IMPACTS OF LAND USE/COVER CHANGE ON WATER QUALITY IN LAKE BOSOMTWI BASIN OF GHANA

BY

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DECLARATION

I do hereby declare that this thesis is the result of my own research work. Except for the references of other people's work which has been duly acknowledged and that, no part or whole has been presented for any degree in this university or elsewhere.

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DEDICATION

I dedicate this thesis work to all mothers especially Comfort Serwaa Mensah Dwirah and Georgina Anowuo.

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LIST OF ABBREVIATIONS

ANZECC	Australian and New Zealand Environment and Conservation Council
APHA	American Public Health Association
CEPA	Center for Policy Analysis
DFAS	Department of Fisheries and Aquatic Science
F.A.O	Food and Agricultural Organization
GSA	Ghana Standard Authority
G.P.A.C.W.Q.T.F	Great Plains Agricultural Council Water Quality Task Force
IPCC	Inter-governmental Panel on Climate Change
LUCC	Land Use/ Cover Change
LW0	Lake Water (sampling sites)
NLWRA	National Land and Water Resources Audit (Austria)
NTU	Nephelometric Turbidity Units
Ppm	Parts per million
SD	Standard deviation
UNCHS	United Nations Centre for Human Settlement
UNEP-GPA	United Nations Environmental Protection- Global Program of Action
UNEP- IETC	United Nations Environmental Protection- International Environmental Technology Centre
UNEP-ITC	United Nations Environmental Protection- International Trade Centre
UNEP GEMS	United Nations Environmental protection- Global Environmental Monitoring System
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency
WRC	Water Resources Commission

WSMP	Water and Sanitation Monitoring Platform
W.H.O	World Health Organization

ABSTRACT

Land use/cover alteration within lake basins is occurring at accelerated rate most importantly in developing countries like Ghana. Anthropogenic activities (livelihood change, population growth, agricultural intensification and practices) and natural factors like seasonal variations are in most situations the major cause. To examine the effects of land use/cover on the physico-chemical and biological properties of Lake Bosomtwi, satellite images of the Lake's watershed covering the study periods (1990, 2000 and 2010) were obtained and processed to determine the land use /cover changes that have taken place over the study period. Samples of water and soil were collected from December 2013 to May 2014 from seven different sites within the lake Bosomtwi watershed for investigation. All physical water quality parameters were measured in-situ.

The observed temperature of the Lake water was relatively high varying from a minimum of 27.6 ˚C to 33.6 ˚C, with a mean value of 30.4±1.5 and an average pH value (9.0±0.6) depicting a highly alkaline Lake water. The result showed salinity range of 0.40 ppt to 0.56 ppt which was slightly above the WHO standard of 0.5 ppt for drinking water. Conductivity values were also generally high with a mean value of 1352.7±27.6 µS/cm. The mean values recorded for the other physico-chemical parameters were; Turbidity 6.1±4.6 (NTU), Apparent Color 67.8±22.4 pt.co, TDS 645.6±48.1 mg/L, TSS 6.8±5.3 mg/L, DO 7.5±0.9 mg/L, BOD 3.7±1.0 mg/L, COD 98.9±10.8 mg/L, Nitrate 1.3±0.3 mg/L, Nitrite 0.01±0.02 mg/L, Phosphate 0.40±0.19 mg/L and Ammonium 0.018±0.017 mg/L. All the studied biological indicators were significantly high compared to the WHO standard for good water quality making the Lake water unfit for most domestic purposes without partial treatment. The result from the soil analysis showed that, soil EC varied from 176 to 454 µs/cm, pH 6.7 to 8.6, total coliform and *E.coli* ranged from non-detectable levels to 350000 mg/L and 120000 mg/L, respectively. Also, average soil nutrients levels were; nitrogen 0.24 ±0.17 mg/L, phosphorus 5.38±4.45 mg/L and ammonium-nitrogen 0.39±0.52 mg/L.

Several strong correlations (using Pearson's Correlation) was found among the studied parameters; temperature was significantly related positively with Conductivity and Salinity while total suspended solids correlated with eight parameters including temperature, apparent color, nitrate and others. Strong correlations were also established between some of the studied water parameters and that of the soil from the various land use/cover which includes EC, pH, TC and *E. coli*.

The study revealed that, there has been a continuous transformation of the vegetation cover within the Lake Bosomtwi watershed in the twenty year period. As close forest vegetation and the Lake water reduced in coverage, agricultural/cultivated areas, bare surface/built up areas inter alia increased in coverage over the years. It was evident that the reduction in fish catch from the lake has negatively impacted on the lives of the people including unemployment, increased poverty among others. The study recommends that, land use activities within the lake Bosomtwi watershed should be regulated and also the buffer zone created around the lake should be well demarcated and maintained. Providing alternate source of employment/livelihood can help reduce the pressure exerted on the land around the Lake and to allow the vegetation around the lake to replenish itself.

CHAPTER ONE

INTRODUCTION

The increase in population and inappropriate human settlement correspond to an increase in the extent to which people will encroach upon the environment. The drivers of change (human activities and other natural factors) have transformed the natural landscape and subsequently the hydrological cycle which often results in detrimental impacts on human well-being. The need to increase food production, income and shelter has resulted in naturally vegetated areas been converted to arable lands for crops cultivation, bare fields striped for timber or settlement resulting in myriad of deleterious effects on aquatic environment. The changes in land use are rapid and anthropogenic impacts in these ecosystems have become a matter of concern to researchers and policy makers in an era of sustainable development.

Over the last two decades, about 75 million hectares of forested land have been converted to farmlands and pasture in Africa alone (F.A.O, 2010). Undoubtedly, achieving development (both economic and social) cannot take place without exploiting the natural resources. However, they also come at a cost to the natural environment. One such inevitable impact is the degradation of water quality.

Land use changes within the immediate environments of a water body impact on the physical, chemical and microbiological characteristics of the water. Thus, the quality of water is directly affected by the type, extent, location of human land uses and the inputs from the watershed. Water quality problems arise when the type and extent of human land use exceeds the natural ability of the watershed to accumulate land use related stress (UNEP- IETC, 1997).

Excessive human activities over the years have transformed the Lake Bosomtwi watershed. The incessant human activities in and around the immediate environment apparently pose serious danger to the lake which apart from providing income to the indigenes also serves as a tourist center. However, little effort has been made to establish the possible effect of land use change within the Lake Bosomtwi basin on quality of water in the lake.

Analyzing the chemical, biological and physical characteristics of water in the lake will help establish the relationship between the changing land use and the quality of water in the lake and consequently the impacts on the people who depend on the lake for survival.

1.1 Problem Statement

Traditionally, the people around Lake Bosomtwi were fishermen and fishmongers. However, studies reveal that excessive stress on the lake by fishermen due to the growing demand for fish and pollution has resulted in a reduction in size and stock of fish (Dassah and Agbo, 2003). The reduction in the fish stock in the lake has affected the rural economy of settlements around the lake. This has resulted in the search for alternate source of livelihood by the people around the lake. Consequently, there has been an intensive cultivation of the immediate lands that surround the lake, rearing of animals and development of tourism infrastructures by private developers.

Most of the forest areas around the lake are now converted to arable lands where cash crop such as cocoa and food crops like plantain, cassava and maize, among others, are cultivated. As a result of the farming activities, the heavy use of pesticides and herbicides has become an important source of pollution of the lake.

The trend of more intensive field cultivation coupled with inappropriate farming methods (like "slash and burn" and farming along slopes), could significantly impact on the quality of water in Lake Bosomtwi. However, most studies are focused on the eco-tourism potential of the Lake, impacts of climate change on the lake, paleo-climatic records of the lake and other environmental issues like waste management within the catchment of the lake (Boamah and Koberl, 2007). Currently, there is little information on the proportion of the vegetative cover that has been converted to other forms of land use and how it has affected the quality of water in the lake. The rural communities around the lake are unaware of the impact of their activities on the quality of water in the lake.

There is therefore, the need to assess the extent to which land use and land cover change within the lake's watershed have affected the quality of water in the lake and its subsequent effect on the local economies.

1.2 Objectives of the Study

The general objective of the study is to assess the impact of land cover / land use changes and other socio-economic activities on the water quality of Lake Bosomtwi in the Ashanti Region of Ghana.

1.2.1 Specific Objectives

Specifically, the study aims at:

- Identifying the land use changes in the Lake Bosomtwi basin over the years.
- Assessing the impact of land use changes on lake water quality.
- Determining the long-term socio economic effects on the peoples' livelihood

- Suggesting appropriate measures to stakeholders on the sustainable management of Lake Bosomtwi.

1.3 Research Questions

To achieve these objectives, these questions would be addressed:

1. What are the causes of changing land use/cover in the past two decades?
2. What is the extent of land use/land cover change in the past years?
3. Has the change in land cover affected the water quality of the lake?
4. How would change in the quality of water affect the livelihood of the people?
5. What is the link, if any, between land use/cover change and water quality?

1.4 Scope of the Study

The study was carried out at Lake Bosomtwi and was limited to only the boundaries of the Bosomtwi watershed. Water samples were analysed for biological, chemical and physical water quality from seven sites within the lake. The various land use activities along the lake were identified using satellite images. The social survey covered eleven (11) communities around the lake.

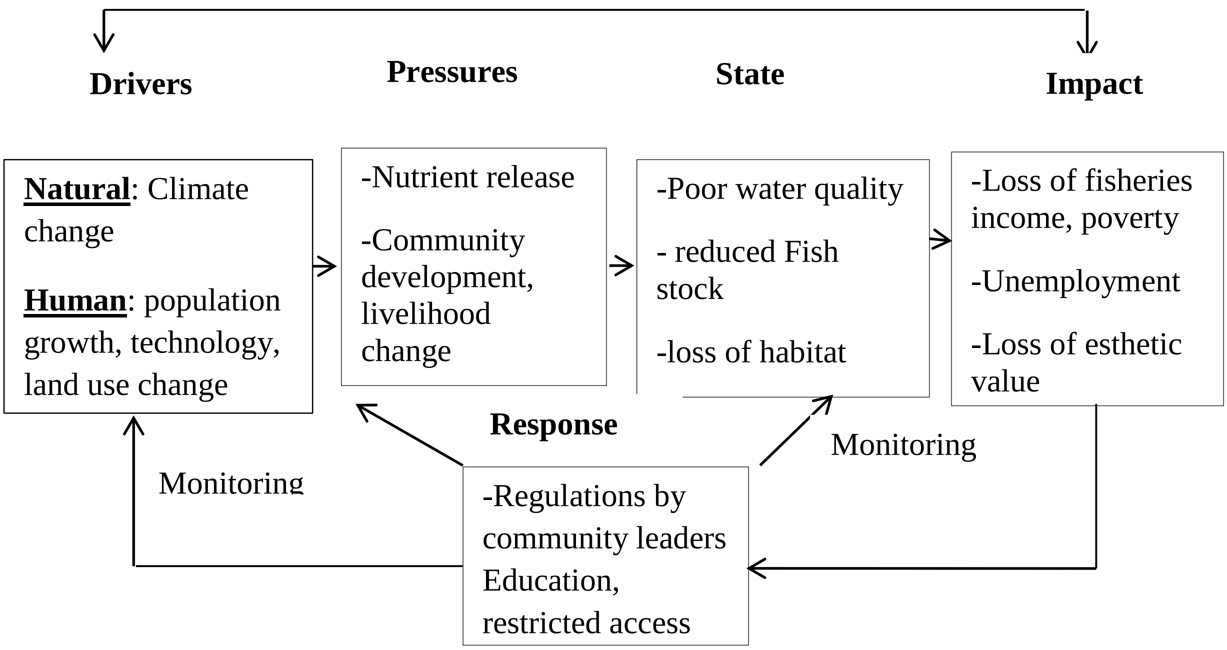

Figure 1.1: Conceptual Framework (DPSIR: Drivers-Pressures-State-Impact-Response)

Source: Adapted from Benini *et al.*, 2010

1.5 Explanation of Theoretical Framework (DPSIR)

An integral aspect of the DPSIR framework is the **State (S)** of environmental variables. In the case of this study, the lake and its qualities/ attributes that have changed over time. This is done by identifying the major **Pressures (P)** within the watershed which influences the environmental variables. The pressures identified are related to some **Driving** forces **(D)** in the society which are the factors (natural or anthropogenic) that influence human activities which **Impacts (I)** on the quality of water (ecosystem and human health). Finally, the society finds a way to **Respond (R)** to this impact resulting from the driving forces and pressures usually through regulations, education and monitoring (Smeeth and Wetering, 1999).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Water is a universal solvent which is able to dissolve most substances and this makes it susceptible to pollution. The current global environmental change has impacted negatively on the quality of water especially in tropical regions like Africa. The change in the environment due to alteration of land use/cover has compromised some of the ecosystem benefits of waterbodies. Thus, maintaining the status of the quality of water has become a major international problem.

As a linchpin of society, fresh water bodies, like lakes, provide ecosystem services such as carbon sink and information on past climate change. However, many water bodies in Ghana suffer from pollution especially the fresh surface water bodies such as rivers and lakes. This, subsequently, affects the health of both humans and the aquatic environment. The ubiquitous nature of this phenomenon has led the scientific community researching on the impacts of anthropogenic activities within a watershed on water quality and its possible dysgenic consequences.

Water quality has been explained by USGS (2013) as a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. This is because the quality of any given water mirrors the natural and anthropogenic factors that influence the water. As noted by Azeez and Raj (2009), the quality and quantity of water is influenced by climate, geography and human interventions which changes in space and time. Arguably, areas within the watershed where human activities are concentrated will impact more on the quality of water.

Natural factors such as climate, topography and the mineral contents of the bedrocks that underlie the water body and other factors contribute to the degradation of water (Boyd, 2000). For instance, nutrient concentration in sediment from weathered material can be forced up through capillary means to mix with overlying water column making it easily available and accessible to localized microalgae.

As reiterated by Meybeck and Norman (2000), even under natural undisturbed conditions or environment water may become toxic or unsuitable for human and aquatic organism. The slope of a watershed shares an inherent link with runoff volume. Arguably, with high gradient, there will be an increase in surface flow and consequently high levels of sedimentation compared to areas with relatively gentle slope. Thus, water flowing from a hilly area has a more erosive power and consequently high sedimentation in the receiving water. This may be true with Lake Bosomtwi which is surrounded by ridges with steep gradients. However, most of these natural impacts that affect the quality of water are most often enhanced by unplanned and uncoordinated human activities on the environment especially on lands proximate to fresh water bodies. In the 21st Century, anthropogenic activities/development such as settlement, tourism and agriculture continues to exert pressure on the quality of surface water, most importantly in the tropical regions like Ghana.

In a study on the effects of natural and anthropogenic changes on ecosystem process, Hornung and Reynolds (1995) averred that, anthropogenic sources have modified the morphology of most basins and also the chemical environment. When water becomes degraded, it serves as fertile grounds for water-borne disease-carrying vectors. In the rural setting where mostly there is poor sanitation, fecal contamination of surface water could be highly prevalent (Twongo *et al*., 1999).

In 2009, W.H.O reported that about 3.4 million people especially children lose their lives every year in developing countries due to water-related diseases. In Ghana, majority of people (about 50.7 %) resides in the rural areas where accessibility to potable water is limited with close to 30 % of the rural populace without potable water (WSMP, 2009) and resort to sources like rivers, borehole and lakes for drinking and other domestic use. The quality of these water sources is uncertain, making people in the rural communities more vulnerable to water prone diseases.

Poor water quality may increase the risk of humans and aquatic life making it unfit to consume fish and other water resources from such water bodies. In most cases, untreated raw domestic waste; human excreta, food residue and animal feces are transported by surface runoff either when it rains or are directly discharged into the lake. Since, to most people, the suitable way of disposing off their waste is throwing it into the lake.

2.2 Land Use/Cover Change

One of the pervasive factors directly affecting the quality and quantity of fresh water is land cover/ use. Land use and management practices to a large degree, determine the quality and quantity of surface runoffs and the biodiversity of aquatic organisms in the recipient water. In most parts of the world, natural vegetation or land cover is being converted from lands that serve as storage of nutrients to those that serve as sources of nutrients into the terrestrial environment especially fresh water bodies (Rosegrant *et al*., 2000).

In Ghana, about 70 % of the once naturally forested areas have been lost primarily to agriculture, settlement, logging and bush fires at a rate of about 120,000 ha per annum (Tabi Agyako, 2001). At the global level, close to 41 % of the earth surface is covered with agriculture, pasture and urban land use which directly or indirectly affect the quality and availability of freshwater (Leff *et al.*, 2004). Thus, land use change can be said to be a global phenomenon affecting the ecological system.

To Debarry (2002), a watershed is an area of land that captures water in any form and drains into a common water body. It is an axiom that before any form of flowing water drains into a receiving water body it travels through different forms of land uses, carrying with it and depositing pollutants collected as it moves over the land surface into the recipient water body. The deposition of these pollutants into the receiving water body could compromise the quality of water within the receiving water body.

According to USGS (2006), land use involves human activities that take place on the land such as grazing, farming, logging and recreation whiles land cover refers to the vegetation and artificial structures that cover the land surface. Land use/cover changes may result from either conversion (changing from its natural status to another use) or modification (partially changing the features) of a given parcel of land or vegetation mostly resulting from social, economic, cultural or political needs (Stolbovoi, 2002). To understand the interaction between land use and water quality, both land use and land cover (hereafter land use) patterns should be studied.

Land use change within watershed is known to alter water balance, the process that controls water quality (Zampella *et al*, 2007) and the vegetative cover located in and around the immediate environment of surface water bodies either directly (concentrated) or indirectly (diffused). In the same way, human settlement (urban and rural) and cultivation in close proximity to surface water bodies (lake) have substantially altered the once semi-deciduous rain forest to patches of fragmented secondary vegetation and farmlands and consequently increasing the intensity of surface flow. For instance, major towns like Abono, Obo, Abaase and others near Lake Bosomtwi have seen significant improvement in infrastructural development and conversion of large tracks of land to farmlands especially near the lake shore.

As posited by Foley *et al*. (2005), the current land use is changing the structure of ecosystem within the lake basins. The health of any aquatic environment relies heavily on the interactions between the water (lake), the riparian vegetation and the alterations made to the landscape around the water body. The riparian vegetation cover serves as a natural protection for water bodies, by reducing erosion, nutrient input and sedimentation through the gradual infiltration of surface run off and absorption of nutrient. Converting riparian vegetation to other forms of land use can affect water quality.

The near shore areas of lakes are characterized by unique flora and fauna communities which are environmentally susceptible making them vulnerable to the slightest disturbances. This is because it is the interface between the land and the water bodies, and one of the most productive ecosystems in the world which is impacted by both aquatic and terrestrial activities (Thorp *et al.*, 1997). The uniqueness of lake shores has been a springboard for all forms of development which are most often unplanned and uncoordinated.

These land use influence adjacent water bodies ranging from nutrient enrichment, alteration of hydrologic cycle, biodiversity change, and animal waste to modification of the landscape. A study by Goolsby *et al*, (1999) on the role of agriculture on changes in nitrogen levels in river Mississippi concluded that, changes in nitrogen (N) levels in the river was about three times higher in less than half a decade (1996-1999) than that of the levels recorded in about more than a decade (1980-1996). In Canada, agriculture is seen as the probable cause of about 77 % of degradation of rivers and streams in the Great Plains (GPACWQTF 1992).

For instance, settlement (both rural and urban) within water basin is associated with non-point source pollution and upland-agriculture practices which affect the quality of water especially in endorheic lakes like Bosomtwi. As observed by Schueler (2000), impervious layers such as roads, pavements, rooftops and others result in accelerated run-off to the receiving lake. Similarly, a study in India attributed changes in water quality to changes in land use practices (Raj and Azeez, 2009).

In our contemporary world, nutrient enrichment has been attributed mainly to non-point source mainly from human settlement and farmlands which has led to the degradation of many aquatic systems (Carpenter *et al*., 1998). A survey by USEPA (2006) on the major source of water quality problem reported that nonpoint source of nutrient enrichment is the major cause of 20 % of rivers and 50 % of lake's impairment. Similarly, Goolsby *et al.* (1999) observed that, diffused source alone contributed about 90 % of nitrogen to the Mississippi river. The wide-spread nature of diffused pollution makes it difficult to minimize its impact on water quality especially in a developing country like Ghana where water quality monitoring is mostly not carried out.

A report by F.A.O (2003) indicated that, globally, the major land use change includes forest change (deforestation), change in agricultural area and management. Land use activity such as agricultural intensification has both positive and negative effects on the environment. While the use of inputs like fertilizer, manure and agro-chemicals has helped to increase crop yield, their indiscriminate use leaves residual particles on the soil which can result in deterioration of downstream aquatic ecosystem (Beman *et al.*, 2005).

As has been observed by Reed *et al*, (2008) the conversion of tropical forest within the watershed to lands for grazing and crop production result in increased ammonium ions (NH_4^+) and dissolved organic nitrogen in the water given that there are different types of soil, nutrient availability and how each ecosystem assimilate to nutrient in the tropical region like Ghana. In Ghana like many developing countries, agricultural intensification is gradually gaining grounds. The irony is that, most of the farmers in Ghana are not well informed. Thus, application of farm inputs like fertilizer and manure are mostly done without any prior soil testing to determine the type of nutrient supplement to apply to specific soil. Nutrients applied are mostly not required or applied in excess making such nutrients available to be eroded and deposited in a receiving water body.

Similarly, Turner and Rabalais (2003) affirmed that, where agricultural activity is intense, there is the production of high levels of dissolved salt, sedimentation and nutrient enrichment (phosphorus and nitrogen). Thus, there is a strong correlation between nutrient losses and land use decision. However, in recent times, there is a growing evidence that atmospheric deposition may contribute significantly to nutrient enrichment especially nitrogen (Jaworsk *et al*., 1997).

Whiles Vano (2009) suggested the effect of climate change on hydrology to be significant than development. Carpenter *et al.* (2007) also argued that, the quality of water will decline in more developed areas and in areas where residential and recreational activity is dense, the food chain of lake is affected.

In studying the correlation between watershed and how it impacts on water quality, it has been established that land use activities whether far or proximate to the water do affect the water quality (Sliver and Williams, 2001). In contrast, Smith *et al.* (2010) and others concluded that, land use activities close to water body is the best predictor of water quality than more distant land use. Thus, the locations of land use activity whether close to the water body or remote do affect the quality of water so far as it is carried out within the watershed.

The level and trend of water quality degradation within a water body is a factor of the intensity of land use within the watershed. Land use change especially agriculture intensification and settlement/residential areas is perhaps the most salient signature of human activities on both terrestrial and aquatic environment.

2.3 Nutrient Enrichment

The major water quality problem facing tropical surface water bodies and indeed at a global scale is the direct or indirect introduction of nutrients into aquatic system. According to USEPA (2000), excessive nutrient enrichment is one of the leading causes of water impairment. Related to this is a study by UNEP-GPA (2006) which observed that, about 50% of waste water discharged into fresh water bodies is not treated and this has a potential to threaten aquatic environment. Similarly, a report by U.S EPA (2006) concludes that agricultural runoff containing nutrients and agro-chemicals is the major source of non-point source pollution to surface water bodies. Like most developing countries, agriculture in Ghana most especially vegetable farming is marked by excessive application and misuse of agrochemicals which mostly compromise the quality of water. At least, in most situations, about half of these agrochemicals applied are lost to air and surface water bodies (Asante and Ntow, 2009).

In 1999, the UNEP-ITC established that, rivers and streams are the main conduit by which lakes and reservoirs are enriched with nutrient serving as sediment and pollutant transport mostly from agricultural land use. Thus, the quality and content of a river entering a receiving water body (lake) to a large extent influences the fate of water in the receiving water, the aquatic habitat, and the health of those using the water. A river that meanders through agricultural farmlands (which most rivers do in Ghana) will carry with it sediments, nutrients (like nitrogen, phosphorus) and pesticides and redeposit them into a receiving water. Similarly, Schilling and Lutz (2004) observed that, agricultural landscape results in the transportation of excessive nitrate into water bodies whiles phosphorus is due to high sediment loads transported by rivers and runoff during heavy rainfall which fuels serious eutrophication.

One thing is constant throughout literature; excessive nutrient enrichment within the watershed will result in nutrient build up in soil and consequently in water bodies leading to eutrophication. Meybeck *et al.* (1989) described eutrophication as a natural process which may have little or no effect on water quality. However, if it is accelerated by human activities within the watershed in a process referred to as cultural eutrophication, it becomes problematic (Encyclopedia Britannica, 2013). Thus, eutrophication is a natural process of lake aging but with human activities accelerating nutrient inputs into lakes, the aging process is accelerated.

The problem is exacerbated by increase in temperature, placing water bodies in tropics at a vulnerable situation. It has been established that in most tropical lakes like Lake Bosomtwi, the increase in eutrophication is consequent to the growth of lake *macrophytes* which serves as fertile ground for the growth of secondary host for human parasites like *Schistosoma* (UNEP, 1996).

Surface run-off carries with it sediments from agricultural lands during intense rainfall which can move residual nutrients and redeposit them in receiving water. This negatively affects the water quality by producing dense noxious and toxic algae bloom, hypoxia and anoxia, impair aquatic habitats, and the consequent fish kill in extreme cases (Galloway *et al.*, 2002).

In the following sections, literatures on some important parameters that affect water quality are reviewed.

2.3.1 Phosphorus (P)

Phosphorus which usually exists as phosphate (PO_4) is one of the macro-nutrients needed by plants for growth. It is either found in nature (in soil and atmosphere) or applied to the soil through fertilizer, manure and organic waste (failing septic tank) and several other means. Though essential for plant growth, it has a deleterious effect when introduced from terrestrial environment to the aquatic system (Watson, 2001). When phosphorus becomes too concentrated in a lake, the production of algae and aquatic plants increase. This results in excessive algae growth, reduced water clarity, unpleasant odor and taste, changes in fish populations or fish kills and several others (Smolen, 2004).

One major pathway through enrichment of phosphorus in water bodies especially lakes mostly occur from non-point source with shoreline residential lands, roads and agriculture lands as some of the leading sources. The transfer of phosphorus to water bodies is rapid in hilly areas. In steep slopes, phosphorus is not able to mix well with the soil matrix and this makes crater lakes like Lake Bosomtwi, which is surrounded by hills, prone to phosphorus enrichment (Preedy *et al*., 2001). In a similar study by Drok and Koncan (2002) on phosphorus loading in Krka catchment, 42% of P load was attributed to non-point source mainly from agricultural lands. Contrary to this assertion, the main source of phosphorus input to Lake Victoria has been attributed to atmospheric deposition (COWI, 2002).

When phosphorus is applied in the form of fertilizer/manure, residual particles are left in the soil. This surplus is stored in the soil by bounding/adsorbing itself to soil particles (Neal *et al.*, 1990) and transported through run-off to surface water bodies. Excess phosphorus in water can result in eutrophication; a complex interrelationship between nutrient status and ecological circumstances that result in accelerated growth of algae or water plants (Glozier *et al*., 2006).

Phosphorus in soil, especially on farm lands, is increasing significantly. Globally, it is estimated that about one-third of all phosphorus loading to water bodies is from agricultural activities especially agricultural intensification (McCandless *et al.*, 2011). According to Cameron *et al.* (2002), close to about 10% of shallow lakes in New Zealand are minimally/excessively enriched with phosphorus. In Ghana, a study by Ansa-Asare and Karikari (2003) reported mean phosphate load of 100.4 t per annum for Weija Lake, a situation which can result in eutrophication. Thus, continuous application of phosphorus will result in a situation where the soil becomes saturated with phosphorus, making it more mobile to be transported into a receiving water body. As reiterated by Wither *et al.* (2002), application of inorganic fertilizer or liquid manure poses higher risk of phosphorus loading into water bodies through leaching and surface runoffs and, consequently, risk of eutrophication.

Excessive inputs of nutrients into the aquatic system will have little or no effect on aquatic biomass (plant and algae growth) unless phosphorus is present. Phosphorus is often described as the nutrient that limits growth in lakes (Holmstrom *et al*., 2000). Thus, the slightest input of phosphorus can stimulate an excessive aquatic production.

2.3.2 Ammonium-Nitrogen (NH_4^+ - N)

In the environment, ammonia which is the most dissolved form of nitrogen may exist as ionized (NH_4) and non-ionized (NH_3). Ammonium ion naturally occurs in water though in smaller quantity. However, when present in higher levels (above 0.2 mg/l) it becomes toxic to aquatic species (W.H.O, 2003). The excess concentration of ammonium in water especially freshwater bodies, mostly emanate from cultivated lands (use of manure and synthetic fertilizers) and in areas where there is intensive rearing of livestock. It is estimated that about 90 % of ammonium found in the environment is from the agricultural industry through surface run-offs and leaching (USEPA, 2013). Excess concentration of ammonia especially the un-ionized form (NH_3) is highly toxic and may affect fish species by causing damage to the gills, disruption of the circulatory process, the aesthetics features of water, retard growth and reproduction. When ammonium gets in contact with the skin or ingested, it can cause damage to the skin. The level of ammonium concentrate and its toxicity in water is dependent on temperature and pH of the water (USEPA, 2013).

2.3.3 Nitrogen Nitrate (NO_3^- - N)

Nitrogen, one of the primary nutrients needed in sufficient quantity for plant growth, abounds in the earth's atmosphere (about 78 %) and may exist as ammonia (NH_3), nitrates (NO_3), and nitrites (NO_2). Nitrogen is naturally part of the aquatic environment but excessive nitrogen especially due to human activities has the potential to threaten both the terrestrial and aquatic environment. It is reported that more than half of all nitrogen applied to the soil is not utilized by plants but lost to the air, dissolved in surface water or adsorbed into groundwater (UNEP, 2000).

