Kwame Nkrumah University of Science and Technology
Faculty of Renewable Natural Resources
Department of Fisheries and Watershed Management
Kumasi, Ghana

Assessment of Environmental Impacts of Cage Aquaculture on Lake Volta of Ghana

A thesis submitted to the Department of Fisheries and Watershed Management in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy (Ph.D) in Aquaculture and Environment

BY Anthony Yaw Karikari

June, 2016

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Acknowledgements

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Dedication

Dedicated

To

My wife, Francisca Nyamekye Karikari

and

my daughter, Ruth Maame Dufie Karikari

Abstract

In recent years, tilapia cage farming has become important aspect of commercial fish production in Lake Volta and the number of the cage culture establishments (now 467) continues to expand in the multipurpose lake. Cage farms release nutrients that can cause pollution to water and sediment quality. However, there is paucity of information on the impact of cage culture on the lake's environment. Consequently, a study was conducted from August 2013 to April 2015 at two fish farms in the Lake Volta to assess the potential impact of cage culture on the environment of the lake.

The study utilized four methods. The first was through structured questionnaire to gather information on the cage farms. The second method used physico-chemical analyses of water and sediment following standard procedures. The third method considered mass balance model to estimate the amount of nutrients discharged from the cage farms into the environment. The fourth method used Dillon Rigler phosphorus mass balance model for the prediction of ecological carrying capacities of two selected farm areas in the lake.

The results from the questionnaire survey on the cage farms revealed that only large scale farmers have adequate environmental awareness and therefore monitor the water and sediment quality in their farm areas. The study on the nutrient waste emission from the cages indicated that 64.8–68.1 % of C, 72.0–75.8 % of N, and 81.0–84.7 % of P of the total feed input were released into the lake's environment for each tonne of fish produced, and only 31.9–35.0 % of C, 24.2–28.3 % of N and 15.3–19.2 % of P were harvested as fish biomass. Despite the large discharges of particulate and dissolved nutrients estimated by the mass balance models, physico-chemical water quality parameters including dissolved inorganic nutrients (NO_3-N, NO_2-N, NH_4-N and PO_4-P), chlorophyll-a varied temporally and showed no significant differences between the fish farm sites and the reference sites (ANOVA, $p > 0.05$). The low impact of the cage aquaculture could be attributed to the nutrient losses through the outflow at the dam which was 43.56 km^3 per annum (i.e about one-third of the lake's volume); dispersion of the wastes by water currents, consumption of waste by schools of wild fish species found around the fish cages and also by dilution.

Sediment analysis revealed the sediment texture of all monitoring sites to be sandy clay loam with moderate impact on sediment quality with respect to organic matter. The total organic carbon (TOC), total organic matter (TOM), and total nitrogen (TN) content in the sediment under the cages were significantly lower than those of the reference sites (ANOVA, $p<0.05$). The results showed that concentrations of heavy metals in the water column and sediments were low and within the range of tolerable levels for the lake ecosystem. The estimated ecological capacities were from 3,697 to 4,621 ty^{-1} for Farm A and from 28,322 to 33,042 ty^{-1} for Farm B zones. The estimated ranges of values are higher than the present production in the zones. This suggests that more cage culture of tilapia could be established in the lake without compromising the water quality and the ecosystem. However, water quality monitoring should be undertaken periodically to accurately determine the current state of the lake in order to both confirm and refine predictions, and ensure sustainable cage culture development in Lake Volta. Overall, the water quality indices (CCME-QI and GWQI) carried out indicted that the lake water is good and suitable for tilapia production and other ecosystem uses such as irrigation, recreation and water supply.

Declaration

I hereby declare that this work, submitted to the Department of Fisheries and Watershed Management of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, for the award of Doctor of Philosophy (Ph.D) is the result of original work carried out by myself under the guidance of Prof. Steve Amisah Prof. Lindsay G. Ross, Prof. Trevor C. Telfer, Dr. Ruby AsmahandDr. Nelson W. Agbo. Any technical and analytical assistance during the experimental period and citations of other work have been duly acknowledged. I further declare that the results of this work have not been submitted for the award of any other degree in the above-mentioned University or any other university elsewhere or for fellowship considerations.

Kumasi, Ghana, June, 2016 Anthony Yaw Karikari

Certified by…………………………… ……………………………….
Prof. Steve Amisah Date
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(Head of Department) Date

List of Abbreviations

AAS: Atomic absorption Spectrophotometer

ANOVA: Analysis of Variance

ARDEC: Agriculture Research and Development Centre

CCME WQI: Canadian Council of Ministers of the Environment Water Quality Index

COD: Chemical Oxygen Demand

CSIR: Council for Scientific and Industrial Research

DO: Dissolved Oxygen

DoF: Directorate of Fisheries

EAA: Ecosystem Approach to Aquaculture

EIA: Environmental Impact Assessment

FAO: Food and Agriculture Organisation of the United Nations

FCR: Feed Conversion Ratio

FFAs: Fish Farm Associations

GDP: Gross Domestic Product

GEPA: Ghana Environmental Protection Agency

GNAP: Ghana National Agriculture Development Plan

GOG: Government of Ghana

GPS: Geographic Positioning System

GWQI: Ghana Water Quality Index

LDCs: Least Developed Countries

LIFDCs: Low Income Food Deficit Countries

MoFA: Ministry of Food and Agriculture

MoFAD: Ministry of Food and Agriculture Development

NCR: National Research Council

NGO: Non Governmental Organisation

NH_4-N: Ammonia-Nitrogen

NO_2-N:	Nitrite-Nitrogen
NO_3-N:	Nitrate- Nitrogen
OECD:	Organisation of Economic Corporation for Development
PO_4-P:	Phosphate-Phosphorus
POC:	Particulate Organic Carbon
PON:	Particulate Organic Nitrogen
POP:	Particulate Organic Phosphorus
PVC:	Poly-Vinyl Chloride
SHS:	Senior High School
SPSS:	Statistical Software Package for Social Sciences
TC:	Total Carbon
TN:	Total Nitrogen
TP:	Total Phosphorus
VRA:	Volta River Authority
WRC:	Water Resources Commission

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
GENERAL INTRODUCTION

1.1 Background of Study

Aquaculture is playing a major role in fish production worldwide; increasing from 25.7 % in 2000 to 42.2 % in 2012, recording annual mean growth rate of 6.2%, reaching over 90 million tonnes (FAO 2014). The growth performance has been attributed to the rising need for fish in the face of declining catches, increasing populations and the possible socio-economic benefits. In Ghana, tilapia cage farming continues to expand in the Lake Volta, providing fish, employment,income, revenue, labour and livelihood to the public, government and the surrounding communities(FAO 2005). Major sources of aquaculture production in Ghana are from cages, ponds, tanks, dugouts and small reservoirs (Rurangwa *et al.,* 2015). Currently, aquaculture production keeps increasing annually. The total production increased from 10,200 tonnes in 2010 to a production of 38,547 tonnes in 2014 (MoFAD 2015). Of the total aquaculture production, cage production alone constituted 7,581 tonnes in 2010, representing 74 % of total aquaculture production. In 2014, cage aquaculture production was 33,500 tonnes thus, contributing about 87 % of total aquaculture production, indicating the important role of cage aquaculture in fish production in Ghana (MoFAD, 2015; Rurangwa *et al.,* 2015). Ghana's demand for fish in 2014 was 1,088,749 tonnes per annum and the total production was 413,077.23 tonnes, giving an annual deficit of 675,671.77 tonnes
(MoFAD, 2015). In view of the yearly deficit, the government of Ghana launched the Ghana National Aquaculture Development Plan (GNADP) 2012-2016 (MoFAD, 2012).

The plan aims at increasing aquaculture production from the 10,200 tonnes in 2010 to 100,000 tonnes by the end of 2016.To achieve the objective of the government; there is the need to intensify aquaculture production and cage farming on the Lake Volta.

Cage cultured fish rely on artificial feed (Phuong, 1998), and the waste (uneaten feed and faeces) produced is released directly to the lake. This contributes nitrogen, phosphorus, suspended solids and organic matter that cause water quality problems and pollution tobiota (Pillay, 1992). The particulate and the dissolved feed wastes which are rich in nutrients can either sink to the sediment or affect the water column causing eutrophication and pollution to benthic organisms.

Lake Volta which contributes about 88 % of the nation's aquaculture production is a multipurpose water body. The lake supports a range of uses including cage aquaculture operations, wild capture fisheries, agriculture, transportation, tourism, water supply for domestic use, industrial uses such as hydropower and textile production. Such a diverse range of uses calls for a critical and proper management of the water body to sustainably perform all these functions to improve the well-being of society. There is therefore the need to assess the impact of tilapia cage aquaculture activities on the water and sediment quality in order to provide plans for sustainable aquaculture in Lake Volta of Ghana.

1.2 Problem Statement

In Ghana fish is recognized as the most importantant source of animal protein and over 60 % of animal protein in Ghanaian diet comes from fish (DoF, 2007). Fish in Ghana is obtained from sources such as marine, lagoons, lakes, reservoirs and rivers. It has been observed that fish production is dwindling due to overfishing (Atta-Mills *et al.,* 2004). One of the effectivemitigations is the establishment of cage farms in Lake Volta. Presently, cage culture appears to be successful in that, there are now large-scale aquaculture farms on the lake.

To ensure sustainable fish culture production in Ghana, commercial fish farmers are required to submit Environmental Impact Assessment (EIA) reports to the Ghana Environmental Protection Agency (GEPA) for approval prior to commencement of production (MoFAD, 2010). Good environmental assessment requires good data. What is lacking, therefore, as far as sustainable aquaculture development in the country is concerned, is water and sediment quality monitoring, without which EIA is futile (FAO 2009a). Among recommendations for cage aquaculture expansion in Africa is the need for countries to create an effective policy framework to ensure among others its equitable and sustainable development (Halwart and Moehl, 2006).

Over the last decade, there has been significant expansion of cage culture with a number of commercial cage farms in the Lake Volta. Cage culture production has increased from 4,912 tonnes in 2009 to a production of 38,547 tonnes per annum in 2014 (MoFAD, 2015). Excretary products from cages are dispersed in the water column by currents while solids (uneaten feed, faeces) settle towards the lake bottom (Beveridge, 2004). The quantity of nutrients emitted from cages is dependent on the quality and quantity of feed inputs and management practices (Wang *et al.,* 2005).

Information on impacts of cage aquaculture on the Volta Lake is scanty. Some works have been done by researchers on specific aspects of the lake which are unrelated to cages.

These include studies on the environmental impacts of Akosombo dam (GyauBoakye, 2001; Fobil *et al.,* 2003; Akrasi, 2005; Agodzo, 2013), the biological and fishery aspects of the lake (Amakye, 2001; Ofori-Danson, 2002; Bene, 2007; Akongyuure *et al.,* 2012) and water quality (Ofori Danson and Ntow, 2005; Ansa-Asare *et al.,* 2012; Karikari *et al.,* 2013; Olalekan et al., 2015). Few studies have also been undertaken on the impact of cage culture on water quality of Lake Volta (Ofori *et al.,* 2010; Mensah and Attipoe, 2013; Asmah *et al.,* 2014). However, these studies have been limited to water quality in the vicinity of the cages. Sediment qualities under the cages, estimation of nutrient discharges from the cages into the environment and the ecological carrying capacity of the lake have not received any attention. Hence this study aims to fill this gap by concentrating on the lakes water and sediment quality, nutrient discharge estimation and ecological carrying capacity of the lake. To allow for more fish farms in the lake, development of tools for the prediction of environmental impact from cage farms is important (Beveridge, 1996).

The quantities of waste been deposited under fish cages at intensively managed farms have been found to be a magnitude higher than those recorded at reference sites or in undisturbed water bodies (Beveridge, 2004). The wastes are generated from uneaten foods, faecal and metabolites. The extent of accumulation is variable and depends on local site conditions, species, feed type and management (Beveridge, 2004). Wastes lost to the environment could be estimated using a mass balance approach. However, in Ghana, attempts have not been made to estimate the waste lost to the lake’s environment due to aquaculture in order to find ways of reducing the impact.

Solid wastes (uneaten feed and faeces) emanating from cage farms consist of particles of varying sizes and densities and with varying settling velocities (SECRU, 2002). These particles are affected by water currents that may vary with depth. The resulting dispersion may cause settlement well away from the farm. The eventual site of deposition depends on local bathymetry, water movement, and flocculation (SECRU, 2002). Information on the bathymetry and hydrographic data of the lake's stratum II is unavailable. Bacteria may break down slow settling particles, leading to the release of nutrients into solution. Particulate waste eventually finds itself in the sediments. There is the need to develop appropriate dispersion models to predict the potential zones of organic enrichment in the Lake Volta. There is no information on the assimilative capacity of the lake. For sustainable aquaculture, it is important to predict the carrying capacity of the lake which is essentially to sustain culture, protect the ecosystem and to reduce risks of eutrophication.

1.3 Justification

Inspite of the numerous benefits derived from aquaculture, aquaculture could cause environmental pollution. Some cases of environmental degradation have occurred due to intensive cage culture operations in Europe, in Southeast Asia and Latin America (Barg, 1992). Reduction of negative effects of aquaculture has necessitated that governments come out with measures to curb environmental pollution in water bodies focusing on wastes from fish farms, water quality and the environments (Cornel and Whoriskey, 1993).

While the Fisheries Regulations of 2010 covers aquaculture, there is currently no regulation specifically designed for cage culture (Kassam, 2013). There are no formal regulations specifying forexample minimum distances between cage farms and this can cause conflict (Kassam, 2013). Similarly, there are no specific guidelines for interactions between aquaculture and fishing rights (Kaunda *et al.,* 2010). Along with the lack of regulations relating to cage culture there is also a lack of enforcement of current legislation. For example all cage farmers, small and large, are required to undertake environmental impact assessments (EIAs) before starting operations. However due to the high cost of undertaking EIA's for small-scale farmers, this is only being enforced for medium and large farms. There are a number of large cage farms operating in the Lake Volta in Ghana. However, there is non-enforcement of guidelines exclusively formulated for cage farms (Kassam, 2013). To ensure sustainable lake management, zonation of the lake is necessary to recognize suitable areas for aquaculture production and other uses such as local fishing activity, transportation and water supply (nfds, 2009).

It is important to measure and quantify environmental impacts of existing aquaculture facilities so that licensing authorities can estimate potential impacts of new aquaculture proposals. Regulatory agencies can use this information to restrict the expansion of sites to a safe level that minimizes the risk of damage to existing sites or other forms of environmental degradation. The environmental impact assessment of the lake will be essential for decision making on the number and size of fish farms that could be established in a water area. Such knowledge is vital also for the fish farmer as it is related to the fish health and hence to the profitability of the farm.

The physical, chemical and biological characteristics of the lake environment need to be assessed for better understanding of the levels since they are affected by the nutrient discharges from cages. Cage aquaculture growth must be seriously monitored. For sustainability, aquaculture development should take into consideration the carrying capacity of the environment by using methods that does not damage the natural environment.

The benefits derived from the ecological processes and the life-supporting ecosystems must be recognised and must play an important role in aquaculture development. Hence there is a need to have guidelines for aquaculture that cover issues regarding the prevention and reduction of the negative environmental impact of aquaculture. Not much work has been conducted to evaluate the environmental effect of freshwater cage farming in tropical settings where tilapia fish is cultured. In Ghana most of the studies on cages have concentrated on production parameters and economics (Ofori *et al.,* 2009; Ofori *et al.,* 2010; Asase, 2013; Mensah and Attipoe, 2013), cage culture practices, constraints and opportunities (Anane-Taabeah *et al.,* 2011; Asmah *et al.,* 2014).

There are considerable economic and social benefits to the continued growth of cage farm in inland fisheries of Ghana, particularly in the Volta Lake, naturally nutrient poor lake which is suited for cage culture. There will be increasing demand on the freshwater resource due to high freshwater aquaculture production and competition with other water uses and water pollution resulting from aquaculture (Boyd *et al.,* 2007). It is important that valid scientific information on the environmental impact of cage culture is considered for rational development of such an important resource. As this is the first study on the impacts of cage aquaculture in Ghana, it will make an important contribution to the future development of similar farms. The findings will strengthen the knowledge of cage culture in Ghana.

1.4 Research Objectives

This thesis therefore aims at assessing the environmental impacts of tilapia aquaculture production in the Lake Volta of Ghana. The specific objectives of this thesis are outlined below:

- To gather information on the status and production practices of selected cage farms in the study area and to assess their potential effects on Lake Volta;
- To monitor the water and sediment quality for prediction of potential changes in the natural water body and potential impacts of deposited wastes on bottom sediments resulting from aquaculture activity;
- To estimate the amount of waste discharged from cage farms into the lake's environment using input-output mass balance model;
- To predict the ecological carrying capacity of tilapia cage culture in the Lake Volta using phosphorus mass balance model.

1.5 Thesis Approach

The thesis is organized into six chapters. The first chapter presents a general introduction with a brief background, problem statement and justification for the research. The second chapter gives some information and data on selected farms, productionpractices, inputs, sales and current constraints. Chapter three assesses the water and sediment quality of the fish farms on the lake by measuring the concentrations of dissolved and total nutrients, dissolved oxygen, transparency, turbidity, chlorophyll-a, etc. in the water column and total organic matter (TOM), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), etc. in the sediment. The hypothesis was that concentrations of nutrients, dissolved oxygen, transparency, turbidity, chlorophyll-a etc. in the water column and TOM, TOC, TN, TP, etc. in the sediment would be higher in the vicinity of the cages than at a reference site further away from it. The fourth chapter estimates the N, P and C wastes from the cage farms into the lake's environment by using a mass balance approach. The hypothesis was that considerable amount of nutrient in the feed given to cage fish would be lost from the cages to the surrounding environment in the water column and the underlying sediment.

Chapter five predicts the ecological carrying capacity of tilapia cage culture in the Volta Lake using mass balance model. The hypothesis was that wastes emanating from farms may increase phytoplankton levels and settle at the bottom and the accumulation of the waste may exceed the assimilative capacity of the lake. Chapter six presents the general conclusions and recommendations from the study and further research for sustainable aquaculture development in the Lake Volta.

1.6 Fisheries and Aquaculture

Fish products are very precious protein source which are important ingredients in human diet and their wellbeing. It is prominent in the nutrition and food security of the poor (FAO, 2009b). Fish contains high levels of vitamins, selenium and iodine (FAO, 2009b). It is believed that fish helps in the development of the brain, protects vision and shields us from some cancers and cardiovascular disease (FAO 2009c).The share of the developing countries fish intake of animal protein is about 19.2 percent (World Bank, 2004). About half of the population of the world obtains their protein needs from fish and over 50 % of people in many countries depend on fish as the major source of daily animal protein (World Bank, 2004).

Capture fisheries per capita food fish supply was 18.4 kg in 2009 and almost stable at 18.6 kg in 2010. Capture fisheries production is stagnating however, aquaculture production continues to expand (FAO, 2012). As seafood production from fisheries is at or near its peak, there is the likelihood that aquaculture will become the main source of seafood production (Lucas and Southgate 2003). There are predictions that aquaculture production will surpass capture fisheries by 2030 (Brugere and Ridler, 2004).

The world's rapidly growing food production sector is therefore aquaculture (FAO, 2012). Aquaculture's contribution to global fish production continues to grow; increasing from 25.7 % in 2000 to 42.2 % in 2012 with annual mean growth rate of 6.2%, reaching over 90 million tonnes with a share in total production of 54 % (FAO, 2014). The reasons for the growth include generation of profit and income, the pressing need for fish, improved scientific and technological management skills and meeting market needs (Barg, 1992: Eng and Tech, 2002).

Aquaculture plays a key role in the growth of several economies. It provides incomes and makes fish products affordable and readily available to low-income people (FAO, 2006; Kawarazuka and Béné, 2010). It contributes to food security and poverty reduction (World Bank, 2006; Hishamunda *et al*., 2009; De Silva and Davy, 2010). Aquaculture provides, jobs, alternative livelihood to rural farmers and high quality protein (Gurung *et al*., 2010). Aquaculture development can solve the problem of rural urban drift of the youth for rural development (NACA, 1994).

1.6.1 Overview of Global Cage Culture

Cage culture, also known as net-pen culture, consists of a net suspended in the water column with a flotation system around its perimeter. Most often the net is hung in a square or rectangular configuration (four sides and a bottom), but some cage systems employ circular nets (Beveridge, 1996). The size of a cage can vary considerably depending on the needs of the culturist: a small cage may enclose an area of only a few square metres;

larger cages, particularly those intended for use in offshore areas, may enclose 500 m^2. The cage is moored by one or more anchor lines extending out from the perimeter. In most cases a farm is comprised of multiple cages, either moored in close proximity or physically connected to form a large array (Beveridge, 2004). In the U.S. for example, marine cage systems for salmonids typically consist of 10 to 50 cages moored together in a single large array. Cage culture can be applied in existing water bodies including lakes, large reservoirs, farm ponds, rivers, sea, estuaries and coastal embayments. Advantages of cage culture include low capital cost, simple technology and close monitoring of fish (Coche, 1983; Beveridge, 1984).

It is believed that cage culture started about two hundred years ago in Asia (Pillay and Kutty, 2005), and it was even a former local practices of the fisher folk in the Mekong (Ling, 1977; de Silva and Phillips, 2007). In the seventies Norway started the development of commercial cage salmon farm in the sea (Beveridge, 2004). Since the last two decades, cage culture has developed very quikcly due to population growth and the rising demand for fish globally.

A number of factors informed the practice of intensive cage farming systems. Among them are the growing struggle for available resources, the benefit of large scale production and the necessity for improved productivity per unit area (Foley *et al*., 2005). The cage culture sector expanded into open water areas including reservoirs, lakes, and rivers, coastal and offshore marine waters due to the quest for suitable sites. Presently, cage culture is the leading sector of aquaculture production in the world. The worry now is how to reduce the possible ecosystem effects of existing open farming systems (Tacon and Forster, 2003).

Cage culture systems employed by farmers vary from small-scale family-owned type and operated cage farming operations (Pillay and Kutty, 2005; Silva and Phillips, 2007) to commercial cages (Grottum and Beveridge, 2007; Masser and Bridger, 2007). In 2005, the main cage culture producers globally included China 29%, Norway 19%, Chile 17% , Japan 8% etc. (Figure 1.1). Currently, about 80 species are farmed in cages. However, about half (51 %) of all cage culture production is accounted for by one specie (*Salmo salar*) (Figure1. 2). Four species (*Oncorhynchus mykiss*, *Seriolaquinqueradiata*, *Pangasius* spp. and *Oncorhynchuskisutch*) represent about one fourth (27 %).

