KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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KUMASI – GHANA.

IMPACTS OF WASTE ON URBAN SURFACE WATER RESOURCES. CASE STUDY OF ABOABO STREAM, KUMASI, GHANA

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AUGUST, 2012

IMPACTS OF WASTE ON URBAN SURFACE WATER RESOURCES. CASE STUDY OF ABOABO STREAM, KUMASI, GHANA.

BY

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Certification

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

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To God be the Glory

Dedication

This dissertation is dedicated to my family;

Nyamah Beatrice

Nana Afrah Hemaah Boakye

You form a great and united team of which I am proud to be part

“For those God foreknew, He also predestined to be conformed to the likeness of His Son that He might be the First born among many brothers. Those He predestined, He also called; those He called, He also justified; those He justified, He also glorified.

Romans 8:29-30.

NIV

Abstract

Urban surface water resources have been under increasing threat of pollution in recent years due to improper management of vast amount of wastes generated by various human activities. Freshwater resources, which are the major sources of drinking water, are now major receptacles of treated and untreated or partially treated industrial wastes. The Aboabo Stream is not an exception. The study therefore aims at determining the solid and liquid waste handling practices within the communities along the Aboabo Stream (Pankrono, Moshie Zongo, Buokrom, Dichemso, Aboabo, Asokwa, and Atonsu); monitoring the water quality characteristics from the upstream to downstream and determining the sources of pollution. In addition, mitigating measures have been proposed to reduce pollution of the Aboabo Stream.

Fourteen sampling points made up of eight sampling points located on the Aboabo stream, four secondary drains from the study communities that emptied directly into the Aboabo stream and two sampling points on the Sisal Stream, a tributary that joins the Aboabo Stream were chosen. Water samples were collected from the mid-stream at depth of 10-15 cm on a bi-weekly basis for a period of three months (November 2011 and January 2012).

No formal conventional treatment plants exist within the Aboabo catchment for treatment of both solid and liquid waste. Therefore, most of the residents in the communities dispose off their solid waste by uncontrolled burning, burying, dumping into the gutters, and open spaces. The physicochemical analyses using parameters such as pH, TDS, TSS, total Phosphorus, Nitrate, BOD_{5}, COD, total coliformis, E-coli, and DO of the upstream gave values well below the maximum permissible level set by the EPA.

On the contrary, the downstream values for these physicochemical parameters were to a larger extent far above the maximum permissible level set by the EPA. The CCME Water Quality Index also showed the Aboabo Stream to be of poor quality.

It is recommended that, the most important mitigation measure to reduce pollution of the Aboabo Stream is the provision of adequate sanitary (solid and liquid waste) facilities. Thus, improving sanitation in these communities will serve a greater good of reducing the pollutant level of the Aboabo Stream.

Keywords: Pollution, liquid waste, solid waste, CCME Water Quality Index.

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Abbreviations used in text

APHA	American Public Health Association
AWWA	American Water Works Association
BOD	Biochemical Oxygen Demand
CCMEWQI	Canadian Council of Ministers of the Environment Water Quality Index
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPA EGV	Environmental Protection Agency Effluent Guideline Value
EPA	Environmental Protection Agency
KMA	Kumasi Metropolitan Assembly
KNUST	Kwame Nkrumah University of Science and Technology
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency

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CHAPTER ONE

1.0 Introduction

One of the most critical problems of developing countries is improper management of vast amounts of wastes generated by various human activities. Open and indiscriminate dumping of solid wastes in drainage channels and riverbanks is among the problems of improper management of waste in the developing countries of the world (Omoleke, 2004). In Ghana, current urban sanitation infrastructures are inadequate and seem not to be keeping pace with population growth rate. Water bodies, especially freshwater resources, which are the major sources of drinking water, are now major receptacles of treated and untreated or partially treated industrial wastes. These water resources are becoming highly polluted by the activities of the adjoining populations and industrial establishments.

According to UNESCO (2003) some 2 million tons of waste including industrial wastes and chemicals, human waste and agricultural wastes such as fertilizers, pesticides and pesticide residues are dumped into water bodies per day. This has often rendered these natural resources unsuitable for both primary and/or secondary usage (Fakayode, 2005). Increased industrial, agricultural and domestic activities have led to pollution stress on surface waters (Ajayi and Osibanji 1981). These wastes alter the physical, chemical and biological nature of the receiving water body. High levels of pollutants in stream water systems cause an increase in biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), toxic metals such as Cd, Cr, Ni and Pb and fecal coliform hence making such water unsuitable for drinking, irrigation and aquatic life (Phiri *et al*, 2005).

As a result of rapid increase in urbanization, industrial and agricultural land use, there is growing appreciation that regionally, nationally, and globally, the management of surface water resources need to be improved and that the amount of waste and pollution generated by human activity reduced. With competing demands on limited water resources, the problem of improper management of both solid and liquid waste should be addressed.

1.1 Problem Statement

A high amount of solid waste generated within the Kumasi Metropolis is not collected. As a result, a lot of solid wastes are left within the communities. Most of the houses in the communities lack appropriate sanitary infrastructure for liquid waste disposal and therefore major portion of grey water and black water generated are disposed off into the Aboabo Stream. Several cottage industries within the catchment also discharge their effluent directly into the Aboabo Stream.

In order to prevent the Aboabo Stream from pollution, it is imperative that, the uncollected solid waste and the practice of discharge of untreated liquid waste into the Aboabo Stream should be addressed and prevented.

1.2 Justification

Undertaking this study will provide key information for taking appropriate action to improve the water quality of the Aboabo Stream. Major sources of pollution of the Aboabo Stream will be known. This study will also provide information on sanitary infrastructure of the study area and propose measures for proper handling of solid and liquid waste generated in the catchment to avoid pollution of Aboabo Stream.

The study will also provide information to educate communities and individuals about the links between their solid and liquid waste handling practices and its impacts on the Aboabo Stream. The water quality monitoring will also provide information on the characteristics of Aboabo Stream. The information gathered through the monitoring could be used to educate the public on better environmental management practices. The research will also be beneficial to policymakers, and environmental organizations in sanitation and water resources management.

1.3 Research Objectives

The goal of this research is to determine the impacts of waste on the Aboabo stream, an urban surface water resource in Kumasi. The specific objectives are to:

- Determine the solid and liquid waste handling practices within the communities (Pankrono, Moshie Zongo, Buokrom, Dichemso, Aboabo, Asokwa, and Atonsu) along the Aboabo Stream.
- Monitor the water quality characteristics from the upstream to downstream of the Aboabo Steam.
- Determine the sources of pollution of the Aboabo Stream and to propose some mitigating measures to reduce pollution of the Aboabo Stream.

CHAPTER TWO

2.0 Literature Review

2.1 Waste Management Situation in Ghana and Kumasi.

Waste management situation in Ghana is poor. For human excreta management, about 20 % of households in Ghana have no toilets with the percentage increasing to about 70 for the three Northern Regions. Concerning grey water management, only 5 % of the population disposes their grey waste through sewage networks connected to treatment plants, 38 % dispose off their grey waste onto the bare soil whilst 21 % discharge it directly into gutters.

According to the current developmental plan for Kumasi Metropolitan Area (2010-2013) with regard to the management of human faecal matter, over a third (38%) of residents in the Metropolis still use public toilets. Only a quarter (25%) of the residents uses household water closet facilities. Some enclaves within the Metropolis such as Asafo, 4BN, KATH, KNUST, Ahinsan and Chirapatre Housing Estates, which constitute 8% of the population, use sewerage networks. The bucket latrine and pit latrine systems cater for 12 % and 10 % of the population respectively. Due to their inability to have access to proper sanitary facility, 6 % of the population uses the free range system. According to the Ghana Statistical service (2005), inadequate logistics and lack of adequate education on proper waste disposal have contributed to the development of waste problems that the country faces. Waste management systems are inadequate to support the growing population and this creates environmental management problems. The Environmental Protection Agency of Ghana (EPA) maintains that developing countries like Ghana have very little capacity for treating their effluents and consequently large volumes of untreated effluents are discharged into water bodies and open drains (EPA, 2002). Population increase and lack of investment have overstretched the few available sanitation facilities.

The principal generators of waste water in the Metropolis are the industrial facilities. Industries known for discharging large volumes of effluent in Kumasi are Guinness Ghana Brewery limited, Coca Cola Bottling Company and Kumasi Abattoir. To conform to the principle of environmental sustainability as enshrined in the Millennium Development Goal, the Guinness Ghana Brewery limited and Coca Cola Bottling Company have installed treatment plants on their sites. The beverages industries have Environmental Health Officers at post who ensure that the effluent discharged into the water bodies in the Metropolis are free from contaminants. The abattoir, however, does not have this facility hence has been discharging their untreated effluents directly into the water bodies. Other institutions that have contributed to the discharge of large volume of effluents in the Metropolis are the tertiary institutions and the boarding Senior High Schools. Unlike the breweries with the treatment plant for treating effluents before discharging, these schools do not have such facilities hence they discharge their grey water directly into the streams. These untreated effluents discharged by residents and some institutions have contributed immensely to the pollution of the terrestrial habitat. Light industrial activities in Suame Magazine and saw dust from some saw mills also generate significant amounts of waste oil and leachate adding to environmental pollution (Omane, 2002, 2001; Obuobie *et al*., 2006).

2.2 Water Quality of Streams and Rivers in Kumasi

Pollution has been a problem in Kumasi Metropolitan Area because controls on discharges are difficult to enforce (CEDAR, 1999). Most rivers are used for washing (clothes and vehicles). According to McGregor *et al* (2000) the potential water quality problems in and around Kumasi include; river pollution in and downstream from Kumasi resulting from untreated sewage and other domestic waste; hospital waste; industrial waste (chemical, heavy metal, oils, sawmill waste, brewing waste, abattoir waste etc). Ghesquiere (1999) carried out a review of studies by some students at the UST on the quality of most of the Streams and Rivers passing through Kumasi. Although the studies were done at different times with samples taken from different locations, clear pattern of pollution could be discerned, and the values obtained were herein higher compared to the EPA guidelines.

Ghesquiere (1999) reported that, the Subin River is the most highly polluted, with very high levels of suspended solids and faecal coliform (over 60 million per 100ml). He argued that, the high values of the pollutants may probably be attributed to the fact that the river passes through the densely populated residential areas of the City as well as through the Kumasi market area where lots of commercial activities take place. This Stream also receives raw night soil and septage from some hotels located within its catchments (Cornish *et al*, 1999). Ghesquiere (1999) again observed from his studies that, the Aboabo Stream is polluted largely due to the effluents it gathers from the large part of northern Kumasi and this is reflected in relatively high levels of suspended solids and very high numbers of faecal coliform. He also found out that, the Sisal River shows lower levels of suspended solids and faecal coliform compared with either the Subin or Aboabo Stream. He further observed that, the

Wiwi, located upstream of the City, is clear than all the other rivers draining Kumasi, probably due to the fact that only a small portion of its catchments is under urban development. According to Ghesquiere (1999) the pattern of pollution level of these rivers is such that the pollution is higher in the more urbanized areas (Subin area), and this reflects in Rivers and Streams downstream of Kumasi. The higher values of faecal coliform are as a result of faecal matter disposal, which is explained by the precarious sanitary conditions (Ghesquiere, 1999).

Danquah (2010) also did a study on the causes of pollution and health effects of Aboabo River pollution. He tested water sampled from the Aboabo Stream for Hardness, pH, Dissolved Oxygen, Total Dissolved solids, Total Suspended Solids, Phosphate, Sulphate, Nitrate, Calcium and Magnesium. He reported that the pH of the Aboabo Stream at both sampling stations was found to be acceptable within the limits of WHO guidelines ($\geq$ 6.5 and $\leq$ 9.5). The dissolved oxygen content of the water was low at all stations. High BOD and COD levels were recorded each exceeding the maximum threshold 50 mg/L and 250 mg/L respectively set by the EPA. He stated that the high values of BOD and COD at both sampling sites indicate that the water has a low potential to support aquatic life such as fish.

2.3 Effects of Poor Water Quality on Water Quantity

Peters and Meybeck (2000) assert that water quality degradation is a principal cause of water scarcity and could reduce the amount of freshwater available for domestic, agricultural and industrial use. The quantity of available freshwater is thus linked to quality which may limit its use (Chapman, 1996). Human activity such as the indiscriminate dumping of refuse and the channeling of untreated domestic and industrial effluents into rivers reduce water quality and also reduce the uses to which water can be put. Poor water quality has an impact on the quantity of potable water in a number of ways. Generally, treatment processes for polluted water remove pollutants through creation of a waste sludge. The poorer the water quality of the source water, the greater the level of treatment that will be required to bring it to a useable standard, and the less clean the water that will result from treatment. Also, more polluted water requires a significant amount of energy to treat.

2.4 Origin, Characteristics and Composition of Wastewater

Available literature (Hrudey, 2003; Metcalf and Eddy, 2003), established that an understanding of the nature (characteristics and situational analysis) of wastewater creates awareness on the need to treat wastewater prior to discharge into the environment. Moreover, this is also essential in the design and operation of wastewater collection, treatment and reuse facilities (Metcalf and Eddy, 2003). Wastewater, according to Lee (2007), originates from household wastes, human and animal wastes, industries, storm runoff, and groundwater infiltration. Each of these sources however, produces wastewater with specific characteristics (Spellman, 2003). The characteristics of wastewater include physical, chemical, and biological characteristics which depend on the water usage in the community, the industrial and commercial contributions, weather, and infiltration/inflow (Lee, 2007). It also depends on the type of diet, health status and water use patterns (Awuah, 2006). Estimates from literature (Lee, 2007; Carden *et al*., 2007; Van Rooijen *et al*., 2009) indicate that, approximately 60 to 85 per cent of per capita water consumption becomes wastewater. According to Liu (1999), domestic water consumption, resulting in wastewater production is influenced by various factors such as by climate, community size, density of development, community affluence, dependability and quality of water supply, water conservation requirements or practices, and the extent of metered services. Other factors include degree of industrialization and cost of water (Liu, 1999). It also depends on the type of diet, health status and water use patterns (Awuah, 2006). Metcalf & Eddy (2003) classified wastewater into three categories depending on its strength; weak, medium and strong wastewater. In countries where water is inadequate (Awuah, 2006), it is observed that the wastewater is generally strong.

2.4.1 Physical Characteristics of Wastewater

The most important physical characteristics of wastewater are its temperature and its solids concentration (Lee, 2007). The temperature influences chemical reactions and biological activities whiles solids, affect the operation and sizing of treatment units (Liu, 1999). The Solids consist of matter suspended or dissolved in water and wastewater (APHA/AWWA/WEF, 2003; Lee, 2007). Dissolved solids refer to the portion of solids that passes through a filter of 2.0 μm (or smaller) nominal pore size under specified conditions whiles the portion retained on the filter is the suspended solids. Other important physical characteristics include particle size distribution, colour, transmittance, conductivity, density, specific gravity, specific weight and odour (Metcalf and Eddy, 2003). In terms of colour, fresh wastewater is usually a light brownish-gray colour (Spellman, 2003). Odours in wastewater are generally as a result of gases produced by the decomposition of organic matter or by other substances added to the wastewater (Spellman, 2003).

Fresh domestic wastewater has a musty odour and changes to a rotten egg odour in septic wastewater due to the production of hydrogen sulphide. Electrical conductivity (EC) is a measure of the capacity of an aqueous solution to conduct an electric current due to the presence of ions. Electrical conductivity (EC) increases with increasing concentration of ions and temperature of solution. Pescod (1992) established that, EC increases by approximately 2 percent per °C increase in temperature.

2.4.2 Chemical Characteristics of Wastewater

The chemical constituents of wastewater are typically classified as inorganic and organic (Metcalf and Eddy, 2003). Inorganic chemical parameters according to Liu, (1999), include salinity, hardness, pH, alkalinity, iron, manganese, chlorides, sulphates, sulphides, heavy metals (Mercury, lead, chromium, Copper, and Zinc), nitrogen (organic, ammonia, nitrite, and nitrate) phosphorus and gases. The pH of wastewater indicates the activity of hydrogen ions and describes its acidity or basicity. Wastewater becomes extremely difficult to treat by biological means if it has excessive concentration of hydrogen ion (low pH) (Metcalf and Eddy, 2003). According to Awuah, (2006), pH is very important in an aquatic environment to many metabolic reactions in microbial cells which includes energy generation and ion transport.

Phosphorus in domestic wastewater normally originates from phosphate compounds in detergents (Lee, 2007) and usually exists in the form of orthophosphate, polyphosphate and organic phosphate (Metcalf and Eddy, 2003). The orthophosphates are available for biological metabolism without further breakdown whiles the polyphosphates undergo hydrolysis and revert to the orthophosphate forms in aqueous solution. Nitrogen compounds in wastewater originate principally from plant and animal origin, sodium nitrate and atmospheric nitrogen. It exists in wastewater usually in the form of ammonia (NH_3), ammonium (NH_4^+), nitrogen gas (N_2), nitrite ion (NO_2^-) and nitrate ion (NO_3^-) (Metcalf and Eddy, 2003). Chemical parameters associated with the organic content of wastewater include the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), and Total Oxygen Demand (TOD). Both BOD5 and COD are often used as a measurement of pollutants in wastewater and natural waters (Karikari *et al*., 2007; APHA/AWWA, 2003). Primarily, BOD as explained by Reynolds *et al*. (2002) is the level of organic content in wastewater measured by the demand for oxygen that can be consumed by living organisms in the wastewater. Wastewater with high BOD content is characterized by low oxygen content and high biological activity.

Chemical Oxygen Demand, according to Spellman, (2003) measures the amount of oxidizable matter present in wastewater. It increases significantly with the presence of industrial wastes. Because nearly all organic compounds are oxidized in the COD test, while only some are decomposed during the BOD test, COD results are always higher than BOD results (Weiner *et al*., 2003). However, COD does not differentiate between biologically degradable and non-degradable organic matter. According to Helmer (1997) biological degradation consumes the oxygen present in surface water and results in anaerobic conditions, odour formation, fish kills and ecological imbalance. The sources of BOD according to Spellman (2003) include leaves and wood debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants; failing septic systems; and urban stormwater runoff. Lui (1999) reported that, heavy metals are usually added to wastewater from commercial and industrial activities and may have to be removed if the wastewater is to be reused. Many of these metals such as Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni) and Zinc (Zn) in trace quantities, promote the growth of biological life in most waters. However, in excessive quantities they become toxic and interfere with many beneficial uses of the water.

2.4.3 Biological Characteristics of Wastewater

The major groups of microorganisms present in wastewater are bacteria, fungi, protozoa, microscopic plants and animals, viruses and helminths (Lee, 2007). Most microorganisms (bacteria, protozoa) are responsible and also beneficial for biological treatment processes of wastewater (Liu, 1999; Lee, 2007). However, Awuah (2006) reported that, depending on the dose and susceptibility of the host, some of these organisms found in wastewater can cause diseases of the gastrointestinal tract such as typhoid and paratyphoid fever, dysentery, diarrhoea and cholera. Table 2.4 shows the concentration and infectious doses of pathogenic organisms present in wastewater. From the table, it can be observed that *Clostridium perfringens* is highly infectious – as low as 1 per 100mL can cause infections.

Table 2.1: Concentration and infectious doses of pathogenic organisms in wastewater.

Organisms	Concentration in raw wastewater (No./100mL)	Infectious dose
Bacteria	-	-
Total coliforms	107 – 109	(unknown
Faecal coliforms	106 – 108	106 – 1010
Clostridium perfringens	103 – 105	1 – 1010
Faecal streptococci	104 – 105	-
Pseudomonas aeruginosa	103 – 104	-
Shigella	100 – 103	10 – 100
Salmonella	102 – 104	104 – 107

Source: Awuah, 2006

Strauss (2000) reported that faecal coliforms are the most commonly used indicator bacteria for faecal contamination, since their excreted load is similar or larger than that of pathogenic organisms, and their survival time in the environment is longer.

2.5 Wastewater Sampling

Generally, two types of samples are used for water quality monitoring: grab samples and composite samples, depending on the specific test, rationale for collecting water samples and the applicable regulatory requirements (Spellman, 2003). Single samples collected at a specific spot at a site over a short period of time (typically seconds or minutes) are referred to as grab samples (APHA/AWWA/WEF, 1999). They represent only the conditions at the time of collection of samples. Composite samples are obtained from a mixture of a series of individual grab samples collected over a specified period in proportion to flow (Spellman, 2003). This type of sample is taken to determine average conditions in a large volume of water whose properties vary significantly over the course of the day.

2.6 Surface Water Quality Monitoring

Water quality monitoring, as defined by UNESCO/WHO/UNEP (2006) refers to the actual collection of information at specific locations and at regular intervals in order to provide the data which may be used to define current conditions, establish trends, etc. According to Helmer (1997) and Abdul-Razak *et al*. (2009), water quality monitoring is an essential tool for environmental agencies to determine the quality of water bodies and make management decisions for improving or protecting the intended uses. It is therefore necessary that consistent information on water quality is collected, analysed and evaluated in a timely and efficient manner (Helmer, 1997). To achieve this, authors of various guidelines for surface water monitoring (USEPA, 2007; Tennessee Valley Authority (TVA), 2009) assert that appropriate documentation of data and the use of clean sampling equipment are imperative.