Commercial nitrogen fertilizer is highly soluble to ease accessibility by plants making it also mobile to be transported into surface water bodies (Vall and Vidal, 2004). The basic conduit by which nitrogen is transported into surface water bodies are erosion from agricultural areas, runoff, subsurface drainage, groundwater flow and atmospheric deposition (Goolsby and Buttaglin, 1997). According to Webster *et al.* (2001), agriculture is probably the largest contributor to nitrogen concentration (about 50 % to 90 %) in surface waters.

Though nitrogen is in abundance, it is often a limiting nutrient for photosynthetic organisms (primary producers) such as algae and aquatic bacteria. Excessive nitrogen with phosphorus in water can facilitate production of algae and other aquatic plants (University of Florida, 2013). Nitrate, the most reactive form of nitrogen, is the most common form of nitrogen in lakes which when in excess causes cultural eutrophication (Environmental Canada, 2001).

Nitrogen in its various forms (nitrate-NO_3, nitrite-NO_2) continue to impact on the quality of water, aquatic habitats and even the health of humans as level in freshwater bodies continue to rise (Kumar *et al.*, 2011). Studying/ monitoring the characteristics and levels of the various forms of nitrogen in surface water will help determine the quality of water within specific geographic area.

2.3.4 Total Solids

Total solids simply refer to any substance that is suspended or dissolved in water. Any matter found in water that cannot pass through a filter with pores sizes of usually 2.0 µm is classified as suspended solid (measured as Total Suspended Solids- TSS). The substance that cannot be retained by the filter (2.0 µm) is classified as dissolved solids and its concentration is determined as Total Dissolved Solids (APHA, 1998). Total suspended solids are permanently suspended in water. The major sources of suspended solids in water are from decaying animals, silt and sediments resulting from increased erosion activities and high flow of surface runoffs and other sources. In higher concentrations, TSS can impact negatively on aquatic organisms; slow photosynthesis by limiting light penetration. It has the potential to absorb and retain radiation from the sun which can result in increased temperatures, and lowering oxygen levels, and several others.

Total Dissolved Solids is the mass of the organic and inorganic dissolved compound in water mostly from dissolved inorganic salts and other dissolved organic matter (Addo *et al.*, 2011). Though these ions are needed for survival in the aquatic environment, they become harmful when in excess, causing injuries or damage to the cells of aquatic organisms and the aesthetics of water bodies. The ions may be introduced into the aquatic environment through increasing use of agrochemicals like fertilizers in farmlands, effluent from septic tanks, increased soil erosion and surface runoffs (Mitchell and Stapp, 1992). Determining total solids in water can be useful in assessing the impact of land use activities within the watershed such as logging, agriculture, construction activities and other human activities.

2.3.5 Apparent Color

By nature pure water is supposed to be colorless. However, it is often tainted by dissolved and suspended materials or particles. The color of water may be expressed as true or apparent color depending on the material found in it. The color of water can be used to determine the presence of some contaminants in the water. The color of water, especially surface water, may be influenced by sediments or silts resulting from surface runoffs, algae, decayed organic substances and several other substances (DFAS, 2004). Apparent color mostly affects the aesthetics of water and other quality indicators. Highly colored water has significant effects on aquatic plants and algal growth since colored water can limit the penetration of light. Thus, highly colored body of water may not sustain aquatic life (Quality Assurance Plan, 2003).

2.3.6 Total Coliform, Fecal Coliform, E.coli and Total Heterotrophic Bacteria

The use of microbes as a yardstick for determining the level of pollution and sanitary conditions of a water body has been well recognized. Bacteria contamination of surface water results from direct deposition of waste in the water and runoff from areas with high concentration of livestock (such as cattle, pigs, poultry and others), leakages from septic tanks and other source (Barbara and Nancy, 2010). Pathogens such as total and fecal coliforms, *E.coli*, and total heterotrophic bacteria (THB) can pose significant risk to recreational waters, aquatic ecosystem and consequently human health (Environmental Canada, 2001).

Fecal Coliforms are naturally occurring bacteria found in the intestines of all warm-blooded animals (including humans) and birds (USEPA, 2000). *Escherichia coli* (*E. coli*) are one subgroup of fecal coliform bacteria which is mostly used as an indicator of the presence of fecal contamination. It is found in animal and human waste, and forms about 1% of the total biomass in the large intestine (Ewa *et al.*, 2011). This group of bacteria does not naturally occur in water. Hence, the presence of *E. coli* in water shows a recent fecal contamination. They are not pathogenic (disease-causing) but indicate that pathogenic bacteria and viruses may be present (www.waterwatch.nsw.gov.au). As reported by LeChevallier (2007), lower level of *total coliforms* in water connotes that, the probability of diseases-causing organisms in the water is limited.

Fecal contamination of surface water may be higher in the rural areas of Ghana where it is estimated that only about 11 % of the rural population has access to sanitation/toilet facility

(Oxfam Ghana, 2013). In such a situation, there is high probability of unsanitary activities such as open defecation and indiscriminate disposal of liquid waste and subsequent run off into surface water. *E. coli* levels may increase in the rainy season (Colorado River Watch Network, 2012).

Lake Bosomtwi provides recreational services to tourists in Ashanti region and even beyond. As a result, the bacterial content of the lake should be monitored since it has the greatest potential to affect the health of those who use the lake for swimming and other body contact activities.

2.3.7 Salinity/ Electrical Conductivity (EC)

Salinity is a measure of the level of salt concentration in water. When salt dissolves in water, it begins to dissociate into cation (like calcium (Ca^{2+}), potassium (K^{+}) and magnesium Mg^{2+}) and anions (chloride (Cl-), sulfate ($SO^{4}{}_{2-}$), and bicarbonate HCO_3^{-} ; Nitrates (NO_3^{2-}) and phosphates PO_4^{3-}). Salinity is often measured in part per thousand (% ppt) or practical salinity unit (USEPA; http://www.epa.gov/).

Higher salt concentration in fresh water has significant influence on aquatic life since every organism has certain tolerance to salt level for which it can survive. A study by Wardoyo (1991) revealed that increasing salinity levels in water affects the spawning success and egg hatchability on tilapia in Ghana. The major sources of salinity in surface water are natural (rainfall, evaporation, weathering and erosion of surface rock and groundwater) and anthropogenic sources; including clearing of vegetation, agricultural activities and others (Department of Natural Resources and Mines, 2012). An increase in imperviousness may alter the hydrodynamic process and add to the salinity levels in surface water bodies.

Conductivity is a measure of the ease with which electrical current will pass through water which is influenced by the salinity level of the water (Last and Gina, 2000). It has been established that electrical conductivity increases with an increase in the Total Dissolved Solids (TDS). Electrical conductivity is an indirect measure of TDS. Thus, to assess the salinity of given surface water the electrical conductivity is measured to determine the TDS. Conductivity is also affected by temperature, type of soil and land use surrounding the water and the type of bedrock been weathered (ANZECC 2000). Higher level of conductivity over a period of time is most often a good indicator of water quality impairment.

2.3.8 Water pH

pH, the negative log of the hydrogen ion (H^+) concentration is important because it is closely linked to the biological productivity (UNEP, 2007). When particular water has pH values of less than 7, it is acidic, above 7 is alkaline (base) and 7 as neutral. According to EPA (2005), the ideal pH values for most aquatic species range from 6.5 to 8.0. Excessively high or low pH may be an indicative that the chemistry of the water is being altered and subsequent negative impacts on those who use the water and aquatic life. High pH causes a bitter taste and a possible fish kill while low pH values will result in a decrease in the amount and available dissolved inorganic phosphorus and carbon dioxide in the water (Zweig *et al.*, 1999).

The pH establishes the solubility and biological availability of chemical constituents such as nutrients within the water body/ lake (EPA, 2005). Thus, the availability and toxicity of certain elements and compounds to aquatic organisms is determined by pH. The table below shows pH levels and their effect on fish production.

Table 2.1: pH tolerance levels and possible impacts on fish production

pH levels	Effects on warm water bodies
<4.0	Acid death point
4.0-5.0	No fish production
6.5-9.0	Ideal for fish production and survival
9.0-11.0	Slow growth
>11.0	Alkaline death point

Adapted from Lawson, 1995

2.3.9 Turbidity and Transparency

One of the most important indicators for measuring the health of fresh surface water like lakes is water clarity and suspended solids. Most common water impairment issues are concerned with suspended solids/matter. Though, it may occur naturally especially during a heavy downpour, human activities especially land use/ cover patterns (agriculture, grazing, logging) within the water catchment can greatly increase the concentrations of suspended solids in water. According to Chung (2009), impacts of human enhanced turbidity and re-suspension are often localized and depend on sediment grain size and type, hydrologic and other conditions.

Turbidity indicates how suspended particles affect water transparency/clarity. The clarity of any given water would be affected by the amount of suspended and dissolved materials (Davies-Colley and Smith, 2000). In other words, turbidity is a measure of the cloudiness or murkiness of water due to the presence of suspended particles. According to NLWRA (2001), suspended materials in water can result from both organic/inorganic sources like; phytoplankton, zooplankton, decomposed plants and animals, silt, clay, as well as natural chemical compounds like calcium carbonate which interferes with the passage of light through water.

Pollutants, like nutrients, heavy metals and pesticides are known to attach themselves to suspended solids/eroded particles (Callendar and Rice, 2001). Usually, sediments from erosion and plankton form the major part of materials that cause turbidity in lakes. Evidence is accumulating that, much of sediments in water mostly stem from improper agricultural practice especially on upland areas (Chambers *et al.*, 2000).

In the open water zones of lakes, the main source of turbidity is phytoplankton while closer to the shoreline, particulate matter may include clays and silt from shoreline erosion, re-suspended bottom sediments and organic detritus from streams or waste water discharges (www.waterontheweb.org). Extreme suspended solids are key cause of habitat degradation in water particularly a fall in oxygen levels and the aging process of lakes making it unsuitable for aquatic organisms, recreation and aesthetic use (USEPA, 2000). Studies reveal that, suspended materials affect the spawning, growth, reproduction, movement and efficiency of the methods of catching fish (APEM, 2007). It also makes water unfit for domestic purposes.

2.3.10 Dissolved Oxygen (D.O)

Oxygen is measured in its dissolved form as dissolved oxygen (DO) and is one of the limiting factors in aquatic respiration and metabolism. The survival of all forms of lives revolves around the availability and accessibility of oxygen within the niche of organisms (University of Wisconsin, 2006). To be able to determine the level of alteration of the environment due to natural phenomena and anthropogenic activities especially within the watershed, there is the need to establish the accurate concentrations of dissolved oxygen (DO) in water.

Oxygen dissolves into water through diffusion from the atmosphere and as a by-product of photosynthesis of aquatic plants. For good water quality, oxygen should be adequately dissolved in it. When more oxygen is consumed than is produced or dissolved in water, oxygen levels will decline which may affect certain aquatic life forms like fish (APHA, 1992). Oxygen levels below 3 ppm would be detrimental to the survival of most aquatic forms such as fish with most noticeable symptoms like stress in fish, increased in susceptibility to diseases, and poor growth.

The level of oxygen in water is influenced by many factors especially temperature, salinity levels, excessive nutrients, turbidity and others. Accumulation of organic wastes and pollutants, such as nitrate (NO_3), ammonia (NH_4^+), sulfite (SO_3^+) and others consume oxygen when they are introduced into the aquatic environment resulting in the depletion of oxygen levels.

An anoxic condition, which is detrimental to most aquatic life, is a consequent of excessive oxygen depletion in water. Inadequate oxygen does not only influence biogeochemical but aesthetic features like odor, clarity and taste. Thus, for a given water to support and sustain aquatic life there should be a certain minimum amount of oxygen in the water. Table 2.2 depicts some DO levels in water and its possible impacts on fish.

Table 2.2: DO levels and possible effects on aquatic species

DO (ml/L)	**Possible Impact on fish sp.**
>5.0	Ideal for fish survival
3.0-4.0	Tolerable
>1.5	Survival rate is in days
>1.0	Survival rates is in hours
<0.3	Lethal concentration to survive

Adapted from Lloyd, R. 1992

2.3.11 Temperature

Life in aquatic environment is to a large extent influenced/controlled by temperature. Water temperature affects the rate of metabolic activities, reproduction, survival and distribution of aquatic species like fish and other micro-organisms (Rounds, 2007). Increase in temperatures affects the water quality in lakes through a fall in oxygen concentrations, increased thermal stability and alterations in the mixing patterns (IPCC, 2007). Water temperature is affected by many anthropogenic activities or land use changes within the watershed including vegetation removal and construction which may result in fluctuations in water temperature on daily and seasonal basis. These activities mostly result in accelerated erosion, increased sedimentation and higher exposure of water surface to direct sun radiation (Kienholz *et al.*, 2000).

A study by Neal *et al.* (1992) observed that, deforestation and clearing of riparian vegetation cause stream water temperatures to increase during the summer by 4-9^{o} C due to direct penetration of the radiation. Similarly, a study by Leblanc (1997) posited that, of the 14 variables studied on the effects of land use change on water temperature, it was evident that, shade of riparian vegetation was one of the major factors that influence water temperature. Thus, human activities that result in the removal of the vegetation cover around the lake can influence the temperature of the lake.

Natural factors like stream size, altitude, season and weather/climate may influence water temperature. Variations in temperature may also influence other water quality parameters. Thus, a marginal change in water temperature has the probability of affecting the survival of certain fresh water aquatic organisms. For a healthy water to support aquatic organisms there should be optimal water temperature level which is normally between 0^{o} C and 30^{o} C (Schlosser, 1991).

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 Study Area

3.1.1 Location (Topography)

Lake Bosomtwi is the only naturally formed fresh water lake in the Sahel- Guinea coast region of West Africa (Karp *et al*., 2002). The inland lake is located in the Ashanti Region of Ghana, about 30 km south-east of the regional capital, Kumasi. Specifically, it lies within latitudes 6º 30'3" to 6º 50'50" N and longitudes 1º 24'5" to 1º40'83" West (Jourdan *et al*., 2009). The lake is bounded by three main administrative districts: Amansie East, Bosome Freho and the Bosomtwi District Assemblies.

The terminal/endorheic lake (it has no outlet) with maximum depth of 78 m and average depth of 43 m, has a diameter of about 8 km and a surface area of 52 km^2 at an elevation of 150 m above sea level (Bosomtwi District Assembly, 2010).

3.1.2 Water Resources/Drainage

Lake Bosomtwi forms part of the main Pra Basin with River Prah and its major tributaries forming a dense drainage network (Owusu *et al.*, 2014). The lake is hydrologically isolated from the surrounding regional and national drainage system of Ghana by the bedrocks and the high crater walls (LakeNet, 2007).

The dominant sources of inflows to the lake are through the seasonal rainfall (direct precipitation), underground water supply from some valleys and the few intermittent rivers (Abrewa, Obo, Obokwakye and Kantakyi). The rivers are perineal in nature which flows in a north-south direction in a dendritic pattern into the lake (Birkett and Mason, 1995).

Water balance is maintained by the combined action of rainfall (direct precipitation), surface runoff and evaporation of lake surface water (Turner et al 1996). The deep impact crater lake serves as a habitat for eleven (11) known species of fish including the world's near endemic Cichlid (*T. discolour* and *T. Busumana*) and the endemic Cichlid *Hemichromis Frengepongis* (Froese *et al.*, 2012) which provides fish protein for the people around the lake. The Lake serves as a means of transport and important tourist centre with an estimated 30000 on holidays.

3.1.3 Geology

Lake Bosomtwi and the surrounding crater was created by a meteor impact during the Pleistocene era (Danuor, 2004). The lake is surrounded by a circular depression with a central uplift rising up to 200 m beneath the lake floor. The crater walls that surrounds the lake is characterized by very high gradient reaching up to 460 m in some parts.

The lake bosomtwi crater is dominated by metamorphosed and crystalline rocks which belongs to the Precambrian-age Birimian and Tarkwaian formations. The dominant rocks include meta-sandstones, shales, phyletic, and schist (Hirdes *et al*., 1992; Boamah and Koeberl *et al*., 2002). At the northeastern sector of the crater is the Pepiakese intrusion consisting of rock types ranging from amphibole diorite, biotite-muscovite granite and albite rock (Koeberl *et al.*, 1998). Polymict breccias averaging at least 20 m thick with clasts as much as 5 m long occur on the outer ridge and patches of suevite have been found in the circular depression north and south of the crater (Koeberl *et al*., 1994).

3.1.4 Soils

The dominant soil type around the lake is the forest ochrosols (The Atukrom- Asikuma Association mostly in the eastern portion of the lake) and the forest lithosols (Obeng, 2000). The soil is alkaline in nature. These types of soil are shallow and excessively well drained. Thus, they have the potential for nutrients to be washed into the lake due to the high rainfall regime, chemical weathering and high organic activities (CDM, 2007). The soil type found around the lake has been produced from a wide range of weathered parent materials (metamorphosed and basic intrusive rock) including granite, Tarkwaian and Birimian rocks (Obeng, 2000). The shallow and sloping nature of these soils do not make it suitable for excessive cultivation because it can easily be washed away by erosion resulting in the pollution of the aquatic environment.

3.1.5 Climate

Lake Bosomtwi lies within the equatorial zone with rainfall regime (double maxima) typical of the moist semi-deciduous forest zone of Ghana (Nicholson, 2009). The area has an average annual rainfall of 1270 mm. The major rainy season starts in March and peaks in June. The minor raining season starts in July to August, reducing gradually in November to usher in the dry season (harmattan season) from December through to February (Shanahan *et al*., 2007).

Temperature of the area seems to be uniformly high throughout the year. The mean annual temperature in the region is around 24 ºC, with average minimum temperatures of 21.5 ºC and maximum of 27.8 ºC (Bosomtwi District Profile, 2010). The highest mean temperature occurs just before the major wet season in February whilst the mean minimum occurs during the minor wet season. Relative humidity (RH) is mostly high in most part of the year especially in the wet season (about 90 %) and lowest (around 42 %) towards the end of the dry season (Turner *et al*., 1996; Shanahan *et al*., 2007).

3.1.6 Vegetation

The natural vegetation of the area falls within the semi- deciduous forest zone of Ghana (Olson *et al*., 2001). There is a patch of grassland (*imperata cylindrical*) at the north-eastern part of the crater rim. The natural vegetation that used to occupy most parts of the lake's basin has been degraded to mosaic of secondary forest and thicket due to consistent and extensive farming, logging and bush burning activities both in the past and in the present (Ghana Districts, retrieved 2013). The Bosomtwi forest reserve at Ankaase remains relatively undisturbed forest vegetation around the lake.

3.1.7 Economic Activities/Land Use

The major economic activity of the study area is farming (more than 60%) which is mostly concentrated along the undulating shores and the steep rocky uplands around the lake (Ghana Statistical Service, 2010). Much of the natural vegetation which is supposed to protect the lake and its watershed has been cleared for farming using mainly method like "slash and burn method". The major crops that are cultivated include cash crops (cocoa and oil palm), food crops (plantain, cassava, and yam), and vegetables (okra, cabbage, garden eggs, and carrots). Animal rearing (such as goats, sheep, cattle and few donkeys) is also practise.

The lake also provides an important inland commercial fishing ground and livelihood support for about 1000 inhabitants (Ghana Fisheries Report, 2004), especially the men operating as fishermen and fishmongers (traders) in the 22 communities with a total population of about 30,000 (Ghana Statistical Service, 2002). The fishmongers mostly obtain their fish from either their husbands or buy from fishermen and sell the fish in the nearby towns within the Kumasi metropolis. Other source of employment is the tourism industry as hotels and restaurants spring up around the lake in recent times.

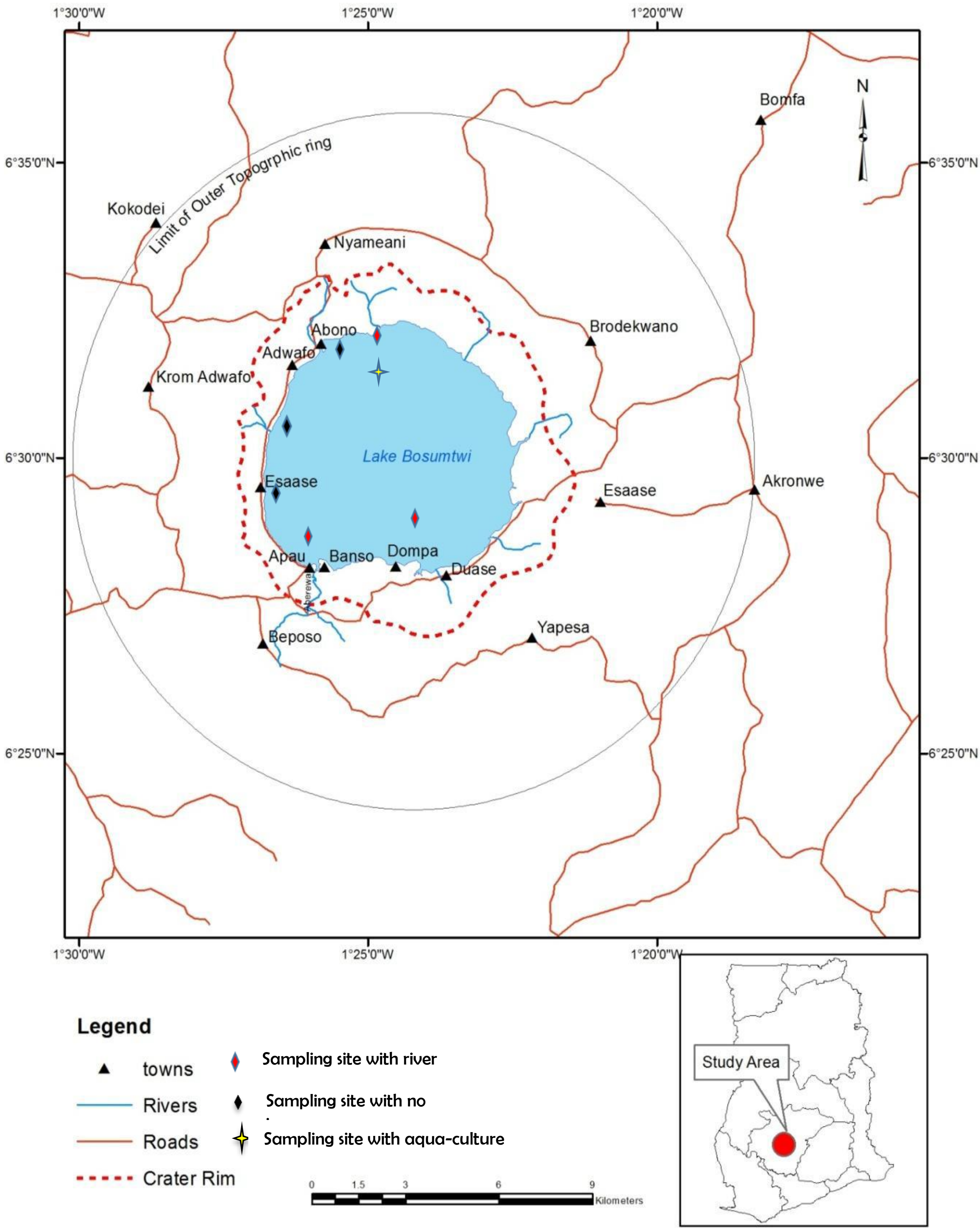

Figure 3.1: Map of study area showing the sampling sites (Source***:*** Adapted from Anim *et al.*, 2013)

3.2 Field Survey and Data Collection

Several sources of data were exploited to investigate the impacts of the changing land use/cover on the Lake's water quality. Primary data were obtained through informal and formal interviews, physical field observation, administering of questionnaire, visual interpretation of satellite images and sampling of lake water and soil for analysis. The secondary data were obtained from notable institutional repositories (like the EPA, Friends of Rivers and Water Bodies, Ghana Meteorological Agency), appropriate scientific journals, magazines, newspapers, books (both published and unpublished) and the internet.

3.2.1 Land use and land cover change analysis

To ascertain the trend of land use/cover changes within the watershed, land use data from satellite images (Landsat TM 1990, 2000, and 2010) covering the same area was acquired from the Centre for Remote Sensing and Geographic Information System (CERSGIS) of the University of Ghana, Legon. The images were geometrically corrected using topographic data obtained from the Ghana Survey Department. Thus, map coordinates were assigned to the data (geo-referencing). The raw satellite images were converted to UTM (Universal Transverse Mercator) coordinate systems using the Ghana standard topographic scale of 1:50000. To avoid displacement of features like points and lines which may result in false interpretation, image enhancement techniques were employed. For the purpose of this study, ERDAS IMAGINE Software (version 10.1) was used to further categorise the images.

3.2.1.1 Classification of Images

Satellite images depicting land cover and land use systems of an area often comprise of diverse spectral signatures arising from the mosaic of land cover types. According to Moller-Jensen (1990), for an enhanced classification of such complex areas, the spatial setting of each pixel must be considered. The first attempt was to classify the various land uses/cover in IDRISI GIS and image processing software (ISODATA) in ERDAS (version 10.1) using unsupervised classification technique. The process of sorting pixels into a finite number of individual classes or categories of data based on their data file values is called classification. If a pixel satisfies a certain set of criteria, then the pixel is assigned to the class that corresponds to the criteria.

The unsupervised classification technique was seen as the best option for the study since human errors are limited. In an unsupervised classification**,** the objective is to group similar spectral response patterns into clusters that are statistically separable by means of classification algorithm (Lu and Weng, 2005). Thus, each pixel is compared to each discrete cluster to establish which pixels are closest to each other. After the classification, the various classes were validated (ground truthing) in the field using Global Positioning System (GPS). Thus, the different clusters/classes obtained were related to meaningful ground categories or real world vista. The classification assessment is done to determine its accuracy (the degree to which derived images conforms to reality) by randomly generating reference points using stratified random algorithm (Jensen 1996). Field surveys and photographs of the study area taken in the field were used as reference data for the accuracy assessment. The next step was recoding, thus, assigning a new class value number to all classes of the same spectral characteristics, creating a new thematic raster layer using the new class numbers. The essence of the recoding was to be able to raise statistics for each class. Some of the classes were combined through this process. After recoding, the various areas of the classes were generated in ERDAS Imagine (version 10.1). Five land use classes were generated which included; Water body, Bare surface/Built-up areas, Agricultural Areas/Lands, Open Active Vegetation and Close Active Vegetation. The final time series maps were composed showing the general changes in the cover types and land use with statistics indicating the changes for the study period (from 1990, 2000 and 2010). Figure 3.2 presents the simplified methods involved in unsupervised classification.

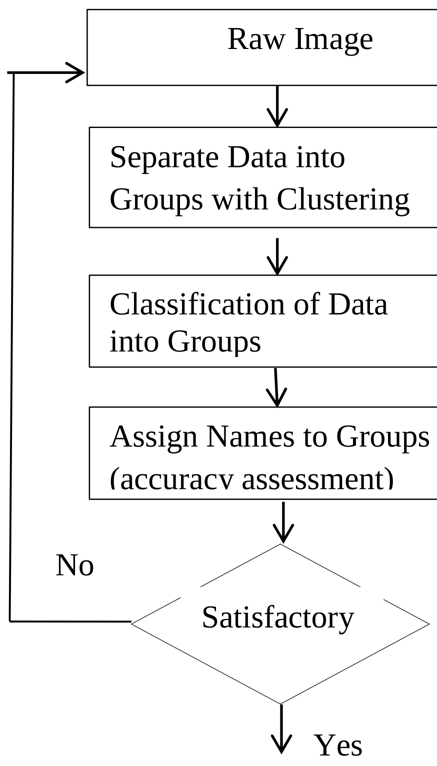

Figure 3.2: *Unsupervised classifications method* **(Adapted** from Short, 1998)

3.2.2 Limnological and Soil sampling

Samples of water were collected monthly (from December 2013 to May 2014) from seven sites within Lake Bosomtwi. The sites were strategically selected due to their anthropogenic importance. For accurate sampling, water samples were taken using the composite sampling technique (Blomqvist, 2001). Thus, three points were selected at each sampling sites at a distance of 50 m from the shore (at a depth of 5 cm) and 50 m between two points within a site (at a depth of 10 cm and 15 cm, respectively) and mixed manually in a bottle to achieve a homogenous sample. The water samples were analysed at the

Ecological Laboratory Centre (ECOLAB) while the soil samples were analysed at the Soil Science Department (University of Ghana, Legon). Table 3.1 presents absolute location of **sampling sites.**

Table 3.1: Location of sampling sites

Sampling Site	**GPS Coordinates**	**Major Towns**
LW0A	N 06º 31' 063", W 001º 26' 377"	Abrodwum & Abaase
LW0B	N 06º 29' 984", W 001º 26' 721"	Anyinatiase & Esaase
LW0C	N 06º 28' 479", W 001º 25' 769"	Apawu and Bansu
LW0D	N 06º 28' 323", W 001º 24' 019"	Dompa
LW0E	N 06º 32' 425", W 001º 24' 287"	Nkwawi and Pipie #2
LW0F	N 06º 35' 085", W 001º 24' 957"	Obo
LW0G	N 06º31'005", W 001º25' 27"	Abono

Source: Field Work 2014

Soil samples were taken from all the land cover types at a distance of 100 m off the shores at each site. The samples were taken from the top 15 cm using a soil auger. Samples were taken at this depth because the top 15 cm of soil has the most root activity and fertilizer applications are generally restricted to this depth (USDA, 2010). Soil samples were taken to the laboratory (University of Ghana Soil Science Department) for analysis. The soil samples were dried at room temperature after which stones and debris were removed by sieving with a 2 mm meshed-size sieve. The resulting samples were wrapped in an iron foil and stored at room temperature. Analysis was done to determine available potassium (K), Nitrogen (N), soil Electrical Conductivity (EC), pH and E.*coli*.