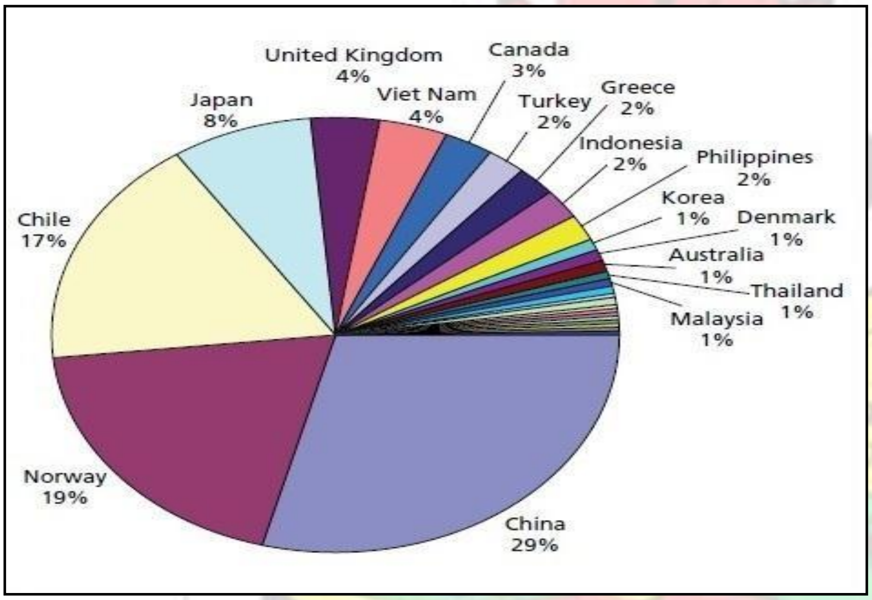


Figure 1. 1: Keyglobal cage culture producing countries[Source: FAO, 2007]

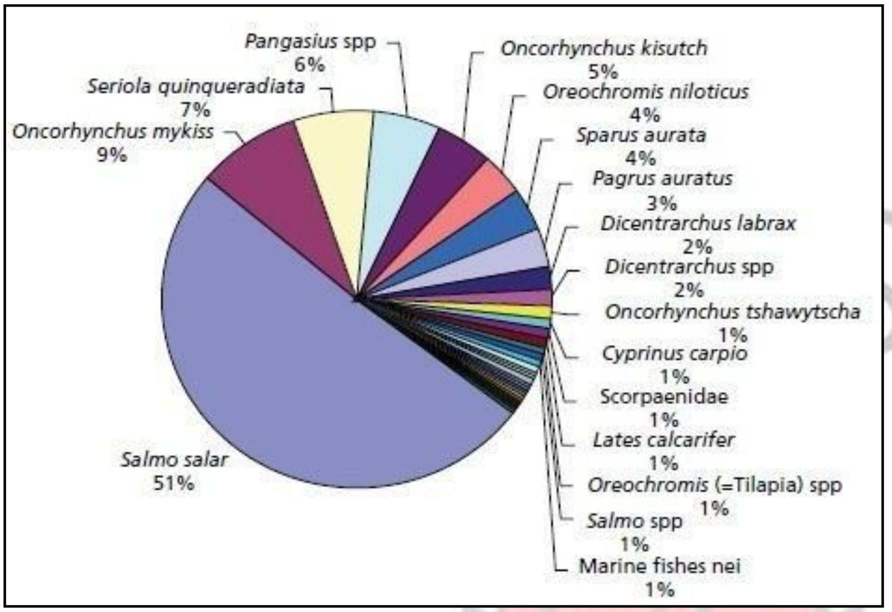


Figure 1. 2: Global cage culture production by fish species.
[Source: FAO, 2007]

Freshwater aquaculture accounts for 35.0 million tonnes/yr or 63.5 % of current aquaculture production (50 %) with average growth rate of 7.2 % (FAO, 2010). Freshwater fishes dominate global aquaculture production (56.4%, 33.7 mt), followed by molluscs (23.6%, 14.2 mt), crustaceans (9.6%, 5.7 mt), diadromous fishes (6.0%, 3.6 mt), marine fishes (3.1 percent, 1.8 million tonnes) and other aquatic animals (1.4%, 814, 300 t). The main negative environmental issues related to high freshwater aquaculture production at the country level are competition with other water uses and water pollution resulting from aquaculture (Boyd *et al.,* 2007).

1.6.2 Aquaculture in Africa

The development of aquaculture in Africa since the 1950s has been on subsistencelevel (Masser, 1988). Cage culture was presented to Africa in the 1980s when the various governments in Africa realised the necessity to include aquaculture research in their development plans (Masser, 1988). According to FAO (2001), aquaculture is currently pursued in many African countries and it is on the top of their development agenda. Countries such as Kenya, Ghana, Uganda, Malawi, Rwanda, South Africa, Zambia and Zimbabwe are now engaged in commercial cage fish farming. The main fishesthat are cultured in freshwater cages in the region are mostly Nile tilapia (*Oreochromisniloticus*), and “chambo” (*O. shiranus* and *O.karongae*). The continuous expansion of cage cultue which is already at various levels of development in Africa is dependent on the existence of sound economic, political and regulatory framework (Rana and Telfer, 2006).

In the last decade, Africa aquaculture contribution to the world‘s production has improved from 1.2 % to 2.2 % mostly due to quick cage culture development in freshwater environments. Aquaculture in Africa is mostly concentrated in few countries however; they have produced an estimated value of approximately US$ 3 billion per year (FAO, 2014). Fin fishes dominatein African aquaculture production with only a tiny proportion from marine shrimps and marine mollusks (FAO, 2012). Eventhough Africa’s share of global aquaculture production is minor; countries such as Ghana, Nigeria, Kenya and Uganda are fast developing their aquaculture industry.

1.6.3 Cage Culture Production Systems

Freshwater, marine and brackish waters are the common aquaculture production systems. According to Food and Agriculture Organisation of United Nations (FAO) freshwater aquaculture production increased from 50 % in the 1980s to about 62 % in 2010, corresponding to 58.1 % of the world’s production by value (FAO, 2012). The marine aquaculture production reduced to about 30 % which represented about 29.2 % of global aquaculture production by value. The brackish water aquaculture was 7.9 % of global production representing 12.8 % of total production value. From 2000 to 2010 the mean freshwater production growth rate per annum was 7.2 %, while the marine production growth rate was 4.4 %. Many developing countries practice small-scale aquaculture in freshwater systems (FAO, 2012).

1.7 Environmental Impacts of Cage Aquaculture.

Due to the extensive development in cage aquaculture in both advanced and the developing countries, its effects are well known. A lot of information is available on environmental effects of cage culture in many countries including United Kingdom Australia, Norway, Canada, United States, Chile, Malawi, Mediterranean, and the China (Winsby *et al.* 1996; ASI, 1999; Heining, 2000; Nash, 2001; Buschmann, 2002; SECRU 2002; Crawford *et al.* 2002; Carroll *et al.* 2003; Gondwe, 2009). These research works have shown related effects, even though the scale of impacts are site specific and may differ at different sites. The major wastes from cage aquaculture include uneaten feed, faeces, organic matter and chemicals (Liu *et al.,* 2002). The main nutrients in the waste are nitrogen, phosphorus and carbon. These wastes are discharged into the water column and the bottom sediment with the potential to cause eutrophication to the water and build up of organic matter in the sediments. The nature of waste from cage aquaculture is dependent mostly on the quality of feed, species cultured and management practices (Wang *et al.,* 2005).

1.7.1 Impact of Cage Aquaculture on Water Quality

Cage aquaculture releases N, P, and organic matter that results in nutrient enrichment in the water column and a build up of organic matter in the sediment. Over-enrichment of a water body by nutrients (C, N, P), fuel primary production resulting in eutrophication. Dissolved Oxygen levels may get depleted due to respiration of farmed fish and can also result from degradation of organic wastes leading to high biochemial oxygen demand (BOD) and chemical oxygen demand (COD). The impacts of cage fish farming also include increased level of suspended solids and turbidity, and decreased secchi depth, dissolved oxygen and levels of pH (Beveridge, 1984; Philips *et al.,* 1985; Pitta *et al.,* 1999). A drop in pH in a cage farm in Anatonian Dam Lake was attributed to waste deposits (Demir *et al.,* 2001). However, a rainbow trout cage farm in the oligotrophic Lac du Passage with a capacity of 14 tonnes did not cause any changes in pH, chlorophyll a, conductivity or nutrients (Cornel and Whoriskey, 1993), while inorganic nitrogen, orthophosphate, suspended solids and phytoplankton were significantly more numerous near the cages than near the control station in a 300 tonnes capacity trout farm in shallow, unstratified Fad Lad (Stirling and Dey, 1990).

Phosphorus is said to be a limiting factor in freshwater systems (Hudson *et al.,* 2000).Phosphorus is an important nutrient for growth of algae.Addition of phosphorus often results in increases in primary production with abundance of phytoplankton (Boyd, 1990). Phosphorus discharges from cage culture can increase phytoplankton in freshwater reservoirs, and will reflect in high chlorophyll-a levels. Diaz *et al.* (2001) observe high phytoplankton abundance in a freshwater reservoir, Alicura in Argentina which was attributed to phosphorus from salmon cages and natural inputs.Guo & Li (2003) found high levels ofN, P and chlorophyll-a from a fish farm in a Chinese Lake.

Gondwe *et al.* (2011) demonstrated that the establishment of cage culture in a lake can be a significant source of C, N and P nutrients into the lake's epilimnion. Estimates from aquaculture production records indicated that 71% to 88% of nutrients added through feed to fish cages in Lake Malawi were lost into the surrounding environment from fish cages. The amount of nutrients discharged from the fish cages were related to the amount of feed used so that as the fish farming expands, the levels of nutrients discharged increases. Similar losses of between 70% and 80% C, N and P have been reported from temperate cages by Gowen and Bradbury (1987), Holby and Hall (1991), Hall *et al.,*(1992) and Kaushik (1998).

1.7.2 Impact of Cage Culture on Sediments and Benthic Organisms

The major effect of cage culture on sediments is the build up of organic matter that causes oxygen depletion and changes in benthic communities. Elevated levels of waste deposition in the sediments beneath cages can lead to anaerobic conditions (Chen *et al*., 2000). The formation of gases such as ammonia, hydrogen sulphide and methane in sediments are as a result of severe anaerobic conditions due to accumulation of organic matter. Such conditions are capable of affecting negatively the fish farm, the environment and can change the sediment quality and the structure of the benthic community (Chen *et al*., 2000). The decline of species number is the most intense impact of cage culture on benthic fauna (Mazzola *et al.,* 2000; La Rosa *et al.,* 2001). Another effect is the change in species composition where the pollution loving organisms become more prominent in the environment, where copepods, nematodes and polychaeta take over the affected area (Mazzola *et al.,* 2000; Mirto *et al.*, 2000; La Rosa *et al.,* 2001). Brown *et al.,* (1987), and

Weston (1990), observed *Capitella cf. capitata* dominance of the macrofaunal community directly below cage sites.

High levels of organic carbon, total nitrogen and microbial biomass together with negative oxidation-reduction potential values have been found in the sediments close to cage farm sites than uninterrupted sites (Karakassis *et al.,* 2000). Holmer and Kristensen (1992) noted high concentrations of particulate organic carbon (POC) and particulate organic nitrogen (PON) under trout cages in Denmark. In the North Atlantic, Kupka-Hansen *et al.,* (1991), reported the absence of macrofauna in salmon cage farm due to anoxic conditions in the sediment. Generally, emissions from cage culture cause changes in the sediment chemistry.

Although, water currents bring in freshwater that can quickly dilute organic wastes, when the rate of accumulation far exceeds the rate of removal excess food and fish wastes can be deposited underneath cages or near them, thus affecting the benthic communities. Benthic fauna are sensitive to environmental disturbances and are especially sensitive to organic matter enrichment (Pearson and Black 2001). Changes may occur in species number, organism abundance, and community biomass. Polychaetes usually are good indicators of organic enrichment, especially the family *capitedallidae*, in areas with decreased species richness and increase of individual abundance (Bybee and Bailey-Brock, 2003). Benthic fauna are also characterized and distributed in relation to the sediment grain size classification and interstitial spaces. Organic matter causes enrichment, resulting in changes in the number of species, the abundance of organisms, and biomass of the communities.

1.7.3 Impacts of Metals

Metals are naturalconstituents of aquatic environment. They enter aquatic ecosystems through different sources such as geological weathering of rocks and anthropogenic input from industrial activities. Metals such as zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), arsenic (As), cobalt (Co), magnesium (Mg) and selenium (Se) are added tofish feeds to fulfill mineral requirements (CIESM, 2007). Therefore, sediments under cage farms can further be polluted with heavy metals from uneaten feed, fish faeces and antifouling chemicals used to protect cage nets from fouling (Basaran *et al*., 2010). It has been established that fish feeds fortified with metals are responsible for metal contamination in sediments underneath fish cages (Sapkota *et al.,* 2008). Metals including copper (Cu), iron (Fe), zinc (Zn), lead (Pb), cadmium (Cd)and nickel (Ni) have been analysed in the water column and sediment under cage sites from eastern Mediterranean (Belias *et al.,* 2003; Basaran *et al.,* 2010). Some studies have observed high concentrations of metals in sediments as a result of aquaculture activities (Mendiguchia *et al.,* 2006; Sutherland *et al.,* 2007). Basaran *et al.,* (2010) established a direct relationship betweeen metals (Fe and Zn) and organic matter accumulation in sediment. The dangers in connection with heavy metals are varied and mostly include neurotoxic and carcinogenic effects (Sapkota *et al.,* 2008).

1.7.4 Other Chemicals

Aquaculture industry uses chemicals such asstabilizers, pigments, antifoulants disinfectants and chemotherapeutants (antibacterial, antifungal and antiparasite compounds). In spite of the careful use of chemicals, considerable amounts of drugs may be discharged through various pathways into the fish farms environment (Rigos and Troisi, 2005). Unabsorbed drugs, non-ingested pellets, and unprocessed drug canbe excreted from different parts of the fish (Rigos *et al.,* 2004). Several studies have looked at the existence of residual chemicals in fish farm products and the dangers pose to consumers (Cabello, 2004; Angulo *et al.,* 2004; Hastein *et al.,* 2006; Rigos *et al.,* 2010). There is high loss of antibacterial via different routes into the immediate environment of the cage farms (Halling- Sorensen *et al.,* 1998; Lalumera *et al.,* 2004).According to Kerry *et al.*, (1994), due to the extensive use of antimicrobials in aquaculture; pathogens have developed resistance to it. The excessive use of drugs in fish farms will affect the water column and sediment and eventually enter the aquatic food chain, causing pollution to other organisms.

1.7.5 Models for Environmental Capacity

Carrying-capacity models using phosphorus mass balance for aquaculture are best developed for freshwater systems since phoshorus is the limiting nutrient in most freshwater ecosystems. Several models for determining the response of aquatic ecosystems to phosphorus loading are available, including dynamic models and empirically derived mass balance models. Dynamic models consist of a series of interrelated differential equations which attempt to describe the biological, chemical and physical interactions that govern algal growth. Such models require detailed data inputs and tend to be site-specific. Mass-balance models are based on correlations between phosphorus loading and indicators of trophic state (Vollenweider, 1968; Dillon and Rigler, 1974; OECD 1982). Such models have been widely applied to lake management because of simpler data requirements, and have been modified for use in cage fish farming (Beveridge, 1984; Phillips, 1985).

The model is a modification of Vollenweider's original model (Vollenweider, 1968) by Dillon and Rigler (1974) and states that "the concentration of total-P in a water body, [*P*], is determined by the P loading, the size of the lake (area, mean depth), the flushing rate (i.e. the fraction of the water body lost annually through the outflow) and the fraction of P lost permanently to the sediments" (Beveridge, 2004, pp. 186). At steady state:

$$[P] = \frac{L(I-R)}{Z\square} \qquad (1.1)$$

"Where [*P*] is in m gm^{-3} total-P or TP; *L* = the total-P loading in gm^{-2} per year; Z= is the mean depth in m; *R* = the fraction of total-P retained by the sediments; and □ = the flushing rate, per year (Y^{-1}) (Beveridge, 2004, pp. 186).

For cage farms, the increase in phosphorus due to fish culture must be added to the background concentration to give a final predicted concentration. In principle, a massbalance approach should account for all the routes by which phosphorus compounds are transported through a lake system. The model is based on the assumptions that algal population densities are negatively correlated with water quality in general, and growth and survival of fish stocks in particular, and that phosphorus is the limiting nutrient that controls phytoplankton abundance in most lakes and reservoirs.It is assumed that nutrient input from other sources such as surface runoff from the catchment areas are considered negligible and that the lake is properly mixed and flow is constant without concern for seasonal variations.

Once total phosphorus is predicted through application of the Dillon and Rigler model, it must be related to trophic state (e.g., oligotrophic, eutrophic). Several studies have linked total phosphorus concentration to lake trophic status (Vollenweider, 1968; Dillon and Rigler, 1974; OECD 1982; David *et al.,* 2015). Comparison of the predicted total phosphorus concentration with such criteria enables some assessment of the likely impact of fish farm development to be made. Such models have proven useful in Scotland and have been widely used by pollution control authorities there to determine potential impacts (NCC 1990). However, follow-up water quality monitoring is also recommended to both confirm and refine predictions. Although, there are problems, these models have been recognized as a positive step towards the development of more effective tools for environmental impact assessment and management of freshwater lakes for aquaculture.

The OECD model states that "the total-P concentration in the lake is a function of the concentration of total-P in the inflows $[P]_i$ and the residence time, T(w)" (Beveridge, 2004, pp. 186). The equation is empirically based and derived from a large data set of temperate freshwaters (OECD, 1982), including Nordic and Alpine water bodies.

$$[P] = \frac{[P]i}{(1+T(w))} \qquad (1.2)$$

Where [P] is in mg m^{-3} and T(w) in years. This model has been tested and verified in marine and freshwater environments in Sweden (Johansson and Nordvarg, 2002). These models are precise and compare with complex data intensive models and are said to have the best predictive abilities. The models do very well in lakes and reservoirs in both temperate and tropical areas (Mueller, 1982).

1.8.1 Aquaculture in Ghana

The development of aquaculture in Ghana began in the 1950s. Construction of fish ponds was done in 1953 by the former Department of Fisheries in the northern part of Ghana. The ponds were used as hatcheries to sustain the culture-based reservoir fishery. This augmented the national demand for fish and increasing livelihood opportunities.

Between the 1950's and the early 1970's, the country started stocking fish in small reservoirs and dugouts (Prein and Ofori, 1996). Generally, the types of fish farming practices include small-scale subsistence farming and few large-scale farmers. Majority of fish producers were small-scale farmers that practiced extensive farming systems and semi-intensive farming systems (FAO, 1991). Within the various systems some practiced polyculture while others practiced monoculture and mono-sex culture (FAO, 1990a). In these culture systems, farmers reared different types of fish species. The primary species cultured by about 90% of farmers was tilapia (*Oreochromis niloticus*), with 54% producing it in a mixed culture with catfish (*Clarias gariepinus*) and mudfish (*Heterobranchus spp*.) (Asmah, 2008). Generally, the farming units were tiny and very isolated with various earthen pond (96%) sizes from less than a hectare to about a hectare with an average pond size of 0.36 ha (Asmah, 2008). Water sources used included rivers, streams, underground and rainfall (FAO, 2000, 2009). However, the fertility of these ponds is maintained mainly through the use of organic manure (chicken droppings, pig manure, cow dung) and inorganic fertilisers, NPK and urea (Asmah, 2008: FAO, 2009).

In 1980's, aquaculture was popularized by a countrywide crusade as a way of promoting fish farming business by the Government of Ghana. This influenced a lot of people to join the fish farming industry. However, lack of technical support in many areas of fish farming including pond construction, pond supervision, availability of fingerlings and fish feed, feeding, harvesting strategies and processing, led to a near collapse of the sector (Quagraine *et al.,* 2009).

Inspite of these challenges the government of Ghana took the initiative again in 2000 to develop aquaculture. The government provided training in fish culture skills, pond construction, fingerling production and equipped the capacity of organizations and Fish Farm Associations (Quagraine *et al.,* 2009).

The first commercial cage farm was established in 2001 (Kassam, 2014). Currently, most of the aquaculture production is from cage farming, contributing about 88 % in 2014 (MoFAD, 2015). Aquaculture production increased due to availability of quality feeds and fingerlings, as well as the production from large-scale cage farms. Between 2009 and 2014 cage farming is reported to have developed at an average annual growth of 73 % (Rurangwa *et al.,* 2015) (Figure 1.4).

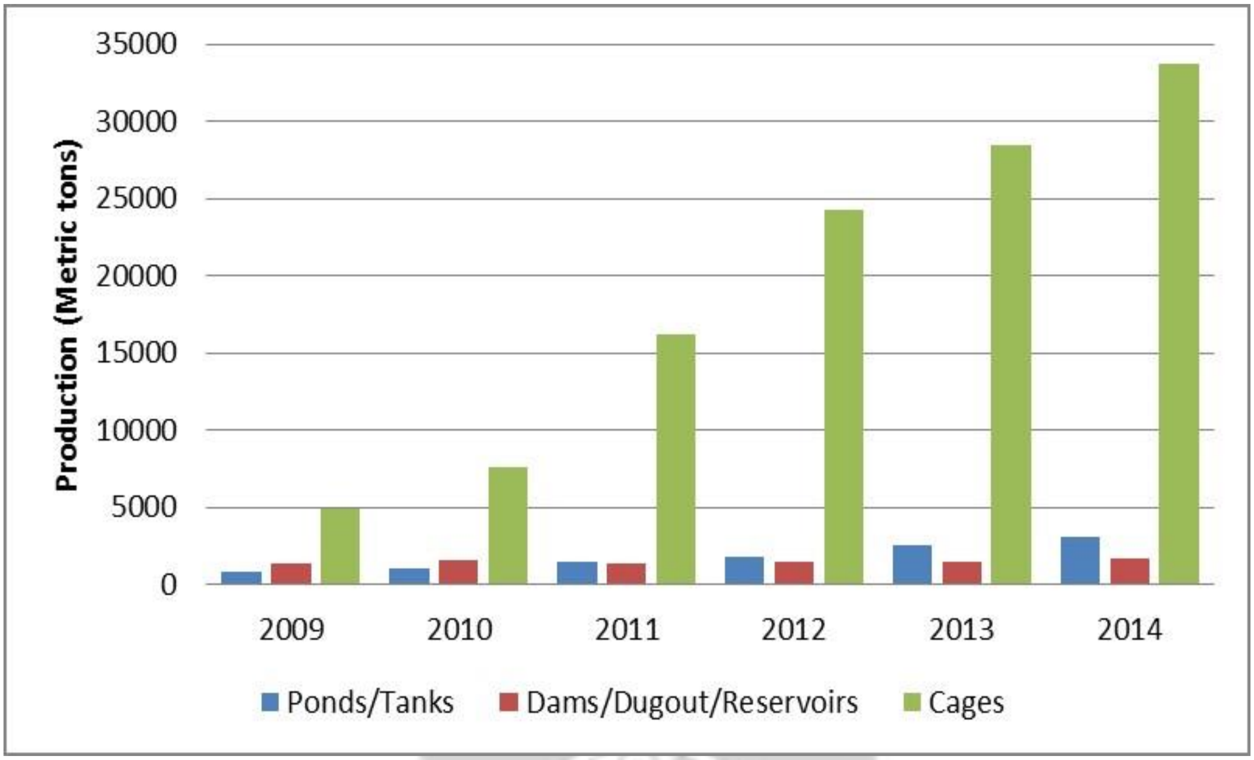


Figure 1. 3: Aquaculture production systems from 2009 to 2014in Ghana

Source: Ministry of Fisheries and Aquaculture Development (MoFAD). Provisional data from the Fisheries Commission for 2014.

The cage farming of small to medium-scale and large-sacle farms are predominantly done on the Lake Volta. Over 60 cage farms are situated in Asuogyaman District in Eastern Region, with majority of cage farms sited upstream of Akosombo Dam and between Akosombo Dam and Kpong Dam (Kassam, 2014). Intensive culture of Nile tilapia (*Oreochromis niloticus)* is the common practice of fish farming in the lake.