USEPA (1994) also recommends that, the hydrology and morphometrics (eg measurements of volume, depth, etc.) of a stream or impoundment are also important factors to be determined prior to sampling. This will aid in determining the presence of phases or layers in Streams or impoundments, flow patterns in streams, and appropriate sample locations and depths. Although there are no universal sampling procedures due to widely varying sampling situations, the following surface water sampling techniques, as described in Table 2.6, are commonly used. They range from simply dipping sample containers manually to pick water samples to the use of automatic samplers. The water samples can be in the form of grab or composite samples depending on the field conditions and study data needs (TVA, 2009; USEPA, 2007). A surface grab sample may be necessitated based on the following conditions; stream velocity is such that penetration to depth is not easily obtained, surface sheen/film is identified, low water exists, or a sample from the upper surface of the water body is required (TVA, 2009). But, when the sample will be used to describe general water quality bracketing a period of time, a composite sample can be collected using an automated composite sampler.

Table 2.2: Surface water sampling techniques

Sampling technique	***Applicable situation***
Dip sampler	Useful in situations where a sample is to be recovered from an outfall pipe or along a Lagoon where direct access is limited. The device therefore allows access from a discrete location with the aid of its long handle
Peristaltic pumps	Used to collect a water sample from any depth if the pump is located at or near the surface water elevation.
Discrete Depth samplers; e.g., Kemmerer or Van Dorn bottles	Used to collect discrete samples from a specific depth.
Stainless steel scoops	Provide a means of collecting surface water samples from surface water bodies that are too deep to access by wading. Used directly to collect and transfer a surface water sample to the sample container or it may be attached to an extension in order to access the selected sampling location.
Dipping Using Sample Container	Useful when the surface water source is accessible by wading or other means. Sample is collected directly into the sample container
Automatic samplers	Where unattended sampling is required (e.g., storm-event sampling, time-of-travel studies) an automatic sampler may be used

Source: USEPA, 2007

2.7 The CCME Water Quality Index

An integral part of any environmental monitoring program is the reporting of results to both managers and the general public. This poses a particular problem in the case of water quality monitoring because of the complexity associated with analyzing a large number of measured variables (Saffran, 2001). The data sets contain rich information about the characteristics of the water resources. The classification, modeling and interpretation of data are the most important steps in the assessment of water quality. The CCME Water Quality Index is used to evaluate success and failures in management strategies for improving water quality. In general, the index incorporate data from multiple water quality parameters into a mathematical equation that rates the health of water body with a single number. That number is placed on a relative scale to justify the water quality in categories ranging from poor to excellent. The water quality is characterized as excellent (95-100), good (80-94), fair (65-79), marginal (45-64) and poor (0-44). This number can be easily interpreted and understood by political decision makers, non-technical water managers and the general public as a whole. The CCME Water Quality Index provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience and, like any other tool requires knowledge about principles and basic concepts of water and related issues (Nikbakht, 2004). It is a well-known method of expressing water quality that offers a stable and reproducible unit of measure which responds to changes in the principal characteristics of water (Brown *et al,* 1972

The specific variables, objectives, and time period used in the index are not specified and indeed, could vary from region to region, depending on local conditions and issues (CCME, 2001). It is recommended that at a minimum, four variables sampled at least four times be used in the calculation of index values. However, a maximum number of variables or samples are not specified. The selection of appropriate water quality variables for a particular region is necessary for the index to yield meaningful results. Clearly, choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. It is up to the professional judgement of the user to determine which and how many variables should be included in the CCME Water Quality Index to most adequately summarize water quality in a particular region. It is also expected that the variables and objectives chosen will provide relevant information about a particular site. The index can be used both for tracking changes at one site over time, and for comparisons among sites. Sites can be compared directly only if the same variables and objectives are used. However, if the variables and objectives that feed into the index vary across sites, comparing among sites can be complicated. In these cases, it is best to compare sites only as to their ability to meet relevant objectives.

The advantages of this approach are as follows; it is flexible with respect to the type and number of water quality variables to be tested, the period of application, and the type of water body (stream, river reach, lake, *etc.*) tested. These decisions are left to the user. Therefore, before the index is calculated, the water body, time period, variables, and appropriate objectives need to be defined. The body of water to which the index will apply can be defined by one station (*e.g.,* a monitoring site on a particular river reach) or by a number of different stations (*e.g.,* sites throughout a lake). Individual stations work well, but only if there are enough data available for them. The more stations that are combined, the more general the conclusions will be. The time period chosen will depend on the amount of data available and the reporting requirements of the user. Secondly, this model is flexible, allowing one to choose the parameters to use and standardize them according to the objectives and area of study. It is a useful tool for describing the state of the water column, sediments and aquatic life and for ranking the suitability of water for use by humans, aquatic life, wildlife, etc. As with most monitoring programs, the index will not usually show the effect of spills, and other such random and transient events, unless these are relatively frequent or long lasting.

CHAPTER THREE

3.0 Study Area and Methodology

3.1 General Background of the Study Area

3.2.1 Location, Size and Climate

Kumasi is located in the transitional forest zone, about 270km north of the national capital, Accra. It covers a total land area of 254 square kilometer, stretching between latitude 6.35^o – 6.40' N and longitude 1.30^o – 1.35' W , an elevation which ranges between 250 – 300 meters above sea level. The Kumasi metropolis falls within the Wet sub equatorial climatic region and has an average minimum temperature of 21.5°C and an average maximum temperature of 30.7°C. On the average humidity is about 84.16 percent at 0900 GMT and 60 percent at 1500 GMT. The Kumasi metropolis experiences a double maxima rainfall regime (214.3mm in June and 165.2mm in September). The first rainy season is from mid–March to early July whilst the second starts from late August to early October. The dry season is experienced from November to early March (Suraj, 2004). Kumasi is bounded to the north by Afigya Kwabre District and Kwabre East District, to the east by Ejisu Juabeng District and Bosomtwe-Atwima Kwanwoma District, to the west by Atwima Nwabiagya District and to the south by Atwima Kwanwoma District.

3.2.2 Geology and Minerals

In terms of geology, KMA is dominated by the Middle Precambrian Rock whose unique geological structure in the metropolis has both positive and negative impacts on the local economy (KMA D-Plan, 2006-09). The existence of this type of rock has led to the development of the construction industry in the metropolis in addition to a few small-scale mining activities and a proliferation of stone quarrying and sand winning industries. Although these to some extent have contributed to job creation in the metropolis, the extraction of these resources is to a large extent uncontrolled exposing the area and its inhabitants to environmental hazards.

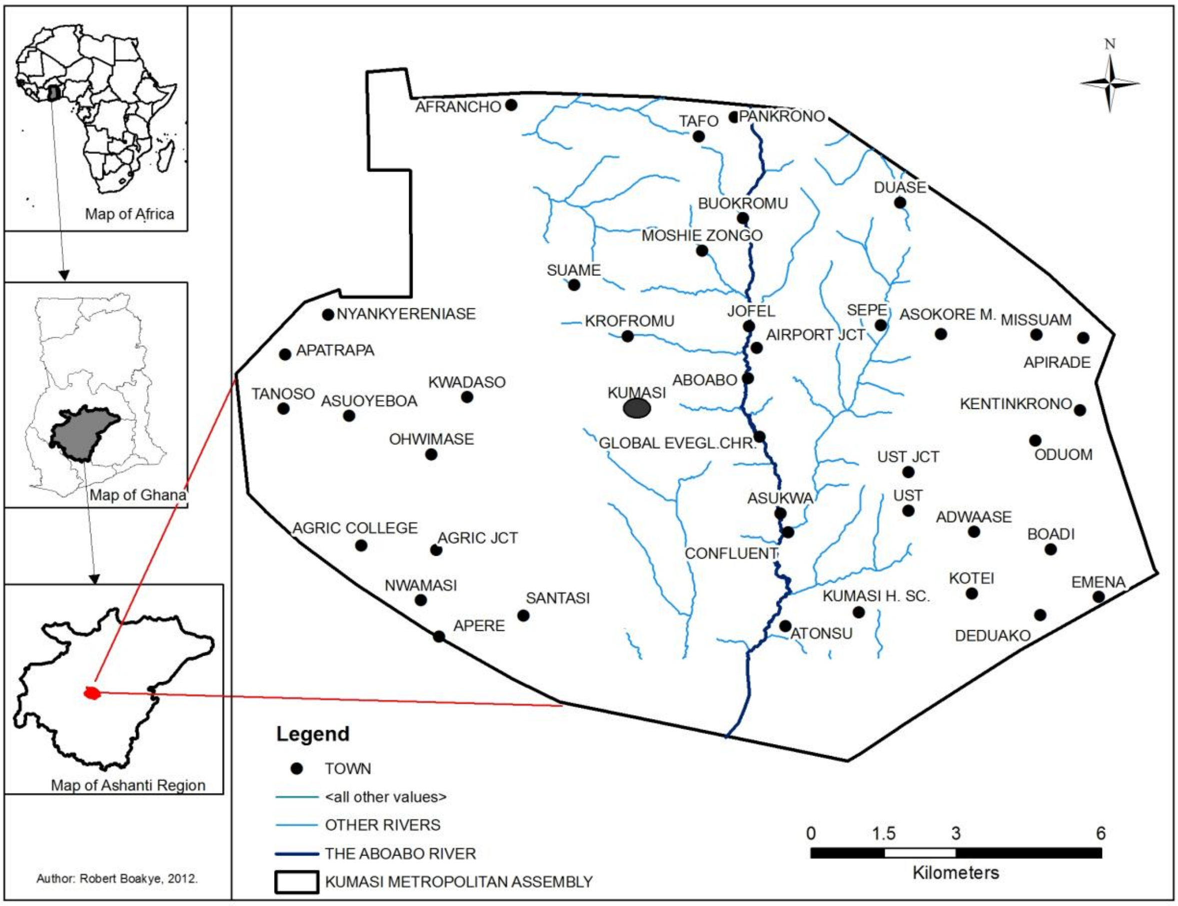

Fig. 3.2.2: Map of the study area. (Authors own map)

3.2.3 Population Size, Growth Rate and Density

Kumasi accommodated a total of 1,170,270 people as of 2000, reflecting an inter-censual growth of 5.4% between 1984 and 2000. It has been projected to a population of 1,915,179 in 2009 based on the inter-censual growth rate of 5.4%. This unprecedented growth of the population between 1984 and 2000 has made Kumasi the most populous district in the Ashanti Region in that it accounts for almost a third of the region's population. Compared to the national and regional growth rate of 3.4% and 2.7 % respectively, the Metropolis is growing at a faster rate indicating the attractiveness of Kumasi in the region. The growth of industrial activities and the large volume of commercial activities in and around the Metropolis have been partially the recipe for the upsurge in urbanization. Kumasi has been estimated to have a daytime population of about 2.5 million due to commuters from neighbouring districts that come to transact business activities in the Metropolis.

3.3 Description of Project Area

3.3.1 Population Growth in the Aboabo River Basin

The Aboabo River Basin has a very large percentage of the population of the metropolis. It is estimated that about 449,692 persons live in the basin making a quarter of the total population (23%) of the Kumasi metropolis. Population in the Aboabo River basin has increased rapidly over the 30 year period (1970-2000). Fig 3.3.1 shows that from 1970 to 1984, the population of the river basin increased from 33,363 to 71,026 indicating a 113 percent increase. From 1984 to 2000 the population of the basin increased from 71,026 to 204,049 indicating a 187 percent increase. Thus from 1970 to 2000, the river basin has had a 512 percent increase in its population.

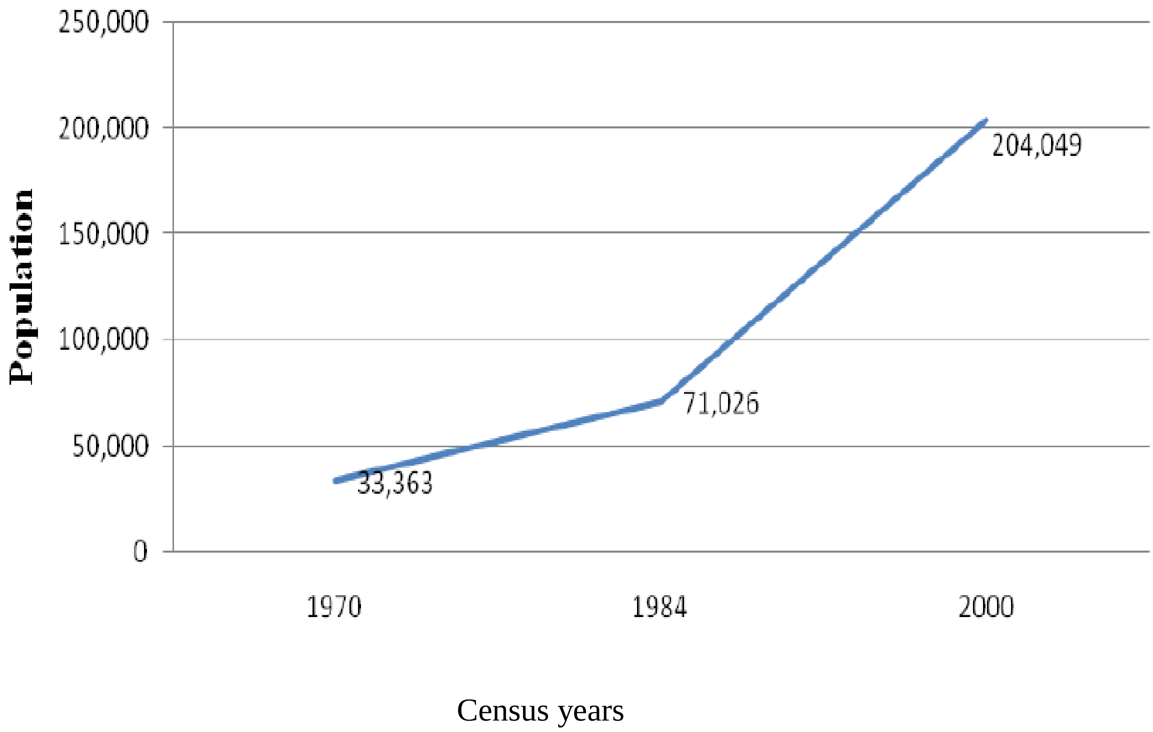

Fig.3.3.1. Trend lines of population growth within the Aboabo river basin 1970-2000. Source: KMA, 2006

3.3.2 Soils in the Aboabo Basin

The Kumasi – Asuansi and Nta – Ofin compound associations are the predominant soil types which occur fairly extensively in the entire Aboabo basin. This compound association consists of the Kumasi, Asuansi, Akroso, Nta, Ofin and Densu Series. In a catena arrangement, the reddish brown to red, well drained Kumasi series and the yellowish red, well drained Asuansi series occur on summits and on upper to middle slopes of the undulations in the Aboabo basin. The Kumasi series are noticeably found in the up hills of the Aboabo basin in the townships of Pankrono, Moshie Zongo and Buokurom. The soils of New Tafo (Krufofrom) and at the eastern boundaries of the Aboabo basin particularly Kwadaso come under the Asuansi series classification. The Nta series is located in the southern part of the Aboabo basin. It is found mainly in the New Amakom area. These series consist of deep brownish yellow to yellowish brown, loamy coarse sands developed mostly in hill wash material. Within valley bottoms, for example at Anloga are found deep, grey, poorly drained alluvial coarse sands classified as Ofin series. In the southern most part of the Aboabo basin is found the clayey soils of the Densu series typology. The Densu series, which are soils that are characterised by slow internal drainage very low permeability and very high water holding capacity as well as prolonged water logging, are found in lowland at Kaase below the Aboabo basin.

3.3.3 The Aboabo River Basin

The Aboabo River basin and its immediate environs generally form the study area of this research. The Aboabo River originates from Tafo-Pankrono at the northern part of the Kumasi Metropolis. It flows through Moshie Zongo, Buokrom, to Aboabo, Anloga Junction and joins the Sisa at a confluence at Asokwa. It is located at the central part of the Kumasi Metropolis. The length of the Aboabo stream within Kumasi Metropolis from the source (Pankrono) to Atonsu, the downstream end is 16.633 Km. It is about 2.5 meters wide upstream and 30.5 meters wide downstream during floods (Hydrological Services Department, Kumasi). At varied points, the Aboabo River yields an average velocity of 0.87m/s (Omane, 2002). The drainage density is very high especially in the central part of the basin and generally exhibits a dendritic pattern. It is characterised in greater portions of the region by ridges covering the entire eastern and northern sections with high altitudes which reach as high as 950ft above sea level. This can be observed mostly in Pankrono and Southern Anhwiaa at the peripheries of the Kumasi metropolis. The central part of the basin on the other hand is covered extensively by lowland running from Moshie Zongo to the Asokwa Extension in the south. This area is mostly undulating in nature with much flat land area in the north-western and southern part of the central lowlands. The main river in the Aboabo basin is the Aboabo Stream flowing from the north to south. Its major tributaries are the Owusu Ansa and Dichemso Streams.

3.3.4 Activities along the Aboabo River Basin

Persons living in the river basin engage themselves in a number of economic activities to earn a living. These include urban agriculture, quarrying, manufacturing, construction, wholesale, retail trade, hotel and restaurant, transportation, storage, communication, real estate, public administration and education. Many housing units are built just along the stream banks and their outfalls are connected to the stream at various sections. Small scale and large scale industries are located within the Aboabo River basin providing employment to many. The small scale industries include palm kennel oil extraction at Atonsu and Moshie Zongo, wood processing industries at Anloga, Atonsu, Asokwa and Ahensan, charcoal producing businesses at Atonsu and Anloga, metal cooking pots production at Aboabo, metal scrape dealers, leather tanning industry at Aboabo and car washes have been developed just along the banks of the stream, refer to appendix7, plate 7.1 to 7.3. In addition, large scale industries like wood processing industries and soap manufacturing companies are located at Aboabo and Asokwa respectively. These industries dispose of their waste generated directly into the river water, which affects the BOD, COD, and also causes the physico-chemical changes.

3.4 Research Methodology

3.4.1 Desk Study

This aspect of the study gathered as much as possible, all relevant secondary data on the research topic. Published and unpublished reports were used. Moreover, peer-reviewed journals and articles were also accessed via the internet for the literature review forming the secondary data.

3.4. 2 Field Visits

Reconnaissance surveys were undertaken on several occasions to get a general idea of the existing situation in the study area. Location and referencing of sampling points, establishment of contacts with opinion leaders, brief interview with members of purposively selected households of the study area and determination of their existing solid and liquid waste handling practices were carried out.

3.4.3 Data Collection

In this study, data collection has been divided into two separate aspects; collection of wastewater samples from drains in the communities and water samples at various points on the stream for laboratory analysis and questionnaire administration – making up the quantitative data. The qualitative data were also collected through Focus Group Discussions and field observations. Fourteen sampling points made up of seven sampling points located on the Aboabo stream, four secondary drains from the study communities that emptied directly into the Aboabo stream and two sampling points on the Sisal Stream, a tributary that joins the Aboabo Stream were identified and referenced to ensure consistency in the sampling points. The seven sampling points located on the Aboabo stream were selected on the basis of potential of water quality impact. These were Pankrono (PSP), Moshie Zongo (MZSP), Krofofrom (KSP), Jofel (JSP), Aboabo (ASP), Anoga junction (AJSP), Asokwa (AKSP) and Atosu (ATSP) sampling points. The Pankrono sampling point is the reference station that provides water quality of the stream close to the source.

The four secondary drains were from Moshie Zongo (MZDSP), Krofofrom (KDSP), Aboabo (ADSP) and Atonsu (ATDSP) communities. These sampling points provided information about the pollution load transported by these drains joining the Aboabo Stream. The two sampling points on the Sisal Stream were Duase (DSP), the upstream and confluent (CFSP) at Asokwa with the Aboabo stream. These sampling points provide information about the impact this tributary has on the Aboabo stream. Grab river water samples were collected from the midstream (½ width of river) from the well mixed zone at all the sample points from a depth of about10-15 cm. Grab wastewater samples were also collected from the drain in the communities before their merger with the Aboabo Stream**.** For verification of the grab samples, composite samples made up of 2 hour grab samples for a 12-hour period (6 am to 6pm) were taken from Pankrono, Aboabo and Atonsu representing the upstream, midstream and downstream respectively in the study area.

