorded the presence of both total and feacal coliform. The coliform group of organisms is used as and indicator of faecal contamination when their presence is detected in water. They are normally present in very large numbers in faeces of man and other warm-blooded animals.

Site SS2 recorded the highest number of feacal coliforms. Amoah (1989) also showed that the Akosombo Sewage Treatment Plant effluent encouraged the growth and multiplication of indicator bacteria when discharged into the river. Ideally, a drinking water supply should be free from total and feacal coliforms (WHO, 1993). Since all the sites recorded the presence of these indicator bacteria, it suggests that the water in the headpond is not free from feacal contamination hence unsafe for direct drinking purposes. Similar observations were made by WRI (1999).

Widespread occurrence of coliform indicates a major water quality problem in the Headpond. It also shows that water whose quality may appear satisfactory on the basis of physico-chemical parameters may still not qualify for direct potable use because of their poor biological quality. The presence of these indicator bacteria at all the sites could be attributed to human activities by the lakeside communities. Poor sanitation practices

within these communities are mainly the cause of this situation. During the rainy seasons, feacal matter may be carried by runoff water to the Headpond. The manure used on the banana plantations could also be a potential source of coliform bacteria in the Headpond. Another potential source of feacal pollution is the droppings of cattle and other livestock, which sometimes drink directly from the Headpond.

5.2 MACROINVERTEBRATE DISTRIBUTION

Lamb (1985) stated that the ecological system in a clean water body usually includes many species of organism, but relatively few of any one type. This type of biological balance is termed a "diverse" population and is viewed as a desirable stream characteristic because it results in increased community stability (Odum, 1971).

All the sites, with the exception of site SS4, recorded a significant population of macroinvertebrates. The Shannon-Wiener index, evenness index and species richness calculated for the various sites indicated that, there was a high diversity of organisms at the sites. The *Insecta*, especially *Ephemeroptera*, dominated the organisms collected. *Ephemeroptera* are known to be intolerant to organic pollution (Cao *et al.*, 1996), hence their presence at the sites indicated good quality of water.

Only one organism was collected at site SS4 during the study. This was however expected due to the harsh conditions at the site as a result of the discharge of ATL effluents. Mensah (1976) similarly observed that fauna at the point of discharge of the ATL effluent were greatly affected compared with those found upstream and downstream the point of discharge. Haslam (1990) noted that macroinvertebrates are affected by the

habitat in which they grow. Lamb (1985) similarly noted that various types of organisms have different sensitivities to water quality conditions. Absence of invertebrates occurs with excess of any type of pollution in any type of stream (Haslam, 1990). The low dissolved oxygen and high pH of the water would therefore not support any desirable forms of organisms (Cunningham and Saigo, 1990).

5.3 SANITATION AND WATER SUPPLY

The survey conducted in the lakeside communities revealed that the inhabitants much lacked sanitation facilities such as toilets and appropriate solid waste collection services. As much as 86 % of the respondents did not have access to private toilet facilities. They therefore depended on public toilets (which were filthy due to excessive pressure and lack of maintenance) and the bush. Although only about 20 % of the respondents said they engaged in open defeacation, it is believed that the percentage is much higher due to the inadequacy of the toilets. Refuse disposal facilities in the communities visited left much to be desired. The few dumping sites located were not well maintained and posed a great danger to the inhabitants. One such dump was located at Dzidzorkope (Atimpoku) where a heap of refuse was located very close to settlements. It was also located close to the Headpond and was a potential source of pathogens into the Headpond especially in the wet season.

Sanitation, as a development sector, is one of the least developed in Ghana (Noi-Nortey, 1990). Akuffo (1998) noted that in a developing country where much of the pollution loads come from domestic rather than industrial sources, the neglect of sanitation makes

it almost impossible to control water pollution. The presence of indicator bacteria along the whole shoreline in the study area indicated that the poor sanitation in the lakeside communities had a direct impact on the quality of water. The coliform bacteria indicated the probable presence of pathogens in the water (Spellman, 2000) hence making it very unsafe for direct drinking purposes. Unfortunately however, most of the respondents who depended on the water for drinking purposes said they did not treat the water in any way before drinking. Only about 30 % of the respondents claimed they boiled or treated their water before drinking. Some of the respondents interviewed disclosed that in times past, the Ministry of Health (MOH) supplied them with filters to filter their water before drinking but the supply had ceased for a long time now. They had therefore reverted to drinking the water raw. Although almost all the settlements had at least a public tap, the respondents complained the number was highly inadequate and water supply was very unreliable due to frequent interruptions. This often left them with no choice but to fetch water from the Headpond for domestic purposes. It is believed that, provision of more public taps in the communities will assist in protecting the inhabitants against water borne diseases such as diarrhoea, worm infestations and cholera. Some of the respondents also said they used more of the water from the Volta than the tap water because they have no money to pay for the water they fetch from the taps. It is therefore very important that the inhabitants are educated on these issues.

5.4 PUBLIC HEALTH

Data collected from the VRA hospital and Asuogyaman MOH clinic (Appendices E and F) showed a rather high incidence of malaria, worm infestations and diarrhoea diseases.

The unsanitary conditions and poor state of water in the area could account for this. Studies undertaken along the Headpond before impoundment similarly indicated a high incidence of malaria, gastrointestinal infections and worm infestations (VRA, 1977). Contrary to the expectation that reported cases of Bilharzia would be high, this was not found to be so. In fact, in all the data collected, there was a declining trend in the number of reported cases. This may however not imply that there is a fall in the prevalence of the disease. In the survey, about 60 % of households reported that, people in their households suffered from bilharzia but only about 50 % of them sought medical attention. This situation could therefore lead to a lower number of reported cases at the clinics.

5.5 WASTE MANAGEMENT EFFICIENCY AND WATER QUALITY

Two major industrial treatment plants and a sewage treatment plant were identified in the study area. These are the Juapong Textiles Limited (JTL) treatment plant, Akosombo Textiles Limited (ATL) treatment plant and the Akosombo sewage treatment plant (ASTP).

5.5.1 JTL Waste Treatment Plant

Juapong Textiles Limited (JTL) was established in .Its main activities involve spinning and weaving. No dyeing and printing takes place at the factory. JTL uses an activated sludge system to treat its wastewater whose main components are suspended solids and BOD. The effluent from the plant is discharged into the Kadikadi stream, which eventually enters the Kpong Headpond. Wastewater discharged from the treatment plant average 112.3 m^3/day (JTL, 2000).

5.5.2 ATL Waste Treatment Plant

The Akosombo Textiles Limited was established in 1967. All the processes of textiles production are carried out at the factory. These are spinning, weaving, printing and dyeing. The average production level of the factory is 1.2-1.5 million metres per month (Tsang, pers.com). The main raw materials used in production include cotton, various chemicals such as caustic soda and dyestuff and cassava starch. The Akosombo Textiles Limited abstracts water from the Kpong Headpond for its activities. The main uses of water at the factory include steam generation in the boilers, washing of cloth after every procedure and mixing of chemicals and dyestuff.

The ATL waste treatment plant (Plate 10) was also built when the factory was established in 1967. It is composed of a recovery plant where some of the chemicals used (Wax) are recovered for reuse; stabilization ponds and trickling filter systems. The effluent then flows into stabilization ponds where some suspended solids settle out of the effluent. The effluent is then passed on to a trickling filter bed to remove colour, smell and more suspended solids before final discharge into the Kpong Headpond. According to Tsang (Pers. com), the treatment plant has undergone expansion since the production level at the textiles factory was increased while the sedimentation ponds are cleaned annually to maintain them.

Plate 10 Part of the ATL Treatment Plant showing perforated pipes on filter bed.

Although some treatment of the effluent is done, this is highly inefficient as shown by the concentration of the parameters measured during the study. Data from EPA (Appendix I) confirm the inefficiency of the treatment plant since some of the parameters measured exceeded the EPA permissible levels. Mensah (1976) reported that the quantity of effluent discharged was about 118,000,000 l/month. However, the quantity discharged presently is about 66,000 m^3 /month i.e., about 66,000,000 L/month (Source, EPA). The reduction in volume of wastewater released cannot be readily explained since an increase was rather anticipated.

5.5.3 Akosombo Sewage Treatment Plant

The Akosombo Sewage Treatment Plant is a waste stabilization plant and comprises a facultative pond and a maturation pond (Plate 11). It was constructed in 1993 to replace an outmoded Trickling Filter system. A sewerage system has been provided for the collection, treatment and disposal of liquid waste. This system comprises of a central drainage, which flows into the stabilization ponds for treatment before final discharge.

Larmie and Hodgson (1998) estimated that the surface area of the ponds is in the region of 25,000 m^2. The final effluent is discharged through a 60 cm diameter asbestos pipe, which enters the main stormwater drain to the Headpond. The discharge rate of the effluent is about 4,200 m^3/day. Table 5.1 shows data on which the construction of the Akosombo sewage treatment plant was based (Source: VRA, Engineering dept.).