3.2.2.1 Pre-Sampling Preparation

Sampling containers with well-fitted stoppers were pre-treated by washing with acetone to get rid of organic substances such as grease and fat residues. They were then washed with detergent and rinsed with de-ionized water and then soaked in 1.0 M nitric acid solution for 48 hours. The containers were finally rinsed several times with de-ionized water before using them for taking and holding the water samples.

3.2.2.2 Treatment and Handling of Samples

Standard working conditions and measures were carefully selected and adhered to in order to avoid contamination of samples both before and during sampling; handling of samples and sampling material; transporting and storage of samples. Water samples were collected mostly in the morning in a relatively undisturbed area.

At each sampling site, physical parameters were carried out in-situ by directly inserting meter probes (Model: Horiba U-51 and Model: HACH 2100 P) into the water body. Accurate reading and recordings of water Temperature, Conductivity, Salinity, Turbidity, TDS, DO and pH were then carried out. At each sampling site, a two-liter polyethylene sampling container was filled with water for laboratory analysis. For Biological Oxygen Demand (BOD) analysis, amber bottle was used for sampling water to avoid photosynthesis.

All sampling bottles were labeled clearly with dates, sites and time. All samples to be measured ex-situ were kept on ice in an ice chest and transported to the laboratory for analysis in less than 24 hours of collection. At the laboratory, water samples that were not analyzed immediately were stored in a refrigerator below 4^0C to be analysed within forty eight hours.

3.2.2.3 Laboratory Analysis

Ex-situ method of measurement of the various parameters was performed in accordance with the Standard Method for the Examination of Water and Wastewater (APHA 1995). With respect to research purposes, methodology of those with significant difference in association to World Health Organization (WHO) guideline standards is discussed in this section.

3.2.2.4 Chemical Oxygen Demand (COD)

The chemical oxygen demand was analyzed by adding 2 ml of each water sample to a COD digestion vial, with the proper reagents already in them. Then the vials were capped securely and wiped clean with a lint free paper towel and later placed into the HACH reactor, which has been preheated to a temperature of 1500° C, for a period of two hours. After allowing the vials to cool to room temperature and entering the proper program, the blank was used to zero the photo spectrometer. Then each sample was placed into the photo spectrometer, and its COD concentration displayed and recorded in mg/l.

3.2.2.5 Nitrate (NO_3^- -N) Determination

Cadmium Reduction Method (APHA, 1998) was used to determine the Nitrate levels in sampled water. The nitrate level in each sample was measured using Nitrate Powder Pillows and a direct reading from HATCH Spectrophotometer Model DR/2010. A 25 ml of the sample was measured into a sample cell of the Spectrophotometer and one Nitraver 5 Nitrate Reagent Powder Pillow was added to the sample. The solution was vigorously shaken for a minute and allowed to stay undisturbed for five minutes for chemical reaction to take place. The color of the solution was then observed. An orange color of the mixture indicates the presence of Nitrate. After five minutes, another cell was filled with 25 ml of only the sample (blank). The blank sample was placed in the spectrophotometer for calibration. Then the prepared sample was placed into the cell holder to determine the Nitrate concentration at 500 nm in mg/l (HACH, 1996)

3.2.2.6 Nitrite (NO_2^-) Determination

The nitrite level in each sample was measured using Nitrite Powder Pillows in a direct reading HACH Spectrophotometer Model DR. 2010. Twenty five (25) ml of the sample was measured into sample cell. One Nitriver 3 Nitrate Reagent Powder Pillow was added to the sample and shaken to dissolve the powder. A 20-minute reaction period was allowed after which the color of the sample was observed. A pink coloration indicated the presence of Nitrite Nitrogen. After the 20-minutes, another sample cell was filled with 25 ml of only the sample (blank). The blank sample was placed in the sample cell of the spectrophotometer for calibration. The prepared sample was placed into the cell holder to determine and record the Nitrite concentration at 507 nm. The result was displayed in mg/l (Hach, 1996)

3.2.2.7 Determination of Phosphate (PO_4^{3-})

A 25 ml of water sample (the prepared sample) was placed in the sample cell. Phosver 3 Phosphate Powder Pillow (ascorbic acid) was added to the cell content and swirled immediately to mix. A two-minute reaction time was allowed to determine the presence of phosphate in the sample. A blue coloration of the mixture indicates the presence of phosphate. Another sample cell (the blank) was filled with 25 ml of sample and placed into the cell holder to calibrate it. After reaction period, the prepared sample was placed into the cell holder to determine the level of phosphorus at 890 nm in mg/l (HACH, 1996).

3.2.2.8 Determination of Ammonium-Nitrogen (NH_3^+ - N) concentration

Direct nesslerization and spectrophotometric determination at wave length of 425 nm was used to determine Ammonium-nitrogen. Water sample of 25 ml (the prepared sample) was measured using graduated mixing cylinder. A second graduated mixing cylinder was filled with the 25 ml of demineralized water (blank). Three drops of Mineral Stabilizer was added to each of the cylinder, this complexes hardness in the sample. The solutions were inverted several times to obtain a thorough mixture. Three drops of polyvinyl alcohol-dispensing agent was added to each cylinder and inverted several times to mix to aid the color formation in the reaction of Nessler reagent with ammonia ions. A 1.0 ml of Nessler Reagent was pipetted into each cylinder and inverted several times to mix. A 1-minute reaction period was allowed during which each solution was poured into respective blank and prepared cells. The blank was placed into the cell holder of the Spectrophotometer to calibrate it. The prepared sample was placed into the cell holder to determine the ammonium nitrogen level at 425 nm. A yellow color is formed proportional to the ammonium concentration (HACH, 1996).

3.2.2.9 Apparent Color Determination

The Platinum-Cobalt Standard method was used. A sample cell was filled with 25 ml of demineralized water and placed into spectrophotometer to standardize it. Next, the prepared sample was placed into the cell holder and the result was displayed in platinum-cobalt units at 455 nm (HACH Company, 2002).

3.2.2.10 Determination of Biological Oxygen Demand (BOD)

The 5-day BOD test was used (Winkler Azine Modification). A specified air tight bottle was filled with sample of water (280 ml). The initial Dissolved Oxygen (DO) was determined and recorded. The sample was then incubated at the required temperature (20 ˚C) for five (5) days after which the DO was again determined. The BOD was computed from the difference between the initial and final DO (APHA, 1998). Mathematically the DO is represented as;

BOD**5** = DO**1**-DO**5** **(**where BOD**5** is biological oxygen demand after day five, DO**1** is initial dissolved oxygen (measured in-situ) and DO**5** is dissolved oxygen after period (5 days) of incubation).

3.2.2.11 Determination of Total Suspended Solids (TSS)

The Photometric Method (Non-filterable residue) was used; 500 ml of sample was blended at high speed for two minutes and poured into a 600 ml beaker. The sample was stirred and immediately poured into a 25 ml sample cell (the prepared sample). The stored program number for suspended solids, 630, was entered at a wavelength of 810 nm. Another sample cell was filled with 25 ml demineralized water to serve as the blank sample. This was placed into the cell holder and standardized. Similarly, the sample was placed into the cell holder and the reading in mg/l (HACH, 2002).

3.2.2.12 Microbiological Analysis

The Membrane Filter (MF) technique was used to determine fecal and the total coliforms. Membrane filters with 0.45 um pore sizes were used to filter 100 ml of the sample. The membrane filter was lifted from the system with sterilized forceps and carefully placed on the sterile media in a petri dish. The petri dish was then covered and inverted for incubation at 37° C for total coli form and 44° C for fecal coliform. After 24 hours, the petri dishes were removed from the incubator and the colonies collected and recorded in coliform forming unit per 100 ml (cfu/100 ml). The *E.coli* and the total heterotrophic bacteria were determined using the pour/standard plate method.

3.2.3 Social Survey

Questionnaires which were made up of both open and close-ended questions were administered to respondents in seven of the major communities located around the lake. The communities were selected based on their population size, strategic location to the lake and the activities carried out by the people. In all, the questionnaires were administered to 200 respondents (60 % males and 40 % females) randomly selected from the seven communities. This distribution was selected because in the rural areas, men in most cases are the decision makers in land use activities. Formal and informal interviews were conducted with representatives, opinion leaders and hotel managers and workers from the selected communities. The questionnaires were structured to solicit respondents views on dominant land use activities within community, knowledge of land use activities and how it impacts on water quality, frequency in use of agro-chemicals, socio-economic effects of poor water quality and water management systems within community.

3.2.4 Data management and statistical analysis

The data gathered were analysed (both qualitatively and quantitatively) using Statistical Package for Social Scientist (SPSS) software to generate graphs, tables and charts to help in determining the major cause of water quality problem of the lake. One way Analysis of Variance (ANOVA) was used to establish variations in water quality parameters existing between the sampling sites within the lake. The average values of water parameters obtained were also compared to internationally minimum acceptable levels of surface water quality for drinking and fishing. All statistical tests were conducted at 5 % significance level.

CHAPTER FOUR

RESULTS

4.1 Land Use and Cover Change Analysis

The magnitude of the various class covers of the land around Lake Bosomtwi and how they have changed from 1990 through 2000 to 2010, based on the satellite images are presented in Table 4.1 and Figure 4.1 below.

Table 4.1: Land Cover in 1990, 2000 and 2010

Years Land use Classification	1990 Hectares	2000 Hectares	2010 Hectares	% change 1990-2000	% change 2000-2010
Closed vegetation	2738.73	2216.01	1860.40	-19.1	-16.1
Open vegetation	1715.84	1776.25	2113.65	3.5	19.0
Agricultural Areas	1170.82	1726.10	1764.79	47.4	2.2
Built up/bare area	12.1501	209.03	216.83	1620.4	3.7
Water body	4880.09	4590.24	4561.96	-5.9	-0.6
Total	10517.63	10517.63	10517.63	10517.63	10517.63

Source: Satellite Images 1990-2010

From the results (Table 4.1) it can be noted that, Lake Bosomtwi decreased from 4880.09 ha (46.4 %) in 1990 to 4561.96 ha (43.64 %) in 2010. Similarly, from 1990 to 2010, closed forest vegetation also reduced from 2738.73 ha (representing 26.4 %) to 1860.40 ha (representing 17.69 %). However, Built Area/Bare lands, Opened forest vegetation and

Agricultural Areas increased progressively between 1990 and 2010 as depicted by both Table 4.1 and Figure 4.1. From Figure 4.1, there is a progressive reduction in close vegetation (the deep green patches) from 1990 through 2000 to 2010 while there is an increase in agricultural/open forest (the light green patches) and settlement areas (brown/ bare patches) respectively.

Thus, open forest vegetation, built up/bare areas and agricultural lands increased from 1715.84 ha (16.31 %), 12.15 ha (0.12 %) and 1170.82 ha (11.13 %) in 1990 to 2113 ha (20.10 %), 216.83 ha (2.06 %) and 1764.79 ha (16.78 %), respectively in 2010.

In all between 1990 and 2010, there was a total reduction of 318.13 ha in the area covered by Lake Bosomtwi, representing 6.5 % while closed forest vegetation was reduced by 35.1 % representing 961.4 ha (Table 4.1). On the contrary, there was an increase in Open forest vegetation and Agricultural areas by margins of 22.5 % (386.1 ha) and 49.6 % (580.7 ha), respectively while Built up/ Bare areas increased by more than sixteen times (1624.1 %). From the result, closed forest cover around Lake Bosomtwi has lost a total of 2738.73 ha to other forms of land cover within the watershed. Within the two decades (1990-2010), there has been a progressive increase in agricultural and built up/bare areas within the lake Bosomtwi watershed. The percentage change in the vegetative cover and built-up areas together with other factors could have resulted in the receding waters of the lake over the years.

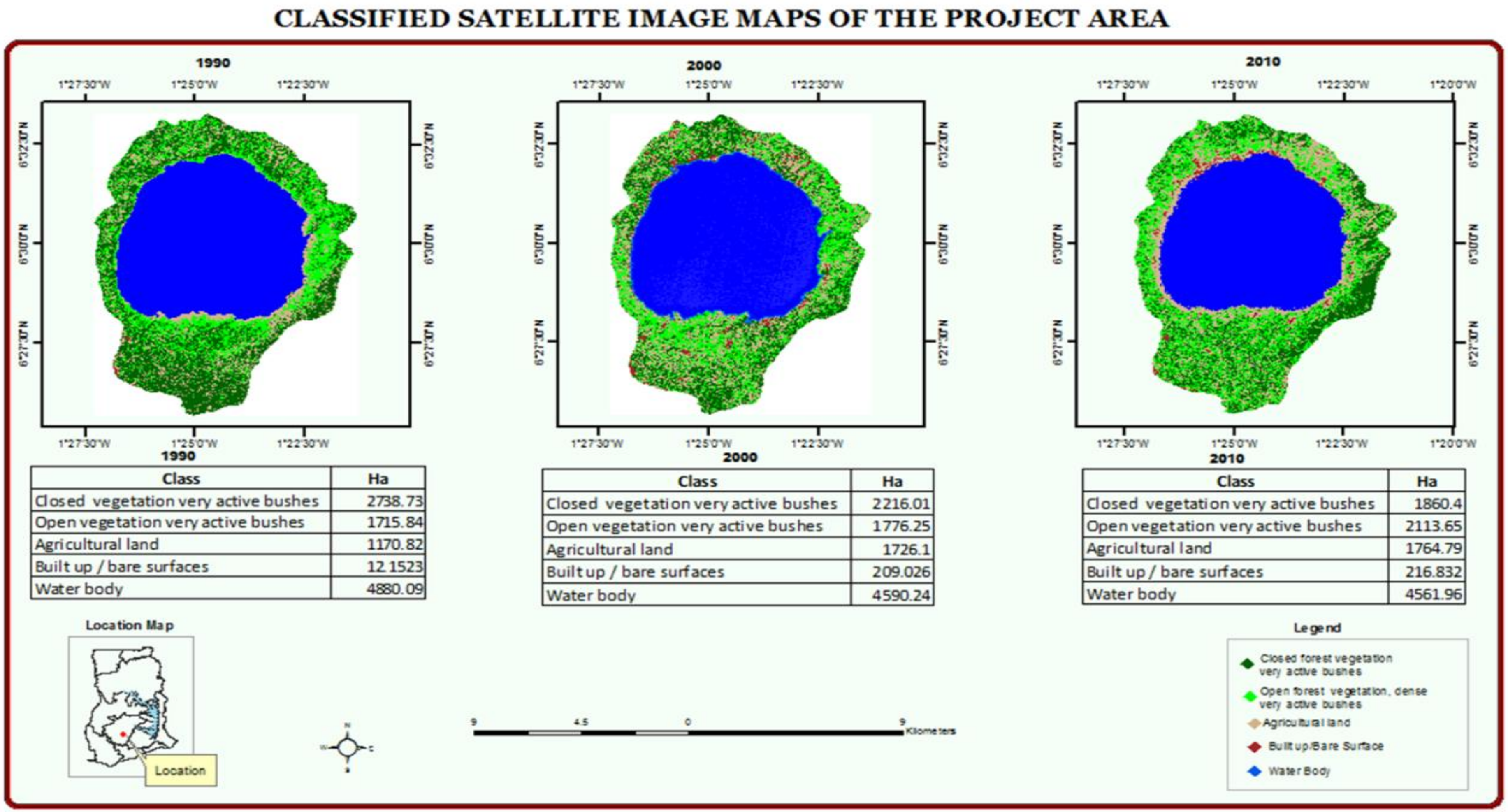

Figure 4.1: Classified Satellite Image of Study Area

4.2 Water Quality Analysis

4.2.1 Physico-Chemical properties of Water

Table 4.2: Physical water quality parameter

SITE	STATISTIC	Temp	pH	EC	TDS	TSS	Turbidity	Salinity	Color
Units		°C		µS/cm	mg/L	mg/L	NTU	ppt	Pt. co
LW0A	Min	29.3	8.5	1312	604	2	4.0	.50	51
	Max	32.5	9.9	1415	678	8	6.0	.60	77
	Mean	30.8	9.1	1362	644	5	4.6	.55	65
	Std. Dev.	1.3	0.6	33	26	2	.8	.05	10
LW0B	Min	29.0	8.4	1311	632	3	3.0	.50	41
	Max	33.2	9.8	1401	674	8	6.0	.60	74
	Mean	30.6	9.1	1360	657	6	4.4	.58	64
	Std. Dev.	1.5	0.5	30	17	2	1.1	.04	14
LW0C	Min	27.9	8.4	1325	633	3	4.0	.40	40
	Max	29.3	9.7	1382	672	9	6.0	.60	79
	Mean	28.7	9.2	1357	657	6	4.7	.55	62
	Std. Dev.	0.7	0.6	21	18	2	.8	.08	17
LW0D	Min	28.4	8.5	1324	633	3	4.0	.50	58
	Max	33.0	9.7	1390	675	10	8.0	.60	78
	Mean	30.6	9.1	1355	653	6	5.2	.55	67
	Std. Dev.	1.7	0.5	26.5	16.3	2.8	1.5	.05	8.0
LW0E	Min	29.4	8.4	1315.0	368.0	5.0	4.8	.50	62.0
	Max	32.6	9.8	1388.0	674.0	10.0	12.0	.70	76.0
	Mean	30.6	8.9	1350.3	609.4	7	6.6	.60	67.3
	Std. Dev.	1.2	0.5	26.7	119.1	2.0	2.8	.06	4.8
LW0F	Min	28.6	7.9	1306.0	604.0	2.0	4.0	.50	53.0
	Max	33.2	9.9	1386.0	672.0	28.0	26.0	.60	166.0
	Mean	30.6	9.0	1345.8	644.3	14	11.8	.57	93.0
	Std. Dev.	1.9	0.7	34.2	24.9	11.2	10.6	.05	47.5
LW0G	Min	28.9	7.6	1296.0	622.0	1.0	4.0	.50	36.0
	Max	33.6	9.7	1372.0	684.0	11.0	6.0	.60	74.0
	Mean	30.9	8.8	1338.8	654.3	5.3	5.1	.53	56.0
	Std. Dev.	1.8	0.8	27.5	25.1	3.5	0.8	.05	14.2
Total	Min	27.9	7.6	1296.0	368.0	1.0	3.0	.40	36.0
	Max	33.6	9.9	1415	684	28	26.0	.70	166
	Mean	30.4	9.0	**1352.7**	**645.6**	6.8	6.1	**.56**	**67.8**
	Std. Dev.	1.5	0.6	27.6	48.1	5.3	4.6	.06	22.4
WHO/GSB		**22-29**	**6.5-8.5**	**250.0**	**600.0**	**NA**	**1 – 5**	**0.5**	**15.0**
ANOVA	F value	1.685	0.363	0.497	0.702	2.326	2.3	**0.926**	1.871
	p-value	0.154	0.897	0.806	0.650	0.054	0.01	**0.488**	0.114

4.2.1.1 Temperature

The descriptive statistics of water quality parameters are shown in Table 4.2. The mean temperature recorded at the study area was 30.4±1.5 ºC with a minimum of 27.9 ºC and a maximum of 33.6 ºC. The lowest temperature was recorded at LW0C while the highest was recorded at LW0G. Generally, there were differences in temperature recorded at the different sites though the differences were not statistically significant (*p> 0.05*).

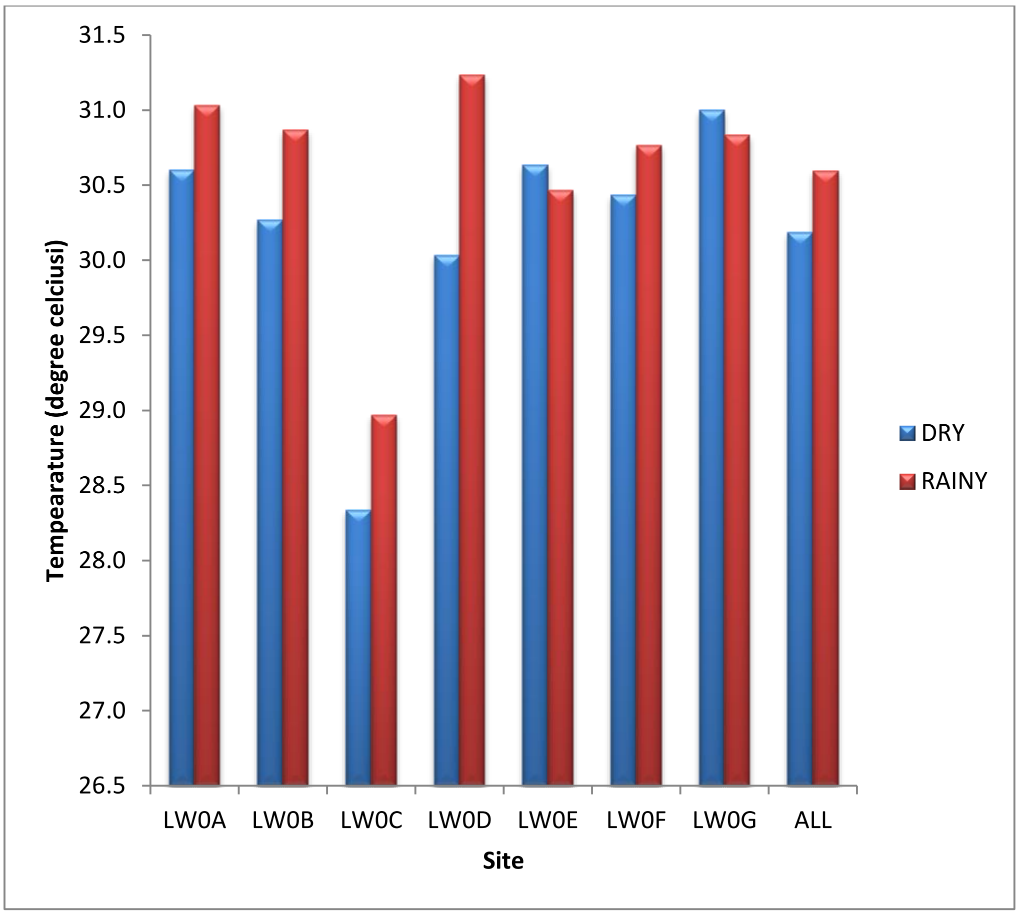

Figure 4.2: Seasonal variations in Temperature

Comparison between seasons showed that average temperature during the rainy season (30.6 ºC) was higher than the dry season (30.2 ºC) though the difference was not significant ($p > 0.05$). All sites showed similar trend except LW0E (Nkwawi and Pipie number 2) and LW0G (Abono) where the recorded temperature for the dry season was higher than in the rainy season (Fig 4.2). The temperature of water in the dry season varied from 28.3 ºC at LW0C to 31.0 ºC at LW0G whereas the rainy season ranged from 29.0 ºC to 31.2 ºC.

4.2.1.2 pH

The overall average pH level of the lake was 9.0±0.6. The pH level of the water was relatively consistent with a minimum value of 7.6 and maximum of 9.9. There were differences in water pH for the sites. However, these differences were not statistically significant ($p>0.05$). Site LW0C and LW0G had average pH levels of 9.2 and 8.8, respectively, representing the sites with the highest and lowest pH levels. Figure 4.3 shows the seasonal results across the sites.

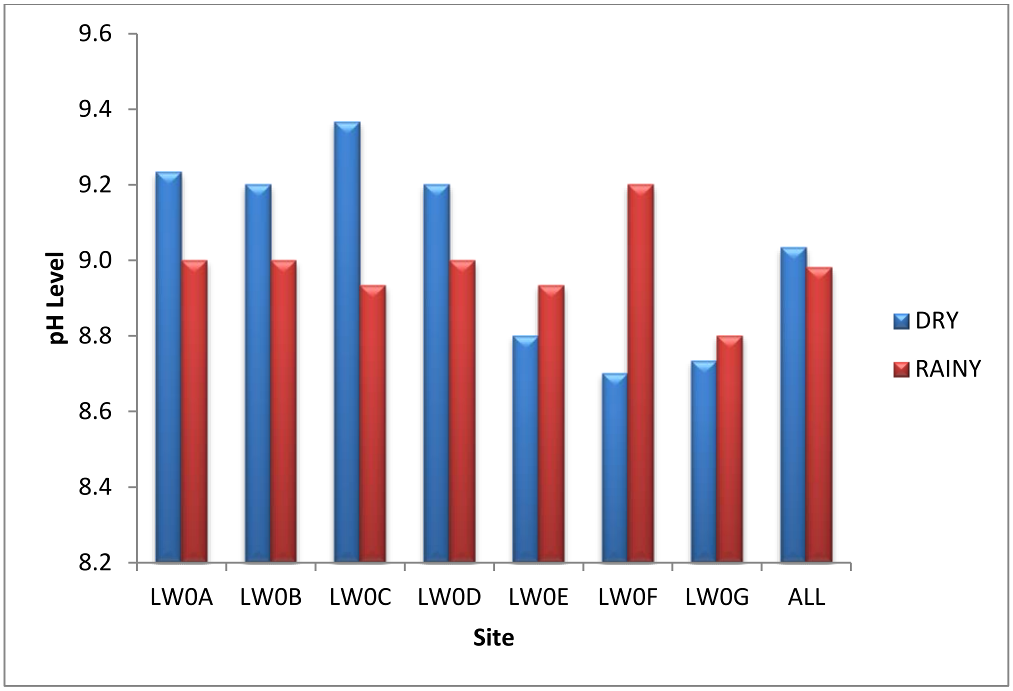

Figure 4.3: **Seasonal variations in pH**

From fig 4.3, pH level during the dry season was relatively higher (9.0) than the rainy season (8.9) though a statistical comparison showed no significant difference *($p > 0.05$)*. The pH values for the dry season ranged from 8.7 at LW0F to 9.4 at LW0C while the rainy season varied from 8.8 at LW0G to 9.2 at LW0F.

4.2.1.3 Conductivity

Electrical conductivity (EC) ranged from 1296 µS/cm to 1415 µS/cm, with an average value of 1353 ±27.6 µs/cm. Site LW0A recorded the highest average conductivity of 1362 µS/cm while LW0G recorded the lowest average of 1339 µS/cm (Table 4.2). A comparison of Conductivity values across the seven sites showed no significant differences *($p > 0.05$)*. Figure 4.4 shows EC during the rainy and the dry seasons.

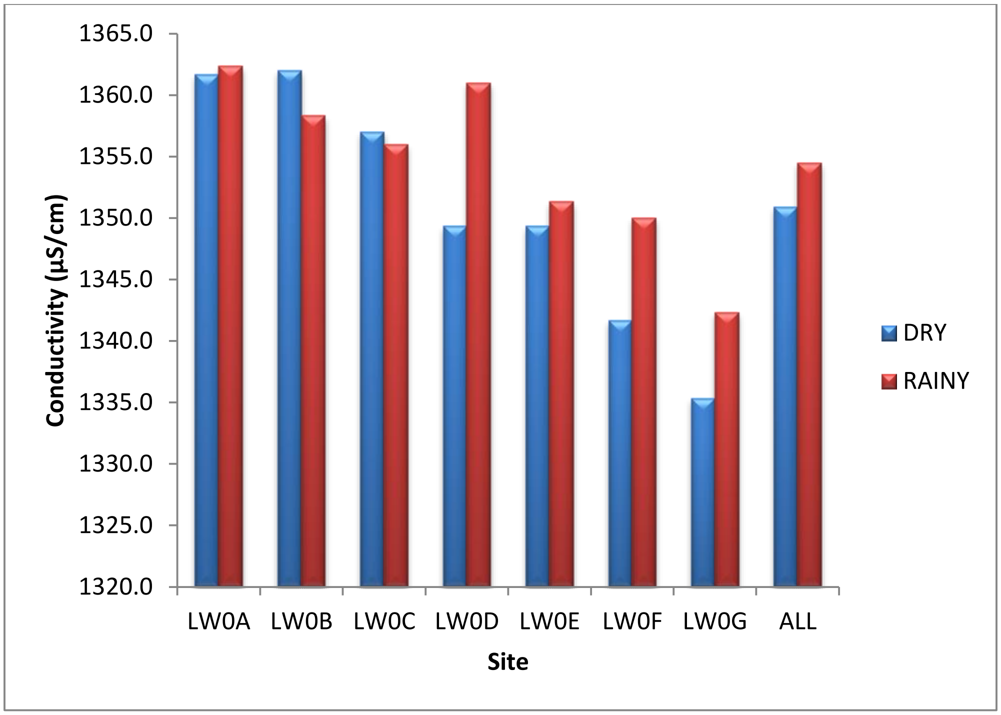

Figure 4.4: Electric conductivity for seasons

From Fig 4.4, the average EC for rainy season was higher (1355.768 µs/cm) than the values recorded in the dry seasons (1350.904 µs/cm) but this difference was not statistically significant (*p>0.05*). The EC values in the dry season ranged from 1335.33 µs/cm at LW0G to 1362.00 µs/cm at LW0B, whereas the rainy season ranged from 1342.3 µs/cm at LW0G to 1362.33 µs/cm at LW0A.

4.2.1.4 Total Dissolved Solids (TDS)

In the case of Total Dissolved Solid (TDS), the overall average recorded was 646±48 mg/L, with a minimum of 368 mg/L at LW0E and a maximum of 684 mg/L at LW0G. A comparison of TDS across the sites showed no significant difference (*p>0.05*). Figure 4.5 shows the results of TDS during the rainy and dry season.