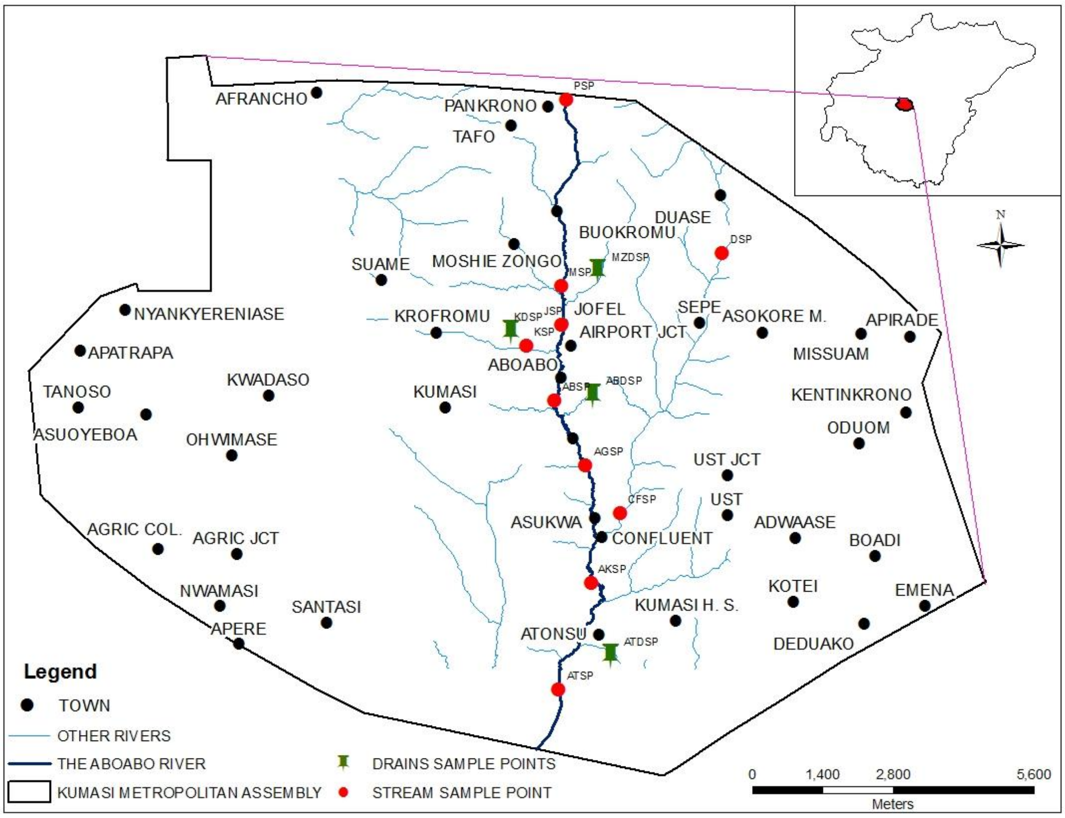

Fig. 3.4.3: Location of sampling points in the study area (Author's map)

Note: all SP are representing "Sampling Points" and DSP are representing "Drain Sampling Point" attached to their various communities.

3.5 Sampling Design

For the qualitative analysis of the waste handling practices within the communities along the Aboabo Stream and to proposed some mitigation measures to reduce pollution of the Aboabo Stream, a sample size of one hundred and twenty three thirty (123) was used in the study. The sample population (n) was computed from the equation adapted from Yamane (1967).

$$n = \frac{N}{1+N(\alpha)^2}$$

Where α is the level of significance or margin of error, n is the sample size and big N is the sample frame. The sample size was determined at a 0.95 % significance level. The statistical formula used to select the sample size for the study based on the fact that the study population is more than 10,000:

$$n = \frac{519513}{1+519513(0.95)^2} = 123$$

The 123 households were randomly selected from the seven major communities in the Aboabo River basin. In the upstream Pankrono, Moshie Zongo and Buokrom 21, 21 and 7 households were studied respectively. Communities that were selected midstream are Dichemso and Aboabo. From these communities, 13 and 21 households were studied respectively. At the downstream, Asokwa and Atonsu communities, 10 and 30 households respectively were studied.

3.6 Administration of Questionnaires

Questionnaires were administered to the residents to find out their existing liquid waste disposal means (grey and black water) as well as their means of solid waste disposal. Structured non-disguised questionnaires with both open and closed ended questions were initially pre-tested and modified to use in the research. All respondents to the questionnaires were residents in the community.

3.7 Data Analysis

This aspect is mainly concerned with analysis of results obtained from:

- Laboratory analysis of wastewater samples from the Aboabo stream and the drains emanating from the communities.
- Administration of questionnaires and focus group discussions.

Results obtained from the laboratory analysis of wastewater samples and questionnaires administered have been analyzed with Microsoft Office Excel, CCME Water Quality Index and Statistical Package for Social Sciences (SPSS) as shown in Appendix 3 and 5.

3.8 Sampling Procedure, Preservation and Laboratory Analyses

The length of the Aboabo stream within Kumasi Metropolis from the source Pankrono to the downstream Atonsu is 16.633 km. Fourteen sampling sites were chosen based on their accessibility, proximity to pollution sources such as communal site, cottage and commercial industry sites. Global Positioning System navigator (GPS etrex VISTA HCX) was used to determine the actual positions of the sampling sites and referenced to ensure consistency in the sampling points during subsequent sample periods. The sampling sites were carefully selected to include the upstream, midstream and the downstream communities as shown in Fig.3.4.3. Water samples were collected from all the fourteen sample sites at the mid-stream at depth of 10-15 cm on a bi-weekly basis for a period of three months (November and January). The samples were put in pre-rinsed clean 1.5 liters voltic bottle. The samples were stored in an icebox at 4 ^{o}C and transported to the Civil Engineering laboratory at KNUST, Kumasi on the same day of collection for analysis for the physical, chemical and bacteriological analysis. Parameters with extremely low stability such as temperature, pH, electrical conductivity, total dissolved solids and dissolved oxygen were measured in-situ with hand-held meters. Other parameters analysed include, colour, turbidity, total suspended solids, E-coli, total coliforms, chemical oxygen demand (COD) and BOD_5. Phosphates and nitrate were determined to assess the nutrient load. All the methodologies for laboratory analysis were conducted according to the Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF, 2003). A detailed description of the methodologies used in this work is shown in appendix 2**.**

3.9 The CCME Water Quality Index procedure

The index ranges from 0 to 100 and depending on the value; the water quality is characterized as excellent (95-100), good (80-94), fair (65-79), marginal (45-64) and poor (0-44). In general, scoring 80 % and above met expectation for water quality and are of "lowest concern" whiles stations with scores below 40 % did not meet expectation and are of "highest concern". The details of the index are presented in appendix 6. These numbers are divided into 5 descriptive categories to simplify presentation. This index doesn't give any weighted numbers but treats the values of parameters in mathematical way to ensure that all parameters contribute adequately in the final number of the index. The CCME WQI model consists of three measures of variance from selected water quality objectives (Scope; Frequency; Amplitude). The "Scope (F1)" represents the extent of water quality guideline non-compliance over the time period of interest. The "Frequency (F2)" represents the percentage of individual tests that do not meet objectives ("failed tests"). The "Amplitude (F3)" represents the amount by which failed tests do not meet their objectives. These three factors combine to produce a value between 0 and 100 that represents the overall water quality. The formulation of the WQI as described in the Canadian Water Quality Index 1.0 – Technical Report is as follows. The measure for scope (F1) is calculated as follows:

$$F_1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) * 100 \ldots\ldots\ldots\ldots 1$$

The measure for frequency (F2) is calculated as follows:

$F_2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right)$*100………………2

The measure for amplitude, F3 is calculated in three steps: 1) Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective. When the test value does not exceed the objective:

$Excursion_i$=100-$\left[\frac{Objective_j}{Failed\ test\ value_i}\right]$-1…………………………..(3a)

For cases in which the test value exceed the objective

$Excursion_i$=100-$\left[\frac{Failed\ test\ value\ _i}{Failed\ t_i}\right]$-1…………………………..(3a)

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse) is calculated as:

$$nse = \sum_{i=1}^{n} excursion\, i$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right)$$

The water quality index (CCME WQI) is then calculated as:

$$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right]$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Socio-economic profile of residents

Projected population of the communities that the Aboabo Stream traverses is 519,513 for 2010 from base year 2000, with a growth rate of 5.4 % for Kumasi (KMA Statistics Department). Field surveys and responses to questionnaires and interviews gave the following information about the communities. The socio-economic profile of 123 residents in the communities who responded to the questionnaires during the study is shown in Figure 4.1. As can been seen in the figure, female respondents were 67% and male respondents were 33%. Respondents were between the age groups of 18 and 59. The level of education of respondents is high. 31% and 16 % of the respondents has senior higher and tertiary education respectively. 67% of respondents are married and 39% are self employed. From the field surveys, it was observed that the residents in the river basin were engaged in a number of economic activities such as palm kennel oil extraction, metal scrape dealers, metal cooking pots production, car washing bays, charcoal production to earn a living. In terms of religion, 58% of respondents are Christians; 36 % Muslims and 6% stated they do not belong to any religion.

According to Dijkgraaf and Gradus (2004) the quantity of waste generated is estimated as a function of socio-economic characteristics. These include gender, marital status, education, age and employment status. Fullerton and Kinnaman (1996) found out that, for proper solid and liquid waste handling practices, education level and employment status have a positive effect. According to Adebo and Ajewole (2012), females play a major role in household keeping and management issues such as solid and liquid waste handling. They reported that, married people having good occupation with a higher level of education and income tend to express willingness to pay for appropriate waste disposal than other counterparts. Again, married people generate more waste than their other counterparts since they eat from their homes. Communities with higher population level of education tend to dispose waste more appropriately than their other counterparts who do not see the need to pay for disposal of waste generated. Lastly, communities with a larger population of elderly people tend to produce more waste per capita than those with less population of adult. The results obtained for the socio-economic characteristics are in agreement with the observation of Fullerton and Kinnaman (1996) and Adebo and Ajewole (2012). Wilson (1994) reported that, households with larger family size tend to demand more garbage collection services. He also reported that, in terms of religion, Muslims use more water than their other counterparts because of ablution.

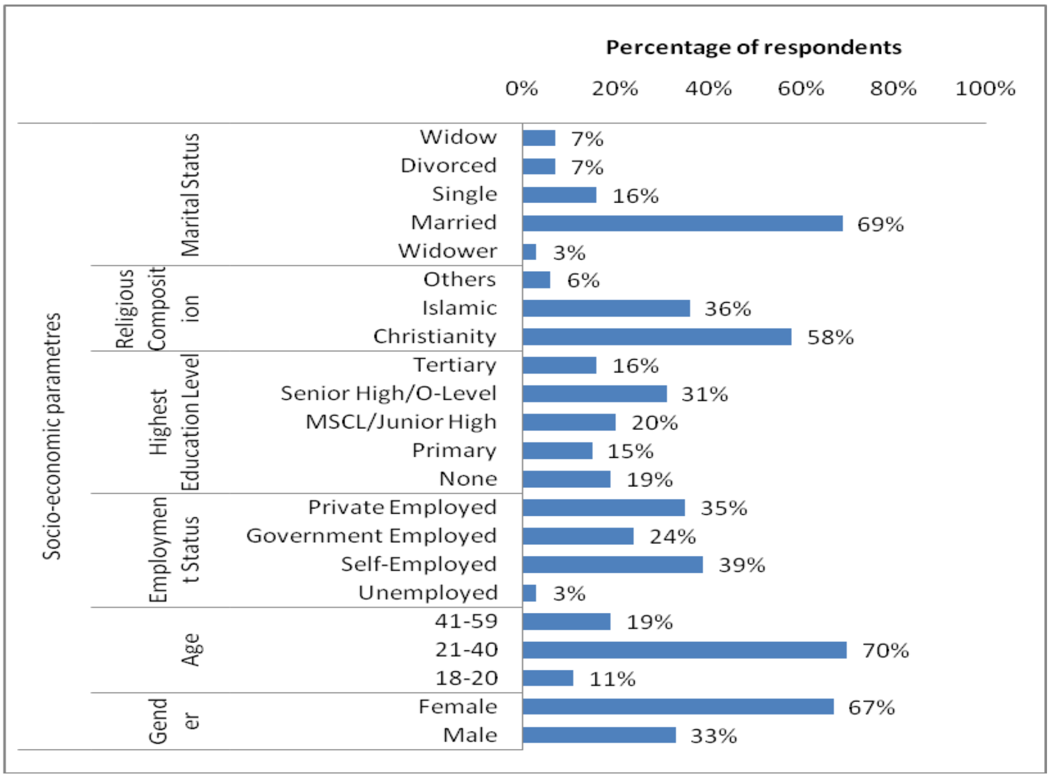

Fig 4.1: Basic socio-economic profile of 123 residents surveyed.

4.2 The solid and liquid waste handling practices among communities along the Aboabo Stream

4.2.1 Solid waste disposal in the communities

The waste generation rate for Kumasi is 0.6 kg/ per/ day (KMA Waste Management Department). The estimated solid waste generated by residents in the study communities is 312 tons /per /day as shown in appendix 7.2. With regard to waste collection, the estimated tonnage of solid waste collected from the study communities also stands at 250 tons leaving 62 tons of estimated waste uncollected per day. From the 123 questionnaire administered 67 % of the respondent in the study communities disposes off their solid waste into the communal bins. 14 % buries their organic solid waste, 9 % practices uncontrolled burning and 10 % into gutters and drains or open spaces. From the respondents of the questionnaire, the following reasons were giving for the indiscriminate dumping of refuse into the Aboabo Stream:

- Designated dumping sites are far from their homes (200 – 250m).
- The Aboabo Stream will carry the refuse away when it rains
- Inability to pay the fee of GH¢ 0.2 – 0.5 (depending on the quantity of waste) for the waste brought to the dump sites for disposal.
- Lack of understanding or knowledge of the essence of paying for waste to be disposed.

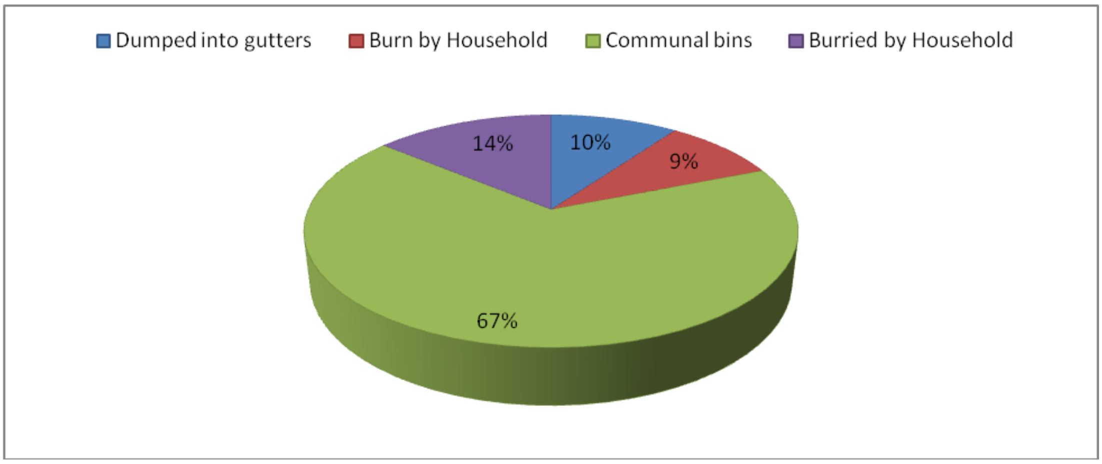

Fig.4.2.1: Solid waste disposal means of the 123 residents surveyed.

4.2.2 Liquid waste disposal in the communities

Analysis of the 123 questionnaire administered shows that, 87 % of the respondent in the study communities' disposes off their liquid waste into the drains, 9 % of the respondents disposes their grey water into the streets or on the open field and only 4

% of the respondent disposes it into the soakaway as evident from fig.4.2.2. Field observation and interviews revealed that, the drains used by households to dispose wastewater emptied their content into the Aboabo Stream. These results are consistent with observation of Shaw (1994), that in less developed countries of South America, Africa, and Asia, it is estimated that 95 percent of all sewage is discharged into rivers, lakes or the ocean. The reasons being low technological capabilities, inadequate funds for pollution control, rapid urbanization and industrialization (Cunningham and Saigo, 1999). The decomposition of the organic matter in the liquid waste contributes to the increase in the BOD, COD and a reduction in the Dissolved Oxygen content of the stream leading to unpleasant odours and giving the river a dark colour.

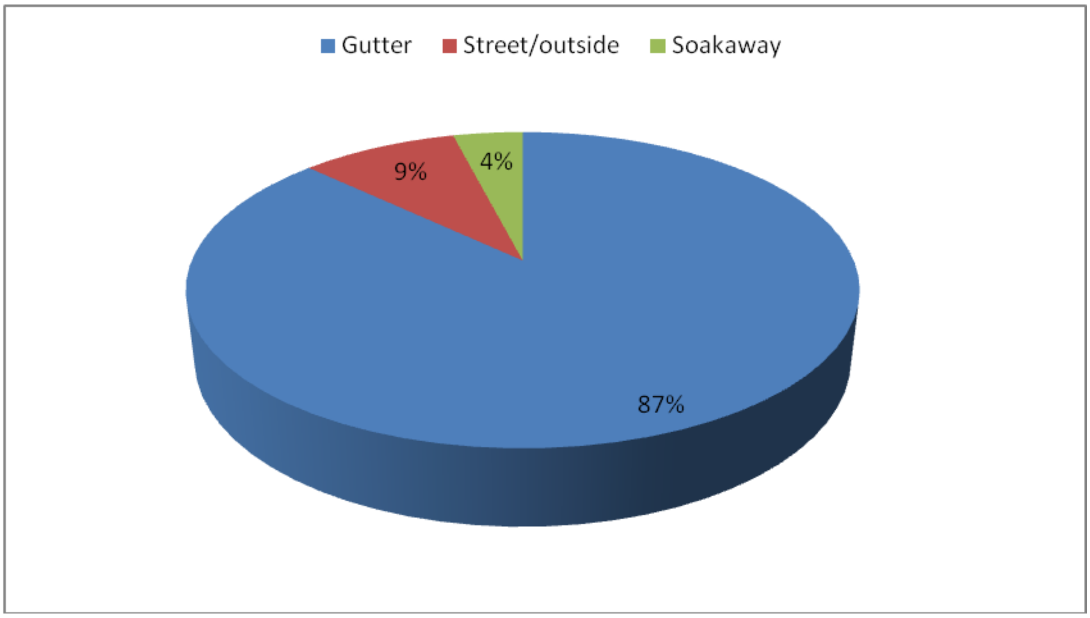

Fig. 4.2.2: Grey water disposal means of the 123 residents surveyed.

4.2.3 Types of Toilets Facilities in the Communities

With regard to the management of human faecal waste in the study communities, from the 123 questionnaire administered, 48% of residents use the public toilets, 30% of the residents use household water closet facilities connected to septic tank, 26 % use water closet connected to the septic tank, and 15 % also use household pit latrine. Due to their inability to have access to proper sanitary facility, 11% of the respondents indicated that they practiced open field defecation (free range) in or along the banks of the Aboabo Stream. According to Robert and Long (2007) the practice of open field defecation (free range) into water bodies pollutes water resources which affects its usability. It also increases its biochemical characteristics and leads to costly averting behavior and/or production impact. It is worth noting that household respondents had various reasons for choosing between the use of public toilets, household toilets and open defecation. Among the reasons given are:

- Lack of money to pay.
- Long queues especially during rush hours.
- Offensive odours

Open field defecation into or along the stream banks leads to the pollution of the stream. This is a contributory factor to the high average total coliform counts of 240 N/100 that was recorded in the wastewater analysis See appendix 3.

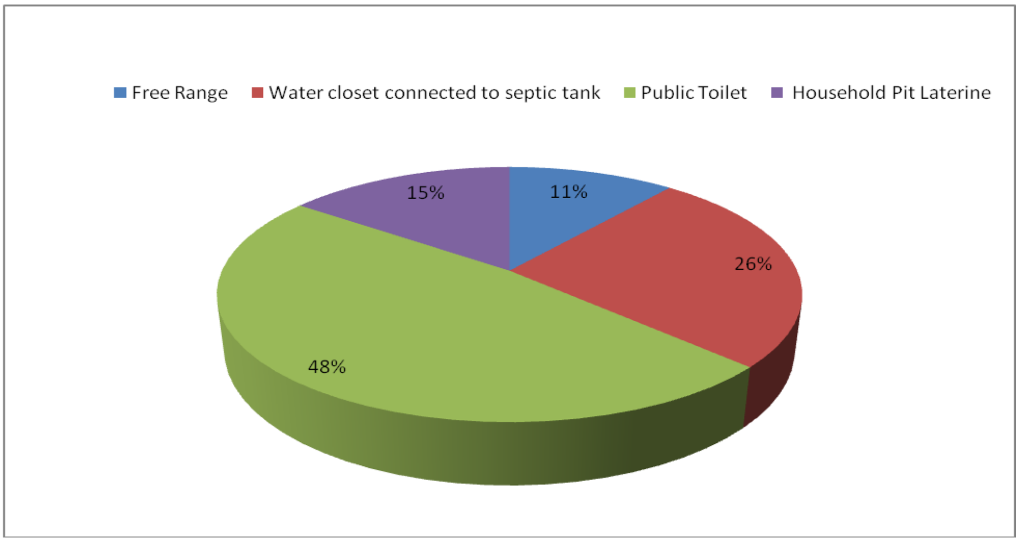

Fig. 4.2.3: Type of toilet facilities of the 123 residents surveyed.

4.3 Propose Mitigating Measures from Respondents to Reduce Pollution of Aboabo Stream

From the 123 questionnaire administered, 45 % of the respondents considered the provision of adequate sanitary (solid and liquid waste) facilities, 22 % suggested education of the residents about the links between their solid and liquid waste handling practices and its impacts on surface waters, 19 % of the respondents also considered the arrest and prosecution of persons who flout KMA bye-laws on sanitation while 14 % of the respondents proposed formation of functional association or volunteer group such as "Save Aboabo Streams". From fig.4.3, the main intervention proposed to reduce the pollution of the Aboabo Stream is the provision of adequate sanitary (solid and liquid waste) facilities in the communities. Interventions to solve the problem of river pollution must not only come from the municipal or national administrative hierarchy, but also from local level residents. For this, the interventions would best serve the interest of those immediately affected.