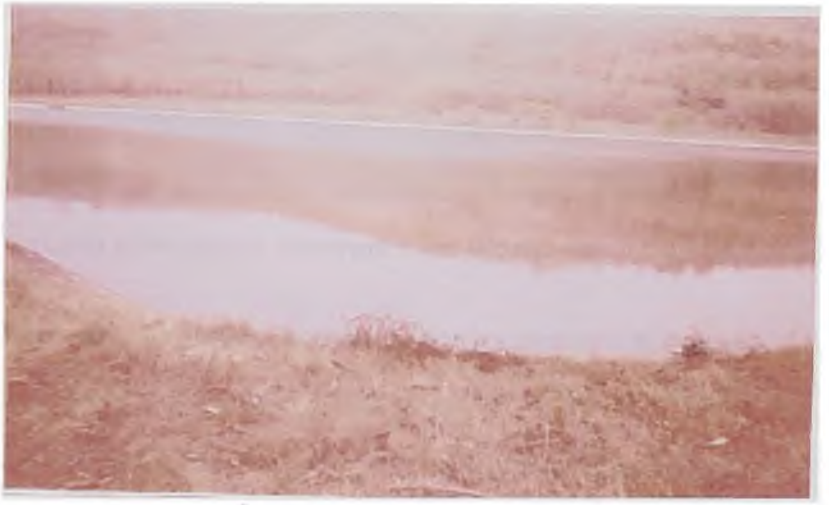

Plate 11 Part of the Akosombo Stabilization Ponds.

Studies conducted by Larmie and Hodgson (1998) indicated that the ASTP was working efficiently (See Appendix H). The treatment ponds were able to achieve mean BOD, ammonia and feacal coliform removal efficiency of 49.5 %, 88.4 % and 99.99 % respectively. The quality of the effluent was therefore not expected to have any adverse effect on the Headpond into which it was discharged (Plate 12).

Plate 12 Outfall of Akosombo Treatment Plant and Stormwater Drains into the Kpong Headpond.

During the study, the physico-chemical parameters measured at the point of discharge into the Headpond, fell within EPA effluent limits, which confirm that the ASTP is still efficient. However the feacal coliform levels were sometimes higher than the permissible limits. The storm water drain, into which the sewage outfall empties before entering the Headpond, is also a potential source of feacal coliform. It is probable that the effluent from the Akosombo slaughterhouse, which is discharged into the stormwater drain, contributes to the high feacal coliform present at the site of discharge into the Headpond.

Pierce *et al.* (1998) noted that the feaces of warm-blooded animals contain a large number of coliforms. The Akosombo sewage treatment plant was based on an estimated population of 30,000 and other parameters (see Table 5.1). The estimated population for the Akosombo Township in the year 2000 was 14,651 hence the capacity of the treatment plant is not exceeded.

Table 5.1 Estimated Data for Akosombo Sewage Treatment Plant Construction
(Source: VRA, Engineering dept.)

Population	30,000	
Sewage flow	50 g/ cap/day	6,800 m^3/day
Biochemical oxygen demand	80 g/cap/day	2,400 kg/day
Suspended solids	90 g/cap/day	2,700 kg/day

6 SUMMARY AND CONCLUSION

The main purpose of the study was to identify and investigate the various sources of pollutants in the Kpong Headpond. An assessment of the effects of the identified pollutants on the quality of water for various uses was also attempted. The study also sought to, among others, determine the mode of treatment and efficiency of treatment of pollutants where they existed, and the general water supply and sanitation conditions in the lakeside communities.

Eleven sites were strategically chosen after a reconnaissance survey for the study. These sites were to monitor impacts of the Akosombo sewage treatment plant (ASTP), Akosombo Textiles Limited (ATL), the Volta River Estates Limited (VREL) banana plantations and lakeside communities. The study was undertaken in three main phases. The first involved water quality monitoring at the selected sites comprising physicochemical and bacteriological analysis. The second phase involved biological monitoring of macro invertebrates at the selected sites, while the third phase involved a social survey of the lakeside communities to identify some of the activities within the settlements, which could impact negatively on the quality of the water. Visits were also paid to some organizations in the study area that depended on the Kpong Headpond in one way or another. These organizations included VRA, Kpong Water Works, VREL and some lakeside recreational spots such as Alos Bay and Senchi Resort.

It was found from the study that, the water quality, in terms of physicochemical parameters, was satisfactory except at site SS4 that was located at the confluence of ATL effluent discharge. Almost all the parameters measured were above natural background levels at this site. Some of them were also higher than acceptable limits proposed by the Environmental Protection Agency (EPA) as guideline values (Appendix C). At this site, the pH for instance was consistently high with values between 10.3 and 11.2. BOD and COD concentrations were also higher than the EPA limits. There was virtually no oxygen in the water. The amount of suspended solids and level of turbidity was also very high. Again, the water was highly coloured with different colours identified at the various sampling times. There was also a pungent odour at the site. The levels or concentrations of these parameters were highly significant from the other sites, which were relatively unpolluted. Site SS2, which was also located at the confluence of Akosombo sewage treatment plant effluent discharge had concentrations of most of the parameters within acceptable limits. Apart from appreciable level of nutrients and apparent colour, all other physico-chemical parameters fell within the natural background levels. All the parameters measured fell within the EPA limits. The study also showed that for most of the parameters measured, there were significant differences between site SS2 and SS4. This implies that the physico-chemistry of the site is within acceptable levels. The nine other sites recorded values, which were all within the natural background levels. However for the nutrients some of the sites sometimes recorded values higher than natural background levels. This could be due to recycling of nutrients within the Headpond and introduction of nutrients from agricultural activities and domestic activities within the study area.

With respect to bacteriological analysis, it was discovered that the whole shoreline was contaminated with feacal matter. Feacal coliform was identified at all the sites. The highest count was observed at site SS2 while the least occurred at site SS4. Since the presence of coliform bacteria indicates the probable presence of pathogens in the water, it implies that the water quality in the Headpond is not safe for direct drinking. However since the concentrations of other parameters fall within acceptable levels, it is a satisfactory source of raw water for treatment.

Macro invertebrate monitoring at the selected stations indicated the presence of a high level of aquatic insects, which were generally associated with the aquatic weeds in the Headpond. Insects such as *ephemeroptera* were dominant and these are usually found in uncontaminated or unpolluted water. Richness of macroinvertebrate species was evident at all the sites with the exception of site SS4. This was however not surprising since it was expected that due to the harsh conditions at the site, most aquatic organisms would not thrive there.

The social survey of the selected lakeside communities revealed that the settlers depended very much on the water for drinking, cooking, washing and other purposes. Although in most of the communities visited, there was at least one public tap, these were highly inadequate for the residents and so they more or less depended on water from the Headpond for their domestic chores. A lot of water contact was also identified with people swimming, bathing and washing in the water. The general sanitation in the communities was unsatisfactory. In most of the communities visited, most of the households did not have access to private toilet facilities and therefore depended on

public toilets or open defeacation. Open defeacation was clearly visible as feaces littered the shorelines of some of the communities. Provision of more toilet facilities by the district assemblies with proper maintenance is expected to reverse this situation. The sullage disposal also left much to be desired. Most of the communities had to make their provision for sullage, which normally flowed in earth drains. This form of sullage disposal gave rise to waterlogged soil and stagnant pools, which convey enteric diseases and provide breeding grounds for mosquitoes, which spread malaria. Most of the respondents also threw wastewater about indiscriminately thereby worsening the sanitation in the communities.

Solid waste (refuse) disposal was unsatisfactory in the lakeside communities. Most of the households disposed of refuse in their backyards and periodically burned them. However this practice is undesirable since it could expose the residents to diseases. Where designated dumping points were located, it was observed that they were generally in a bad state and posed a lot of danger to residents especially to children who went to the dump as scavengers. Some of the dumping grounds (e.g. Dzidzorkope) were too close to settlements and needed an immediate relocation by the district assemblies.

On the quality of water in the Headpond, most of the residents perceived it to be poor due to activities such as washing, dumping of refuse etc in the Headpond. Others attributed the deteriorating state of the water to discharge of effluents from ATL and Akosombo sewage treatment plant. The intense growth of weeds in the Headpond was also mentioned as contributing to the deteriorating water quality. Despite their perception, it was observed from the study that most of the households drank water from the Headpond

raw without any form of treatment. This situation and the unsanitary conditions in the lakeside communities were probably the cause of the rather high incidence of malaria, worm infestations and diarrhoea diseases in the lakeside communities.

From the findings of the study, it may be concluded that the quality of water in the Kpong Headpond is presently satisfactory as a source of raw water. However due to the presence of coliform bacteria in the water, it is not safe for direct drinking. Due to the risk of bilharzia in the area, recreational activities such as swimming are not recommended. The water is satisfactory for industrial activities and could be abstracted for such purposes. However, the VRA and district assemblies should strictly control the use of the Headpond as a receptacle of waste in order to protect its integrity.

7 RECOMMENDATIONS

Arising out of the observations and the results of the study, the following recommendations are made to control and manage the quality of water in the Headpond.

1. The use of the Headpond by animals as a source of drinking water, especially at Fodzoku and surrounding areas, should be discouraged by the district assembly to avoid contamination of the water by feacal coliforms.

2. The VRA and the District assemblies should provide the Lakeside communities with more toilet facilities.

3. The VRA and the Environmental health departments of the district assemblies should intensify environmental and health education of the residents of the Lakeside communities. The communities should be made to know that environmental protection is a common responsibility. They should also be advised to boil water from the Headpond before drinking and avoid direct drinking.

4. There should be enactment of byelaws by the district assemblies to curb pollution practices such as waste dumping, washing, swimming etc, in the Headpond.

5. ATL should be compelled to construct a more efficient waste treatment plant. The VRA should also monitor the efficiency of the waste treatment plant periodically and put in corrective measures where relevant.

