KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

FACULTY OF BIOSCIENCES
DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

EFFECT OF SOME BIOLOGICAL AND PHYSICO-CHEMICALFACTORS ON THE WATER QUALITY OF RIVER ANKOBRA AND ITS MAJOR TRIBUTARIES

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL & APPLIED BIOLOGY, FACULTY OF BIOSCIENCE, COLLEGE OF SCIENCE, KWAME NKRUMAH UNIVERSITY OF SCIENCE & TECHNOLOGY, KUMASI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE)

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SEPTEMBER 2008

DECLARATION

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DEDICATION

This thesis is dedicated to the entire family of Opia-Mensah; Mr. & Mrs. Opia-Mensah, Eric, Daniel, Edward, Lily and Eunice.

It is also dedicated to the entire children in the communities in mining areas whose livelihood depends on the environment.

ABSTRACT

The absence of treated piped-borne water in the Wassa West District and the reliance of communities on River Ankobra as the source of drinking water make its quality important. Water from Mansi, Bonsa and Fure tributaries; up and down streams of Mansi –Ankobra confluence; up and down streams of Bonsa-Ankobra confluence; and the up and down streams of Fure-Ankobra confluence were sampled. Water sampled from these sampling sites were accessed for pH, Conductivity, Total Dissolved and Suspended Solids, Cyanide, Biochemical Oxygen Demand, Turbidity, Total and Faecal Coliforms, over a six month period. Among the sampling sites, Mansi tributary and upstream of Fure-Ankobra confluence recorded high levels of most of the parameters analyzed. Mansi tributary recorded mean Turbidity level of 199.35 NTU, TSS of 74.58 mg/l, and BOD of 2.37 mg/l with the upstream of Ankobra–Fure confluence also recording approximately the same mean levels of Turbidity (281.8 NTU), TSS (73.75 mg/l), and BOD (2.04 mg/l) as Mansi tributary. Additionally, upstream of Fure–Ankobra confluence recorded mean Conductivity levels of 167.19 µs/cm; TDS of 83.61 mg/l; with Total and Faecal Coliforms of 7.09 and 5.17 Geomean/100ml respectively. Among the parameters analyzed pH, TSS, Turbidity, Total and Faecal Coliforms levels did not meet WHO standards for drinking water. Although one expects high levels of cyanide in Mansi tributary, due to occasional cyanide spillage in its sub-tributaries, its level and that of the other sampling sites were below detection limit. Periods of rainfall observed during sampling increased the levels of the parameters analyzed especially within Mansi tributary. The pollution of Ankobra Basin correlates with areas of intense human activities, such as illegal mining activities within the upstream of Fure-Ankobra confluence and run-off water from the activities of Golden Star Resources Limited silting the Mansi tributary. Whiles Fure and Bonsa tributaries contributed significantly to reducing ($P<0.05$) turbidity in the river Ankobra, Mansi tributary significantly increased ($P<0.01$) turbidity levels in it. It is recommended that both tributaries and the river should have 100 metre buffer zones with reforestation in the degraded portions and Community Biodiversity Organizations formed and empowered to guard the demarcated buffer zones from anthropogenic activities.

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ACKNOWLEGEMENTS

The scope of this research and the limitation imposed both by time and materials presented the author with many difficulties. However with the tireless efforts of people who contributed to the fulfillment of this thesis, the author wishes to express his gratitude first and foremost to the Lord Most high and His only Begotten son Jesus Christ, the creator of the world for giving me his Grace, Blessing, Wisdom and Strength to undertake this work.

Secondly I would like to render my sincere thanks to my supervisor, Mr. W.G. Akanwariwiak who through suggestions, guidance, counselling and encouragement and most of all instilled in me the sense of discipline necessary to carry out the research even when the going became tough.

My gratitude also goes to the Chief and people of Mehame, Beposo and Adadekrom for giving me access to the sampling sites within their vicinity and to use their canoes for the sampling. My thanks go to Kwasi Buduo and Oluman who escorted me to the various sampling sites and also to Maxwell Akple (IWMI), Edmund and Paa Grant (Anglogold) for helping me in the analyses.

My hearty appreciation and profound love goes to my wonderful friend Samuel Owireku Gyimah and also to my Auntie Rose, and not forgetting my cousins Mary Ewudzie, Sarah Amoah, Linda Opoku-Afriyie and Stephen Opoku–Afriyie, for their financial support.

CHAPTER ONE

1.0 INTRODUCTION

Ankobra basin is one of the main mining areas in Ghana. The major minerals mined in the area are gold, manganese, bauxite and diamond. The intense and uncontrolled mining activities in the basin have led to environmental degradation, including the pollution of surface water sources. River Ankobra is documented to be highly polluted due to mining activities. Consequently, groundwater has become the principal and sometimes, the only source of drinking water supply in the Ankobra basin (Kortatsi, 2004). The World Health Organization estimated that a larger portion of the population in developing countries resorts to lakes, rivers, streams and wells for domestic water requirement (Ogolla, 1989).

The river Ankobra receives wastes mainly from mining industries especially at the midstream where the confluences of the major tributaries are found. The towns in the basin are also relatively large with poor sanitary facilities. The concentration of mining operations in the basin has been a major source of surface water pollution and chemical pollution of streams, siltation through increased sediment load, and increased faecal matter have been noticed (Akabzaa and Darimani, 2001). The Ankobra River serves as a source of water for domestic use to the inhabitants living along its banks. In recent times bad publicity in newspapers with headlines " 11 die from poisoning" (Daily Graphic, 23rd January 2007) and " another cyanide spill hit Ghanaians" (General News of Sunday, 24th October, 2004), among others are typical of the media's response to the quality of the river Ankobra. A river can carry out natural remediation by diluting the pollutants in them to an extent. When pollutants levels are not known, the natural remediation capacity

of the river may be exceeded. Controlling authorities of rivers need to understand their local water quality and monitor how pollution trends are developing, so that the associated problems may not arrive too suddenly for remedial action to be taken. If pollution is allowed to grow unchecked in the Ankobra River, the result may be sudden loss of aquatic ecosystems and a profound effect on those using the water for domestic requirement (Fatoki *et al.* 2001). We need to control pollution in the Ankobra Basin in order to protect our fresh water resources. For effective control mechanisms, information on the extent to which the various parts of the basin are polluted is necessary because pollutants from the tributaries could also affect the quality of the water and a control of pollution of the tributaries should lead to improved water quality in the main river (Akpabli and Drah, 2001).

Surface water pollution is a continuing and often increasing problem throughout the world. More damaging can be the persistent presence of low-level pollution, which may go undetected for years before its effects are noticed. River pollution is understood better when the chemical, physical and biochemical parameters of the water are considered (Ellis *et al.* 1989).

The rivers within the Ankobra basin receive waste mainly from mining industries. Industries located in the Ankobra basin are: Goldmines at Aboso, Prestea and Tarkwa; Manganese mines at Nsuta; Sawmills and Bauxite Companies at Awaso. The concentration of mining operations in the basin has been a major source of surface water pollution and chemical pollution, siltation, increased faecal matter and dewatering effects have been noticed especially in Tarkwa mining areas. Cyanide is used during gold ore processing and it constitutes the major pollutant of surface water in most mining

communities (Akabzaa and Darimani, 2001). In the process of mining, huge amounts of water are discharged on the surface to facilitate the mining operation. The discharged water often contains high loads of total dissolved solids in the range of 200-860 mg/l which contaminate the surface waters. Suspended solids are also found in mine water discharge (Tiwary, 2001). Rivers could purify themselves of all pollutants that enter it. This self-purification may be interfered with, depending upon the nature and concentration of suspended solids found in them. These suspended solids diminish light penetration into the water which results in reduced photosynthetic reactions.

A heavy pollution is more likely to de-oxygenate a stream and the determination of Biochemical Oxygen Demand is necessary to assess any self- purification in this river basin (Klein *et al.* 1962). Gold mining by both opencast and underground methods affect the environment of the area and runoffs after rainfall give rise to serious pollution problems. If the ore contains high amount of pyrites the mine water may be acidic and pH values of as low as 2.0 may occur. This may pollute the nearby stream after being discharged. According to Kortatsi, (2007) gold ores in the Ankobra Basin are partly sulphidic ores. Run-off water from soils piled up during open cast mining may result in siltation of rivers. A variety of other pollutants may also be transported into waterways by runoff. There are human excreta from these mining communities which become a source of river pollution in the communities if not treated properly before discharge; such water may be contaminated with suspended solids and organic matter also (Tiwary, 2001). It is a common practice for people living along the river catchments to discharge their domestic waste as well as human excreta into rivers. Wild and domestic animals using some drinking water can also contaminate the water through direct defaecation and

urination (Karikari and Ansa-Asare, 2001). Freshwaters polluted by faecal discharges from humans and animals may carry a variety of human pathogenic micro-organisms such as viruses, bacteria, protozoa etc.

Although the total amount of water on earth is generally assumed to remain virtually constant (Seckler *et al.* 1998), the rapid growth of population together with increase of industrial development are taking a heavy toll of the quality and quantity of the available water. Consequently, a consistent policy for rational management of water resources currently and in the near future must be formulated. This management policy must be based on sound scientific data and evidence.

The Ankobra river basin has not been extensively studied and information on the extent to which the various parts of the basin are polluted by anthropogenic activities is necessary because pollutants from the tributaries could affect the quality of the main river. The objective of this project was therefore to assess the extent to which the various parts of the Ankobra Basin have been polluted. Therefore, the study was designed to:

(i) Evaluate the levels of pH, conductivity, TDS, TSS, BOD, turbidity and cyanide content of the water.

(ii) Isolate and enumerate the total and faecal coliforms in the water samples.

(iii) Determine if the anthropogenic activities have influenced the pollution of the river Ankobra.

(iv) Assess the self–purification ability of the river Ankobra.

(v) Assess the influence of the tributaries on the quality of water in river Ankobra.

(vi) Delimit various parts of the Basin into similar water quality levels and assess areas with quality problem.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 SURFACE WATER

The earth's water resources, the 'hydrosphere', consists of the oceans and seas, the ice and snow of the polar regions and mountain glaciers, the water in surface soils and underground strata, and the water in lakes, rivers, and streams. Less than 1% of these resources consist of freshwater; some 2% is freshwater ice and the remaining 97% or so consists of seawater and sea ice (Fish, 1995; Seckler *et al.* 1998). Water comes in the form of precipitation. It is evaporated from the ocean, condenses to form clouds, and precipitates over land. Once rain falls it either evaporates or seeps into the soil and flows to aquifers, or forms surface rills, streams, and eventually rivers. The slopes of a river basin concentrate surface runoff to form a river system leading into lakes or into the sea (WRI, 1992). The water running across the surface of the ground has been designated surface water. It picks up many substances as it flows back to the ocean; these include microorganisms, organic matter, minerals, and many more. Surface water collects in low areas forming lakes and ponds, and being rich in nutrients it becomes a perfect medium for the growth of all types of microorganisms. All forms of microbial life are found in surface waters (McKinney, 1962)

2.2 RIVER QUALITY SURVEY

A river begins at a source and flows by the force of gravity down to its endpoint, called the mouth (which may be another river, a lake, or an ocean). A river can be divided into three parts: the headwaters, middle sections and the lower reaches. The land area drained by a river and its tributaries is known as a river basin (WRI, 1992).

Rivers are dynamic system subjected to variation. A few locations with sufficient numbers of samples to define the results in terms of statistical significance are much more reliable than many stations with only a few samples each. During sampling in relation to source of pollution and tributaries, it is recommended that the investigator establishes a station some distance downstream from the pollutant entry point. Sampling distance should not be located below a junction of a tributary. It is better to locate the station on the main stream above the junction and to establish a secondary station on the tributary just above its mouth. Otherwise the sampling station on the main watercourse should be located sufficiently downstream to ensure dispersion through the cross-section (Nemerow, 1985).

2.3 IMPACT OF TRIBUTARIES ON MAIN STREAMS

River systems can be considered as sequences of nodes (confluences) separated by links. At each node, the tributary stream brings water and sediments into the main stream promoting hydrological, hydraulic, morphological and ecological adjustments. These contributions are especially significant where the main stream is regulated, such that understanding tributary impact is especially important for the management of regulated rivers (Schumm, 2005).

According to Mallin *et al.* (2000), a series of tests carried out found high coliform pollution concentration in tributaries draining into a creek. Visual examination of small watersheds surrounding these feeder creeks showed areas of concentrated mammal populations and wild animal dung. These were constant sources of faecal coliform pollution to the creeks. They observed that the tributary branches which drain sub-watersheds with ongoing construction projects supplied high faecal coliform concentration to the lower creek. Suburban runoff and non-point source runoff from land disturbing activities were the likely source of faecal coliform. Mallin *et al.* (2000) also observed occasional sewage spills occurring on the tributary branches.

Nwokedi *et al.* (1992) showed the extent to which the river was polluted by human activities (agriculture, urbanization and industrialization) through the major tributaries which discharge their waters into the Niger River after passing through some villages, agricultural plains, and cities. A number of industries located near the tributaries discharge their waste effluents through manmade channels. Indirectly during the rainy seasons, industrial wastes ultimately find their way into the River Niger and its tributaries. According to Topalian *et al.* (1999), elsewhere in Argentina, the quality of Reconquista River is deteriorating due to discharges of sewage and untreated effluents from factories; and the contribution of pollutants by Moron stream one of the tributaries of the Reconquista river.

2.4 SOURCES OF CONTAMINATION

If a river is turbid, or coloured, or contains visible suspended matter or has an objectionable smell, it is rightly regarded by the average person as ‘polluted’. The word ‘pollution’ is derived from the Latin word *pollutus*, which means: to soil, or to defile (Klein *et al.,* 1962).

Contamination is the impairment of water quality by sewage or industrial waste causing risk to public health. But pollution involves the introduction of anything which adversely and unreasonable impairs the beneficial use of water even though actual health risk may not be involved (Klein *et al.,* 1962).

Water resources have been the most exploited natural system since man. On the other hand, rapid population growth, increasing living standards, wide spheres of human activities and industrialization have resulted in greater demand of good quality water while on the other, pollution of water resources is increasing steadily (Paliwal, 1983).

It is part of the natural scheme of things that man should cause environmental pollution in almost all what he does. Man-made pollution of water is divided mainly into two kinds; namely point and non-point sources (Fish, 1995). Some water pollution comes from diffuse or "non-point" sources. For instance, airborne pollutants (from automobiles, factories, and power plants) and waterborne pollutants (from croplands, feed lots, logged forests, and urban areas) can contribute significantly to river basin pollution (WRI, 1992).

Apart from industrial and municipal wastes which represent specific point sources, other specific sources of pollutants are bad land-use practices leading to soil erosion, the use of agricultural chemicals to increase yields, and livestock and human waste in rural areas adding to the organic pollution of water bodies (Ogolla, 1989).

Faecal pollution of rivers largely comes from humans, animals and birds. The main faecal pollutants are: (i) coliforms (ii) faecal streptococci and (iii) miscellaneous organisms. These cause diseases such as dysentery, typhoid fever, cholera, and gastroenteritis (Paliwal, 1983).

Natural pollution of rivers may take place as a result of natural causes not necessarily associated with human activities. Pollution of this kind is generally small and intermittent, often connected with adverse weather conditions eg. heavy rain. Thus it may consist of runoff from land carrying silt, vegetable, manure, and many more. washed into the river during a storm (Klein *et al.,* 1962).

2.5 RATIONAL FOR THE USE OF INDICATOR ORGANISMS

Public and environmental health protection requires safe drinking water, which means that it must be free of pathogenic bacteria. Among the pathogens disseminated in water sources, enteric pathogens are the ones most frequently encountered. As a consequence, sources of faecal pollution in waters devoted to human activity must be strictly controlled (Laurent *et al.,* 2002).

The recognition that microbial infections can be waterborne has led to the development of methods for routine examination to ensure that water intended for human consumption is free from faecal pollution. Although it is now possible to detect the presence of many pathogens in water, the methods of isolation and enumeration are often complex and time-consuming. It is therefore impracticable to monitor water for every possible microbial pathogen that might occur with contamination (WHO, 1983). In order to control the spread of pathogenic bacteria in water, Sanitary Microbiologist must know if

the organisms are present. Since the pathogens are fastidious than the common bacteria, they are not detected by normal bacteriological techniques. Rather than look for the specific pathogens, the Microbiologist has found a group of nonpathogenic bacteria whose origin is in faecal matter, and hence is an indicator for the presence of faecal contamination; the coliform bacteria (http://www.ecy.wa.gov/biblio/94149.html).

The criteria for such an indicator are:

1. The indicator bacterium should be suitable for the analysis of all types of water: tap water, river, ground, impounded, recreational, estuary, sea, waste etc.
2. The indicator bacterium should be present whenever enteric pathogens are present.
3. The indicator bacterium should survive longer than the hardiest enteric pathogen.
4. The indicator bacterium should not reproduce in the contaminated water and produce an inflated value.
5. The assay procedure for the indicator organism(s) should have great specificity; in other words, other bacteria should not give positive results. In addition, the procedure should have high sensitivity and detect low levels of indicators.
6. The testing method should be easy to perform.
7. The indicator organism(s) should be harmless to humans.
8. The level of the indicator bacterium in contaminated water should have some direct relationship to the degree of faecal pollution.