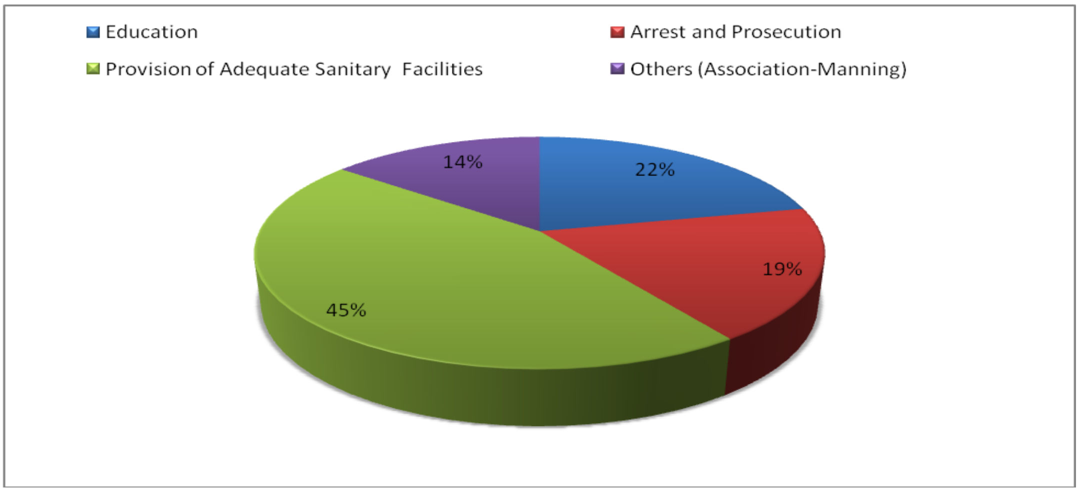

Fig.4.3: Interventions from respondents on how pollution of the Aboabo Stream could be solved.

4.4 Potential uses of the Aboabo Stream after Respondents' Intervention

With regard to the possible uses the Aboabo Stream could be put if the mitigation measures were to succeed, 44 % of the respondent expresses their desire for bathing, 24 % for washing items such as clothes, utensils etc, 22 % for fishing and 10 % for other activities such as gardening, feeding of animals etc.

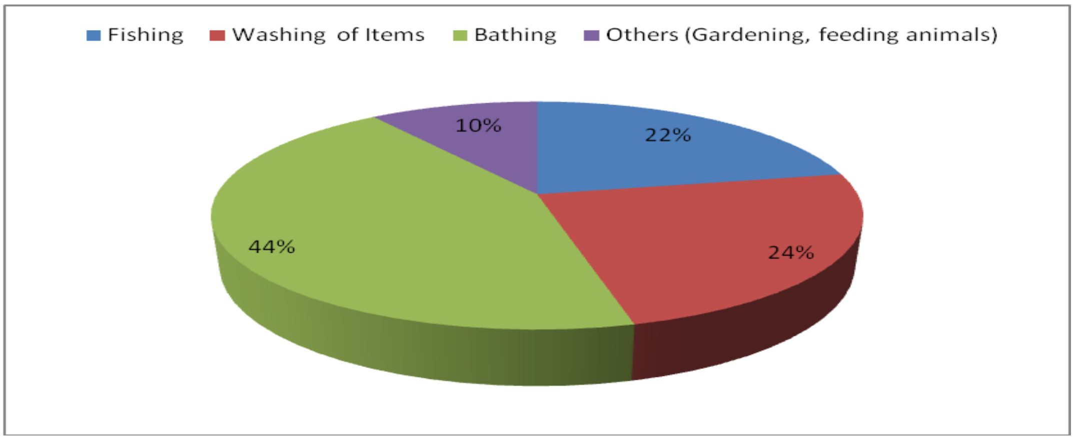

Fig. 4.4: Possible uses of the Aboabo Stream after respondents' intervention.

4.5 Water Quality Analysis of Aboabo Stream and Community Drains

Results of water quality analysis of Aboabo Stream and community drains in terms of various characteristics are discussed below.

4.5.1 Biochemical characteristics

4.5.1.1 Biochemical oxygen demand

The sampling points within the catchment of the Aboabo Stream include the following communities (Pankrono, Moshie Zongo, Kroforom), (Jofel, Aboabo, Anloga Junction), and (Asokwa, Atonsu) for the upstream, midstream and downstream categories respectively (fig.3.4.3). The water quality of Aboabo Stream in terms of organic pollution had relatively good results from the upstream, Pankrono, with a mean BOD_5, value of 38.25 mg/L. This meets the EPA guideline value for wastewater quality discharge into water bodies of 200 mg/L for existing facilities. This could probably be due to the fact that, it is close to the source and fewer discharges of solid and liquid waste have entered the stream. Again, personnel observation revealed that, there were more solid waste collection containers, door to door systems and people there are more enlighten and therefore practice appropriate waste disposal. From Moshie Zongo through Krofofrom, Jofel, Aboabo to Anloga Junction, the BOD value for the Aboabo Stream rose up. The high BOD is attributed to the high organic loading (food and animal waste) resulting from both solid and liquid wastes discharging into the stream from the drains. At Duase, the water quality is good with a mean BOD of 8.25 mg/L. This is below the EPA guideline value. Duase (fig.3.4.3) is at the upstream of Sisal Stream and it is close to the source. The Sisal Stream is a tributary that joins the Aboabo Stream at Asokwa. Although the Sisal Stream passes through urbanized communities in the Metropolis, however, since its quality is relatively better, it dilutes the Aboabo Stream reducing its mean BOD value of 250 mg/L from Anloga Junction to a mean BOD value of 124.9 mg/L at the confluent with the Aboabo Stream at Asokwa. At Atonsu, there was an increase in the mean BOD value to 248.05 mg/L as evident from fig.4.5.1.1**.** This could probably be due to high organic load from grey water, the abattoirs, and effluents from restaurants, storm water as well as faecal matter disposal into the Stream.

The BOD values of the drains were 399 mg/L for Moshie Zongo, 310 mg/L for Krofofrom, 583.5 mg/L for Aboabo and 468 mg/L for Atonsu. The increase in the BOD values of Aboabo and Atonsu drains could be due to discharges of high organic content. According to Metcalf and Eddy, 2003, if the BOD/COD ratio for untreated wastewater is 0.5 (mg/l) or greater, the wastewater is considered to be easily treated by biological means. From the research, BOD/COD ratios had values of 0.97 mg/L and 0.55 mg/L for Pankrono and Atonsu respectively with an average value of 0.7 mg/L for the Stream. For the drains, BOD/COD ratios were also between 0.30 mg/L to 0.54 mg/L for Krofofrom and Atonsu respectively with an average of 0.4 mg/L. Comparing the average values of BOD/COD obtained, it can be inferred that, the Stream is grossly polluted by the drains emanating from the communities that directly empties into the Stream as evident from the figure above fig. 4.5.1.1.

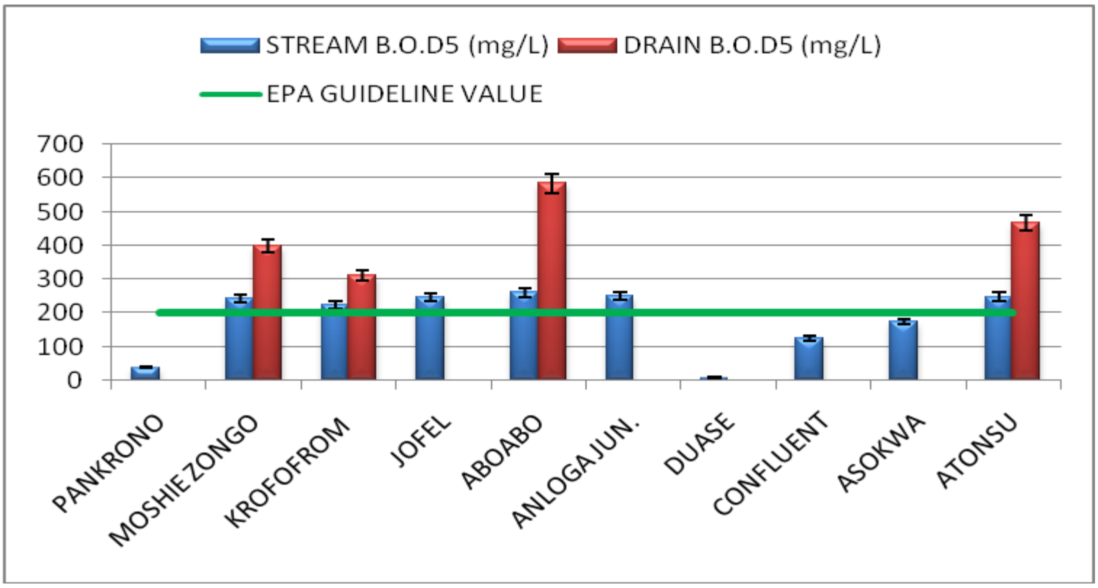

Fig 4.5.1.1: Concentration of BOD_5, 20°C in Aboabo Stream and community drain.

4.5.1.2 Chemical oxygen demand

From the upstream, Pankrono, COD value was 68 mg/L and at the downstream, Atonsu, COD value was 403 mg/L. They all conformed to the EPA guideline value for wastewater quality discharge into water bodies of 1000mg/L (fig.4.5.1.2). This could probably be due to the fact that, the wastes that are being generated from the various communities are biodegradable. From Moshie Zongo, Krofofrom, and Aboabo, the COD value rose slightly, probably due to the discharge of some industrial effluents containing oils, grease and other petrol-chemical from fitting shop (garage) located near the Stream at these locations. At Jofel (fig.3.4.3), the COD value drops a little. This could probably be due to the dilution effect by well or pipe water from the car wash near the filling station at Jofel. Secondly, there are wet lands along the Stream banks at this stretch. According to literature, wetlands serve as natural purification media**.** Thirdly, from Aboabo to Anloga Junction, the decrease in COD value could be due to self-purification of the stream within this long stretch of about 5km. This is in line with Metcalf and Eddy, 2003, who reported that, as the travel time in the collection system increases, natural purification can take place. From the Anloga Junction to Asokwa, the COD values drop slightly probably due to dilution effect of Sisal Stream at the confluent with the Aboabo Stream. According to literature, dilution greatly reduces the impact of all contaminants. It is the only mechanism by which the concentration of some chemical species is naturally reduced. The dilution of a contaminated flow with relatively clean water will improve the biological environment and enhance the natural stabilization processes. COD/BOD ratio had values between 1.03 mg/L to 2.4 mg/L from the upstream, Pankrono to the downstream.

For the COD of the drains, Moshie Zongo, Krofofrom, Aboabo and Atonsu had values of 1040 mg\L, 1027 mg\L, 1066.5 mg\L and 1053.5 mg\L respectively. They were all above the maximum permissible guideline value set by the EPA. This could probably be due to the fact that, the wastewater emanating from these communities may contain household chemical products such as detergents, soaps, shampoos, preservatives, dyes and cleaners. Also increase in COD value could probably be due to presence of excessive chemicals in raw domestic effluents discharged into the Stream from the communities. COD/BOD ratio for the drains were between 0.42 mg/L to 3.31 mg/L for Moshie Zongo to Atonsu, with an average COD/BOD value of 2.03 mg/L. According to Stendahl (1990), COD/BOD ratio indicates how biologically degradable the wastewater is – COD/BOD ≤ 2 shows relatively easily degradable substances while high values indicate that the substances are difficult to break down.

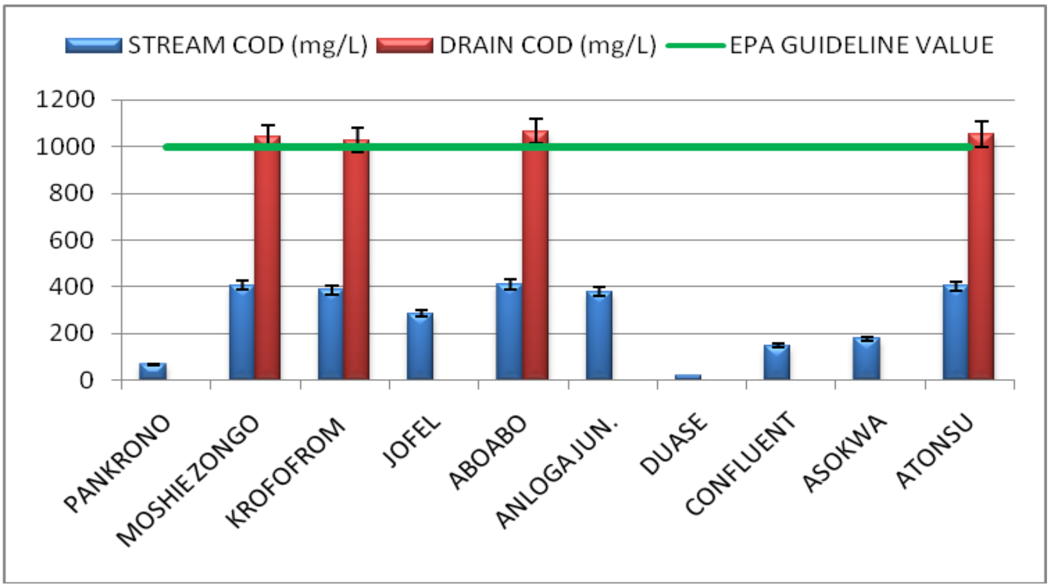

Fig 4.3.1.: Concentration of COD in Aboabo Stream and community drain.

4.5.1.3 Total coliform and *E-coli*

The Stream water quality in terms of total coliforms had been relatively fairly good throughout the sampling points. The upstream, Pankrono, had a total coliforms occurrence value of 20 N/100ml and the downstream, Atonsu, had a total coliforms occurrence value of 184 N/100ml. The Stream total coliforms are generally well below the EPA guideline value of 400 N/100ml (fig. 4.5.1.3). However, the total coliforms for the drains are quite different from Moshie Zongo to Atonsu. They were generally above the prescribed standard. The total coliform count was 410 N/100ml at Moshie Zongo and Krofofrom with a total coliforms occurence value of 410 N/100ml and 408 N/100 ml at Krofofrom. The value for Aboabo and Atonsu are 544 N/100ml and 447 N/100ml respectively. This may be attributed to discharge of wastewater from the community and faecal matter by runoff from the communities into the Aboabo Stream. The faecal matter results from open defecation along the Stream and animal waste from cattle kept on free range in the communities.

Even though the Stream water quality for total coliforms had been relatively below the EPA guideline value throughout the sampling points, that of *E-Coli*, has proven differently for the samples taken from upstream, Pankrono, to the downstream, Atonsu. The water quality of the Stream in terms of *E-coli* occurrence had been relatively good from upstream Pankrono, where it met the EPA guideline value. There was an increase at Moshie Zongo but a decrease at Krofofrom. At Jofel, there was a decrease but at Aboabo, there was a sharp increase with a slight decrease at Anloga Junction. The high counts of *E- coli* can be attributed to the indiscriminate open field defecation along the river banks by both humans and other animals that graze along the river banks. Secondary, it may be either due to the following: higher disposal of faecal materials into the Stream, channeling of black water into the Stream, inadequate sanitary facilities such as toilet facilities etc within this stretch. Also the Stream receives many drains downstream within this location**.** At Duase, the *E- coli* occurrence was 3 N/100ml. This was far below the EPA guideline value of 10 N/100ml for *E- coli* of existing facilities. At the confluent of the Sisal Stream with the Aboabo Stream, the *E- coli* value from Anloga Junction decreases from 131 N/100ml to 40 N/100ml at Asokwa. This could probably be due to dilution effect of Sisal Stream that reduces the *E-coli* occurrence. At Atonsu, there was a slight increase in *E-coli* value and could probably due to presence of wastes containing high concentration of microbial nutrients. This could obviously promote an after growth of significantly high coliform types and other microbial forms as evident from fig. 4.5.1.4.

For the drains sampled, the *E-coli* values are generally high above the prescribed water quality standard. It is more pronounced at the most polluted stretches of the

Aboabo stream; between Moshie Zongo, Aboabo and Atonsu. This may be due to flushing of faecal materials as well as open field defecation practices by some of the residents. Secondary, solid waste that is disposed into the drains might contain human faecal matters which are potential sources of pathogens. It can therefore be inferred that the Stream is mainly polluted by the drains emanating from the communities that empty their content directly into the Stream as evident from the above fig. 4.5.1.4.

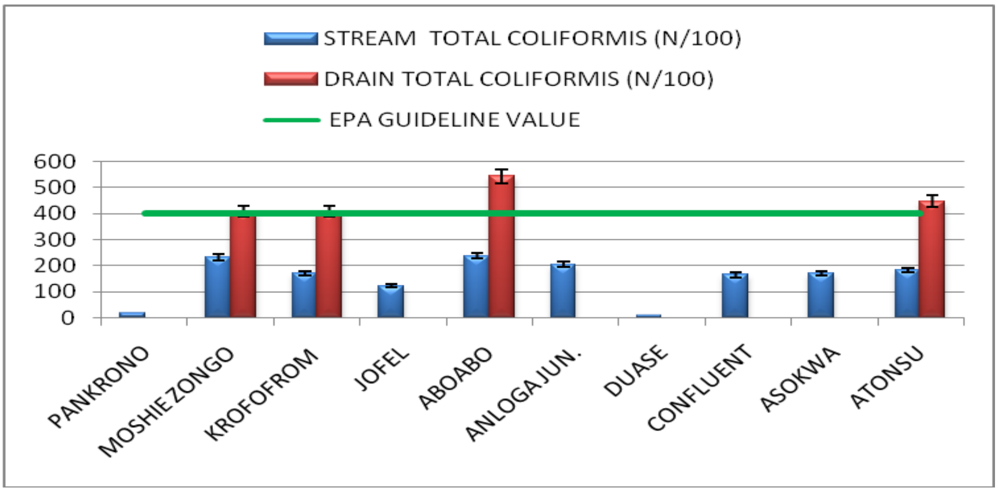

Fig 4.5.1.3: Total coliforms in Aboabo Stream and community drain.

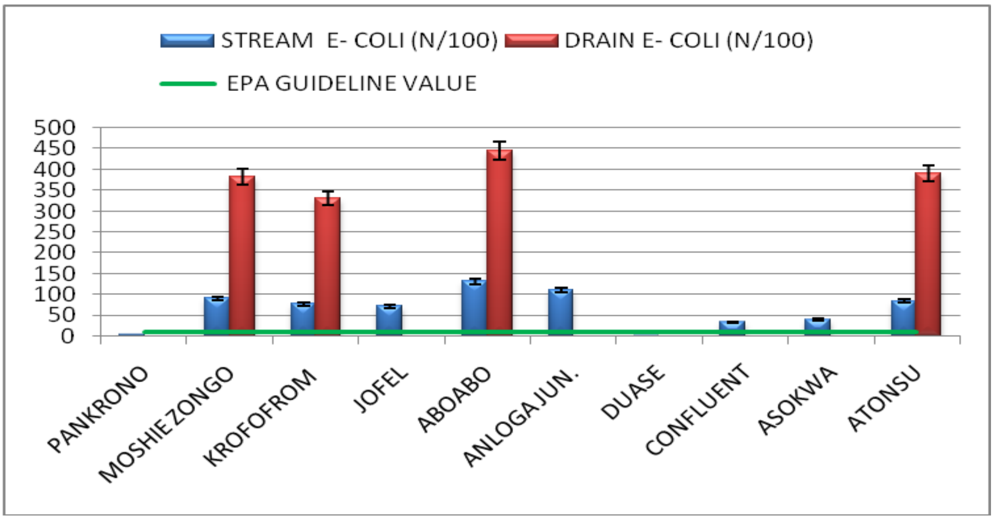

Fig 4.5.1.4: *E. coli* in Aboabo Stream and community drain.

4.5.2 Physico-chemical characteristics

4.5.2.1 Nitrate

Nitrate concentration of both the Stream and the drains are generally well below the EPA guideline value of 100 mg/L (fig. 4.5.2.1). This could probably be due to the absence of DO in the wastewater; a smaller amount of nitrate is produced from ammonia as well as decomposition of food wastes and other sources of protein. According to Weiner *et al*., (2003) sources of nitrates in water include decaying plant or animal material, agricultural fertilizers, manure, human or animal waste and domestic sewage. Nitrates are used in fertilizers and also occur in effluent discharges from wastewater treatment plants and runoff from animal feedlots (Stendahl *et al*, 2004). Nitrate is an essential plant nutrient and its levels in natural waterways are typically low (less than 1 mg/L) Liu (1999). Excessive amounts of nitrate can cause water quality problems and accelerate eutrophication.