6. The Manya and Asuogyaman district assemblies should relocate the waste dumps at Atimpoku (Dzidzorkope) and Kpong, to protect the water from further pollution.

7. The Ghana Water Company and the district assemblies should also provide every lakeside community with at least, one source of potable water. Abume and Kokontekpedzi should be given priority due to their proximity to the Akosombo Sewage Treatment Plant outfall.

8. Due to the threat of the aquatic weeds to the quality and lifespan of the Kpong Headpond, it is recommended that the VRA should purchase a weed harvester to enhance the clearance of weeds. The present mode of periodic manual clearance appears to be ineffective.

9. The VRA and government health institutions in the vicinity of the Headpond should provide free treatment to the bilharzia patients along the Headpond.

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Appendix A. Tables of Field and Laboratory Results

Appendix A1 Summary of pH values obtained

Site	Oct	Dec	Feb.	May	Mean	Std dev	Minimum	Maximum
SS1	6.9	6.9	6.93	7.38	7.0 b*	0.2	6.93	7.38
SS2	7.0	7.1	7.2	7.4	7.2 b	0.2	7	7.4
SS3	6.9	7.1	7.5	7.4	7.2 b	0.3	6.9	7.5
SS4	10.3	11.2	11	10.7	10.8 a	0.4	10.3	11.2
SS5	7.0	7.6	7	7.4	7.3 b	0.3	7	7.6
SS6	7.1	7.1	7.1	7.4	7.2 b	0.2	7.1	7.4
SS7	7.4	7.2	7	7.6	7.3 b	0.3	7	7.63
SS8	7.4	7.1	7	7.3	7.2 b	0.2	7	7.4
SS9	7.4	7.2	7	7.3	7.2 b	0.2	7	7.4
SS10	7.2	7.1	7	7.3	7.2 b	0.1	7	7.3
SS11	6.8	7.0	7.47	7.64	7.2 b	0.4	6.83	7.64
mean	7.4 b	7.5 a	7.5 a	7.7 a				

LSD 0.05 (Sites) = 0.32

LSD 0.05 (Months) = 0.29

* Figures followed by the same letter are not significantly different from each other at $p<0.05$.

Appendix A2 Summary of temperature readings (°C)

Site	Oct	Dec	Feb.	May	Mean	Std dev	Min	Max
SS1	27.8	28.4	28.3	28.8	28.3 c	0.4	27.8	28.8
SS2	27.7	28.4	28.4	30.6	28.8 c	1.3	27.7	30.6
SS3	27.9	28.4	28.7	28.9	28.5 c	0.4	27.9	28.9
SS4	30.4	30.4	31.3	30.5	30.7 a	0.4	30.4	31.3
SS5	28	28.4	29.4	29	28.7 c	0.6	28	29.4
SS6	28.4	28.9	29.5	29.5	29.1 b	0.5	28.4	29.5
SS7	28.2	28.6	29.6	29.8	29.1 b	0.8	28.2	29.8
SS8	28.1	28.5	28.3	29.3	28.6 c	0.5	28.1	29.3
SS9	27.9	28.5	28.5	29.4	28.6 c	0.6	27.9	29.4
SS10	28.6	28.6	28.5	30.7	29.1 b	1.1	28.5	30.7
SS11	30.7	28.3	28.7	31.4	29.8 b	1.5	28.3	31.4
mean	28.5 b	28.7 b	29.0 b	29.8 a				

LSD (0.05) = 0.86 (Sites)

LSD (0.05) = 0.54 (Months)
* Figures followed by same letter are not significantly different from each other

Appendix A3 Summary of Conductivity readings (µS/cm)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	51	53	52	51	51.8b	0.96	51	53
SS2	63	52	56	167	84.5b	55.19	52	167
SS3	51	52	59	51	53.3b	3.86	51	59
SS4	525	1590	655	383	788.3a	545.92	383	1590
SS5	53	64	59	54	57.5b	5.07	53	64
SS6	52	52	54	51	52.3b	1.26	51	54
SS7	52	53	56	52	53.3b	1.89	52	56
SS8	52	53	55	53	53.3b	1.26	52	55
SS9	51	53	55	53	53.0b	1.63	51	55
SS10	52	52	59	55	54.5b	3.32	52	59
SS11	72	86	58	64	70.0b	12.11	58	86

LSD (0.05) = 230

*Figures followed by the same letter are not significantly different from each other at $p < 0.05$.

Appendix A4 Summary of Total Dissolved Solids (TDS) concentrations

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	34.1	35.4	34.1	26.9	32.6b	3.87	26.9	35.4
SS2	41.3	34.3	35.4	98.7	52.4b	31.00	34.3	98.7
SS3	34.2	34	38.8	31.5	34.6b	3.04	31.5	38.8
SS4	341	857	396	194.4	447.1a	286.21	194.4	857
SS5	36.1	48.4	36.7	29.1	37.6b	8.00	29.1	48.4
SS6	36.6	36.7	36.3	28	34.4b	4.27	28	36.7
SS7	34.9	35.3	35.7	33.8	34.9b	0.82	33.8	35.7
SS8	36.5	34.1	33.5	34.1	34.6b	1.33	33.5	36.5
SS9	35.1	34.3	34.8	34.1	34.6b	0.46	34.1	35.1
SS10	38.1	34.3	34.8	33.6	35.2b	1.99	33.6	38.1
SS11	39.6	39.9	34.4	33.6	36.9b	3.34	33.6	39.9

LSD (0.05) = 100.7

Figures followed by the same letter are not significantly different from each other at P<0.05

Appendix A5 Summary of results obtained for Suspended Solids (SS)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	3	2	3	5	3.3b	1.26	2	5
SS2	10	9	8	16	10.8b	3.59	8	16
SS3	10	6	7	13	9.0b	3.16	6	13
SS4	150	91	250	322	203.3a	102.83	91	322
SS5	8	6	6	9	7.3b	1.50	6	9
SS6	10	6	8	13	9.3b	2.99	6	13
SS7	4	2	2	6	3.5b	1.91	2	6
SS8	8	7	6	5	6.5b	1.29	5	8
SS9	6	8	7	11	8.0b	2.16	6	11
SS10	5	9	8	5	6.8b	2.06	5	9
SS11	8	6	6	10	7.5b	1.91	6	10

LSD (0.05) =42.7

*Figures followed by the same letter are not significantly different from each other at p<0.05.

Appendix A6 Summary of results obtained for turbidity (NTU)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	5	3	3	5	4.0c	1.15	3	5
SS2	18	12	16	47	23.3b	16.03	12	47
SS3	8	3	3	10	6.0c	3.56	3	10
SS4	147	145	144	102	134.5a	21.70	102	147
SS5	5	0	2	4	2.8c	2.22	0	5
SS6	11	3	6	13	8.3c	4.57	3	13
SS7	11	0	1	5	4.3c	4.99	0	11
SS8	11	2	5	4	5.5c	3.87	2	11
SS9	11	2	1	10	6.0c	5.23	1	11
SS10	5	0	2	13	5.0c	5.72	0	13
SS11	17	1	1	8	6.8c	7.59	1	17

LSD (0.05) = 12.5

*Figures followed by the same letter are not significantly different from each other at $p<0.05$

Appendix A7 Summary of results for apparent colour (co Pt)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	10	10	8	12	10.0b	1.63	8	12
SS2	60	15	25	175	68.8b	73.41	15	175
SS3	10	6	5	13	8.5b	3.70	5	13
SS4	250	552	400	413	403.8a	123.45	250	552
SS5	10	7	10	13	10.0b	2.45	7	13
SS6	10	6	10	9	8.8b	1.89	6	10
SS7	10	17	20	8	13.8b	5.68	8	20
SS8	8	10	5	8	7.8b	2.06	5	10
SS9	8	5	11	10	8.5b	2.65	5	11
SS10	10	10	25	9	13.5b	7.68	9	25
SS11	10	19	19	19	16.8b	4.50	10	19

LSD (0.05) = 76.1

*Figures followed by same letter are not significantly different from each other at $p<0.05$

Appendix A8 Summary of results obtained for ammonia- nitrogen concentrations

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	< 0.01	<0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	<0.01
SS2	0.01	0.02	< 0.01	0.47	0.1b	0.23	< 0.01	0.47
SS3	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01
SS4	0.8	0.6	0.9	1.3	0.9a	0.29	0.6	1.3
SS5	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01
SS6	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01
SS7	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01
SS8	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01
SS9	< 0.01	< 0.01	0.04	< 0.01	0.0b	0.02	< 0.01	0.04
SS10	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01
SS11	< 0.01	< 0.01	< 0.01	< 0.01	0.0b	0.00	< 0.01	< 0.01

LSD (0.05) = 0.47

* Figures followed by same letter are not significantly different from each other

Appendix A9 summary of values obtained for Nitrate- nitrogen (mg/L)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	0.12	0.04	0.02	< 0.01	0.05 c	0.05	< 0.01	0.12
SS2	0.22	0.09	0.20	0.33	0.21 b	0.10	0.09	0.33
SS3	< 0.01	0.02	0.03	< 0.01	0.01 c	0.02	< 0.01	0.03
SS4	1.00	0.20	0.06	0.43	0.42 a	0.41	0.06	1.00
SS5	0.07	0.02	0.05	< 0.01	0.04 c	0.03	< 0.01	0.07
SS6	0.00	0.06	0.05	< 0.01	0.03 c	0.03	< 0.01	0.06
SS7	0.04	0.07	0.06	< 0.01	0.04 c	0.03	< 0.01	0.07
SS8	0.07	0.04	0.00	< 0.01	0.03 c	0.03	< 0.01	0.07
SS9	0.07	0.08	0.03	< 0.01	0.04 c	0.04	< 0.01	0.08
SS10	0.09	0.22	0.02	< 0.01	0.08 c	0.10	< 0.01	0.22
SS11	0.02	0.09	< 0.01	< 0.01	0.03 c	0.04	< 0.01	0.09

LSD (0.05) =

* Figures followed by same letter are not significantly different from one another at $p<0.05$.