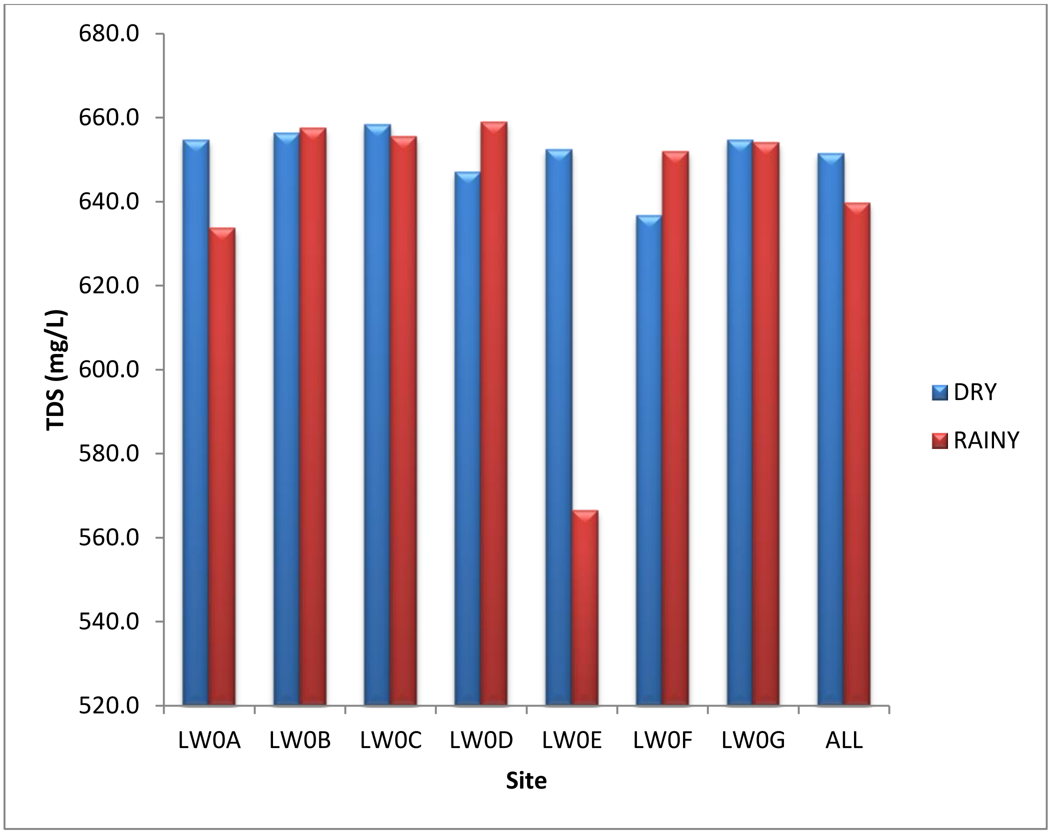

Figure 4.5: Seasonal variations in total dissolved solid

There was seasonal variability in TDS concentrations. From the results (Fig 4.5), average TDS concentration was slightly higher during the dry season than the rainy season though there was no significant difference *($p>0.05$)*. At site LW0F however, TDS was higher in the rainy season than the dry season. The TDS values in the dry season varied from 636.7 mg/L at LW0F to 658.3 mg/L at LW0C. However, the TDS values recorded during the rainy season ranged from 566.5 at LW0E to 659.0 at LW0D. The very significant difference between the rainy season and the dry season at site LW0E could be due to excessive release of organic feed by the aquaculture.

4.2.1.5 Total Suspended Solids (TSS)

Table 4.2 shows results of Total Suspended Solid (TSS). The average TSS for the lake water was 6.8±5.3 mg/L. The recorded TSS in the lake water varied from 1 mg/L at sites LW0G to 28 mg/L at site LW0F. Comparison of TSS values across the sites showed no significant difference (*p>0.05*) in TSS averages among the sites.

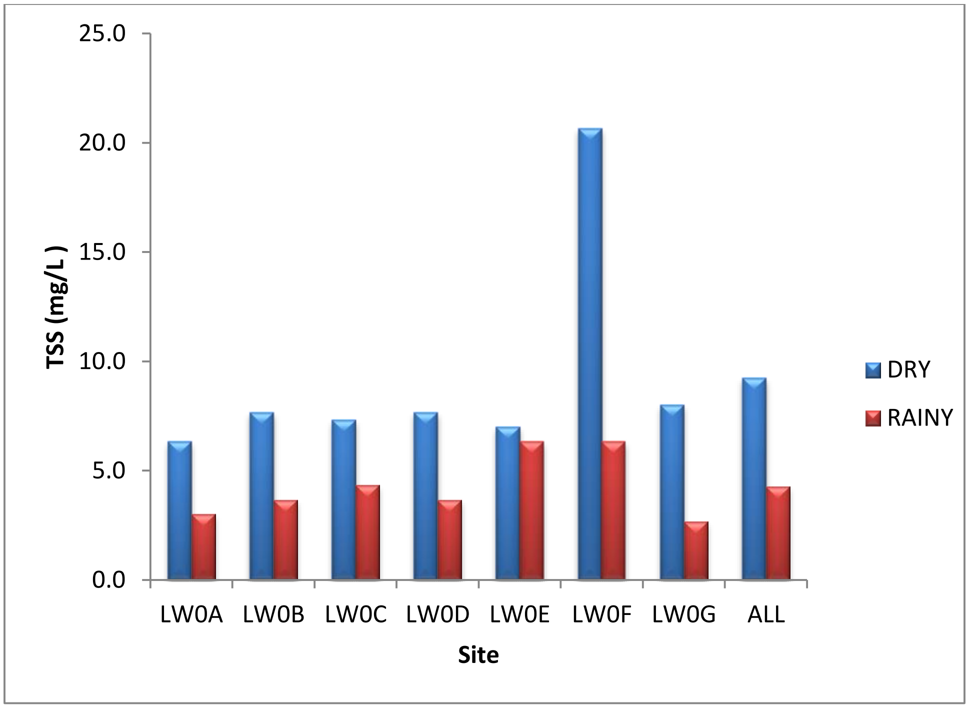

Figure 4.6: Seasonal variations in Total Suspended Solid

Seasonal variations were recorded for Total Suspended Solid (TSS). The results showed that, TSS was significantly higher (*p<0.05*) during the rainy season (9.24 mg/L) than the dry season (4.286 mg/L). The TSS values in the dry season varied from 6.3 mg/L at LW0A to 20.67 mg/L at LW0F whiles the rainy season ranged from 2.67 mg/L at LW0G to 6.33 mg/L at LW0E and LW0F respectively.

4.2.1.6 Turbidity

Turbidity values varied from 3 NTU at site LW0B to 26 NTU at site LW0F. The average turbidity of the lake was 6.1 ±4.6 NTU. The sites that recorded the highest turbidity were sites that had highly developed areas (settlement and farms). Turbidity showed no significant difference (*p>0.05*) across the sites. Fig 4.7 shows Turbidity for dry and rainy season.

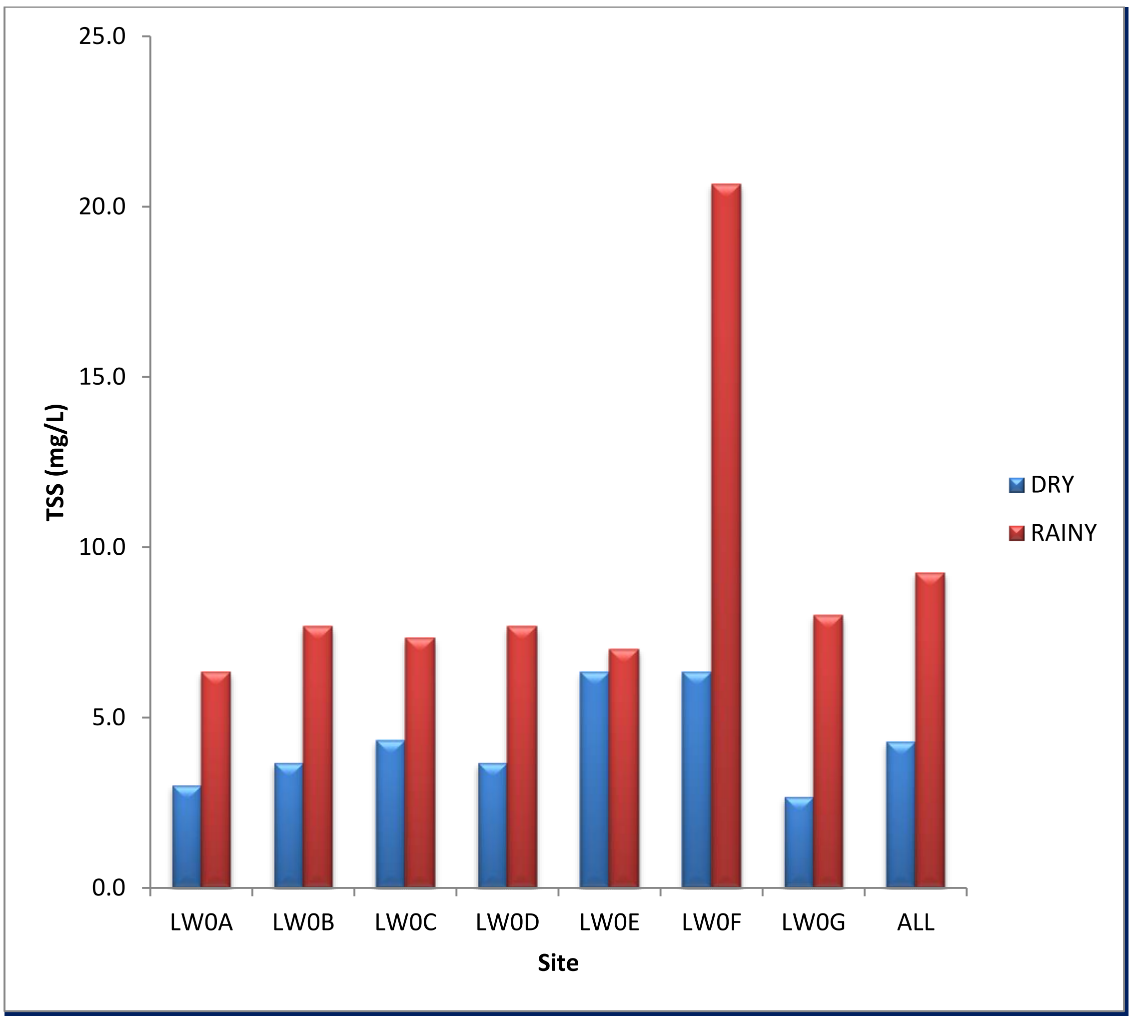

Figure 4.7: Seasonal turbidity variation

Generally, turbidity was slightly elevated during the rainy season than dry season though the difference was not significant (*p>0.05*) by a statistical test. The results of turbidity in the rainy season ranged from 4.33 NTU at LW0A to 18.67 NTU at LW0F while the dry season varied from 3.53 NTU at LW0B to 7.93 NTU at LW0E.

4.2.1.7 Salinity

The average Salinity of the lake was 0.56±0.06 ppt. Salinity values ranged from a minimum of 0.4 ppt at site LW0C to a maximum of 0.7 ppt at site LW0E. Comparing the salinity level across the various sites using ANOVA showed no significant difference (*p>0.05*) in the averages across the sites.

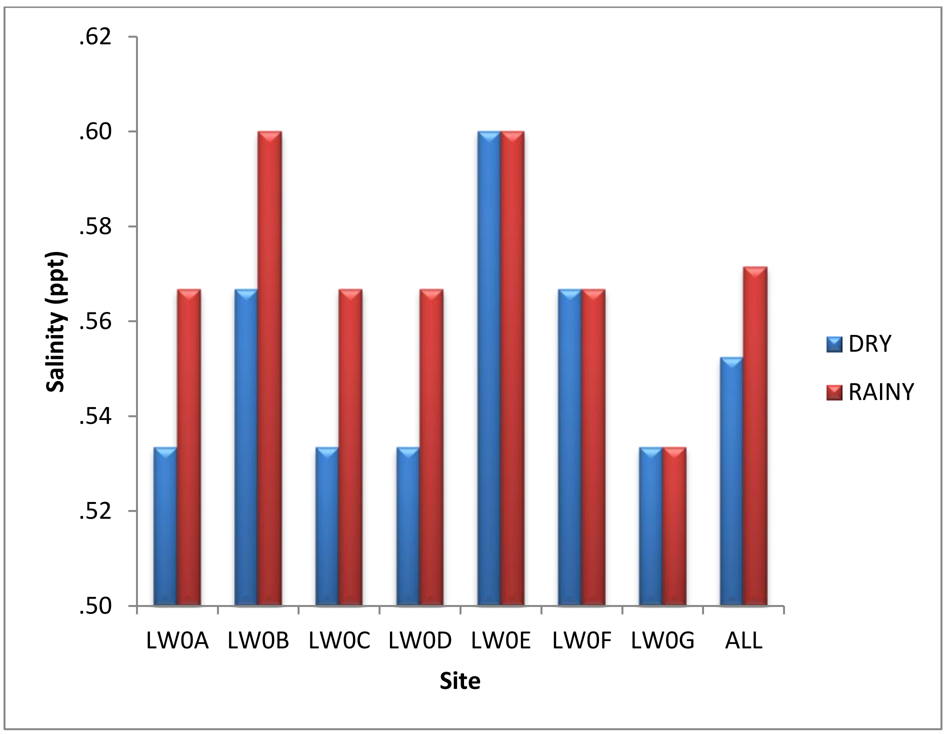

Figure 4.8: Seasonal variations in Salinity

Average salinity of the lake was higher during the rainy season (0.571 ppt) than the dry season (0.552 ppt). This difference was however not statistically significant *(p>0.05).* The salinity values of the lake in the dry season ranged from 0.533 at LW0A, LW0C, LW0D and LW0G to 0.600 at LW0E. Similarly, salinity values for the rainy season varied from 0.533 ppt at LW0G to 0.600 ppt at LW0B and LW0E respectively.

4.2.1.8 Apparent Color

The apparent color of the lake ranges from 37 Pt.co at LW0G to 166 Pt.co at LW0F with an average of 67±22 Pt. co. Seasonal variation in lake color is presented in Fig 4.9. From the results, the average color during the dry season (79.67 Pt.co) was significantly higher *($p<0.05$)* than the rainy season (55.91 Pt.co). All sites showed similar trend. The color values of the lake in the dry season ranged from 70.33 Pt.co at LW0E to 125.00 Pt.co at LW0F whereas the rainy season ranged from 45.00 Pt.co at LW0G to 64.00 Pt.co at LW0E.

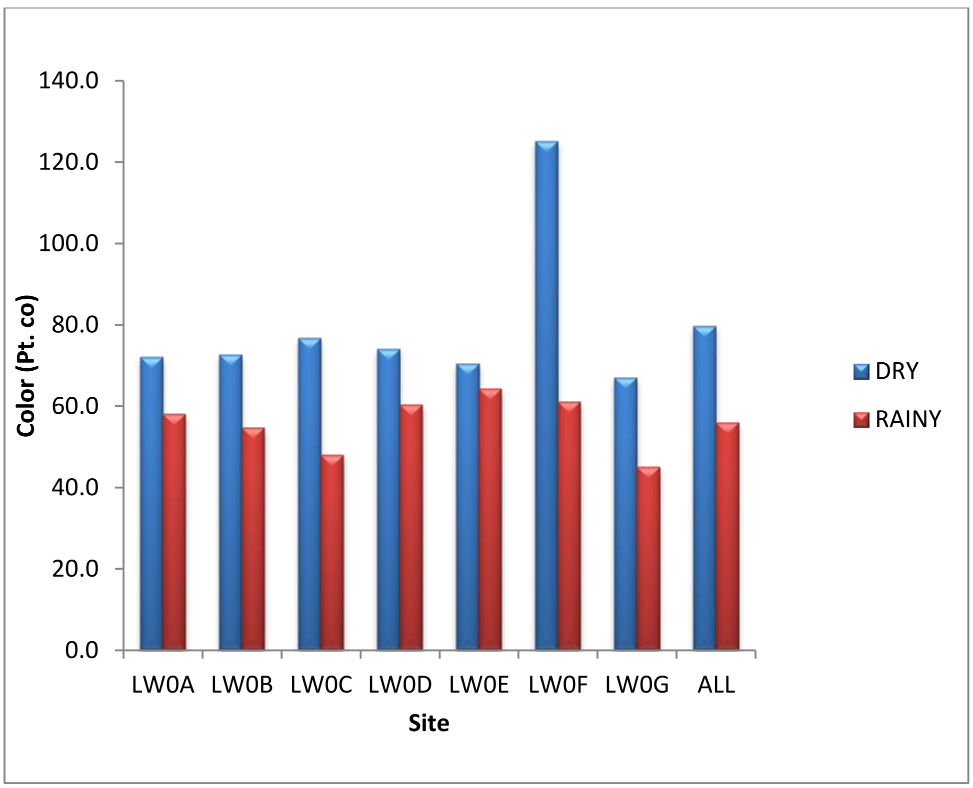

Figure 4.9: Seasonal variations in Lake color

4.2.2 Chemical Properties of the water

Table 4.3 shows the results of chemical analysis of the water quality

Table 4.3: Chemical properties of Lake Water

SITE	STATISTIC	DO mg/L	BOD mg/L	COD mg/L	Nitrate mg/L	Nitrite mg/L	Phosphate mg/L	Ammonium mg/L
LW0A	Min	7.4	3.1	91	.8	.01	.15	.000
	Max	8.7	4.7	98	1.5	.05	1.16	.100
	Mean	8.0	4.1	95	1.0	.01	.52	.027
	Std. Dev.	.47	.56	3	.30	.02	.38	.037
LW0B	Min	6.8	2.8	88	.9	.01	.04	.000
	Max	7.8	3.9	105	1.5	.06	.51	.020
	Mean	7.4	3.2	96	1.3	.02	.34	.012
	Std. Dev.	0.7	.3971	6	.20	.02	.17	.008
LW0C	Min	6.6	3.5	88	.9	.01	.04	.000
	Max	9.0	5.0	98	1.4	.08	.55	.020
	Mean	7.8	4.2	94	1.2	.02	.36	.013
	Std. Dev.	.8337	.67	4	.23	.03	.18	.008
LW0D	Min	6.2	3.5	86	.9	.00	.03	.000
	Max	8.9	5.0	107	1.5	.01	.51	.020
	Mean	7.4	4.3	98	1.2	.01	.34	.012
	Std. Dev.	1.0	0.7	8.1	0.2	.00	.16	.010
LW0E	Min	6.0	3.6	96.0	1.0	.01	.05	.000
	Max	8.5	4.5	123.0	1.5	.02	.57	.030
	Mean	7.6	4.1	106.8	1.2	.01	.43	.018
	Std. Dev.	1.0	0.4	10.3	0.2	.00	.19	.012
LW0F	Min	5.2	0.7	88.0	1.3	.01	.29	.010
	Max	8.2	4.4	135.0	2.5	.02	.50	.060
	Mean	6.9	2.6	107.2	1.6	.01	.40	.027
	Std. Dev.	1.2	1.6	20.3	0.4	.01	.08	.018
LW0G	Min	6.2	0.9	85.0	1.0	.00	.26	.010
	Max	8.7	4.5	108.0	1.4	.01	.49	.030
	Mean	7.6	3.1	95.8	1.2	.01	.38	.015
	Std. Dev.	1.0	1.3	8.8	0.1	.00	.09	.008
Total	Min	5.2	0.7	85.0	0.8	0.00	.03	0.000
	Max	9.0	5.0	135	2.5	0.08	1.16	0.100
	Mean	7.5	3.7	98.9	1.3	0.01	0.40	0.018
	Std. Dev.	0.9	1.0	10.8	0.3	0.02	0.19	0.017
WHO/GSB		**7.5**	**NA**	**20**	**10.0**	**1.00**	**2.50**	**1.500**
ANOVA	F value	0.873	3.375	1.855	2.531	0.668	0.604	0.876
	p-value	0.524	**0.010**	0.117	**0.039**	0.676	0.725	0.522

Source: Field Work 2014

4.2.2.1 Dissolved Oxygen (DO)

From Table 4.3, average DO level in the water was 7.5±0.9 mg/L. The DO levels varied from a minimum of 5.2 mg/L at LW0F to a maximum of 9.0 mg/L at LW0C. The site with the least average DO level was LW0F (6.9 mg/L) while site LW0A recorded the highest average DO level of 8.0 mg/L. There was difference in DO levels across sites but the difference was not statistically significant *($p > 0.05$)*. Similarly, there was no significant difference in Dissolved Oxygen between the seasons (Figure 4.10).

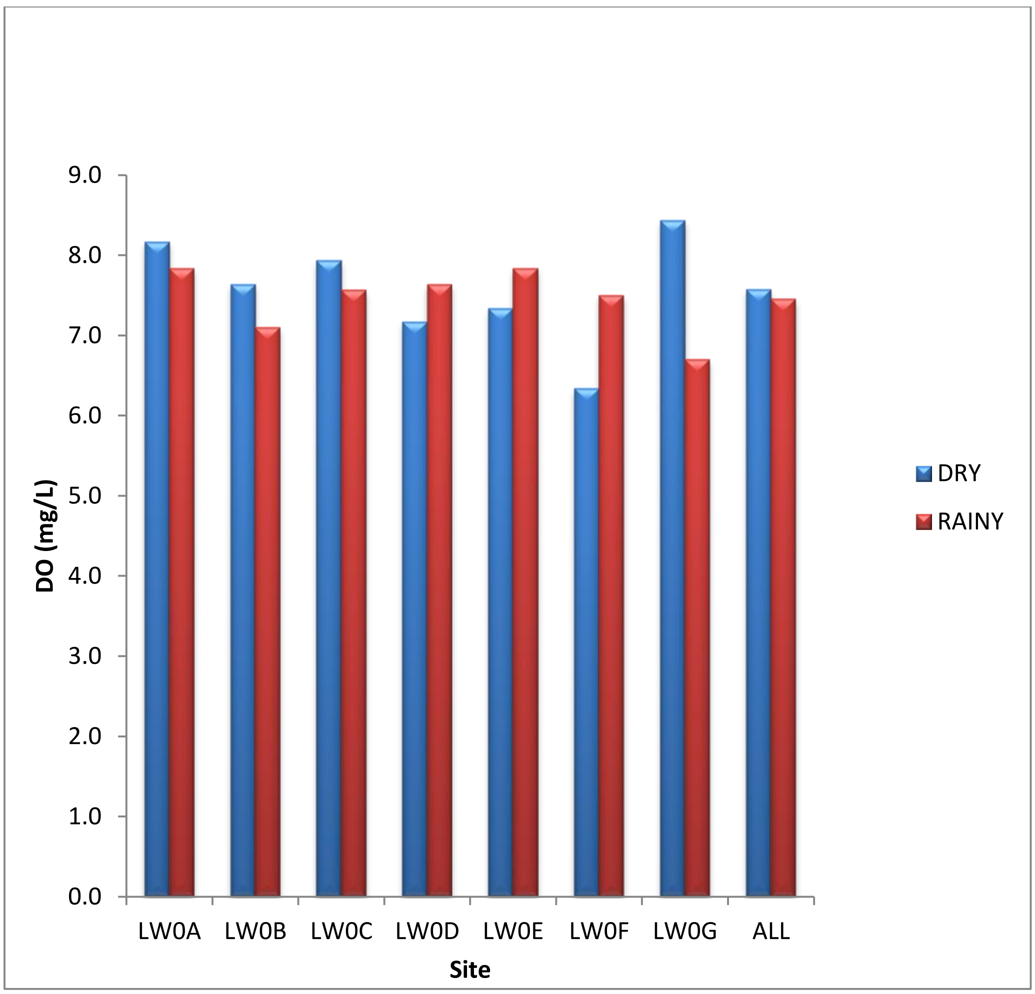

Figure 4.10: Dissolved Oxygen levels between seasons

4.2.2.2 Biochemical Oxygen Demand (BOD)

For Biochemical Oxygen Demand (BOD), the recorded average for the Lake Water was 3.7±1.0 mg/L. The BOD of the lake varied from 0.7 mg/L at LW0F to 5.0 mg/L at LW0C and LW0D. A comparison of average BOD levels across sites showed significant difference *($p < 0.05$).* Figure 4.11 presents seasonal variations in BOD.

Seasonal comparison of the average BOD level showed that, BOD was higher in the dry season (3.91 mg/L) than in the rainy season (3.419 mg/L) but the difference was not statistically significant ($p > 0.05$). However, sites LW0E and LW0F deviated from this trend recording higher average BOD values in the rainy season (4.33 mg/L and 3.30 mg/L respectively) than in the dry season (3.90 mg/L and 4.07 mg/l, respectively).

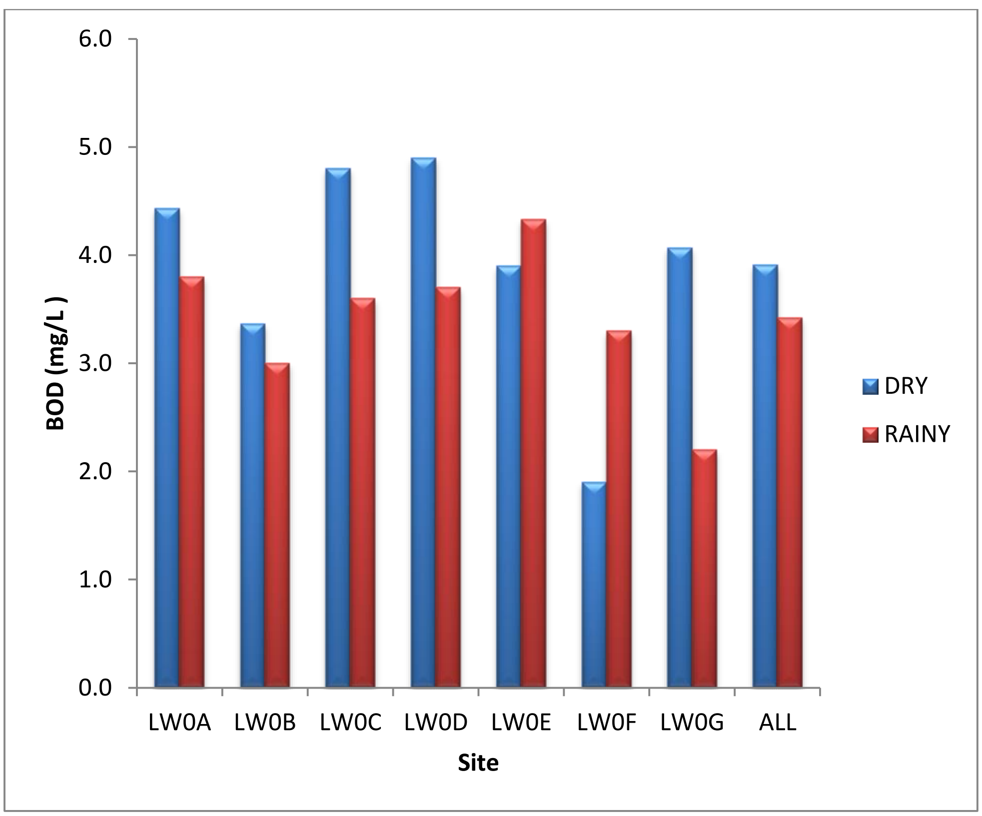

Figure 4.11: Seasonal variations in BOD

4.2.2.3 Chemical Oxygen Demand (COD)

The average Chemical Oxygen Demand (COD) level of the Lake Water was 99±11 mg/L. COD values varied from 85 mg/L at LW0G to 135 mg/L at LW0F. However, a statistical comparison of the average COD across sites recorded was not significant *($p>0.05$)*. Figure 4.12 presents the average COD level over the seasons for the various sites. The Average Chemical Oxygen Demand (COD) for the Lake Water during the dry season (103.52 mg/L) was higher than rainy season (94.333 mg/L). The difference observed was statistically significant ($p < 0.05$). The COD values recorded in the dry season ranged from 94.67 at LW0A to 120.33 at LW0F whereas the rainy season ranged from 91.00 at LW0B to 102.33 at LW0E.

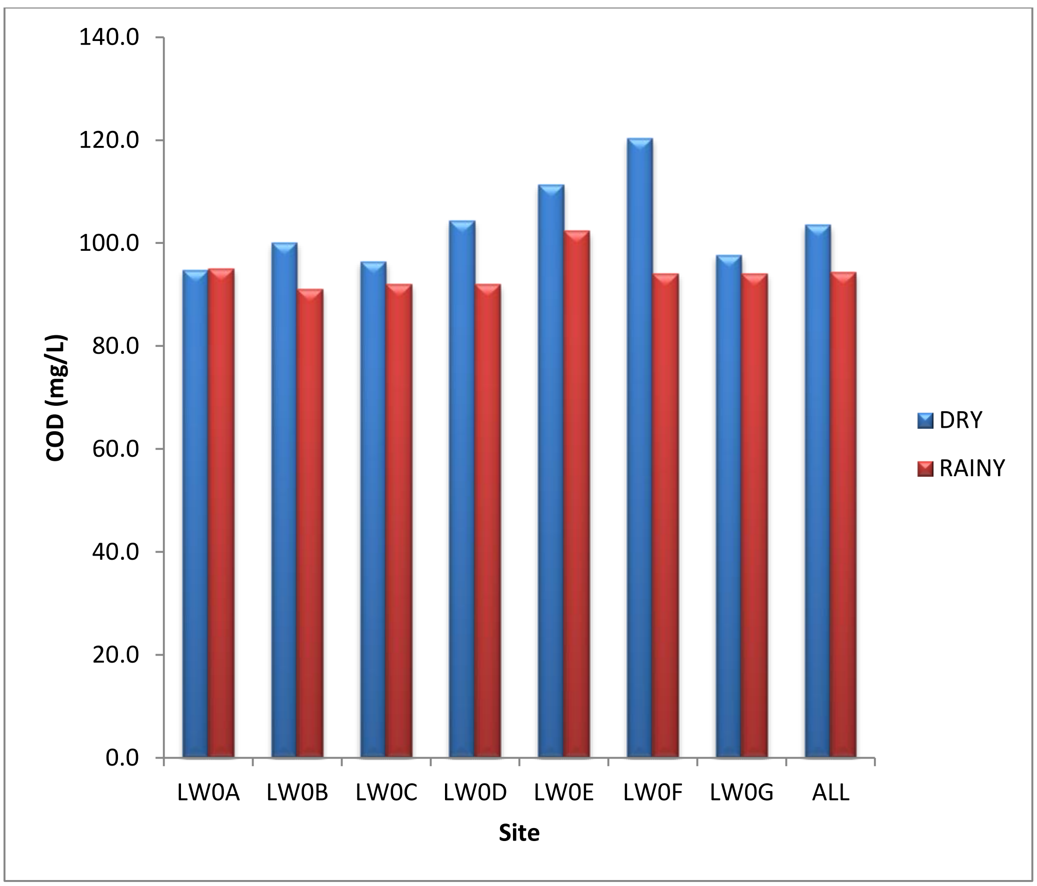

Figure 4.12: **Seasonal variations in Chemical Oxygen Demand**

4.2.2.4 Nitrate

The average Nitrate level of the lake was 1.3±0.3 mg/L with a minimum of 0.8 mg/L at site LW0A and a maximum of 2.5 mg/L at site LW0F. This falls within the WHO/GSB permissible limit for surface water. There was significant difference ($p<0.05$) in nitrate levels between seasons (Figure 4.13). Nitrate concentration was higher in the rainy season than in the dry season especially at site LW0F.