For water quality monitoring and assessment, reliance has been placed on relatively simple and more rapid tests for the detection of faecal indicator bacteria and other coliform bacteria. These bacteria are easy to isolate and characterize, and are, almost

always, present in the faeces of humans and warm-blooded animals. The bacteriological examination of water is particularly important as it remains the most sensitive method for detecting faecal and, therefore, potentially dangerous contamination (Environmental Agency, 2002).

2.6 COLIFORM ORGANISMS (total coliforms)

Normally, faecal contamination is indicated by the presence of a group of coliforms. These organisms are a bacteria group of unknown quantity rather than a single species (Borchardt and Walton, 1971).

The coliform is nevertheless the best index to safe water and to the effectiveness of treatment and dispersion of sewage into receiving waters (Camp and Meserve, 1974). Coliform bacteria belong to the family Enterobacteriaceae and share similar cultural characteristics. Typical genera encountered in water supplies are *Citrobacter, Enterobacter, Escherichia, Hafnia, Klebsiella, Serratia* and *Yersinia*. Coliform bacteria are defined as Gram-negative, non-spore-forming, rod shaped bacteria which are capable of aerobic and facultative anaerobic growth in the presence of bile-salts or other surface-active agents with similar growth-inhibiting properties. They usually ferment lactose at 37 °C within 48 hours, possess the enzyme galactosidase and are oxidase-negative. Several members of the coliform group are known to be present in soil and other environmental materials, and are capable of growth in nutrient-rich water and biofilms. As a result, coliform bacteria are no longer considered to be specific indicators of faecal contamination (Borchardt and Walton, 1971).

Coliform organisms have long been recognized as a suitable microbial indicator of water quality, largely because these organisms are easy to detect and enumerate in water. Furthermore, coliform bacteria are derived not only from the faeces of warm-blooded animals but also from vegetation and soil. Under certain conditions, coliform organisms may also persist on nutrients derived from non-metallic construction materials. For these reasons, the presence of small numbers of coliform organisms (1-10 organisms per 100ml), particularly in untreated groundwater, may be of limited sanitary significance provided faecal coliform organisms are absent (WHO, 1983).

2.7 FAECAL COLIFORM ORGANISMS (thermotolerant)

Faecal coliform (FC) bacteria have been used as indicators of contamination by humans and other warm-blooded animals. These are coliform organisms that are able to ferment lactose at 44.0^{o}C or 44.5^{o}C; they comprise the genus *Escherichia* and to a lesser extent occasional strains of *Enterobacter, Citrobacter,* and *Klebsiella.* They are always present in the faeces of man, animals, and birds in large numbers, and rarely found in water or soil that has not been subject to faecal pollution (WHO, 1983).

Faecal coliforms are in the intestinal tract of animals and reach water bodies through faecal discharge. Identification of faecal coliform bacteria in a water body can suggest the possible presence of pathogenic organisms, which cause cholera, diarrhoea and other diseases (Ntengwe, 2006). Faecal contamination of surface waters, shallow wells and boreholes is a problem, which is largely due to a lack of proper sewage disposal facilities. Sewage, land and urban run-off and domestic waste waters are widely discharged into water bodies, particularly rivers. Pathogens associated with these discharges subsequently

become distributed through the water body, presenting a risk to communities using it for domestic activities (Davies, 1996).

Faecal coliform bacteria are the most commonly isolated organisms for identifying sewage input into streams (Mallin *et al.* 2000). Bacterial numbers increase markedly on pasture land when compared with virgin soils and faecal coliforms is found to be low in forests and higher in pasture land. Faecal coliforms were found to have been introduced into rural watersheds from adjacent pastures due to surface flushing. Point source of faecal pollution due to feed lots, watering sites and substandard septic tank system were also located. In areas of high faecal coliform count, it appears that human habitation or industrialization is the cause for the input of the majority of the faecal coliforms and in areas of low count it is most likely due to wildlife (Cowan *et al.*, 1989).

2.8 IMPACTS OF PHYSICOCHEMICAL PARAMETERS ON WATER

Water for drinking and food preparation must be free from organisms capable of causing disease and from minerals and organic substances producing adverse physiological effects (Borchardt and Walton, 1971).

The adverse effects of waste materials became acute in inland water systems due to their traditional role as receiving bodies for effluents. Simultaneously, more areas have become dependent on surface water for their water supply due to depletion of natural groundwater reserves and the difficulty in exploiting new sources. At the same time this precarious situation is not limited to inland waters since rivers carry their load of pollutants- either in dissolved, colloidal or particulate form, to oceans. In many cases harmful substances also enter the food chain and are concentrated in fish and other edible organisms particularly in near shore areas. This development gives rise to greater concern, especially at a time when serious consideration is being given to the exploitation of the oceans as future sources of proteins for the growing world population (Förstner and Wittmann, 1981). The concentration of pollutants in drinking water is very important since adults drink an average 1.5 litres/day and are therefore likely to be more rapidly affected by pollution from this route than the diet (Alloway and Aryes, 1993).

2.8.1 IMPACTS OF CYANIDE ON WATER

Cyanide (CN^-) is toxic to humans and other organisms. The discovery that gold dissolves in cyanide solution has led to the development of the hydrometallurgical process called cyanidation of gold from ore (Wang and Forssberg, 1990).

Gold has received considerable scientific and technical interest for many years because of its growing applications that demand high reliability. Several, very large gold mines have opened for production in Ghana, most of them using the recently developed heap-leaching technology. The most common leaching process for gold dissolution involves cyanidation (Wan and Miller, 1990). Barbour, (1994) described the process of cyanidation and indicated that the effluent from the process passes to the tailings dam after chemical treatment to remove organic reagents and any cyanide which may be present.

Accidental discharge of cyanide from tailings dam has occurred in many parts of the world. Some accidents such as floods, earthquakes, landslips, mud-rock flows, quality of engineering or other reasons cause the tailings dam to collapse which release cyanide into streams. The reduction of cyanide concentration in streams depends on dilution and natural decomposition. In short distance, dilution is the main reason and only for long flow distances will natural decomposition come into play. Ultraviolet radiation in sunlight plays a more important role than dissolved oxygen in the cyanide degradation process. There would be little hazard to the trunk of a river in the combined action of dilution and natural degradation even if the tailings impoundment collapsed. In most goldmine enterprises, 0.05 – 0.1% sodium cyanide solution with the help of bacterial action is used to extract gold. So cyanidation of goldmines is one of the main sources of cyanide pollution. Cyanide in surface water will form hydrogen cyanide and evaporate and will not build up in the bodies of fish (Shehong *et al.,* 2005).

2.8.2 HYDROGEN ION CONCENTRATION (pH) OF RIVERS

Acidity is the measurement of the base neutralization capacity of a volume of water. There are three types of acidity associated with pH; organic acidity associated with dissolved organic compounds and mineral acidity associated with dissolved metals (Hyo – Taek and Ji – Ho, 2000). Acid Mine Drainage is produced when pyrite (FeS_2) – rich ore are exposed to oxygen and water, primarily due to anthropogenic activities such as mining of gold. The sulphuric acid produced from the oxidation decreases the pH of water thus polluting the surrounding surface water (Barbour, 1994; Soucek *et al.*, 2000). Where sulphate deposition is highest minerogenic acidity is a more important factor affecting the acidity of a water body (Mattsson *et al.*, 2007).

Although there are natural causes, the more common concern for changes in pH of water is that discharged from industrial effluents. Substances with pH less than 7 or more than 7 are acidic and basic respectively and the pH in most natural waters ranges from 6.5 to 8.5 (www.ecy.wa.gov/biblio/94149.html). A low pH value in rivers as indicated by Morrison *et al.* (2001) could impair recreational uses of the water, affect aquatic life and decrease the solubility of certain essential elements such as selenium and increase solubility of Aluminium, Boron, Calcium, Cadmium, Mercury, Manganese and Iron.

2.8.3 EFFECT OF TURBIDITY ON RIVER WATER QUALITY

Turbidity measures the amount of light scattered from a sample (more suspended particles cause greater scattering) (www.ecy.wa.gov/biblio/94149.html). Water is normally transparent and colourless, but the environmental water that we see is turbid in many cases. Turbidity is divided broadly into the following, turbidity from soil particles,

turbidity by organic pollutants drained from homes and factories, and turbidity caused by the growth of phytoplankton occurring in the stagnant water such as lakes and wetlands. Many cases of turbidity from soil particles are attributed to soil erosion, and are closely related to the destruction of forests (Kawashima, 1997). High turbidity, apart from seriously detracting aesthetic characteristics of water, may render the water unsuitable for domestic, industrial, agricultural and recreational uses. Excessive turbidity in water causes water purification problems with processes such as flocculation and filtration. Elevated turbidities are often associated with the possibility of microbiological contamination, as high turbidity makes it difficult to disinfect water properly (Fatoki *et al.*, 2001).

As a rule, when sewage is continuously discharge into a river, turbidity levels increase and this affect the water quality of the river. The degree of turbidity of stream water is, therefore, often taken to be an approximate measure of the intensity of the pollution. Indeed measurement of turbidity of rivers can be used to evaluate the effects of pollution by waste waters and even to follow the course of self-purification of streams (Klein *et al.*, 1962).

2.8.4 CONDUCTIVITY AS AN INDICATOR OF SALINITY IN RIVERS

Conductivity is a measure of the ability of water to conduct an electric current. It is sensitive to variations of dissolved solids mostly mineral salts, and is also affected by temperature. The warmer the water, the higher the conductivity and for this reason conductivity is reported as conductivity at 25^{o}C. It is used to judge presence of metals. A high conductivity value indicates a high level of metals. The high conductivities could be

attributed to high mineral salt concentration which comes from the dissolution of minerals in the soil or by run – off from dumps at the source of the stream or by effluent discharges into the stream. The presence of inorganic compounds makes water to exhibit high conductivities (Ntengwe, 2006).

High salt concentration in waste effluents can increase the salinity of the receiving water, which may result in adverse ecological effects on aquatic biota. Very high salt concentration (>1000 mg/l) imparts a brackish salty taste to water and this causes health risk. For this reason electrical conductivity can serve as a useful salinity indicator when considered with other factors and when a natural geological origin does not apply in terms of the source of dissolved salts (Morrison *et al.,* 2001). Barnes *et al.* (2002) indicated that, concentration of dissolved salts of a single body of water varies systematically with evaporation (causing increased conductivity) or rainfall (causing decreased conductivity).

2.8.5 EFFECT OF TOTAL SUSPENDED SOLIDS ON WATER QUALITY OF RIVERS

Inorganic solids such as clay and silt constitute total suspended solids (TSS). Total suspended solids are particles of different materials that remain suspended in water. Water with high TSS value is unacceptable to human beings and reduces the growth rate of fish. The TSS also provides adsorption sites for chemicals and biological agents. It is related to turbidity in that if TSS is high, turbidity will also be high (Ntengwe, 2006).

As levels of TSS increase, a water body begins to lose its ability to support diversity of aquatic life. Suspended solids absorb heat from sunlight, which increases water temperature and subsequently decreases levels of dissolved oxygen (warmer water holds

less oxygen than cooler water). Photosynthesis also decreases, since less light penetrates the water. As less oxygen is produced by plants and algae, there is a further drop in dissolved oxygen levels. TSS can also destroy fish habitat because suspended solids settle to the bottom and can eventually blanket the river bed. Suspended solids can smother the eggs of fish and aquatic insects, and can suffocate newly-hatched insect larvae. Suspended solids can also harm fish directly by clogging gills, reducing growth rates, and lowering resistance to disease. Changes to the aquatic environment may result in diminished food sources, and increased difficulties in finding food. Natural movements and migrations of aquatic populations may be disrupted (Carlson, 2005). TSS and turbidity values vary naturally for two main reasons – one physical, the other biological. Heavy rains and fast-moving water are erosive. They can pick up and carry enough dirt and debris to make any stream look dirty. So, heavy rainfall may cause higher TSS concentrations or turbidity, unless the additional particles are dispersed throughout large volumes of flood water. The native soils and geology of the watershed of course determine how easily erosion occurs (www.ecy.wa.gov/biblio/94149.html).

2.8.6 TOTAL DISSOLVED SOLIDS AS A MEASURE OF WATER QUALITY

The total dissolved solids (TDS) in water comprise inorganic salts and small amounts of organic matter which could be filtered through a sieve of mesh size 2µm. The principal ions contributing to TDS are carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium. The total dissolved solids originate from natural sources, sewage effluent discharges, urban run-off, or industrial waste discharges (Ntengwe, 2006).

According to Davies, (1996) bouts of heavy rainfall and the consequent rapid erosion of soil and leaching of associated bedrock can dramatically raise the dissolved solids content. A high TDS as indicated by Ntengwe, (2006) has a high concentration of mineral salts which is not good for human consumption. Increased levels of dissolved solids also result in reduction of dissolved oxygen in water and fish die of sudden lowering of oxygen in streams/ rivers. Carlson, (2005) noted that, the amount of dissolved material in a sample correlates to electrical conductivity.

2.8.7 BIOCHEMICAL OXYGEN DEMAND IN RIVERS

The biochemical oxygen demand (BOD) is an approximate measure of the amount of degradable organic matter in water. It is defined as the amount of oxygen required by aerobic micro-organisms to oxidize the organic matter to stable inorganic form (Ntengwe, 2006). When the river basin is covered with rainforest, that is, a big reservoir of plant and animal wastes in substantial quantity, this can account for large amounts of organic matter in a river and high values of BOD (Tian *et al.*, 1995).

Most of the organic compounds and materials can be broken down by micro-organisms present in river water, and dissolved oxygen is used up in these biochemical reactions. If the organic pollution load is small and the dilution by well oxygenated stream water is high, sufficient dissolved oxygen (DO) may be present to enable certain bacteria, thus aerobic bacteria which require free oxygen, to break down the organic matter completely to relatively harmless, stable and odourless end products. The river thus recovers naturally from the effects of pollution and is said to have undergone ‘self-purification’ (Klein, 1962).

Typical BOD values are <3mg/l for class 1A rivers in the UK (the least polluted class), <5mg/l for class 1B, < 9mg/l for class 2 (more polluted and only suitable for portable supply after advanced treatment) and < 17mg/l for class 3 (poor quality water with few fish present) (Alloway and Aryes, 1993).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of study sites

The study was carried out on the River Ankobra and its major tributaries namely: Mansi, Bonsa and Fure, all within Prestea and its environs (Fig.1).

The nine sampling sites with their location, codes, name of tributary/river and GPS readings are presented in Table 1.

Table 1 Main Sampling Sites at Ankobra River and its major tributaries

Location and Codes	Tributary/River	GPS reading
Beposo (MU)	upstream of Mansi-Ankobra Confluence	5°29.582N 2°06.324W
Beposo (MT)	Mansi tributary	5°29.523N 2°06.284W
Beposo (MD)	downstream of Mansi-Ankobra Confluence	5°29.515N 2°06.389W
Adadekrom (BU)	upstream of Bonsa-Ankobra Confluence	5°16.319N 2°09.072W
Adadekrom (BT)	Bonsa tributary	5°16.191N 2°09.119W
Adadekrom (BD)	downstream of Bonsa-Ankobra Confluence	5°16.251 N 2°09.221 W
Mehame (FU)	upstream of Fure-Ankobra Confluence	5°15.137N 2°11.790W
Mehame (FT)	Fure tributary	5°16.222N 2°09.821W
Mehame (FD)	downstream of Fure-Ankobra Confluence	5°14.890N 2°11.757W

Field Survey: 29/04/07 with a Garmin hand-held GPS

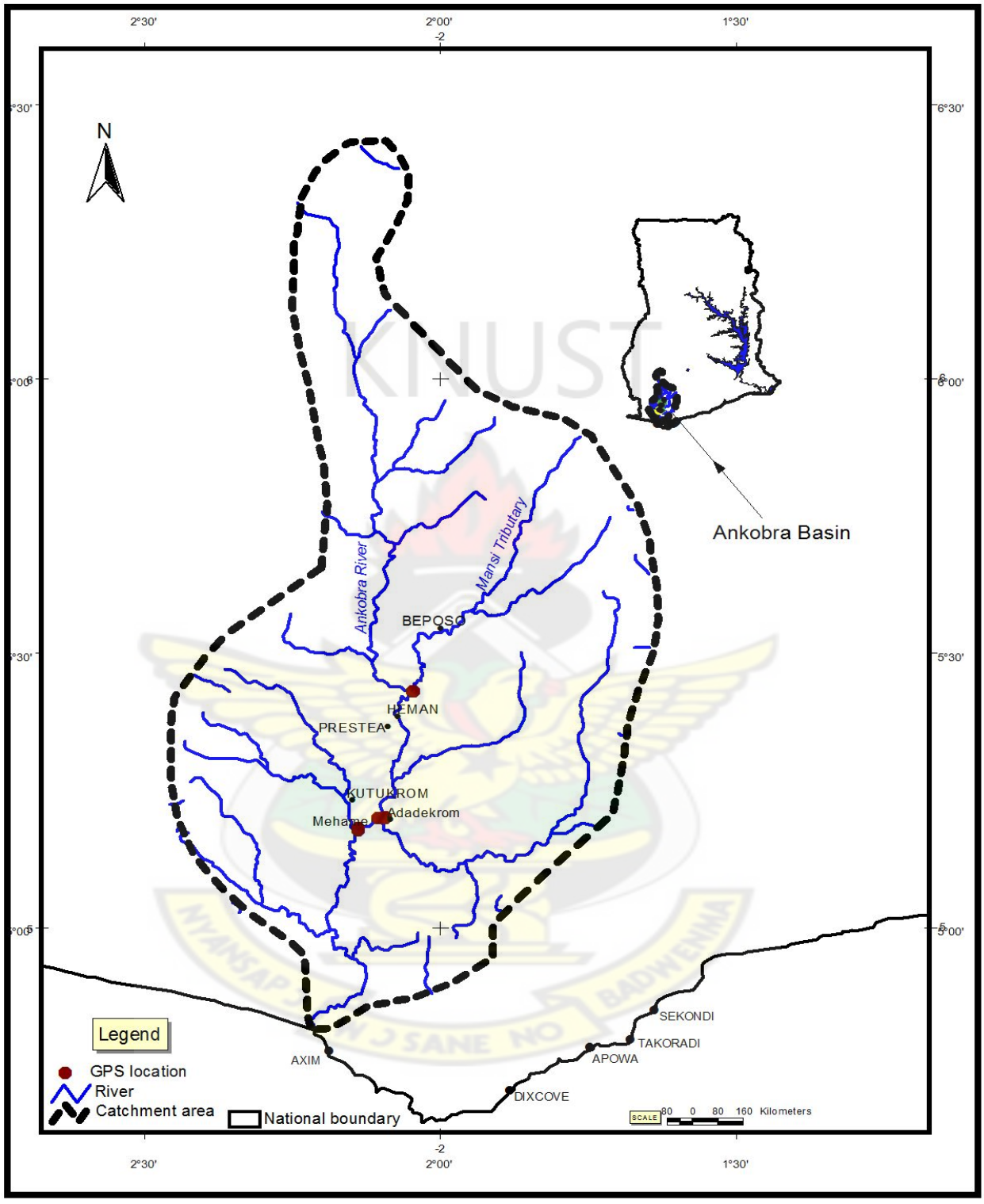

Fig 1 Map of the Ankobra Basin showing the major tributaries and sampling areas
Insert: Map of Ghana showing the Ankobra Basin