1.8.2 Constraints in Cage Aquaculture in Ghana

The key challenges to aquaculture development suggested for Sub-Saharan Africa are feed and seed quality availability, cost of cage design and construction, and financing

(Ridler and Hishamunda, 2001; Halwart and Moehl , 2006; Moehl *et al.,* 2006; Blow and Leonard, 2007; Asmah, 2008). Other constraints identified include lack of technical know-how (Ridler Hishamunda, 2001; Halwart and Moehl, 2006; Blow and Leonard, 2007), lack of market (Hambrey, 2006; Moehl *et al.,* 2006), lack of processing (Blow and Leonard, 2007), among others. A recent study by Anane-Taabeah *et al.,* (2011) revealed that the main constraint in cage culture in Ghana is lack of funds to purchase inputs. While lack of funds prevented farmers who have abandoned cage farming from resuming, the constraint barred potential adopters from starting cage aquaculture even though they showed a high interest in the business. In addition, lack of extension services, cage destruction by storms and theft were mentioned.

The main constraints facing aquaculture development in Ghana identified by Rurangwa *et al.,* (2015) amongst others, were the following:

- Inadequateaccessibility of reasonable priced feeds, seed (broodstock) quality and quantity;
- Lack of capital for aquaculture operations to make profit;
- Poorparticipation of private sector in aquaculture development;
- Weak human resource base reflected in the lack of appropriate skills or trained persons at the different levels of the aquaculture sector;
- Absence of efficient extension systems for technology transfer;
- Lack of research agenda that is quick to respond to the needs of the aquaculture sector.

Financially, aquaculture farmers experience lack of access to credit from Banks, and where available with high interest rates (23-30 %) (Rurangwa *et al.,* 2015). Finally, to secure an operational permit for cage culture, a prospective farmer would have to acquire different permits from five different institutions (Ghana Environmental Protection Agency, Fisheries Commission, Water Resources Commission, Volta River Authority and District Assembly) (MoFAD, 2010). This is considered as complex licensing procedures and bureaucracy. These constraints affect the sustainable expansion of the industry.

1.8.3 Cage Aquaculture Potential in Ghana

Ghana has a high domestic demand for fish. Fish is the preferred animal protein source and accounts for 74% of total animal protein ingested (Kawarazuka, 2010). Demand for fish is higher than the supply and currently 25 % of the domestic fish consumption is catered for by imports, mainly low value, frozen pelagic species (Orchard and Abban, 2011), imported from other African nations and the EU (GAIN, 2010). Average per capita consumption is estimated at 18.5 kg/year (MoFAD, 2015). Kaunda *et al,* (2010) estimated tilapia demand to be between 60,000 and 120,000 t per year in Ghana and explained that the market can absorb a considerable increase in tilapia supplies without leading to major price reductions.

In cage culture, feed, seed and water availability are important determinants of production potential (Kassam, 2013). Ghana's Lake Volta is not polluted and the water quality is exceptionally suitable for tilapia culture and has a consistent year round warm temperature (Blow and Leonard, 2007). There are rivers, reservoirs, old mining pits, and other water storage bodies which have the potential to be used for cage aquaculture since they are less likely to raise major concerns (Anane-Taabeah *et al.,* 2011). Floating feeds are imported into Ghana, but currently Raanan Fish Feed, produces 30,000 t of extruded fish feed annually for domestic and the export market (Rurangwa *et al.,* 2015). Over the years, fingerlings availability and quality has been a problem to aquaculture operators. However, with the rapid growth of cage farming, the number of private hatcheries has increased from 4 in 2005 to 24 hatcheries in 2013 (MoFAD, 2014).

There are 3 public hatcheries namely: Ashiaman aquaculture Development Centre, the Pilot Aquaculture Centre (PAC) in Kumasi, and the hatchery of the CSIR Water Research Institute in Akosombo. The total number of fingerlings produced in all the hatcheries was 157,000,000 in 2014 (MoFAD, 2015). Several medium and large-scale cage farms produce their own fingerlings and sell to other farmers.

Since the establishment of the first commercial cage on the lake in 2001 (Kassam, 2014), aquaculture production has largely increased due to the production from large scale cage farms and increased availability of quality feeds and fingerlings (Rurangwa *et al.,* 2015). Cage culture production has increased from 4,912 t in 2009 to 33,500 t in 2014 (MoFAD, 2015), indicating the importance of cage production to total aquaculture production, and its potential role in ensuring employment and food security in Ghana.

The government of Ghana has produced Ghana National Aquaculture Development Plan (GNADP), with the aim of increasing fish production from 10,000 t in 2010 to 100,000 tin 2016 (MoFA, 2012). The primary focus of the plan is increasing fish production through commercial aquaculture development to reduce fish deficit.

Although, GNADP's vision includes food security, employment creation, increased incomes, economic growth and poverty reduction, it also emphasizes the need for support mechanisms and services for aquaculture businesses to be private sector led with government playing facilitation and monitoring roles (MoFA, 2012). Over recent years, Ghana's macroeconomic performance has been positively supported by relative political stability and macroeconomic reforms whichhasbeen a fundamental asset to foreign investors (KPMG, 2012). This can be seen in the level of foreign investment in medium and large-scale cagefarms in Lake Volta. The government has been actively building a policy andregulatory environment that is more conducive to enterprise developmentand Ghana was ranked twice as a top 10 reformer globally by the World Bank's Doing Business report (World Bank, 2013). However there are stillmany constraints in the area of permit acquisition, access to finance and registration of cage fish farming enterprise that needs to be addressed.

Regarding the availabilityof financial resources for the cage culture business, banks such as Prudential Bank Ltd., Agricultural Development Bank, Stanbic Bank and the Merchant Banks are ready to provide credits to interested fish farmer and fish farmers Associations even though the interest rates may be on the high side (Kaunda *et al.,* 2010).

According to Blow and Leonard, (2007), most part of Ghana has been found to have favourable biophysical factors suitable for aquaculture. Road networks, electricity and telecommunication infrastructure is growing. However, their presence in rural areas of Ghana is still inadequate. Road networks and electricity connectivity to potential sites along the Volta Lake for aquaculture remain a major challenge (Rurangwa *et al.,* 2015). Large-scale cage farms located on the main Lake Volta have had to build access roads and provision of eelectricity at their own expense. To make aquaculture attractive to local and foreign investors, government must address this concern to facilitate aquaculture production.

Institutions such as CSIR Water Research institute, the Universities and the Agriculture colleges are a support to the aquaculture development in the country. They provide research and development, training of students, farmers and extension officers to help in the management of the farms and ensure sustainable development of cage culture in Ghana.

Ghana undoubtedly has a huge potential for cage culture production, however, there are clearly important constraints (see section 1.8.2) to the development of cage culture that must be overcomed if the full potential is to be realised.

CHAPTER 2:

CHARACTERISTICS OF CAGE CULTURE IN GHANA: A CASE STUDY OF LAKE VOLTA

2.1 Introduction

Aquaculture has been practiced in Ghana since the 1950's but it is in the last few years that it has proven to be very successful. Although production is undertaken in ponds, pens or cages, cage culture has become increasingly important, currently accounting for more than 80 % of aquaculture fish production in Ghana (MoFA, 2014). It is believed to have the capacity to contribute considerably to the total fish production and food security in Ghana by providing employment, income, revenue and livelihood to the public, government and the surrounding communities (FAO, 2005).

Fish farming has been adopted by the Directorate of Fisheries (DoF) as one of the means of increasing fish production and offsetting the deficit in supply (DoF, 2008). As a result, tilapia culture has gained prominence in Ghana.

Tilapia (*Oreochromis niloticus*) is the main species cultured and constitutes over 80 percent of aquaculture production in Ghana. The catfishes (*Clarias* sp., *Heterobranchus* sp.) and *Heterotis niloticus* account for the remaining 20 percent (FAO 2010). The culture of fish in cages has several advantages such as flexibility of management, ease and low cost of harvesting, relatively low capital investment compared to ponds and raceways (Beveridge, 1996). The disadvantages of cage culture are its dependence on formulated feed supply, risk of a major loss from poaching or damage to cages from predators or storms, its sensitivity to environmental change and relatively expensive supplementary feed. The cost for feed in intensive cage culture is usually the highest variable cost averaging 50 to 60 % of the total operational costs (Beveridge 2004).

During intensive production of tilapia in open cages, the discharges of organic wastes such as faecesand uneaten feed and inorganic nutrients suchas ammonium (NH_4^+) and phosphate (PO_4^{-3}) are released directly into the environment and maycause negative ecological effects on the surroundingwaters (MacDonald*et al.,* 2011).

Earlier surveys conducted looked at different aspects of the cage farming. Anaglo *et al.,* (2014) during a survey of 2013 examined the influence of the entrepreneur and enterprise characteristics on success of cage farming while Ahmed (2013) reported on on-farm feed management practices. A study into stocking densities noted that the small scale farmers in Asuogyaman area stocked their cages at densities from 50 to 200 fish/m^3 with 2 to 4 g fingerlings (Asase 2013). (Simpson 2012) reported on the opportunities within the tilapia value chain in Ghana. Asmah *et al.,* (2014) looked at the farm practices and its potential impact on water quality.

The challenges to the development of aquaculture suggested for Sub-Saharan Africa are feed and seed quality and availability, cost of cage design and construction, and financing (Ridler and Hishamunda 2001; Halwart and Moehl 2006; Moehl *et al*. 2006; Blow and Leonard 2007; Asmah 2008).Other constraints identified include lack of technical know-how (Ridler and Hishamunda 2001; Halwart and Moehl 2006; Blow and Leonard 2007; Asmah 2008), lack of market (Hambrey 2006; Moehl *et al*. 2006) among others. Anane-Taabeah *et al.,* 2011 identified lack of funds, high cost of feed, theft and lack of extention officers as constraints.

For sustainability, aquaculture must meet economic, social as well as environmental factors (Barg and Philips, 1997). The aquaculture business must be self-sufficient financially. If profits are not generated, the farm will either close down or rely on subsidies, which are a drain on owner's budget (Hashimunda and Ridler, 2002). There should be a stable level of returns. Prices of inputs and outputs must not escalate and mortality rates should be moderate. There should be general culture, gender and social acceptability and finally, aquaculture operations must be environmentally neutral over a long period of time (Hashimunda and Ridler, 2002).

This study is intended to gather general information on the activities and practices of the farms and their potential environmental effects in order to provide sustainable plans for aquaculture in the Lake Volta.

2.2 Methodology

2.2.1 Data Collection

The field studies were conducted between February and May 2013. Primary information on cage aquaculture was predominantly from the fish farmers in Asuogyaman district in the Eastern Region of Ghana and a few from the Afadjato South district of Volta Region. The Asuogyaman district was selected because it is the area where most of the commercial cage aquaculture activities are sited. Twenty-three fish farmers were selected within the project area for interviews in the survey, which included large, medium and small scale fish farmers. Scale of classification was based on Ghana Environmental Protecton Agency (GEPA) classification of fish farms, where large-scale farms are those with production capacities of more than 100 tonnes per annum; medium-scale farms have production capacities of 50 to 100 tonnes per annum and small-scale farms below 50 tonnes per annum of fish production.

Structured questionnaires surveys (Appendix 1) and interviews were employed to obtain information from the fish farmers or farm managers, whichever was available at the time of the visit. To facilitate data collection, all the questionnaire forms were administered in person and individually completed with the fish farmers to ensure that answers provided were directed to the exact questions posed. Where the farmers or the respondents were unable to fully complete the questionnaire due to unavailability of key records at the farm sites at the time of visit, telephones interviews were conducted to supplement the information already obtained. The questionnaire was in four parts. The first part sought to gather general information in relation to farm location, size of cages, year of establishment, construction cost and personal information of farmers such as gender, age, educational status, sources of income besides fish farming, as well as formal training in fish farming. The second part of the questionnaire focused on the inputs in relation to sources, cost of fingerlings and feed and stocking densities. The third part was on production figures and marketing and the final part dealt with constraints. The locations of the farms visited are shown in Figure 2.1.

2.2.2 Data Analysis

Data and information collected were compiled and entered into computerized data bases using Statistical Software Package for Social Sciences (SPSS Inc, Chicago, Illinois) version 21 and excel software. The data were structured into socioeconomic factors such as age, occupation, educational levels and farm practices. The results were expressed in descriptive statistics such as percentages, means, and in tables and pictorial representation.

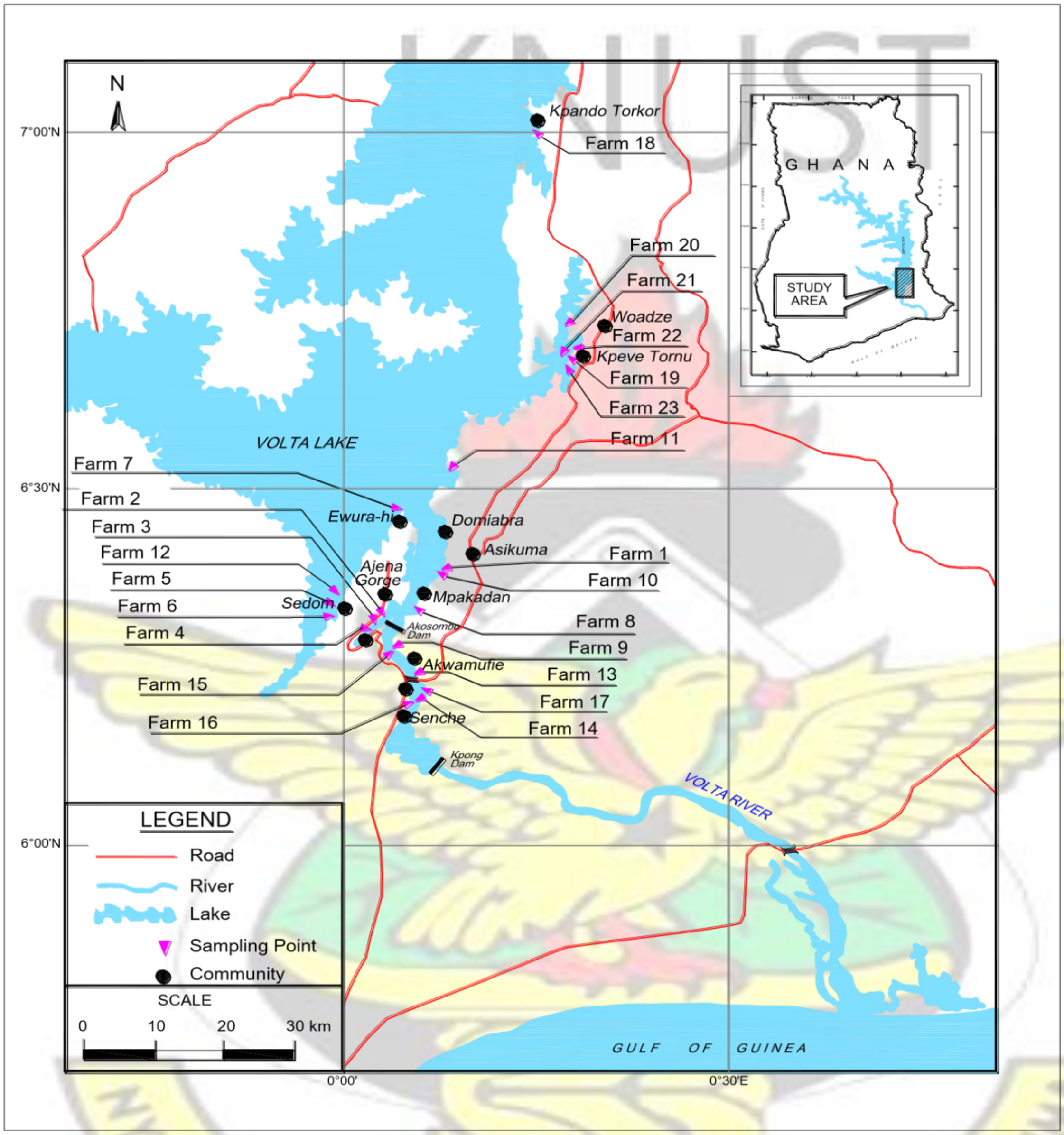


Figure 2. 1: Map of the Lake Volta in Ghana showing location of cage fish farms visited in the study area.

2.3 Results

2.3.1 Main Occupation

Most of the cage farms were not directly operated and managed by the farm owners but by a hired farm manager or supervisor. The farm owners generally, practiced cage culture as an alternative source of income. From the survey only (23 %) of the owners interviewed depended solely on the farm as the main source of income. The rest (77.0 %) had other jobs as their primary income source. The main occupations of the cage farm owners are presented in Table 1. About 26.0 % were businessmen, 17.0 % were traders/farmers and 13.0 % were accountants. The owners of the farms were mostly not resident in the community but hailed from different parts of the country. However, the farm managers or the supervisors were resident in the communities and were responsible for the daily management of the farms.

Table 2. 1: Occupation of cage farm owners in the Asuogyaman District.

Occupation of farm owners	Number	percentage
Accountants	3	13.0
Aqua culturists	3	13.0
Auditors	1	4.3
Businessmen	6	26.1
Clearing agents	1	4.3
Traders/farmers	4	17.4
Fish farmers	2	9.0
Pastors	1	4.3
Civil servant	1	4.3
Teachers	1	4.3
total	23	100

2.3.2 Age and Gender of Farmers in Asuogyaman District

The age of the farmers recorded in this study ranged from 35 to 65 years (Figure 2.2). The proportion of farmers between the ages of 35 to 45 was 37.0 %, while the farmers between the ages of 50 to 65 were 47.0 %. From the interview, almost all the farm owners were males, only one farm was owned by a woman.

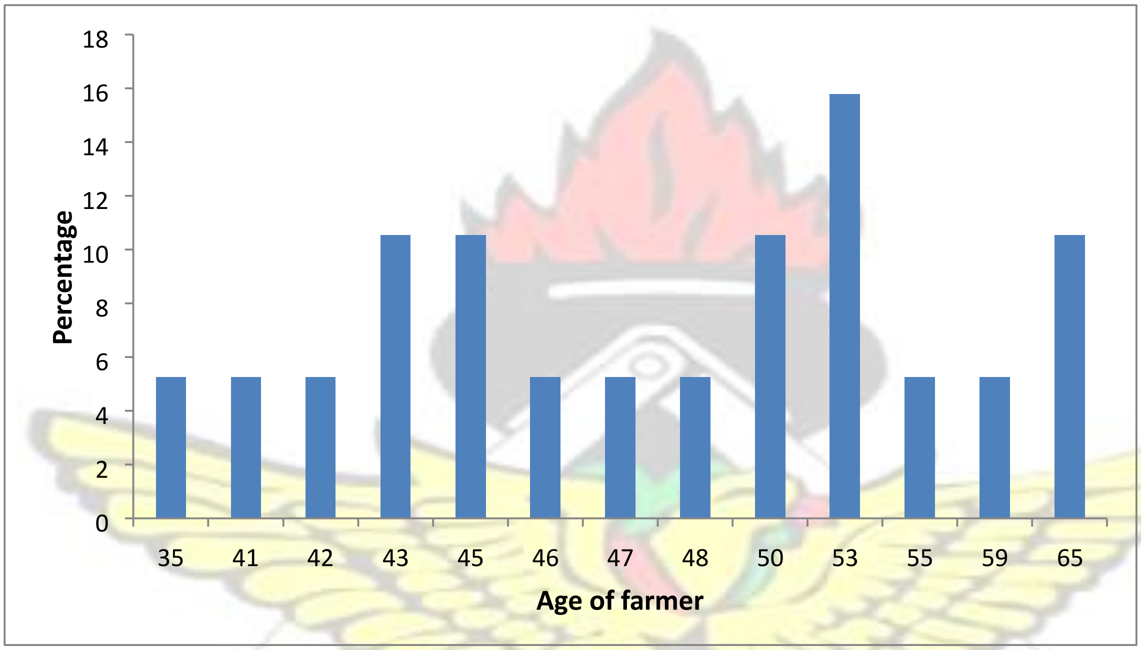


Figure 2. 2: Age of fish farmers expressed as percentage in the study area

2.3.3 Educational Levels

The educational background of the farm owners was high with only 10.53 % having basic school education, 15.79 % beingsecondary graduates and 73.68 % tertiary graduates (Figure. 2.3). However, the educational levels of the farm managers were relatively low, with 18.18% basic school education, 36.36 % secondary school graduates and 45.45 % were tertiary graduates.

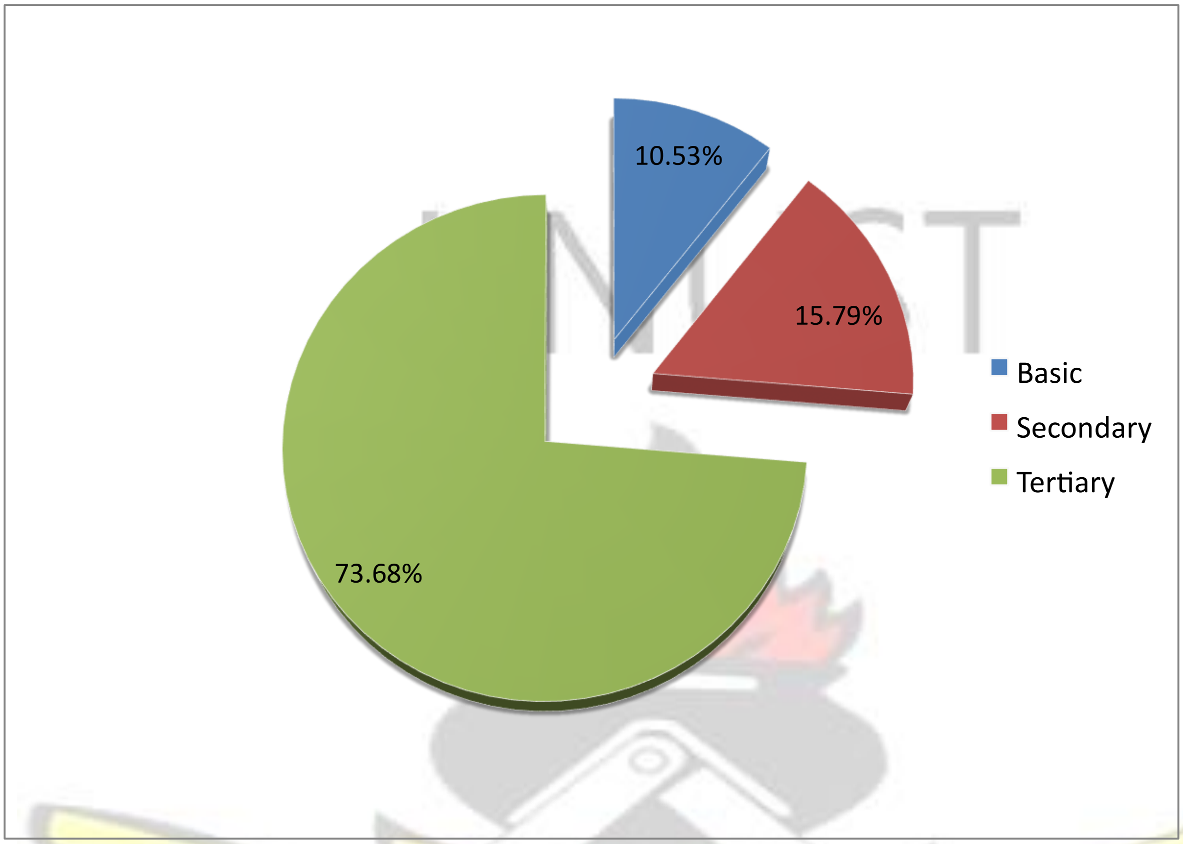


Figure 2. 3: Educational background of farm owners in the study area.