Appendix A10 Summary of results obtained for Orthophosphate (mg/L)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	0.02	0.01	0.05	< 0.01	0.02 c	0.02	< 0.01	0.05
SS2	0.19	0.75	0.13	0.27	0.34 a	0.28	0.13	0.75
SS3	0.02	0.02	0.03	0.02	0.02 c	0.01	0.02	0.03
SS4	0.48	0.29	0.12	0.26	0.29 b	0.15	0.12	0.48
SS5	0.02	0.01	0.07	< 0.01	0.03 c	0.03	< 0.01	0.07
SS6	0.07	0.06	0.05	< 0.01	0.05 c	0.03	< 0.01	0.07
SS7	< 0.01	0.10	0.16	< 0.01	0.07 c	0.08	< 0.01	0.16
SS8	0.04	0.01	0.03	< 0.01	0.02 c	0.02	< 0.01	0.04
SS9	0.03	0.06	0.12	< 0.01	0.05 c	0.05	< 0.01	0.12
SS10	0.02	0.08	0.06	< 0.01	0.04 c	0.04	< 0.01	0.08
SS11	0.01	0.09	0.05	< 0.01	0.04 c	0.04	< 0.01	0.09

LSD (0.05) = 0.14

* Figures followed by same letter are not significantly different from each other.

Appendix A11 Summary of results of DO concentrations obtained

Site	Oct	Dec	Feb	May	Mean	% Satn	Std.dev	Min	Max
SS1	6.8	5.5	5.8	5.4	5.9 ab	73.44	0.6	5.4	6.8
SS2	4.5	5.7	3.1	3.4	4.2 d	52.19	1.2	3.1	5.7
SS3	6.5	4.5	3.1	5.4	4.9 c	60.94	1.4	3.1	6.5
SS4	0	0.6	0	0	0.2 e	1.88	0.3	0	0.6
SS5	4.2	4.2	3.2	4	3.9 d	48.75	0.5	3.2	4.2
SS6	5.2	5.3	4.1	4.6	4.8 c	60.00	0.6	4.1	5.3
SS7	5	5.1	3.9	4.8	4.7 c	58.75	0.5	3.9	5.1
SS8	4.1	5.2	3.6	4	4.2 d	52.81	0.7	3.6	5.2
SS9	4.1	4.9	3.4	4.2	4.2 d	51.88	0.6	3.4	4.9
SS10	5.4	6.2	5	5	5.4 bc	67.50	0.6	5	6.2
SS11	6	6.4	6.6	6.8	6.5 a	80.63	0.3	6	6.8
	4.7 a	4.9 a	3.8 b	4.3 b					

LSD (0.05) = 0.83 (Sites)

LSD (0.05) = 0.5 (Months)

*Figures followed by same letter are not significantly different from each other.

Appendix A12 Summary of results obtained for BOD concentrations

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	1.5	1.2	0.6	0.8	1.0b	0.40	0.6	1.5
SS2	5	2.9	4.8	4.8	4.4b	0.99	2.9	5
SS3	3	3.5	3	1.2	2.7b	1.01	1.2	3.5
SS4	120	50	70	110	87.5a	33.04	50	120
SS5	1.5	2	2.4	1.8	1.9b	0.38	1.5	2.4
SS6	3	3.3	3.6	1	2.7b	1.18	1	3.6
SS7	2	2.6	0.6	2.2	1.9b	0.87	0.6	2.6
SS8	2.8	2.6	1.2	1.6	2.1b	0.77	1.2	2.8
SS9	3	3.9	4.2	0.4	2.9b	1.73	0.4	4.2
SS10	0.8	2.4	0.6	2	1.5b	0.89	0.6	2.4
SS11	3	2.9	4.8	3.6	3.6b	0.87	2.9	4.8

LSD (0.05) = 14

* Figures followed by the same letter are not significantly different from each other at $p<0.05$

Appendix A13 Summary of results for COD (mg/L)

Site	Feb	May	Mean	Std dev	Min	Max
SS1	7.2	7.9	7.6c	0	7.2	7.9
SS2	14.4	39.4	26.9b	17.68	14.4	39.4
SS3	7.2	39.4	23.3b	22.77	7.2	39.4
SS4	316.8	314.9	315.9a	1.34	314.9	316.8
SS5	7.2	23.6	15.4b	11.60	7.2	23.6
SS6	7.2	31.5	19.4b	17.18	7.2	31.5
SS7	14.4	23.6	19.0b	6.51	14.4	23.6
SS8	28.8	7.9	18.4b	14.78	7.9	28.8
SS9	21.6	7.9	14.8b	9.69	7.9	21.6
SS10	7.2	23.6	15.4b	11.60	7.2	23.6
SS11	21.6	7.9	14.8b	9.69	7.9	21.6

LSD (0.05) = 17.5

* Figures followed by the same letter are not significantly different from each other

** COD was not determined in October and December

Appendix A14 Summary of results obtained for Total coliform counts (cfu)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	0	40	380	100	130.0 c	171.66	0	380
SS2	100	60	1760	960	720.0 a	808.13	60	1760
SS3	40	0	120	140	75.0 c	66.08	0	140
SS4	80	20	0	40	35.0 d	34.16	0	80
SS5	60	40	80	260	110.0 c	101.32	40	260
SS6	100	40	40	160	85.0c	57.45	40	160
SS7	140	100	20	40	75.0 c	55.08	20	140
SS8	360	500	400	580	460.0 abc	99.33	360	580
SS9	40	40	160	440	170.0 c	188.68	40	440
SS10	80	800	180	200	315.0 b	327.57	80	800
SS11	680	460	1060	300	625.0 ab	329.19	300	1060

LSD (0.05)= 403.6

*Figures followed by the same letters are not significantly different from each other at P<0.05.

Appendix A15 Summary of results obtained for Feacal coliform counts (cfu)

Site	Oct	Dec	Feb	May	Mean	Std dev	Min	Max
SS1	0	0	0	20	5.0	10.00	0	20
SS2	0	20	100	700	205.0	332.82	0	700
SS3	0	0	0	60	15.0	30.00	0	60
SS4	20	0	0	20	10.0	11.55	0	20
SS5	20	20	40	40	30.0	11.55	20	40
SS6	20	20	20	100	40.0	40.00	20	100
SS7	40	80	0	20	35.0	34.16	0	80
SS8	80	220	240	60	150.0	93.09	60	240
SS9	0	20	100	80	50.0	47.61	0	100
SS10	20	500	0	60	145.0	237.98	0	500
SS11	80	100	100	220	125.0	64.03	80	220

Appendix 4.16a. Occurrence of macro invertebrates from October 2000 to May 2001.

	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	SS11
Insecta											
Ephemeroptera	+	-	-	-	+	+	+	+	+	+	+
Diptera	-	+	+	-	+	+	+	+	+	+	-
Coleoptera	+	+	+	+	+	-	+	-	+	+	-
H. geridinae	-	-	-	-	-	+		+	-	-	-
H. ranatridae	+	+	+	-	-		+	-	+	-	-
O. zygoptera	+	+	+	-	+	+	+	+	+	+	-
O. anisoptera	+	-	-	-	+	+	-	-	-	+	-
Hirudinea	-	-	-	-	-	+	+	-	-	+	-
Crustacea	-	-	+	-	-	+	+	+	+	+	-
Mollusca	-	+	+	-	+	+	+	+	+	+	+
Hydracarina	+	+	+	-	+	+	+	+	+	+	+
fish	-	-	-	-	-	-	+		+	+	-
Oligochaete	-	-	-	-	-	+	-	-	-	+	-
Tubifera	-	+	-	-	-	-	-	-	-	-	-

Appendix A16b. Summary of Shannon-Wiener index calculated for the sites

Sampling sites	Mean	Std dev	Min	Max
SS1	1.265543 a	0.244492	0.950271	1.54448
SS2	1.032786 a	0.119595	0.867563	1.153742
SS3	1.061501 a	0.31265	0.636514	1.386294
SS4	0 c	0	0	0
SS5	1.342969 a	0.32051	0.950271	1.735126
SS6	1.384086 a	0.292148	1.06709	1.764374
SS7	1.341475 a	0.311235	0.917031	1.664027
SS8	1.126427 a	0.471558	0.562335	1.634167
SS9	1.302463 a	0.386116	0.974315	1.767009
SS10	1.196924 a	0.551304	0.408698	1.675086
SS11	0.655392 b	0.462018	0	1.060857

LSD (0.05) = 0.46

* Figures followed by the same letter are not significantly different from each other at $p<0.05$.