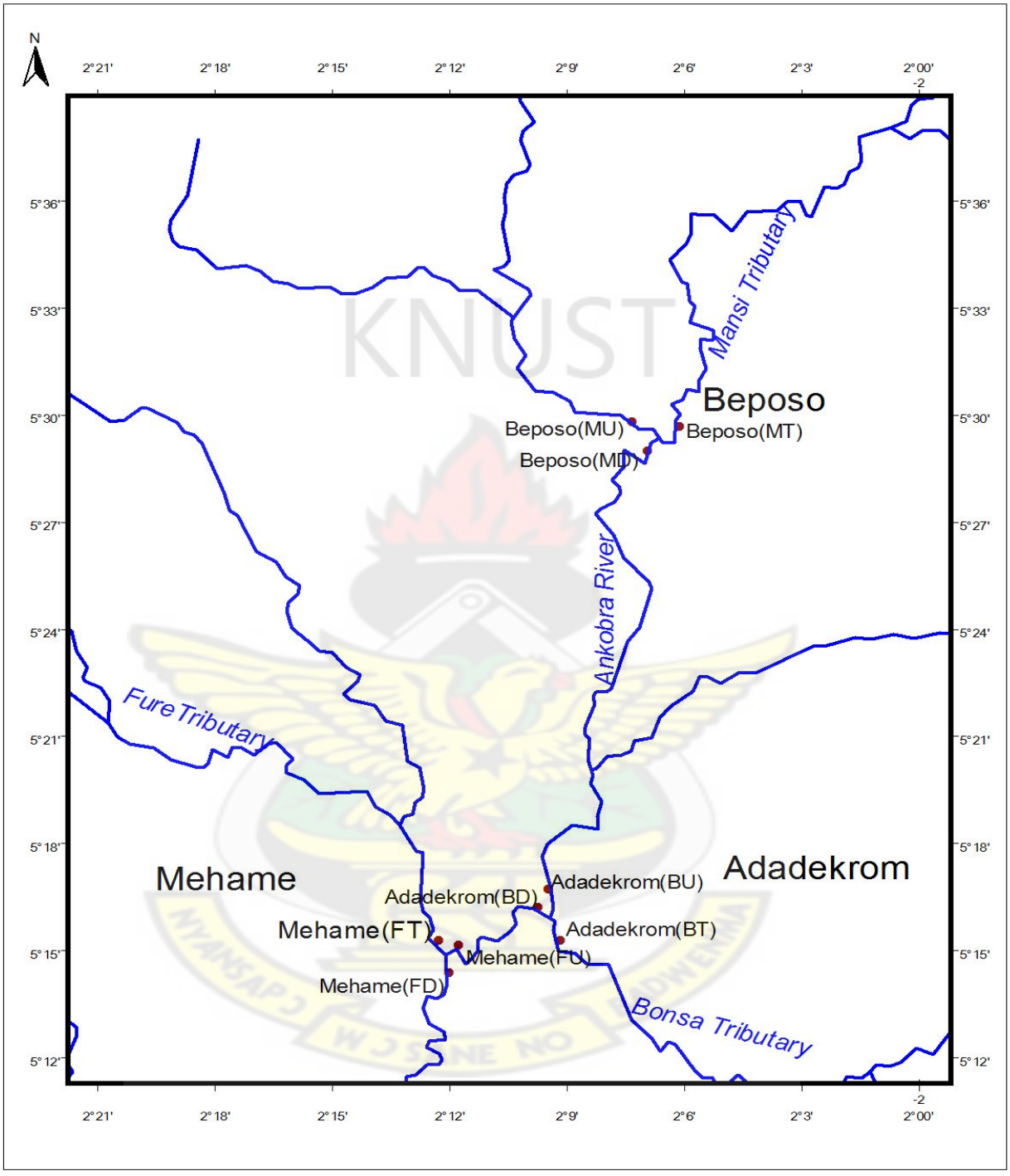

Fig 2 Map of the Ankobra River showing the major tributaries and sampling points

Sampling points (Figure 2) on the tributaries (Mansi, Bonsa and Fure) were located 50 metres before their mouths join the main river. Those sampling sites on the Ankobra river were located 70 metre before the water flows into the confluence (MU, BU and FU) and 150 metres after the water flows out of the confluence (MD, BD and FD).

3.2 Geology of the Ankobra Basin

The soil of the study area is underlain by metamorphosed sedimentary rocks and granites of the Birimian (middle Pre-Cambian) system with isolated basic intrusive rocks (WRRI, 2003). In addition a narrow belt of sedimentary rocks referred to as the Tarkwaian (upper pre-Cambian) system is present in the valleys of the River Ankobra. Rocks of the Tarkwaian system consist of a thick series of shaly and sandy sediments, conglomerates, and phyllites which are younger than the Birimian rocks. The Tarkwaian rocks extend from the Tarkwa- Prestea area to the Konongo area.

3.3 Description of sampling area

The Ankobra River is approximately 222 km and has a catchment area of 8,366 km^2 with an annual rainfall between 1520-2200 mm (WRRI, 2003). The major rainy season occurs around May-August and a minor one in September-October. The river Ankobra takes its source from Bibiani Hills at 368 m above sea level in the Sefwi Bekwai District. The principal tributaries of river Ankobra are Mansi, Bonsa, Fure and Nhwini rivers. The Ankobra Basin lies deeply to the forest ecological zone of Ghana; a Semi-deciduous forest lies in the north of the basin and the main forest zone is to the south. The principal soil type is the forest ochrosols (WRRI, 2003).

The population in the study area is sparse except in the mining communities, where the people are employed in mining companies, and the rest engaged in illegal mining activities (galamsey), farming and petty trading. There are a few ephemeral streams in the area such as Asuokofie, Asesere, Subri, Mesamesa and others, which are utilized by natives further away from the river Ankobra for domestic activities. In the dry season, particularly from the months of November to April, most inhabitants resort to the use of the water in the River Ankobra and its principal tributaries. The River Ankobra and its tributaries lie within valleys, hence serve as a sink for pollutants from mining industries, farms and towns with poor sanitary facilities during rainfall (Osafo, 1989).

3.4 Materials for isolation of Coliforms

3.4.1 Preparation of MaConkey broth

40g of MaConkey powder was poured on an aluminum foil and weighed. This was poured into a 1000ml beaker and distilled water added and stirred to the mark. Thirty (30) column test-tube racks were filled with test-tubes. A 50ml syringe was used to pull the prepared MaConkey broth in beaker and 5ml of the broth was poured into each test-tube. The test-tubes were firmly corked using a clean cotton wool. In addition 10ml of distilled water were also poured into a different set of test-tubes and corked to serve as diluents.

3.4.2 Autoclave

The corked test-tubes containing the 5ml MaConkey broth were removed from the racks and arranged vertically in autoclave baskets. The baskets were filled with the corked test-tubes and sets of 1ml pipette tips and placed in the autoclave. The autoclave had water poured into it and heated to a temperature of 121°C and a pressure of 1.5 kg/m^2.

3.4.3 Incubators

Two Gallenkamp Plus II Incubators were used to incubate the tubes after inoculation. One of the incubators was set at 37°C for the isolation of total coliforms and the other set at 44.5°C for faecal coliform isolation.

3.5 Cleaning of sampling containers

Transparent and opaque (amber) plastic bottles used for the determination of the physico-chemical parameters were washed with a detergent OMO® (washing powder) solution under running water and finally rinsed with distilled water. The bottles were made to dry by using air from a blower. Pre-cleaned transparent plastic bottles were used as sampling containers for determination of the coliforms.

3.6 Sampling Methods

3.6.1 Sampling

Monthly water samples were collected from river Ankobra and three (3) of the principal tributaries namely: Mansi, Bonsa and Fure from November, 2006 to April 2007. The sampling period was designed to cover the dry season in order to have easy access to the sampling sites. In addition most inhabitants resort to the use of the river Ankobra in the dry season when the ephemeral streams formed during the rainy season are dried up.

3.6.2 Sample collection

Water samples were collected in the middle of the river and where the middle of the river could not be reached unaided, canoes were used. Prior to sampling the sampling

containers were rinsed with water from the river. The samples were collected downstream and then upstream before sampling the tributary. When using the canoe the samples where collected upstream of the canoe by lowering the containers under the water surface with its neck facing upstream.

When stepping into the water, rubber boots were worn for personal protection. The sediments were allowed to settle prior to sampling. The sample containers where lowered into the water without disturbing the sediment. The necks of the containers were directed upstream. The containers were filled and capped under the surface of the water. Water samples for microbiological analysis were sampled first and those containers for BOD determinations were filled to the brim and tightly capped to exclude the entering of air. The sample containers were wiped dry with clean towels, labeled and placed on ice in an ice chest.

Duplicate samples were collected in sterilized transparent bottles for all the parameters but cyanide was collected in sterilized opaque bottles. Water samples were transported to the laboratory and analyses were performed within 12 hours.

3.7 Procedures

3.7.1 Isolation and enumeration of Total Coliforms

Total Coliforms were estimated using a three-tube Most Probable Number (MPN) method. Serial dilutions of water samples from 10^{-1} to 10^{-9} were prepared in sterilized distilled water and 1ml aliquots from each of the dilutions were inoculated in triplicates into 5ml MaConkey broth. The tubes were incubated at 37^{o}C for 24 h and the tubes which showed colour change due to acid production were positive for total coliforms.

3.7.2 Isolation and enumeration of Faecal Coliforms

Faecal Coliforms were estimated using a three-tube Most Probable Number (MPN) method. Serial dilutions of water samples from 10^{-1} to 10^{-9} were prepared in sterilized distilled water and 1ml aliquots from each of the dilutions were inoculated in triplicates into 5ml MaConkey broth. The tubes were incubated at 44.5^{o}C for 24 h and those tubes with acid production causing a change in colour of the media were positive for faecal coliforms. The number of coliforms per 100ml was calculated from most probable number (MPN) table.

3.7.3 Determination of pH, Conductivity, Total Dissolved Solids and Turbidity

Turbidity was determined on the field, using a Cyberscan IR TB 100 Turbidimeter with two cuvette bottles. The Turbidimeter was calibrated in the laboratory with the 1000 NTU, 100 NTU, 10 NTU, and 0.02 NTU calibration standards. The cuvette bottles were opened and rinsed three times with the river water before sampling. The bottles were closed and all the outside surfaces were cleaned and made dry. The cuvette bottle was pushed firmly into the optical well in the turbidimeter and index to the lowest reading. The NTU values were measured by pressing and releasing the arrow button on the turbidimeter and the value was recorded after the display on the screen was not flashing.

Conductivity and TDS were determined in the laboratory using the Hanna instrument HI 9032 microcomputer conductivity meter. The conductivity meter was calibrated by using a reference buffer of 12880 µS/cm. The water sample was poured into a beaker and the electrode of the conductivity meter was lowered into the sample. The conductivity of the sample was displayed on the LCD and the value was recorded. Total Dissolved Solids

were also measured using the conductivity meter by selecting the TDS key and the values displayed on the LCD were recorded.

The pH of the water sample was also determined in the laboratory. The pH meter was calibrated by immersing the electrode in a buffer solution of pH 4 and 7 prepared from capsules of BDH buffer and on each occasion adjusting the pH meter reading to correspond to the standard buffers. The water sample was placed in a beaker and the electrode was rinsed with distilled water and lowered into the sample in the beaker. The pH knob of the Yokogawa model pH82, pH meter was selected, and allowed to stabilize before the pH of the sample was read.

3.7.4 Determination of Total Suspended Solids (TSS)

A cellulose nitrate membrane filter with pore size 0.45 µm was placed on the Teflon-faced glass filter holder and wetted by filtering about 20ml distilled water using the Millipore vacuum filtration. This process was used to open the pores of the filter paper. The wet filter paper was removed carefully using a pair of a stainless steel or plastic forceps and placed on a watch glass. The watch glass and its contents were put in a Memmert electric Oven at 103 to 105^{o}C for 15 minutes to dry. The filter paper together with the watch glass were removed from the oven and placed in a desiccator for about 1 h to cool. The filter paper was marked and weighed on a BDH analytical balance, and its weight recorded (W1).

The test sample was shaken to obtain a homogenous mixture, and thereafter, a reasonable quantity was measured in a graduated glass cylinder. The volume of the sample was recorded and the procedure used to obtain W1 was repeated.

The membrane filter and the residue was removed and dried at 103 to 105^{o}C for 20 minutes. Drying was repeated until constant weight was achieved (W2).

3.7.4.1 Calculation

$$mgTSS/L = \frac{(W2-W1)\times 10^{6}}{Vs}$$

Where

W1 = weight of the filter paper only, in grams

W2 = weight of the filter paper and solids, in grams

Vs = volume of test sample, in mL.

3.7.5 Determination of free cyanide in water

3.7.5.1 Colorimetric Method

The Micro quant 14798 CN test kit with a detection range of 0.03 – 5ppm designed by Merck was used in determining the concentration of cyanide by matching the colours using a comparator.

A standard solution containing 5ppm of cyanide freshly prepared by taking 2ml from a 10ppm NaCN and diluted to the mark in 10ml volumetric flask was obtained.

A 10mm cuvette was filled with 6ml of the standard solution and by using the micro spoons provided in the CN kit, a spoonful of each of the reagents Chloramine-T Hydrate 98% Cyanide and followed with 1, 3 dimethyl barbiturate acid Seasure 98% cyanide were added. The cuvette was corked and shaken by turning it up and down to give a homogenous mixture. After the mixture was formed 3 drops of Pyridine was added and a period of 5 minutes was allowed for the reactions to complete. The presence of cyanide

was indicated by the presence of a pink colour, which turned blue after some few minutes.

3.7.5.2 Principle

Cyanide ion, reacts with chlorine in Chloro-T-amine with the formation of cyanogen chloride:

$$CI_2 + CN^- \rightarrow ClCN + Cl^-$$

The cyanogen chloride reacts with pyridine to form cyano-1-pyridine:

$$ClCN + C_5H_5N^- \rightarrow C_5H_5NCN + Cl^-$$

The cyano- 1-pyridine then reacts with dimethyl- 1, 3 barbituric acid to form a complex dye with red-blue colourations.

The colour produced was compared with the comparator and the concentration of cyanide was determined. Thus, for the standard solution a 5 ppm cyanide concentration was determined. Cyanide concentration in the test samples were determined by using the same quantity of water to feel the cuvette and the procedure above was repeated to obtain the concentrations of the various samples.

3.7.6 Determination of Biochemical Oxygen Demand

3.7.6.1 Winkler Method

Four BOD bottles were filled with the undiluted river water sample. 1ml of manganous sulphate solution was added to the sample in the BOD bottle followed by 1ml of Alkaline-Iodide Azide reagent. The bottle was stoppered and its content mixed by inverting it several times. Shaking was repeated when the precipitate had settled leaving a clear supernatant solution above the manganese hydroxide floc. The precipitate was allowed to settle again leaving at least 100ml clear supernatant. The stopper was carefully removed and immediately 1ml of sulphuric acid was added by allowing the acid to run down the neck of the bottle. The bottles were restoppered and contents mixed by gentle inversion until the solution was complete, with iodine uniformly distributed throughout the bottle. The Dissolved Oxygen in two of the bottles was determined by the Winkler method.

203ml of the samples in the BOD bottle was decanted and titrated with 0.025N Sodium thiosulphate to pale straw colour. About 1-2 ml of freshly prepared starch solution was added. Titration was continued to the first disappearance of the blue colour. The burette reading was recorded. The other two bottles were incubated at $20^{o}C$ for 5 days and dissolved oxygen was determined in the incubated samples on the fifth day.