2.3.4 Fish Farm Information (type of cages, labour and cage farm development)

From the twenty-three (23) farms covered in the study, the earliest cage farm was established in 2005. The rest of the farms began operation from 2008 (Table 2.2). The cages employed in the farms are circular (in case of large farms), rectangular (5x8) and square in shape. The dimensions of the square cages ranged from 3 x 3 x 3 m, 4 x 4 x 4m to 8 x 8 x 8 m. The circular cages found in a large farm had diameter of 16 m and a depth of 6 m.

The least number of cages per farm was five (5) cages and the highest was 300 cages. The number of operational cages in the farms was varied depending on the demand for the product and the general environment according to respondents. The cage farms altogether employed 674. Some of the farms had contributed to infrastructural development of their operation area through the construction of access roads and extension of electricity to their locality as their contribution to society. Labour employed by the famers were both skilled and unskilled as well as casual and permanent staff and were engaged in various capacities such as farm manager/supervisor, accounting clerk, secretaries, administrative personnel, storekeepers, cooks, drivers, feeders, security, divers, graders, net menders, fingerling producers, pond/hatchery workers and maintenance staff.

Table 2. 2: Cage farm information in the study area in 2013

Farm	Year established	Type/Size of cages (m)	Total No. of cages	No. of workers
1	2008	Circular*	80	60
2	2008	4x4x1.5 / 5x5x4	168	37
3	2009	3x4x2 /3x3x2 / 5x5x5 / 6x6x6	249	55
4	2012	4x4x4	100	8
5	2012	6x6x4	30	8
6	2012	6x6x6	40	8
7	2009	3x3x3 / 6x6x6	18	4
8	2006	3x3x3 / 6x6x6	> 200	315
9	2010	Circular**	5	7
10	2010	6x6x6	120***	15
11	2011	5x5x5	80	50
12	2011	5x5x5	300	38
13	2011	5x5x10 / 6x6x11	24	5

14	2010	5x5x5	9	7
15	2010	5x5x5 / 6x6x5	18	10
16	2008	5x5x5 / 5x8x5	10	5
17	2008	5x5x2.5	12	4
18	2011	5x5x5 / 6x6x6	18	5
19	2012	3x3x3 / 5x5x5 / 6x6x6	12	9
20	2011	3x3x3 / 5x5x5	17	5
21	2011	7x7x6 / 8x8x7.5	22	7
22	2005	5x5x5	21	4
23	2010	5x5x5	246****	8

* 16m diameter **21m diameter ***68 stocked ****30 stocked

2.3.5 Cage Construction

Most of the cages were constructed with local materials. A greater number of the cages were square in shape except few large scale farms which had circular cages (Figure 2.4). Most of the cages were constructed using a galvanized pipe frames (Figure 2.5). The hardwood decking bolted onto the metal frame makes feeding and working around the cages easier and makes them strong enough to withstand the constant pressure of the water current. The cages were floated by plastic or metal barrels and the netting were nylon of various mesh sizes. Cages were anchored with concrete blocks to which ropes are tied and connected to each corner of the floating cage framework from which the cage was suspended. Cages were categorized into small, medium and large. The average dimensions of the small, medium and large cages were 3x3x3 m, 5x5x5 m and 8x8x8 m, respectively. The construction cost of a cage was dependent on the time it was constructed. At the time of the study in 2013, the costs of cages constructed between 2008 and 2012 ranged from GH¢1,500.00 to 6,460.00, equivalent to US$ 750.00 to US$

3,230.00 for 5x5x5, 6x6x6, and 7x7x6 m cages. A circular cage of 16 m diameter and 6 m depth constructed in 2008 was estimated at GH¢ 45,000.00 (US$ 22,500.00).

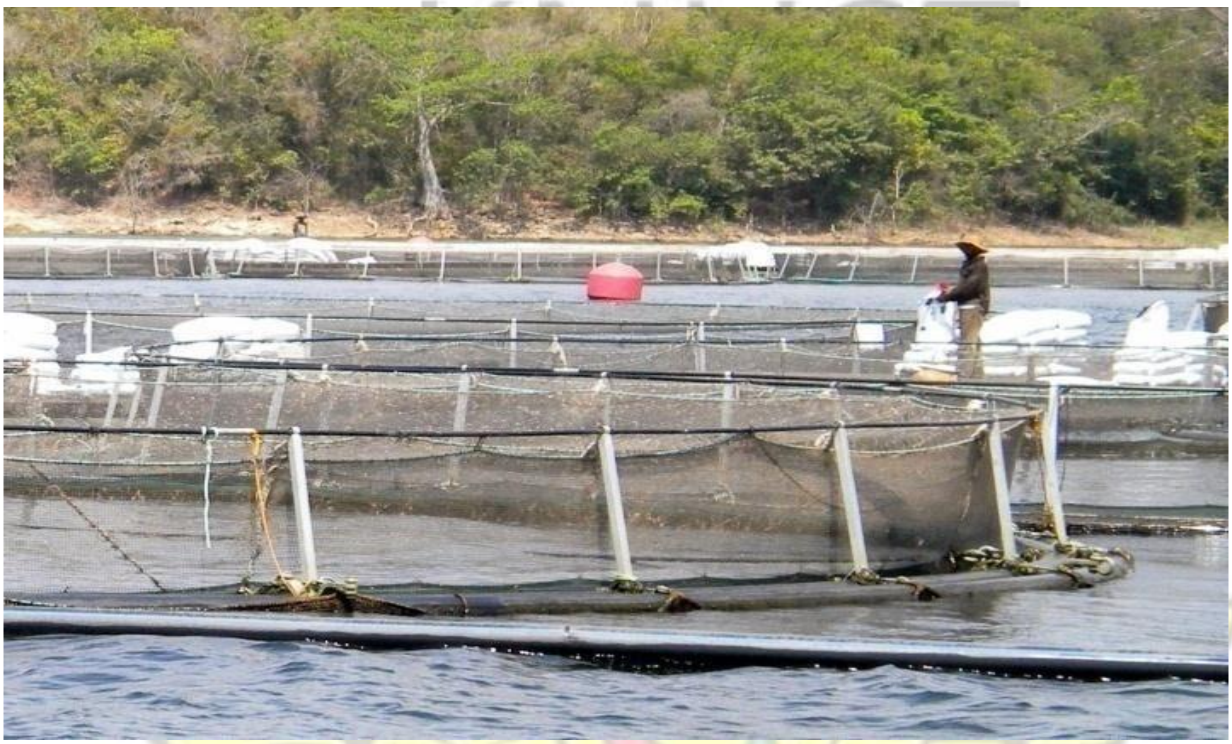


Figure 2. 4: A circular cage on the Volta Lake

Figure 2.5: A square cage with galvanized pipe frames on the Lake Volta

2.3.6 Production and Culture Technique

The only species cultured in the Lake Volta on commercial basis was Nile tilapia (*Oreochromis niloticus*). All the seed used came from hatcheries and not wild capture. Cage culture fish production spans two seasons of six months duration each and fish was stocked anytime of the year. Harvesting time was chosen by farmers to maximize profit. For the small scale to medium scale, harvesting was done monthly, bimonthly, quarterly or at half yearly interval. However, the large scale farms harvested weekly or biweekly. Before stocking into grow-out cages, fry were nursed to a size between 2 and 5 g depending on the farmer. Fish nursery was normally done in 3 x 3 x 3 m cages, while grow-out was done in 5 x 5 x 5 m, 6 x 6 x 6 m, 8 x 8 x 8 m and big circular cages. About 77.3 % of the farmers stocked 2g sized fish and only 13.6 % stocked 5 g sized fish. The average stocking densities per farm ranged from 23 to 96 fish/m^3.

The two main feeding regimes practiced by the farmers were feeding to satiation and feeding per biomass of fish. All the fish cage operations covered in the Lake Volta use the intensive method of culture where imported commercial feeds are used. All the imported feeds are extruded floating pelleted tilapia feeds. The total annual production varied from 1 metric tonne for small scale farms to over 5,000 metric tonnes for the large scale farms in 2013 (Table 2.3). The FCR for the study area ranged from about 1.5 to 2.0.

Table 2. 3: Stocking density and annual fish production of farms

Size of Farm* Operation	Strain of Tilapia Produced	Type of feed used	Stocking density (fish/m^3)	Annual production (tonnes)
Small scale (< 50 t/yr)	Akosombo strain	Extruded pelletised feed	23 - 50	1 - 50
Medium Scale (50 - 100 t/yr)	Akosombo strain	Extruded pelletised feed	28 - 96	50 - 84
Large Scale (≥ 100 t/yr)	Akosombo strain	Extruded pelletised feed	41 - 80	165 - 5150

*Based on Ghana EPA farm scale definition

2.3.7 Aquaculture Inputs

The survey indicated that fingerlings were obtained from three main sources; the Aquaculture Research and Development Centre (ARDEC, Akosombo) of the CSIR

Water Research Institute, private commercial hatcheries (e.g. Lee farm, Fish Reit, Crystal Lake farm and Tropo farm) and own farm production. Over 22.73 % of the respondents reported that their source of fingerlings were from ARDEC, 36.36 % from commercial fingerling producers and 40.91 % from own production and others. ARDEC was the main source of broodstock for all the hatcheries, which is the improved “Akosombo strain” of *O. niloticus*, specie indigenous to the Volta Lake. The fingerlings stocked by the farmers were all males. Some of the respondents revealed that they prefer fingerlings from ARDEC, but their orders are often delayed or under supplied, as a result customers turn to look elsewhere to stock their cages. Those who produced their own fingerlings reported that they sometimes sourced for fingerlings from other hatcheries. Regarding the cost of fingerlings, about 50 % of farmers indicated that a 2g fingerling costs twelve Ghana pesewas (GH¢0.12p = 6 US Cents). Others, either paid slightly lower (GH¢0.10p = 5 US Cents)or higher amount (GH¢0.14p = 7 US Cents)per fingerling of 2g size depending on the source. About Seventy-seven percent (77.3 %) of the farmers stocked 2 g fingerlings and only 13.6 % stocked at 5 g.

The cage farms on the lake use mostly imported and locally produced diets. The tilapia farms use a range of commercial feeds, with protein content of 48 % as starter (fry to about 4g), 40 % protein content as pre-grower (fingerlings from 5 g to about 40 g), 33 to 38 % as grow-out (from about 50 g to 250 g) and 30 % protein content as finisher (for fish from 250 g until harvest). Table 2.4 shows the types of feed that were in use at the time of the survey. The fish feeds are mainly imported into the country by private individuals and not the government.

Premix fuel is used in motorized boats by fish farmers in the Volta Lake to transport farm workers, fish and other inputs to and from the cages, for monitoring and surveillance activities around the cages, and also during stocking and harvesting. Ice blocks were used to preserve the fish after harvesting. Pesticides and other chemicals were not heavily utilised by farmers on the lake.

Table 2. 4: Feed types in use in the study area in 2013

Feed name	**Country of origin**	**Cost/ kg (GH¢)** ≥40 % Protein	**Cost/ kg (US$)***	**Cost /kg (GH¢)** 30-36 % Protein	**Cost /kg (US$)***
Ranaan	Ghana	2.95	1.48	2.10	1.05
Beacon Hills	Ghana	-	-	2.25	1.13
Coppens	Netherlands	6.00	3.00	2.60	1.30
Aller	Denmark	5.00	2.50	2.50	1.25
Carghil	USA	5.00	2.50	2.50	1.25
Zeigler	USA	3.60	1.80	2.50	1.25
Inter-aquafeed	Vietnam	3.00	1.50	2.00	1.00
Pira	Brazil	3.50	1.75	2.48	1.24
Nutron	Brazil	-	-	2.20	1.10
Vasa	Vietnam	-	-	2.10	1.05
Nicoluzzi	Brazil	3.80	1.90	2.60	1.30

*1US$ = 2.0 GH¢ in 2013

2.3.8 Technical Assistance

The survey observed that technical assistance to farmers was provided by the Fisheries Directorate, ARDEC of WRI, NGO's, fish farms and input dealers (feed and fingerlings suppliers). Thirty-seven percent (37.5 %) of the farmers recorded that they received assistance from technical officers and 50 % of the farmers indicated that they did not receive any technical assistance; while 12.5 % did not respond. The assistance received was in the areas of feeding, stocking and water quality management. The technical assistance was received through workshops and hands on training at the farms. Most of the farmers however, indicated that the assistance was not regular.

2.3.9 Sales and Fish Prices

The clients of the fish farmers were market women, general public, hotels, restaurants, agents (fish dealers) and marketing companies. However, the market women, agents and fish dealers were the main reliable clients. Cage farmers preferred to sell to wholesalers with whom they have established good relations and usually pay cash at the farm gate. Seventy-five percent of the farmers sold their fish at the farm gate and 12.6 % sold at both the farm gate and the local market.Over 87 % of the farmers sold their product fresh. However, large farms have discontinued selling at the farm gate, but rather have established sales points in nearby towns and cities. Wholesalers who buy from the cage operators resell them to retailers and final consumers. Some hotels and restaurants buy directly from the cage farmers. At the sales points, anyone could buy as much as one desired. Market women also bought in bulk and sold the fish in established fish markets dotted around the cities. Figure 2.6 shows the marketing flow chart.

The price of farmed fish is dependent on the size. Fish are graded into different sizes and sold on per kg basis. The sizes of tilapia fish according to the farmers ranged from 3 to 'school boys' with size 3 being the biggest. Below size 1 are the "regular" then the "economy" and the lowest size is dubbed "school boys" (Table 2.5). Generally, the prices of the fish were uniform in almost all the fish farms. Upon interrogation we were informed that the going price of fish at any particular time is determined or dictated by the big commercial farms such as Tropo and West Africa Fish farms. The timing of harvest at a period where there is shortage could also affect the price of fish. It is believed that there is occasional if not continuous importation of tilapia fish into the country which were comparatively cheaper than those produced in Ghana.

At the time of the survey in 2013, the average prices of tilapia were GH¢ 7.90 (US$ 3.95) per kilogramme for size 3, GH¢ 6.50 (US$ 3.25) per kilogramme for size 1, and GH¢ 4.00 (US$ 2.00) for "school boys" (Table 2. 5).

Table 2. 5: Average price per kilogramme of different sized tilapia in the study area.

Sizes	**weight range g**	**Price/ kg (GH¢)**	**Price/ kg (US$)***
3	700 - 1000	7.90	3.95
2	500 - 700	7.20	3.60
1	300 – 500	6.50	3.25
Regular	200 - 300	6.00	3.00
Economy	150 - 200	5.00	2.50
School boys	< 150	4.00	2.00

* 1US$ = 2.0 GH¢ in 2013

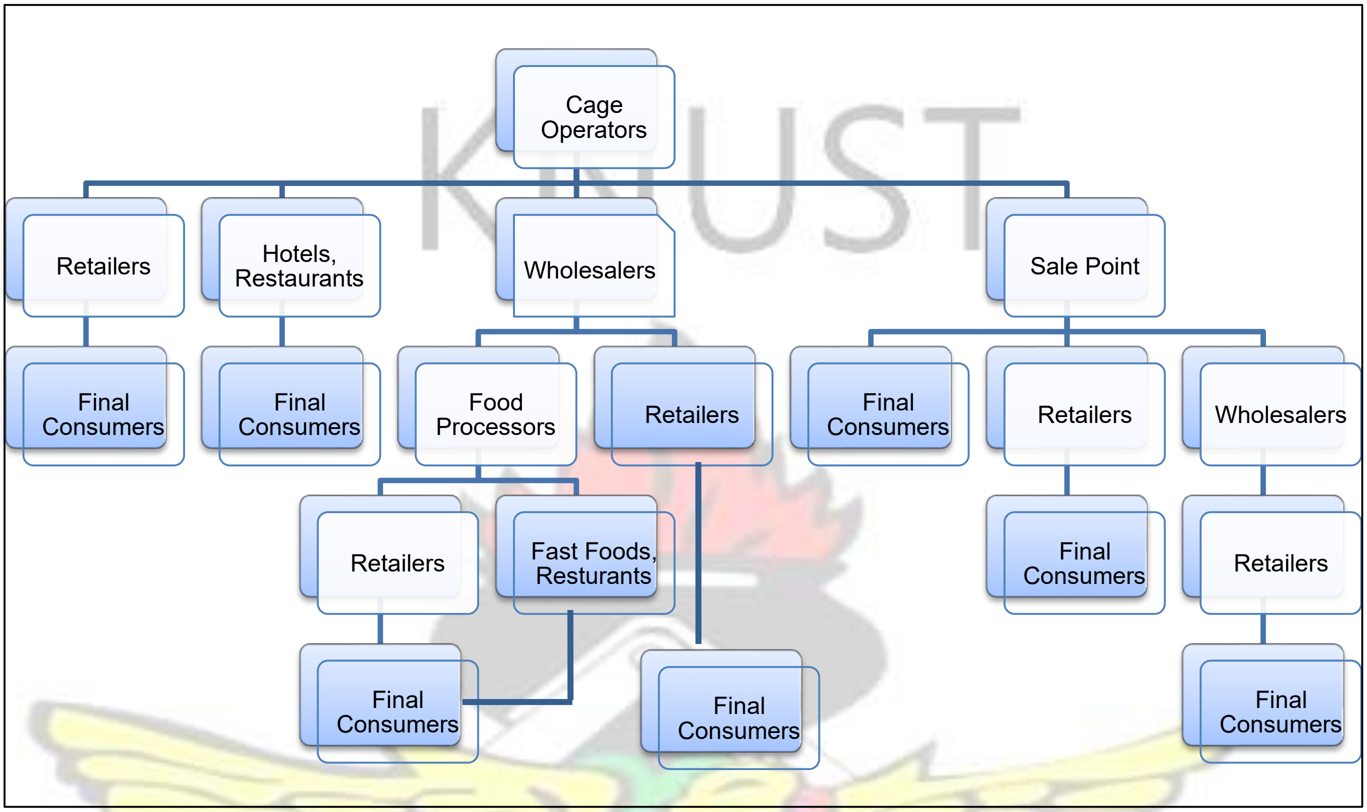


Figure 2. 6: Flow Chart for Fish Marketing by Cage Operators in Volta Lake

2.4 Constraints or Challenges in the Practice of Cage Culture in the Volta Lake

From the survey, sections 2.4.1 to 2.4.6 provide the constraints mentioned by the cage culture farmers. These are classified as technical, environmental, production, economic, social and institutional, and are interconnected.

2.4.1 Technical Constraints

Under technical, the following were listed as constraints: lack of trained and qualified managers, post harvest loss and inadequate facilities. The issue of inadequate facilities were problem of a boat, out-board motor, diving equipment, car, nets etc. that must be provided by the farm owners.

2.4.2 Economic / Environmental Constraints

Lack of credit and water quality was mentioned by the farmers. According to the fish farmers, episodes of low DO or deterioration of water quality resulting from low DO levels normally occurs in January and February every year in certain portions of the lake resulting in fish mortalities and low fish quality. Figure 2.7 shows fish kills in a cage on the Volta Lake in 2015 due to low DO levels.

Figure 2. 7: Fish kills in April 2015 at Ajena in a Tilapia cage farm.

2.4.3 Production Constraints

High feed costs, insufficient and irregular availability of fingerlings and irregular starter feed supply were given as production contraints.

2.4.4 Social Constraints

Cage farmers mentioned poaching or stealing and conflict by community as social problems encountered in their business. In some communities, the cage operators have occupied substantial shore lands which used to be farm lands for the communities, leaving them limited areas for their crop farming. Again, the cages have crowded a long stretch with not much area left for fishing and this results conflict between the cage operators and the communities.

2.4.5 Institutional Constraints

The institutional constraints which were enumerated by the farmers were inadequate skilled personnel, bureaucracy in dealing with state agencies, and shipping logistics problems for the cage farm operators who import feed and other facilities themselves have to go through, these include long processes and delays at the port which eventually affect their operations. Some of the operators consider the processes for obtaining permit and other registrations from state agencies to be cumbersome and long. This prolongs the time for the commencement of the project and ultimately increases the financial cost of the aquaculture project.

2.4.6 Other Constraints

Other constraints were storms damaging cages and net destruction by wild predatory fish. These were not widespread problems.

2.5 Sustainability and Environmental issues

Ghana Environmental Protection Agency (GEPA) requires environmental impact assessment statement from would be aquaculture entrepreneur prior to the establishment of a farm and environmental management plans during the production phases of the farm (MoFAD, 2010). It was observed that the large scale farmers have adequate environmental awareness and was monitoring the water and sediment quality in their farm areas quarterly. However, the small scale farmers had little or no environmental awareness since they were not undertaking any water quality checks. Large-scale farms are required to submit environmental impact statement, while medium-scale farms are required to submit Preliminary Environmental Report (PER).

The small-scale farms are not required to submit environmental impact statement nor Preliminary Environmental Report. They are only required to register their farms with the GEPA.

Some of the small-scale farm managers interviewed believed that given the large size of the lake and the wind action, accumulated nutrient inputs will quickly be diluted and dispersed. These fish farmers were not convinced that their activities could impact on the water quality to a large extent. Localised impacts on the water quality with low DO levels occur usually during the dry season (December-April). The impacts are primarily on the fish farms where loss of fish occurs.

There were reported conflicts between the indigenous fisher folks and the cage farmers. There was a perception that the presence of cages improves local catches; this may be true due to availability of feed around the cages and some escapees from the cages. As such, indigenous fisher folks prefer to fish close to cages where schools of fish congregate for food. This practice is not acceptable to the fish farmers. And this was usually observed in the places where the boundaries of the fish farms are not properly demarcated.

The access to and use of public water ways was another issue of concern. At some locations of the lake, fish farmers have spread their cages in a haphazard manner hindering navigation and the activities of the local fisher folks and boat users.
Expression of dissatisfaction over access to waterways was made by the local people.

2.6 Discussion

In the last two decades, Ghana has seen expansion in cage culture. There were only two known cage culture companies in the 1990's but now we have over 60 cage culture establishments operating in the study area (Blow and Leonard, 2007). Between 2009 and 2014, the development of cage fish farming has been so rapid with a mean annual growth of 73 % (Rurangwa *et al.,* 2015). The contribution of cage fish farming to total aquaculture production in Ghana from 2011 to 2014 was over 88 % (Rurangwa *et al.,* 2015).

From the survey, intensive culture of *O. niloticus* is the common practice of fish farming in Volta Lake of Ghana. Tilapias are the world's second most important fish species for aquaculture after the carp and this is due to their high growth rates, being prolific breeders, completing their life cycle in captivity, tolerance to environmental stress and high market demand (El-Sayed, 2002).

Aquaculture is perceived as a male dominated occupation and this was confirmed by this study where only 4 % (1) of female was engaged in cage aquaculture. A similar result was reported in Hongugu, Vietnam; where they looked at environmental impact of catfish and

about 91 % were males and 9.0 % were female (Yang *et al.,* 2004). In Jalari community in Napal, men dominated the cage culture industry, comprising 84.0 % compared to 16.0 % female (Akbal Husen, 2010). However, in Bangladesh 62 % of the cage farmers were found to be female and 38% were male (Data Management Aid,
2013). Agricultural technologies are not easily embraced by women (Kumar, 2001; Adesina and Chianu, 2002). Anane-Taabeah (2012) in her study of harnessing the opportunities and overcoming constraints to widespread adoption of cage culture in Ghana, noted that It was less likely for women to accept cage aquaculture and suggested that specific packages should be designed focusing on women to encourage them to adopt aquaculture. Women have been mainly concerned in the post harvest sector, focussing on processing and marketing (Heck *et al*., 2007; Weerantuge *et al.,* 2010). Lebel *et al.,* (2009) observed that women were flourishing in aquaculture as their male colleagues in Thailand. Nandeesha (2009), looking at enhancing women participation and strengthening capacity of small holder ASEAN aquaculture farmers, recommended that women should concern themselves in typical aquaculture production. In Bangladesh, WorldFish promoted gender equality that influenced social norms by bridging the gaps in access to, and control of agricultural resources.Women must be supported and encouraged to fully be involved in aquaculture production.