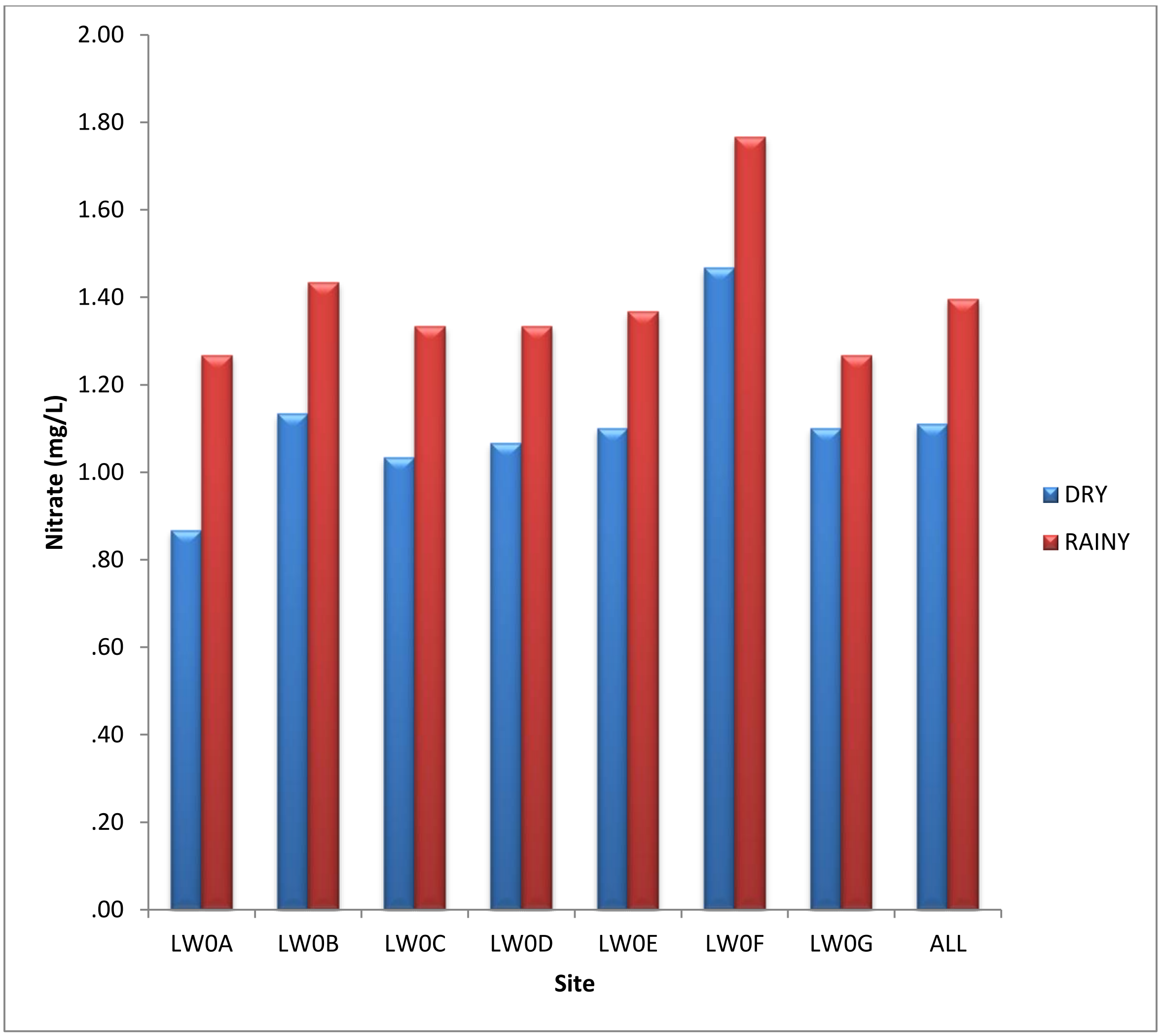

Figure 4.13: **Nitrate level over seasons**

4.2.2.5 Nitrite

Average level of nitrite for the Lake Water was 0.01±0.02 mg/L. Nitrite concentrations in the lake water varied from non-detectable limits at site LW0A to a maximum of 0.08 mg/L at site LW0C. Also, there was no significant difference *($p>0.05$)* in the average Nitrite levels across the sites. Figure 4.14 shows seasonal changes in nitrite concentration in the lake.

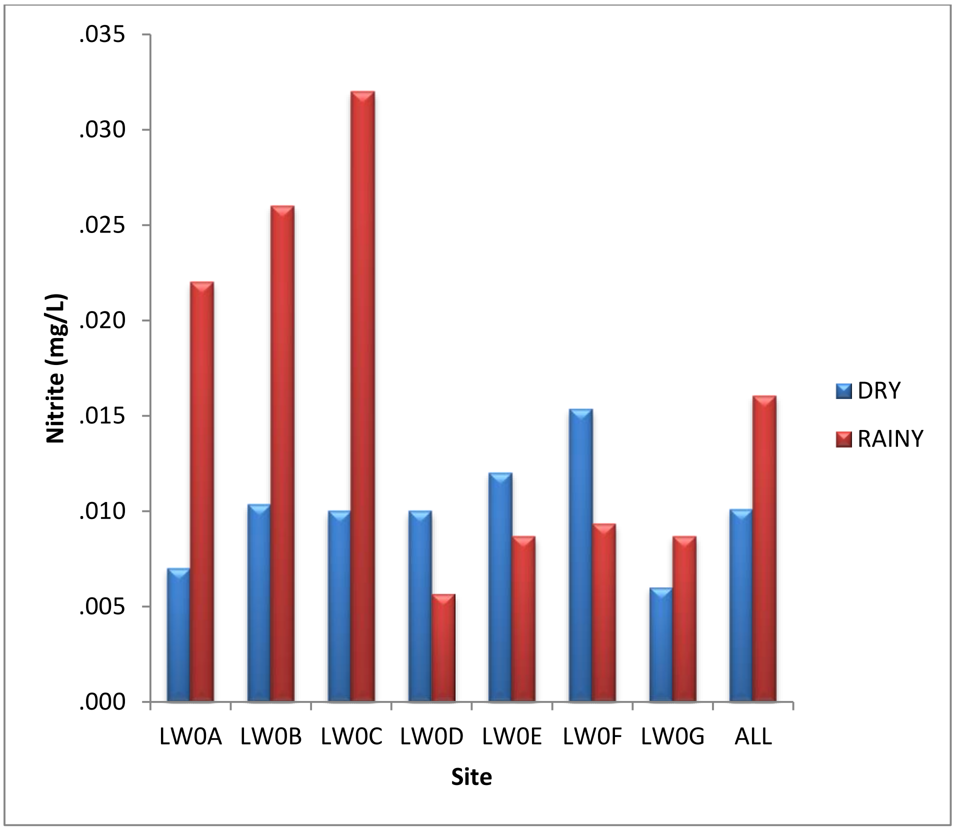

Figure 4.14: Nitrite Levels over seasons

The results indicate that, average Nitrite concentration of the Lake was higher in the rainy season (0.016 mg/L) than the dry season (0.010 mg/L) except for sites LW0D, LW0E and LW0F. However, the difference was not significant *($p> 0.05$)*.

4.2.2.6 Phosphate

Phosphate level of the Lake varied from a minimum of 0.03 mg/L recorded at site LW0D to a maximum of 1.16 mg/L at site LW0A with an average of 0.40±0.19 mg/L. Comparing phosphate concentrations across the sites showed no significant difference *(p> 0.05)* in their averages. Figure 4.15 presents seasonal variations in phosphate levels. The result indicated that, higher concentration of Phosphate was recorded in the dry season (0.4357 mg/L) than in the rainy season (0.357 mg/L) except site LW0A (0.723 mg/L). However, the difference was not significant ($p > 0.05$).

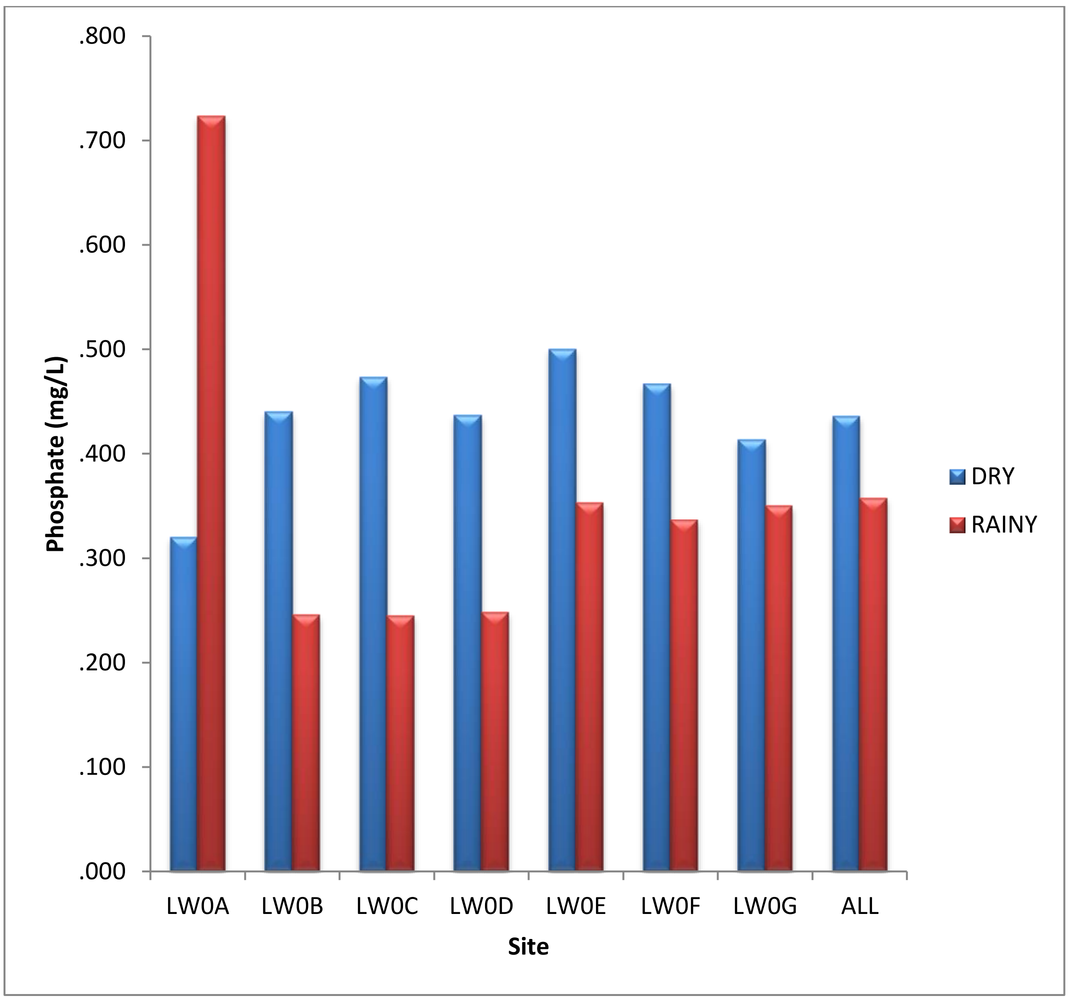

Figure 4.15: **Seasonal variation in Phosphate levels**

4.2.2.7 Ammonium

The average concentration of ammonium in the lake was 0.018±0.017 mg/L. Concentration of Ammonia in the lake varied from non-detectable limits in almost all the sites except sites LW0F and LW0G in the dry periods to 0.10 mg/L (at LW0F and LW0G) in the rainy season. In addition, a comparison of the average Ammonium levels across the sites indicated no significant difference *($p > 0.05$)* in their averages. Figure 4.15 presents the seasonal variations of ammonium in the lake. From Fig 4.15, average concentration of ammonium in the lake was higher during the dry season (0.186 mg/L) than the rainy season (0.017 mg/L) but this difference was not statistically significant *($p > 0.05$)*. All the sites followed the same trend except for sites LW0B, LW0D and LW0E.

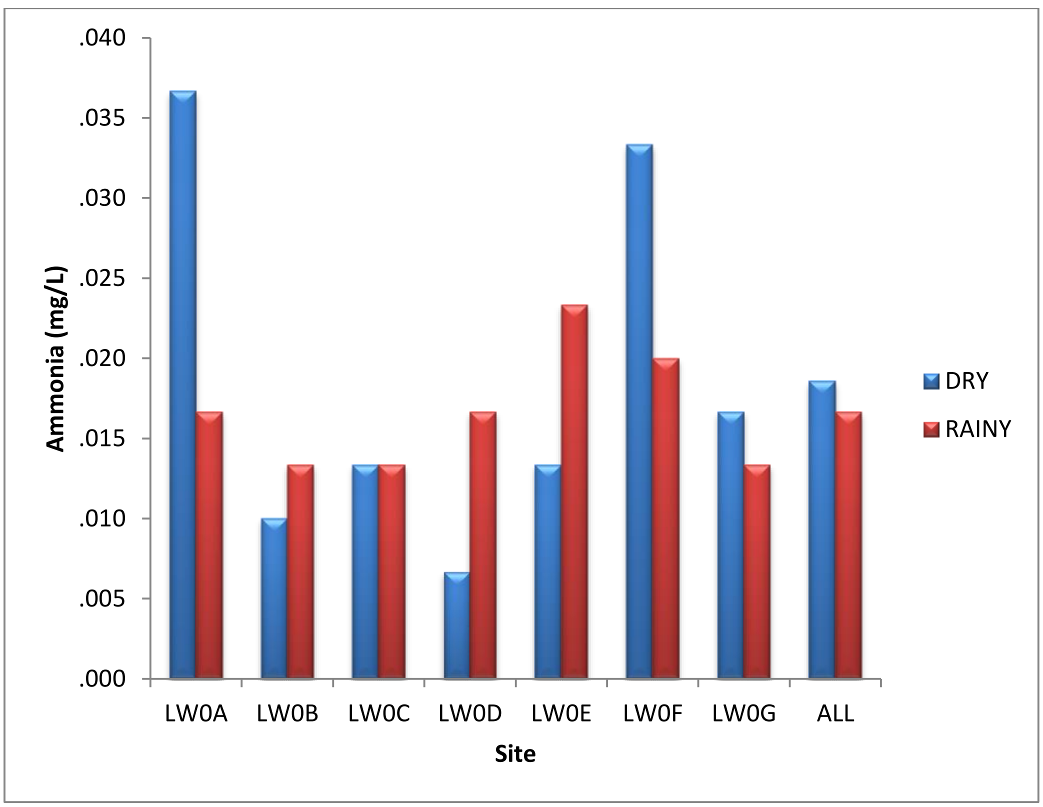

Figure 4. 16: **Ammonium levels in water over seasons**

4.2.3 Biological Properties of Water

The results of biological parameters of the lake compared with W.H.O/G.S.A standard is presented in Table 4.4.

Table 4.4: Biological parameter of lake water

SITE	**STATISTIC**	Total Coliform 100M/L	Fecal Coliform 1OOM/L	E Coli 100M/L	Total Heterotrophic Bacteria(THB) 1OOM/L
LW0A	Min	230	11	0	734
	Max	496	28	6	884
	Mean	330	19	3	833
	Std. Dev.	106	7	2	55
LW0B	Min	488	12	0	894
	Max	749	26	5	1142
	Mean	626	20	3	1012
	Std. Dev.	90	5	2	106
LW0C	Min	735	19	0	1242
	Max	920	38	11	1420
	Mean	815	30	6	1331
	Std. Dev.	69	6	4	73
LW0D	Min	521	15	0	524
	Max	881	20	8	748
	Mean	695	17	6	649
	Std. Dev.	114	2	3	98
LW0E	Min	908	61	2	695
	Max	1304	72	14	1488
	Mean	1060	66	8	913
	Std. Dev.	134	4	5	287
LW0F	Min	1029	56	4	820
	Max	1301	81	17	1428
	Mean	1174	72	12	1192
	Std. Dev.	100	9	5	230
LW0G	Min	1023	60	2	821
	Max	1312	86	14	1329
	Mean	1166	72	9	1094
	Std. Dev.	122	12	5	182
Total	Min	230	11	0	524
	Max	1312	86	17	1488
	Mean	**838**	**42**	**6**	**1004**
	Std. Dev.	311	26	5	265
W.H.O/G.S.B		**0.0**	**0.0**	**0.0**	**0.0**
ANOVA	F value	51.699	84.024	4.053	11.117
	p-value	**0.000**	**0.000**	**0.003**	**0.000**

Source: Field Work 2014

4.2.3.1 Faecal coliform

From Table 4.4, the average Total coliform (TC) count of the Lake was 838±311 CFU/100 ml. Total Coliform of the Lake ranged from a minimum of 230 CFU/100 ml at site LW0A to a maximum of 1312 CFU/100 ml at site LW0G. Average Total Coliform of the lake was significantly higher (*$p<0.05$*) when compared with WHO/GSB permissible limit for surface water. The result of the seasonal variation in total coliform is presented in Figure 4.17. The results indicated that, the average TC counts in the lake was slightly higher in the dry season with the maximum values recorded at sites LW0F (1222.13 CFU/100 ml) and LW0G (1231 CFU/100 ml) than in the rainy season except for site LW0A and LW0D (Fig 4.17) though this was not significantly different ($p > 0.05$).

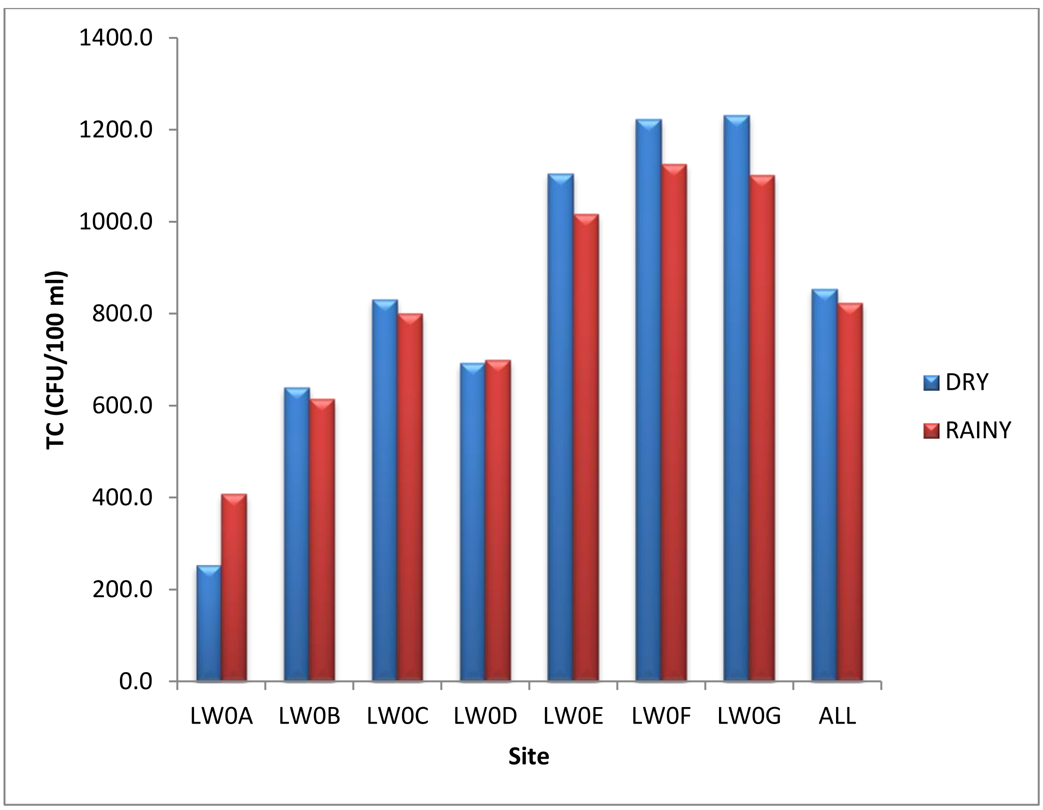

Figure 4.17: Total Coliform levels in water over seasons

4.2.3.2 Faecal Coliform

The average Fecal Coliform counts in the Lake was 42±26 CFU/100 ml. Fecal Coliform concentrations ranged from 11 CFU/100 ml to 86 CFU/100 ml in the Lake. Fecal Coliform levels in the lake was significantly higher ($p < 0.05$) than the WHO/ GSB standard for surface water. The minimum average fecal coliform was recorded at site LW0D (17 CFU/100 ml) while site LW0G recorded the highest average with 72 CFU/100 ml. The seasonal variation in Fecal Coliform concentrations in the lake is presented in Figure 4.18. From the result (Figure 4.18), except for site LW0B and LW0C average Fecal Coliform in the Lake was higher during the rainy season than in the dry season but the difference was not significant ($p > 0.05$).

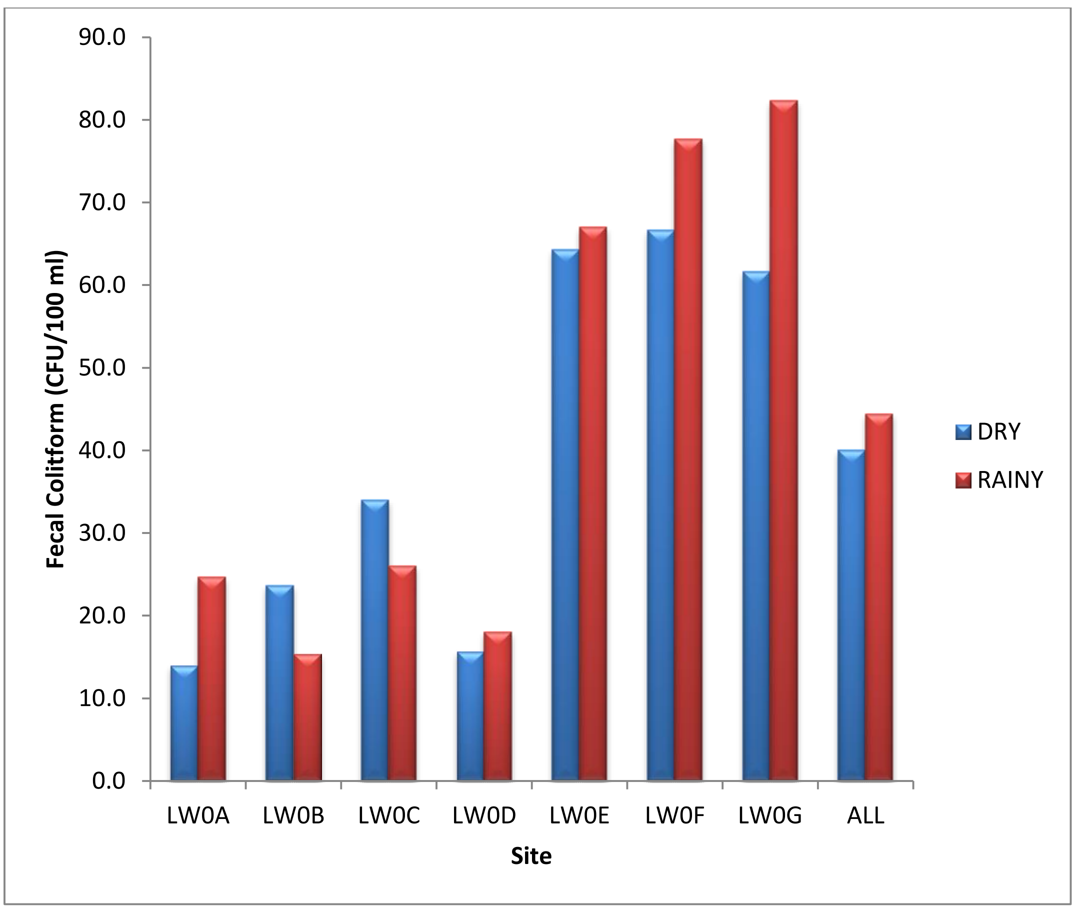

Figure 4.18: Seasonal Variation in Fecal Coliform

4.2.3.3 *E.coli*

Similarly, for *E. coli*, the average level in the Lake was 6±5 CFU/100 ml. *E. coli* levels in the Lake ranged from non-detectable levels at site LW0A, LW0B and LW0C to 17 CFU/100 ml at site LW0F. *E.coli* level in the water was significantly higher *($p < 0.05$)* than the WHO/GSB permissible levels for either recreation or drinking purposes. A comparison of *E. coli* levels across sites was significant (p-value; 0.003).

Seasonal comparison of *E. coli* in the lake water is presented in Figure 4.19. The results indicated that, average *E. coli* concentrations for all sites in the lake were significantly higher ($p<0.05$) during the rainy season than the dry season.

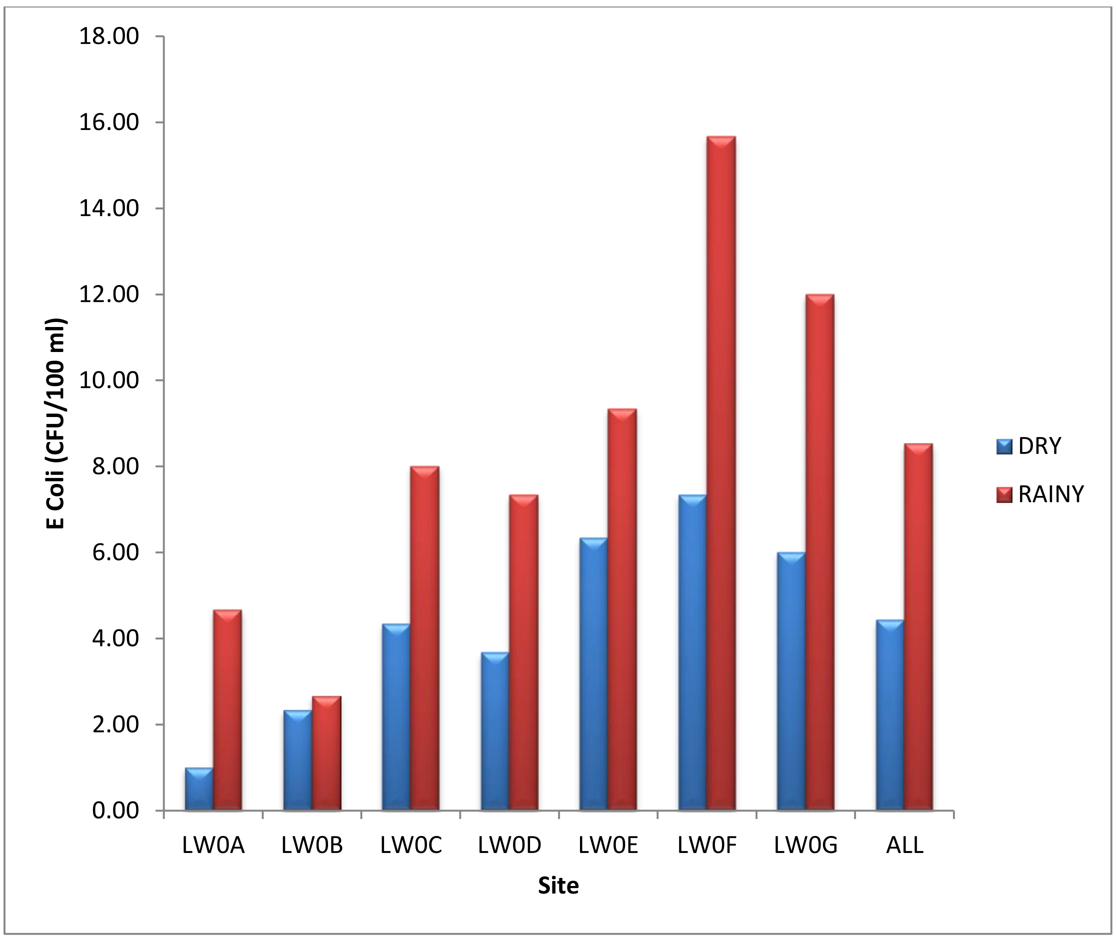

Figure 4.19*:* *E Coli* levels in water over season

4.2.3.4 Total Heterotrophic Bacteria (THB)

Total Heterotrophic Bacteria (THB) level in the lake ranged from a minimum of 524 CFU/100 at site LW0D to a maximum of 1488 CFU/100 ml at site LW0E with an average of 1004±265 CFU/100 ml. The average THB level in the water was higher than the WHO/GSB standard value of zero. There was a significant difference ($p < 0.05$) between THB across all the sites. Figure 4.20 presents seasonal variations in THB. The result (Fig 4.20) showed that, average THB level was higher during the dry season than the rainy season but this difference was not statistically significant ($p > 0.05$). Sites LW0D and LW0G however had average THB higher during the rainy season than the dry season.