Appendix A16c Evenness index for the sites

Sampling sites	Mean	Std dev	Minimum	Maximum
SS1	0.919154 a	0.042548	0.864974	0.959639
SS2	0.8856 ab	0.08791	0.78969	0.96023
SS3	0.89679 a	0.068566	0.825369	0.982141
SS4	0 c	0	0	0
SS5	0.90899 a	0.065765	0.840507	0.968393
SS6	0.875107 ab	0.072654	0.798771	0.971307
SS7	0.817182 ab	0.059437	0.763349	0.880497
SS8	0.847266 ab	0.132266	0.680264	0.985475
SS9	0.904043 a	0.012198	0.88686	0.915539
SS10	0.655799 b	0.193538	0.372013	0.805546
SS11	0.688831a	0.468368	0	1

LSD (0.05) = 0.23

*Figures followed by the same letter are not significantly different from each other at $p<0.05$.

Appendix A16d. Summary of species richness indices obtained

Sampling sites	Mean	Std dev	Minimum	Maximum
SS1	1.147013 a	0.242928	0.868589	1.365359
SS2	1.285814 a	0.180702	1.116221	1.541695
SS3	1.2496 a	0.458752	0.910239	1.923593
SS4	0 c	0	0	0
SS5	1.452298 a	0.550822	1.13677	2.275598
SS6	1.383033 a	0.497477	0.834065	2.038447
SS7	1.428773 a	0.411282	0.920783	1.820478
SS8	1.105575 a	0.545273	0.40243	1.698116
SS9	1.424343 a	0.616098	0.910239	2.215616
SS10	1.251674 a	0.53697	0.600203	1.828325
SS11	0.686952 b	0.485529	0	1.116221

LSD (0.05) = 0.56

* Figures followed by the same letter are not significantly different from each other at $p<0.05$.

Appendix A16e. Summary of seasonal changes in Species Richness

	Oct	Dec	Feb	May
Mean	1.065177 b	0.993002 a	1.470816 b	0.985578 b
Std dev	0.439027	0.509116	0.645577	0.608895
Minimum	0	0	0	0
Maximum	1.609718	1.820478	2.275598	1.923593

LSD (0.05) = 0.34

* Figures followed by the same letter are not significantly different from each other at $p<$ 0.05.

Appendix A16f Counts of aquatic macroinvertebrates at the various sites

Group	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	SS11	TOTAL
Insecta												
Ephemeroptera	11	0	0	0	9	18	32	3	12	102	4	**191**
Diptera (Chironomid)	0	1	1	0	4	9	1	3	8	19	0	**46**
Coleoptera	21	1	1	1	14	2	12	0	1	4	0	**57**
H. geridinae	0	0	0	0	0	5	0	25	0	0	0	**30**
H. ranatridae	4	2	4	0	0	0	4	0	3	0	0	**17**
O. zygoptera	11	2	13	0	19	12	20	6	9	13	0	**105**
O. anisoptera	2	0	0	0	1	3	0	0	0	8	0	**14**
Total	**49**	**6**	**19**	**1**	**47**	**49**	**69**	**37**	**33**	**146**	**4**	
Hirudinae	0	0	0	0	0	1	1	0	1	1	0	**4**
Crustacea	0	0	4	0	0	1	1	10	3	52	0	**71**
Mollusca	0	8	5	0	1	9	3	10	2	8	7	**53**
Hydracarina	9	7	5	0	12	21	20	3	2	25	10	**114**
fish	0	0	0	0	0	0	1	0	3	4	0	**8**
oligochaete	0	0	0	0	0	1	0	0	0	2	0	**3**
tubifera	0	2	0	0	0	0	0	0	0	0	0	**2**
TOTAL	**58**	**23**	**33**	**1**	**60**	**82**	**95**	**60**	**44**	**238**	**21**	**715**

Appendix A 16g Spacial and temporal distribution of macro invertebrates

October		December		February		May	
SS1		**SS1**		**SS1**		**SS1**	
Hemiptera (Ranitra)	2	Hydracarina	2	Odonata Anisoptera	2	Hemiptera Ranitra	2
Coleoptera	6	Ephemeroptera	3	Hydracarina	3	Odonata Zygoptera	2
Ephemeroptera	5	Coleoptera	8	Ephemeroptera	3	Coleoptera	6
Odonata (zygoptera)	3	Odonata Zygoptera	6	Coleoptera	1		10
Hydracarina	4		19		9		
	20						
SS2		**SS2**		**SS2**		**SS2**	
Gastropod	2	Hydracarina	4	gastropod	4	Tubifera (syrphidae)	2
Hemiptera (Ranitra)	1	Odonata(zygoptera)	1	Odonata(Zygoptera)	1	Gastopoda	2
Hydracarina	2	Hemiptera(Ranitra)	1	Hydracarina	1	Chironomid Larva	1
	5	Coleoptera	1		6		5
SS3		**SS3**		**SS3**		**SS3**	
Hydracarina	3	Hydracarina	2	Hemiptera(Ranitra)	1	Hemiptera Ranitra	1
Hemiptera (Ranitra)	2	Odonata (zygoptera)	1	gastropod	2	Odonata (Zygoptera)	4
Gastropod	2		3	Odonata(zygoptera)	8	Chironomid	1
	7			Crustacea	4	Coleoptera	1
					14	gastropod	1
							8
SS4		**SS4**		**SS4**		**SS4**	
Nil		Coleoptera	1	Nil		Nil	
SS5	4	**SS5**		**SS5**		**SS5**	
Ephemeroptera	5	Coleoptera	8	Gastropod	1	Chironomid larva	1
Odonata (Zygoptera)	2	Odonata(Zygoptera)	12	Odonata(anisoptera)	1	Coleoptera	3
Hydracarina	3	Ephemeroptera	2	Chironomid	2	Ephemeroptera	1
Coleoptera	14	Hydracarina	9	Ephemeroptera	2		5
		Chironomid	1	Hydracarina	1		
			32	Odonata (zygoptera)	2		
					9		
SS6		**SS6**		**SS6**		**SS6**	
Odonata (anisoptera)	3	Odonata(Zygoptera)	2	Odonata(exuvium)	1	Gastropods	3
Hydracarina	5	Hydracarina	8	Odonata(zygoptera)	7	Hemiptera (Geridinea)	5
Ephemeroptera	12	Ephemeroptera	5	Crustacea	1	Odonata (zygoptera)	3
Chironomid	2	Coleoptera	2	Gastropod	6		11
Oligochaete	1	Diptera(Chironomid)	1	Hirudinea	1		
	23		18	Hydracarina	8		
				Chironomid	6		

				Ephemeroptera	1		
SS7		**SS7**		**SS7**		**SS7**	
Hydracarina	6	Hydracarina	11	Fish	1	Ephemeroptera	18
Odonata (Zygoptera)	2	Hemiptera(Ranatridae)	3	Gastropod	2	Hydracarina	3
Ephemeroptera	6	Odonata(Zygoptera)	4	Crustacea	1	Odonata (zygoptera)	4
Coleoptera	8	Ephemeroptera	4	Odonata(zygoptera)	10	Coleoptera	1
Gastropod	1	Diptera (Chironomid)	1	Ephemeroptera	4		**26**
	23	Coleoptera	3	Hemiptera(Ranatridae)	1		
		Hirudinea	1		**19**		
SS8		**SS8**		**SS8**		**SS8**	
Gastropod	2	Gastropod	3	Gastropod	3	Gastropoda	2
Hemiptera (Geridinae)	2	Hemiptera (Geridinae)	9	Crustacea	7	Crustacea	3
Chironomid	3		**12**	Hemiptera (Geridinae)	1	Hemiptera (Geridinae)	13
Odonata (Zygoptera)	3			Ephemeroptera	3	Odonata (zygoptera)	1
	10			Odonata(zygoptera)	2		**19**
				Hydracarina	3		
					19		
SS9		**SS9**		**SS9**	**3**	**SS9**	
Chironomid	3	Gastropod	2	Fish	1	Hemiptera (Ranitra)	1
Odonata (Zygoptera)	4	Chironomid larva	5	Crustacea	2	Odonata (zygoptera)	3
Coleoptera	1	Crustacea	2	Odonata (zygoptera)	5	Ephemeroptera	4
Hydracarina	1		**9**	Ephemeroptera	2		**8**
Ephemeroptera	3			Hemiptera	1		
	12			Hirudinea	1		
				Hydracarina	**15**		
SS10		**SS10**		**SS10**		**SS10**	
Crustacea	2	Crustacea	11	Gastropod	1	Gastropod	6
Ephemeroptera	25	Odonata(zygoptera)	12	Fish	2	Odonata (anisoptera)	8
Gastropod	1	Ephemeroptera	64	Oligochaete	1	Fish	2
	28	Diptera (Chironomid)	19	Crustacea	25	Crustacea	14
		Hydracarina	5	Coleoptera	4	Hydracarina	13
		Oligochaete	1	Ephemeroptera	12	Hirudinea	1
			112	Hydracarina	7	Odonata (zygoptera)	1
					52	Ephemeroptera	1
							46
SS11		**SS11**		**SS11**		**SS11**	
Gastropod	4	Gastropod	2	Gastropod	1	Hydracarina	2
Ephemeroptera	3	Hydracarina	2	Hydracarina	4		
Hydracarina	2		4	Ephemeroptera	1		
	9				**6**		

Appendix B. Interview Guide for Communities

Settlement.....

Age .....

Sex Male.... Female.....

WATER SUPPLY

1. Do you have access to water in your home? Yes..... No.....

If yes, indicate type.

Tap.....

Well.....

Borehole.....