3.7.6.2 Calculation

203 ml of sample used for titration = 200ml of original sample

1ml of 0.025N Na_2So_3 = 0.2 mg O_2

1mg/l = 1ml of titrant used

mg/l BOD $= \frac{DO_i - DO_f}{P}$

Where,

DO_i = Initial Dissolved Oxygen in water sample after preparation

DO_f = Final Dissolved Oxygen after incubation

P = Decimal fraction of sample used (P =1)

3.8 Statistical Analysis

Raw data of microbiological analysis were converted to Log_{10} after Geomean was calculated. Differences between sampling sites and within period of sampling (months) were determined using Analysis of Variance (ANOVA) using data analysis in Microsoft Excel 2003. Comparison of each parameter level between the upstream of Mansi – Ankobra confluence and down stream of Fure – Ankobra confluence to assess the self – purification of the river was made using paired *t*- test. Additionally, each parameter level at both the up and down streams of the confluence formed by the Ankobra river and its tributaries, were compared using paired *t*- test. The results were used to assess the influence of the tributaries on the River Ankobra.

The SPSS version 11.0 was used to run hierarchical cluster on the water chemistry data. The hierarchical cluster analysis, which groups similar cases based on measured variables, provided a preliminary sampling grouping in the form of a dendogram (Shrestha and Kazama, 2007).

CHAPTER FOUR

4.0 RESULTS

4.1 Sampling Results (Mean Values)

Total and Faecal coliforms and some physicochemical parameters such as pH, Conductivity, Total Dissolved and Suspended Solids, Biochemical Oxygen Demand, Turbidity and Cyanide were determined in all water samples from the nine sampling sites throughout the study period. The mean values of Hydrogen ion concentration (pH), Conductivity (µS/cm), Total Dissolved Solids (mg/l), Total Suspended Solids (mg/l), free Cyanide (mg/l), and Biochemical Oxygen Demand (mg/l), as well as Turbidity (NTU), Total and Faecal coliforms numbers (Geomean /100ml) in river Ankobra and its major tributaries were compared with WHO drinking water guidelines as shown in Figures 3-10.

4.1.1 pH levels at the sampling sites

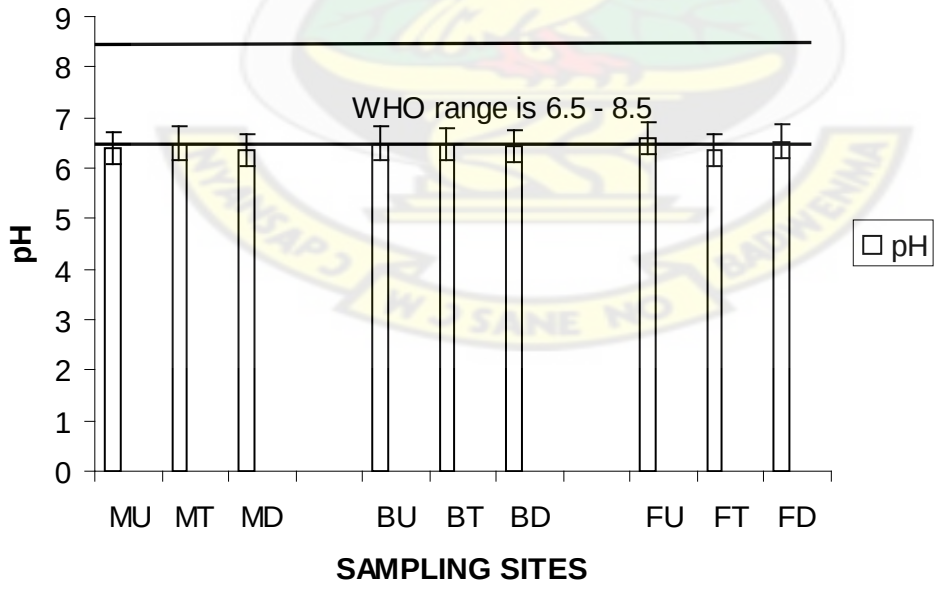

Fig. 3 pH levels in River Ankobra and its major tributaries

As shown in Figure 3 above, the pH levels at both the up and down streams of Mansi-Ankobra confluence (MU and MD) and Bonsa-Ankobra confluence (BU and BD) were pH 6.4, 6.35, 6.49 and 6.44 respectively, with the tributaries; Mansi (MT), Bonsa (BT), and Fure (FT) recording 6.49, 6.47 and 6.34 respectively. These pH levels were all below the minimum WHO drinking water guideline range of 6.5-8.5 units. Fure tributary (FT) recorded the lowest mean pH level of 6.34 and the upstream of Fure-Ankobra confluence (FU) recorded the highest mean pH level of 6.59. Both the up and down streams of Fure–Ankobra confluence (FU and FD) with 6.59 and 6.53 pH units respectively met the minimum WHO drinking water guideline range.

The mean pH levels between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD) were significantly different (P=0.04). This significant difference shows that the Ankobra river was able to dilute the hydrogen ions concentrated (pH= 6.4) at the upstream of Mansi-Ankobra confluence to a higher pH of 6.53 at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the pH levels of the tributaries to the main river. The tributaries could not significantly change (P> 0.05) the pH levels in the Ankobra River. The mean pH level at Mansi tributary (MT) was not significantly different from the pH levels at both the upstream (P= 0.2) and downstream (P= 0.13) of Mansi–Ankobra confluence (MU and MD). There was no significant difference (P= 0.2) in mean pH levels between the up and down streams of Mansi-Ankobra confluence (MU and MD). Similarly, the mean pH level at Bonsa tributary (BT) was not significantly different from the pH levels at both the upstream (P= 0.37) and downstream (P= 0.34) of Bonsa–Ankobra confluence (BU and BD). There was

also no significant difference (P= 0.06) between the up and down streams of Bonsa-Ankobra confluence (BU and BD). On the contrary, the mean pH levels at Fure tributary (FT) was significantly lower than the levels at the upstream (P= 0.000) and downstream (P= 0.001) of Fure–Ankobra confluence (FU and FD). However, there was no difference (P= 0.09) in mean pH levels between the up and down streams of Fure–Ankobra confluence (FU and FD).

4.1.2 Conductivity levels at the sampling sites

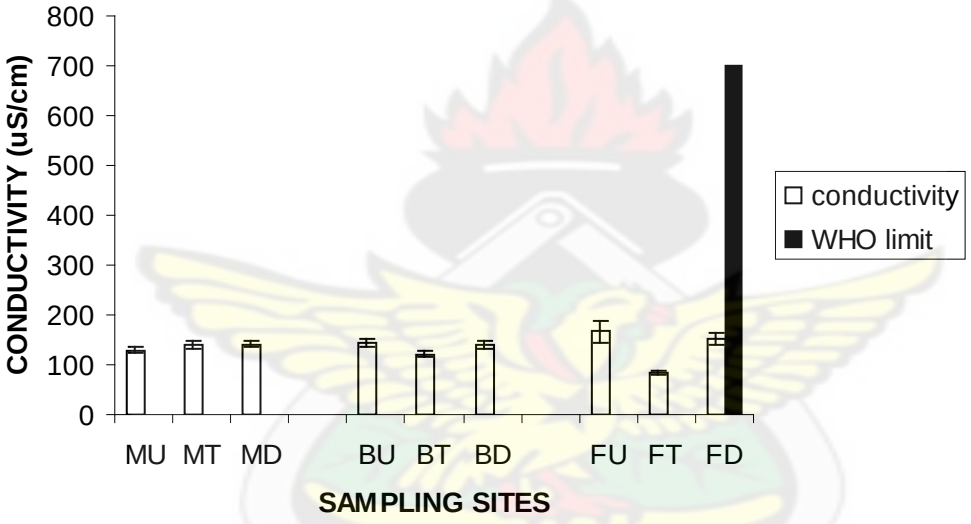

Fig. 4 Conductivity levels in River Ankobra and its major Tributaries

Figure 4 shows that the Conductivity levels at both the up and down streams of Mansi-Ankobra confluence (MU and MD) and Bonsa-Ankobra confluence (BU and BD) were 129.20, 140.09, 144.58 and 139.10 µS/cm respectively. The upstream and downstream of Fure–Ankobra confluence (FU and FD) recorded 167.19 and 151.78 µS/cm respectively with the tributaries; Mansi (MT), Bonsa (BT) and Fure (FT) recording conductivity levels of 140.58, 121.78 and 84.73 µS/cm. Among the sampling sites, Fure tributary (FT) recorded the lowest mean Conductivity level of 84.73 µS/cm and the upstream of Fure -

Ankobra confluence (FU) recorded the highest mean Conductivity level of 167.19 µS/cm. The conductivity levels in the sampling sites were below the WHO drinking water guideline limit of 700 µS/cm.

The mean conductivity levels between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD) were significantly different (P=0.005). This significant difference shows that dissolved solids in the Ankobra River increased from a low conductivity level of 129.2 µS/cm at the upstream of Mansi-Ankobra confluence to a high conductivity level of 151.78 µS/cm at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the conductivity levels of the tributaries to the main river. Bonsa and Fure tributaries could not significantly change (P> 0.05) the conductivity levels in the Ankobra River. The mean conductivity levels at Mansi tributary (MT) was not significantly different from the conductivity levels at both the upstream (P= 0.1) and downstream (P= 0.46) of Mansi–Ankobra confluence (MU and MD). There was significant increase (P= 0.002) in mean conductivity levels between the up and down streams of Mansi-Ankobra confluence (MU and MD). The mean conductivity level at Bonsa tributary (BT) was lower than both upstream (P= 0.017) and downstream (P= 0.04) of Bonsa–Ankobra confluence (BU and BD). There was a significant decrease (P= 0.000) in mean conductivity levels between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The mean conductivity levels at Fure tributary (FT) is significantly lower than the levels in the upstream (P= 0.001) and downstream (P= 0.000) of Fure – Ankobra confluence (FU and

FD). However there was no significant difference (P= 0.08) in the mean conductivity levels between the up and down streams of Fure–Ankobra confluence (FU and FD).

4.1.3 Total Dissolved Solids levels at the sampling site

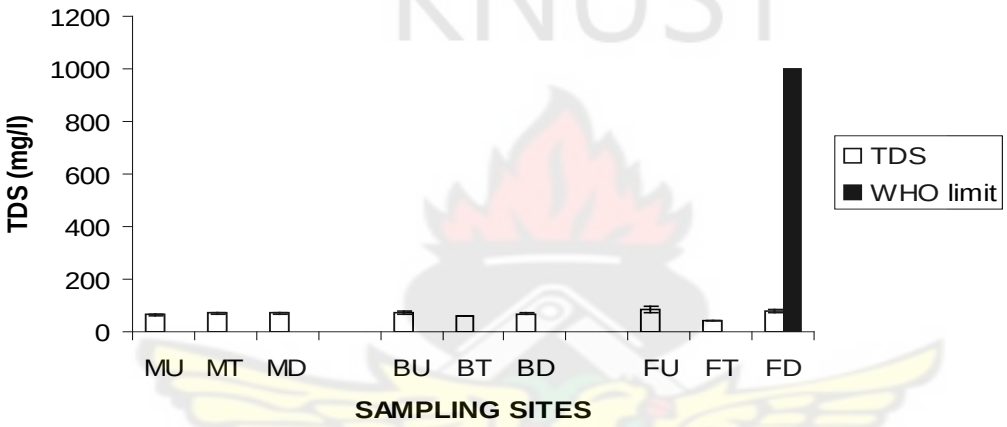

Fig. 5 Total Dissolved Solids levels in River Ankobra and its major Tributaries

Figure 5 shows that TDS levels at both the up and down streams of Mansi-Ankobra confluence (MU and MD) and Bonsa-Ankobra confluence (BU and BD) were 64.58, 70.04, 72.42 and 69.62 mg/l respectively. The up and down streams of Fure-Ankobra confluence (FU and FD) recorded mean TDS levels of 83.61and 75.79 mg/l respectively, with the tributaries; Mansi (MT), Bonsa (BT), and Fure (FT) recording 70.49, 60.99 and 42.35 mg/l respectively. Fure tributary (FT) recorded the lowest mean TDS level of 42.35 mg/l and the upstream of Fure-Ankobra confluence (FU) recorded the highest mean TDS level of 83.61 mg/l. All the sampling sites had TDS concentrations lower than the WHO drinking water guideline limit of 1000 mg/l.

The mean TDS levels between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD) were significantly different (P=0.005). This significant difference shows that dissolved solids in the Ankobra River increased from a TDS level of 64.58 mg/l at the upstream of Mansi-Ankobra confluence to TDS level of 75.79 mg/l at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the TDS levels of the tributaries to the main river. Fure tributary could not significantly change (P> 0.05) the TDS levels in the Ankobra River. The mean TDS levels at Mansi tributary (MT) was not significantly different from the TDS levels at both the upstream (P= 0.1) and downstream (P= 0.46) of Mansi–Ankobra confluence (MU and MD). There was a significant increase (P= 0.002) in mean TDS levels between the up and down streams of Mansi-Ankobra confluence (MU and MD). The mean TDS level of Bonsa tributary (BT) is lower than both upstream (P= 0.017) and downstream (P= 0.04) of Bonsa–Ankobra confluence (BU and BD). There was a significant decrease (P= 0.000) in mean TDS levels between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The mean TDS levels at Fure tributary (FT) is significantly lower than the levels in the upstream (P= 0.001) and downstream (P= 0.000) of Fure–Ankobra confluence (FU and FD). However there was no significant difference (P= 0.08) in the mean TDS levels between the up and down streams of Fure–Ankobra confluence (FU and FD).

4.1.4 Total Suspended Solids levels at the sampling site

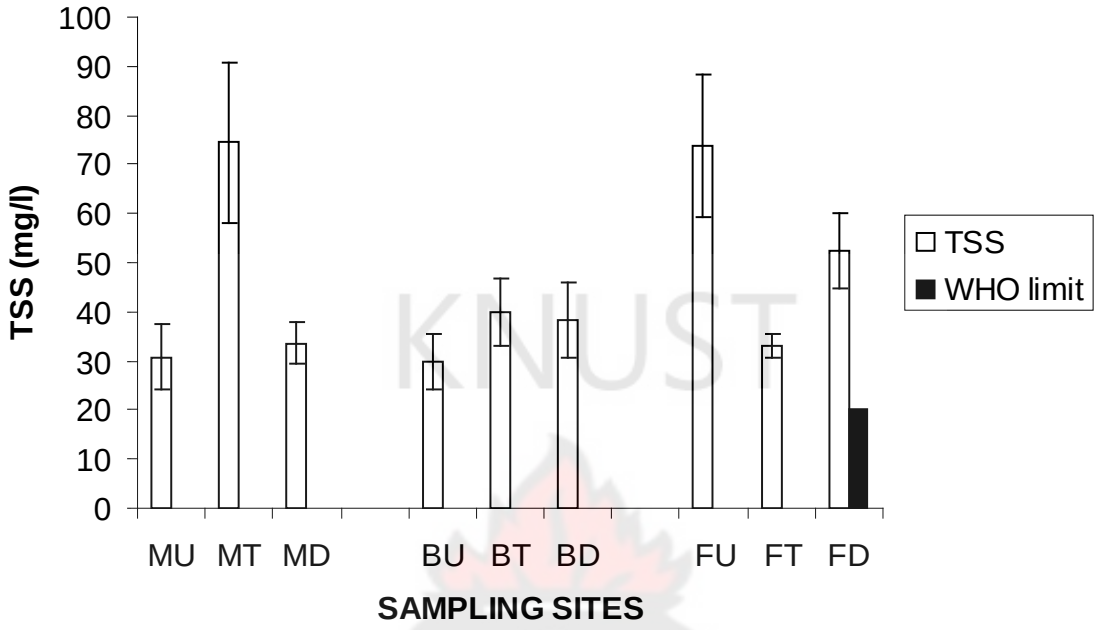

Fig. 6 Total Suspended Solids levels in River Ankobra and its major Tributaries

Figure 6 indicates that TSS levels at both up and down streams of Mansi-Ankobra confluence (MU and MD) and Bonsa-Ankobra confluence (BU and BD) were 30.75, 33.58, 29.75 and 38.25 mg/l respectively. The up and down streams of Fure-Ankobra confluence (FU and FD) recorded 73.75 and 52.42 mg/l respectively, with Mansi tributary (MT), Bonsa tributary (BT) and Fure tributary (FT) recording 74.58, 39.91 and 33.08 mg/l respectively. Among the sampling sites, upstream of Bonsa-Ankobra confluence (BU) recorded the lowest mean TSS level of 29.75 mg/l and Mansi tributary (MT) recorded the highest mean TSS level of 74.58 mg/l. The WHO drinking water guideline limit of 20 mg/l was exceeded by all the sampling sites.

The mean TSS levels between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD) were significantly different (P=0.01). This

significant difference shows that suspended solids in the Ankobra River increased from a TSS level of 30.75 mg/l at the upstream of Mansi-Ankobra confluence to a high TSS level of 52.42 mg/l at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the TSS levels of the tributaries to the main river. Mansi and Bonsa tributaries could not significantly change ($P > 0.05$) the TSS levels in the Ankobra River. The mean TSS levels at Mansi tributary (MT) was significantly higher than the levels in both upstream ($P = 0.01$) and downstream ($P = 0.015$) of Mansi–Ankobra confluence (MU and MD). There was no significant difference ($P = 0.29$) in mean TSS levels between the up and down streams of Mansi-Ankobra confluence (MU and MD). The mean TSS level at Bonsa tributary (BT) was not significantly different from the TSS levels at both the upstream ($P = 0.14$) and downstream ($P = 0.44$) of Bonsa–Ankobra confluence (BU and BD). There was also no significant difference ($P = 0.16$) between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The mean TSS levels of Fure tributary (FT) was significantly lower than the levels in the upstream ($P = 0.005$) and downstream ($P = 0.01$) of Fure–Ankobra confluence (FU and FD). On the contrary, the mean TSS levels between the up and down streams of Fure–Ankobra confluence (FU and FD) were significantly different ($P = 0.007$). The mean TSS levels decreased from upstream to downstream of Fure–Ankobra confluence (FU to FD).