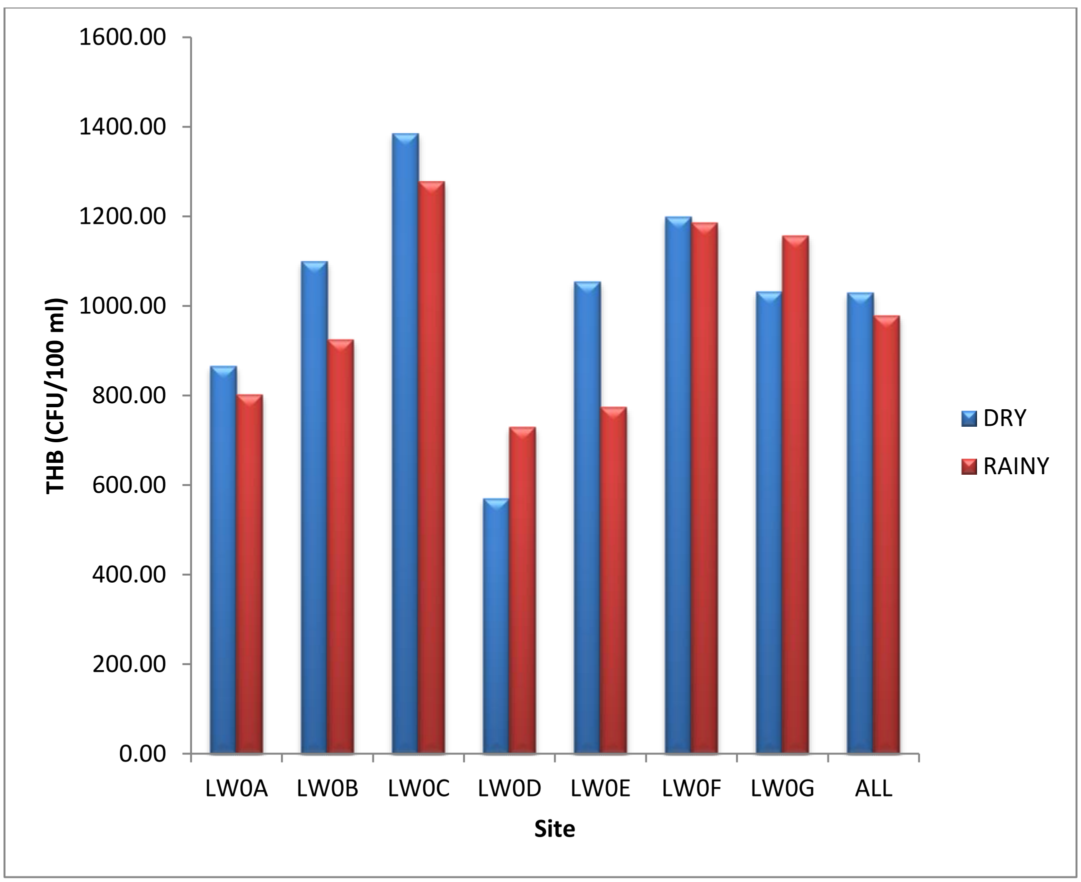

Figure 4.20: Seasonal variations in Total Heterotrophic Bacteria

4.2.4 Correlation among water parameters

A correlation analysis was used to determine relationships among water quality parameters. Table 4.5 presents the results of correlation analysis. From the results, it is observed that, there was a significantly positive correlation between temperature, Electrical Conductivity (EC) and Salinity but negatively with Total Suspended Solids (TSS). pH was significantly positively correlated with Conductivity, Nitrate and *E. coli*.

Total Suspend Solid was the most significant (5 %) correlated parameter as it significantly correlates with eight different parameters (Temperature, Turbidity, Color, DO, BOD, COD and TC). Turbidity, Conductivity, and Biochemical Oxygen Demand were the next most correlated parameter. These correlated significantly with seven different parameters.

Table 4.5: Pearson Pairwise Correlation Coefficients among Parameters

	Temp	pH	EC	TDS	TSS	Turbidity	Colour	DO	BOD	COD	Nitrate	Nitirite	Phosphate	Ammonia	Salinity	TC	Feacal Coliform	E Coli
Temp	1																	
pH	.086	1																
EC	**.567****	**.384***	1															
TDS	-.246	-.173	-.213	1														
TSS	**-.322***	.015	**.349***	.011	1													
Turbidity	-.172	.022	-.243	-.086	**.905****	1												
Color	-.295	-.011	**-.334***	-.064	**.921****	**.847****	1											
DO	.219	-.077	**.307***	-.149	**-.388***	**-.488****	**-.361***	1										
BOD	-.005	.029	.234	-.043	**-.425****	**-.543****	**-.306***	**.565****	1									
COD	-.121	-.097	-.250	-.123	**.689****	**.708****	**.795****	**-.386***	-.229	1								
Nitrate	-.008	**-.323***	-.109	-.022	.190	.261	.058	-.226	**-.411****	.017	1							
Nitirite	-.153	-.202	-.018	.158	.006	.034	-.030	-.101	-.107	.050	.196	1						
Phosphate	-.053	-.148	**-.310***	-.254	.138	.151	.216	-.039	.010	.225	.005	-.241	1					
Ammonia	.057	.022	.072	-.100	.259	.284	.297	.021	-.117	.157	.088	-.083	-.143	1				
Salinity	**.341***	.008	**.336***	-.147	-.109	.011	-.143	.180	-.059	-.051	.246	.006	-.041	-.142	1			
TC	-.032	-.187	-.257	-.045	**.349***	**.335***	.179	-.193	**-.314***	.276	.296	-.075	-.053	-.077	.010	1		
Fecal Coliform	.090	-.151	-.224	-.193	.248	**.336***	.132	-.177	**-.376***	**.319***	**.313***	-.154	.065	.101	.034	**.823****	1	
E .coli	.256	**-.350***	.095	-.225	-.160	-.012	-.230	.105	-.214	-.092	**.543****	-.093	-.064	.098	.243	**.501****	**.619****	1
THB	-.246	-.055	-.097	.175	.159	.051	.013	.082	-.230	-.080	.030	.066	-.023	-.126	-.066	**.398****	**.342***	.162

Significant correlations (*);Temp; Temperature (ºC), EC: Electrical Conductivity (µS/cm):TDS: Total Dissolved Substances (mg/L), TSS: Total Suspended Solids (mg/L),DO: Dissolved Oxygen (mg/L), BOD: Biological Oxygen Demand (mg/L), COD: Chemical Oxygen Demand (mg/L), Nitrate (mg/L),Nitrite)mg/L), Phosphate (mg/L),*E.coli* (ml/L)

4.3 Comparison of Present Physico-chemical Data to Past Data

Some physiochemical data collected through this study were compared to similar past data collected by Turner *et al*. (1996). Four parameters including pH, NO_3, PO_4 and NH_4 were compared to current data due to data scarcity on the other parameters. Table 4.6 compares data from the current study to past study by Turner *et al.* (1996). Between 1996 and 2014, there was remarkable increase in major nutrients like NO_3 (319.4 %) representing 0.99 and PO_4 (1190.3 %) representing 0.369 mg/L (Table 4.6). Relative elevation in pH (0.2 %) was observed by this study compared to those reported by Turner *et al.* (1996) though the variation was not significant (0.2 %). However, there was 40 % reduction in NH_4 levels between 1996 and 2014 (Table 4.6).

Table 4.6: Comparison of some physico-chemical characteristics of surface water from Lake Bosomtwi between 1996 and 2014

Parameter	WHO/GSB	Turner *et al* 1996	Current study	Change (1996-2014)	Percentage change
pH	6.5-8.5	8.98	9	0.02	0.2 %
NO_3	10	0.31	1.3	0.99	319.4 %
PO_4	2.5	0.031	0.4	0.369	1190.3 %
NH_4	1.5	0.03	0.018	-0.012	-40.0 %

4.4. Soil Analysis

Soil samples were analyzed. The various components of the soil and how they relate to the water parameter is presented in Table 4.3.

Table 4.7: Soil Properties

Samples Sites	EC (µS/cm)	pH (pH units)	Total Coliform	E.coli (CFU/100 ml)	NH_4 (cmol(+)/kg)	P (mg/L)	N (%)
LW0A	262	7.5	9×10^4	3×10^4	0.51	5.16	0.25
LW0B	454	7.8	5×10^4	1×10^4	1.53	14.31	0.48
LW0C	291	7.3	2.3×10^5	8×10^4	0.19	3.79	0.32
LW0D	176	8.6	-	-	0.05	1.35	0.04
LW0E	196	7.5	2.8×10^5	3×10^4	0.12	2.5	0.09
LW0F	182	7.3	3.5×10^5	1.2×10^5	0.12	2.82	0.11
LW0G	216	6.7	-	-	0.23	7.72	0.42
Mean	254	7.5	2×10^5	5.4×10^5	0.39	5.38	0.24
Std. Dev.	98	0.6	126886	45056	0.52	4.45	0.17

Source: Field Data 2014

From Table 4.7, the observed average soil Electrical Conductivity (EC) was 254 µS/cm with Site LW0B recording the highest Conductivity level (454 µS/cm) while the minimum value was recorded at site LW0D (176 µS/cm). Average soil pH recorded was 7.6. The highest soil pH was recorded at site LW0D (8.6) with the lowest soil pH at site LW0G (6.7).

As indicated in the table (Table 4.7), total coliform concentrations in the soil recorded during the study period ranged from non-detectable limits at sites LW0D and LW0G to as high as 3.5×10^5 CFU/100 ml at site LW0C. Also, no traces of *E.coli* could be identified at sites LW0D and LW0G, though a higher concentration of *E.coli* was recorded at all the other sites with site LW0C recording the highest (1.2×10^5 CFU/100 ml).

Phosphate (mg/L) concentrations in sampled soil ranged from a minimum of 1.35 at site LW0D to a maximum of 14.7 cmol+/kg at site LW0B. The overall average concentration of phosphate in the soil was 5.38± 4.45 mg/L. Site LW0B recorded the highest available phosphorus (1.5) and nitrogen (0.48) while site LW0D recorded the lowest averages.

4.5 Association between Soil and Water Parameters

From Table 4.8, there was significantly positive correlation for the parameters; EC, pH, TC and *E.coli* between water and soil samples. This implies that the sites with higher EC, pH, TC and *E.coli* in the soil generally could account for the higher concentration of these parameters in the water. The coefficients of determination were also computed. It could be explained that, land use activities within the watershed do affect some water quality parameters.

Table 4.8: Correlation analysis between soil and water parameters

		Soil Parameters						
		EC	pH	T Coli	E Coli	Ammonia	Phosphate	Nitrogen
Water Parameters	EC	**.551***	**.569***	**-0.932***	-.678	.483	.177	.057
	pH	.417	.530	-.484	.039	.255	-.008	-.006
	T Coli	-.464	-.499	**0.903***	**.619***	-.458	-.226	-.146
	E Coli	**-.673***	-.411	**0.959***	**.810***	**-.631***	-.463	-.393
	Ammonium	-.352	-.291	.300	.389	-.223	-.300	-.328
	Phosphate	-.236	-.267	-.084	-.157	-.152	-.229	-.189
	Nitrate	**0.828***	.025	-.432	-.182	**.610***	.563	**.621***

*= significant at 0.01 level

4.6 Social Survey

4.6.1 Demographic Background of Respondents

Analysis of respondents' educational background (Fig 4.21) showed that, majority of the respondents (49 %) had completed Junior High School while 14 % had primary/basic education. Only 11 % of the respondents had tertiary education while 5 % had completed Senior High School or O'Level. However, more than one-fifth (21 %) of the respondent had no form of formal education.

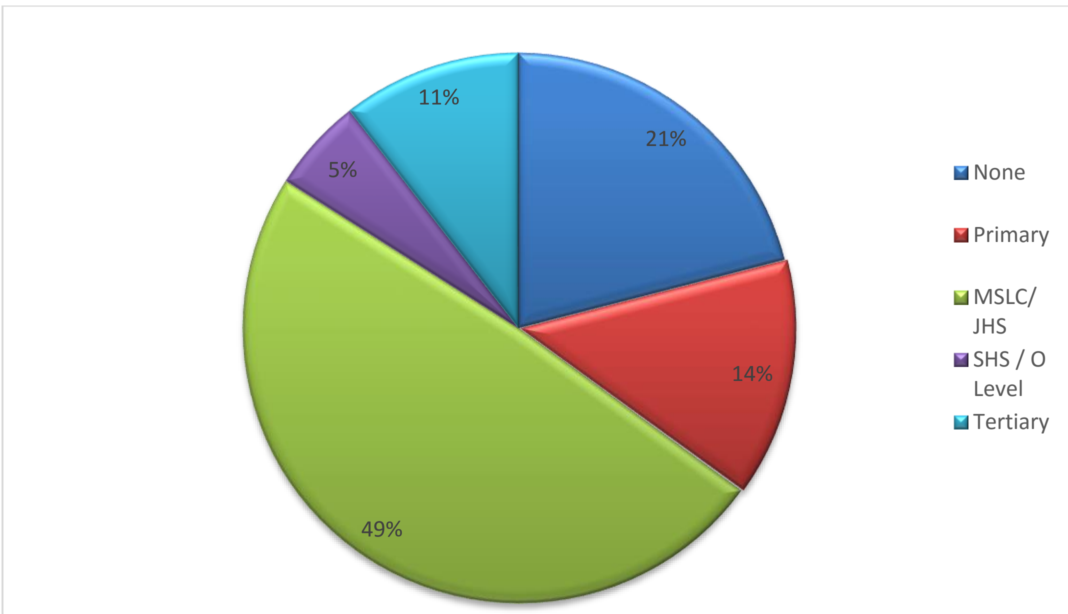

Figure 4. 21: Educational level of respondents (bars do not match y-axis)

Majority of the residents (147), representing 74 %, were involved in both fishing (including fish mongering) and farming (Table 4.9) activities, while 38 respondents representing 19.1 % were engaged in farming only. The remaining 7 % were engaged in the tourism industry. Those engaged in the tourism industry included pool attendants, receptionists, waitresses and restaurant operators.

Table 4.9: Occupational status of respondents

OCCUPATION	Frequency	Percent (%)
Fishing and Farming	147	73.9
Farming Only	38	19.1
Tourism Industry	14	7.0

Source: Field Work 2014

Figure 4.22 shows the results of the length of stay of respondents in the study area. From the graph, majority of the respondents (136), representing 68 %, had stayed around the lake for more than 30 years. While 44 of the respondents (representing 22 %) had stayed in the area for more than 10 years (10-30 years). Only 20 of the respondents, representing 10 % had stayed in the area for less than a decade (10 years).

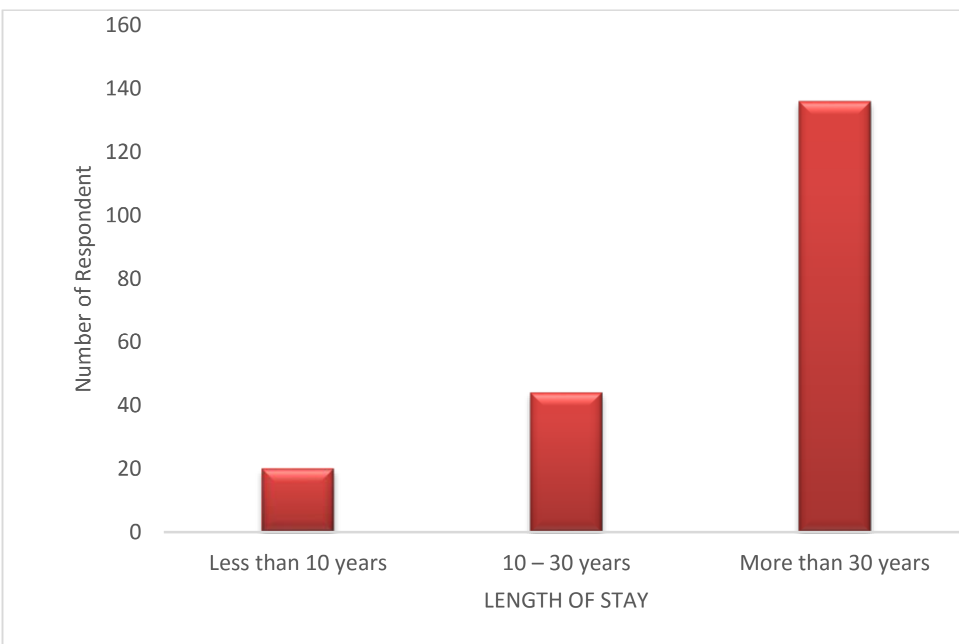

Figure 4.22: Respondents' length of stay

4.6.2 Observed change in land use/cover and causes

When respondents were asked to indicate, in their views, the perceived changes in land cover and factors that caused the changes, majority (76 %) of them indicated that there is a decrease in land cover while 15.5 % indicated there was no change (stable) in land cover over the past two decades (Table 4.10). Only 3.5 % of the respondents indicated that land cover has increased over the years. Among the causes of the changes, the respondents rated farming (24 %) and livelihood change (23 %) as the major causes of the changes in the land cover followed by continuous deforestation (22 %) and human settlement (20 %). However, 6 % of the respondents did not agree that farming was responsible for the changes in land cover while 4 % also strongly disagreed that deforestation played a role in the land cover changes around the lake

Table 4.10: **State of land cover**

RATING	Strongly Agree	Agree	Disagree	Strongly Disagree	Mean	Std. Dev
STATE OF LAND COVER						
Stable	11	20	-	-	-	-
	5.5%	10.0%				
Decreasing	140	12	-	-	-	-
	70.0%	6.0%				
Increasing	2	5	-	-	-	-
	1.0%	2.5%				
CAUSE OF CHANGE						
Farming	40	8	10	2	1.6	0.7
	20.0%	4.0%	5.0%	1%		
Settlement	30	8	2	-	1.8	1.0
	15.0%	4.0%	1.0%	-		
Livelihood	28	18	2	-	1.8	1.0
	14.0%	9.0%	1.5%	-		
Deforestation	13	30	-	8	2.3	0.8
	6.5%	15.0%	-	4.0%		

4.6.3 Observed changes in lake and possible cause as indicated by respondents

Table 4.11 shows the results of perceived physical changes in lake resources (water and fish stock) by the respondents. From the results, majority 98 % (196) of the respondents indicated observed changes in the lake while 2 % (4) said they have not observed any physical changes. Majority (108) of the respondents (55.1 %) indicated the major observed change as reduction in fish catch and lake size 34.7 % (68) with only 5.1 % (10) indicating growth of worms (reddish worms) in the lake.

When asked to state the probable factors which caused these observed changes, majority of the respondents (78), representing 39 %, stated non-observance of tradition, scientific research (the Intercontinental Drilling Project- ICDP) carried out in the lake (43, representing 21.5 %), desecration of the lake (38, representing 19 %) as well as human activities (35, representing 17.5 %) and the use of unapproved nets (6, representing 3.0 %).

Table 4.11: Perceived physical changes in lake resources and possible cause by respondents

	Frequency	**Percent**	Pearson's X^2 (*P*-value, df)
Observed changes in lake			
Yes	196	98	
No	4	2	
Changes observed			
Reduction in fish catch	108	55.1	
Reduction in lake size	78	39.8	
Growth of worms	10	5.1	
Causes of Trend			
Scientific Research	43	21.5	
Non-observance of tradition	78	39.0	
Desecration of the Lake	38	19.0	
Human activities	35	17.5	
Unapproved usage	6	3.0	

4.6.4 Land Use Activities that May Impact on Lake

Respondents' views on specific land use activities that may impact negatively on the Lake was solicited and the results are presented in Table 4.12. From Table 4.12, majority of the respondents (192), representing 96 %, indicated using agrochemicals on their farms. Out of this, 77 % used weedicides and pesticides while 22.9 % used fertilizer and manure in their farming activities. In addition, about 83 % of the respondents reported frequently using "slash and burn" in preparing their farmland while 17 % used "slash and burn" occasionally.

The survey revealed that (Table 4.12), 63 % of the respondents were engaged in livestock rearing mostly (65.9 %) in a free ranged system. The free ranged system practiced by residents suggests that animals are likely to come into contact with the lake which can cause contamination. Apart from rearing of animals, other observable activities around the lake that may affect the quality of water were; washing of clothes and bathing in the lake (89 %), removing stones around the lake for sale (stone mining – 50 %), and defecating around the lake (20.5 %). Plate 1 shows some land use activities around the lake.

Table 4.12: Land use activities that affects the lake

	Frequency	**Percent**
Tourist Facility		
Yes	88	44.0
No	112	56.0
Agrochemical Use		
Yes	192	96
No	8	4
Fertilizer and Manure	44	22.9
Not Often	29	65.9
Often	15	34.09
Pesticides and Weedicide	148	77
Not Often	2	1.4
Often	146	98.6
Livestock Rearing		
Yes	126	63.0
No	74	37.0
Practice		
Caged	14	11.1
Semi-Caged	83	65.9
Free Range	29	14.5
Other Activities		
Stone Mining	100	50.0
Washing	179	89.5
Defecating	41	20.5

Source: Field Work 2014

a. *pig pen near the lake*

b*. farm on a sloping land*

c. *evidence of agro-chemicals usage*

d. *stone mining*

Plate 1: Some Land use activities that affect lake

A logistic regression was used to assess the factors affecting awareness of effects of agrochemicals usage (on their farms) on the quality of the lake. The result is presented in Table 4.13. A positive coefficient means the sub-factor had better proportion of knowledge on buffer zone compared to the reference category. The logistic regression analysis showed that gender and level of education significantly (*p<0.05*) influenced knowledge of possible impact of agrochemicals usage (on their farms) on the quality of the lake. Thus, respondents with higher education levels were more informed about the impact of agrochemicals on the lake (Table 4.13). However, length of stay was not a significant factor (p>0.05) as those who have stayed there for less than 10 years showed higher knowledge compared to the rest of the other categories.

Table 4.13: Logistic regression showing factors affecting knowledge on agrochemical effects

Variables	Coefficient	χ^2-statistic	df	p-value
Gender				
Male	*Reference*			
Female	-0.769	4.081	1	0.043
Education level		9.639	4	0.047
None	*Reference*			
primary	0.770	1.209	1	0.272
MSLC OR JHS	2.087	5.199	1	0.023
SHS OR O Level	2.400	5.550	1	0.018
Tertiary	3.451	7.286	1	0.007
Length of stay		9.224	2	0.010
Below 10 years	*Reference*			
From 20-30	-0.913	3.751	1	0.053
Above 30 years	-1.270	8.512	1	0.004
Constant	1.966	18.395	1	0.000

significant at < 0.05

4.6.5 Distance of Land Use Activities from Lake

The distance of certain land use activities from the lake were enquired from respondents and the result presented in Table 4.14. From the result, apart from fishing and the aquaculture business which is carried out directly in the lake, majority of the respondents indicated that, certain human activities like farming, livestock, tourism and toilet facilities (pit latrine) were done/ sited very close to the lake. Majority of the respondents (72.5 %) had their farms located within 300 m or less from the lake while 27.5 % had their farms located within 400 m (or more) from the lake. Also, tourism facilities and livestock cages (especially piggeries) were mostly located close to the lake; less than 20 m (89.8 %) and 50 m (63.0 %), respectively. This indicates that organic waste, agro-chemicals and liquid waste are likely to be washed into the lake.

In all the communities visited, each community had only one toilet facility (pit latrine) serving the whole community which was mostly sited closed to the lake. Majority of the respondents (64.5 %) confirmed that, the distance of the public toilet from the Lake was less than 100 m which indicates that leachate can get into the lake.

Table 4.14: Distance of Land Use Activities from Lake

	Frequency	Percent (%)	Pearson Chi-square	df	p-value
Farm Distance From Lake					
50 m or less	13	6.5			
50 – 100 m	26	13			
100 – 200 m	45	22.5	40.400	4	0.000
200 – 300 m	61	30.5			
above 400 m	55	27.5			
Toilet Facility					
Public	200	100			
Distance from Lake					
Less than 100 m	129	64.5	16.800	1	0.000
100 m and above	71	35.5			
Distance of Tourism facility from Lake					
Below 20 m	79	89.8	55.682	1	0.000
Above 20 m	9	10.2			
Livestock Rearing					
Yes	126	63	13.520	1	0.000
No	74	37			
Distance From Lake					
Below 50 m	80	63.5	9.175	1	0.002
Above 50 m	46	36.5			

Source: Field Work 2014

4.6.6 Awareness of Buffer Zone around the Lake

When the knowledge of respondents on buffer zone was enquired, majority of the respondent (77.5 %) indicated they were not aware of any buffer zone around the lake, while 22.5 % of them indicated their awareness of a buffer zone around the lake. A logistic regression analysis was carried out to determine the factors that affect respondents' awareness of the existence of a buffer zone around the lake. The result is presented in Table 4.15. The Logistic regression analysis indicated that, gender was not a significant ($p>0.05$) factor in determining respondents' awareness of buffer zone around the lake. Also, education did not significantly influence respondents' awareness of buffer zone around the lake. However, length of stay significantly ($p<0.05$) influenced one's awareness of the existence of a buffer zone around the lake.

Table 4.15: Logistic regression showing factors affecting awareness of buffer zone

Variables	Coefficient	χ^2-statistic	df	p-value
Gender				
Male	*Reference*			
Female	.030	.006	1	.938
Education level		5.009	4	.286
None	*Reference*			
primary	0.784	1.064	1	.302
MSLC OR JHS	-1.047	1.720	1	.190
SHS OR O Level	0.897	.535	1	.464
Tertiary	-1.787	3.624	1	.057
Length of stay		10.361	2	.006
Below 10 years	*Reference*			
From 20-30	-1.759	9.452	1	.002
Above 30 years	-2.049	10.010	1	.001
Constant	2.123	8.708	1	.003

Source: Field Work 2014

4.6.7 Socio-economic Effects of Changes in Water Quality

Respondents' views were solicited on the impacts of the change in water quality on their lives. Table 4.16 shows the results of the response of respondents. From the results, majority (97 %) of the respondents indicated that the domestic use of the lake water has been restricted to only washing and cooking due to the deteriorating water quality while the remaining 3 % said they do not use the lake water for any domestic activity. About 65 % of the respondents reported of negative health effects such as skin rashes, typhoid and body itching experienced from using the lake water for bathing. Other socio-economic effects indicated by the people due to deteriorating lake water quality were; poverty/ low income (40 %) due to reduced fish income and increased unemployment (60 %) due to reduced fishing hour/days. Similarly, 42 % of the residents indicated that there has been a reduction in fish food due to low fish catch, a situation which is likely to affect their nutritional status (fish protein).

Table 4.16: Socio-Economic Effects of Poor Lake Water Quality

	Frequency	Percent	Pearson Chi-square	df	p-value
Domestic Lake Use					
Yes (not for drinking)	194	97	176.720	1	0.000
No	6	3			
Effects of Poor Water Quality					
Poverty/Hardship	191	95.5	106.657	4	0.000
Reduction in Fish Food	84	42			
Unemployment	145	72.5			
Epidemics	126	63			
Out-migration	45	22.5			
Fishing Activity (Frequency)					
Everyday	83	41	8.170	2	0.017
Weekly	50	25			
Monthly	67	33.5			
Tourism Benefits					
Individual					
Yes	9	4.5	165.620	1	0.000
No	191	95.5			
Community					
Yes	15	7.5	142.545	1	0.000
No	183	91.5			

Source: Field Work 2014

The logistic regression analysis demonstrated that gender significantly (*$p<0.05$*) determined respondents' knowledge on the negative health effects arising from using lake water for domestic activities. However, respondents level of education did not significantly (*$p>0.05$*) influenced their knowledge on the negative health effects of using the lake water for domestic activities. In addition, respondents' length of stay significantly (*p<0.05*) influenced their knowledge on negative health effects from using water from the lake.

Table 4.17: Logistic regression showing factors affecting knowledge on health effects of lake water

Variables	Coefficient	χ^2 -statistic	df	p-value
Gender				
Male	*Reference*			
Female	-.844	6.373	1	.012
Education level		12.465	4	.014
None	*Reference*			
primary	2.787	4.257	1	.039
MSLC OR JHS	1.826	2.809	1	.094
SHS OR O Level	1.561	2.810	1	.094
Tertiary	.390	0.452	1	.501
Length of stay		3.765	2	.152
Below 10 years	*Reference*			
From 20-30	-.315	.283	1	.594
Above 30 years	.656	2.845	1	.092
Constant	-.990	7.095	1	.008

Source: Field Work 2014

4.6.8 Current Lake Management and Appropriate Suggestions

To assess the current lake management practices, residents were asked to indicate some of the measures put in place to protect the lake and suggest how these measures could be improved to prevent the lake from deteriorating further. From the results, majority (86 %) of the respondents indicated that there exist some rules and regulations in their communities to protect the lake. These include prohibition of defecation or throwing waste into the Lake, forbidding women in their menstrual period to visit the Lake due to tradition and proscription of washing in the Lake. However, 14 % representing 28 respondents said they were not aware of any rules or regulations to protect the lake. The enforcement of these rules was carried out by the chiefs and unit committee members of the various towns. Respondents also acknowledged that, other Non-Governmental and Government organizations were helping in the management of the Lake. The notable ones in order of their popularity were Friends of Water and River Bodies (60 %), Friends of Earth (46 %) and Forest Commission (3 %).