In this study, most of the farmers (63.0 %) were between the ages of 46 to 60 years. Anaglo *et al.,* (2014) observed 83.3 % of respondents in cage farming above 40 years in the same study area. The reason for high percentage of old people in cage farming could be high start up capital. It was observed from the study that professionals such as Accountant, Clearing agents, Aquaculturists and Businessmen were the owners of the cage farms. Yang *et al.,* (2004) working on environmental impact of catfish in Vietnam, found that among the interviewed farmers, those between 40 and 49 years were most abundant and attributed the probable cause to lack of capital. According to Lebel *et al.,* (2009) starting or expanding cage farming require significant amount of cash. Many fish farms use credits or loans from banks and Agricultural cooperatives. Access to financial capital is potentially a more significant barrier to entry than acquiring the necessary aquaculture knowledge (Lebel *et al.,* 2009). For sustainability of the aquaculture industry, there is the need to sensitize some of the banks to provide affordable loans which will be guaranteed by government or special funds set aside to new entrants into aquaculture especially the youth.

The survey revealed that record keeping was a problem in most of the farms, and even those who had the information were not forthcoming with them. Some of the managers had to obtain clearance from the farm owners who were not present at the interview time before releasing simple farm production information. They were unwilling to give information perhaps for fear of their competitors knowing of their secret production techniques or relaying of the information on their activities to the tax officials or any regulatory bodies. From the survey, only 13.0 % of the farm owners were trained aquaculturist though greater percentages (73.68 %) had attained tertiary education. Relative to the farm owners, the educational levels of the managers who were running the day to day activities of the fish farming business were low. Education and training have been identified as contributors to the growth and success of enterprises (Kolstead and Wiig, 2013). The level of manager's education has been shown by several studies as an important factor to the success and growth of companies (McPherson, 1996; Unger *et al.,* 2011). Managerial and technical knowledge in aquaculture were also mentioned by Simpson G. (2012) as major constraints in fish farming in Achavanyo in the Dangme West

District of Ghana. A study by Kamdle (2011) suggested that a manager with skills such as analytical skills, time management, interpersonal, communication and conceptual skills has the greater likelihood to increase profitability and size of an enterprise.

Farmers mentioned lack of skilled personnel as one of their problems. Most of the farms do not have skilled personnel perhaps due to the high cost of skilled labour. Inadequate training and exposure was a problem for some of the cage operators. They relied on the experience acquired from the previous farms. This does not encourage innovative aquaculture practices but seek to perpetuate old traditional practices. Hormiga *et al.,* (2011) observed in a research on the role of intellectual capital in the success of new ventures, that the likelihood of a business enterprise to succeed is dependent on the entrepreneur's level of technical knowledge. Higher technical knowledge of entrepreneurs reflects in good customer satisfaction, higher profits and ultimately high growth (Anaglo *et al.,* 2014). Properly trained and qualified people must be employed to manage the fish cage farms. These must be well resourced and well remunerated. They should have access to continuous training of best management practices (feed management, water quality management, record keeping etc.) to enhance innovative aquaculture practices on the lake. The training could be in a form of workshop, hands on, farm visit by extension officers, training from research organizations, Universities and Fisheries Commission.

The study showed that cage farmers in the lake are all using intensive system of farming where imported commercial feeds which are pelletized floating extruded protein rich feeds are employed. Most of the extruded feeds are imported into Ghana. Fish feed importation into Ghana escalated from 21.5 tonnes in 2006 to 518.7 tonnes in 2009 (Fisheries Commission, 2010). During the survey, it was clear from all the farmers that feed was expensive. According to Drakeford and Pascoe (2008) one of the highest cost elements in aquaculture is feed. Generally the cost of feed varies between 50–60 % of the overall production cost (Beveridge, 2004). According to Rurangwa *et al.,* (2015), averagely, feed cost for tilapia cage farming in Ghana is 70 % of total cost. It has been reported that imported feed cost 30 % more than locally produced Raanan feed. For good fish harvest, good quality feed must be used, and the use of high quality feed would reflect in high prices of fish. In 2013 at the time of the survey, the average price of a kilogramme of size 3 (700-1000 g) fish was US$3.95.

Apart from the high cost of feed, irregular supply of starter feed (mostly imported) added to the woes of the fish farmers. The irregular supply of starter feed was due to the importation bureaucracies and delays. Raanan, the locally feed production company was not producing starter feed. Raanan was working on production of starter feed locally. As soon as that materializes, the supply of starter feed is likely to be regular. However, because of the monopoly the company is enjoying, the price of starter feed is likely to be still high.

Reliable, steady price and good quality feed is needed by the aquaculture industry to facilitate growth and sustainability. Rurangwa *et al.,* (2015) suggested that another feed manufacturing plant is necessary to meet feed demand of 20-30 thousand tonnes. The high price of caged tilapia fish in Ghana compared with imported and captured fish is as a result of high production cost including fingerling, feed, labour and equipment. Fish production will increase if high quality feed is manufactured locally in reasonable quantities. Since feed costs constitute about 60 to 70 % of the total production cost (Rurangwa *et al.,* 2015), availability of affordable good quality feed will promote growth and sustainable development of aquaculture in Ghana. It is hoped that with two or more local feed manufacturing compnies, there will be a healthy competition which will eventually lower prices favouring all fish farmers. With cheaper local feed and similar quality to imported feed, more people will join the fish farming enterprise and create employment and income to Ghanaians and subsequently contribute to food security and reduction of fish imports into the country.

Farmers indicated during the survey that fingerlings for stocking were sometimes not available and where available, the supply was irregular. Farmers do not get the quantities they request for on time due to high demand on the market. This results in low stocking or non stocking of cages. For any aquaculture venture, fingerlings are a vital input. Fingerling production and availability has remained a significant bottleneck to the continued expansion of tilapia cage culture throughout the world (Green, 2006). Several studies have reported lack of fingerlings as major constraint in aquaculture (Ridler and Hishamunda 2001; Moehl *et al.,* 2006; Blow and Leonard 2007; Asmah 2008). In Ghana, the supply of fingerlings has increased greatly since 2005 from 6,844,900 (Kassam, 2014) to 130,127,500 fingerlings in 2013 (MoFAD, 2014) with private sector contributing 96 % of the production (Kassam, 2014). This increase notwithstanding, there is still the need to up the fingerling production because supply cannot meet demand. In this study, a greater percentage of the farmers (77.3 %) stocked their cages using 2 g fingerlings, and only 13.6 % of farmers stocked with 5 g fingerlings. It is important to note that 40.9 % of the farmers produced their own fingerlings from their hatcheries, and therefore can stock at the recommended weight. The weight of fingerlings for stocking encountered in the study area is far below the recommended weight of 15 g for cage stocking (Beveridge, 2004). This may be due to lack of preferred size of fingerlings at the time of stocking. According to Attipoe (2006) and Ofori *et al.,* (2009), cages were stocked with fingerlings weighing 10–30 g, but the difficulty in procuring these weights of fingerlings has now compelled farmers to stock cages with relatively smaller fingerlings (2 g - 5 g). Stocking density has a direct impact on the potential feed loss from the cage and feed access by the fish (Schmittou, 2006). As density increases not only growth but both water quality and feed access decrease and limit production performance through its effect on water quality and feed access. The stocking density i.e. the concentration at which fish are initially stocked into cages by the farmers ranged from 23 fingerlings to 96 fish/m^3 of 2 g fish. The recommended minimum stocking density for tilapia is 80 fish/m^3 (Jadhav, 2009). A good number of the farmers in the study area were stocking below the minimum recommended level. Low intensities of production may have less impact on the environment but production operation may be expensive and could be less profitable.

2.7 Conclusion

The study of cage fish farms on the Lake Volta revealed that the enterprise is economically and socially important, providing and maintaining employment and incomes in the riparian communities and fish for the whole country and thereby contributing to food security. The cage owners were professionals such as accountants, businesmen, clearing agents, traders and aquaculturists, who have hired mangers to take care of the day-to-day activities of the enterprise for them. The cage industry is characterized by men who are in their mid-forties and above due to difficulty on the part of young people in accessing financial capital to enter into the business.

Tilapia (*Oreochromis niloticus*) was the only species being cultured. Very small size (2g) fingerlings was used for stocking due to unavailability of fingerling at stocking periods which is an indication that more hatcheries are needed to fill the gap in the system. The fish farmers used imported and locally manufactured extruded feeds. Generally, the price of feed was high; however, the locally manufactured feed was 30% cheaper. To get the price of tilapia cheap on the market, extruded feed price must come down. Another feed manufacturing plant is needed to break the monopoly of the existing company and offer reasonable price to fish farmers. To ensure the growth of cage fish farming, more feed with good quality and affordable price is needed.

It was noted from the survey that, technical assistance to cage fish farmers received from Fisheries Directorate, Water Reseach Institute, feed suppliers and NGO's was inadequate and irregular. With governments's plan to increase fish production, technical training on culture techniques, feed management, water quality is key to reduce nutrient waste from cage culture into the lake's environment and ensure quality fish all the time to increase profit.

Some of the challenges to cage culture growth were high cost of skilled labour, water quality, lack of credit facility to start and operate cage farming. Some social challenges faced by the industry were stealing, conflict between fish farmers and the fisher folks over fishng areas and access to water space

For sustainable cage culture in the lake, a concerted effort must be made by all stakeholders to address the above enumerated constraints to safe the lake and the industry.

CHAPTER 3:

WATER AND SEDIMENT QUALITY MONITORING OF TILAPIA CAGE FARMS IN LAKE VOLTA

3.1 Introduction

The Lake Volta, which is a multipurpose lake, is the main source of freshwater fish in Ghana, supplying about 90% of the total inland fishery production, which is around 76,845 t (MoFAD, 2015). Fish species encountered are predominantly*Chrysichthys* spp. (34.4 %), Tilapias (28.1 %), *Synodontis* (11.4 %) and few other fish species (MoFA, 2003).

Intensive fish farming in the Volta Lake is a relatively new pressure on Ghana's aquatic ecosystem. Although, still regarded a small industry in Ghana, cage fish farming is rapidly expanding, particularly in Asuogyaman district in the Eastern Region, where cage production of tilapia has increased dramatically since mid 2000's (Kassam, 2013). The Lake Volta cage farming contributed about 90 % (34,692 t) of the total aquaculture production in 2014 (MoFAD, 2015), and consequently may receive considerable nutrient loadings from fish wastes (uneaten fish feed and faeces). Nutrients from cage culture have the potential to cause eutrophication to the lake water. Eutrophication can result in the degradation of the water quality, thus increasing pH levels, depleting oxygen, increasing hydrogen sulphide and ammonia. Phytoplankton growth is often stimulated as well as change in phytoplankton communities. The extent of the effects of cage aquaculture operations depends greatly on the underlying geology, intensity of production, the water volume and the water exchange rate (Boyd *et al.,* 2001).

The environmental impact of waste (fish faeces, uneaten food and metabolic wastes) from cage fish farms is a growing issue of concern around the world. The faeces and the uneated feed have greater contents of carbon, nitrogen and phosphorus than the natural sediments (Morrisey et al., 2000). This causes the lakebed underneath these farming systems to have a high content of organic matter and nutrients.High organic matter enrichment in sediments beneath cages can lead to anoxic conditions (Chen *et al.,* 2000).

It has been noted that cage fish farming has a relatively lesser effect on the water column compared to the sediment (La Rosa *et al.,* 2004; Schendel *et al.,* 2004). Most field surveys on water column characteristics in the vicinity of fish farms have shown little or no effect of dissolved wastes on most of the studied variables (Pitta *et al.,* 1999; Nordvarg & Johansson, 2002; Soto & Norambuena, 2004). The percentage increase of nutrients is higher in more oligotrophic areas than in mesotrophic or eutrophic ones and therefore evidence of fish farming waste should be more readily detectable in such areas (Cornel and Whoriskey, 1993). Annual cage waste loading in the Lake Volta is unknown. Untreated wastes from these cage operations are discharged directly into the aquatic environment, and so there is growing concern that cage farming poses a serious risk of eutrophication. Freshwater cage culture is now receiving increasing attention as an emerging environmental issue. However, there is limited understanding of the environmental impacts of cage aquaculture as long-term water quality data are often lacking.

This chapter provides results of a study carried out from 2013 to 2015 aimed at determining the impact of cage aquaculture on the water column and the underlying sediments compared to control stations further away from the farms.

3.2 Material and Methods

3.2.1 The Study Area (Lake Volta)

The Lake lies between longitude 1° 30'W and 0° 20'E and Latitude 6° 15'N and 9° 10'N (Figure 1.3). At the maximum level, the lake has a volume of 149 km^3, a surface area of about 8,500 km^2 and its length is 400 km. The mean depth is 19 m. It constitutes 3.6% of the surface area of Ghana (Moxon, 1984). The Volta Lake has been divided into eight segments called strata to facilitate hydrobiological and limnological studies (Evans and Vanderpuye, 1973).

The catchment area of the Volta basin is approximately 394,000 km^2 and shared by six countries; Mali, Burkina Faso, Ivory Coast, Benin, Togo, and Ghana. The Volta basin system occupies about 70% of the total land area of Ghana, with the portion in Ghana representing about 42 % of the total basin area. The main rivers draining the Volta basin system are the Black Volta, White Volta, Daka, Oti, Afram, Pru, Dayi and Asukawkaw (Moxon, 1984).

The Volta basin is underlain by the Voltaian formation, composed of sandstone, shales and mudstones. Another formation is pre-Cambrian, classified into Birimian, Buem and Tarkwaian rocks (Dickson & Benneh, 2004).

The climate of the basin is tropical continental or savanna type.The north has only one wet season, from May to November, with peak rainfall occurring in September. In the south, there are two rainy seasons, with peaks in June–July and September–October. The annual rainfall ranges between 1000 and 1150 mm. Mean annual temperatures approach 30 °C, and humidity varies between 90 percent in coastal areas to below 20 percent in the north during the harmattan (northeasterly winds) (Ewer, 1966;

MacCartney *et al.,* 2012). The harmattan, typically occurring from December to February, brings hot, rainless conditions and haze originating in the Sahara. In June and July, easterly winds predominate over the reservoir, bringing squally thunderstorms and heavy precipitation. By August, the whole reservoir comes under the influence of the moist southwesterly to southeasterly monsoon, with prolonged light rain (Biswas, 1969; MacCartney *et al.,* 2012). The very cold harmattan winds in the dry season in January and the heavy rains together with the southwesterly monsoon from June to September cause lower water temperatures and mixing of the waters (Ewer, 1966; Biswas, 1969; Viner, 1969). Reservoir stratification takes place from April to June. Agriculture is the major land use activity in the basin, with remaining areas characterised by extensive livestock grazing. Most of the basin inhabitants being farmers engaged in both cultivation of crops and livestock rearing. During the last decade, intensive cage fish farming is undertaken in the Lake (Kassam, 2014).

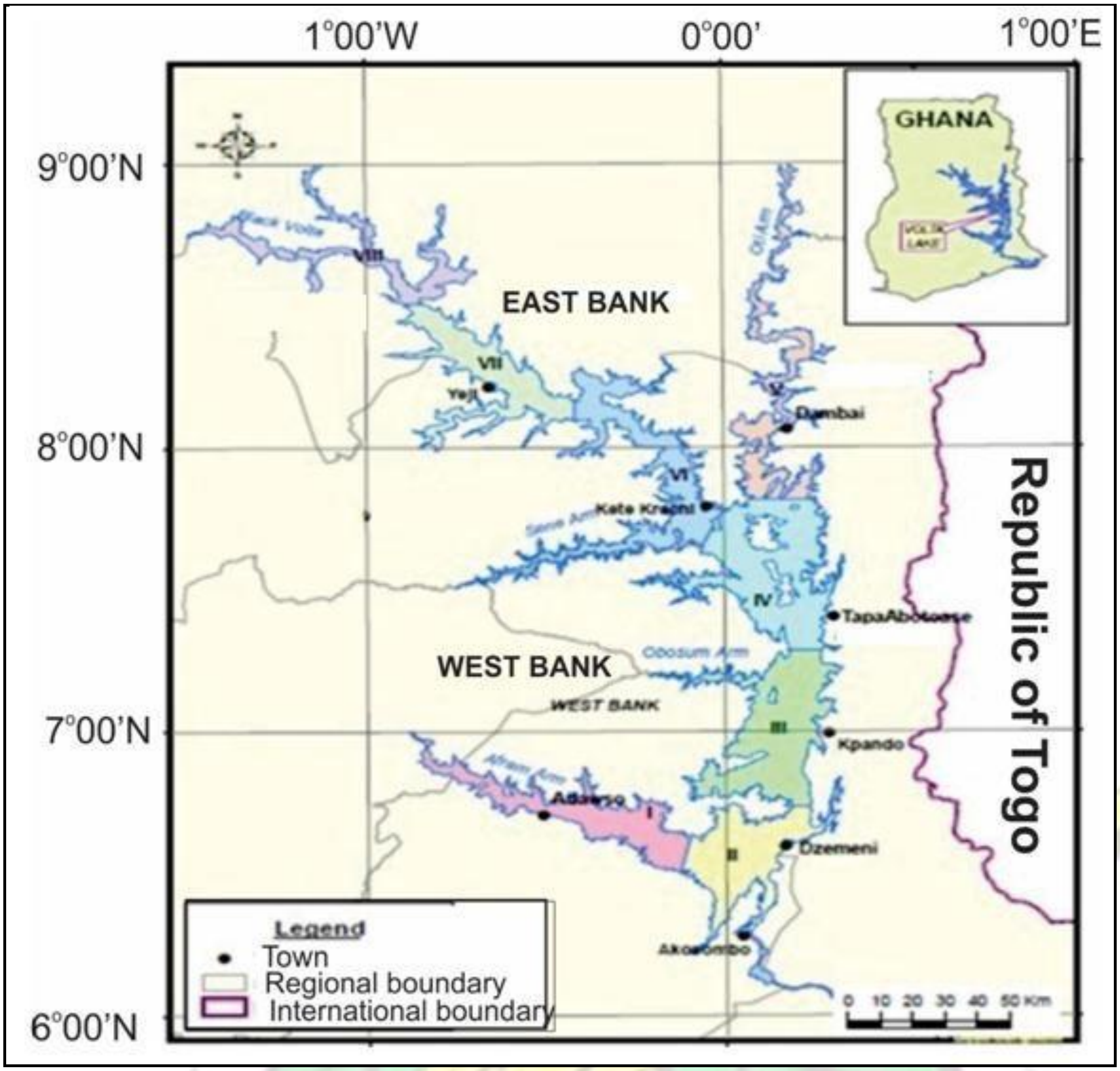


Figure 3. 1: The Volta Lake indicating its management strata

(strata: I = Afram arm; II = lower main body; III = middle main body; IV = upper main body; V = Oti river arm; VI = lower Volta riverine body; VII = middle Volta riverine body; and VIII = Upper Volta riverine body)

3.2.2 Study Sites

Two study sites were chosen from stratum II of Volta Lake based on their hydrological differences such as the current speed and the water depth. Also, the willingness of the farm owners to avail their farms for the study was considered. Two tilapia cage farms, one medium to large (Farm A) at Adjena-Dorno and one large scale cage (Farm B) located near Asikuma (about 16 km from Farm A) were selected for the assessment study (Figure 3.2).

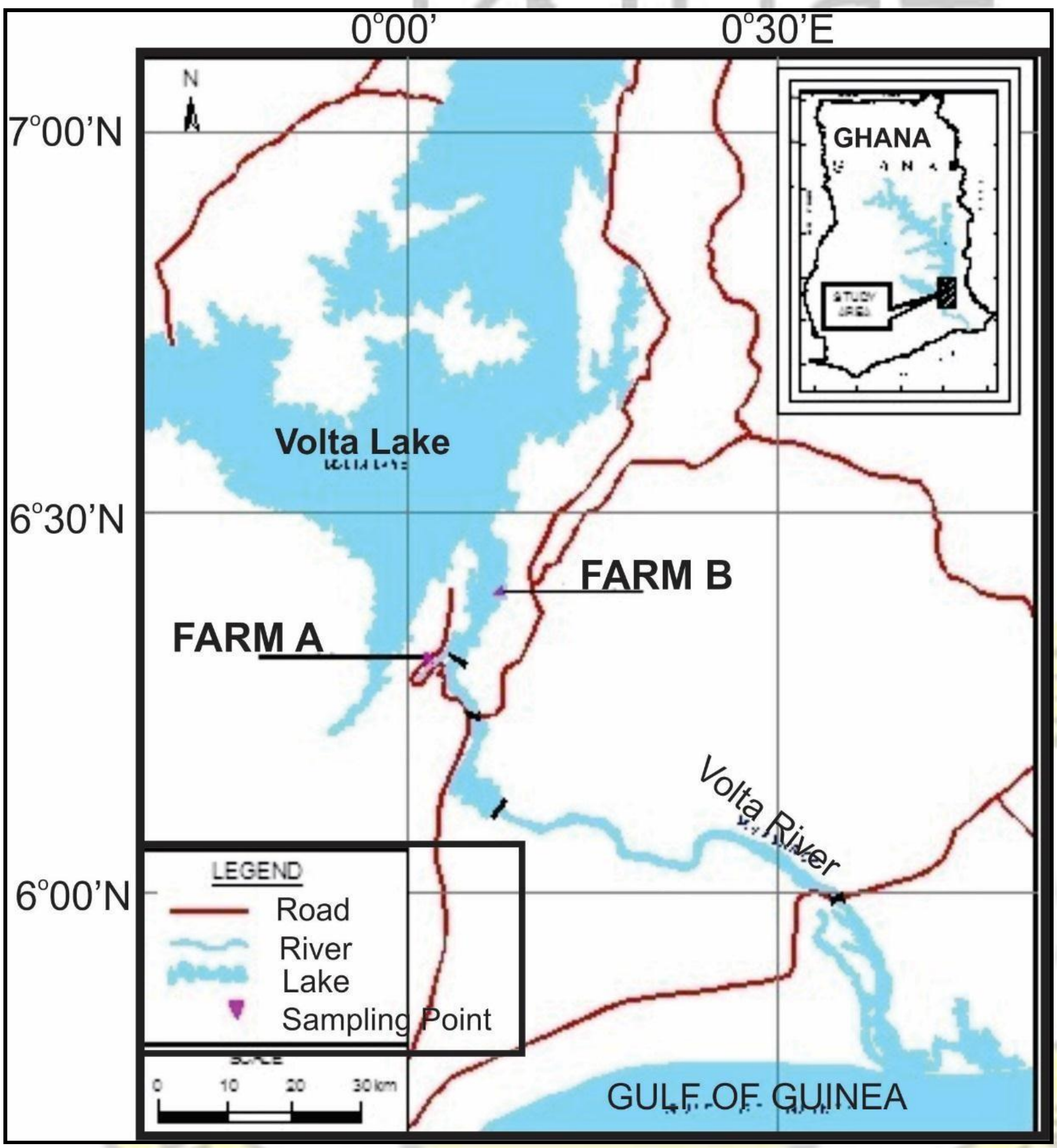


Figure 3. 2: Map of the Lake Volta in Ghana, showing the locations of Farms A and B

3.2.2 Farm A

This is a medium-scale farm with 80 cages of 5m x 5m x5 m. The farm produces its own fry and fingerlings. The farm is located close to the dead end of a side channel of Lake

Volta, near to Akosombo, an inland port with a mean depth of 20 m and a surface current speed of 0.037 m s^{-1} (Figure 3.3). The cages are arranged in five (5) batteries. The stocking density was 80 fish/m^3 using 2 g fish. The farm practiced intensive system of farming and used predominantly locally manufactured extruded feed. Feeding of the fish was by hand. The total production of the farm was estimated at 106 tonnes in 2014 with feed input of 211 tonnes per annum and FCR of 1.99.