Other (specify).....

3.If no, indicate source of water for household.

Community Borehole

Volta

Neighbour

Other (specify)

4.Are you satisfied with the source of water for your household?

Yes..... No.....

If no, indicate reason(s)

6. Do you boil or treat your water before drinking? Yes... No.....

7. What diseases do you associate with water at this locality?

.....

.....

.....

8.Do you experience water shortage? Yes.... No.....

9.If yes, at what time during the year?

Dry Season...

All the time...

Other (specify)....

10.How do you cope with water shortage? (multiple answers possible)

By walking long distances to other places for water.....

Buying water.....

Other (specify).....

TOILET FACILITIES

15.Do you have access to private toilet facilities in your home? Yes... No....

16. If yes, indicate type.

KVIP .....

Pit latrine .....

Pan latrine...

Water closet .....

Other (specify)....

17.If no, state where you attend to natures call.....

Public Toilet.....

Other (Specify).....

18.Do you pay to use the facility? Yes ..... No .....

19.If yes, how much do you pay? .....

20.Are you satisfied with toilet facilities in your area? Yes.... No.....

21.If no, what dissatisfies you?.....

22If no, how would you like this improved?.....

WASTE DISPOSAL

23.How do you dispose of solid waste(refuse) in your household?

Store in home.....

Official dumping point....

Other(specify).....

24.How do you dispose of wastewater e.g. from the kitchen, Bathroom and washing?

25. Are you satisfied with waste disposal facilities in your locality? Yes... No....

26. If no, how would you like this improved?.....

.....

.....

.....

PERCEPTION OF COMMUNITY

27.What is your perception about the quality of water it the Volta?

Very good....

Good.....

Bad.....

28.What in your view, are some of the activities in your locality that do pollute the Volta and render it unfit for human consumption?.....

.....

.....

.....

29.What should be done to enhance the quality of the Volta?.....

.....

.....

.....

BILHARZIA

30.Do you or anyone in your household suffer from bilharzia? Yes.....No.....

31.If yes, how do you treat it?.....

Go to hospital or clinic

Seek herbal treatment

Self medicate

Do not treat in anyform

Other (Specify)

Appendix C. EPA General Effluent Quality Guidelines for Discharges into Natural Water Bodies

PARAMETER	MAXIMUM PERMISSIBLE LEVEL
pH	6-9
Temperature	< 3 °C
Colour (TCU)	200
Oil and Grease	5
BOD (mg/L)	50
COD (mg/L)	250
Total Dissolved Solids (mg/L) (TDS)	1000
Total Suspended Solids (mg/L) (TSS)	50
Turbidity (NTU)	75
Conductivity (µS/cm)	1500
Total Coliforms (MPN/100 mL)	400
E.Coli (MPN/100 mL)	0
Ammonia as N (mg/L)	1.0
Nitrate (mg/L)	50
Flouride (mg/L)	1.0
Phenol (mg/L)	2.0
Sulphide (mg/L)	1.5
Total Phosphorus (mg/L)	2.0
Total Cyanide (mg/L)	1.0
Free cyanide (mg/L)	0.2
Cyanide as Weak Acid Dissociable (mg/L)	0.6
Total Pesticides (mg/L)	0.5
Total Arsenic (mg/L)	1.0
Soluble Arsenic (mg/L)	0.1
Cadmium (mg/L)	0.1
Chromium (+6) mg/L	0.1
Total Chromium (mg/L)	0.5
Copper (mg/L)	5.0
Lead (mg/L)	0.1
Nickel (mg/L)	0.5
Selenium (mg/L)	1.0
Zinc (mg/L)	10
Mercury (mg/L)	0.005
Silver (mg/L)	5.0
Tin (mg/L)	5.0

Appendix D. Discharge Rates for Kpong and Akosombo Plants

KPONG PLANT DISCHARGES 1983-2000 (m^3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981												
1982												
1983												
1984												
1985	477	525	540	542	610	685	596	580	464	567	669	651
1986	688	701	702	704	743	792	869	880	892	879	857	806
1987	817	894	918	898	907	912	899	882	835	821	847	848
1988	830	882	899	938	950	986	918	879	790	796	876	894
1989	889	925	948	994	1,000	1,004	988	947	818	813	896	947
1990	978	978	987	961	971	973	945	987	978	1,000	977	1,024
1991	1,025	1,034	1,068	1,092	1,076	1,006	1,087	1,037	1,025	1,022	1,075	1,072
1992	1,081	1,115	1,144	1,152	1,124	1,140	1,142	1,109	1,131	1,124	1,152	1,181
1993	1,133	1,136	1,161	1,175	1,151	1,156	1,143	1,145	1,141	1,044	984	994
1994	965	1,073	1,246	1,238	1,207	1,177	1,165	1,084	1,043	917	950	1,113
1995	1,117	1,153	1,128	1,085	1,087	1,097	1,114	1,129	1,111	1,091	1,159	1,159
1996	1,210	1,245	1,259	1,217	1,212	1,210	1,231	1,229	1,165	1,132	1,224	1,221
1997	1,275	1,298	1,233	1,279	1,267	1,239	1,243	1,236	1,289	1,280	1,320	1,253
1998	1,070	827	637	529	529	505	532	590	698	894	990	1,076
1999	1,092	969	900	908	836	951	1,073	1,078	891	982	1,056	1,064
2000	1,073	1,032	1,077	1,089	1,075	1,063	1,053	1,278	1,313	1,274	1,340	1,280

KOSOMBO PLANT DISCHARGES 1965-2000 (m^3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1965								
1966	153	156	154	172	157	160	165	162
1967	174	194	227	268	303	372	396	419
1968	527	523	523	526	528	525	525	536
1969	541	551	559	565	568	568	571	565
1970	583	595	585	594	596	593	596	594
1971	601	604	610	610	614	621	621	626
1972	576	594	597	616	623	706	735	742
1973	771	786	738	790	809	812	816	812
1974	842	861	861	856	870	864	874	864
1975	851	875	851	861	825	806	791	787
1976	852	863	872	864	863	864	856	864
1977	873	894	951	975	1,027	1,016	699	805
1978	1,024	1,030	998	1,003	496	512	570	662
1979	957	971	972	972	999	982	971	1,004
1980	1,082	1,098	1,119	1,122	1,127	1,151	1,155	1,140
1981	1,110	1,142	1,143	1,146	1,148	1,177	1,164	1,150
1982	960	975	973	975	965	959	964	983
1983	717	655	634	602	602	460	368	379
1984	277	268	251	266	337	331	335	347
1985	476	512	525	521	598	662	565	554
1986	690	699	710	707	750	801	884	898
1987	831	891	921	897	904	924	899	874
1988	831	883	900	954	974	982	905	863
1989	899	948	975	1,012	1,008	1,014	999	938
1990	992	993	1,000	987	981	991	953	978
1991	1,075	1,114	1,117	1,110	1,118	1,102	1,057	1,004
1992	1,108	1,139	1,174	1,178	1,145	1,171	1,159	1,123
1993	1,129	1,120	1,140	1,142	1,128	1,115	1,102	1,090
1994	1,298	1,301	1,282	1,249	1,210	1,181	1,197	1,115
1995	1,147	1,182	1,170	1,119	1,118	1,114	1,123	1,133
1996	1,244	1,269	1,276	1,247	1,244	1,236	1,241	1,241
1997	1,325	1,352	1,297	1,307	1,297	1,290	1,280	1,266
1998	1,073	834	645	531	519	492	529	585
1999	1,093	992	928	895	822	963	1,004	1,084
2000	1,114	1,065	1,110	1,146	1,143	1,138	1,076	1,325

Sep	Oct	Nov	Dec
67	106	128	140
160	160	162	168
404	437	500	512
543	539	535	536
571	573	580	574
593	591	592	591
608	561	574	576
743	745	755	751
801	813	823	831
850	833	850	834
782	776	802	834
869	873	879	879
894	940	1,001	1,002
751	813	916	930
998	1,014	1,046	1,055
1,132	1,025	1,085	1,104
1,153	1,117	1,032	973
977	950	734	734
393	414	388	283
389	424	466	469
444	543	650	650
897	891	865	818
831	787	817	829
759	772	866	887
801	799	893	964
984	1,009	991	1,032
1,001	1,008	1,070	1,111
1,114	1,106	1,127	1,145
1,107	1,166	1,229	1,277
1,058	920	954	1,133
1,117	1,111	1,183	1,189
1,187	1,150	1,255	1,242
1,311	1,321	1,336	1,297
700	901	1,003	1,095
867	991	1,094	1,121
1,372	1,370	1,450	1,393