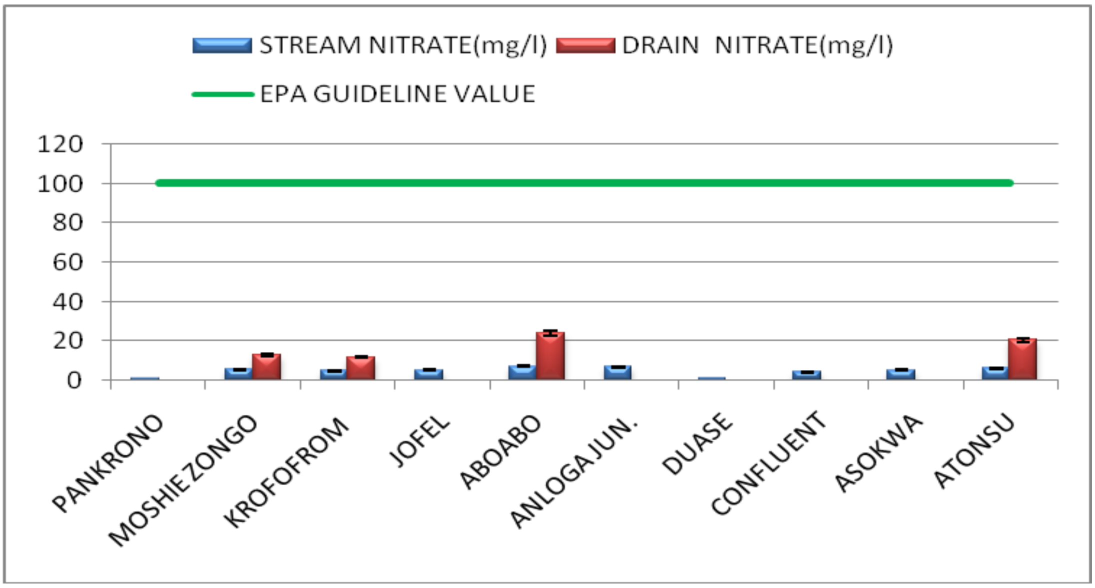

Fig 4.5.2.1: Concentration of Nitrate-nitrogen in Aboabo Stream and community drain.

4.5.2.2 Phosphate

In this research, the presence of phosphate in the form of orthophosphate in Stream and some selected drains were determined. This is because the organically bound phosphorus is usually of minor importance in most domestic wastes whiles the polyphosphates also go through hydrolysis in aqueous solution and degenerate into orthophosphate forms (Metcalf and Eddy, 2003). Moreover, dissolved orthophosphate, according to Weiner *et al*., (2003) is readily taken up by biota and therefore almost never found in high concentrations in unpolluted waters.

Phosphorus concentration in the Stream was lower at Pankrono, the origin where it met the EPA guideline value of 10 mg/L (fig. 4.5.2.2). From Moshie Zongo through Krofofrom, Jofel, Aboabo and Anloga Junction, phosphorus concentrations were generally high above the prescribed water quality standard as seen in fig. 4.5.2.2. This could be due to an increase in the uses of phosphate producing items such as cleaning products (soaps, detergents), cosmetics, medicated shampoos, food products and other sources including (human excretions **(**faeces and urine) (Tjandraatmadja *et al*. (2010). High concentrations of phosphates indicate the presence of pollution and are largely responsible for eutrophic conditions. At Asokwa and Atonsu, they conform to the EPA guideline value of 10 mg/L for existing facilities. This could be due to the dilution effect of the Sisal Stream which reduces the phosphorus concentration of the Aboabo Stream from Anloga Junction to make the Asokwa and Atonsu sample conform to the EPA guideline value.

For phosphorus concentration of the drains, they were all higher above the EPA guideline value. This could be due to the predominant discharge of wastewater with high phosphate levels from the communities. Secondly, runoff containing soil-bound phosphate, yard waste, runoff from animal feedlots, storm water and certain industrial wastewaters can also cause an increase in phosphorus level.

Phosphorus is essential to the growth of algae and other biological organisms. Tjandraatmadja *et al*., (2010) argued that, excessive discharge of liquid waste into aquatic environments can result in excessive algae growth, eutrophication and the depletion of oxygen in water bodies.

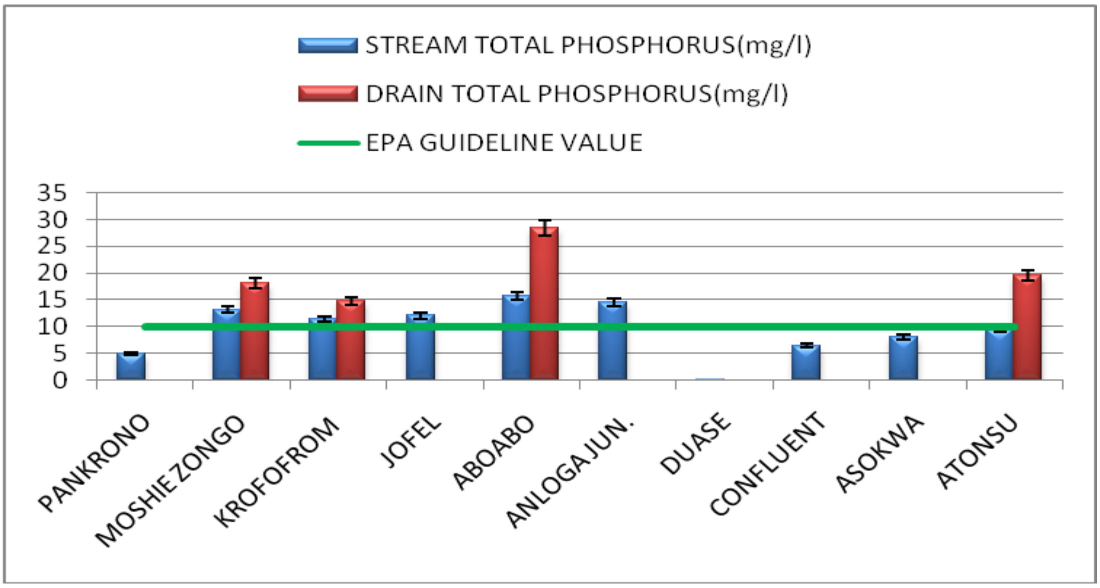

Fig 4.5.2.2: Concentration of Phosphorus in Aboabo Stream and community drain.

4.5.2.3 Total Suspended Solids

From the studies, except Pankrono and Duase sample values, all other values of TSS were above the EPA effluent guideline value of 50 mg/L (fig.4.5.2.3) for both the drains and the Stream. This can be attributed to the fact that, the Stream contains large floating and suspended solids (such as faces, rags, plastic container etc), smaller suspended solids (such as partially disintegrated faces, paper, vegetables peel) and very small solids in colloidal (non-settleable) suspension, as well as pollutants in true solution (Christova-Boal *et al* 1996). Secondly, it could be attribute to high suspended organic particles (food debris and animal wastes) as well as inorganic particles from the community drains. At Aboabo, the high value of TSS is caused by wood chippings carried by runoff from the community into the Stream. The reduction in TSS at Asokwa and Atonsu could be due to the dilution effect by the Sisal Stream. Also at Jofel, the drop in the TSS could be due to dilution effects by the well or pipe water for the car washing industry. Total Suspended Solids (TSS) is an essential wastewater treatment effluent standard that affects the operation and sizing of treatment units (Lee, 2007). Total suspended solids test results are used routinely to assess the performance of conventional treatment processes and the need for effluent filtration in reuse applications (Metcalf and Eddy, 2003). According to Spellman (2003) higher concentrations of suspended solids can act as carriers of toxics, which are readily absorbed by suspended particles and also increase the murkiness of wastewater.

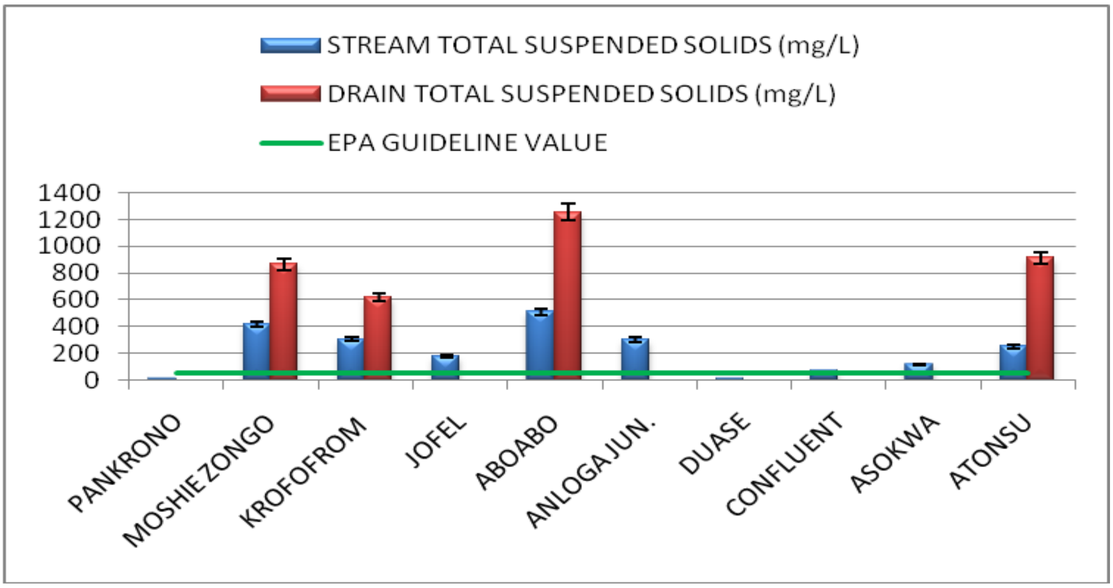

Fig. 4.5.2.3: Concentration of TSS in Aboabo Stream and community drain.

4.5.2.4 Electrical conductivity

From the studies, all the electrical conductivity of the Stream were below the EPA guideline value for wastewater quality discharge into water bodies of 1500 µS/cm (fig.4.5.2.4). This could be due to the low concentration of dissolved solids in the water. In aquatic studies, low values of EC are characteristic of low nutrient waters whiles high values are indicative of salinity problems.

The electrical conductivity of the wastewater in the drains were below the EPA guideline value of 1500 µS/cm (fig.4.5.2.4) for Moshie Zongo, Krofofrom and Atonsu. The electrical conductivity for the drains from the Aboabo community was higher above the EPA guideline value. This could be due to the high concentration of dissolved solids in the drains as indicated by the total dissolved solids. Electrical conductivity (EC), is affected by temperature and the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, phosphate anions, sodium, magnesium, calcium, iron, and aluminium cations (Spellman, 2003). Electrical conductivity determinations are useful in aquatic studies because they provide a direct measurement of dissolved ionic matter in the water.

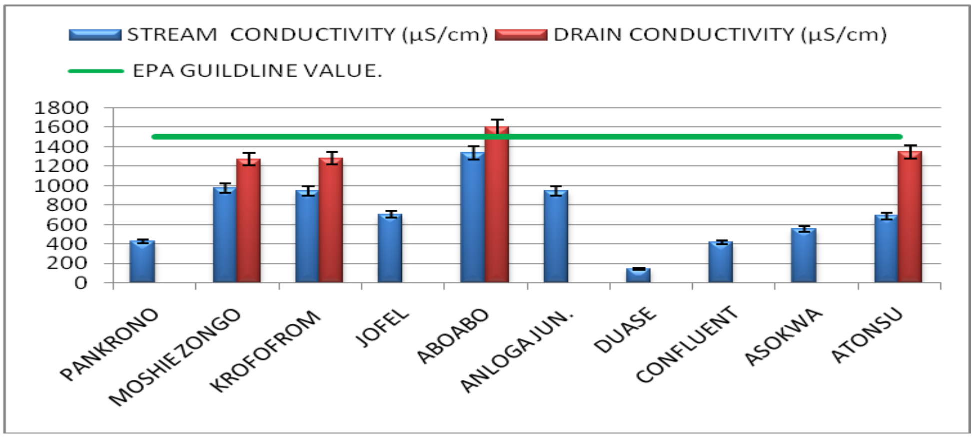

Fig. 4.5.2.4: Electrical Conductivity in Aboabo Stream and community drain

4.5.2.5 Total dissolved solids

From the studies, the total dissolved solids were relatively good throughout the Stream stretch as well as the drains from the communities (fig. 4.5.2.5). Although they all conform to the EPA guideline value for wastewater quality discharge into water bodies of 100 mg/L, the drains total dissolved solids were higher than that of the Stream. High values can be attributed to total dissolved solids made up of colloidal and dissolved solids as well as smaller particle sizes of the samples analyzed. By definition, solids contained in the filtrate that passes through a filter with a nominal pore size of 2.0um or less are classified as dissolved (Standard Methods, 1998).

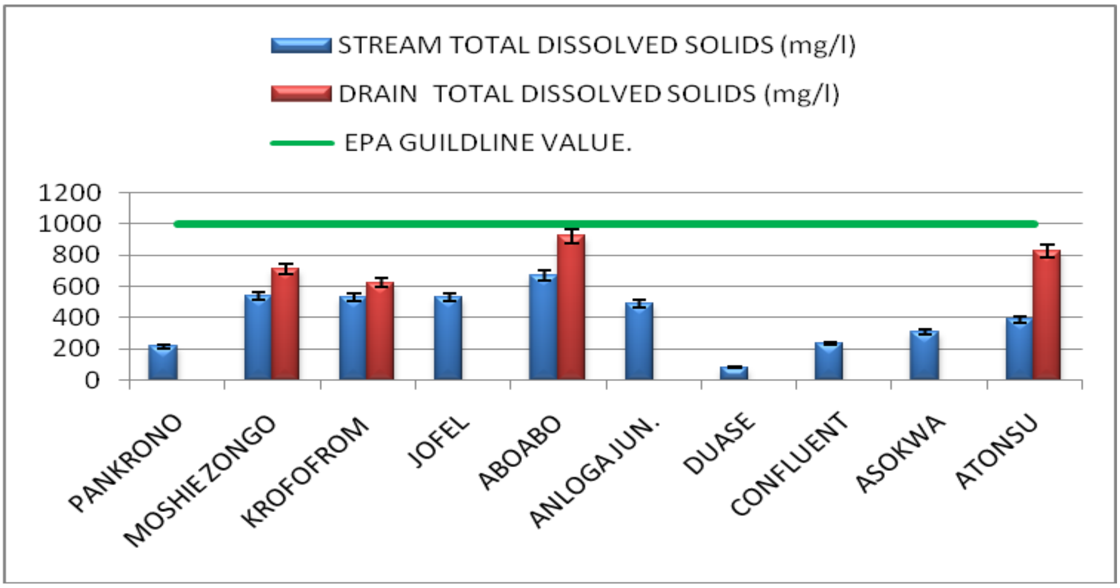

Fig. 4.5.2.5 Concentration of TDS in Aboabo Stream and community drain

4.5.2.6 Colour

From the research, the colour of the Stream was relatively good at the origin, Pankrono. However, as the travel time in the stream increases and more anaerobic conditions develop, the colour of the Stream changes subsequently from grey at

Pankrono to dark grey at Moshie Zongo and ultimately to black at Aboabo. Comparing the colour of the Stream to those in the drains, it could be observed that, the colour in the drains is far darker than that of the Stream. This could be due to more polluted water in the drains which may, therefore, have quite strong apparent colour. In most cases the grey, dark grey and black colour of the wastewater is due to the formation of metallic sulfides, which form as the sulfides produced under anaerobic conditions react with the metals in the grey water (Awuah, 2006). The colour of water is measured as a result of the different wavelengths that is not absorbed by the water itself or the result of particulate and dissolved substances present (Chapman, 1996). Fresh wastewater is usually a light brownish-grey colour (Spellman, 2003). Discoloured waters absorb more heat from the sun. According to Awuah (2006) sources of colour include organic debris, leaves, humus, tannin, iron oxides, manganese oxides, dyes, slaughterhouse wastewater.

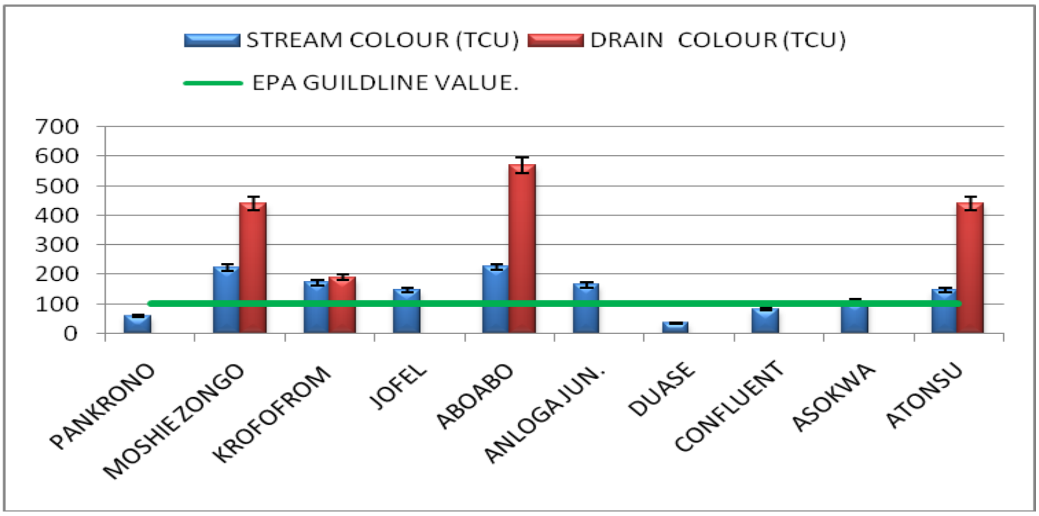

Fig. 4.5.2.6: Colour of Aboabo Stream and community drain.

4.5.2.7 Turbidity

Colloidal matter would scatter or absorb light and thus prevent its transmission (Metcalf and Eddy, 2003). From the studies, the Stream turbidity was relatively good for Pankrono, the origin, Jofel, Asokwa and Atonsu (fig. 4.5.2.7). The significantly higher transparency of the water at Pankrono stretch may be attributed to low amount of silt and nutrients that stimulate algal and cyanobacterial growth. For the other sampling points which were below the EPA guideline value, it could be due to the dilution effect by pipe or well water for the Jofel, as well as the Sisal Stream dilution at the confluent. At Moshie Zongo, Krofofrom, Aboabo and Anloga Junction, there was an increase in turbidity value above the EPA guideline value of 75 NTU (fig. 4.5.2.7). This rise could be due to waste discharges, runoff from watershed (especially those that are disturbed or eroding), and products of their breakdown in water resulting from decay of plants, leaves, etc. in water sources.

The turbidity of the drains were generally higher and above the EPA guideline values. This may be due to high suspended matter or impurities that interfere with the clarity of the water and may include finely divided inorganic and organic matter, soluble coloured organic compounds, and other microscopic organisms. It could result from domestic effluents which may contribute large amounts of suspended solids. Soaps, detergents, emulfying agents also produce stable colloids that results in turbidity (Metcalf and Eddy, 2003).

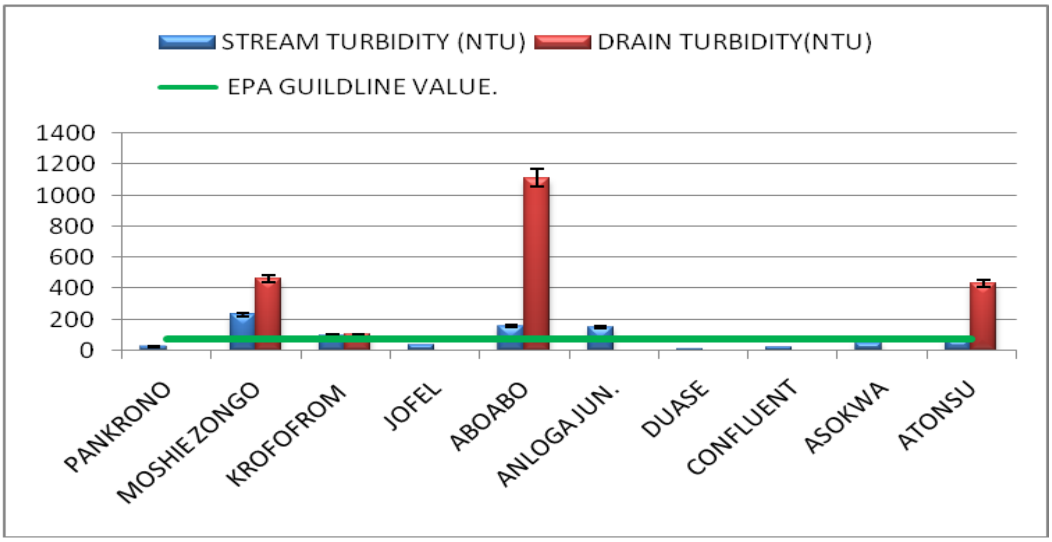

Fig. 4.5.2.7: Turbidity of Aboabo Stream and community drain

4.5.2.8 pH

The pH of both the Stream and the drains were generally relatively good throughout the sampling locations (fig. 4.5.2.8). They all conform to the EPA guideline value for wastewater quality discharge into water bodies or water courses of 6-9. Although they all conform to the standard set by the EPA, the Stream pH for Pankrono, Jofel and Duase are lower than all. At Moshie Zongo,Krofofrom, Aboabo,Anloga Junction, Asokwa and Atonsu, the Stream pH are slightly higher than the rest. Harris et al, 2000, found out that, high or low pH will adversely affect the availability of certain chemicals or nutrients in the water for use by plants. According to Metcalf and Eddy (2003) when hydrogen ions are in extreme concentration in wastewater, it is difficult to treat by biological means. If the concentration is not altered before discharge, the wastewater effluent may alter the concentration in the natural waters. According to Awuah (2006) this parameter is very important in an aquatic environment to many metabolic reactions in microbial cells which includes energy generation and ion transport. Pankow, 1991, reported that, most freshwater fish prefer water with a pH range between 6.5 and 8.4.