3.2.3 Farm B

The fish farm has a land-based hatchery facility located about 100 m from the lake for fingerlings production, and lake-based grow out cages deployed in near shore waters extending to approximately 500 m from the shore with a mean depth of 30 m and current speed of 0.062 m s^{-1}. The fish farm used 60 circular and 60 rectangular-shaped cages for fish production. The circular cages were (16 m in diameter and 6 m deep), whilst the rectangular cages were 5 m x 5m x 6 m. The cages were organized in two arms in a V-shape, with each arm being about 500 m long with cages on both sides (Figure 3.4). Feeding is done by hand with imported and locally manufactured extruded feeds. The feed applied per annum was 3,910 tonnes in 2014 with a stocking density of about 41 fish/m^3 with 2 g fish. The annual production of the farm for year 2014 was 2,300 tonnes and the FCR was 1.7.

Figure 3. 3: A picture of Farm A on Lake Volta

Figure 3. 4: A picture of Farm B on Lake Volta

3.2.4 Sampling

Due to the wide spread nature of the cages at both fish farms a randomized sampling design was employed. Ten stations were sampled in Farm A with two (2) reference sites, upstream (1,500 m) and downstream (1,100 m) of the farm. In Farm B site, the sampling stations included two (2) reference sites, upstream (460 m) and downstream (100 m) of the farm and fifteen (15) sampling stations within the farm. Figures 3.5 to 3.6 show the sampling stations.

The reference sites were necessary in this study to act as pre-impact conditions in situations where no environmental impact assessment (EIA) study was conducted prior to the establishment of the farms. It could therefore be said that any observed statistically significant variation in any environmental parameters between the cage areas and the reference site might be attributed to cage operations.

Water samples were collected bi-monthly with a 3.0 L Van Don sampler from the surface and bottom into clean 1 litre plastic bottles. The water was sampled from 1 m below the water surface and 1 m above the sediment. Sediment samples were also collected bi-monthly using an Ekman grab and kept in clean plastic bags and chilled on ice and transported to the CSIR Water Research Laboratory for analysis. Ten (10) sediment samples were collected from Farm A including two reference sites. Seventeen (17) sediment samples were collected from Farm B including two reference sites located at the downstream and upstream.

Figure 3.5: Sampling stations at Farm A in the Volta Lake, Ghana.

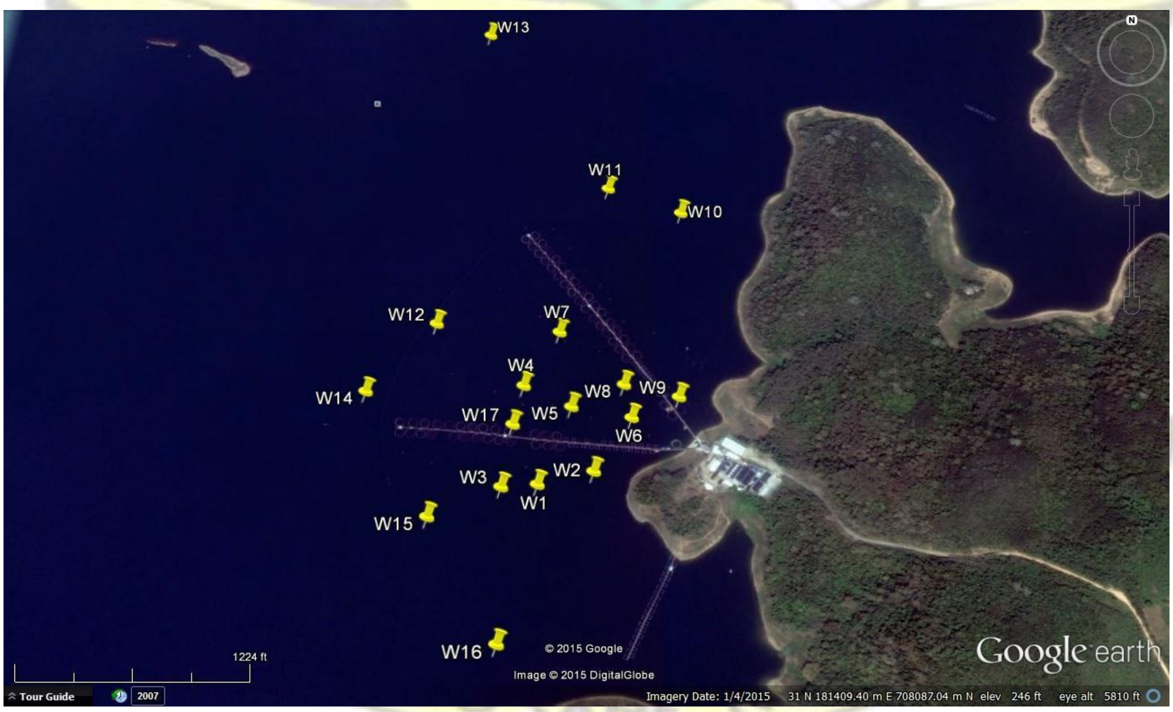


Figure 3. 6: Sampling stations at Farm B in the Volta Lake, Ghana.

3.3 Measurement of Water and Sediment Quality Variables 3.3.1 Temperature, pH, Conductivity, DO, Turbidity and Transparency in Water

Samples

Temperature, pH, and conductivity measures were obtained *in situ* using a multiparametric water probe/meter (Wagtech Maji-Meter, WAG-WE 51000, UK). The water transparency (secchi) was measured with a 20 cm–diameter, black-and- white secchi disk. Dissolved Oxygen (DO) was measured *in- situ* using YSI model 13J100771, version 3.3.0 meter, USA. In the laboratory, turbidity was determined with a HACH 2100P turbidimeter using distilled water as a blank.

3.3.2 Metals in Water Column

For tests on water samples for heavy metals (Cu, Fe, Mn, Zn, Cd, Pb and Se) analyses,100 ml samples were filtered using nitrate filter papers (0.45 µm pore size) and preserved by adding drops of concentrated nitric acid (68.5 %) to the sample until pH less than 2 was achieved. The samples were then analysed with Agilent 240 Atomic Absorption Spectrophotometer (AAS-flame) with deionised water as blank. Seleniun (Se) was analysed using AAS-graphite furnace. The metals investigated are usually additives to fish feed. The AAS was programmed to analyse each parameter in triplicates and report the mean.

3.3.3 Chlorophyll-a and COD Determinations

At the field, water samples for chlorophyll-a determination were collected into 1 litre clean plastic containers and kept in the cold and dark conditions in an ice box and transported to the laboratory. In the laboratory, 1000 ml of water was immediately filtered through Whatman GF/C filter paper. Chlorophyll-a was extracted with ninety percent acetone overnight and centrifuged at 3200 rpm for 10 minutes and about 4 ml of the supernatant poured into cuvettes and measured at 663, 645, and 630 nm, respectively using PG Intruments T60 UV-Visible spectrophotometer (Method No.10200 H, APHA, AWWA, WEF, 2012). Chemical Oxygen Demand (COD) was determined using closed tube reflux, titrimetric method (Method No. 5220 C, APHA, AWWA, WEF, 2012).

3.3.4 Nutrient Levels in Water Column

Hundred milliliters of water samples were filtered through Whatman GF/C filter paper for analysis of dissolved inorganic nutrient (NO_3-N, NO_2-N, NH_4-N and PO_4-P). Nitratenitrogen was determined by hydrazine reduction method, nitrite-nitrogen by dizotization, Ammonium-nitrogen by direct nesslerisation method and orthophosphate or dissolved reactive phosphate by stannous chloride method. They were all determined by colorimetric analysis following procedures outlined in Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF, 2012).

3.3.5 Total Phosphate in Water Column

Persulphate digestion was employed. To 25 ml of the water sample, 1 drop of phenolphthalein indicator was added. Where red colour developed, sulphuric acid

(H_2SO_4) solution was added dropwise to discharge the colour. Then 0.5 ml H_2SO_4 and 0.25 g solid potassium thiosulphate ($K_2S_2O_8$) were added to the solution and boiled on a pre-heated hotplate for about 1 hour until a final volume of 5 ml was reached. The solution was then cooled and diluted to 15 ml with de-ionised water. A drop of phenolphthalein was added to neutralize to a faint pink colour with NaOH solution and made up to 50 ml with de-ionised water. To this sample 8 ml of combined reagent (50 ml of 2.5 M H_2SO_4 + 5 ml $K(SbO)C_4H_40_6.2H_20$ + 15 ml $(NH4)_6Mo_7.0_{24}.4H_20$ + 30 ml ascorbic acid solution) was added and thoroughly mixed and allowed to stand for about
10 mins and then the absorbance of the samples measured at 880 nm, using PG Intruments T60 UV-VIS spectrophotometer and reagent blank as the reference solution.

3.3.6 Moisture Content

About 80 g of the wet sediment samples were weighed and oven dried at a temperature of 110°C for 4 hours and cooled in a descicator and weighed. It was further dried and cooled until a constant weight was achieved. The moisture contents were determined by the formular:

$$Moisture\ (\%) = \left(\frac{Wt.of\ wet\ sediment - Wt.of dry\ sediment}{Wt.of\ dry\ sediment}\right) \times 100 \qquad (3.1)$$

3.3.7 Oxidation Reduction Potential

A grab sediment was collected into a polyethylene bag, and the redox potential measured *in situ* by vertical penetration of a Wagtech Maji-meter probe. Calibration was performed with Wagtech Maji–Cal solution.

3.3.8 Metals in Sediment

About 25 g of wet sediment sampleswere weighed and oven dried at a temperature of 110°C for 4 hours and cooled in a descicator and weighed. It was further dried and cooled until a constant weight was achieved. The dried sediment was grounded and passed through a sieve of 200 mm. About 0.2 g of the dried sediment was weighed and digested with 8 ml nitric acid (65%) and 2 ml hydrogen fluoride (40%) combination in a 'milestone' Ethos microwave digester (START D) at a temperature of 180° C for about 45 minutes. The solution was diluted to 50 ml and left overnight for precipitation of suspended solids prior to analysis by the AAS.

3.3.9 Organic Carbon Content in Sediment

The Walkley-Black procedure was followed. Approximately 0.1g of the fine sediment was weighed using analytical scale (ADAM-PW 254) into 500 ml wide-mouth Erlenmeyer flask. Ten (10) ml of 0.167 M dichromate ($K_2Cr_2O_7$) solution was added. Then, 20 ml sulphuric acid (96 %) was carefully added, swired gently to mix and allowed to stand for 30 minutes in a fume cupboard. Two hundred and fifty millilitres of water and 10 ml phosphoric acid (85 %) were added and allowed to cool.One (1) ml of ferroin indicator solution was added and titrated with 0.5 M ferrous sulphate solution while the mixture is being stirred. Near to the end point, the titration was slowed down and at the end point the colour changed sharply to green. Reagent blank (deionised water) was run using the above procedure without sediment to standardize the ferrous solution.

The carbon content of the sediment is obtained by:

$$\% \, C = M \times \frac{V1 - V2}{S} \times \ 0.39 \ \times mcf \qquad (3.2)$$

Where:

M = Molarity of the ferrous sulphate solution from blank titration

V_1 = ml ferrous sulphate solution required in blank

V_2 = ml ferrous sulphate solution required in sample

S = Weight of dry sediment in grams

0.39 = 3 x 10^3 x 100% x 1.3 (3 equivalent weight of carbon) mcf

= moisture correction factor

% Organic matter = 1.7 x % carbon

3.3.10 Particle Size Analysis- Sieve Method

Empty laboratory test sieves of 200 mm in diameter were weighed and were arranged based on the mesh sizes of the sieve in the descending order of millimeters; 5.0, 2.5,

1.25, 0.63, 0.50, 0.315, 0.20, 0.16, 0.071, and 0.050. The arranged sieves were placed on a shaker and dry sediment sample poured to the largest sieve opening (5 mm). A cover was placed on it and the shaker turned on for 5 minutes. The weight of the sediment retained on each sieve was obtained by subtracting the weight of the empty sieve from the weight of the sieve and retained sediment.The percentage of retained sediment on each sieve was calculated by dividing the weight retained on each sieve by the original sample weight. Sediment type was classified according to United States Department of Agriculture (USDA) textural soil chart.

3.3.11 Sediment Kjedahl Nitrogen

One (1) g of fine sediment was weighed into a digestion tube and 2.5 ml digestion mixture (sulphuric acid (96 %) - selenium) was added. Three (3) aliquots of 1 ml hydrogen peroxide (30 %) were added. The tubes were placed on a heater and heated for about an hour at a temperature of 200°C. The temperature was then increased to approximately 330°C and continued heating for 2 hours until the mixture was transparent. The tubes were then removed from the heater and allowed to cool, and about 10 ml water was added while swirling.

Twenty (20) ml of boric acid indicator solution was added into a 250 ml beaker and placed on stand beneath the condenser tip. Twenty millilitres of NaOH (38%) was added to the digestion tube and distilled for about 7 minutes during which, approximately 75 ml distillate was produced. The beaker was removed from the distiller and the condenser tip was rinsed and the distillate titrated with 0.01 M HCl until colour changed from green to pink. The percent nitrogen was calculated as follows:

$$\%N = \frac{(a-b)}{s} \times M \times 1.4 \times mcf \qquad (3.3)$$

Where:

a = ml HCl required for titration of sample.

b = ml HCl required for titration sample s = air- dry

sample weight in grams

M = Molarity of HCl

1.4 = 14 x 10^3 x 100% (14 = atomic weight of nitrogen) mcf

= moisture correction factor

3.3.12 Sediment Total Phosphate

About 0.3 g of oven dried sediment sample was digested with 8 ml nitric acid (65%) and 2 ml hydrogen fluoride (40%) combination in a 'milestone' Ethos microwave digester (START D) at a temperature of 180° C for about 45 minutes. The solution was diluted to 50 ml and left overnight for precipitation of suspended solids. Exact volume of 0.5 ml of the prepared digested sample was pipetted into a 50 ml flask and diluted to 25 ml with distilled water. Total phosphate was then determined at 880 nm using T 60 UVVisible spectrophotometer after formation of molybdate complex and reduction by ascorbic acid.

3.4 Other Data

Other data such as meteorological, lake water level and water current data were collected from appropriate agencies and presented as follows:

3.4.1 Meteorological Data

Rainfall data and daily average wind speed for the period between January 2010 and

December 2014 were collected from a government operated meteorological station at Akuse (1° 38.532'N, 4° 33.87'E) located about 26 km from the lake. This was the closest well operated station to the fish farms. The recorded data from the station is assumed to represent the general meteorological conditions of the whole area including the fish farms.

3.4.2 Lake Water Level Data

Daily water level data in metres for the period between January 2010 and April 2015 were obtained from the Volta River Authority (VRA) office at Akosombo. The level of water in the lake is read daily at the dam site.

3.4.3 Water Current Data

Drogues were used to determine the water movement at varied depths of the lake. The drogues were deployed horinzontally across the lake at about 50 m intervals. At approximately 30 minute's intervals, the positions and time were recorded using a GARMIN 72 H Global positioning System. In this way movement patterns, direction and velocity were determined. The drogues were deployed at 2 depths, 1 m and 5 m or 1 m and 10 m depending on the depth of water in a specific farm area at the time of drogue deployment.

Three (3) deployments were completed in and outside the farms in 2014 and 2015. The average resultant current velocity and direction was calculated using a model set up in an excel spreadsheet. Measurements were sometimes confirmed with self recording meter (Valeport model 0012B, version 4.01). The data generated are useful for modeling the dispersion of particulate waste.

3.4.4 Sediment Trap

Sediment traps were made of transparent plastic water bottles with height to width ratio of 5.2 (height 43 mm long and 8.3 mm internal diameter). A trap consisted of four water bottles attached to a poly-vinyl chloride (PVC) tube with a string (Figure 3.6). These were deployed in between cages and reference sites to trap particulate material under the cages for analysis of total carbon and nitrogen content. The sediment trap which was suspended I m from the lake bottom was secured in position with a based weight of about 20–25 kg. The trap was attached to a tight rope between the anchor at the bottom and a buoy on the water surface to ensure correct vertical orientation. The traps were deployed 3 times in Farm Aand 5 times in Farm B and in the months of August and December 2014 and February 2015 for different days and the GPS coordinates recorded. The traps which were deployed at the reference sites were all removed by the local fisher folks. At the farm sites one was successful in Farm A and three were successful at Farm B. The length of deployment in Farm A was 4 days; while Farm B was 8, 35 and 56 days. The samples in the trap were carefully transferred into clean transparent plastic bottles and transported in ice chest to the CSIR Water Research Laboratories for analysis. At the laboratory the samples were agitated in the bottles and filtered through pre-weighed Whatman GF/F glass fibre filters for analysis. The particulate material was dried in an oven for over 48 hours at 60° C until a constant weight and stored in a desiccator. Part of the dried sample was used for analysis of total organic carbon, organic matter and nitrogen.

Figure 3. 7: Fabricated sediment trap with a base weight

3.4.5 Wild Fishes Observation

A lot of wild fish species of different sizes were observed in the immediate vicinity of the cages in the fish farms. These schools of wild fish consumed feeds that were dispersed from the cages. According to Katz *et al.,* (2002), the consumption of waste by wild fishes around cages may reduce the quantity of food that reaches the bottom and diminish effects upon benthos. The wild fishes were so numerous that, it was possible to catch some fish with a hand net, but no attempt was made.

3.5 Water Quality Indices

Two different water quality indices were chosen to compute the water quality status of Lake Volta for intended purposes. The first is the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) which has been used in this study to compute the WQI for tilapia cage farming. The second is the adapted Ghana water quality index which is based on Solway to calculate the WQI for other intended ecosystem use.

3.5.1 CCME WQI

The CCME WQI provides a flexible index template adaptable to the specificity and treatment considerations of water source. The CCME WQI is an objective-based index that compares measured water quality values to guidelines to produce a score ranging from 0, representing worst quality, to 100, representing the best quality. Practitioners are free to select appropriate parameters and guidelines for their purpose. Accordingly, the CCME WQ index of categorization is presented in Table 3.1 and parameters sensitive to tilapia production and their guidelines for considerations associated for assessing the water source in Table 3.2.

Index scores of CCME (2001) are calculated as follows:

$$CCME\_WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \qquad (3.4)$$

Calculation of the index is based on three terms:

Scope (F1) – number of parameters that are not compliant with the water quality guidelines,

Frequency (F2) – number of times that the guidelines are not respected and

Amplitude (F3) – the difference between non-compliant measurements and the corresponding guidelines.

Division of these terms by 1.732 is based on the fact that each of the three factors contributing to the index can reach the value of 100. The maximal length is, therefore, expressed as:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30,000} = 173.2 \qquad (3.5)$$

Division by 1.732 reduces the maximal length to 100. First of all, the term **F1** (scope) expresses the percentage of parameters for which at least one measurement did not comply with the corresponding guideline during the period under study:

$$F_1 = \left(\frac{\text{Number of failed parameters}}{\text{Total number of parameters}}\right) \times 100 \qquad (3.6)$$

The term **F2** (frequency) represents the percentage of analytical results that do not comply with the guidelines

$$F_2 = \left(\frac{\text{Number of failed results}}{\text{Total number of results}}\right) \times 100 \qquad (3.7)$$

Finally, the term **F3** (amplitude) represents the *difference* between the non-compliant analytical results and the guidelines to which they refer. The term F3 is an asymptotic function, representing the normalized sum of excursions (nse) in relation to guidelines within the range of values from 0 to 100.

$$F_3 = \left(\frac{\text{nse}}{0.01 \times \text{nse} + 0.01}\right) \qquad (3.8)$$

To calculate the overall degree of non-compliance, we add the excursions of noncompliant analytical results and divide the sum by the total number of analytical results.

This variable is called the normalized sum of excursions (nse).

$$nse = \left(\frac{\sum_{i} \text{excursion}_{i}}{\text{Total number of results}} \right) \tag{3.9}$$

There are three possible ways of determining the excursion:

- If the finding must not exceed the guideline:

$$Excursion_{i} = \left(\frac{\text{Failed test result}_{i}}{\text{Guideline}_{i}} \right) - 1 \tag{3.10}$$

- If the finding must not be lower than the guideline:

$$Excursion_{i} = \left(\frac{\text{Guideline}_{i}}{\text{Failed test result}_{i}} \right) - 1 \tag{3.11}$$

If the guideline is zero (equal to zero):

$$Excursion_{i} = Failed\ \ test\ result \tag{3.12}$$

Table 3. 1: CCME WQ Index of categorisation

Rank	Score	Interpretation
Excellent	95 - 100	Water quality is intact.
Good	80 - 94.9	Water quality is intact, only minor threat is observed.
Fair	65 - 79.9	Water quality is intact, but occasionally deteriorated.
Marginal	45 - 64.9	Water quality is frequently endangered or deteriorated.
Poor	0 - 44.9	Water quality is almost always deteriorated;

Source: CCME, 2001

Table 3. 2: Optimum ranges for physico-chemical variables for culture of tilapia (*Oreochromis niloticus*) in Volta Lake

Variables	**Optimum ranges**	**Reference**
Temperature (° C)	22 -38	Ross, 2000; Mires, 1995
pH	6.5 -9.0	Ross, 2000; Nandlal & Pickering, 2004
DO (mg/L)	3-15	Buttner *et al.,* 1993
Total hardness (mg/L)	20-350	Buttner *et al.,* 1993
Alkalinity (mg/L)	54-200	Buttner *et al.,* 1993
Dissolved reactive phosphate (mg/L)	0.5-1.5	Ross, 2000
Nitrite- nitrogen (mg/L)	< 0.1-0.3	Buttner *et al.,* 1993 Boyd & Tucker, 1998
Nitrate (mg/L)	<400	Cantor, 2007
Ammonium-nitrogen (mg/L)	<5.0	Schmittou, 2006
Unionized ammonia (mg/L)	<0.01	Francis-Floyd *et al.,* 2009 El-Sherif *et al.,* 2008
Sulphate (mg/L)	0-500	Nandlal & Pickering, 2004
Total Dissolved Solids (mg/L)	<300	Nandlal & Pickering, 2004

3.5.2 Ghana Water Quality Index (GWQI)

The adapted water quality index for Ghana was proposed for assessing surface water quality in Ghana with respect to intended use such as drinking, water supply, irrigation, recreation and aquatic ecosystem protection. The adapted WQI used in assessing the state of the various basins in Ghana is based on the Solway River Purification Board (RPB) Weighted Water Quality Index developed by Bolton *et al*. (1978).
The Adapted Solway Water Quality Index (WQI) is calculated from the following equation:

$$Waterqualityindex = \frac{1}{100} \times \left(\sum_{i=1}^{n} qiwi\right)^2 \quad (3.13)$$

Where, *qi* = water quality score of parameter *i*; *wi*= weighting factor of parameter *i* and *n* = number of parameters. The aggregation equation generates a single number between 0 and 100, with 0 indicating worst water quality and 100 indicating best water quality. The Ghana adopted water quality classification of surface waters is presented in Table 3.3.