Appendix E. Morbidity Data (1998-2000) from VRA hospital

MONTHLY OUT-PATIENTS MORBIDITY RETURNS

INSTITUTION V.R.A. AKOSOMBO DISTRICT CODE ASUOGYAMAN REGION EASTERN MONTH JAN – DEC 98

NO	DISEASE	MALE <1	MALE 1-4	MALE 5-14	MALE 15-44	MALE 45-59	MALE 60 & Above	MALE TOTAL	FEMALE <1	FEMALE 1-4	FEMALE 5-14	FEMALE 15-44	FEMALE 45-59	FEMALE 60 & Above	FEMALE TOTAL	GRAND TOTAL
1	DIARRHOEAL DISEASES	74	66	27	116	23	9	309	40	59	24	105	9	9	[illegible]	[illegible]
2	TYPHOID FEVER			3	5	1		9		1		1			[illegible]	[illegible]
3	TUBERCULOSIS				13	2	2	17			1	12	2		15	24
4	WHOOPING COUGH	1					1	2			1				1	3
5	MENINGITIS			4	1			5	1		3	2	1		7	12
6	TETANUS	1			1			2								2
7	[illegible] POLIOMYELITIS															
8	CHICKEN POX										1	1			2	2
9	[illegible]		3	21	22	4	1	61		6	21	30	3		62	123
10	INFECTIOUS HEPATITIS	2	5	3	3			13	3	5	12	2			23	36
11	MUMPS			2	16	2	4	24		1	2	9	1		13	37
												1			1	1
12	MALARIA	209	708	273	1590	379	112	4471	410	[illegible]	[illegible]	[illegible]	[illegible]	134	6035	10504
13	GONORRHOEA				3		1	4				2	1		3	7
14	YAWS															
15	[illegible]			26	40	6	2	74			16	11	1	2	30	104
16	INTESTINAL WORMS	1	30	57	157	37	15	297	4	28	58	175	34	14	313	610
17	GUINEA WORM				1			1				1			1	2
18	MALNUTRITION	1	1	1				2		4	2				6	9
19	ANAEMIA	13	40	25	12	1	6	97	8	34	11	80	11	8	152	249
20	MENTAL [illegible]				1			1			1				1	2
21	ACUTE EYE INFECTION	61	129	199	520	189	42	1140	46	111	240	[illegible]	112	41	1154	[illegible]
22	CATARACT			2	4	18	26	50				6	10	26	42	[illegible]
23	EAR [illegible]	27	68	58	125	56	14	348	7	39	68	205	19	13	351	[illegible]
24	HYPERTENSION			1	170	201	112	484				342	257	105	684	[illegible]
25	OTHER HEART DISEASES				5	1	5	11				2	1	3	6	[illegible]
26	UPPER RESP. [illegible] INF	127	326	244	242	86	28	1053	99	288	287	509	117	[illegible]	[illegible]	[illegible]
27	PNEUMONIA	14	15	14	54	3	8	108	9		12	7	34	7	6	75	183
28	[illegible]		19	96	341	85	49	590		14	89	[illegible]	83	29	642	[illegible]
29	GYNAECOLOGICAL DIS.								1	3	19	1037	126	12	1198	1198
30	[illegible]										3	1521	2		1526	1526
31	DISEASES OF SKIN & ULCERS	59	149	204	294	75	24	805	41	107	217	343	42	9	759	1564
32	RHEUMATISM & JOINT PAINS		6	23	717	225	158	1129	1	3	17	527	265	99	912	2041
33	PUO (NOT MALARIA)			1	3	1		5			3	4			7	12
34	[illegible] INCLUDING FRACTURE, BURNS	5	54	191	526	107	31	[illegible]	3	32	109	331	62	22	559	1473
35	[illegible]															
36	[illegible]															
37	[illegible]	2						2								2
38	DIABETES				10	17	10	37			1	20	19	11	51	88
39	HIV/AIDS			1	60	14	2	77			1	56	4	1	62	139
40	U.T.I.	5	6	19	69	16	13	126	1	6	11	167	16	10	211	337
41																
42	ALL OTHER DISEASES	235	501	1026	[illegible]	1232	614	7422	193	389	[illegible]	5380	905	342	8277	15905
	TOTAL NEW CASES	875	2314	2532	[illegible]	[illegible]	1319	19899	864	[illegible]	[illegible]	[illegible]	[illegible]	931	[illegible]	[illegible]
	RE-ATTENDANCES	31	135	33	[illegible]	2298	1182	5971	23	92	238	5478	2151	362	8749	14715
	REFERRALS			2	6		3	11	2	1	1	5	2		11	22

DISTRIBUTION: (1) District Medical Officer of Health
(2) Regional Director of Health Services

Medical Officer In-charge
(NAME AND SIGNATURE)

MONTHLY OUT-PATIENTS MORBIDITY RETURNS

INSTITUTION: V.R.A. Akosombo DISTRICT CODE: Asuogyaman REGION: Eastern MONTH: Jan–Dec 1999

NO	DISEASE	MALE <1	MALE 1-4	MALE 5-14	MALE 15-44	MALE 45-59	MALE 60 & Above	MALE TOTAL	FEMALE <1	FEMALE 1-4	FEMALE 5-14	FEMALE 15-44	FEMALE 45-59	FEMALE 60 & Above	FEMALE TOTAL	GRAND TOTAL
1	Diarrhoeal Diseases	21	41	13	50	21	10	156	12	33	10	69	19	10	153	309
2	Sickle Cell Dis.	—	1	7	4	—	—	12	—	—	—	—	—	—	—	12
3	Tuberculosis	—	—	—	13	—	—	13	—	—	—	6	—	—	6	19
4	Cerebral Malaria	—	2	1	—	—	—	3	—	2	—	—	—	—	2	5
5	Meningitis	—	—	—	1	—	1	2	—	1	—	—	—	—	1	2
6	C.S.M	—	—	1	—	—	—	1	—	—	—	—	—	—	—	1
7	Acute Poliomyelitis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	Chickenpox	1	6	33	25	3	—	68	—	3	15	30	2	—	50	[illegible]
9	Measles	—	1	—	2	3	—	6	—	3	2	—	—	—	5	11
10	Infectious Hepatitis	—	—	—	7	—	—	7	—	1	—	2	—	—	3	10
11	Mumps	—	3	—	1	—	—	4	—	2	1	—	—	—	3	7
12	Malaria	142	616	1037	1135	443	125	3498	136	659	1029	2634	418	136	5012	8510
13	Gonorrhoea	—	—	—	2	2	—	4	—	—	—	—	—	—	—	4
14	Yaws	—	—	—	1	—	—	1	—	—	—	—	—	—	—	1
15	Bilharzia	—	2	18	34	1	—	55	1	1	4	20	1	—	27	82
16	Intestinal Worms	1	21	36	138	42	11	249	2	12	37	190	40	12	293	542
17	Asthma	—	—	—	2	5	2	9	—	—	—	10	4	4	18	27
18	Malnutrition	—	1	—	—	—	1	2	—	—	2	1	1	—	4	6
19	Anaemia	7	30	8	11	14	7	77	9	34	15	54	5	6	123	200
20	Mental Disorder	—	—	—	—	—	1	1	—	—	—	—	—	—	—	1
21	Acute Eye Infection	38	111	223	564	249	87	1272	34	81	226	441	122	36	1140	2412
22	Cataract	—	1	1	7	9	33	51	—	—	1	4	11	18	34	85
23	Ear Infection	16	38	40	109	24	10	237	13	41	49	163	26	4	296	533
24	Hypertension	—	—	—	112	194	104	411	—	—	—	232	201	88	521	932
25	Other Heart Diseases	—	1	—	—	—	—	1	—	—	—	—	—	—	—	1
26	Upper Resp. Tract Inf.	133	320	269	486	166	67	1374	106	311	277	665	148	58	1560	2934
27	Pneumonia	11	20	7	22	12	5	77	9	14	3	17	6	3	52	129
28	Diseases of Oral Cavity	1	15	85	406	118	61	686	—	14	100	529	100	50	803	1489
29	Gynaecological Dis.	—	—	—	—	—	—	—	—	5	26	1144	97	7	1279	[illegible]
30	Pregnancy & Rel. Compl.	—	—	—	—	—	—	—	—	—	—	1631	4	—	1625	1635
31	Diseases of Skin & Ulcers	36	87	137	220	79	34	595	36	91	138	236	70	14	625	1220
32	Rheumatism & Joint Pains	—	3	14	327	233	146	723	—	3	15	363	148	64	543	1266
33	PUO (Not Malaria)	—	1	1	2	2	—	6	—	1	2	3	1	—	7	13
34	Accidents (Including Fractures, Burns)	3	29	128	503	109	25	801	—	27	69	237	48	20	441	1242
35	Snake Bite	—	—	2	3	1	1	7	—	—	1	—	—	—	1	8
36	Leprosy	—	—	—	1	—	—	1	—	—	—	—	—	—	—	1
37	Neonatal Tetanus	1	—	—	—	—	—	1	—	—	—	—	—	—	—	1
38	Diabetes	—	—	—	22	25	28	75	—	—	—	20	52	14	86	161
39	HIV/AIDS	—	—	2	61	19	3	85	—	—	1	49	6	1	57	142
40	U.T.I	3	10	16	77	43	32	181	—	4	17	207	32	15	275	456
41	Urethritis	—	—	3	6	—	—	9	—	—	—	1	—	—	[illegible]	10
42	All Other Diseases	234	340	755	2571	1200	598	6718	115	291	716	4894	830	121	[illegible]	[illegible]
	Total New Cases	641	1712	2837	7880	3017	1392	17479	473	1624	[illegible]	3452	2437	781	22622	[illegible]
	Re-attendances	56	92	305	1778	2100	1317	5728	27	91	206	5201	1961	952	[illegible]	[illegible]
	Referrals	1	1	—	6	3	1	12	—	—	4	11	2	—	17	29

DISTRIBUTION (1) District Medical Officer of Health
(2) Regional Director of Health Services

J. Nkrumah-Mills
Medical Officer In-charge
(NAME AND SIGNATURE)

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VOLTA RIVER AUTHORITY

MONTHLY OUT-PATIENTS MORBIDITY RETURNS

INSTITUTION: V.R.A. Akosombo DISTRICT: Asuogyaman REGION: Eastern MONTH: Jan – Dec 2000