4.1.5 Biochemical Oxygen Demand at the sampling sites

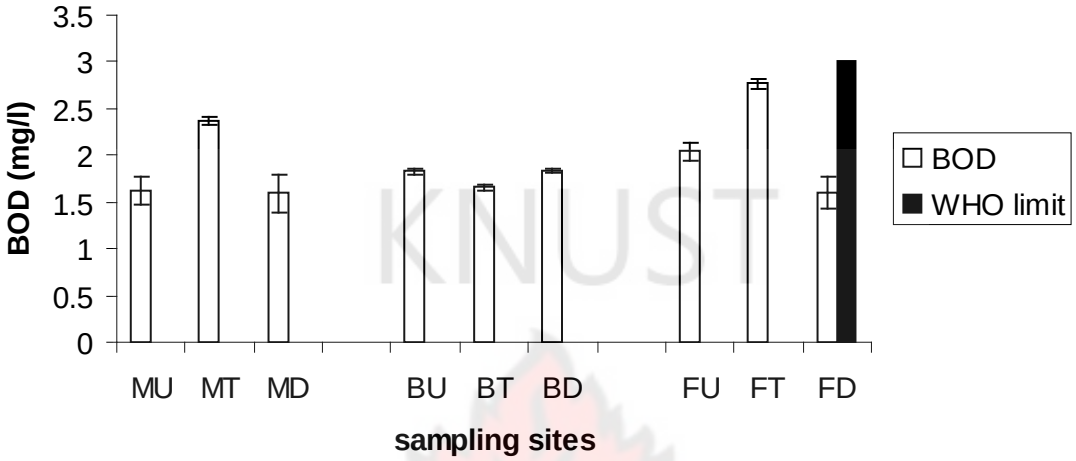

Fig. 7 Biochemical Oxygen Demand levels in River Ankobra and its major Tributaries

Figure 7 above shows that, the BOD levels at both the up and down streams of Mansi - Ankobra confluence (MU and MD) and Bonsa–Ankobra confluence (BU and BD) were 1.62, 1.59, 1.83 and 1.83 mg/l respectively. Additionally, the tributaries; Mansi (MT), Bonsa (BT) and Fure (FT) recorded BOD levels of 2.37, 1.66 and 2.77 respectively with the up and down streams of Fure–Ankobra confluence (FU and FD) recording 2.04 and 1.60 mg/l respectively. Among the sampling sites, downstream of Mansi-Ankobra confluence (MD) and Fure tributary (FT) recorded the lowest (1.59 mg/l) and highest (2.77 mg/l) mean BOD levels respectively. The oxygen demands of all the sampling sites were not much, because they met the WHO drinking water guideline limit of 3 mg/l.

The mean TSS levels between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD) were not significantly different (P=0.35). The influence of tributaries on the Ankobra River was assessed by comparing the BOD

levels of the tributaries to the main river. Mansi and Bonsa tributaries could not significantly change (P> 0.05) the BOD levels in the Ankobra River. The mean BOD levels at Mansi tributary (MT) was significantly higher than the levels in both upstream (P= 0.000) and downstream (P= 0.000) of Mansi – Ankobra confluence (MU and MD). There was no significant difference (P= 0.3) in mean BOD levels between the up and down streams of Mansi-Ankobra confluence (MU and MD). The mean BOD level of Bonsa tributary (BT) is significantly lower than the levels in both upstream (P= 0.000) and downstream (P= 0.000) of Bonsa–Ankobra confluence (BU and BD). There was no significant difference (P= 0.29) between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The mean BOD levels of Fure tributary (FT) is significantly higher than the levels in the upstream (P= 0.000) and downstream (P= 0.000) of Fure – Ankobra confluence (FU and FD). The mean BOD levels between the up and down streams of Fure–Ankobra confluence (FU and FD) are significantly different (P= 0.000). The mean BOD levels decreased from upstream to downstream of Fure–Ankobra confluence (FU to FD).

4.1.6 Turbidity levels at the sampling sites

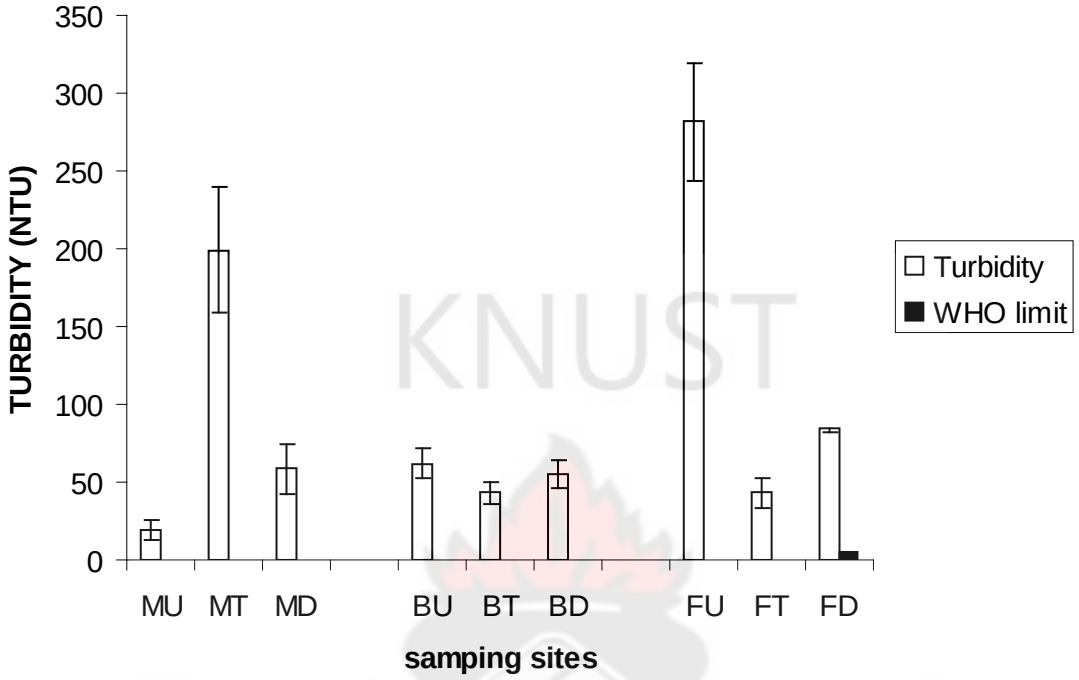

Fig. 8 Turbidity levels in River Ankobra and its major Tributaries

Figure 8 indicates that Turbidity levels at both the up and down streams of Mansi - Ankobra confluence (MU and MD) and Bonsa – Ankobra confluence (BU and BD) were 19.51, 58.35, 62.03 and 54.91 NTU respectively. The tributaries; Mansi (MT), Bonsa (BT) and Fure (FT) recorded turbidity levels of 199.35, 43.00 and 43.23 NTU respectively with the up and down streams of Fure–Ankobra confluence (FU and FD) recording 281.80 and 85.10 NTU respectively. Among the sampling sites, upstream of Mansi-Ankobra confluence (MU) recorded the lowest mean Turbidity level of 19.51 NTU and the upstream of Fure-Ankobra confluence (FU) recorded the highest mean turbidity level of 281.80 NTU. The turbidity levels in the sampling sites were above the WHO drinking water guideline limit of 5 NTU.

The mean Turbidity levels between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD) were significantly different (P=0.000). This significant difference shows that scattering and absorption of light on the Ankobra River increased from a low Turbidity level of 19.51 NTU at the upstream of Mansi-Ankobra confluence to a high Turbidity level of 85.1 NTU at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the Turbidity levels of the tributaries to the main river. Mansi, Bonsa and Fure tributaries significantly change (P< 0.05) the Turbidity levels in the Ankobra River. The mean Turbidity levels at Mansi tributary (MT) was significantly higher than the levels in both upstream (P= 0.000) and downstream (P= 0.002) of Mansi – Ankobra confluence (MU and MD). There was a significant increase (P= 0.001) in mean Turbidity levels between the up and down streams of Mansi-Ankobra confluence (MU and MD). The mean Turbidity level at Bonsa tributary (BT) was not significantly different from the Turbidity levels at both the upstream (P= 0.06) and downstream (P= 0.14) of Bonsa–Ankobra confluence (BU and BD). There was a significant decrease (P= 0.006) in mean Turbidity levels between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The mean Turbidity levels of Fure tributary (FT) were significantly lower than the levels in the upstream (P= 0.000) and downstream (P= 0.000) of Fure–Ankobra confluence (FU and FD). There was a significant difference (P= 0.000) in mean Turbidity levels between the up and down streams of Fure–Ankobra confluence (FU and FD). The mean Turbidity levels decreased from upstream to downstream of Fure – Ankobra confluence (FU to FD).

4.1.7 Total Coliform Numbers in sampling sites

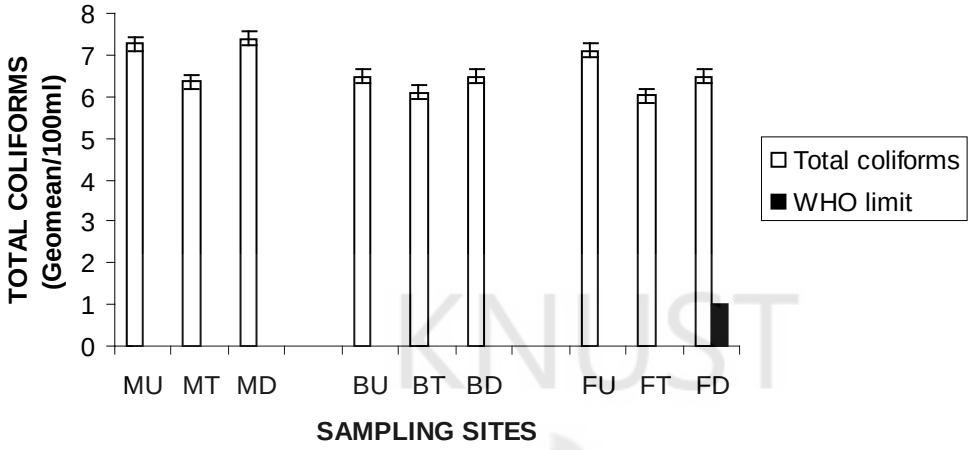

Fig. 9 Total Coliform Numbers in River Ankobra and its major Tributaries

Figure 9 shows that, the total coliform numbers at both the up and down streams of Mansi-Ankobra confluence (MU and MD) and Bonsa–Ankobra confluence (BU and BD) are 7.27, 7.40, 6.49 and 6.47 Geomean/100ml respectively. The up and down streams of Fure–Ankobra confluence (FU and FD) recorded 7.09 and 6.47 Geomean/100ml respectively with the tributaries; Mansi (MT), Bonsa (BT) and Fure (FT) recording total coliform numbers of 6.36, 6.09 and 6.02 Geomean/100ml respectively. Among the sampling sites, Fure tributary (FT) recorded the lowest total coliform numbers of 6.02 Geomean/100ml and downstream of Mansi-Ankobra confluence (MD) recorded the highest total coliform numbers of 7.4 Geomean/100ml. All the sampling sites did not meet the WHO drinking water guideline of 1.00 Geomean/100ml.

There was a significant difference (P=0.000) in Geomean of total coliform numbers between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD). This significant difference shows that total coliforms in the

Ankobra River decreased from 7.27 Geomean/100ml at the upstream of Mansi-Ankobra confluence to 6.47 Geomean/100ml at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the total coliform numbers of the tributaries to the main river. Mansi and Bonsa tributaries could not significantly change (P> 0.05) the total coliform numbers in the Ankobra River. The Geomean of total coliform numbers at Mansi tributary (MT) was significantly higher than the levels in both upstream (P= 0.005) and downstream (P= 0.01) of Mansi – Ankobra confluence (MU and MD). There was no significant difference (P= 0.24) in Geomean of total coliform numbers between the up and down streams of Mansi-Ankobra confluence (MU and MD). The Geomean of total coliform numbers at Bonsa tributary (BT) is higher than both the upstream (P= 0.03) and downstream (P= 0.02) of Bonsa–Ankobra confluence (BU and BD). There was no significant difference (P= 0.08) in Geomean of total coliform numbers between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The Geomean of total coliform numbers of Fure tributary (FT) was significantly lower than the levels in the upstream (P= 0.000) and downstream (P= 0.02) of Fure–Ankobra confluence (FU and FD). There was a significant difference (P= 0.000) in Geomean of total coliform numbers between the up and down streams of Fure–Ankobra confluence (FU and FD). The Geomean of total coliform numbers decreased from upstream to downstream of Fure –Ankobra confluence (FU to FD).

4.1.8 Faecal Coliform Numbers in sampling sites

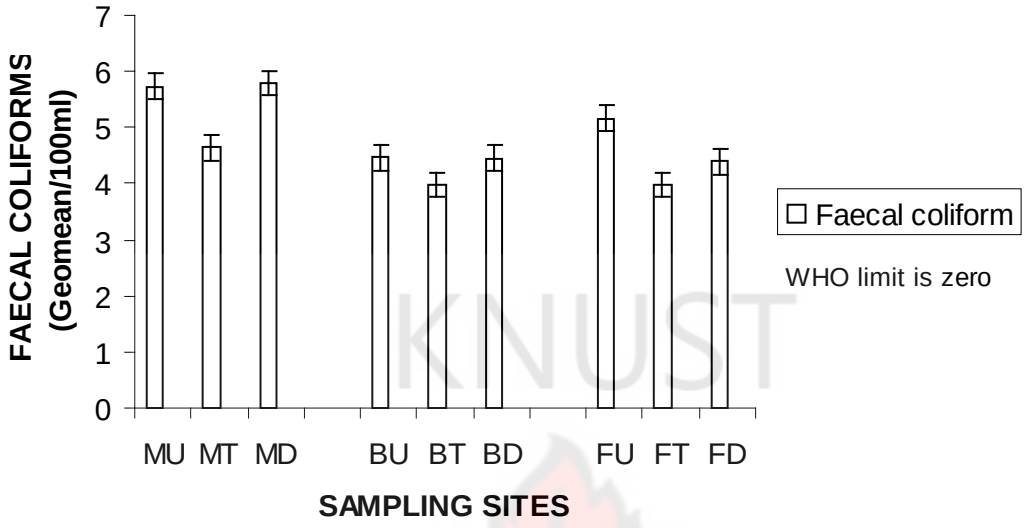

Fig. 10 Faecal Coliform Numbers in River Ankobra and its major Tributaries

Figure 10 indicates that, the faecal coliform numbers at both the up and down streams of Mansi-Ankobra confluence (MU and MD) and Bonsa–Ankobra confluence (BU and BD) are 5.73, 5.79, 4.47 and 4.45 Geomean/100ml respectively. The tributaries; Mansi (MT), Bonsa (BT) and Fure (FT) recorded faecal coliform numbers of 4.65, 3.98 and 3.98 Geomean/100ml respectively with the up and down streams of Fure–Ankobra confluence (FU and FD) recording 5.17 and 4.4 Geomean/100ml respectively. Among the sampling sites, Fure and Bonsa tributaries recorded the lowest faecal coliform numbers of 3.98 Geomean/100ml and downstream of Mansi-Ankobra confluence (MD) recorded the highest faecal coliform numbers of 5.79 Geomean/100ml. All the sampling sites did not meet the WHO drinking water guideline of zero Geomean/100ml.

There was a significant difference (P=0.000) in Geomean of faecal coliform numbers between the upstream of Mansi-Ankobra confluence (MU) and downstream of Fure-Ankobra confluence (FD). This significant difference shows that faecal coliforms in the

Ankobra River decreased from 5.73 Geomean/100ml at the upstream of Mansi-Ankobra confluence to 4.4 Geomean/100ml at the downstream of Fure-Ankobra confluence.

The influence of tributaries on the Ankobra River was assessed by comparing the faecal coliform numbers of the tributaries to the main river. Mansi and Bonsa tributaries could not significantly change ($P > 0.05$) the faecal coliform numbers in the Ankobra River. The Geomean of faecal coliform numbers at Mansi tributary (MT) was significantly higher than the levels in both upstream ($P = 0.002$) and downstream ($P = 0.002$) of Mansi – Ankobra confluence (MU and MD). There was no significant difference ($P = 0.4$) in Geomean of faecal coliform numbers between the up and down streams of Mansi-Ankobra confluence (MU and MD). The Geomean of faecal coliform numbers at Bonsa tributary (BT) is higher than both the upstream ($P = 0.05$) and downstream ($P = 0.05$) of Bonsa–Ankobra confluence (BU and BD). There was no significant difference ($P = 0.3$) in Geomean of faecal coliform numbers between the up and down streams of Bonsa-Ankobra confluence (BU and BD). The Geomean of faecal coliform numbers at Fure tributary (FT) was significantly lower than the levels in the upstream ($P = 0.000$) and downstream ($P = 0.01$) of Fure–Ankobra confluence (FU and FD). There was a significant difference ($P = 0.000$) in Geomean of faecal coliform numbers between the up and down streams of Fure–Ankobra confluence (FU and FD). The Geomean of faecal coliform numbers decreased from upstream to downstream of Fure –Ankobra confluence (FU to FD).