Separate models were prepared which is implemented in the Microsoft excel spreadsheet for computing CCME WQI scores and GWQI scores.

Table 3. 3: Ghana adapted water quality classification of surface waters

Class	Range	Description
I	>80	**Good**, unpolluted.
II	50 – 80	**Fairly good**, Few of uses are impaired.
III	25 - 50	**Poor quality**, Several uses are impaired.
IV	<25	**Grossly polluted**, Most uses of the water are impaired.

Source: WRC, 2003

3.6 Statistical Analysis

Statistical analysis was carried out using SPSS version 21. To determine whether significant differences existed between the different physico-chemical parameters monitored in the farms and the reference sites, all results were analyzed using a oneway analysis of variance (ANOVA) followed by Tukey's multiple comparisons of means. Probabilities of $p < 0.05$ were considered significant. Relationships between TOC, TOM, TN and TP were compaired by Pearson's correlation coefficients. Relationships between turbidity and transparency; between Chlorophyll-a and total phosphate; between metals were also estimated by Pearson's correlation coefficients.

3.6 Results

The meteorological data, lake water level, water current data and the results of the water and sediment quality monitoring are presented in the subsequent Tables and Figures.

3.6.1 Meteorological Data

The rainfall and wind speed data collected from the meteorological station at Akuse covered the period between January 2010 and December 2014. The station is approximately 36 km and 26 km from Farms A and B, respectively.The basin under study experiences bimodal rainfall pattern. The first rainy season starts from April with a peak in May/June as shown in Figure 3.6. The second rainy season has a peak in

September/October. The rest of the year was drier from November to March and July to August. From the data, August recorded the lowest rainfall of 0 mm in 2013; 5.1 mm in 2011 and 34.2 mm in 2010. The highest rainfall amount of 227.1 mm was recorded in June 2014 (Figure 3.8).The wind speed indicated moderate values with the lowest value of 0.342 m s^{-1} recorded in December 2013 and the highest value of 1.842 m s^{-1} in August 2014 (Figure 3.9).

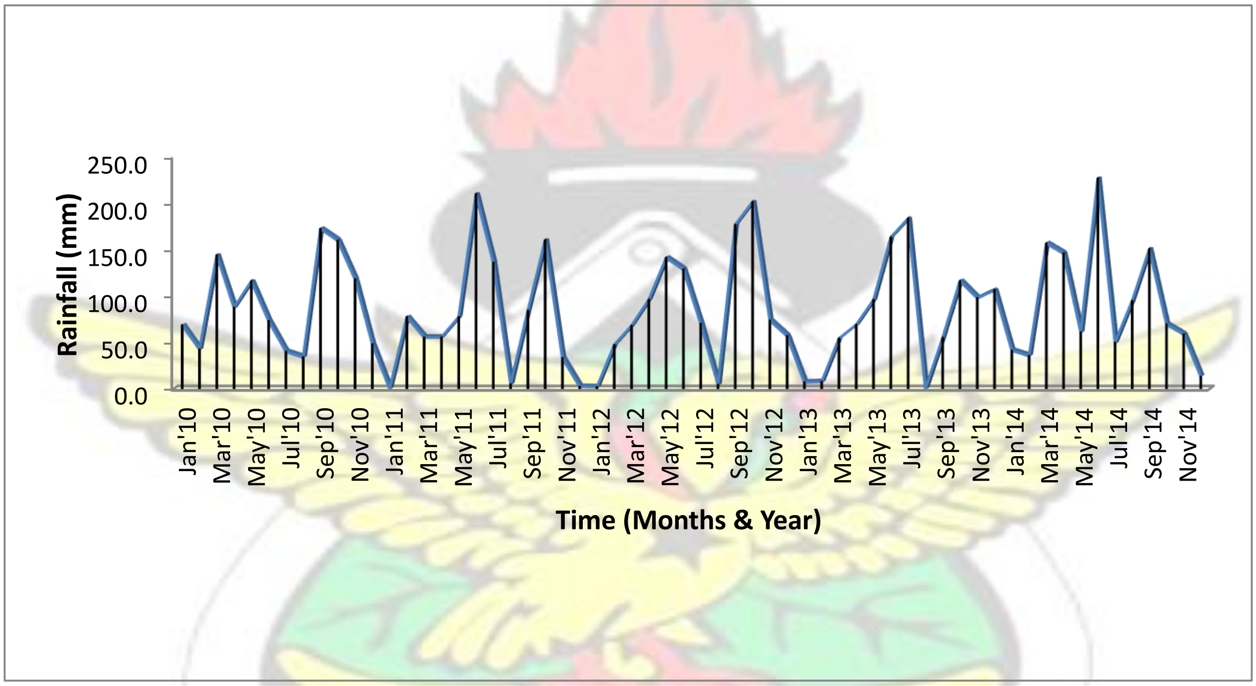


Figure 3. 8: Monthly total rainfall (mm) observed at Akuse Meterological station.

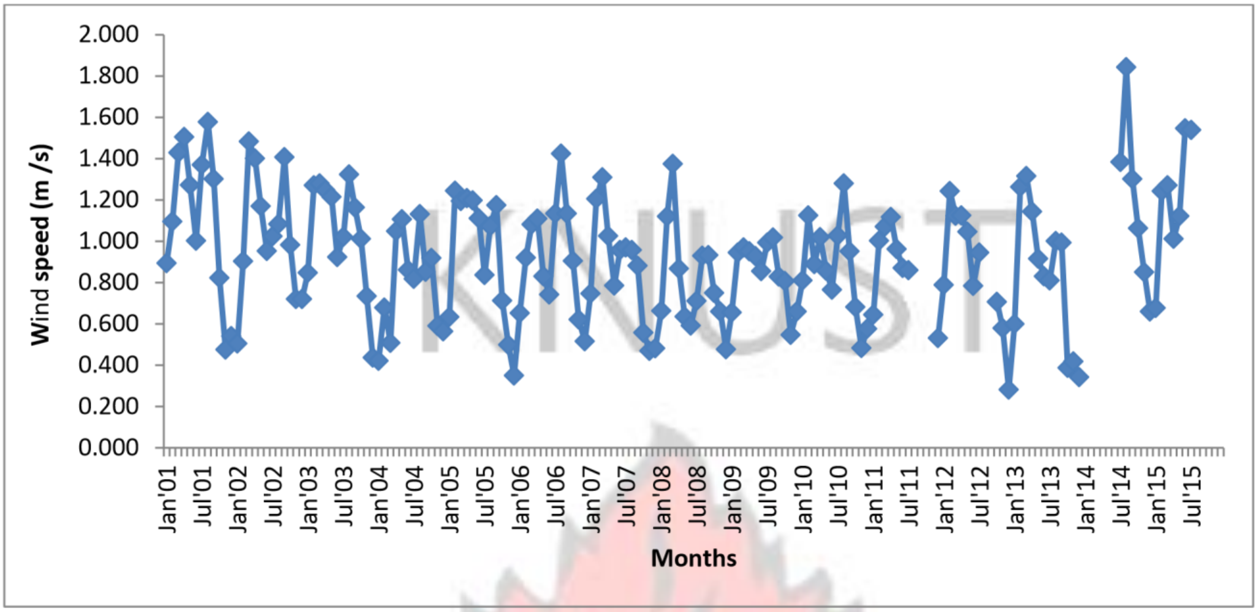


Figure 3. 9: Daily average wind speed (ms^{-1}) observed at Akuse Meterological station

3.6.2 Lake Water Level

The Lake level since the beginning of the study has been dropping from March 2013 (79.3 m) to April 2015 (73.7 m). It was observed that the lake recorded one of the lowest levels of 72.7 m in June 2014. From the lake's water level curve Figure 3.10, the lake begins to fills up in August–September and starts dropping in December until the lowest level in May–July. However, since February 2013, the water level has continued to drop until April 2015.

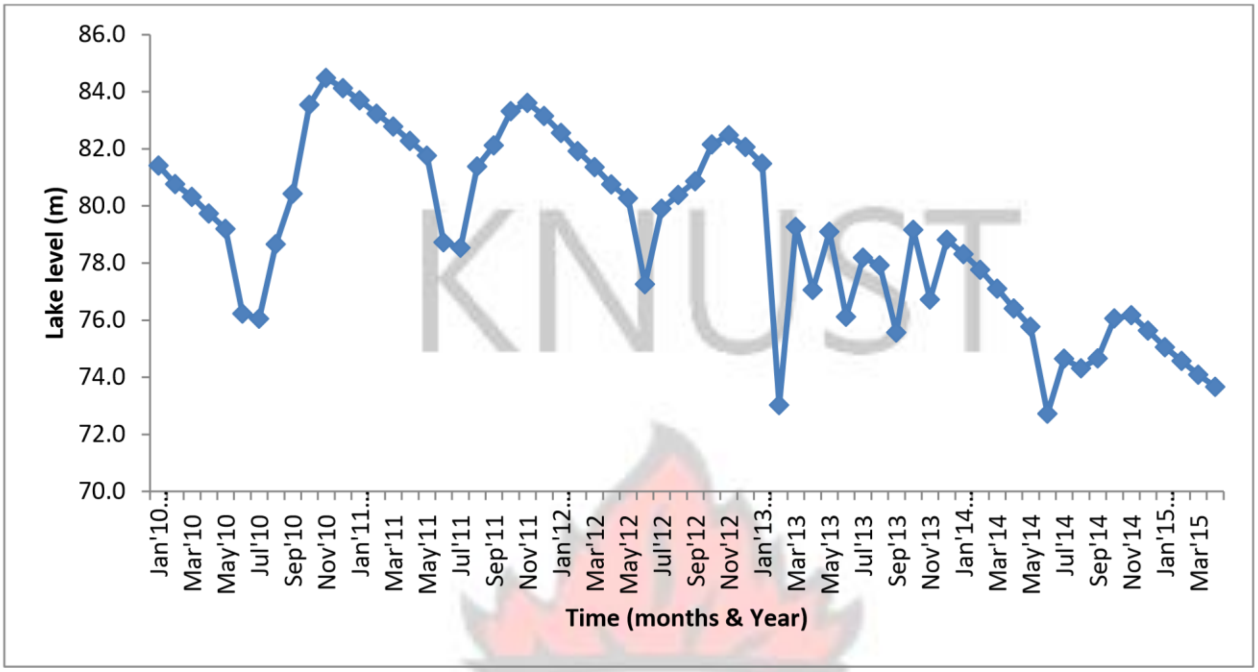


Figure 3.10: Lake Volta level (m) fluctuation observed at the dam site

3.6.3 Water Current Data

The hydrographic current flows are given in Figures 3.11 to 3.14 for Farm A and Figures 3.15 to 3.18 for Farm B.

The Farm A is situated in a narrow and shallow arm of the lake. The mean current speeds were 0.056 and 0.039 m s^{-1} at I m surface and 10 m respectively, indicating a good dispersion capacity. The scatter plots (Figure. 3.11) indicate similar patterns. The residual flow though differs at different depths, have the same direction, the surface water moved considerably faster than at the 10 m depth (Figure 3.12). In March 2015, the Farm A surface (1 m) current was characterisedby slow flow rate with the average current speed of 0.017 m s^{-1}. A 5 m depth current speed was 0.036 m s^{-1}. The average speeds recorded by the valeport were 0.038 and 0.044 m s^{-1} for the 1 m and 5 m, respectively. The residual flows were in the same direction of north east (Figure. 3.14).

The current within Farm B cage site in August 2014 recorded an average current speed of 0.105 m s^{-1} and 0.057 m s^{-1} at 1 m from the surface and 10 m depth, respectively. These may be considered high current especially the 1 m surface current. Both currents were moving in the same direction. The currents were primarily to the north east. Any distribution of waste from this area would be towards the north east (Figure. 3.15). However, the current speed at Farm B cage sites in March 2015 were, respectively 0.037 m s^{-1} and 0.036 m s^{-1} for 1 m from surface and 10 m depth. These currents were lower than the August 2014 but still have the potential to distribute waste. The resultant current direction was towards the south (Figure 3.18). A valeport impeller current meter used to confirm the current speed at the same site on the same day recorded mean current speed of 0.042 m s^{-1} for the 1 m from surface and 0.041 m s^{-1} for the 10 m depth.

The current speeds outside the farms were also measured. Outside Farm A in the month of March 2015, drogue current speed recorded for 1 m surface was 0.063 m s^{-1}, while the valeport gave a speed of 0.046 m s^{-1}. At depth 5 m, the water current was respectively 0.039 and 0.041 m s^{-1} for drogue and valeport.During March 2015 deployment, current speed of 0.111 and 0.073 m s^{-1} were measured at 1 m surface at Farm B using drogue and valeport, respectively. At depth 10 m, 0.060 and 0.061 m s^{-1} were recorded by drogue and valeport, respectively.

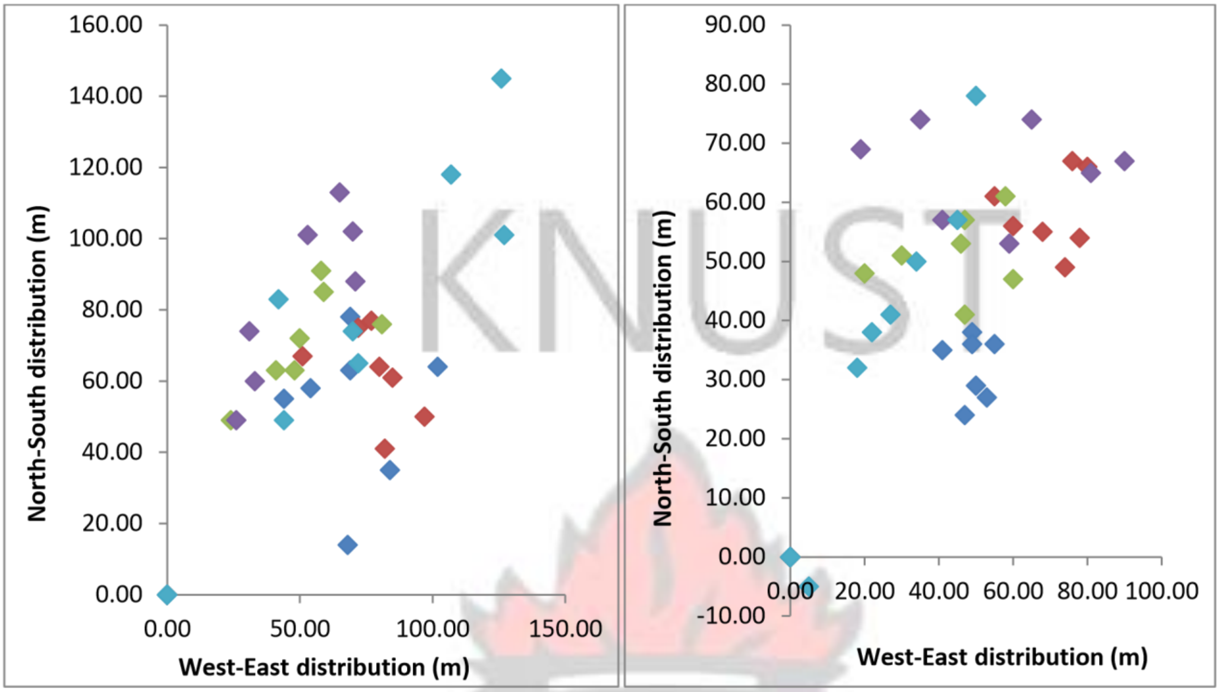


Figure 3. 11: Scatter plot of 1 m and 10 m current at Farm A (13th August 2014)

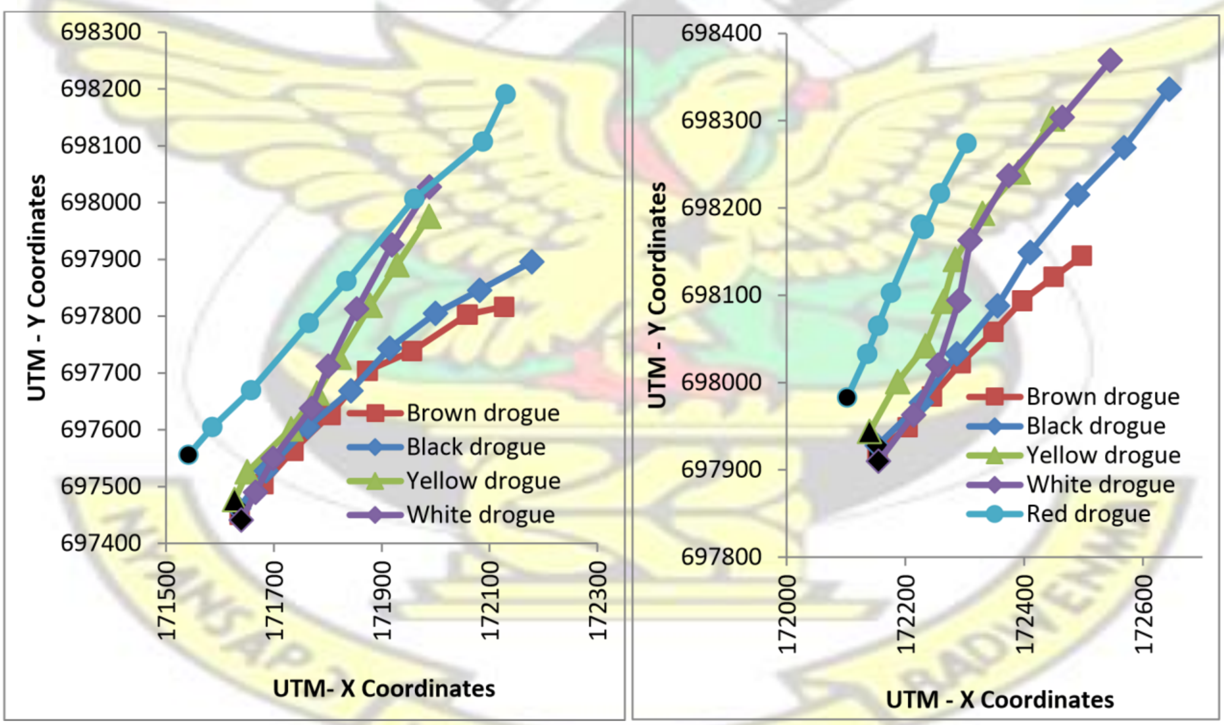


Figure 3. 12: Track plot showing residual current at Farm A (13th August 2014)

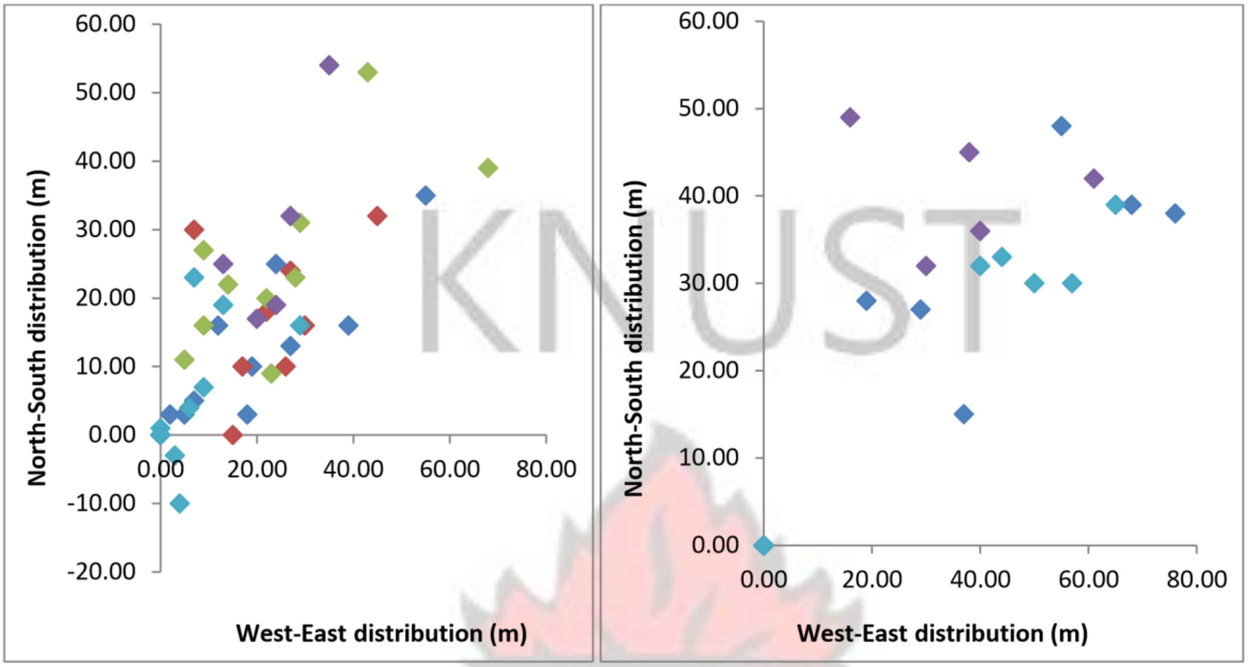


Figure 3. 13: Scatter plot of 1 m and 10 m current at Farm A (16th March 2015)

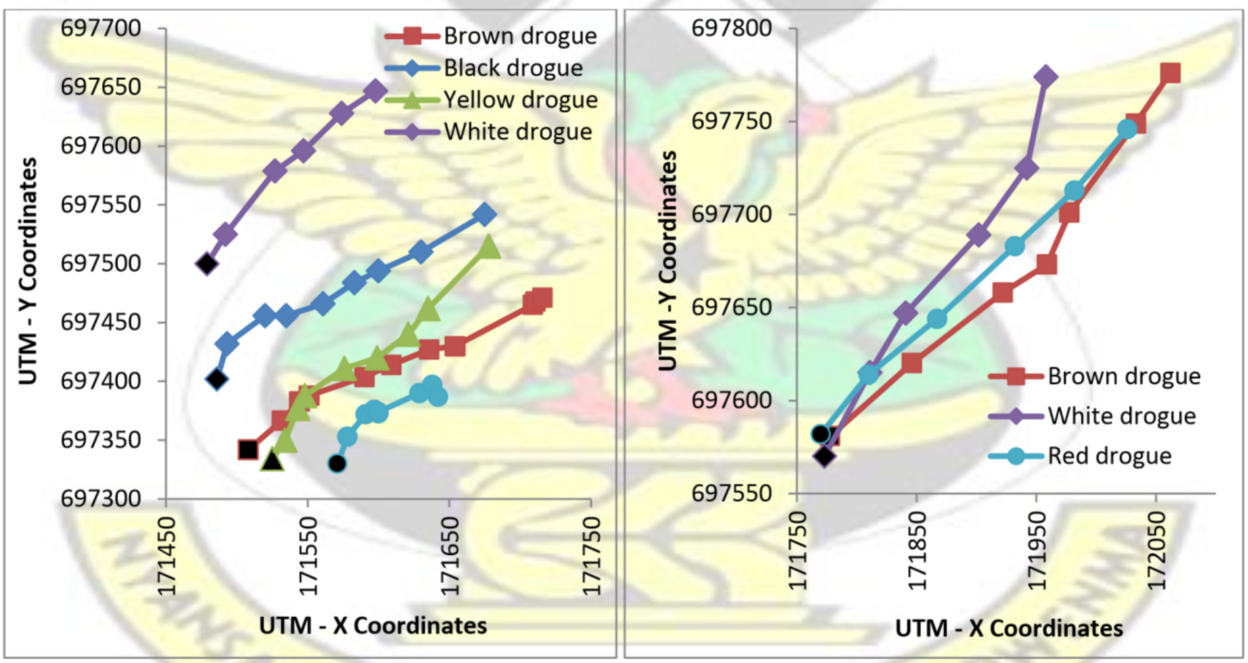


Figure 3. 14: Track plot showing residual current at Farm A (16th March 2015)