ICD CODE	DISEASE	MALE <1	1-4	5-14	15-44	45-60	>61	TOTAL	FEMALE <1	1-4	[illegible]	[illegible]	[illegible]	>61	[illegible]	GRAND TOTAL
[illegible]	[illegible]	—	—	—	1	—	—	1	—	—	—	1	—	—	1	[illegible]
010	TUBERCULOSIS	—	—	—	5	2	2	9	—	—	1	1	4	1	7	[illegible]
030	LEPROSY	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[illegible]
033	WHOOPING COUGH	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[illegible]
320	MENINGITIS	—	—	4	1	1	—	6	1	—	1	1	—	—	3	9
037	TETANUS	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
045	ACUTE POLIOMYELITIS	—	—	1	—	—	—	1	—	—	—	—	—	—	—	1
052	CHICKEN POX	1	2	5	10	1	—	19	—	1	6	10	1	—	18	37
055	MEASLES	1	1	7	1	—	—	10	—	1	6	2	—	—	9	19
070	[illegible]	1	—	2	7	2	—	12	—	—	1	5	—	—	6	18
072	MUMPS	—	1	—	—	—	—	1	—	—	—	—	—	—	—	1
084	MALARIA	154	653	1083	1833	461	121	4305	125	621	1029	2551	[illegible]	100	4858	9163
[illegible]	YAWS	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
120	SCHISTOSOMIASIS (BILHARZIA)	—	—	16	30	1	—	[illegible]	—	—	8	1	1	—	10	57
[illegible]	ANAEMIA	16	25	16	12	13	7	89	9	27	7	51	11	4	109	198
[illegible]	[illegible]	—	—	3	22	42	14	81	—	—	1	23	27	11	[illegible]	148
290	MENTAL DISORDERS	—	—	—	2	—	—	2	—	—	—	1	—	—	1	3
360	ACUTE EYE INFECTION	48	94	178	446	153	44	937	23	20	177	488	113	22	912	1850
	Snake Bite	—	—	2	17	5	1	25	—	—	4	4	1	—	9	34
366	CATARACT	1	—	—	8	9	15	33	—	—	—	4	8	15	27	60
380	[illegible] INFECTION	24	59	47	96	20	4	250	25	35	36	134	23	7	260	510
401	[illegible]	—	—	1	119	197	30	397	—	—	—	190	175	74	439	836
410	OTHER HEART DISEASES	—	—	—	—	—	2	2	—	—	—	—	1	—	1	3
480	[illegible]	19	24	16	9	8	7	83	13	26	12	11	8	3	72	155
493	[illegible]	—	6	22	65	20	9	122	1	11	17	63	17	5	114	236
520	DISEASES OF ORAL CAVITY	3	20	119	498	141	62	843	2	27	103	616	140	65	952	[illegible]
550	HERNIA	4	26	19	70	82	30	251	2	6	12	44	20	15	[illegible]	[illegible]
597	[illegible]	—	1	1	9	—	—	11	—	—	—	1	—	—	1	[illegible]
599	URINARY [illegible] INFECTION	—	1	14	41	22	16	94	—	1	8	139	12	9	175	[illegible]
634	GYNAECOLOGICAL DISORDERS	—	—	—	—	—	—	—	—	2	19	1243	92	5	1361	[illegible]
650	PREGNANCY & REL. COMPL.	—	—	—	—	—	—	—	—	—	2	1353	28	—	1382	[illegible]
[illegible]	DISEASES OF SKIN & ULCERS	48	101	117	196	86	32	580	46	83	117	222	71	22	567	1147
710	RHEUMATISM & JOINT PAINS	6	15	38	444	177	126	906	1	9	27	280	257	72	[illegible]	[illegible]
771.3	NEONATAL TETANUS	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
[illegible]	P.U.O. (NOT MALARIA)	—	—	—	—	—	—	—	—	1	1	—	—	—	2	2
[illegible]	[illegible]	5	32	132	501	124	38	828	2	32	35	231	73	15	428	1266
[illegible]	DIARRHOEA DISEASES	26	58	21	83	34	12	234	22	85	23	88	13	5	190	424
[illegible]	[illegible]	3	1	—	51	19	1	75	1	1	—	45	9	—	56	131
[illegible]	[illegible]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
[illegible]	[illegible]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
[illegible]	[illegible] WORMS	4	16	42	39	5	1	107	6	7	24	71	27	6	141	248
[illegible]	[illegible]	—	3	—	—	7	—	10	—	—	2	6	2	—	10	20
[illegible]	[illegible]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
[illegible]	SICKLE CELL DISEASES (S.C.D.)	—	6	31	51	7	—	96	3	10	32	20	4	—	87	183
[illegible]	Upper Resp. Tract Infe.	111	255	214	273	86	[illegible]	1050	82	241	216	[illegible]	[illegible]	41	1154	[illegible]
[illegible]	Cerebral Malaria	7	10	4	—	—	—	21	2	4	1	—	—	—	7	28
																[illegible]
																[illegible]
[illegible]	ALL OTHER DISEASES	183	285	531	2516	874	209	4784	97	268	525	[illegible]	773	266	5845	[illegible]
[illegible]	TOTAL NEW CASES	669	1731	2626	3456	2692	1060	11334	459	1502	[illegible]	[illegible]	2447	713	20134	[illegible]
[illegible]	RE-ATTENDANCES	80	126	204	1959	2183	1636	6335	39	128	[illegible]	[illegible]	1854	585	[illegible]	[illegible]
[illegible]	[illegible]	1	2	2	2	2	—	9	—	—	—	12	—	—	12	[illegible]

DISTRIBUTION: (1) District Medical Officer of Health

(2) Regional Director of Health Services

[signature]

Medical Officer in-charge

(NAME AND SIGNATURE)

Appendix F. Data from MOH (Asuogyaman District)

DISEASE	1997	1998	1999	2000
Malaria*	16,452	15,941	15,444	15,977
Diarrhoea*	948	838	863	1074
Measles	137	162	66	54
Yaws	210	190	176	168
AIDS	115	90	76	53
Enteric fever	----	------	-----	4
Chicken pox	173	138	159	59
Schistosomiasis*	114	114	99	51
Tuberculosis	35	31	15	13
Hepatitis	10	19	7	13
Onchocerciasis*	---	5	-----	-----
Gonorrhoea	35	6	12	24
Leprosy	---	---	---	4
Buruli Ulcer	---	---	---	2
CSM	---	---	1	---
Cholera*	---	---	---	---

- * Water borne / water related diseases.

Appendix G. Bilharzia Prevalence at the Kpong Headpond

A) Prevalence (%) in children*

1997	1998	1999
46.6	40.4	31.7

B) Prevalence (%) in adults *

1997	1998	1999
55.8	49.3	39.8

* Source VRA (Public health section, Akosombo).

Appendix H. Data on Efficiency of Akosombo Sewage Treatment Plant

Table 3: Quality of final effluent compared to the EPA guideline values

Parameter	Final Effluent		EPA Guideline Values
	Range	Mean	
pH	9.25 - 9.75	9.59	6 - 9
Conductivity	198 - 260	218	1500
Sodium	4.73 - 35.7	19.6	-
Potassium	2.33 - 11.8	8.3	-
Calcium	10.7 - 14.2	12.6	-
Chloride	27.3 - 37.6	32.7	250
Sulphate	0.2 - 8.0	3.9	-
Nitrate	0 - 7.9	2.2	50
Phosphate	0.19 - 2.1	1.05	2.0
Ammonia	0.33 - 5.8	1.38	1.0
Suspended Solids	46.0 - 92.0	63.8	50.0
BOD	19 - 33.0	25.0	50.0
Chlorophyll a	172.7 - 506.9	396.3	-
Total Coliform	45 1,430	429	
Faecal Coliform	0 - 670	160	
Aluminium	0.1	0.1	5.0
Nickel	0.01 - 0.16	0.09	0.5

Results are in mg/l, unless otherwise stated.

Table 2: Mean Overall Removal

Parameter	Raw Sewage	Pond 1 Effluent	Pond 2 Effluent	% Removal
Suspended Solids	71.7	69.0	63.8	11
BOD	49.5	29.6	25.0	49.5
Ammonia	11.9	2.0	1.38	88.4
Nitrate	4.3	2.8	2.6	39.5
Phosphate	2.0	1.2	1.05	47.5
Total Coliform, counts/100ml	7,328,000	58,560	429	99.99
Faecal Coliform, counts/100ml	4,316,000	8,780	160	99.99

Results are in mg/l unless otherwise stated.

Appendix I. Data on Effluent Quality of ATL Treatment Plant.

Month	Temperature (^{O}c)	pH	Conductivity (µs/cm)
March	37.4	11.4	4150
April	38.1	11.3	2800
May	36.0	11.5	4000
June	36.6	11.5	4,400
July	37.6	11.4	3000
EPA LIMIT	**< 3 °C ambient temp**	**6-9**	**1500**

Appendix J. List of Accronyms

ASTP	Akosombo Sewage Treatment Plant
ATL	Akosombo Textiles Limited
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
EPA	Environmental Protection Agency
MOH	Ministry of Health
SS	Suspended solids
TDS	Total dissolved solids
VREL	Volta River Estates Limited
WHO	World Health Organisation