The rise in pH of the drains confirms the fact that most of the wastewater emanating from kitchens, bathrooms and local restaurants within the communities are alkaline in nature. This is the most predominant form of wastewater in the earth drains which finally empty into the Aboabo Stream. According to Albrechtsen, 1998, wastewater produced from laundry will contain different types of detergents, bleaches and perfumes. In addition, runoff from the communities could also contribute to the increase in pH of the drains. Humans contribute to elevated pH primarily in the form of nutrient runoff (most commonly fertilizer), which leads to increased algae growth and higher pH.

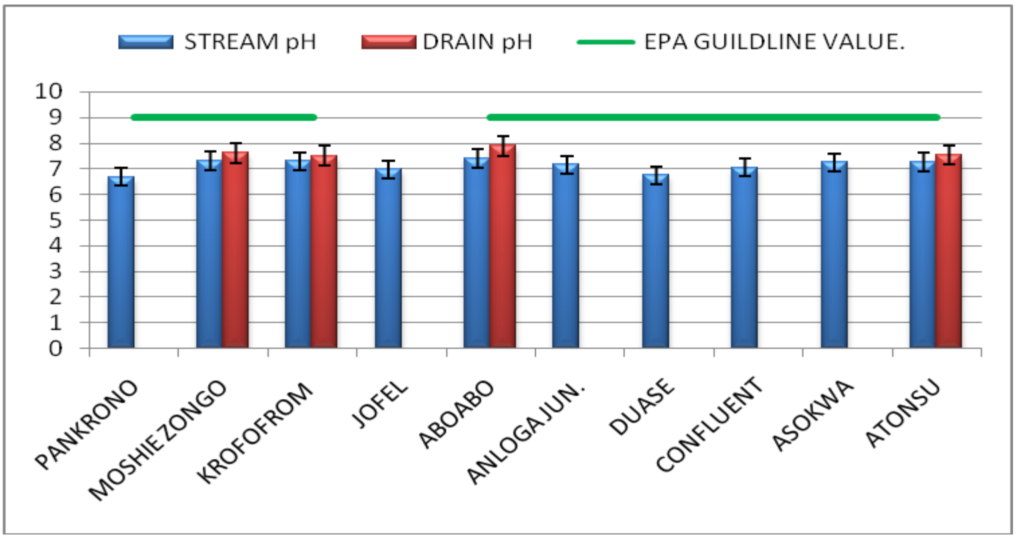

Fig. 4.5.2.8 pH values for Aboabo Stream and community drain.

4.5.2.9 Temperature

The temperature of the Stream varies from the upstream, Pankrono to the downstream Atonsu (fig. 4.5.2.9). This could be due to several factors that influence the rise and fall of temperature in a Stream. The most important being the climatic fluctuations and responds to factors such as season, time of day, air circulation, cloud cover, depth and flow of water in the natural system. Increase temperature for example could cause a change in the species of fish that could exist in the receiving water body. In addition, oxygen is less soluble in warm water than in cold water and this could result in serious depletion of oxygen concentration. Many of the physical, biological and chemical characteristics of surface water are dependent on temperature (Smith, 2002). The optimal health of aquatic organisms from microbes to fish depends on temperature (Pankow, 1991). Pankow, 1991 reported that, the temperature of the water also affects the following: the volume of dissolved oxygen it can hold (water's ability to contain dissolved oxygen decreases as water temperature rises), the rate of photosynthesis by aquatic plants, metabolic rates of aquatic organisms and the sensitivity of organisms to pollution. The rise in temperature for the drains could be due to the addition of warm water from point sources including kitchens and bathrooms.

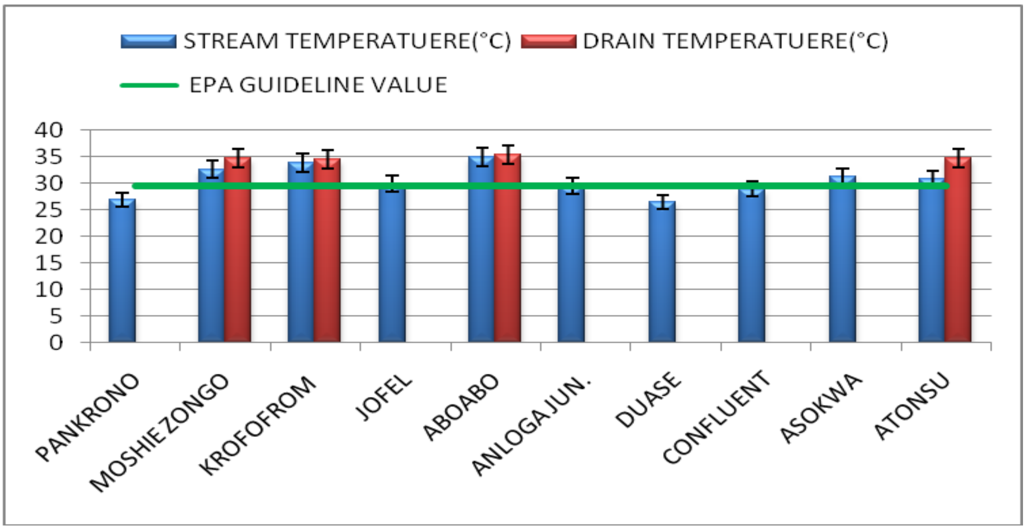

Fig. 4.5.2.9 Temperature of Aboabo Stream and community drain

4.5.3 Dissolved oxygen

From the research, the DO for the Aboabo Stream was relatively good for Pankrono (fig. 4.5.3). At Pankron, it could be due to less disposal of both organic waste and wastewater from human activities into the Stream at this stretch. For Jofel and Asokwa, it could be due to dilution effects of both pipe water the Sisal Stream respectively. This could probably reduce the temperature of the Stream and hence increasing the DO, since cold water has plenty DO than warm water. The decrease in the Stream DO could be attributed to the fact that, in natural waters, man-made contamination, or natural organic material will be consumed by microorganisms. As this microbial activity increases, oxygen will be consumed out of the water by the organisms to facilitate their digestion process. The water that is near the sediment will be depleted of oxygen for this reason. The high DO at Duase is due to the fact that, it is close to the source of the Sisal Stream. The presence of dissolved oxygen in wastewater according to Metcalf and Eddy (2003) is desirable because it prevents the formation of harmful odours. Dissolved oxygen is required for the respiration of aerobic microorganisms as well as all other aerobic life forms (Metcalf and Eddy, 2003). However, its solubility in water is generally affected by among other factors: temperature, turbulence, salinity and biological processes (Canadian Council of Ministers of the Environment, 1999).

Comparing the DO of the Stream to the drains, it can be inferred that, the drains DO are quite low. This could be due to the presence of organic waste from the communities**.** According to Saffran (2001), the DO of water is affected by raw or poorly treated sewage, contaminated storm water discharges, wastewater from human activities, animal feedlots; natural sources like decaying aquatic plants and animals. More organic waste means more decomposers and more oxygen being used.

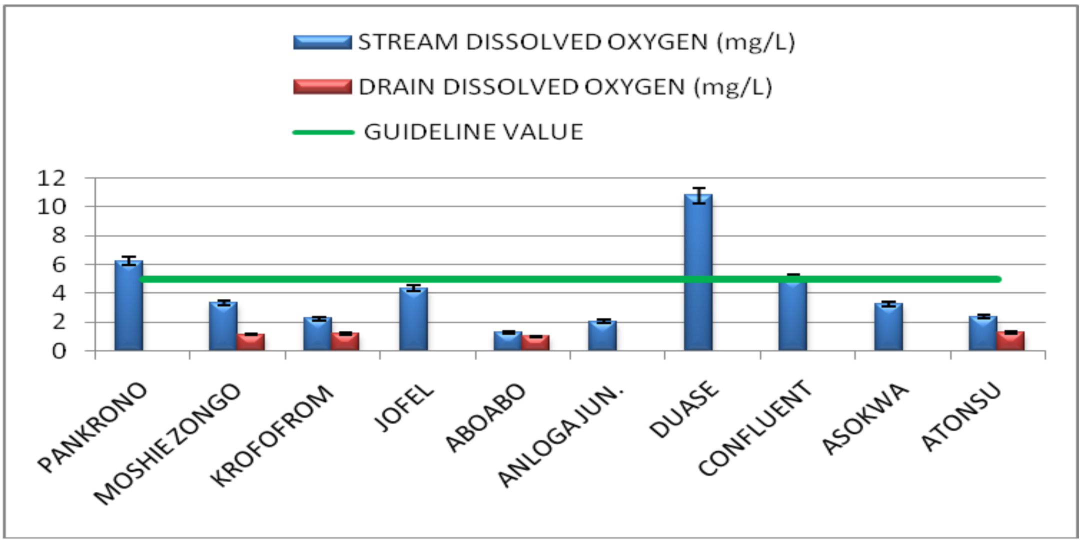

Fig. 4.5.3: Concentration of DO in Aboabo Stream and community drain.

4.5.4 The CCME Water Quality Index for Aboabo stream.

In this study, the CCME Water Quality Index was applied and tested for the Aboabo stream. The index ranges from 0 to 100 and depending on the value; the water quality is characterized as excellent (95-100), good (80-94), fair (65-79), marginal (45-64) and poor (0-44). The CCME WQI was calculated using the method described by CCME 2001 guidelines. The results obtained with respect to the biochemical and physico-chemical characteristics of water samples of the Aboabo Stream are shown in appendix 5**.** The result obtained from the application of CCME WQI has categorized the Aboabo Stream at upstream, Pankrono, as marginal for November 2011 to January 2012 as shown in fig.4.5.4. In this sampling location, water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels. The remaining sampling locations were rated as poor quality for November 2011 to January 2012 as shown in fig 4.5.4. Water quality is almost always threatened or impaired see appendix 6. The CCME Water Quality Index have shown that, the use of the Aboabo Stream for various domestic activities such as drinking, cooking, washing items like clothes and utensils, recreation and livestock are not recommended. The conditions of the Stream have departed from desirable levels in most of its biochemical and physico chemical parameters. Zaheeruddin and Khurshid (1998) and Manish and Pawan (1998) have attributed industrial growth, urbanization and agricultural activities as the major sources of water contamination. It is evident from the results that water quality in the Aboabo Stream is degraded considerably due to human activities such as waste dumping, open field defication, contamination of water by household sewage etc. The results obtained from application of CCME Water Quality Index have shown that most of the values are far from the permissible level as can be seen from fig.4.5.4.

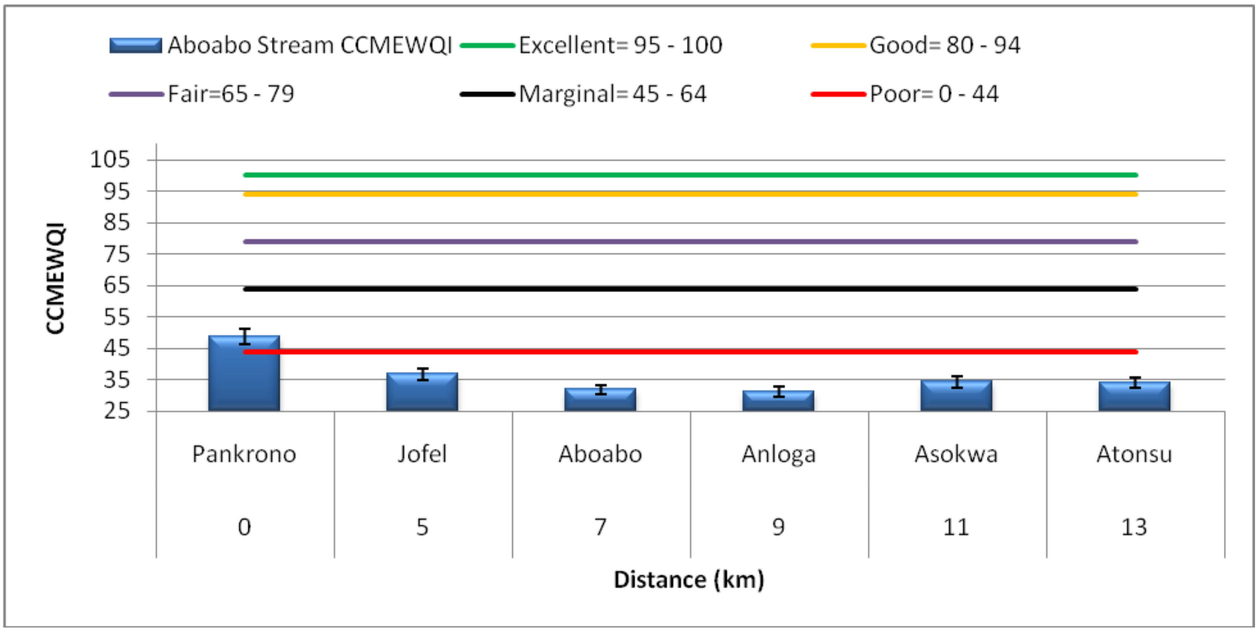

Fig.4.5.4: The CCME Water Quality Index for Aboabo stream.

CHAPTER FIVE

5.0 Conclusions and Recommendations

5.1 Conclusions

No formal conventional treatment plants exist within the Aboabo catchment for treatment of both solid and liquid waste. Therefore, most of the residents in the communities dispose off their solid waste by uncontrolled burning, burying, and dumping into the gutters, drains or open spaces. Again, there is no comprehensive sewerage system which has its terminal at a waste treatment plant within the communities for the disposal of grey water. Most of the residents in the communities therefore disposed off their grey water into the drains, streets or on the open field. The physico-chemical analyses using parameters such as pH, TDS, TSS, total Phosphorus, Nitrate, BOD_5, COD, total coliformis, *E-coli*, and DO of the upstream gave values well below the maximum permissible level set by the EPA. On the contrary, the downstream values for these physicochemical parameters were to a larger extent far above the maximum permissible level set by the EPA. The CCME Water Quality Index also showed the Aboabo Stream to be of poor quality. The anthropogenic activities along the Aboabo Stream have actually impacted on the quality of the Stream.

From the water quality analysis, it is established that, the Aboabo Stream is highly polluted at the downstream. The pollution is mainly due to the drains emanating from the communities that finally discharge their content into the Stream. Again several cottage and commercial industries operates along the banks of the Aboabo Stream at several portions without treatment facilities also contributes to pollution of the Aboabo Stream. These are the point sources of pollution to the Stream. Lastly, the indiscriminate dumping, open field defecation, streets, lawns, roofs, pavements and compounds of homes which washes into the Stream as an urban runoff carries sand, silt, particulate matter and organic matter into the Aboabo Stream during rains and are among the non-point sources of pollution of the Aboabo Stream.

5.2. Recommendations

1. KMA should assist households to obtain soft loans for the construction of affordable soakaways and toilet facilities. KMA must put at the disposal of households technical support for designing and siting of these facilities.
2. Direct disposal of waste (liquid and solid) into the Stream should be avoided. The KMA must ensure provision of adequate sanitary (solid and liquid waste) facilities in the communities and should arrest and prosecute persons who flout these KMA bye-laws on sanitation.
3. Industries operating within the Aboabo catchment without waste treatment plant should either be relocated or be made to install waste treatment plants.
4. KMA should come out with strategic action plan for the restoration of the Aboabo Stream.
5. EPA should educate the residents about the links between their behaviour in terms of waste handling and its impacts on the Aboabo Stream. EPA must also enforce environmental protection laws through regular monitoring of effluents discharged into water bodies.

6. KMA should encourage the formation of Functional association or volunteer group such as “Save Aboabo Stream” to prevent people from dumping waste into the Stream.
7. The variables used to determine the index at the various points should be measured for a long period of time (at least one year) to show the effect of spills, and other such random and transient events which are relatively frequent or long lasting.

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APPENDICES

APPENDIX 1: Questionnaire for residents in the study area

ALL PERSONAL INFORMATION GIVEN WILL BE TREATED AS CONFIDENTIAL. PLEASE ANSWER ALL OF THE QUESTIONS BY TICKING THE APPROPRIATE OPTION WHERE NECESSARY.

Questionnaire No………………… Dialogue date…………….

Community name.................................. Time.......................................

(a) Personal Data of Respondent

1. Gender: a. Male [ ] b. Female [ ]

2. Age a. 18- 20 [ ] b. 21-40 [ ] c.41- 59[ ] d. above 60[ ]

3. Highest level of education:

a. None [ ] b. Primary [ ] c. MSLC/Junior High [ ] d. Senior High / ‘O’ Level [ ] e. Tertiary [ ] f. others (please specify).............................

(b) Socio Economic Characteristics of Respondent

4. employment status

a. Unemployed [ ] b. Self-employed [ ] c. Government employee [ ]

d. Private company employee [ ] e. Others (please specify)....................................

5. Level of income per month? a. Below GH¢50[ ] b. GH¢50- 150[ ] c. GH¢151- 250 [ ] d. GH¢251-350 [ ] e. above GH¢351 [ ] f. others (specify) GH¢……………………………. g. cannot tell [ ] h .Don’t know [ ]

6. Religion affiliation. a. Christianity [ ] b. Islamic [ ] c. Traditiona [ ]

d. None [ ] e. other (please specify)..

7. Marital status. a. Married [ ] b. Single[ ] c. Divorced [ ] d. Widow [ ]

e. widower [ ] f. Others (please specify)..

LIQUID WASTE MANAGEMENT

(a) Grey / Sullage water

8. What is the primary means by which wastewater from your bathing facility is disposed off? a. Soakaways [ ] b. Into gutters [ ] c. In the yard or street [ ]

e. Others (please specify)..…………

9. What is the primary means by which wastewater from other domestic activities is disposed off? a. Soakaways [ ] b. into gutters [ ] c. In the yard or street [ ]

(b) Black Water

10. Which of the following toilet facilities do you use in your?

a. Water closet connected to septic tank [ ] b. Public toilet [ ] c. Household Pit latrine [ ] d. Other (specify)……………..

Do you join a queue when you use a public toilet facility? a. Yes [ ] b. No [ ]

11. If yes, how long do you usually wait in the queue? …………………..

12. Do you pay for the use of the public toilet facility? a. Yes [ ] b. No [ ]

13. If yes, how much do you pay for using the public toilet facility per visit?

a. 10 pesewas [ ] b. 20 pesewas [ ] c. 50 pesewas [ ] d. Other (specify)............

14. Considering your level of income is the cost of using this toilet facility per visit affordable? a. Yes [ ] b. No [ ]

SOLID WASTE

15. What is the most frequent means by which your household disposes of solid waste?

a. Dump into undefined areas [ ] b. Communal site [ ] c. Burned by household [ ]

d . Burried by households [ ] e. (specify)…………………………………………..

16. How much do you pay for the disposal of your solid? a. 10 pesewas [ ]

b. 20 pesewas [ ] c. 50 pesewas [ ] d. Other (specify)...............................

Residents concern on dumping of waste into the Aboabo stream.

17. Does the dumping of waste into the Aboabo stream bothers you?

a. Yes [ ] b. No [ ]

18. Do you think the Aboabo stream can be revived from the problem of waste dumping? Yes [ ] No [ ]

a. If yes, which of the following is the solution to the waste dumping? a. Arrest and prosecution of persons who contravene the KMA by laws on sanitation. [ ] B. Construction of adequate drains [ ] c. Education of residents on the need to protect urban surface water resources [ ]. d Others (Specify)...

19. Do you think after the mitigation, the stream can provide benefits (if any) to the people in this community?

a. Yes [ ] b. No [ ].

a. If yes, which of the following is possible? (Please indicate 1st, 2nd,3rd, 4th, 5th ,6th in order of most frequently used) a. Flushing [ ]

b. Fishing [ ] c. Washing [ ] d. Bathing [ ] e. Cooking [ ] f. Drinking [ ] g. others (specify the benefits)...

APPENDIX 2: ANALYTICAL METHODS USED IN RESEARCH

APPENDIX 2.1.: Analytical methods and major reagents

PARAMETERS	***METHOD/EQUIPMENT***	***MAJOR REAGENTS***
pH	PC 300 Waterproof Handheld pH/Conductivity/ TDS/ Temperature meter	N/A
Temperature	PC 300 Waterproof Handheld pH/Conductivity/ TDS/ Temperature meter	N/A
Conductivity	PC 300 Waterproof Handheld pH/Conductivity/ TDS/ Temperature meter	N/A
Total Dissolved Solids		N/A
Total Suspended Solids		N/A
Dissolved Oxygen		N/A
Phosphate	Spectrophotometric (DR/2400 Spectrophotometer	PhosVer 3 phosphate Powder Pillow
Nitrogen -Nitrate	Spectrophotometric (DR/2400 Spectrophotometer)	NitraVer 5 Nitrate Reagent Powder Pillow

APPENDIX 3: RESULTS OF WATER QUALITY ANALYSIS.