4.1.9 Cyanide levels at the sampling sites

Table 2 Cyanide levels in the river Ankobra and its major tributaries

Sampling sites	Cyanide levels (mg/l)
MU	< 0.01
MT	< 0.01
MD	< 0.01
BU	< 0.01
BT	< 0.01
BD	< 0.01
FU	< 0.01
FT	< 0.01
FD	< 0.01
WHO Limit	0.01

Cyanide levels in river Ankobra and its major tributaries were all below detection limit of 0.01 mg/l. All the sampling sites met the WHO drinking water guideline of 0.01 mg/l (Table 2).

4.2 Sampling results (mean values) during the period at each sampling site

Tables 3 – 11 below show the mean values of each water quality parameter at the various sampling sites from November 2006 to April 2007.

Table 3 Mean levels of water quality parameters for the periods at the upstream of Mansi–Ankobra confluence (MU)

Periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.55	6.475	6.4	6.1	6.25	6.7
Conductivity	109.8	106.9	148.1	156.8	132.7	124
TDS	54.8	53.4	73.9	78.4	66.15	62.2
TSS	68.5	61.25	15	15	15.5	16.5
BOD_5	2.192	2.269	1.02	1.183	1.374	1.603
Turbidity	7.455	7.903	12.83	16.62	5.26	66.56
Total coliform	8.2488	8.1275	6.5835	6.6075	6.6586	7.374
Faecal coliform	6.2679	6.2679	5.3511	4.5378	6.3919	5.5378
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 3 shows the mean levels of the water quality parameters analyzed from the water sampled in the upstream of Mansi-Ankobra confluence from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for pH (P=0.025), conductivity (P=0.000), TDS (P=0.000), BOD (P=0.000), turbidity (P=0.000) levels and also total and faecal coliform numbers (P=0.000). Cyanide levels were below detection limit during the study period from

November to April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases ($P<0.05$) in conductivity and TDS levels from November to February and a significant decrease ($P<0.05$) from March to April. On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases ($P<0.05$) in the levels of these parameters from November to February and a significant decrease ($P<0.05$) from March to April.

Table 4 Mean levels of water quality parameters for the periods at the Mansi tributary

Periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.75	6.875	6.3	6.15	6.35	6.4
Conductivity	120.7	113.2	173.7	171.1	135.4	129.4
TDS	60.9	58.75	86.9	85.6	67.95	65
TSS	79	77	15.5	17	81	178
BOD_5	2.214	2.212	2.47	2.518	2.3875	2.3945
Turbidity	289.25	277.9	10.04	15.96	275.4	338.9
Total coliform	7.2383	7.2874	6.4954	6.4914	5.0414	5.5772
Faecal coliform	6.1413	5.2272	4.1082	4.5378	3.5834	4.3169
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 4 shows the mean levels of the water quality parameters analyzed from the water sampled in the Mansi tributary from the month of November to April 2007. There were significant differences between the period of sampling from November to April for pH

(P=0.023), conductivity (P=0.000), TDS (P=0.008), BOD (P=0.001), turbidity (P=0.000) levels and also total and faecal coliform numbers (P=0.000). Cyanide levels were below detection limit during the study period from November 2006 to April 2007. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases (P<0.05) in conductivity and TDS levels from November to February and a significant decrease (P<0.05) from March to April. On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases (P<0.05) in the levels of these parameters from November to February and a significant decrease (P<0.05) from March to April.

Table 5 Mean levels of water quality parameters for the periods at the downstream of Mansi–Ankobra confluence (MD)

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.5	6.475	6.1	6.1	6.2	6.75
Conductivity	118.6	113.15	148.2	160.7	155.7	149.65
TDS	59	56.4	74	80.3	78.2	74.95
TSS	49	46.25	12	15.5	39	42.5
BOD_5	2.158	2.341	0.78	0.834	1.425	1.798
Turbidity	57.29	53.92	11.26	16	47.42	167.6
Total coliform	9.2489	8.5620	6.6586	6.7782	6.6586	6.4819
Faecal coliform	7.2629	5.5265	5.1761	5.1139	5.3022	6.3512
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 5 as shown above indicates the mean levels of the water quality parameters analyzed from the water sampled in the downstream of Mansi-Ankobra confluence from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for pH (P=0.009), conductivity (P=0.000), TDS (P=0.000), BOD (P=0.000), turbidity (P=0.000) levels and also total and faecal coliform numbers (P=0.000). Cyanide levels were below detection limit during the study period from November to April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases ($P<0.05$) in conductivity and TDS levels from November to February and a significant decrease ($P<0.05$) from March to April. On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases ($P<0.05$) in the levels of these parameters from November to February and a significant decrease ($P<0.05$) from March to April.

Table 6 Mean levels of water quality parameters for the periods at the upstream of Bonsa– Ankobra confluence (BU)

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.45	6.5	6.3	6.4	6.45	6.8
Conductivity	122.8	118.45	180.5	188.9	133.6	127.55
TDS	61.6	59.55	90	94.4	66.95	64.1
TSS	39	30.25	9.5	11	33	64.5
BOD_5	1.952	1.796	1.783	1.83	1.863	1.936
Turbidity	88.5	84.71	14.86	16.98	77.66	93.26
Total coliform	6.4954	6.4393	6.4294	5.5855	7.3920	6.5835
Faecal coliform	5.1993	4.2271	4.3918	3.4914	4.1082	5.4212
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 6 shows the mean levels of the water quality parameters analyzed from the water sampled in the upstream of Bonsa-Ankobra confluence from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for pH (P=0.043), conductivity (P=0.000), TDS (P=0.000), BOD (P=0.001), turbidity (P=0.000) levels and also total and faecal coliform numbers (P=0.000). Cyanide levels were below detection limit during the study period from November to April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases ($P<0.05$) in conductivity and TDS levels from November to February and a significant decrease ($P<0.05$) from March to April. On the contrary, the remaining parameters

recorded generally low values within the months of January and February. There were significant increases ($P<0.05$) in the levels of these parameters from November to February and a significant decrease ($P<0.05$) from March to April.

Table 7 Mean levels of water quality parameters for the periods at the Bonsa tributary

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.6	6.525	6.35	6.3	6.4	6.7
Conductivity	104.6	102.5	143.8	144	118.2	119.65
TDS	52.6	51.4	71.9	72	59.1	60.15
TSS	70.5	66.25	14	13	26.5	53.5
BOD_5	1.887	1.707	1.624	1.640	1.623	1.685
Turbidity	62.13	59.59	12.17	13.61	56.11	56.96
Total coliform	6.2272	6.3010	6.3919	5.2305	6.0414	6.3766
Faecal coliform	5.1901	4.1761	3.2270	3.1761	3.8993	4.2271
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 7 shows the mean levels of the water quality parameters analyzed from the water sampled in the Bonsa tributary from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for conductivity ($P=0.000$), TDS ($P=0.000$), BOD ($P=0.001$), turbidity ($P=0.000$) levels and also total and faecal coliform numbers ($P=0.000$). There was no significant difference ($P=0.097$) between the pH levels measured in this sampling site during the period. Cyanide levels were below detection limit during the study period from November to

April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases ($P<0.05$) in conductivity and TDS levels, from November to February and a significant decrease ($P<0.05$) from March to April. On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases ($P<0.05$) in the levels of these parameters from November to February and a significant decrease ($P<0.05$) from March to April.

Table 8 Mean levels of water quality parameters for the periods at the downstream of Bonsa– Ankobra confluence (BD)

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.45	6.475	6.4	6.35	6.35	6.6
Conductivity	118.7	114.65	171.9	178.3	129.4	125.7
TDS	59.4	57.35	85.9	89	65	63
TSS	78	67.5	14.5	14	18.5	37
BOD_5	1.944	1.832	1.766	1.793	1.856	1.882
Turbidity	80.92	78.10	13.94	15.1	72.13	72.08
Total coliform	7.2488	6.5378	6.1413	6.1461	6.3293	6.4393
Faecal coliform	5.1274	4.1082	4.5615	3.5855	3.9420	5.3511
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 8 shows the mean levels of the water quality parameters analyzed from the water sampled in the downstream of Bonsa-Ankobra confluence from the month of November 2006 to April 2007. There were significant differences between the period of sampling

from November to April for conductivity (P=0.000), TDS (P=0.007), TSS (P=0.000), BOD (P=0.001), turbidity (P=0.000) levels and also total and faecal coliform numbers (P=0.000). There was no significant difference (P=0.314) between the pH levels measured in this sampling site during the period. Cyanide levels were below detection limit during the study period from November to April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases (P<0.05) in conductivity and TDS levels, from November to February and a significant decrease (P<0.05) from March to April. On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases (P<0.05) in the levels of these parameters from November to February and a significant decrease (P<0.05) from March to April.

Table 9 below shows the mean levels of the water quality parameters analyzed from the water sampled in the upstream of Fure-Ankobra confluence from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for conductivity (P=0.000), TDS (P=0.000), TSS (P=0.000), BOD (P=0.000), turbidity (P=0.000) levels and also total and faecal coliform numbers (P=0.000). There was no significant difference (P=0.414) between the pH levels measured in this sampling site during the period. Cyanide levels were below detection limit during the study period from November to April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases (P<0.05) in conductivity and TDS levels, from

November to February and a significant decrease (P<0.05) from March to April . On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases (P<0.05) in the levels of these parameters from November to February and a significant decrease (P<0.05) from March to April.

Table 9 Mean levels of water quality parameters for the periods at the upstream of Fure–Ankobra confluence (FU)

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.55	6.55	6.6	6.5	6.6	6.75
Conductivity	106.4	104.05	264	278.6	129	123.45
TDS	53	51.9	132.1	139.3	64.55	61.9
TSS	84.5	81.75	19	21	77	162
BOD_5	2.494	2.511	1.72	1.739	1.84	1.944
Turbidity	412.45	405.15	180.6	191.6	402.55	105.795
Total coliform	8.3920	7.2272	6.9216	6.8420	6.6586	6.4892
Faecal coliform	5.4954	6.1995	4.8867	4.4914	5.3765	4.5835
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10 Mean levels of water quality parameters for the periods at the Fure tributary

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.4	6.4	6.2	6.2	6.35	6.5
Conductivity	84.2	75.7	91	100.3	85.15	80.5
TDS	42	37.8	45.5	50.1	42.55	40.35
TSS	44	38.5	25.5	23	29.5	43.5
BOD_5	2.51	2.675	2.98	2.83	2.892	2.553
Turbidity	50.185	49.5025	7.19	8.12	44.21	100.88
Total coliform	6.2382	6.2899	6.4903	5.4914	5.9216	5.6581
Faecal coliform	4.3657	3.8451	4.3313	3.2900	3.8910	4.1584
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10 shows the mean levels of the water quality parameters analyzed from the water sampled in the Fure tributary from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for conductivity (P=0.000), TDS (P=0.000), TSS (P=0.000), BOD (P=0.000), turbidity (P=0.000) levels and also total and faecal coliform numbers (P<0.05). There was no significant difference (P=0.279) between the pH levels measured in this sampling site during the period. Cyanide levels were below detection limit during the study period from November to April. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases (P<0.05) in conductivity and TDS levels, from November to February and a significant decrease (P<0.05) from March to April. On the contrary, the remaining parameters

recorded generally low values within the months of January and February. There were significant increases ($P<0.05$) in the levels of these parameters from November to February and a significant decrease ($P<0.05$) from March to April.

Table 11 Mean levels of water quality parameters for the periods at the downstream of Fure– Ankobra confluence (FD)

periods / *Parameters*	*November*	*December*	*January*	*February*	*March*	*April*
pH	6.5	6.475	6.5	6.6	6.5	6.65
Conductivity	118.7	115.1	204.2	212.2	134.4	129.65
TDS	59.3	57.5	102	105.9	67.05	64.8
TSS	68	65.5	22	23.5	44	94
BOD_5	2.526	2.425	1.07	1.13	1.2045	1.326
Turbidity	90.47	83.8125	78.77	83.71	80.025	100.465
Total coliform	7.2488	7.1414	6.5618	5.5855	5.8994	6.3766
Faecal coliform	4.4891	5.0282	3.5378	4.3979	4.3842	4.5771
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 11 shows the mean levels of the water quality parameters analyzed from the water sampled in the downstream of Fure-Ankobra confluence from the month of November 2006 to April 2007. There were significant differences between the period of sampling from November to April for conductivity ($P=0.000$), TDS ($P=0.000$), TSS ($P=0.000$), BOD ($P=0.000$), turbidity ($P=0.017$) levels and also total and faecal coliform numbers ($P=0.000$). There was no significant difference ($P=0.612$) between the pH levels

measured in this sampling site during the period. Cyanide levels were below detection limit during the study period from November 2006 to April 2007. Among the parameters, conductivity and TDS levels were generally very high in the months of January and February. There were significant increases ($P<0.05$) in conductivity and TDS levels, from November to February and a significant decrease ($P<0.05$) from March to April. On the contrary, the remaining parameters recorded generally low values within the months of January and February. There were significant increases ($P<0.05$) in the levels of these parameters from November to February and a significant decrease ($P<0.05$) from March to April.

4.3 Sampling sites groupings and water quality similarity in Ankobra Basin

As shown in Figure 11 below, all the sampling sites have been clustered according to the water quality parameters analyzed from water sampled in the Ankobra Basin.

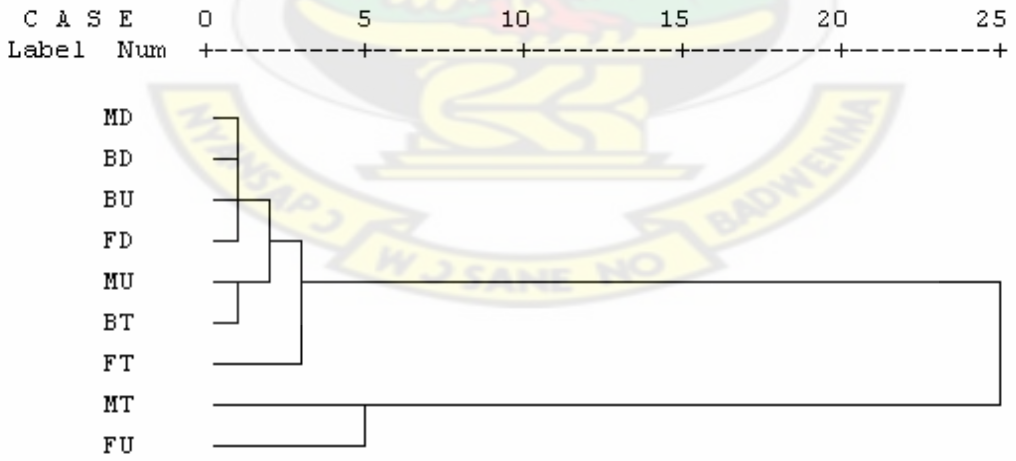

Fig. 11 Dendogram showing clustering of sampling sites into similar water quality levels

There were basically three different water quality levels shown from the Dendogram in Figure 11. These were delimited into less polluted sites (LPS), moderately polluted sites (MPS) and highly polluted sites (HPS). The less polluted sites were the Bonsa and Fure tributaries (BT and FT) and the upstream of Mansi-Ankobra confluence (MU). The moderately polluted sites were the upstream of Bonsa-Ankobra confluence (BU) and the down streams of Mansi-Ankobra confluence (MD); Bonsa-Ankobra confluence (BD); and Fure-Ankobra confluence (FD). Mansi tributary (MT) and the upstream of Fure-Ankobra confluence (FU) represented the highly polluted sites.

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATION

The absence of treated piped-borne water in the Wassa West District and the reliance of communities on River Ankobra as the source of drinking water make its quality important. The river Ankobra and its major tributaries lie within valleys, hence serving as a sink for pollutants from mining industries, farms and towns with poor sanitary facilities during rainfall (Osafo, 1989). These anthropogenic activities pollute the tributaries which could influence the water quality of river Ankobra.

5.1 Pollution of the River Ankobra Basin

It has been estimated that 25,000 deaths occur in a day due to consumption of contaminated water in the developing countries (Poikolainen *et al.,* 1995). To decrease the risk of transmission of water borne diseases, drinking water is tested for compliance with guidelines. From Figures 3 – 10 and Table 2, hydrogen ion concentration, total suspended solids, turbidity, total and faecal coliforms did not meet WHO drinking water quality guideline (WHO, 1987). These high concentrations of the parameters confirms the findings of Kortatsi, (2007) who indicated that intensified and uncontrolled mining activities in the Ankobra Basin by foreign investors have put water resources particularly surface water, at high risk of pollution. He emphasized that due to the pollution of the surface water resources; the Government of Ghana has shifted attention from developing surface water resources to ground water resources for communities in the Ankobra Basin because of the anticipated high cost of treating polluted surface water resources.

The pH levels at the sampling sites were generally below the WHO pH range (Figure 3). Similar results for the river in Prestea were reported by WRM, (1998) who suggested that the low pH was caused by mining activities in the area. Gold ores in the Ankobra Basin contain sulphide and its exposure to the atmosphere through mining has made the water in the Ankobra Basin slightly acidic (Kortatsi, 2007). Water contamination as a result of mining activities can have serious detrimental effects on living things including man and animals (Armah *et al.,* 1998). Hydrogen ion concentration (pH) has the most marked effect upon the growth of bacteria. The rate at which a polluted stream undergoes self-purification is decreased due to the reduction in bacterial numbers caused by a drop in pH of the river. The optimum pH value for good growth usually lies around pH of 7 (Klein *et al.,* 1962). A drop in pH in rivers as indicated by Morrison *et al.* (2001), could impair recreational uses of water, affect aquatic life and decrease the solubility of certain essential elements such as Selenium and increase harmful metals as Cadmium, Mercury and Aluminium.