Respondents' opinions were solicited on how well the lake can sustainably be managed. Majority (99 %) of the respondents suggested that, strict laws should be enacted and enforced to complement the existing ones. Also 77 % of the respondents proposed alternative source of employment to help reduce over-reliance on the lake and the lands around the lake. Continuous education (60.5 %) on the need to prevent the lake from further deteriorating and attitudinal change (27.5 %) among individuals who do things to desecrate the traditions held by the people in maintaining the lake. Table 4.18: Current Lake Management and Appropriate Suggestions

CHAPTER FIVE

DISCUSSION

5.1 LAND USE /COVER CHANGE

An appraisal of past and current land use changes is a major pre-requisite in establishing the changes in quality of water and its resources. This can only be attained by producing spatiotemporal data (both qualitative and quantitative) on the intensity and type of land use activities. Analyses of land-use in the Lake Bosomtwi watershed over the study period revealed a rapidly changing landscape.

The satellite images revealed that, there has been a progressive reduction in the Close forest vegetation from 2738.73 ha (26.04 %) in 1990 to 1860.40 ha (17.69 %) in 2010. The reduction of the Closed Forest Vegetation could be attributed to livelihood change as more people are shifting from fishing-related activities to cash crop farming within the watershed. This has resulted in the degradation of the forest cover which was supposed to protect the lake from harsh environmental conditions. This result is in line with a report by Prakash *et al.* (2005) who attributed the reduction in forest cover to an increase in the number of people opting for cocoa farming in Ankaase, a town within the lake Bosomtwi basin. Similarly, Codjoe (2009) attributed reduction in forest cover (closed forest cover) to increase in population, the need for wood energy and alternate source of livelihood without any proper management. Lambrechts *et al.* (2003) also attributed destruction of forest vegetation to uncontrolled human activities like agricultural intensification. Similarly, Calder *et al.* (1995) observed a 13 % reduction in forest cover around Lake Malawi was due to land use change.

It was observed in the thesis that, from 1990 to 2010, approximately 50 % of the natural forest was converted to agricultural/cultivated lands (Fig. 4.1). The intensive agriculture going on within the watershed is an indication that forest lands are being replaced with arable lands where cash and annual crops are cultivated on large and medium scale. The increasing agricultural activity within the basin at the expense of closed/open forest vegetation could result in nutrient enrichment, aggravated erosion and sedimentation as reflected by the high turbidity, high total solids and nutrients like phosphate in the lake. This result is in line with the finding of Tunner and Rabalias (2003) in the Mississippi river basin. In the same way, a report by Chesapeake Bay Foundation (2012) attributed 40 % of Nitrogen and 50 % of phosphorus in the Chesapeake Bay to agricultural activities. Similar observations were made by Reed *et al.* (2008). Also in an interview, the respondents' stated erosion as one of the major challenges facing their farming operations within the basin.

Between 1990 and 2010, the total land cover of the lake had reduced by 6.5 % (Table 4.1). Parts of this dried up areas are now occupied by farmlands and in some situations settlements. It is likely that, the receding forest cover within the basin together with other factors (climate change) might have contributed to the reduction in fish catch and the dwindling size of the lake. The result is consistent with the Carder *et al.* (1995) assertion that, the 13 % reduction in the forest cover (1967-1990) around Lake Malawi contributed to the reduction in lake levels. However, majority of the respondents interviewed attributed the receding lake to the scientific research (the Inter-continental Drilling Project of Lake Bosomtwi, 2004) and disrespect for traditional values (sacrilege like having sex in the lake by tourists).

It is clear (Fig 4.1) that, over the years, Open Forest Vegetation has increased distinctly from 1990-2010 (1715.84-2113.65 ha) while Bare Surface cover increased from 12.15 ha in 1990 to 216.83 ha in 2010. This is an indication that, the natural vegetation cover around the lake is been degraded and replaced by bare surfaces/ built up areas and farm lands. Between 1990 and 2000, Built up/Settlement Areas increased by more than 100 %, a reflection of the transition of natural vegetation (closed vegetation) to degraded vegetative cover possibly due to livelihood changes.

Though bare surface/built up settlement occupies relatively small area (4.17 %) within the watershed, its impact on the lake could be huge including increased soil erosion, surface runoff, turbidity and total suspended solids. Comparable results were obtained by Mundai and Aniya (2006) in studying land use/cover change over a 24 year period (1976-2000) in Nairobi. They observed a considerable decrease in forest cover with an increase built up/bare area and agricultural areas which they attributed to increased population and unregulated development. Itani (1998) attributed high erosion in mountainous areas to increase in bare surface areas resulting from removal of forest cover and agricultural activities.

The study revealed a significant change in land use patterns from 1990 to 2010, evident by the relatively large conversion of more woodland and forest area within the lake basin into agricultural lands and bare areas. The implication is poor lake water quality, siltation of the lake, loss of fish habitat, reduction in fish catch and loss of community livelihood (Jordan *et al.*, 1993).

5.2 WATER CHEMISTRY

5.2.1 Temperature, EC, pH and Salinity levels

5.2.1.1 Temperature

The chemical and biological activities in aquatic environment are to a greater degree affected by temperature. The permissible limit for drinking water temperature ranges between 22 - 29 ºC (WHO). However, the entire site recorded mean temperature above the permissible limit except LW0C which was within the acceptable limit. The mean water temperature recorded for this study is similar to those of Ansa-Asare and Karikari (2006), and Saidu and Musa (2012) in Ghana and Nigeria respectively. The average lake temperature for the current study was relatively above those recorded (27.8 ºC) by Adu *et al*. (2011). The lowest temperature recorded at site LW0C may be due to the forest cover around the confluence of the Abrewa River (sacred river). The temperature values above the acceptable limit may be attributed to lack of forest cover around this area as excessive farming activities (cocoa and food crop farms) are taking place, extending from the shores of the lake to the bottom of the hills. The reduced forest cover shade, excessive storm drainage and waste water (most of the hotels are located at these sites may have resulted in the increased temperature at these sites (Meyer and Paul, 2001).

A relative elevation in temperature observed in the rainy season than in the dry season could be attributed to the seasonal overturn of the lake which normally occurs in January and August as reported by Turner *et al*. (1996). Other researchers such as Otu (2010) and Ajibadi *et al.* (2008) recorded higher temperature value in the dry season than in the rainy season and attributed it to the warming effects of solar radiation contrary to this study. Similar observation was made by Koeberl *et al.* (2007) during the ICDP Bosomtwi Crater Drilling Project. They concluded that the lake has been warming over the past decades and also maintains a highly stratified water column. The relative warming of the lake has possibly resulted in the fish moving away from the near-shores to relatively deeper waters making it more difficult to catch. This could possibly contribute to the reduction in fish catch.

5.2.1.2 Electrical Conductivity

The mean electrical conductivity value (1353±27.6 µS/cm) recorded in the study was above the WHO permissible limit of 250 µS/cm. The EC values were high when compared with the EC values of other lakes in Ghana like Weija (mean 370 µS/cm by Ansa-Asare, 2005) and Volta (mean; 75 µS/cm by Karikari *et al* 2013). The high conductivity level could be linked to the high input of ions due to anthropogenic activities (use of agrochemicals in farming), built-up intensity and the geology of the area. This finding corresponds to a study by Khazheeva *et al*. (2007). Ansa Asare and Asante (2000) attributed a reduction in EC during the rainy season to increased volume of water caused by seasonal surface runoff. On the contrary, slightly higher EC values ($p > 0.05$) were recorded for Lake Bosomtwi in the rainy season than the dry season possibly; rain input into the lake during the sampling period was not enough to dilute the lake. The early rains could have also resulted in washing and erosion of residue of agrochemicals from the agriculturally dominated fields within the watershed. Similarly, Ajibade (2008) and Pucniak *et al.* (2009) recorded higher conductivity levels in the rainy season which was attributed to leaching of mineral salts and re-suspension of sediments.

5.2.1.3 pH

Aquatic species are mostly sensitive to alterations in water pH. The pH values recorded for the lake ranged from 7.6 to 9.9 pH units with an average value of 9.0±0.6 pH unit. The mean pH values recorded for the lake was above the WHO standard of 6.5-8.5 for drinking water. ANZECC (2000) attributed pH values above 8.3 to the presence of bicarbonate, carbonate and sodium in water. The pH value indicates highly alkaline lake water which is in line with other studies (Nkansah and Ephraim, 2009; Puchniak *et al.* 2009; Otu 2010). However, the average pH values recorded for this study was slightly above those recorded (8.98) by Turner *et al.* (1996). The high pH values recorded in the lake may probably be due to excessive photosynthetic activities, use of agrochemicals, and detergent for washing utensils and bathing in the lake, as suggested by Zweig *et al.* (1999). It also established the idea that, evaporation is the dominant outlet for lake water. Seasonal changes slightly affected the water pH with highest values recorded in the dry season which is a major feature of African lakes as reported by Talling (2001). A similar pH result was obtained by Araoye (2009) in Lake Asaka (Nigeria), Agbugui and Deekae (2014) in the New Calabar-Bonny River (Nigeria) and in Lake Tangayika by Langenberg (2008). This drop in pH was probably due to the stirring effect of the incoming flood from the rivers and drainage storms that enters lake. Thus, resulting in the mixing of the poorly alkaline or acidic bottom waters with alkaline surface water to reduce pH. However, Ajibade *et al.* (2008) recorded a high pH value in the rainy season (8.5) than in the dry season (7.4) in Nigeria and attributed it to the higher water volume in rainy season diluting the water. The pH values recorded is suitable for optimal growth and production for most fish, as reported by Adeyemo *et al* (2008) and Addy *et al.* (2004). As the pH value exceeds 6.5 - 8.5, it can cause stress and reduce survival rate of fish (APHA, 1998). The observed water pH levels can increase the toxicity level of ammonium in the lake which can be detrimental to fish species and other aquatic organisms, as suggested by Lentech (2013). The presence of ammonium (NH_4^+-N) at pH (OH^-) levels beyond 9 will result in the release of ammonia (NH_3) gas into the water (Osmond, 1999).

5.2.1.4 Salinity

Salinity is the concentration of all the dissolved salts in water which is mostly expressed as part per thousand (1 ppt= 1 g/kg) or as 1 ppt to 1000 mg/L in fresh water (Wetzel, 2001). The average salinity level of the Lake was 0.56±0.06 ppt. This finding compares well with that of Turner *et al*. (1996) who attributed the low salinity to recent overflow (geologic past 1500 to 3000 B.P) of dissolved solute resulting in discharge of mass of solute. Although the recorded salinity level may be ideal for aquatic organisms, it is possible the level could be high in the near future due to the commercial aquaculture taking place in the lake. This is evident by the relatively high salinity values recorded in both rainy and dry season (0.60 ppt for both seasons) at site LW0F where the aquaculture is located.

5.2.2 Turbidity, Color, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

The study found significantly higher values of Turbidity, Color, TDS, and TSS in the lake compared with the permissible levels by WHO/GSA for good drinking water quality. In most cases, slightly higher mean values were recorded during the rainy seasons than the dry season. This may be due to human activities (stone mining, increase and construction activities) within the watershed as human population increase (evident by increased in built-up/ bare surfaces) and activities (poor farming practice, aquaculture, and others) taking place around the lake. The situation does not promote the protection of fish live and the aesthetic values of the lake.

5.2.2.1 Turbidity

Turbidity values (ranged from 3 - 26 NTU) of the lake exceeded the background levels of 0-5 NTU by WRC (2003) and WHO (2004). High turbidity in most cases can be attributed to non-point source pollution mostly from agricultural lands and runoff carrying suspended particles due to high rainfall. Similar results were observed by Cotching (2006) and Wang *et al. (*1997) where water draining from agricultural land (cropped paddock) had high turbidity. Similarly, Langenberg (2008) recorded seasonal variation in turbidity in Lake Tanganyika and attributed it to nutrient enrichment during the rainy season. When suspended solid is high, turbidity and the color of water is likely to increase which may diminish migration and visibility (water becomes cloudy or opaque) of aquatic organisms (Wetzel, 2001). The maximum turbidity value recorded at site LW0F (26 NTU) could be attributed to the excessive introduction of nutrients (aquatic feed) at this site due to the presence of the aquaculture while the presence of grass cover/lawn and open vegetation (serves as natural filters) at site LW0B could be contributing to the low turbidity recorded at that site (Fig 4.1). Similar result was observed in Buttons Creek where turbidity level was reduced when the stream passed through native bush riparian area (Cotching & Sims, 2003). Schueler (1997) suggested reduction or loss of sensitive/threatened fish species when turbidity exceeds 100 NTU. The recorded turbidity of the lake could potentially be harmful to aquatic organisms. The recorded turbidity value at site LW0F could potentially be harmful also to native fish species in the lake.

5.2.2.2 Color

The recorded apparent color of the lake ranged from 36.0 Hz to 166.0 Hz at LW0G and LW0F, respectively. The recorded values far exceed the permissible limit set (15.0 Hz) by W.H.O. Similar high color value of 78.9 to 107 Hz was observed by Ansa-Asare and Karikari (2006). They attributed the high apparent color values to excessive input of organic material (refuse, dead plants and sediment) and dissolved colloidal humic material. Similarly, the high color values of lake Bosomtwi, especially at site LW0F (presence of aquaculture) can be attributed to deposition of refuse, organic feed, refuse and decay of dead plants. Elevated level of color (above 15 color unit) may reduce the aesthetic appeal of the water, making it unfit for domestic use. Increased in the lake water color could increase the risk of exposure to diseases as the water could serve as a fertile ground for disease causing organisms. Similarly, light penetration and plant productivity (photosynthesis by phytoplankton) is likely to reduce as well as recreational values and habitat quality (USEPA, 1999). Reduction in the photosynthetic activity can lead to low oxygen concentration, difficulty in respiration and high mortality rate (clogging of fish gills) of aquatic species (Cheapskate Bay Program 2012).

5.2.2.3 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) recorded ranged from 368 mg/l at site LW0E to 684 mg/l at site LW0G (Fig 4.2). The recorded TDS values fall outside the permissible limit 0-450 mg/l by WRC (2003) and WHO (250 mg/L). High TDS value recorded for Lake Bosomtwi can be attributed to settlement activities resulting in agitation and re-suspension of bottom sediments, possible discharge/leakages of septic tank from the hotels around, direct deposition of organic and inorganic waste into the lake or indirectly by rivers and surface runoff flowing from the catchment of the lake (Ebele 2002). Increased toxicity, salinity and changes in ionic composition of water have been attributed to elevated TDS by Duffy (2007).

5.2.2.4 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) varied across the sampling sites ranging from a minimum of 1.0 mg/L at LW0G to a maximum of 28.0 mg/L at LW0F. High TSS is an indication of likely erosion of soil particles into surface water due to bad farming practices and construction activities. Excessive TSS in water could increase water temperature and reduce dissolved oxygen. This could threaten the lives of aquatic species. The type and concentrations of TSS also impacts on lake turbidity and transparency.

5.2.3 Dissolved Oxygen (DO), Biochemical oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

5.2.3.1 Dissolved Oxygen (DO)

The level of dissolved oxygen is important to the survival of all aquatic species (fauna and flora). Hence, it is necessary to maintain appropriate levels in water for the protection of fish and aquatic life. The dissolved oxygen in a relatively unpolluted surface water ranges from 8-10 mg/L and levels below 5 mg/L will cause a health hazard for aquatic organisms (DFID, 1999; LDEG, 2006).

The overall concentration of DO recorded ranged from a minimum of 6.9 mg/L at site LW0F to a maximum of 8.0 mg/L at site LW0C (Fig 4.2). Earlier studies have also recorded related trends of dissolved oxygen in lakes/ fresh water bodies similar to the present study; Karikari (2013) recorded DO values ranging from 7.3 mg/l to 8.1 mg/l at Lake Volta, Ofori Danso and Ntow (2005) 5.2 mg/l to 8.1 mg/l at Yeji, and 5.2 mg/l to 9.3 mg/l by Ajibode *et al*. (2008) at Kainji Lake National Park Nigeria. Dissolved oxygen was slightly higher in the dry season than in the rainy season, contrary to values recorded in the Weija Lake by Asante *et al.* (2008). The slightly lowered DO concentration recorded during the early part of the raining season may be attributed to the excessive deposition of pollutants from surface run-off, low photosynthetic activities compared to the higher photosynthetic activities in the lake during the dry season (Water Action Volunteers, 2006). The DO concentration recorded indicates that, Lake Bosomtwi has an ideal oxygen concentration to sustain and support aquatic organisms. DO is mostly low at night and in the morning, however, the DO values were recorded in the morning were within the acceptable limit (6- 9 mg/l) for a healthy water body (WHO 2006).

5.2.3.2 Biochemical Oxygen Demand (BOD)

BOD indicates how much oxygen is been consumed by aquatic organisms. The recorded BOD concentration for Lake Bosomtwi varied from a minimum of 0.7 mg/L

at site LW0F to a maximum of 5.0 mg/l at sites LW0C and LW0D, with an average value of 3.7 mg/l. Makwe (2013), Iwara *et al.* (2012) and Amakye (2001) recorded mean BOD value of 5.1 mg/l and 1 mg/l in Nigeria and 3.9 mg/l in Lake Volta, respectively. Generally, BOD concentration of Lake Bosomtwi fell within the permissible limit of 5 mg/L by the WHO (2004). The relatively high BOD (5.0 mg/L compared to other sites) recorded at points LW0C and LW0D may be due to anthropogenic activities, high concentration of organic matter and sundry effluent transported and deposited into the lake by surface runoff and rivers that flow through nearby agricultural lands. Iwara *et al.*, (2012) attributed similar reasons to high BOD values recorded in Calabar River in Odukpani, Nigeria. Lake Bosomtwi had higher BOD concentrations in the dry season which was similar to those reported by Makwe (2013). The author attributed this seasonal variation in BOD to concentration of organic substances and possibly increased aquatic productivity in the dry season.

5.2.3.3 Chemical Oxygen Demand (COD)

The presence of organic pollutants in water is indicated by Chemical Oxygen Demand (COD). The highest COD concentration (135 mg/L) for Lake Bosomtwi was recorded at site LW0F while the least value was at site LW0G (85 mg/L), with a total average of 98.9 mg/L. The highest COD recorded at site LW0F may be due to the presence of the aquaculture at this site, resulting in the likely deposition and accumulation of fish feed. The COD value recorded for the lake was slightly higher in the dry season than in the rainy season which is consistent with similar finding by Cotman (2000). Ahipathy and Puttaiah (2006) recorded similar higher values (336 mg/l) of COD in the dry season than in the rainy season (184 mg/l) in Vrishabhavathy River and attributed it to evaporation and higher decomposition process due to high temperatures. Acheampong *et al.* (2012) attributed high COD values in selected water bodies in Accra to the presence of oxygen consuming pollutions. The increasing trend in COD values of Lake Bosomtwi, when compared with WHO permissible limit of 20 mg/l, could be attributed to high decaying process due to high temperatures, wastewater discharge from settlements around the lake particularly from hotels and the transportation and deposition of organic pollutants by surface runoff and rivers that flow through agricultural lands.

5.2.4 Nitrite, Nitrate, Phosphorus and Ammonium

In most cases non-cumulative toxins such as; nitrate, nitrite, phosphorus and ammonium (Dallas and Day 1993) are the dominant nutrients that affect aquatic habitat. This is perhaps, due to their relative abundance (natural) and its utilization (man-made).

5.2.4.1 Nitrate (NO_3)

Nitrate levels exceeding 5 mg/L in most cases are indicative of anthropogenic pollution which could be harmful to aquatic organisms and humans. Nitrate in the lake ranged from a minimum of 0.8 mg/L to 2.5 mg/L at site LW0A and LW0F, respectively (Table 4.2). The aquaculture which is located within this site could have resulted in the relative elevation in nitrate levels at this site. The level of nitrate in the lake was far below the W.H.O limit of 10 mg/L. Nitrate level recorded in the lake compares well with findings by; Ahiarakwem *et al.* (2012) in Lake Oguta (1.40 mg/l), Agwa *et al.* (2013) in Nigeria (0.10-2.60 mg/l), Karikari *et al*. (2013) in Lake Volta (0.2-1.70 mg/l). However, the average nitrate concentration observed for this study (1.3 mg/L) shows a considerable increase (about 24%) in nitrate levels compared to previous observations (0.31 mg/L) by Turner *et al.* (1996) in the same lake. The rise in nitrate levels in the lake is indicative of increased use of nitrogen fertilizer by farmers and deposition of organic waste into the lake from the watershed. Concentration of nitrate in Lake Bosomtwi varied with seasons and was generally high during the wet season. A similar seasonal variation of nitrate was also observed by other authors (Ansa-Asare and Asante 1998; Ajibadi *et al.*, 2008). However, when nitrate level in Lake Bosomtwi was compared with those in Birim River (Asante 2000) and in the Lower Volta River (Gampson *et al.*, 2013), the concentration of nitrate in Lake Bosomtwi was lower. They attributed the high nitrate levels in rainy season to increase in surface runoff, bare areas and leaching of nitrogen fertilizers from nearby farmlands. A study by Maghanga *et al.* (2012) concluded that, nitrogen fertilizer application contributed to an increase in nitrate levels in surface water through surface run-off. Since the lake basin is dominated by agriculture, nitrate concentrations can be attributed to the use of nitrogen fertilizers on farmlands. The observed nitrate concentration at site LW0F (2.5 mg/L) could be sub-lethal to native fish species and other aquatic organisms (Hecnar, 1995). The recorded nitrate level in the lake shows that the lake is slightly polluted by human activities.

5.2.4.2 Nitrite (NO_2)

Nitrite concentration varied from non-detectable levels at site LW0A to 0.08 mg/L at site LW0C, with a mean value of 0.1 mg/l (Table. 4.2). The recorded values show that, there was a gradual increase in nitrite levels from non-detectable levels (0.00 mg/L) in the dry season to 0.08 mg/ L in the raining season, though average nitrite level in the lake was lower when compared to levels in Weija lake (0.533 mg/L) with similar land use activities. However, the nitrite level in Lake Bosomtwi is comparable to levels in most tropical lakes and rivers (Ajibade *et al.,* 2008; Amakye 2001). The observed nitrite level in the lake was high in the wet season than in the dry season. This is in line with observations made by Onyango (2006) in Lake Victoria and Narayana *et al.* (2005) in Basavanahole reservoir. They attributed this variation in nitrite levels in water to deposition of residues of used agrochemicals, increased biomass burning, detergents, untreated sewages, organics and others by surface runoff, leaching and atmospheric deposition. Generally, nitrite level in the lake was within the permissible limit of 1 mg/L by W.H.O and may not pose any health risk.

5.2.4.3 Phosphate (PO_4)

The minimum phosphate level for most uncontaminated lakes ranges from 0.01-0.03 mg/l (Muller and Helsel, 1999). Mean phosphate level (0.40±0.19 mg/L) was found to be high in the dry season. This corresponds well with findings by other studies; 11-0.34 mg/L, 1.4- 11.4 mg/L, 0.059, 0.01-0.26 mg/L by Fadiran (2007), Gampson (2013), Ansa-Asare (2000) and Agwa *et al.* (2013), respectively. They attributed high phosphate levels in the dry season/summer to rapid evaporation and mineralization of decomposed material (high biological activities) in the water. The mean phosphate concentration for this study was slightly lower compared to previous observations (0.031 mg/L) by Turner *et al.*, (1993). This shows that there has been an increase in the concentration of phosphate levels in the lake in the past three decades possibly due to increase in anthropogenic activities. The lake also had higher phosphate concentrations when compared to other Lakes in Ghana such as Volta Lake (0.3 mg/L Elegbede, 2015). Phosphate concentration in water between 0.01-0.02 mg/L is attributed to water draining from intensive agricultural areas (Bobbi *et al.,* 1996). The progressive increase in phosphate level in Lake Bosomtwi can be attributed to the use of phosphate fertilizers, use of detergents in the lake and waste from domesticated animals around the lake. The mean phosphate value recorded, though not very high, is an indication of anthropogenic pollution.

5.2.4.4 Ammonium (NH_3)

The concentrations of ammonium in the lake exceeded the recommended standard for surface water 0.06 mg/L and were high in the wet season than in the dry season.

Concentration in the lake varied from non-detectable limits in the dry season to 0.100 mg/L, with an average of 0.18 mg/L in the rainy season. The observed average concentration of ammonia (0.18 mg/L) in the lake was slightly higher when compared to previous observations (0.03) made by Turner *et al.* (1996). Terrestrial activities such as sewer effluent, agriculture run-off and the use of the lake as a repository of domestic waste by the people might have contributed to the accumulation of ammonium in the lake. This corresponds well with other studies by Ansah-Asare and Asante (2000), Ajibade (2008) and Amakye (2001) in Weija Lake 0.160 mg/L, Kainji Lake 0.185 mg/L, Lake Victoria 6 mg/L and lake Volta 0.8 mg/L, respectively. The authors attributed the presence of ammonium in the water to the use of fertilizer and decomposition of organic matter. Ammonium hydroxide even in low concentrations can cause harm to fish and other forms of aquatic organisms. Concentration levels from 0.06 -0.34 mg/L is known to cause long term effects on growth of fish (Ajibadi, 2001). The recorded value of ammonium in the lake is an indication of anthropogenic pollution within the watershed.

5.3 Biological parameters

5.3.1 Total Coliform, Fecal Coliform, E.*coli*, and THB

The total coliform count of Lake Bosomtwi ranged from 230 to 1312 cfu/100 at site LW0A and LW0G, respectively, with an average of 838±311 cfu/100. Fecal coliform ranged from 11 to 86 cfu/100 (Table 4.3). The higher concentration of these coliforms in the water is an indication of serious bacterial contamination due possibly to recent fecal contamination by human and animals. The highest coliforms recorded at site

LW0G (Obo near the aquaculture) may be due to the open defecation, free movement of domestic animals and the presence of the aquaculture at this site, compared to site LW0A (Abono) which has relatively high sanitation. Site LW0G which had higher level of coliforms may be a source of microbial contamination. The concentration of coliforms in the lake was higher in the wet season than in the rainy season. The high amount of these coliforms in the wet season may be due to the fact that water availability (surface run-off) favors the movement and reproduction of the organisms. This compared favorably with the reports by other authors (Obiri-Danso *et al*., 2005, Ansah Asare 2000, Makwe 2013). They attributed increased high coliforms in the wet season to increased surface runoff that transports human and animal waste into the water. Mehaffey *et al.* (2005) attributed high fecal coliform to agricultural development and erodible materials within the watershed.

The total and fecal coliforms concentrations in the lake exceeded WHO/GSB/EPA guidelines for the protection of aquatic live, drinking and full body contact recreation (WHO, 1993). The high coliforms recorded in the rainy season is an indication that, one is more likely to be exposed to higher disease-causing bacteria when utilizing the lake water in the rainy season than in the dry season. Studies by Wade *et al.* (2003) established that, gastrointestinal illness were low in areas where *E.coli* levels in water were lower than the established limits.

The recorded *E. coli* (0-17*)* and THB levels (524-1488) for this study indicated highly polluted lake water (Table 4.2). This is could be due to human and animal contamination. The recorded *E.coli* was above WHO/GBS/EPA acceptable microbial limit (0 mL) for drinking water but was fairly good for recreational use (126/100 mL).

Elevated levels of *E. coli* in surface water will mean the presence of possible disease-causing bacteria, viruses and protozoans in the water (N.C DHHS, 2009). Higher *E.coli* in the lake was recorded in the rainy season than the dry season due possibly to deposition of organic waste (human and animal feces, untreated sewage and others from nearby settlements) by rivers and surface run-offs from the watershed into the lake. This corroborates with other findings by Asamoa-Boateng (2009) and Kwarteng (2012).

Also, Eze (2000) attributed high levels of heterotrophic bacteria to the presence of organic matter and other favorable physio-chemical conditions of the lake like temperature, oxygen, pH and nitrogen. High THB is an indicative of high rate of bacteria growth which can affect the aesthetic appeal of the lake (WHO, 2002). Though the presence of THB may not pose any health effect to the individual, it may harbor some disease-causing pathogens such as *Acinetobacter, Mycobacterium, Serratia and Pseudomonas,* and others that can cause infections (like urinary tract infections and respiratory infections) in people with weak immune system.

The poor microbial quality of the lake is due to pollution caused mostly by human activities within the watershed making the lake water unfit for most domestic activities without any prior form of treatment like boiling. The risk of contracting water related diseases (diarrhea, cholera) when using the lake especially in the rainy season is likely to be high. Similar high pollution levels have been recorded for most surface water bodies in Ghana (Ansa-Asare *et al.*, 2003).

5.4 Soil Nutrients

5.4.1 Soil phosphorus

Excessive phosphorus in the soil can be detrimental to water quality since the soil's ability to store phosphorus is limited. For this reason, slightly higher concentration of phosphorus in soil samples did not correspond to appreciable increase in phosphate levels in Lake Bosomtwi. The mean concentration of phosphorus in soil was 5.38 mg/L with a maximum value of 14.4 mg/L at site LW0B where farming activity was dense compared to the other sampling sites while average concentration of phosphate in lake water was 0.40 mg/L, with a maximum value of 1.16 mg/L at site LW0A. These suggest that, the accumulation of phosphorus in the lake may not necessarily originate from the soil but possibly from other sources like the use of phosphate detergents (washing in the lake), deposition by wind (atmospheric deposition) and the direct or indirect deposition of organic waste containing phosphorus into the lake. This corroborates well with studies by COWI (2002) who attributed phosphate concentrations in Lake Victoria to atmospheric deposition. Similar observations were made by Foy and Withers (1995) in Western England. They observed that, an increase in phosphorus concentrations in the soil (farmlands) did not lead to an appreciably greater concentration of phosphate in surface waters.