APPENDIX 3.1: Results of water quality analysis of Aboabo Stream and some selected communities drains (November 2011 to January 2012)

Sampling Point Locations
(Mean± Std. Deviation)

Parameters	**Unit**	**EPA Effluent Guideline Value**	**Pankrono**	**Moshie Zongo**	**Krofofrom**	**Jofel**	**Aboabo**	**Anloga Junction**	**Duase**	**Confluent**	**Asokwa**	**Atonsu**	**Mean±Std. Deviation**
Stream pH		6.5-9	6.69±0.36	7.33±0.32	7.29±0.15	6.98±0.16	7.41±0.31	7.16±0.12	6.75±0.11	7.05±0.16	7.245±0.12	7.25±0.29	0.244±7.115
Drain pH		6.5-9	0	7.62±0.10	7.51±0.22	0	7.89±0.12	0	0	0	0	7.55±0.10	3.947±3.057
Stream Turbidity	NTU	75	24.74±33.58	232.8±45.95	97.2±1.75	37.45±30.32	154.14±157.74	147.2±50.83	10.15±4.65	21.15±13.36	49.75±59.39	75.42±41.77	72.68±85
Drain Turbidity	NTU	75	0	462.5±23.19	101.32±46.95	0	1113.2±161.93	0	0	0	0	432.5±31.82	365.9±210.95
Stream Colour	TCU	100	58.75±39.66	222.5±82.26	172.5±22.17	147.5±41.13	225.5±68.50	165±17.32	36.25±12.50	81.25±28.39	110±21.60	148.75±69.09	64.58±136.8
Drain Colour	TCU	100	0	441±14.14	190±55.15	0	570±42.43	0	0	0	0	440±14.14	230.8±164.1

Sampling Point Locations
(Mean± Std. Deviation)

Parameters	Unit	EPA Effluent Guideline Value	Pankrono	Moshie Zongo	Krofofrom	Jofel	Aboabo	Anloga Junction	Duase	Confluent	Asokwa	Atonsu	Mean±Std. Deviation
Stream TDS	mg/L	1000	215.87±104.07	537.5±94.46	531±92.68	530±80.67	668.5±34.89	489.75±99.50	83.275±21.52	235.75±31.88	309.5±64.73	388.25±64.73	183.3±398.93
Drains TDS	mg/L	1000	0	711.5±6.36	625.5±17.68	0	924±39.60	0	0	0	0	829±196.58	406.0±309
Stream Conductivity	µS/cm	1500	428.15±208.93	980.5±203.69	945.5±359.91	705.5±446.55	1338.75±71.87	945.25±368.42	143.25±	417±52.75	554±	689±	348.0±714.69
Drain Conductivity	µS/cm	1500	0	1274±56.57	1280±5.66	0	1599.5±9.19	0	0	0	0	1350.5±618.72	716.0±550.4
Stream TSS	mg/L	50	16.25±14.93	420±362.74	306.5±247.97	178.5±222.50	510±503.36	303.75±265.84	16.7±13.77	72.5±75.35	116.875±64.85	251.5±115.58	168.8±219.25
Drain TSS	mg/L	50	0	867.5±98.99	620±130.81	0	1255±438.41	0	0	0	0	912.5±53.03	495.3±365.5
Stream Total phosphorus	mg/L	10	4.88±5.21	13.2±4.13	11.42±0.93	12.05±1.97	15.77±8.43	14.55±2.78	0.215±0.13	6.445±1.59	8.09±2.37	9.41±1.85	4.801±9.6035

Sampling Point Locations
(Mean± Std. Deviation)

Parameters	Unit	EPA Effluent Guideline Value	Pankrono	Moshie Zongo	Krofofrom	Jofel	Aboabo	Anloga Junction	Duase	Confluent	Asokwa	Atonsu	Mean±Std. Deviation
Drain Total phosphorus	mg/L	10	0	18.1±0.85	14.8±0.42	0	28.35±6.72	0	0	0	0	19.52±5.77	10.94±8.077
Stream Nitrate	mg/L	100	1.0425±0.45	5.56±4.41	4.9±2.80	5.155±1.38	7.19±2.38	6.885±1.82	1.3025±0.30	4.19±3.35	5.19±2.02	6.12±4.36	2.091±4.7542
Drain Nitrate	mg/L	100	0	12.84±0.92	11.85±1.36	0	24±5.37	0	0	0	0	20.6±8.96	9.577±6.929
Stream B.O.D5	mg/L	200	38.25±31.20	243±101.21	224.5±100.05	245.7±84.81	260±105.08	250±94.17	8.25±3.86	124.875±61.49	173.2±96.07	248.05±148.55	93.59±181.58
Drain B.O.D5	mg/L	200	0	399±13.44	310±137.18	0	583.5±92.63	0	0	0	0	468±70.71	236.8±176.05
Stream COD	mg/L	1000	68±42.58	407±144.43	386.5±159.89	286±162.96	410±177.85	378±225.08	20±9.38	148.5±64.74	178.75±126.9	403±140.98	151.9±268.57

Sampling Point Locations
(Mean± Std. Deviation)

Parameters	Unit	EPA Effluent Guideline Value	Pankrono	Moshie Zongo	Krofofrom	Jofel	Aboabo	Anloga Junction	Duase	Confluent	Asokwa	Atonsu	Mean±Std. Deviation
Drain COD	mg/L	1000	0	1040±66.47	1027±124.45	0s	1066.5±324.56	0	0	0	0	1053.5±251.02	540.6±418.7
Stream Total Coliformis	N/100	400	19.5±9.98	232.25±46.59	171.75±29.31	123±87.35	238.5±52.06	204.25±47.84	10.75±10.14	165±32.26	171±46.14	184±8.49	79.54±171.37
Drain Total Coliformis	N/100	400	0	294±22.63	394±5.66	0	544±76.37	0	0	0	0	447±77.78	68.83±391.37
Stream *E-coli*	N/100	10	4±2.16	91±48.46	77.75±62.69	72±64.22	131.25±19.02	110±4.40	2.75±2.75	34±17.63	39.75±23.08	84±14.39	43.27±158.87
Drain *E-coli*	N/100	10	0	382.5±115.97	330±67.18	0	444.5±19.09	0	0	0	0	391.5±30.41	201.7±123.75
Stream Temperature	°C	29.5	26.925±1.54	32.67±0.75	33.85±1.77	30±0.92	34.9±2.11	29.5±1.02	26.47±1.07	28.92±1.36	31.32±2.04	30.8±3.40	2.764±30.537
Drain Temperature	°C	29.5	0	34.7±0.35	34.55±1.56	0	35.33±0.99	0	0	0	0	34.75±1.48	17.98±13.933
Stream DO	mg/L		6.25±1.55	3.33±0.19	2.25±0.06	4.35±0.19	1.31±0.15	2.05±0.18	10.77±1.35	5.03±1.48	3.25±0.18	2.38±0.20	2.784±4.0987
Drain DO	mg/L		0	1.15±0.03	1.22±0.07	0	1.03±0.10	0	0	0	0	1.3±	0.6103±0.47

APPENDIX 4: Comparison of mean wastewater characteristics with results from previous studies on Aboabo Stream

Author	pH	Turbidity (mg\L)	Colour (TCU)	TDS (mg\L)	TSS (mg\L)	Conductivity (µS/cm)	Phosphate (mg\L)	Nitrate(mg\L)	BOD(mg\L)	COD(mg\L)	*E.Coli*(N\100)	T.Coliformis (N\100)	Temp.(°C)	DO(mg\L)
Boakye (2012).This study.	7.11	85	136.8	398.9	714.7	219.3	9.60	4.75	181.60	268.60	151.99	158.9	30.54	4.09
Danquah (2010)	7.17	-	-	578.3	792.5	1160	19	3.65	405	1088	370.5	-	27.13	0.45
Salifu and Mumuni (1998) *	7.01	-	-	318	-	-	-	-	-	-	-	-	-	18
Government of Ghana (1996) *	6.73	-	-	-	121	-	-	-	180	-	-	-	-	0
Gah (1991) *	7.39	-	-	-	147	-	-	-	57	-	-	2.2	-	0
Appiah (1991) *	6.8	-	-	-	-	-	-	-	5	-	-	3.7	-	1.6

NB:*Source: Suraj, M. (2004) and - means data not available.

APPENDIX 5: Calculation of CCME Water Quality Index for Aboabo stream.

APPENDIX 5.1: Biochemical and Physico-Chemical Characteristics of Pankrono Sample Site.

Parameters	***Objective***	***9th November,2011***	***23rd November,2011***	***11th January,2012***	***26th January,2012***
P^H	6-9	6.16	6.87	6.81	6.95
Turbidity (NTU)	75	1.29	6.78	16.7	74.2
Colour (TCU)	100	10	45	80	100
TDS (mg/L)	1000	244	96.5	343	180
Conductivity (µS/cm)	1500	488	192.6	684	348
TSS (mg/L)	50	10	0	20	35
Total Phosphorus (mg/L)	10	0.9	0.02	8.1	10.5*
Nitrate (mg/L)	100	1.2	0.4	1.45	1.12
BOD_5 (mg/L)	200	16	7	68	62
COD (mg/L)	1000	40	24	112	96
Total Coliformis (N/100)	400	21	5	25	27
***E-Coli* (N/100)**	10	3	2	4	7
Temperature (^oC)	29.5	25.8	26.5	26.2	29.2
DO (mg/L)	5	7.1*	8*	5.14*	4.77

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 02.

Total no of tests: 56. No of failed tests: 04.

APPENDIX 5.1.1 The CCME Water Quality Index for Aboabo stream at Source, Pankrono Sampling Point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 2/14*100=14.23

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =4/56*100=7.14

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

=100-$\left[\frac{10.5}{10}\right] - 1 + 100 - \left[\frac{7.1}{5}\right] - 1 + 100 - \left[\frac{8}{5}\right]$-1 +$100 - \left[\frac{5.14}{5}\right] - 1$ =390.9

$nse = \sum_{i=1}^{n} excursion\, i$, = 390.9/56= 6.98

$F_3 = \left(\frac{nse}{0.01_{nse}+0.01}\right)$, =$\left(\frac{6.98}{0.01\times 6.98+0.01}\right)$=87.45

$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right]$, $\frac{\sqrt{14.23^2+7.14^2+87.45^2}}{1.732}$ == 100- 51.33=48.67

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at source, Pankrono, as marginal for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.2: Biochemical and Physico-Chemical Characteristics Moshie Zongo Sampling Site.

Parameters	Objective	9th Nov., 2011	23rd Nov., 2011	11th Jan., 2012	26th Jan., 2012
P^H	6-9	6.91	7.33	7.4	7.69
Turbidity (NTU)	75	57.3	91*	166*	91*
Colour (TCU)	100	200*	300*	280*	120*
TDS (mg/L)	1000	444	454	599	624
Conductivity (µS/cm)	1500	870	943	1278	831
TSS (mg/L)	50	115*	130*	575*	860*
Total Phosphorus (mg/L)	10	10.4*	9.3	15*	18.2*
Nitrate (mg/L)	100	9.88	8.8	2.33	1.24
BOD_5 (mg/L)	200	180	396*	204*	200
COD (mg/L)	1000	304	608	302	432
Total Coliformis (N/100)	400	205	210	212	302
***E-Coli (*N/100)**	10	135*	130*	41*	58*
Temperature (^oC)	29.5	33.6*	32.4*	31.8*	32.8*
DO (mg/L)	5	0.6	0.3	0.14	0.29

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 07.

Total no of tests: 56. No of failed tests: 24.

APPENDIX 5.2.1: The CCME Water Quality Index for Aboabo stream at Moshie Zongo sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 7/14*100=50

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =24/56*100=42.85

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

=100-$\left[\frac{91}{75}\right] - 1 + 100 - \left[\frac{166}{75}\right] - 1 + 100 - \left[\frac{91}{75}\right]$-1 +$100 - \left[\frac{200}{100}\right] - 1 +$ 100-$\left[\frac{300}{100}\right] - 1 + 100 - \left[\frac{280}{100}\right] - 1 + 100 - \left[\frac{120}{100}\right]$-1 +$100 - \left[\frac{115}{50}\right] - 1$ +100-$\left[\frac{130}{50}\right] - 1 + 100 - \left[\frac{575}{50}\right] - 1 + 100 - \left[\frac{860}{50}\right]$-1 +$100 - \left[\frac{10.4}{10}\right] - 1$ + 100-$\left[\frac{15}{10}\right] - 1 + 100 - \left[\frac{18.2}{10}\right] - 1 + 100 - \left[\frac{396}{200}\right]$-1 +$100 - \left[\frac{204}{200}\right] - 1$ + 100-$\left[\frac{135}{10}\right] - 1 + 100 - \left[\frac{130}{10}\right] - 1 + 100 - \left[\frac{41}{10}\right]$-1 +$100 - \left[\frac{58}{10}\right] - 1$ + 100-$\left[\frac{33.6}{29.5}\right] - 1 + 100 - \left[\frac{31.8}{29.5}\right] - 1 + 100 - \left[\frac{32.8}{29.5}\right]$-1 =2327.23

$nse = \sum_{i=1}^{n} excursion\, i$, = 2327.23/56= 41.56

$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right)$, =$\left(\frac{41.56}{0.01 \times 41.56 + 0.01}\right)$=97.66

$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right]$, $\frac{\sqrt{50^2 + 42.85^2 + 97.66^2}}{1.732}$ == 100- 68=32

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Moshie Zongo sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.3: Biochemical and Physico-Chemical Characteristics of Krofofrom Sampling Site.

Parameters	***Objective***	***9th Nov., 2011***	***23rd Nov., 2011***	***11th Jan.,2012***	***26th Jan., 2012***
P^H	6-9	7.4	7.13	7.21	7.44
Turbidity (NTU)	75	95.4*	96.8*	97*	99.6*
Colour (TCU)	100	180*	200*	160*	150*
TDS (mg/L)	1000	440	463	600	621
Conductivity (µS/cm)	1500	880	463	1200	1240
TSS (mg/L)	50	80*	106*	550*	490*
Total Phosphorus (mg/L)	10	12.2*	12.1*	10.2*	11.19*
Nitrate (mg/L)	100	3.32	3.73	3.46	9.1
BOD_5 (mg/L)	200	138	148	265*	347.2*
COD (mg/L)	1000	332	312	278	624
Total Coliformis (N/100)	400	143	156	178	210
***E-Coli* (N/100)**	10	112*	148*	15*	36*
Temperature (^oC)	29.5	34*	34.9*	35.2*	31.3*
DO (mg/L)	5	0.34	0.36	0.25	0.24

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 07.

Total no of tests: 56. No of failed tests: 26.

APPENDIX 5.3.1: The CCME Water Quality Index for Aboabo stream at Krofofrom sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 7/14*100=50

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =26/56*100=46.43

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

$$=100-\left[\frac{95.4}{75}\right]-1+100-\left[\frac{96.8}{75}\right]-1+100-\left[\frac{97}{75}\right]-1+100-\left[\frac{99.5}{75}\right]-1+100-\left[\frac{180}{100}\right]-1+100-\left[\frac{200}{100}\right]-1+100-\left[\frac{160}{100}\right]-1+100-\left[\frac{150}{100}\right]-1+100-\left[\frac{80}{50}\right]-1+100-\left[\frac{106}{50}\right]-1+100-\left[\frac{550}{50}\right]-1+100-\left[\frac{490}{50}\right]-1+100-\left[\frac{12.2}{10}\right]-1+100-\left[\frac{12.1}{10}\right]-1+100-\left[\frac{10.2}{10}\right]-1+100-\left[\frac{11.19}{10}\right]-1+100-\left[\frac{265}{200}\right]-1+100-\left[\frac{347.2}{200}\right]-1+100-\left[\frac{112}{10}\right]-1+100-\left[\frac{148}{10}\right]-1+100-\left[\frac{15}{10}\right]-1+100-\left[\frac{36}{10}\right]-1+100-\left[\frac{34}{29.5}\right]-1+100-\left[\frac{34.9}{29.5}\right]-1+100-\left[\frac{35.2}{29.5}\right]-1+100-\left[\frac{31.3}{29.5}\right]-1=2502.02$$

$nse = \sum_{i=1}^{n} excursion\, i$, = 2502.02/56= 44.68

$F_3 = \left(\frac{nse}{0.01_{nse}+0.01}\right)$, $=\left(\frac{44.68}{0.01\times 44.68+0.01}\right)$=97.81

$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right]$, $\frac{\sqrt{50^2+46.43^2+97.81^2}}{1.732}$ == 100- 68.85=31.15

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Krofofrom sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.4: Biochemical and Physico-Chemical Characteristics of Jofel Sampling Site.

Parameters	***Objective***	***9th November,2011***	***23rd November,2011***	***11th January,2012***	***26th January,2012***
P^H	6-9	7.11	7.15	7.26	7.46
Turbidity (NTU)	75	8	22.3	41.5	78*
Colour (TCU)	100	100	140*	150*	200*
TDS (mg/L)	1000	458	478	608	606
Conductivity (µS/cm)	1500	916	478	213	1215
TSS (mg/L)	50	45	113	50	510
Total Phosphorus (mg/L)	10	12.8*	10.4*	10.5*	14.5*
Nitrate (mg/L)	100	6.87	5.34	4.89	3.52
BOD_5 (mg/L)	200	176	171	299*	336.8*
COD (mg/L)	1000	104	304	240	496
Total Coliformis (N/100)	400	185	211	43	53
***E-Coli* (N/100)**	10	125*	130*	12*	21*
Temperature (^oC)	29.5	29.2	30.8*	29.2	30.8*
DO (mg/L)	5	0.44	0.57	0.37	0.12

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 06.

Total no of tests: 56. No of failed tests: 16.

APPENDIX 5.4.1: The CCME Water Quality Index for Aboabo stream at Jofel sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 6/14*100=42.86

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =16/56*100=28.57

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

=100-$\left[\frac{140}{100}\right] - 1 + 100 - \left[\frac{150}{100}\right] - 1 + 100 - \left[\frac{200}{100}\right]$-1 +$100 - \left[\frac{78}{75}\right] - 1$ +100-$\left[\frac{12.8}{10}\right] - 1$+ 100-$\left[\frac{10.4}{10}\right] - 1 + 100 - \left[\frac{10.5}{10}\right] - 1 + 100 - \left[\frac{14.5}{10}\right]$-1 $+100 - \left[\frac{299}{200}\right] - 1 + 100 - \left[\frac{336.8}{200}\right]$-1+ $100 - \left[\frac{125}{10}\right]$-1 $+100 - \left[\frac{130}{10}\right] - 1$ +100-$\left[\frac{12}{10}\right] - 1 + 100 - \left[\frac{21}{10}\right] - 1 + 100 - \left[\frac{30.8}{29.5}\right]$-1 $+ 100 - \left[\frac{30.8}{29.5}\right]$-1 =1539.19

$nse = \sum_{i=1}^{n} excursion\, i$, = 1539.19/56= 27.49

$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right)$, =$\left(\frac{1539.19}{0.01 \times +1539.190.01}\right)$=96.49

$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right]$, $\frac{\sqrt{42.86^2 + 28.57^2 + 96.49^2}}{1.732}$ == 100- 63.15=37

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Jofel sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.5: Biochemical and Physico-Chemical Characteristics of Aboabo Sampling Site.

Parameters	***Objective***	***9th Nov., 2011***	***23rd Nov., 2011***	***11th Jan., 2012***	***26th Jan., 2012***
P^H	6-9	7.04	7.35	7.47	7.78
Turbidity (NTU)	75	18.78	72.8	148*	377*
Colour (TCU)	100	140*	250*	200*	300*
TDS (mg/L)	1000	630	696	648	700
Conductivity (µS/cm)	1500	1260	1393	1296	1406
TSS (mg/L)	50	95*	135*	645*	1165*
Total Phosphorus (mg/L)	10	9.2	7.8	22.5*	23.6*
Nitrate (mg/L)	100	6.02	4.7	7.84	10.2
BOD_5 (mg/L)	200	201*	390*	153*	296*
COD (mg/L)	1000	176	392	256	688
Total Coliformis (N/100)	400	196	185	163	273
***E-Coli* (N/100)**	10	105*	108*	115*	112*
Temperature (^oC)	29.5	31.4*	33.2*	33.8*	32.65*
DO (mg/L)	5	0.45	0.55	0.35	0.14

Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 07.

Total no of tests: 56. No of failed tests: 24.

APPENDIX 5.5.1 The CCME Water Quality Index for Aboabo stream at Aboabo sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 7/14*100=50

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =25/56*100=44.64

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

$$=100-\left[\frac{148}{75}\right]-1+100-\left[\frac{377}{75}\right]-1+100-\left[\frac{140}{100}\right]-1+100-\left[\frac{250}{100}\right]-1+100-\left[\frac{200}{100}\right]-1+100-\left[\frac{300}{100}\right]-1+100-\left[\frac{95}{50}\right]-1+100-\left[\frac{135}{50}\right]-1+100-\left[\frac{645}{50}\right]-1+100-\left[\frac{1165}{50}\right]-1+100-\left[\frac{22.5}{50}\right]-1+100-\left[\frac{23.6}{10}\right]-1+100-\left[\frac{201}{200}\right]-1+100-\left[\frac{390}{200}\right]-1+100-\left[\frac{153}{200}\right]-1+100-\left[\frac{153}{200}\right]-1+100-\left[\frac{296}{200}\right]-1+100-\left[\frac{105}{10}\right]-1+100-\left[\frac{108}{10}\right]-1+100-\left[\frac{115}{10}\right]-1+100-\left[\frac{112}{10}\right]-1+100-\left[\frac{31.4}{29.5}\right]-1+100-\left[\frac{33.2}{29.5}\right]-1+100-\left[\frac{32.8}{29.5}\right]-1+100-\left[\frac{32.65}{29.5}\right]-1 = 2359.38$$

$nse = \sum_{i=1}^{n} excursion\ i$, $= 2359.38/56 = 42.13$

$$F_3 = \left(\frac{nse}{0.01_{nse}+0.01}\right), =\left(\frac{42.13}{0.01\times 42.13+0.01}\right)=97.69$$

$$CCMEWQI = 100-\left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right] , \frac{\sqrt{50^2+44.64^2+97.69^2}}{1.732} == 100- 68.40=32$$

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Aboabo sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.6: Biochemical and Physico-Chemical Characteristics of Anloga Junction Sampling Site.