The conductivity levels at all the sampling sites are below the minimum WHO drinking water guideline limit (Figure 4). According to WRM, (1998) conductivity levels are satisfactory in the Ankobra Basin because the maximum conductivity of 348 µs/cm detected in Prestea was below the WHO minimum guideline limit. The river Ankobra was found to mineralized at its upper reaches at Ankwaso with a mean of 139.9 µs/cm and at its lower reaches in Dominase with a mean of 73.3 µs/cm. High conductivities in water could be attributed to high mineral salt concentration which comes from the dissolution of minerals in the soil (Ntengwe, 2006; Morrison *et al.,* 2001). When a riverbed is disturbed, for instance, by mining within a river, adsorbed ions are released

from the riverbed into the water (Prowse, 1987). Although gold mining activities within the river were in the form of crashing the bedrock, the conductivity levels met the minimum WHO guideline limit. Thus, inorganic or metal levels are very low in the river and according to Ntengwe, (2006) the presence of inorganic compounds or metals makes water exhibit high conductivities.

In Figure 5 the total dissolved solids (TDS) level at all the sampling sites were below the minimum WHO guideline limit. These areas experienced low rainfall due to the dry season and probably there was not enough mineralization of the bedrock which could result in low concentration of mineral salts. According to Davies, (1996) bouts of heavy rainfall and the consequent rapid erosion of soil and leaching of associated bedrock can dramatically raise the dissolved solids content in a river. A high TDS as indicated by Ntengwe, (2006) has high concentration of mineral salts which is not good for human consumption. Increased levels of dissolve solids also result in reduction of dissolved oxygen in water. Carlson, (2005) noted that, the amount of dissolved material in a sample correlates with electrical conductivity.

The TSS levels at all the sampling sites exceeded the minimum WHO guideline limit (Figure 6). Work done by WRM, (1998) revealed that a high concentration of suspended solids (1005mg/l) has been observed in the river Ankobra in Prestea, and this was attributed to the mining activities in the area. The activities of the gold miners within the river Ankobra coupled with slight rainfall in the dry season could have increased the level of suspended solids at all the sampling sites and thus failing to meet the minimum guideline limit.

As indicated in Figure 7 the biochemical oxygen demand at all the sampling sites were below the minimum WHO guideline limit. This could be due to the fact that wildlife and the presence of few human settlements observed along the banks of the river could not introduce substantial amount of organic matter from their activities into the river. Osafo, (1989) confirmed that most of the human settlements are far away from river Ankobra, and these did not contribute much domestic waste into the river resulting in the low BOD levels observed. Naturally a river basin could have high BOD values because it is covered with rainforest and animal waste and dead plants from such forest will increase the amount of organic matter in the rivers (Tian *et al.*, 1995). Although wildlife was observed in the area coupled with dead branches of trees in the river, the Ankobra River did not experience a massive de-oxygenation and is regarded as unpolluted using BOD as a measure of purity (Alloway and Aryes, 1993).

The turbidity levels at all the sampling sites exceeded the minimum WHO guideline limit (Figure 8). The activities of the gold miners within the river Ankobra and rainfall experienced within the period could have raised the turbidity levels at all the sampling sites resulting in the poor quality of the water observed. Many cases of turbidity from soil particles are attributed to soil erosion (Kawashima, 1997). Additionally, heavy rainfall may cause higher turbidity, because suspended matter on the surface of the water scatters light and the more scattering increases turbidity. Such increased turbidities are often associated with the possibility of microbiological contamination, which makes disinfection of water difficult (Fatoki *et al*., 2001).

As indicated in Figures 9 and 10, both total and faecal coliform numbers at all the sampling sites far exceeded their respective minimum WHO guideline limit. Wildlife and the presence of few human settlements along the banks of the river could have introduced faecal matter into the river. According to Davies, (1996) sewage, urban run-offs and domestic waste waters are widely discharged into water bodies from their catchments. Pathogens associated with these discharges subsequently become distributed through the water body, presenting a risk to downstream users. Cowan *et al.* (1989), also showed that human habitation is the cause of the input of the majority of the faecal coliforms. This is evident from personal observation of people discharging faecal matter along the bank of the river. This confirms the statement by Karikari and Ansa-Asare, (2001) that it is a common practice for people living along the river catchments to discharge human excreta into rivers. These discharges could have been the reason for the increase in both total and faecal coliforms observed in the Ankobra Basin. Human faecal material is generally considered to be a greater risk to human health as it is more likely to contain human enteric pathogens (Baghel *et al.*, 2005). Therefore the most important aspect of water quality is its freedom from contamination with faecal matter. The high total and faecal coliforms observed in the river has consequently made groundwater the principal source of potable water supply for communities within the Ankobra Basin (Kortatsi, 2007).

Toxic organic chemicals such as cyanide could kill bacteria and render a river sterile, which will prevent self-purification (Klein *et al.*, 1962). Cyanide levels were all below detection limit (Table 2). In the Ankobra Basin cyanide spillages do occur and sub-tributaries such as Apepre receives occasional spillages from Golden Star Resources` tailings dam, which eventually discharges them into Mansi tributary. Such spillages are

recorded by Wassa Association of Communities Affected by Mining (WACAM) in the Western Region of Ghana. Cyanide was not detected in the Mansi tributary. According to Shehong *et al.* (2005), the reduction of cyanide concentration in streams depends on the following: dissolved oxygen, dilution, natural decomposition and sunlight. They concluded that dilution and natural decomposition which reduces cyanide concentration in water, occurs during short and long distance flow respectively. The tailings dam which store cyanide effluent from Golden Star Resources is located some kilometers from the Mansi tributary. Mansi tributary which had no detectable cyanide could be attributed to the fact that even if there was a spillage at the tailings dam, due to distance, natural decomposition of cyanide could have taken place in Apepre stream to reduce the cyanide level before discharging into Mansi tributary. Cyanide levels below detection limit in Ankobra Basin could imply that, the chemical spillage reported by Asiedu 2007 was not cyanide. According to Klein *et al.* (1962), one of the earliest indications of the contamination of a river by toxic compounds is the presence of dead or dying fishes. Asiedu, 2007 reported in the Daily Graphic dead fishes in the Ankobra River which may indicate toxic chemical contamination. Personal communication with people from Beposo (a town on Mansi tributary) revealed that, when river Ankobra attains a low level especially in the dry season, people in the vicinity do not utilize the water for drinking. They attributed the contamination of the water to chemicals used in fishing by the upstream communities.

5.2 Influence of tributaries on Self-Purification of the River Ankobra

Mining activities were observed along the banks and within the tributaries of river Ankobra during the study. Nwokedi *et al.* (1992) showed the extent to which the river Niger was polluted by human activities through the major tributaries. Topalian *et al.* (1999) reported that the quality of river Reconquista in Argentina is deteriorating due to discharges of pollutants from one of its tributaries, the highly polluted Moron stream. Schumm, (2005) showed that tributaries bring water into main rivers and these help the main river dilute more pollutants and this brings the solution to pollution (Hull, 1967). Tributaries also add dissolved oxygen to the main river which breaks down unstable organic matter discharged into it (Velz, 1970). It could be inferred from the above mentioned studies on tributaries that the major tributaries of river Ankobra could influence its self-purification. Some rivers are able to undergo self-purification in a fairly short distance and others require dozens of kilometers and even more. Self-purification is a complicated process and each river has its own specific capacity for purifying itself which can only be properly evaluated after an extensive chemical, physical, hydrological and biological survey (Klein *et al.*, 1962). The mean of physicochemical and microbiological parameters at both the upstream of Mansi-Ankobra confluence and downstream of Fure-Ankobra confluence (Figures 3 - 10) with an approximate distance of 50km between them were compared to assess the self purification capability of the river Ankobra.

The pH level of river Ankobra increased from the upstream of Mansi-Ankobra confluence (MU) to the downstream of Fure-Ankobra confluence (FD) (Figure 3). River Ankobra has the capacity to purify itself from the slightly acidic conditions to the nearly

neutral conditions observed. Both Mansi and Bonsa tributaries (Figure 3) did not influence the self-purifications of river Ankobra. The pH levels of both tributaries were similar to the up and down streams of their respective confluence with river Ankobra. The pH levels of the water were very similar because according to Kortatsi, (2007) gold ores in the Ankobra Basin contain sulphide and exposure of it to the atmosphere through natural processes of weathering or anthropogenic processes such as mining has made the river water in the basin slightly acidic. As indicated in Figure 3 the pH level increased gradually from slightly acidic region until the minimum WHO limit was met at upstream of Fure-Ankobra confluence. According to Cowan *et al.* (1989), it is generally agreed that carbonate systems and biological processes control the background pH of natural waters. Similarly, neutralization by alkaline waters and water received from tributaries could increase the pH level of a river (Klein *et al.*, 1962). The pH changes that occurred in the upstream of Fure-Ankobra confluence could be neutralization from alkaline waters and/or dilution of river water. The dredging activities concentrated in the upstream of Fure-Ankobra confluence may have heaped sediments observed in this sampling site. These sediments removed could have left a gap which was filled with more water and consequently lead to the dilution of acidity of the river.

The conductivity and TDS levels increased from the upstream of Mansi-Ankobra confluence to the downstream of Fure-Ankobra confluence (Figures 4 and 5). The capability of the river Ankobra to lower both conductivity and TDS levels was interrupted by the introduction of high conductivity and TDS water from the Mansi tributary. High conductivity and TDS levels in water could be attributed to heavy rainfall and the consequent rapid erosion of soil into rivers and leaching of associated bedrock

(Davies, 1996). The Mansi tributary lies in the concession of a large scale mining company (Golden Star Resources Ltd.). The activities of the Company could have introduced pollutants from road surfaces and soils dumped close to mining pit during surface run off into the river. Run-offs after rainfall give rise to serious pollution problems in Mansi tributary. Another culprit who may increase conductivity and TDS levels in Mansi tributary are the illegal miners (galamsey) operating within the stream. Their activities involve crushing the river bed to remove the ore to be processed into gold. When a river bed is disturbed by mining within a river, adsorbed ions are released from the riverbed into the water (Prowse, 1987). The cumulative effects of both activities of Golden Star Resources and the galamsey operators have increased conductivity and TDS levels in Mansi tributary which then influence the river Ankobra by increasing both conductivity and TDS at the downstream of Mansi-Ankobra confluence, resulting in the observed difference between the up and downstream of Mansi- Ankobra confluence.

The TSS levels as indicated in Figure 6 increased from the upstream of Mansi–Ankobra confluence to the downstream of Fure-Ankobra confluence. This shows that river Ankobra was not able to purify itself from the suspended solids which entered the river as pollutants. Tiwary, (2001) showed that depending upon the nature and concentration; suspended solids may interfere with the self- purification of the water. During rainfall enough silt and debris are washed down from the constructed roads and excavated soils in the Golden Stars Resource concession area into the Mansi tributary, raising its TSS level. Surprisingly, the influence of the high TSS levels in the Mansi tributary on the suspended solids in the river Ankobra was insignificant. Similarly, TSS levels in Bonsa tributary

could not influence the levels in river Ankobra. The inability of the river to purify itself was due to high concentration of suspended solids at the upstream of Fure-Ankobra confluence. Osafo, (1989) worked on pollution and water quality of the Ankobra Basin. She observed that apart from suspended solids coming from the large–scale gold mines through activities which cause erosion, there were also illegal activities of gold extraction along the river in Prestea which increases the suspended solids. This may explain the high levels of TSS observed at the upstream of Fure-Ankobra confluence because five groups of illegal miners were observed at this sampling site extracting gold. The high TSS observed could be due to the disturbance the river bed received when it was being dredged for gold (*wwww.ecy.wa.gov/biblio/19149.html*). The inability of the water at the downstream of Fure-Ankobra confluence (FD) to purify itself from suspended solids to a level lower than those at the upstream of Mansi Ankobra confluence (MU) was due to high concentration of suspended solids at the upstream of Fure-Ankobra confluence (FU). However, the Fure tributary contributed significantly to the dilution of high suspended solids at the downstream of Fure-Ankobra confluence (FD). The Fure tributary with lower TSS levels influenced the water quality of river Ankobra by diluting the high TSS levels of the upstream of Fure-Ankobra confluence to a low level at the downstream of Fure-Ankobra confluence.

According to Klein *et al.* (1962), a heavy pollution load is much more likely to deoxygenate a stream and the determination of BOD at various points in the river is necessary to assess the extent of self purification in a river basin. As indicated in Figure 6 the BOD levels of both the upstream of Mansi–Ankobra confluence and downstream of Fure-Ankobra confluence were similar. According to Osafo, (1989) the similarity

observed was due to most human settlement located far way from the river Ankobra and could not contribute much domestic wastes into the river. Klein *et al.* (1962) showed that domestic sewage and wastes containing protein, sugars and fats are easily decomposed and will give high BOD values in rivers. The BOD levels of both Mansi and Bonsa tributaries could not influence the levels in the river Ankobra. Both their up and down streams of their respective confluences were similar. Fure tributary influenced the BOD levels in the river Ankobra. There was a decrease in BOD levels from the upstream to downstream of Fure-Ankobra confluence. Velz, (1970) showed that tributaries could add dissolved oxygen to the course of a river. This may explain the low levels of BOD observed at the downstream of Fure-Ankobra confluence (FD). Among the sampling site, Mansi and Fure tributaries were observed to have high BOD levels. During the study dead bamboo sticks, tree stumps and dead branches of trees were found in the water at these sampling sites. These may probably have contributed to the organic load of the river. According to Osafo, (1989) vegetation which falls into rivers could also increase the organic matter whose decomposition by bacteria will place a heavy demand on the available dissolved oxygen in the water. The upstream of Fure–Ankobra confluence was observed to have a high BOD level. This sampling site had groups of illegal miners operating within it. It is possible that sewage from these miners is discharged into the river, which increases the organic load. Karikari and Ansa-Asare, (2001) stated that it is a common practice for people living along the banks of rivers to discharge domestic sewage into rivers.

Measurement of turbidity of rivers can be used to follow the course of self–purification of a stream. In Figure 8 turbidity levels increased from the upstream of Mansi–Ankobra

confluence to downstream of Mansi-Ankobra confluence. The river could not purify itself from the pollutants received from the Mansi tributary. Turbidity is an optical property of a medium which causes light to be scattered and adsorbed in water. The constituent of total suspended solids which include suspended silt, clay and other insoluble particulate substances, aid in scattering of light in a medium (Lawler *et al.* 2006). The type and concentration of suspended solids in a water body controls the turbidity of water (Akpabli and Drah, 2001). Packman *et al.* (1999) showed that there is a relationship between turbidity and TSS. The inability of river Ankobra to purify itself was due to high concentration of suspended solids in the Mansi tributary and the upstream of Fure – Ankobra confluence. The high turbidity levels at Mansi tributary could result from erosion of silt from soil dumped close to mining pit and non-bitumen roads in the concession area of Golden Star Resources. Mansi tributary influenced the quality of river Ankobra by increasing the turbidity levels at the downstream of Mansi–Ankobra confluence. Bonsa and Fure tributaries influenced the quality of the river Ankobra by decreasing the turbidity levels at the downstream of their respective confluence. The high turbidity levels observed at the upstream of Fure–Ankobra confluence was due to more illegal mining activities concentrated in this area. Their activities disturb the river bed and consequently increase the suspended solids which shield light from being transmitted in straight lines through the river water (increasing turbidity).

In Figures 9 and 10 total coliforms were 100 times more than faecal coliforms. Poikolainen *et al.* (1995) showed that for the bacteria groups used in microbiological examination of surface water indicating faecal pollution, the concentrations of total coliforms are typically the highest. This they attributed to the occurrence of other species

of no value as faecal indicator. Rufete *et al*. (2006) also added that in general total coliform bacteria numbers were 2–3 log cycles higher than faecal coliforms. Baghel *et al*. (2005) noted that both faecal and total coliforms are bacteria, but faecal coliforms form a proportion of total coliforms. There is a relationship between total and faecal coliforms. The total and faecal coliforms numbers decreased from the upstream of Mansi–Ankobra confluence to the downstream of Fure–Ankobra confluence. The river Ankobra lowered the bacterial numbers thereby enhancing the purification of the river. According to Poikolainen *et al.* (1995) when faecal bacteria are released into water they are outside their normal habitat and their concentrations begin to decrease. The river water has factors which affects the occurrence and die-off of the faecal bacteria. These factors are: water temperature, dry and wet periods, sedimentation, solar radiation and predation. These factors could have probably affected the coliform bacteria numbers in river Ankobra, which eventually resulted in a decrease in the number of coliform organism downstream of Fure–Ankobra confluence (discharging point). According to Obiri–Danso and Jones, (1999) the difference in indicator numbers is most likely due to the die-off and dilution predicted by the "distance-decay relationship" of faecal indicators. Among the sampling sites, the up and down streams of Mansi–Ankobra confluence and upstream of Fure–Ankobra confluence recorded the highest total and faecal coliform numbers. At the upstream of Mansi–Ankobra confluence, human settlements were not visible at the immediate vicinity, so possibly human habitation at the very upstream of the river Ankobra coupled with wildlife within the vicinity could have caused coliforms numbers to rise. According to Cowan *et al*. (1989) both human habitation and wildlife could be responsible for input of faecal coliforms into water. The high coliforms numbers

observed at the downstream of Mansi–Ankobra confluence could be due to the influence of human habitation. There are palm-wine tappers and illegal miners operating along the bank and within the downstream of Mansi–Ankobra confluence respectively. At the upstream of Fure–Ankobra confluence, groups of illegal miners were observed extracting gold during the study. All these people working both along and within the river could discharge their faecal matter into them. In some communities, people living along river catchments discharge human excreta into rivers (Holtzclaw and Robinson, 1988). This could be the reason for the increased in faecal coliforms observed in the Ankobra Basin. Hipsey *et al.* (2006) indicated that bacteria show affinity for inorganic particle surfaces and they are washed from surrounding catchments with the most easily transported clay particles. The settling and scouring process associated with suspended solids also affects pathogens levels of water (Rogers *et al*., 2003). This could explain why both TSS and coliforms organisms were similar in their respective levels at the up and down streams of both Mansi–Ankobra and Bonsa–Ankobra confluences (Figure 6, 9 and 10). On the contrary both TSS and coliforms decreased from upstream to the downstream of the Fure–Ankobra confluence. The decrease could be due to the influence of Fure tributary on river Ankobra by aiding in diluting the high TSS levels in the upstream of Fure–Ankobra confluence, resulting in the reduction of coliform numbers in the downstream of Fure–Ankobra confluence.