5.4.2 Soil Nitrogen

Total nitrogen observed in the soil during the study period ranged from 0.04 mg/L to 0.48 mg/L with an average concentration of 0.24±0.17 mg/L (Table 4.3). However, levels in lake ranged from a minimum of 0.8 mg/L to a maximum of 2.5 mg/L, with a mean value of 1.3 mg/L (Table 4.2). The average concentration of nitrate recorded in the lake water was about five times higher than in soil samples. Probably, nitrate pollutants in the lake is as a result of wet atmospheric deposition (evident by the increase in nitrate levels during the raining season) together with other sources like the use of detergent, bush burning, deposition and the decomposition of organic waste. This corroborates well with findings by Scheren (1995) in Lake Victoria. It could also be argued that, due to the geology of the Lake's watershed and possibly some bad farming practices employed by the rural communities; nitrogen fertilizers could be washed directly into the lake water through soil erosion, leaching and surface runoff before it could be absorbed into the soil for plants used. This agrees with report by Lamb *et al.* (2014) and Lenat *et al.*, (1994). They attributed higher nitrate concentrations in water in a watershed characterized by relatively steep slopes to the direct movement of nutrients into water.

5.4.3 Soil Potassium

The natural background levels of available potassium in soil is mostly low, about 5-10 ppm. Potassium levels in soil samples for this study were very minimal, ranging from 0.05 to 1.53 ppm, with an average of 0.39 ppm (Table 4.3). The high rainfall accompanied by high temperatures experienced at the study area might have resulted in the low levels of potassium in the soil. The potassium concentration recorded in the soil compares favorably with soils from the tropical world and other parts of the world which may have minimal effects on the quality of water in the lake (Yawson *et al.*, 2011). Most of the nutrients studied were relatively low in the soil compared to those found in the lake water.

5.4.4 Soil Pathogens

Soil samples from selected sites within the lake Bosomtwi watershed showed high levels of pathogens (*E.coli and total coliforms*) except for sites LW0D and LW0G where E.coli and total coliforms were below detectable levels. The mean value for *E. coli* and Total coliforms in the soil was very high at 2 X 10^5 colonies per 100 ml and 54 X 10^3 colonies per 100 ml, respectively (Table 4.3). Except for sites LW0D and LW0G, bacteria levels in soil samples correlated with levels in the lake water. The deviation at these sites may be due to the presence of River Abrewa (Sacred River) where people are often prevented from carrying out any inimical activity and the presence of relatively undisturbed forest at these sites. The high concentration of pathogens in the soil is a reflection of the indiscriminate defecation and deposition of waste around the shores of the lake. Arguably, the soil could serve as a form of pathogen reservoir to contaminate the lake water since bacteria like *E.coli* are known to survive in soil for several weeks. The high concentration of the studied bacteria in the lake (indicating recent fecal contamination of the lake) could have been transported from the watershed (soil) through surface run-off as reflected by the increase in bacteria in lake water during the rainy season.

5.4.5 Soil pH and Electrical Conductivity (EC) of Soil

5.4.5.1 Soil pH

As observed by Allard (2010), soil acidity in the Amazon lowered the pH levels of most lakes and rivers. The recorded pH levels of soil ranged from 6.7 to 8.6, with a mean value of 7.5 (Table 4.3), which is ideal for maximum nutrients availability to plants and also soluble enough to leach or washed into ground water system and the lake (Owusu, 1998). Possibly, this could be the reason for the relatively low levels of soil nutrients in the soil than the observed nutrients in the lake water.

5.4.5.2 Soil electrical conductivity (EC)

Soil conductivity measures the amount of salt in the soil. Soil conductivity level recorded ranged from a minimum of 176 µS/cm at site LW0D to a maximum of 454 µS/cm at site LW0B, with an average of 254 ±98 µS/cm (Table 4.3). Adviento-Borbe *et al*. (2006) indicated that, high soil conductivity values recorded during the study period could be attributed to use of agrochemicals, high decomposition of organic waste, continuous cropping and poor land management since continuous cropping can increase salt content in soil.

5.5 Social Survey

The surveys revealed that majority of the respondents were engaged in fishing and farming (more than 80 %). This shows that, the rural economy within the basin is supported by the lake (fishing) and its surrounding lands (agriculture). The large number of residents who are engaged in farming could also be an indicator of the shift in the rural economy (from fishing to agriculture). It also became evident that literacy rates within the basin is low, majority of the respondents had basic education (49 %) while 21 % had no form of formal education**.**

The low level of education could also be an indicator of poor or misapplication of agrochemicals on farms while the "slash and burn method" method of farming employed by the farmers could contribute to destruction of forest around the lake (Appendix D). This subsequently could lead to accelerated erosion and nutrient enrichment. Similar observations were made in Lake Victoria by Hecky *et al.,* (2000) who attributed pollution of Lake Victoria to poor farming practices by the rural folks. The survey further indicated that the settlements around the lake were highly aware of the changes in the land cover as well as the deteriorating water quality (Table 4.8). Averagely, each of the respondents had stayed in the study area for more than 20 years as a result they could give or make a fair judgement of the land use change.

5.5.1 Perceived Changes in Lake Water Resources and Land Cover

The survey indicates that the respondents were highly aware of the changes in the lake and the land cover. A greater number of respondents attributed the changing land cover to increased farming (24 %), settlement (23 %) and deforestation (22 %). A high proportion of the respondents perceived negative changes like reduced lake size, reduction in fish catch or stock and the growth of worms in the lake which could be a sign of deterioration of the water. However, only 17.5 % of the respondents were able to link the observed changes in the lake to negative human activities while majority attributed it to non-observance of tradition (39 %) and the conduct of a scientific (21

%) research in the lake (Table 4.11). Thus, majority of the residents were ignorant of the impacts of some of their activities on the lake, especially with the use of agrochemicals and washing / bathing in the lake.

5.5.2 Other Human Activities Affecting the Lake

One noticeable observation that could possibly have negative impact on the lake is the stone mining activities going on around the lake. Removal of stones from the shores of the lake on a commercial scale is a new industry gradually gaining grounds around the lake. The stones naturally play a role in filtration mechanism. That is, traps sediment been transported by surface run-off before it enters the lake. Harvesting these stones could result in the direct deposition of sediment into the lake, which gradually will lead to lake sedimentation and increased total solids. Those engaged in this form of activity are possibly those who have been pushed out of the fishing industry.

The rearing of livestock to sell or as a form of security is common in most households as a livelihood diversification strategy. In most situations, livestock cages especially piggeries were sited very close to the lake (Plate 2 a). The waste (mostly from feed and the droppings) is discharged near the lake or directly into the lake. The animals, in most cases were free to graze around the lake and this could contaminate the lake.

Also, the washing of cooking utensils and clothes in the lake is adversely affecting the Lake's water quality. The use of detergents and soap is a contributing factor to the nutrient built up like nitrate in the lake which can result in eutrophication.

5.5.3 Socio-Economic Effects of Poor Water Quality on Livelihood.

The field data gathered during the study period established that fishing and its related activities provide the major source of livelihood to majority of people around Lake Bosomtwi. The poor water quality in the lake and subsequent reduction in fish catch have affected the rural economy including increased unemployment, low income/poverty, reduction in fish food and out-migration. The reductions in fish catch over the past decades has forced majority of people especially the youth out of the fishing business. This has increased the unemployment rate within the lake's basin. As a result, most of the people have diversified into farming which is not as profitable as fishing in the lake. Fishing in the lake is now carried out on a weekly or monthly basis, rendering most people redundant or unemployed. Most of the women (fishmongers) now rely on the aquaculture in the lake by a private investor for their livelihood. This is not as profitable as the fish caught from the lake which is a common good.

With their basic livelihood support disappearing, poverty is on the rise making life in the Lake Bosomtwi basin very unbearable. Fishing in the Lake used to provide the rural communities with regular and sustained level of income but reduction in fish catch over the years has affected the income levels of the fisher folks. Farming, which is the alternate livelihood support base of the people, is not as lucrative as the fishing due to; poor soils, small farm holdings (subsistence in nature) and inadequate capital to practice intensive agriculture. Thus, the reduction in fish from the lake over the years due to poor water quality, climate change and other anthropogenic activities has resulted in poverty and hardship among the communities around the lake.

With the dwindling fish catch from the lake coupled with unemployment, most of the youth have migrated to the nearby municipalities and metropolis to seek for greener pastures leaving the weak and the aged in most of the communities. As Prakash *et al*, (2005) reported, with time most of the people are expected to migrate from the lake's basin as the lake water quality continuous to deteriorate.

5.5.4 Other Socio-Economic Effects of Poor Water Quality

Poor lake water quality has also resulted in water stress in the communities around the Lake. The lake water previously was used for a number of domestic activities such as drinking, cooking, bathing and washing. However, because the quality of water has been compromised, the domestic use of the lake water has been restricted basically to washing and cooking. Most people now avoid using the water for bathing unless boiled because of negative health effects (such as body itching, skin rashes and others) experienced after using the lake water for bathing or swimming in the lake.

Fish from the Lake also served as the dominant fish protein for the people around the lake. The reduction in fish catch both in size and in quantity is likely to affect their nutritional status since they now have to resort to other forms of animal protein which may not be readily available and affordable to the rural communities.

Generally, the changing land cover/ land use and its possible impacts on fish stock and water quality has affected the communities within the lake Bosomtwi basin. The impact includes high unemployment, reduced fish food, poverty and out-migration. The study has also revealed that, apart from the Water Resources Commission (WRC), there is no other recognizable body tasked with the sustainable management of the lake. This has contributed to the unregulated development and consequently poor water quality.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Lake Bosomtwi is a vital resource to the communities around the lake and Ghana as a whole. The lake provides a source of employment, protein (fish), water for farming (especially vegetable farming) and recreation. Satellite images for the period 1990, 200 and 2010 were acquired and used to analyze the changing land use/cover pattern within the lake Bosomtwi watershed. The results revealed that closed forest cover and the lake water reduced by 11 % and 6 %, respectively. However, open forest, agricultural/cultivated lands and bare surface/ built up areas experienced dramatic increase in coverage. The general trend observed was that, as the lake and closed forest vegetation cover decreased in size, bare surface/built-up areas, agriculture and open forest increased over the years. This indicates that the land cover within the lake Bosomtwi basin is undergoing tremendous changes.

It became apparent that past and current land use activities (agriculture, settlement and recreation) around the lake Bosomtwi watershed has resulted in the removal of vegetation cover that used to protect the lake. The depletion of the natural vegetation cover may continue due to increase in agricultural activities along the steep terraces (http://ucaes.edu.gh/lake-bosumtwi/.accessed; 7.20.2015) to feed the ever increasing population.

The study revealed that the physico-chemical parameters of water in the study area especially in areas which were predominantly dominated by agricultural activities had significantly higher turbidity, TSS, TDS and high bacterial levels which could be attributed to erosion of soil, fertilizer and chemical residues, keeping of livestock, stone mining and construction activities round the lake. High turbidity means high suspended and dissolved materials, a favorable condition that facilitates the growth of micro-organisms, reduced light intensity, clogging of fish gills and possibly death of aquatic organisms. The pH recorded during the study period exceeded the WHO permissible limit for drinking water. The observed DO and BOD were all within WHO guidelines levels of 6.9- 8.0 mg/L and 0.7- 5.0 mg/L respectively, for drinking water.

The concentration of nitrate, ammonium, potassium and phosphate in the lake was in most cases high in the wet season probably due to discharge and transportation from agricultural fields, domestic effluents and the hospitality industry compared to the dry season. The observed microbe levels during the study indicated that the lake water was polluted. Hence, the lake water may be unsuitable for either drinking or for direct body contact recreation such as swimming and wading. In almost all the studied parameters, site LW0F (where the aquaculture was located) and the sites at the confluence of rivers recorded higher values. The high values recorded at site LW0F indicate that the aquaculture activities are the major source of pollution of the lake.

It has been established that human (land cover change) and natural factors such as climatic variations (seasonal alterations) can significantly compromise the quality of water. Wetter or drier periods can significantly influence the concentration of studied parameters in the lake. In most cases, increase in nutrients and bacterial concentrations were observed during the rainy season than the dry season.

Analysis of the social survey demonstrated that poor lake water quality with its attendant low fish catch and loss of livelihood support has resulted in increased poverty an d unemployment of the people around the lake. Also, certain human activities like stone mining, farming, keeping of livestock and construction of tourism facilities are mostly done in closed proximity to the lake which is contributing to lake water deterioration.

It can be concluded that land use/cover within the lake Bosomtwi Basin has changed tremendously over the past decade. Water quality analysis established that, there is a correlation between land use/ cover change and water quality.

6.2 RECOMMENDATIONS

Land use and land cover change within the watershed have noticeable impacts on the water quality of Lake Bosomtwi. It is recommended that;

i. NGO's, traditional rulers, the Bosomtwi District Assembly and other stakeholders should educate the people on the benefits of riparian management and soil conservation to protect the lake and its watershed to reduce.

ii. There should be constant study and monitoring of the quality of water by an appropriate scientific agency to protect and sustain the health of the lake water and its resources.

iii. Immediate steps should be taken to halt the aquaculture activity going on in the lake. The enclosed nature of the lake does not favor aquaculture as this could lead to rapid nutrient build up and pollution in the lake

iv. The over reliance on farming and the use of destructive methods of farming are the result of lack of alternative sources of livelihood. Government, NGO's and other private sector organizations should create alternative economic opportunities in the communities around the lake to reduce the reliance and pressure on the lands around the lake.

v. Scenarios for future land use change and its impacts on the lake were not included in the present study. It is imperative that future studies predict the possible future scenario for the changing land use/ cover within the Lake Bosomtwi watershed and its impact on the health of the lake.

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APPENDICES

APPENDIX A: QUESTIONNAIRE FOR SOCIAL DATA

Section A: Demographic information

1. Gender. a) Male b) Female
2. Age group. a) 20 b) 21-40 c) 41-60 d) above 60
3. Marital Status…………………………………………
4. Level of education?
   a) Primary b) MSLC/JHS b) SHS/ A &O Level c) Tertiary d) None
5. What do you do for a living?
   a) Fishing and farming b) farming c) fish mongering and farming d) in the tourism industry (e) other (specify)……...
6. Are you a native of this town? a) Yes b) No
7. How long have you been living in this town?
   a) Less than 10 years b) 20 years c) 30 years d) more than 30 years

Section B: Land use Changes

1. In your view, the general state of natural land cover around the lake shows that it is…….(*mark the appropriate box*)

State of land cover	Agree	Strongly agree	Disagree	Strongly disagree	Not sure
Stable					
Decreasing					
Increasing					

2. What are/is the drivers or causes of the change in land use/ cover over the past 30 years?

Causes	**Agree**	**Strongly agree**	**Disagree**	**Strongly disagree**	**Not sure**
Increase in farming					
Settlement expansion					
Livelihood change					
Timber extractions					
Over grazing					

3. What are the major factors that affect your decision related to land use or management in order of importance?..

4. In your view, if you think the land cover is changing what should be done to avert the situation?...

   Do you practice slash and burn agriculture? a) Yes b) No

5. If yes, how often? a) Regularly b) Occasionally c) Once in a while

6. Which time of the year do you prepare your lands for farming? ....

7. What is the size of your farm? a)1 acre b) 2 acres c) 3 acres d) 4 acres e) less than an acre

8. Which of the following crops do you cultivate/grow?

<u>Crops</u>	**Yes**	**No**
Cash Crops (cocoa/oil palm)		
Food Crops(cassava, maize)		
Vegetables (onions, cabbage)		

9. Is there any tourism facility in your community? a) Yes b) No

If yes, what is the distance of the facility from the shores of the lake?

a) 20 m b) 50 m c) 100 d) 400 m e) 500 m

10. Do you use any of the following agrochemicals in your farming activities?

Inputs	**Yes**	**No**	**Frequency**
Fertilizers			
Weedicides			
Pesticides			
Animal dropping			

11. Do you know any possible effects of the use of these farm inputs on the lake?

a) Yes b) No If Yes, how?..................................

12. Are you engaged in any livestock rearing? a) Yes b) No

If yes what animal………… What is the total number?.................

Are the animals caged or on free range?......................

13. What other human activities do you observe around the lake?..............

14. What would you say is the dominant land use activity within your community?

15. Are you aware of the buffer zone created around the Lake? a)Yes b) No

SECTION C: IMPACT OF LAND USE ON WATER

1. What is the distance of your farm from the lake?

   a) 100 m b) 200 m c) 400 m d) 500 m e) other…..

2. Have you bathed/ washed in the lake before?a)Yes b) No

3. Do you think our activities can affect the quality of water in the lake?

   a) Yes b) No

4. Do you have toilet facility in your house?

   a) Yes b) No If No, where do you go to toilet?.................

5. What is the distance of your toilet facility from the lake?

6. The trend in size and fish catch shows that, fish stock is……………

Trend	Yes	No	Not Sure
Stable			
Declining			
Increasing			

7. In your own view what do you think is the cause of the reduction or otherwise of the fish stock in the lake?..

8. Have you observed any changes in the Lake in recent years?

   a) Yes b) No Give reasons for your answer………

Section D: Socio- economic effects of change in the quality of water in Lake Bosomtwe

1. What is the main source of drinking water for your household?

    a) Lake water b) Borehole water c) Pipe borne water

    If from the lake, do you treat it before drinking? a) Yes b) No

2. Do you use water from the lake for any domestic activity other than drinking?

    a) Yes b) No

3. Do you anticipate any negative health effect from using water from the lake in the long term? a)Yes b) No If yes, what are some of them?....

4. What do you think are some of the socio-economic effects of poor water quality in the lake?...

5. Can the land use activities within the watershed affect the sustenance of the lake in the long term? a) Yes b) No

6. Are you engaged in any fishing activity? a) Yes b) No

    If yes: i. How often do you go fishing/fish mongering?........................

    i. How long have you been engaging in the activity?................

7. How much do you make in a day if you are engaged in fishing activities?

8. How many occupants of your house are engaged in fishing activities?.............

9. Has the fish stock in the lake over the years changed? a) Yes b) No

    If yes, what is the change? a) Increasing b) Decreasing

10. Has the change in fish catch from the lake affected your income? a) Yes b) No

    If yes, how?...

11. Is there any alternative source of livelihood program in your community?

    a) Yes b) No

12. Have you benefitted directly from the tourism activities around the lake?

    a) Yes b) No

13. If you are engaged in any activity apart from fishing, would you say is more profitable compared to the fishing? a) Yes b) No
14. Has the tourism activities around the lake brought any observable physical development in your community? a) Yes b) No

Section E: Management of lake and land use activities

1. Are there any rules and regulations in your community to ensure maintenance of the lake? a) Yes b) No

   If yes, what are some of these regulations?...
2. Who ensures that the rules are obeyed in the community?.......................
3. Which organizations are working towards management of the lake resources in your locality?**...**
4. How do you evaluate the efforts made?
5. What's not achieved so far and what could have been done differently?...........
6. What are the most priority issues in your locality that needs intervention? ….
7. Are you aware of the activities of the Friends of Rivers and Water bodies?

   a) Yes b) No

   If yes, are you in support of their activities? a) Yes b) No
8. In your view, what should be done to regulate human and land use activities around the lake?...
9. What do you think should be done as a community to ensure that the buffer zone is maintained?...
10. Do you have anything to say about the activities that are carried out around the lake?..

APPENDIX B: MULTIPLE COMPARISONS FOR PARAMETERS WITH UNEQUAL AVERAGES ACROSS SITES

Table 1B: Multiple Comparisons for BO

		Mean Difference	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
LWA	LWB	.9333	.5208	.082	-.124	1.991
	LWC	-.0833	.5208	.874	-1.141	.974
	LWD	-.1833	.5208	.727	-1.241	.874
	LWE	0.0000	.5208	1.000	-1.057	1.057
	LWF	1.5167*	.5208	.006	.459	2.574
	LWG	.9833	.5208	.067	-.074	2.041
LWB	LWC	-1.0167	.5208	.059	-2.074	.041
	LWD	-1.1167*	.5208	.039	-2.174	-.059
	LWE	-.9333	.5208	.082	-1.991	.124
	LWF	.5833	.5208	.270	-.474	1.641
	LWG	.0500	.5208	.924	-1.007	1.107
LWC	LWD	-.1000	.5208	.849	-1.157	.957
	LWE	.0833	.5208	.874	-.974	1.141
	LWF	1.6000*	.5208	.004	.543	2.657
	LWG	1.0667*	.5208	.048	.009	2.124
LWD	LWE	.1833	.5208	.727	-.874	1.241
	LWF	1.7000*	.5208	.002	.643	2.757
	LWG	1.1667*	.5208	.032	.109	2.224
LWE	LWF	1.5167*	.5208	.006	.459	2.574
	LWG	.9833	.5208	.067	-.074	2.041
LWF	LWG	-.5333	.5208	.313	-1.591	.524

Table 2B: Multiple Comparisons for Nitrate

		Mean Difference	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
LWA	LWB	-.2167	.1543	.169	-.530	.097
	LWC	-.1167	.1543	.455	-.430	.197
	LWD	-.1333	.1543	.393	-.447	.180
	LWE	-.1667	.1543	.287	-.480	.147
	LWF	-.5500*	.1543	.001	-.863	-.237
	LWG	-.1167	.1543	.455	-.430	.197
LWB	LWC	.1000	.1543	.521	-.213	.413
	LWD	.0833	.1543	.593	-.230	.397
	LWE	.0500	.1543	.748	-.263	.363
	LWF	-.3333*	.1543	.038	-.647	-.020
	LWG	.1000	.1543	.521	-.213	.413
LWC	LWD	-.0167	.1543	.915	-.330	.297
	LWE	-.0500	.1543	.748	-.363	.263
	LWF	-.4333*	.1543	.008	-.747	-.120
	LWG	0.0000	.1543	1.000	-.313	.313
LWD	LWE	-.0333	.1543	.830	-.347	.280
	LWF	-.4167*	.1543	.011	-.730	-.103
	LWG	.0167	.1543	.915	-.297	.330
LWE	LWF	-.3833*	.1543	.018	-.697	-.070
	LWG	.0500	.1543	.748	-.263	.363
LWF	LWG	.4333*	.1543	.008	.120	.747

Table 3B: Multiple Comparisons for Total Coliform

		Mean Difference	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
LWA	LWB	-296.500*	61.880	.000	-422.12	-170.88
	LWC	-485.333*	61.880	.000	-610.96	-359.71
	LWD	-365.667*	61.880	.000	-491.29	-240.04
	LWE	-730.500*	61.880	.000	-856.12	-604.88
	LWF	-844.000*	61.880	.000	-969.62	-718.38
	LWG	-836.500*	61.880	.000	-962.12	-710.88
LWB	LWC	-188.833*	61.880	.004	-314.46	-63.21
	LWD	-69.167	61.880	.271	-194.79	56.46
	LWE	-434.000*	61.880	.000	-559.62	-308.38
	LWF	-547.500*	61.880	.000	-673.12	-421.88
	LWG	-540.000*	61.880	.000	-665.62	-414.38
LWC	LWD	119.667	61.880	.061	-5.96	245.29
	LWE	-245.167*	61.880	.000	-370.79	-119.54
	LWF	-358.667*	61.880	.000	-484.29	-233.04
	LWG	-351.167*	61.880	.000	-476.79	-225.54
LWD	LWE	-364.833*	61.880	.000	-490.46	-239.21
	LWF	-478.333*	61.880	.000	-603.96	-352.71
	LWG	-470.833*	61.880	.000	-596.46	-345.21
LWE	LWF	-113.500	61.880	.075	-239.12	12.12
	LWG	-106.000	61.880	.096	-231.62	19.62
LWF	LWG	7.500	61.880	.904	-118.12	133.12

Table 4B: Multiple Comparisons for Fecal Coliform

		Mean Difference	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
LWA	LWB	-.167	4.066	.968	-8.42	8.09
	LWC	-10.667*	4.066	.013	-18.92	-2.41
	LWD	2.500	4.066	.543	-5.75	10.75
	LWE	-46.333*	4.066	.000	-54.59	-38.08
	LWF	-52.833*	4.066	.000	-61.09	-44.58
	LWG	-52.667*	4.066	.000	-60.92	-44.41
LWB	LWC	-10.500*	4.066	.014	-18.75	-2.25
	LWD	2.667	4.066	.516	-5.59	10.92
	LWE	-46.167*	4.066	.000	-54.42	-37.91
	LWF	-52.667*	4.066	.000	-60.92	-44.41
	LWG	-52.500*	4.066	.000	-60.75	-44.25
LWC	LWD	13.167*	4.066	.003	4.91	21.42
	LWE	-35.667*	4.066	.000	-43.92	-27.41
	LWF	-42.167*	4.066	.000	-50.42	-33.91
	LWG	-42.000*	4.066	.000	-50.25	-33.75
LWD	LWE	-48.833*	4.066	.000	-57.09	-40.58
	LWF	-55.333*	4.066	.000	-63.59	-47.08
	LWG	-55.167*	4.066	.000	-63.42	-46.91
LWE	LWF	-6.500	4.066	.119	-14.75	1.75
	LWG	-6.333	4.066	.128	-14.59	1.92
LWF	LWG	.167	4.066	.968	-8.09	8.42

Table 5B: Multiple Comparisons for E Coli

		Mean Difference	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
LWA	LWB	.333	2.287	.885	-4.31	4.98
	LWC	-3.333	2.287	.154	-7.98	1.31
	LWD	-2.667	2.287	.251	-7.31	1.98
	LWE	-5.000*	2.287	.036	-9.64	-.36
	LWF	-8.667*	2.287	.001	-13.31	-4.02
	LWG	-6.167*	2.287	.011	-10.81	-1.52
LWB	LWC	-3.667	2.287	.118	-8.31	.98
	LWD	-3.000	2.287	.198	-7.64	1.64
	LWE	-5.333*	2.287	.026	-9.98	-.69
	LWF	-9.000*	2.287	.000	-13.64	-4.36
	LWG	-6.500*	2.287	.007	-11.14	-1.86
LWC	LWD	.667	2.287	.772	-3.98	5.31
	LWE	-1.667	2.287	.471	-6.31	2.98
	LWF	-5.333*	2.287	.026	-9.98	-.69
	LWG	-2.833	2.287	.224	-7.48	1.81
LWD	LWE	-2.333	2.287	.315	-6.98	2.31
	LWF	-6.000*	2.287	.013	-10.64	-1.36
	LWG	-3.500	2.287	.135	-8.14	1.14
LWE	LWF	-3.667	2.287	.118	-8.31	.98
	LWG	-1.167	2.287	.613	-5.81	3.48
LWF	LWG	2.500	2.287	.282	-2.14	7.14

Table 6B: Multiple Comparisons for THB

		Mean Difference	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
LWA	LWB	-178.333	96.971	.074	-375.19	18.53
	LWC	-497.833*	96.971	.000	-694.69	-300.97
	LWD	184.000	96.971	.066	-12.86	380.86
	LWE	-80.000	96.971	.415	-276.86	116.86
	LWF	-358.500*	96.971	.001	-555.36	-161.64
	LWG	-260.667*	96.971	.011	-457.53	-63.81
LWB	LWC	-319.500*	96.971	.002	-516.36	-122.64
	LWD	362.333*	96.971	.001	165.47	559.19
	LWE	98.333	96.971	.318	-98.53	295.19
	LWF	-180.167	96.971	.072	-377.03	16.69
	LWG	-82.333	96.971	.402	-279.19	114.53
LWC	LWD	681.833*	96.971	.000	484.97	878.69
	LWE	417.833*	96.971	.000	220.97	614.69
	LWF	139.333	96.971	.160	-57.53	336.19
	LWG	237.167*	96.971	.020	40.31	434.03
LWD	LWE	-264.000*	96.971	.010	-460.86	-67.14
	LWF	-542.500*	96.971	.000	-739.36	-345.64
	LWG	-444.667*	96.971	.000	-641.53	-247.81
LWE	LWF	-278.500*	96.971	.007	-475.36	-81.64
	LWG	-180.667	96.971	.071	-377.53	16.19
LWF	LWG	97.833	96.971	.320	-99.03	294.69

Table 7B: Multiple Comparisons for Seasonal Variation of Water Parameters

	DRY Mean	RAINY Mean	t	df	p-value
Temperature	30.2	30.6	-.857	40	.397
pH	9.0	9.0	.294	40	.770
EC	1351	1354	-.416	40	.680
TDS	651	640	.783	40	.438
TSS	9	4	3.379	40	**.002**
Turbidity	7.1	5.0	1.470	40	.149
Salinity	.6	.6	-1.061	40	.295
Colour	80	56	4.035	40	**.000**
DO	7.6	7.5	.433	40	.667
BOD	3.9	3.4	1.543	40	.131
COD	104	94	3.024	40	**.004**
Nitrate	1.1	1.4	-3.545	40	**.001**
Nitirite	.010	.016	-1.291	40	.204
Phosphate	.436	.357	1.324	40	.193
Ammonia	.019	.017	.357	40	.723
TC	853	823	.310	40	.758
Feacal Coliform	40	44	-.557	40	.581
E Coli	4	9	-3.056	40	**.004**
THB	1029	978	.616	40	.541

APPENDIX C: Current Lake Management and Appropriate Suggestions

	Frequency	Percent
RULES AND REGULATIONS		
Availability		
Yes	172	86.0
No	28	14.0
Example of Rules		
Prohibition of Indiscriminate Defecation	36	18.0
Washing disallowed	160	80.0
Forbid visit of women in menses	113	56.5
Law Enforcer		
Chief and Unit Committee	172	86.0
Other Management Organizations		
Friends of Earth	92	46.0
Friends of Water and River Bodies	120	60.0
Forest Commission	6	3.0
RECOMMENDATIONS		
Afforestation	197	98.5
Education	121	60.5
Law Enforcement	198	99.0
Change in attitudes	55	27.5
Employment Creation	142	71.0

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a.*washing of cooking utensiles in/near the lake* b.*connected drain into the lake (abono)*

c.crop farm near the lake

Plate 1a: Some negative human activities around the lake

a) Satellite image showing bare surfaces (patches of brown color) around the lake

b) Satellite image showing the aqua-culture (rectangular shape) in the lake

Plate 1b: Satellite images showing some negative human activities around the lake