Parameters	***Objective***	***9th Nov., 2011***	***23rd Nov., 2011***	***11th Jan., 2012***	***26th Jan., 2012***
P^H	6-9	7.1	7.13	7.07	7.34
Turbidity (NTU)	75	199.2*	99.4*	182.2*	108*
Colour (TCU)	100	150*	150*	180*	180*
TDS (mg/L)	1000	435	472	635	417
Conductivity (µS/cm)	1500	888	454	1195	1244
TSS (mg/L)	50	115*	165*	695*	240*
Total Phosphorus (mg/L)	10	11.4*	13.6*	18*	15.2*
Nitrate (mg/L)	100	5.8	7.2	9.31	5.23
BOD_5 (mg/L)	200	221*	390*	193	196
COD (mg/L)	1000	176	392	256	688
Total Coliformis (N/100)	400	196	185	163	273
***E-Coli* (N/100)**	10	105*	108*	115*	112*
Temperature (^oC)	29.5	31.4*	33.2*	33.8*	32.65*
DO (mg/L)	5	0.45	0.55	0.35	0.14

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 07

Total no of tests: 56. No of failed tests: 26.

APPENDIX 5.6.1: The CCME Water Quality Index for Aboabo stream at Anloga Junction sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 7/14*100=50

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =26/56*100=46.43

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

=100-$\left[\frac{199.2}{75}\right] - 1 + 100 - \left[\frac{99.4}{75}\right] - 1 + 100 - \left[\frac{182.2}{75}\right]$-1 $+100 - \left[\frac{108}{75}\right] - 1 +$ 100-$\left[\frac{150}{100}\right] - 1 + 100 - \left[\frac{150}{100}\right] - 1 + 100 - \left[\frac{180}{100}\right]$-1 $+100 - \left[\frac{180}{100}\right] - 1$ +100-$\left[\frac{115}{50}\right] - 1 + 100 - \left[\frac{165}{50}\right] - 1 + 100 - \left[\frac{695}{50}\right]$-1 $+100 - \left[\frac{240}{50}\right] - 1 +$ 100-$\left[\frac{11.4}{10}\right] - 1 + 100 - \left[\frac{13.6}{10}\right] - 1 + 100 - \left[\frac{18}{10}\right]$-1 +100-$\left[\frac{15.2}{10}\right] - 1 + 100 - \left[\frac{221}{200}\right] - 1 + 100 - \left[\frac{390}{200}\right]$-1+ $100 - \left[\frac{105}{10}\right]$-1 $+100 - \left[\frac{108}{10}\right] - 1$ +100-$\left[\frac{115}{10}\right] - 1 + 100 - \left[\frac{112}{10}\right] - 1 + 100 - \left[\frac{31.4}{29.5}\right]$-1 $+ 100 - \left[\frac{33.2}{29.5}\right]$-1 $+ 100 - \left[\frac{33.8}{29.5}\right]$-1 + $100 - \left[\frac{32.65}{29.5}\right]$-1 =2485.79

$nse = \sum_{i=1}^{n} excursion\, i$, = 2485.79/56= 44.39

$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right)$, =$\left(\frac{44.39}{0.01 \times 44.39 + 0.01}\right)$=97.79

$$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right] , \frac{\sqrt{50^2 + 46.43^2 + 97.79^2}}{1.732}$$ == 100- 68.85=32

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Anloga Junction sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.7: Biochemical and Physico-Chemical Characteristics of Duase Sampling Site.

Parameters	*Objective*	*9th Nov., 2011*	*23rd Nov., 2011*	*11th Jan., 2012*	*26th Jan., 2012*
P^H	6-9	7.05	6.91	7.08	7.18
Turbidity (NTU)	75	5.9	6.83	12.1	15.8
Colour (TCU)	100	35	50	40	20
TDS (mg/L)	1000	104	93.3	81.8	54
Conductivity (µS/cm)	1500	208	93.3	163.7	108
TSS (mg/L)	50	18	3	10	35
Total Phosphorus (mg/L)	10	0.25	0.06	0.17	0.38
Nitrate (mg/L)	100	0.93	1.2	1.45	1.63
BOD_5 (mg/L)	200	12	8	10	3
COD (mg/L)	1000	24	30	18	8
Total Coliformis (N/100)	400	25	11	3	4
***E-Coli* (N/100)**	10	6	4	0	1
Temperature (^oC)	29.5	26.4	27.9	25.3	26.3
DO (mg/L)	5	12.3*	11.32*	10.34*	9.14*

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 01.

Total no of tests: 56. No of failed tests: 04.

APPENDIX 5.7.1: The CCME Water Quality Index for Aboabo stream at Duase Sampling Point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 1/14*100=7.14

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =4/56*100=7.14

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

$$=100-\left[\frac{12.3}{5}\right]-1+100-\left[\frac{11.32}{5}\right]-1\ +100-\left[\frac{10.34}{5}\right]-1\ +100-\left[\frac{9.14}{5}\right]-1=387.38$$

$$nse=\sum_{i=1}^{n} excursion\ i\ , \qquad = 387.38/56= 6.92$$

$$F_3=\left(\frac{nse}{0.01_{nse}+0.01}\right), =\left(\frac{6.92}{0.01\times6.92+0.01}\right)=87.37$$

$$CCMEWQI=100-\left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right]\ ,\ \frac{\sqrt{7.14^2+7.14^2+87.37^2}}{1.732} == 100- 50.78=49.2$$

The result obtained from the application of CCME WQI has categorized the Sisal Stream at Duase as marginal, a tributary that joints the Aboabo Stream for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.8: Biochemical and Physico-Chemical Characteristics of Confluent Sampling Site.

Parameters	*Objective*	*9th November,2011*	*23rd November,2011*	*11th January,2012*	*26th January,2012*
P^H	6-9	6.84	7.01	6.89	7.19
Turbidity (NTU)	75	13.5	12.1	18.2	40.8
Colour (TCU)	100	120*	85	60	60
TDS (mg/L)	1000	211	214	238	280
Conductivity (µS/cm)	1500	422	214	475	557
TSS (mg/L)	50	32	28	45	185*
Total Phosphorus (mg/L)	10	4.28	8.1	6.8	6.6
Nitrate (mg/L)	100	1.02	1.7	7.84	6.2
BOD_5	200	90	95.5	97	217*

(mg/L)					
COD (mg/L)	1000	64	216	138	176
Total Coliformis (N/100)	400	120	165	194	181
***E-Coli* (N/100)**	10	19	25	59	33
Temperature (^oC)	29.5	30.2*	29.8*	27.2	28.5
DO (mg/L)	5	3.24	0.52	0.19	0.17

NB: Numbers with'*' are failed tests.

Total number of variables: 14. Total number of failed variables: 04.

Total no of tests: 56. No of failed tests: 05.

APPENDIX 5.8.1: The CCME Water Quality Index for Aboabo stream at Confluent Point Location.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 4/14*100=28.57

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =5/56*100=8.92

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

=100-$\left[\frac{120}{100}\right] - 1 + 100 - \left[\frac{185}{50}\right] - 1 + 100 - \left[\frac{217}{200}\right]$-1 $+100 - \left[\frac{30.2}{29.5}\right] - 1 + 100 - \left[\frac{29.8}{29.5}\right] - 1$

=486.98

$nse = \sum_{i=1}^{n} excursion\ i$, = 486.98/56= 8.69

$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right)$, =$\left(\frac{8.69}{0.01 \times 8.69 + 0.01}\right)$=89.68

$$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \quad , \quad \frac{\sqrt{28.57^2 + 8.92^2 + 89.68^2}}{1.732} == 100\text{- } 54.59 = 45$$

The result obtained from the application of CCME WQI has categorized the Sisal Stream at Confluent with the Aboabo Stream at Asokwa as marginal for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.9: Biochemical and Physico-Chemical Characteristics of Asokwa Sampling Site.

Parameters	***Objective***	***9th Nov., 2011***	***23rd Nov., 2011***	***11th Jan., 2012***	***26th Jan., 2012***
P^H	6-9	6.64	6.78	6.91	6.7
Turbidity (NTU)	75	20.7	10.2	30.1	138*
Colour (TCU)	100	80	120*	130*	110*
TDS (mg/L)	1000	252	256	354	376
Conductivity (µS/cm)	1500	504	256	706	750
TSS (mg/L)	50	115*	59.5*	85*	208*
Total Phosphorus (mg/L)	10	6.16	10.95*	9.15	6.12
Nitrate (mg/L)	100	3.37	4.2	8.02	5.2
BOD_5 (mg/L)	200	132	167	281*	112.8*
COD (mg/L)	1000	32	240	123	320
Total Coliformis (N/100)	400	153	233	124	174
***E-Coli* (N/100)**	10	55*	63*	14*	27*
Temperature (^oC)	29.5	29.4	30.9*	30.8*	34.2*
DO (mg/L)	5	0.48	0.42	0.11	0.18

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 07.

Total no of tests: 56. No of failed tests: 18.

APPENDIX 5.9.1: The CCME Water Quality Index for Aboabo stream at Asokwa sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 7/14*100=50

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =18/56*100=32.14

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

$$=100-\left[\frac{120}{100}\right]-1+100-\left[\frac{130}{100}\right]-1+100-\left[\frac{110}{100}\right]-1+100-\left[\frac{138}{75}\right]-1+100-\left[\frac{115}{50}\right]-1+100-\left[\frac{59.5}{50}\right]-1+100-\left[\frac{85}{50}\right]-1+100-\left[\frac{85}{50}\right]-1+100-\left[\frac{208}{50}\right]-1+100-\left[\frac{10.95}{10}\right]-1+100-\left[\frac{281}{200}\right]-1+100-\left[\frac{112.8}{200}\right]-1+100-\left[\frac{55}{10}\right]-1+100-\left[\frac{63}{10}\right]-1+100-\left[\frac{14}{10}\right]-1+100-\left[\frac{27}{10}\right]-1+100-\left[\frac{30.9}{29.5}\right]-1+100-\left[\frac{30.8}{10}\right]-1+100-\left[\frac{34.2}{29.5}\right]-1=1840.59$$

$nse = \sum_{i=1}^{n} excursion\, i$, = 1840.59/56= 32.87

$F_3 = \left(\frac{nse}{0.01_{nse}+0.01}\right)$, $=\left(\frac{32.87}{0.01\times 32.87+0.01}\right)$ = 97.05

$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right]$, $\frac{\sqrt{50^2+32.14^2+97.05^2}}{1.732}$ == 100- 65.70=34

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Asokwa sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 5.10: Biochemical and Physico-Chemical Characteristics of Atonsu Sampling Site.

Parameters	*Objective*	*9th Nov., 2011*	*23rd Nov., 2011*	*11th Jan., 2012*	*26th Jan., 2012*
P^H	6-9	6.95	7.11	7.33	7.62
Turbidity (NTU)	75	110*	25.8	55.9	110*
Colour (TCU)	100	130*	95	120*	250*
TDS (mg/L)	1000	343	368	452	390
Conductivity (μS/cm)	1500	687	368	913	788
TSS (mg/L)	50	150*	156*	325*	375*
Total Phosphorus (mg/L)	10	7.8	7.9	11.5*	10.44*
Nitrate (mg/L)	100	2.17	10	9.8	2.53
BOD_5 (mg/L)	200	96	162	206*	324.2*
COD (mg/L)	1000	256	568	340	288
Total Coliformis (N/100)	400	188	178	194	176
***E-Coli* (N/100)**	10	42*	52	73*	43*
Temperature (^oC)	29.5	31.9*	28.2	28.1	35.2*
DO (mg/L)	5	0.39	0.6	0.44	0.11

NB: Numbers with '*' are failed tests.

Total number of variables: 14. Total number of failed variables: 07.

Total no of tests: 56. No of failed tests: 19.

APPENDIX 5.10.1: The CCME Water Quality Index for Aboabo stream at Atonsu sampling point.

$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)$*100, = 7/14*100=50

$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)$*100, =19/56*100=33.92

$excursion_j$=100-$\left[\frac{\text{Failed test value}_i}{\text{OObjective}_j}\right]$-1

=100-$\left[\frac{110}{75}\right] - 1 + 100 - \left[\frac{110}{75}\right] - 1 + 100 - \left[\frac{130}{100}\right]$-1 +$100 - \left[\frac{120}{100}\right] - 1$ +100-$\left[\frac{250}{100}\right] - 1$+ 100-$\left[\frac{150}{50}\right] - 1 + 100 - \left[\frac{156}{50}\right] - 1 + 100 - \left[\frac{325}{50}\right]$-1 $+100 - \left[\frac{375}{50}\right] - 1 + 100 - \left[\frac{11.5}{10}\right]$-1+ $100 - \left[\frac{10.44}{10}\right]$-1 $+100 - \left[\frac{206}{200}\right] - 1$ +100-$\left[\frac{324.2}{200}\right] - 1 + 100 - \left[\frac{42}{10}\right] - 1 + 100 - \left[\frac{52}{10}\right]$-1 $+ 100 - \left[\frac{73}{10}\right]$-1 $+ 100 - \left[\frac{43}{10}\right] - 1 + 100 - \left[\frac{31.9}{29.5}\right]$-1 $+ 100 - \left[\frac{35.2}{29.5}\right]$-1=1824.84

$nse = \sum_{i=1}^{n} excursion\, i$, = 1824.84/56= 32.59

$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right)$, =$\left(\frac{32.59}{0.01 \times 32.59 + 0.01}\right)$ = 97.02

$CCMEWQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right]$, $\frac{\sqrt{50^2 + 33.92^2 + 97.02^2}}{1.732}$ == 100- 65.99=34

The result obtained from the application of CCME WQI has categorized the Aboabo Stream at Atonsu sampling point as poor for November 2011 to January 2012; refer to appendix 6.

APPENDIX 6: CCME WQI and categorization of water quality

Sl.No	***Rating***	***WQI***	***Categorization***
1	Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
2	Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
3	Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
4	Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
5	Poor	0-44	Water quality is almost always threatened or impaired

The assignment of CCME WQI values to these categories is termed "categorization" and represents a critical but somewhat subjective process. The categorization is based on the best available information, expert judgment, and the general public's expectations of water quality. The categorization presented here is preliminary and will no doubt be modified as the index is tested further.

APPENDIX 7: STUDY AREA DATA

APPENDIX 7.1: Projected Population (2010) for the study communities.

Community Selected.	*Projected Population (2010).*	*Projected Total Number of Houses (2010).*	*Percentage (%).*	*Sample Size Selected from Community*
Upstream. Pankrono.	117833	2594	23	21
Moshie Zongo	67926	1320	13	21
Buokrom Estate	26645	1362	5	7
Midstream. Dichemso	26823	934	5	13
Aboabo	44276	830	9	21
Downstream. Asokwa	31619	1102	6	10
Atonsu	204391	2489	39	30
Total	**519,513**	**10,631**	**100**	**123**

Source: KMA Statistician, 2011.

APPENDIX 7.2: Estimated Tonnage of waste generated, collected and uncollected /per/day for the study communities.

Community	*Estimated Tonnage of Waste Generated /per/day.*	*Estimated Tonnage of Waste Collected /per/day.*	*Estimate Tonnage of Waste Uncollected/day*
Pankrono	117833*0.6=71	71*1200/1500=57	14
Moshie Zongo	67926*0.6=40	40*1200/1500=32	8
Buokrom	26645*0.6=16	16*1200/1500=13	3
Dichemso	26823*0.6=16	16*1200/1500=13	3
Aboabo	44276*0.6=27	27*1200/1500=22	5
Asokwa	31619*0.6=19	19*1200/1500=15	4
Atonsu	204391*0.6=123	123*1200/1500=98	25
Total	312	250	62

Source: Author's calculation, 2012

*NB: The waste generation rate of 0.6kg/capital/day and the collection rate of 1200/1500*100% =80% were adapted from the KMA, Development Plan 2010-2013.*

APPENDIX 7.3: **Sample size distribution**

Upstream Communities	Midstream Communities	Downstream Communities
Pankrono = 2594÷10631×123 = 30.01 ≈ 30	**Dichemso** = 934÷10631×123 = 10.08 ≈ 10.	**Asokwa** = 1102÷10631×123 =12.75 ≈ 13.
Moshie Zongo =1320÷10631×123 =15.27 ≈ 15	**Aboabo** = 830÷10631×123 = 9.6 ≈ 10.	**Atonsu** =2489÷10631×123 =28.78 ≈ 29.
Buokrom = 1362÷10631×123 =15.7		
Total = 61	**20**	**42**

Source: Author's calculation, 2012

NB: The projected population and the projected total number of houses figures for 2010 were adapted from KMA Statistician 2011.

Definition of terms

Composite samples: A mixture of a series of individual grab samples collected over a specified period in proportion to flow.

Degradation of water quality: A decrease in quality, which makes water unsuitable for specific uses.

Domestic wastewater: Wastewater principally derived from households, business buildings, institutions, etc., which may or may not contain surface runoff, groundwater or storm water.

Domestic water use: The use of water for household purposes and personal hygiene.

Effluent discharge: This is fluid such as municipal sewage and industrial liquid waste (untreated, partially treated, or completely treated), which flows out of a treatment plant, sewer, or industrial outlet or domestic outlets. Generally it refers to wastes discharged into surface waters.

Effluent standard: This is the maximum amount of specific pollutants allowable in wastewater discharged by an industrial facility or wastewater treatment plant. The standards are set for individual pollutants and apply across all industrial categories.

Grab samples: Single samples collected at a specific spot at a site over a short period of time (typically seconds or minutes).

Pollutant: This is generally any substance when introduced into the environment in excess quantities of the natural background concentrations, adversely affects the usefulness of a resource or the health of humans, animals, or ecosystems

Pollution: In relation to a water resource, this means any direct or indirect alteration of the physical, thermal, chemical or biological properties of the water resource so as to make it less fit for any beneficial purpose for which it is or may reasonably be expected to be used; or harmful

Questionnaire: a set of common questions laid out in a standard and logical form to record individual respondent's attitudes and behaviour.

River basin: The land area drained by a river and its tributaries or the land area surrounding one river from its headwaters to its mouth.

Surface water: includes all water on the surface of the ground directly exposed to the atmosphere, including, but not limited to, lakes, ponds, reservoirs, artificial impoundments, streams, rivers, springs, seeps, and wetlands

Urban area: is an area with an increased density of human-created structure, thus refers to both the build-up agglomeration and the areas for which it provides services and facilities. Urban areas may be cities or towns.

Waste disposal facility: means any site or premise used for the accumulation of waste with the purpose of disposing of that waste at that site or on that premise.

Waste management: consists of waste prevention, reuse, material recycling, composting, energy recovery and final disposal.

Waste treatment facility: means any site that is used to accumulate waste for the purpose of storage, recovery, treatment, reprocessing, recycling or sorting of that waste.

Waste: an undesirable or superfluous by-product, emission, or residue of any process or activity which has been discarded, accumulated or been stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area. This definition includes industrial waste water, sewage, radioactive substances, mining, metallurgical and power generation waste

Water quality monitoring: The actual collection of information at set locations and at regular intervals in order to provide the data which may be used to define current conditions, establish trends, suggest that a water body requires improvement to meet its designated use, inform citizens about the health and value of a stream etc.

Water resources: A general term encompassing the concepts of availability (the location, spatial distribution, or natural fluctuations of water); accessibility (given availability, whether consumers can have water or can afford water in adequate quantities); and quality (whether accessed water is free of contaminants and safe for consumption.

APPENDIX 7: Activities along the Aboabo Stream

Plate 7.1: Car wash along the Aboabo Stream at Jofel.

Plate 7.2: Metal scrapes dealers along the Aboabo Stream at Aboabo.

Plate 7.3: Palm kernel oil industry sitting along the Aboabo Stream at Moshie Zongo.

Plate 7.4: Wood processing industry sitting along the Aboabo Stream at Anloga Junction.

APPENDIX 8: Pictures of Study Area

Plate 8.1: Chocked drain inside Aboabo Community.

Plate 8.2: Drain emptying its content into the Aboabo Stream from Aboabo Community.

Plate 8.3: Waste dumping along the Aboabo Stream at Anloga Junction.

Plate 8.4: Skip container sitting along the Aboabo Stream at Asokwa.

Plate 8.5: Washroom sitting along the Aboabo Stream in the Aboabo community

Plate 8.6: Sampling at different locations on the Aboabo Stream.

Plate 8.6.1: Taking water samples at Moshie Zongo sampling location.

Plate 8.6.2: Taking water samples at Krofofrom sampling location.

Plate 8.6.3: Taking water samples at Duase sampling location.

Plate 8.6.4: Taking the DO, pH, and Temperature at Duase sampling location.

Plate 8.6.5: Taking the DO, pH, and Temperature at Moshie Zongo sampling location.

Plate 8.6.6: Taking water samples at Jofel sampling location.

Plate 8.6.7: Taking the DO, pH, and Temperature at Aboabo sampling location.

Plate 8.6.7: Taking the DO, pH, and Temperature at Atonsu sampling location.

Plate 8.6.8: Taking water sample at Anloga Junction sampling location.

Plate 8.6.8: Taking the DO, pH, and Temperature at Anloga Junction sampling location.