5.3 Assessment of Sampling Sites with similar water quality levels

Three different water quality levels were shown from the Dendogram (Figure11). These were delimited into Less, Moderate and High polluted sites. According to Klein, *et al.* (1962) turbidity in a river is a measure of the intensity of pollution. So, turbidity levels were used to indicate pollution in the Ankobra River.

The Less Polluted Sites had similar turbidity levels (Table 3, 7 and 10). These were as a result of soil erosion from the banks of the river. Kawashima, 1997 showed that many cases of turbidity from soil particle are attributed to soil erosion. The upstream of Mansi-Ankobra confluence and both Bonsa and Fure tributaries do not receive water from any major tributaries which could influence their quality. Tributaries could discharge pollutants into main rivers to deteriorate their quality (Topalian *et al.* 1999 and Nwokedi *et al.* 1992).

The Moderately Polluted Sites also had similar turbidity levels (Table 5, 6, 8 and 11). The turbidity levels recorded at these sampling sites were as a result of both soil erosion from the banks of the river; and mining activities occurring at the vicinity of Mansi tributary and within the upstream of Fure-Ankobra confluence. Kortatsi, 2007 showed that mining activities in the Ankobra Basin has resulted in the pollution of the river. Work done by Water Resources Management, 1998 showed that, the Ankobra River received a high concentration of suspended solids (1005 mg/l) from the mining activities in Prestea. The high levels of pollutants in the Mansi tributary (MT) influenced the quality of water at the downstream of Mansi-Ankobra confluence (MD) and the up and down streams of Bonsa-Ankobra confluence (BU and BD). The Ankobra River could not dilute pollutants entering it from the Mansi tributary. This confirms reports from Nwokedi *et al.* (1992)

and Topalian *et al.* (1999) that the quality of main rivers could be deteriorated by discharges of pollutants from their tributaries. The illegal mining activities within the upstream of Fure-Ankobra confluence (FU) also discharge pollutants to deteriorate the quality of water at the downstream of Fure-Ankobra confluence (FD).

The Highly Polluted Sites had similar turbidity levels (Table 4 and 9). The turbidity levels recorded at these sampling sites resulted from soil erosion from run-offs at the banks of the river and also mining activities occurring in the river. The surface operations of Golden Star Resources Limited pile up soils on site during their excavations. The Mansi tributary passes through the mining concession area of Golden Star Resources and receives run-off water from pile up soils. This run-offs increases suspended solids in the tributary resulting in high turbidity (Akpabli and Drah, 2001; Packman *et al*. 1999). During the period of sampling slight rainfall was observed in the months of November, December and March but this became intensive in April. Rainfall events results in increases in parameters which indicate pollution in surface water (Shutes *et al.* 1996; Chigbu *et al*. 2004). As indicated in Table 4 turbidity and TSS levels in Mansi tributary were very high in the months of November, December, March and April, because it received run-offs from the activities of Golden Star Resources Limited. On the contrary, turbidity and TSS levels in Mansi tributary were low in the months of January and February. There was no rainfall within these months so surface run-off from the activities of Golden Star Resources Limited did not occur. When rainfall was very intensive in the month of April, the Mansi tributary recorded the highest turbidity level. Turbidity in a river is a measure of intensity of pollution (Klein *et al.* 1962). We could infer that the intensity of pollution in Mansi tributary is greatest during periods of heavy rainfall.

Mining activities within the upstream of Fure-Ankobra confluence increased the turbidity levels as indicated in Table 9. During the study five groups of illegal miners were seen extracting gold ores from the river. Their activities disturb the river bed and consequently increase turbidity levels. Osafo, 1989 observed that apart from run-offs coming from the activities of large-scale mining, there were also illegal activities of gold extraction along the river in Prestea which increases the suspended solids in them. Mining activities within the upstream of Fure-Ankobra confluence were at its peak during the dry period (January and February). Conductivity and TDS levels in all sampling sites generally increased during the dry periods. This was confirmed by Fall, 2007 who stated that TDS increases in the dry seasons but is lowered in the wet season due to dilution of the TDS concentration. Turbidity levels were high in the upstream of Fure-Ankobra confluence which went contrary to the low levels recorded in the Mansi tributary (Table 3 and 9). However, turbidity levels in the upstream of Fure-Ankobra confluence was lower than those levels recorded in the Mansi tributary during the month of April; which had intensive rainfall. Illegal mining activities within the upstream of Fure-Ankobra confluence was halted, due to the rise in water level of the river in the rainy season. This could explain why lower turbidity levels were recorded in the month of April. The turbidity level recorded in the upstream of Fure-Ankobra confluence in April was due to run-off from the bank of the river which may transport a variety of pollutants into the water (Tiwary, 2001).

In conclusion, surface water pollution does occurs when a source of faecal bacteria, siltation, increase in organic matter and natural geological conditions are present, and

rainfall and other anthropogenic activities elevate faecal bacteria numbers, turbidity, Biochemical Oxygen Demand, Total Suspended Solids and Conductivity in Ankobra River Basin. The pollution of this river basin correlates with areas of intense human activities such as the upstream of Ankobra – Fure confluence with its dredging activities and the production of pollutants from roads constructed through the concession area of Golden Star Resources and excavated soils piled up near mining pits both occurring at the vicinity of the Mansi tributary.

Minimizing faecal pollution, siltation and organic matter increases in Ankobra River Basin must therefore be an integrated approach. The components of this should include:

1. Education of the river bank communities not to make rivers disposal sites for sewage.
2. Government should out of the common fund given to the constituencies consider constructing improved pit latrines (KVIP) for these river bank communities.
3. Gold mining within rivers must be aborted and illegal miners encouraged to form organizations to acquire concessional areas from the Minerals Commission.
4. Felling of trees by chain saw operators or removing vegetation by farmers along the river banks must be discouraged.
5. The Forest Service Division (FSD) of Forest Commission in each district where the river lies should embark on a massive reforestation of the degraded parts of the river's catchment.
6. The creation of a hundred metre buffer zone to protect the river from anthropogenic activities is needed.

7. Community Biodiversity Organizations (CBO's) should be formed in communities close to these rivers and empowered to guard the demarcated buffer zones from activities of man.
8. Environmental Protection Agency (EPA) should monitor the Ankobra River for chemical spillage especially during periods of low water level or in the dry season.
9. Management of Golden Star Resources needs to increase vegetation close to the Mansi tributary which could reduce eroded material from their activities.

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Appendix A: Field Research results in November 2006

REPORT OF ANALYSIS

Date sampled:24/11/2006

PARAMETERS	MU	MT	MD	BU	BT	BD	FU	FT	FD
pH	6.6	7	6.4	6.5	6.7	6.5	6.6	6.3	6.4
	6.5	6.5	6.6	6.4	6.5	6.4	6.5	6.5	6.6
CONDUCTIVITY	108.4	119.6	117.8	121.4	103	117.6	105	82.9	117.6
	111.2	121.8	119.4	124.2	106.2	119.8	107.8	85.5	119.8
TDS	54.1	59.9	58.8	60.5	51.5	58.7	52.1	41.4	58.7
	55.5	61.9	59.2	62.7	53.7	60.1	53.9	42.6	59.9
TSS	68	78	48	38	70	79	84	45	69
	69	80	50	40	71	77	85	43	67
CN^{-1}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD_5	2.163	2.2	2.149	1.94	1.878	1.937	2.481	2.5	2.518
	2.221	2.228	2.167	1.964	1.896	1.951	2.507	2.52	2.534
TURBDITY	5.84	294.6	53.73	84.33	60.84	84.9	416.5	49.77	96.15
	9.07	283.9	60.85	92.67	63.41	76.93	408.4	50.6	84.79
TOTAL COLIFORM	150000000	20000000	2100000000	2800000	1500000	21000000	290000000	1500000	15000000
	210000000	15000000	1500000000	3500000	1900000	15000000	210000000	2000000	21000000
FAECAL COLIFORM	2900000	1200000	16000000	210000	160000	120000	280000	27000	34000
	1200000	1600000	21000000	120000	150000	150000	350000	20000	28000

Appendix B: Field Research results in December 2006

REPORT OF ANALYSIS

Date sampled:29/12/2006

PARAMETERS	MU	MT	MD	BU	BT	BD	FU	FT	FD
pH	6.3	7.1	6.5	6.6	6.5	6.6	6.6	6.5	6.5
	6.5	6.9	6.4	6.5	6.4	6.4	6.5	6.3	6.4
CONDUCTIVITY	103.3	112.4	106.5	113	99.6	109.4	100.8	66.7	110.4
	104.7	114	108.9	115.2	101.2	111.8	102.6	67.7	112.6
TDS	51.5	56	52.8	56.9	49	54.7	50.2	33	55
	52.5	57.2	54.8	58.1	51.4	55.9	51.4	34.2	56.4
TSS	55	78	43	21	63	67	80	34	64
	53	76	44	22	61	68	78	32	62
CN^{-1}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD_5	2.337	2.199	2.515	1.628	1.518	1.71	2.519	2.83	2.313
	2.355	2.221	2.531	1.652	1.534	1.73	2.537	2.85	2.335
TURBDITY	7.74	270.5	48.43	78.3	54.86	78.76	394.9	46.8	78.43
	8.96	262.6	52.66	83.52	59.23	71.79	400.8	50.84	75.88
TOTAL COLIFORM	120000000	14000000	460000000	2700000	2000000	3400000	19000000	2000000	12000000
	150000000	27000000	290000000	2800000	2000000	3500000	15000000	1900000	16000000
FAECAL COLIFORM	2900000	150000	420000	19000	15000	11000	1200000	7000	95000
	1200000	190000	270000	15000	15000	15000	2100000	7000	120000

Appendix C: Field Research results in January 2007

REPORT OF ANALYSIS

Date sampled:26/01/2007

PARAMETERS	MU	MT	MD	BU	BT	BD	FU	FT	FD
pH	6.5	6.2	6	6.4	6.3	6.5	6.7	6.1	6.6
	6.3	6.4	6.2	6.2	6.4	6.3	6.5	6.3	6.4
CONDUCTIVITY	147.4	172.6	149.1	179.7	142.9	171	262.5	90	203.3
	148.8	174.8	147.3	181.3	144.7	172.8	265.5	92	205.1
TDS	73	85.8	73.1	89.8	71.6	85.2	131.4	45	101.2
	74.8	88	74.9	90.2	72.2	86.6	132.8	46	102.8
TSS	14	15	11	9	13	14	20	25	21
	16	16	13	10	15	15	18	26	23
CN^{-1}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD_5	1.012	2.461	0.772	1.772	1.615	1.759	1.71	2.971	1.06
	1.028	2.479	0.788	1.794	1.633	1.773	1.73	2.989	1.08
TURBDITY	11.66	9.1	10.4	13.9	11.06	12.9	178.9	6.7	77.65
	14	10.98	12.12	15.82	13.28	14.98	182.3	7.68	79.89
TOTAL	4200000	2800000	3000000	1600000	2900000	1600000	9300000	2100000	4600000
	3500000	3500000	7000000	4600000	2100000	1200000	7500000	4600000	2900000
FAECAL	210000	15000	150000	21000	1900	29000	64000	16000	3400
	240000	11000	150000	29000	1500	46000	93000	29000	3500

Appendix D: Field Research results in February 2007

REPORT OF ANALYSIS

23/02/07

PARAMETERS	MU	MT	MD	BU	BT	BD	FU	FT	FD
pH	6	6.1	6.2	6.3	6.2	6.3	6.4	6.1	6.7
	6.2	6.2	6	6.5	6.4	6.4	6.6	6.3	6.5
CONDUCTIVITY	155.4	169.9	159.8	187.7	142.8	176.9	277.3	99.1	210.6
	158.2	172.3	161.6	190.1	145.2	179.7	279.9	101.5	213.8
TDS	77.5	84.9	79.9	93.8	71.2	88.1	138.7	49.7	105.2
	79.3	86.3	80.7	95	72.8	89.9	139.9	50.5	106.6
TSS	16	18	16	10	14	13	20	24	24
	14	16	15	12	12	15	22	22	23
CN^{-} 1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD_5	1.176	2.508	0.824	1.821	1.63	1.784	1.729	2.817	1.119
	1.19	2.528	0.844	1.839	1.65	1.802	1.749	2.843	1.141
TURBDITY	15.56	14.5	14.9	15.6	12.8	14	190.1	8	82.3
	17.68	17.42	17.1	18.36	14.42	16.2	193.1	8.24	85.12
TOTAL	3900000	3400000	6000000	350000	190000	1600000	6400000	340000	350000
	4200000	2800000	6000000	420000	150000	1200000	7500000	280000	420000
FAECAL	34000	42000	110000	2800	1500	4200	34000	2000	29000
	35000	27000	150000	3400	1500	3500	28000	1900	21000

Appendix E: Field Research results in March 2007

REPORT OF ANALYSIS **30/03/07**

PARAMETERS	MU	MT	MD	BU	BT	BD	FU	FT	FD
pH	6.2	6.3	6.1	6.4	6.3	6.3	6.5	6.3	6.4
	6.3	6.4	6.3	6.5	6.5	6.4	6.7	6.4	6.6
CONDUCTIVITY	131.6	134.2	154.6	132.4	116.8	128.6	128.4	83.9	133.2
	133.8	136.6	156.8	134.8	119.6	130.2	129.6	86.4	135.6
TDS	65.5	67.2	77.8	66.2	58.4	64.2	64.3	41.9	66.6
	66.8	68.7	78.6	67.7	59.8	65.8	64.8	43.2	67.5
TSS	15	80	38	32	26	18	76	29	43
	16	82	40	34	27	19	78	30	45
CN^{-1}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD_5	1.321	2.363	1.386	1.824	1.584	1.825	1.815	2.886	1.198
	1.426	2.412	1.463	1.902	1.662	1.886	1.865	2.898	1.211
TURBDITY	4.43	279.5	44.19	73.44	53.62	70.6	398.6	43.75	79.76
	6.09	271.3	50.64	81.87	58.6	73.66	406.5	44.67	80.29
TOTAL COLIFORM	7000000	110000	7000000	21000000	1100000	2400000	3000000	930000	700000
	3000000	110000	3000000	29000000	1100000	1900000	7000000	750000	900000
FAECAL COLIFORM	2100000	4200	150000	15000	9000	7000	210000	9500	21000
	2900000	3500	270000	11000	7000	11000	270000	6400	28000

Appendix F: Field Research results in April 2007

REPORT OF ANALYSIS

27/04/07

PARAMETERS	MU	MT	MD	BU	BT	BD	FU	FT	FD
pH	6.6	6.3	6.7	6.7	6.6	6.5	6.7	6.4	6.7
	6.8	6.5	6.8	6.9	6.8	6.7	6.8	6.6	6.6
CONDUCTIVITY	123.6	128.3	148.6	126.8	118.7	124.6	122.4	78.4	128.5
	124.4	130.5	150.7	128.3	120.6	126.8	124.5	82.6	130.8
TDS	61.9	64.7	74.6	63.7	59.8	62.4	61.5	39.4	64.2
	62.5	65.3	75.3	64.5	60.5	63.6	62.3	41.3	65.4
TSS	16	179	42	64	54	36	161	43	95
	17	177	43	65	53	38	163	44	93
CN^{-1}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD_5	1.662	2.454	1.812	1.967	1.711	1.912	1.954	2.594	1.354
	1.543	2.335	1.784	1.905	1.658	1.852	1.934	2.512	1.298
TURBDITY	63.32	376.1	172.3	93.26	57.25	69.04	96.49	105	106
	69.79	301.7	162.9	93.25	56.66	75.12	115.1	96.76	94.93
TOTAL COLIFORM	20000000	340000	9000000	3500000	2100000	2700000	3400000	700000	2100000
	28000000	420000	1100000	4200000	2700000	2800000	2800000	300000	2700000
FAECAL COLIFORM	340000	29000	2100000	290000	19000	210000	35000	11000	34000
	350000	15000	2400000	240000	15000	240000	42000	19000	42000