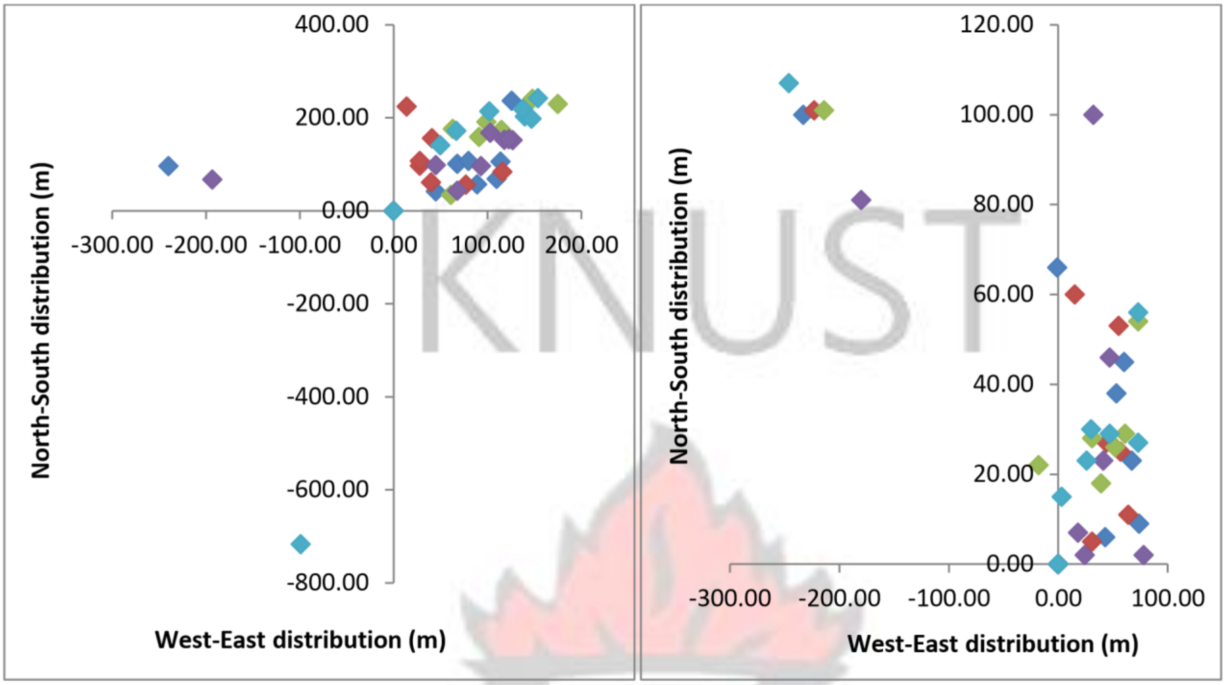


Figure 3. 15: Scatter plot of 1 m and 10 m current at Farm B (9-10th August 2014)

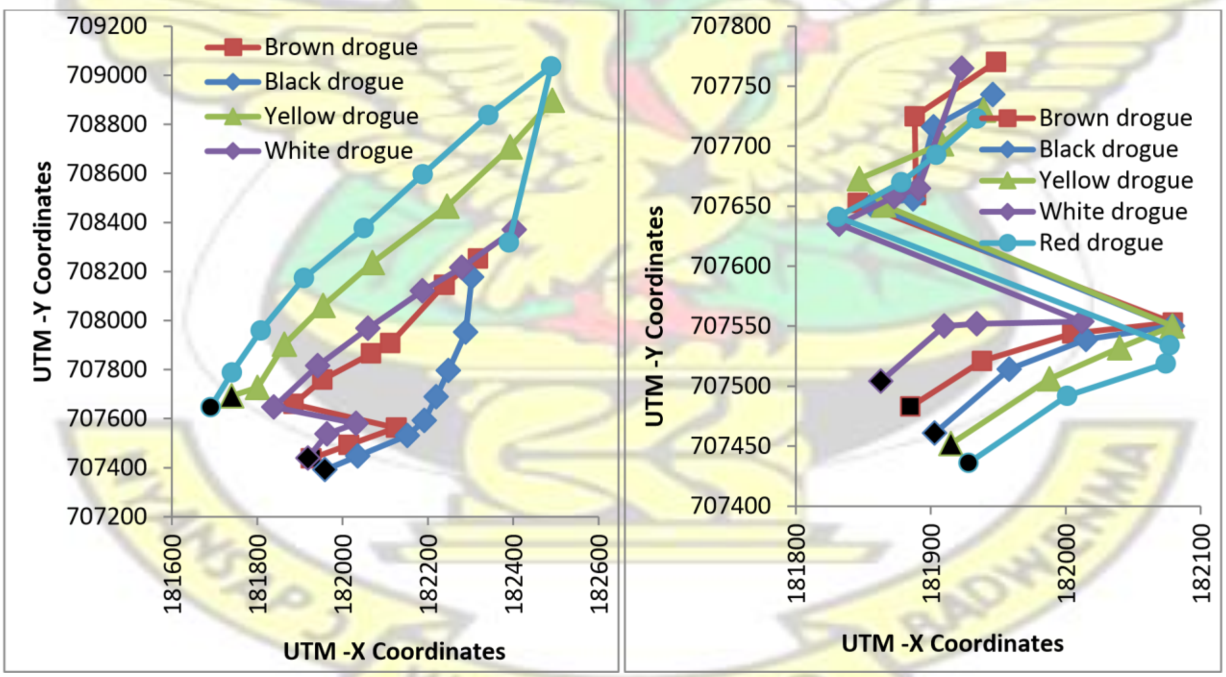


Figure 3. 16: Track plot showing residual current at Farm B (9-10th August 2014)

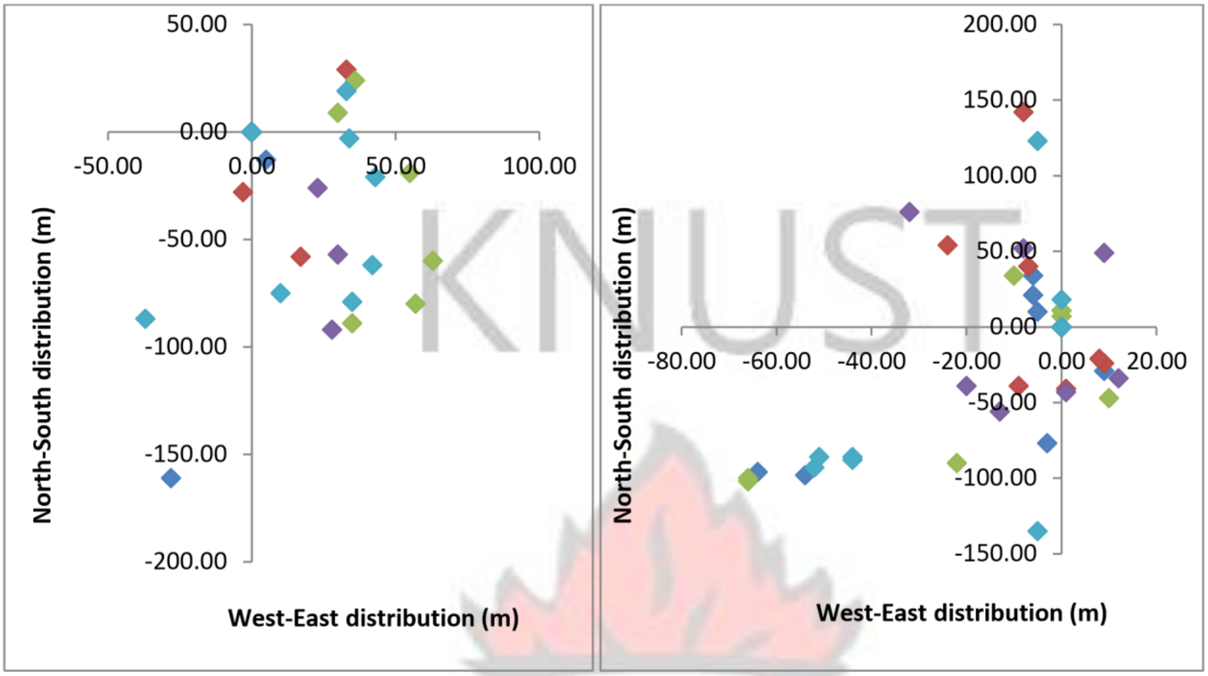


Figure 3. 17: Scatter plot of 1 m and 10 m current at Farm B (14-15th March 2015)

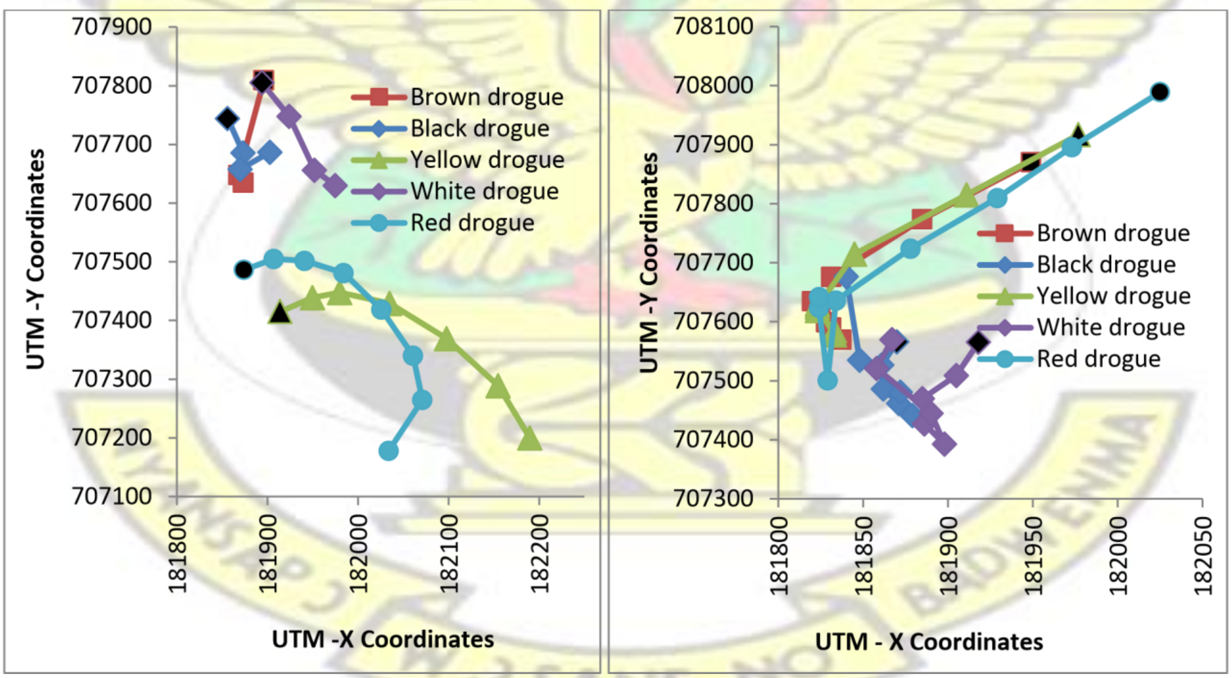


Figure 3. 18: Track plot showing residual current at Farm B (14-15th March 2015)

3.6.4 Nutrients

Temporal variations of nutrients (NO_2-N, NO_3-N, NH_4-N, PO_4-P) concentrations in the water column both surface and bottom for Farms A and B are shown in Figures 3.19 and 3.20. The nutrient levels are the monthly mean recorded in the studied areas. Nitrite concentrations for Farm A ranged from 0.001 to 0.006 mg/L in the surface water and from 0.001 to 0.004 mg/L in the bottom water. The levels of NO_2-N in the reference samples varied from 0.001 to 0.013 mg/L in the surface and from 0.001 to 0.004 mg/L in the bottom. At Farm B, the NO_2-N levels varied from 0.001 to 0.009 mg/L at the surface. The reference site for the surface ranged from 0.001 to 0.009 mg/L. The one way ANOVA showed that there were no significant differences (p > 0.05) between the levels in the farms and the reference sites.

Nitrate concentrations in the water column ranged from 0.001 to 0.250 mg/L at the surface, 0.001 and 0.278 mg/L at the bottom of Farm A and the reference site fluctuated from 0.001 to 0.185 mg/L at the surface, 0.001 and 0.267 mg/L at the bottom. In Farm B, the NO_3-N varied between 0.001 and 0.142 mg/L, and from 0.001 to 0.167 mg/l in the surface and bottom waters, respectively. The reference site levels for NO_3-N ranged from 0.002 to 0.202 mg/L at the surface, while the bottom waters ranged between 0.001 and 0.202 mg/L. There was a temporal pattern observed for NO_3-N which was similar in both farms and the reference sites (Figures 3.19 and 3.20), but the pattern was unclear.The highest NO_3-N value was recorded at the bottom water of Farm A in August 2014. There was no significant difference in NO_3-N levels between those in the farms and the reference sites.

Ammonium-nitrogen (NH_4-N) levels in Farm A oscillated between 0.001 and 0.225 mg/L in the surface water while the bottom ranged from 0.001 to 0.231 mg/L. In Farm B, NH_4N varied from 0.001 to 0.269 mg/L at the surface and from 0.001 to 0.301 mg/L in the bottom. Ammonium-nitrogen concentrations were generally low at the start of the monitoring but peaked in June 2014 and decreased till February 2015. The reference sites recorded similar concentrations as the farm areas (Figures 3.19 and 3.20). No significant differences ($p > 0.05$) were observed in the NH_4-N levels between the farm and the reference sites.

Orthophosphate (PO_4-P) concentrations fluctuated from 0.010 to 0.145 mg/L in the surface and 0.011 to 0.214 mg/L in the bottom waters of Farm A. The reference sites ranged from 0.014 to 0.187 mg/L for the surface and 0.001 to 0.172 mg/L in the bottom. PO_4-P values in Farm B ranged from 0.013 to 0.196 mg/L with at the surface and from 0.016 to 0.199 mg/L in the bottom. The reference sites (0.001-0.261 mg/L) for the surface and (0.001-0.174 mg/L) for bottom, respectively. There were no significant differences ($p > 0.05$) between the farm PO_4-P levels and the reference sites.

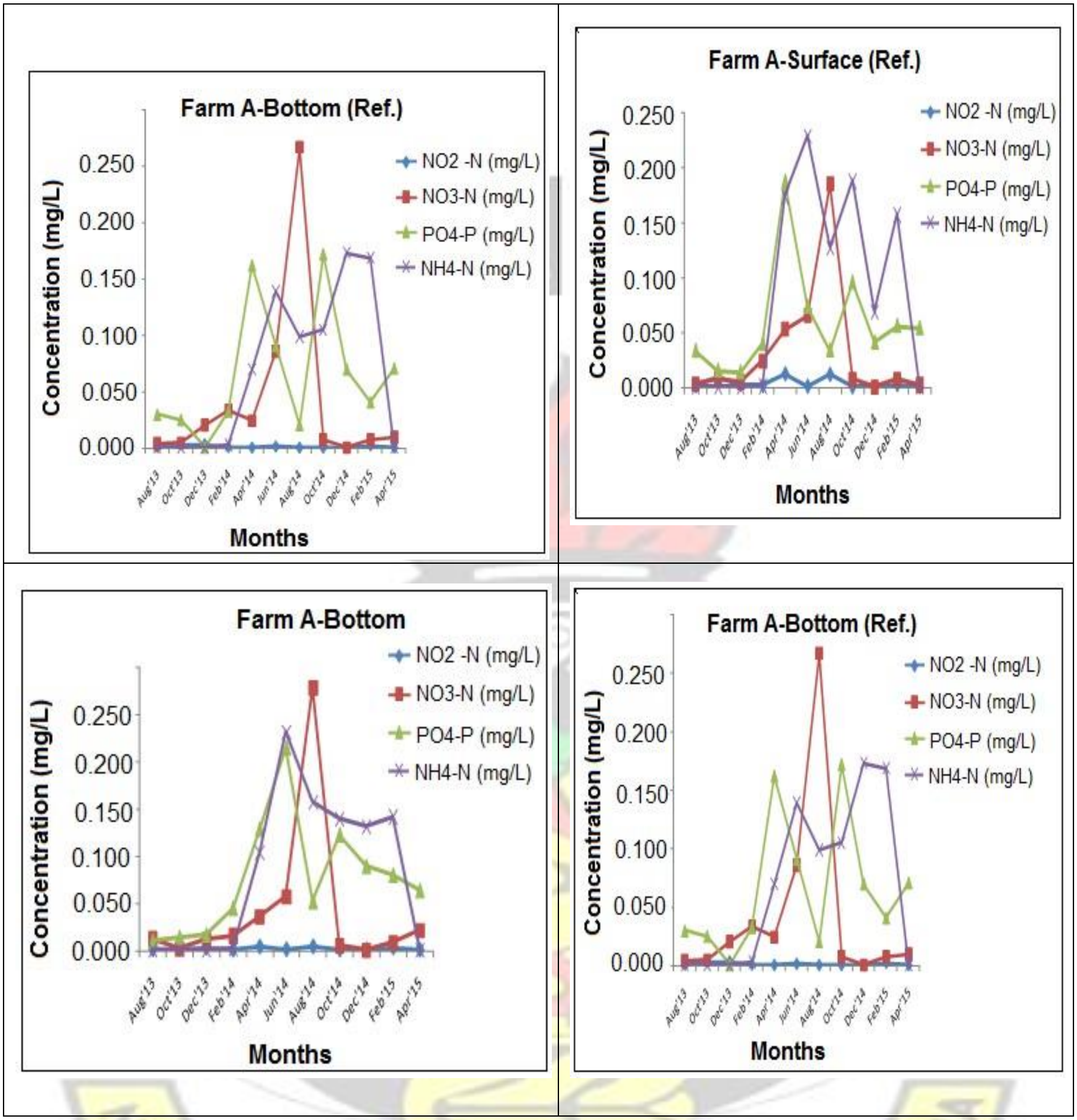


Figure 3. 19: Temporal variation of dissolved nutrients (NO_2-N, NO_3-N, NH_4-N, PO_4-P)in Farm A and reference site of Lake Volta, Ghana

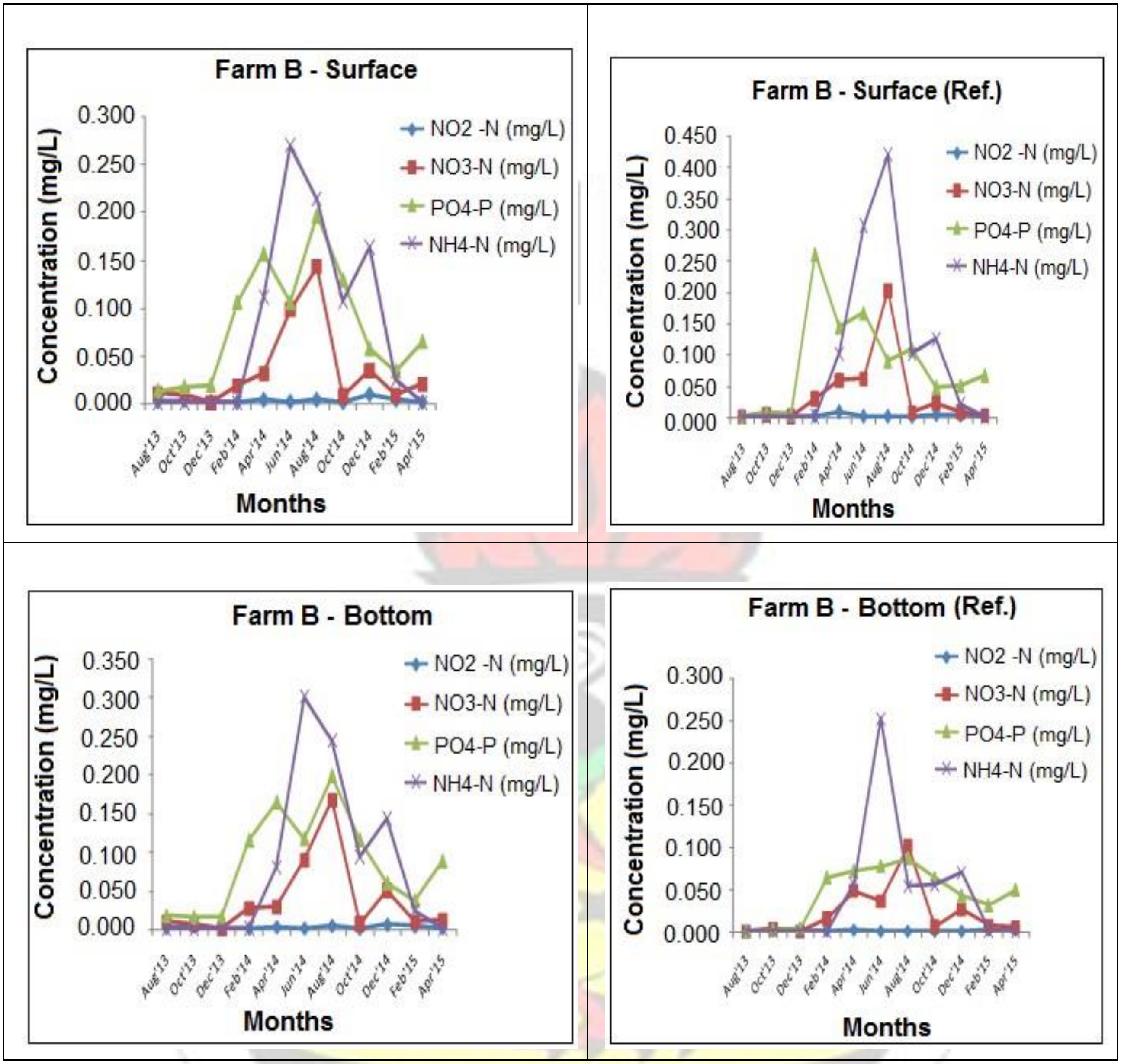


Figure 3. 20: Temporal variation of mean dissolved nutrients (NO_2-N, NO_3-N, NH_4-N, PO4-P) in Farm B and reference site of Lake Volta, Ghana.

3.6.5 Transparency and Turbidity

Transparency and turbidity values are presented in Figure 3.21. Transparency values ranged between 1.37 and 2.41 m with the reference site ranging from 1.02 to 2.21 at Farm A. At Farm B, the transparency varied between 2.12 and 3.28 m, and from 2.22 to 3.80 m at the reference site. Transparency tended to decrease in June (rainy season) and rise towards December – February (Dry season). Turbidity values at Farm A varied from 2.13 to 12.38 NTU at the surface, 1.00 to 11.0 NTU at the reference sites. However, in Farm B, turbidity ranged from 1.00 to 3.43 NTU and from 1.00 to 4.00 NTU at the reference site. Higher transparency values were observed at Farm B which reflected in lower turbidity levels compared to Farm A (Figure 3.21). Turbidity correlated poorly with transparency ($p < 0.05$, r= - 0.196).

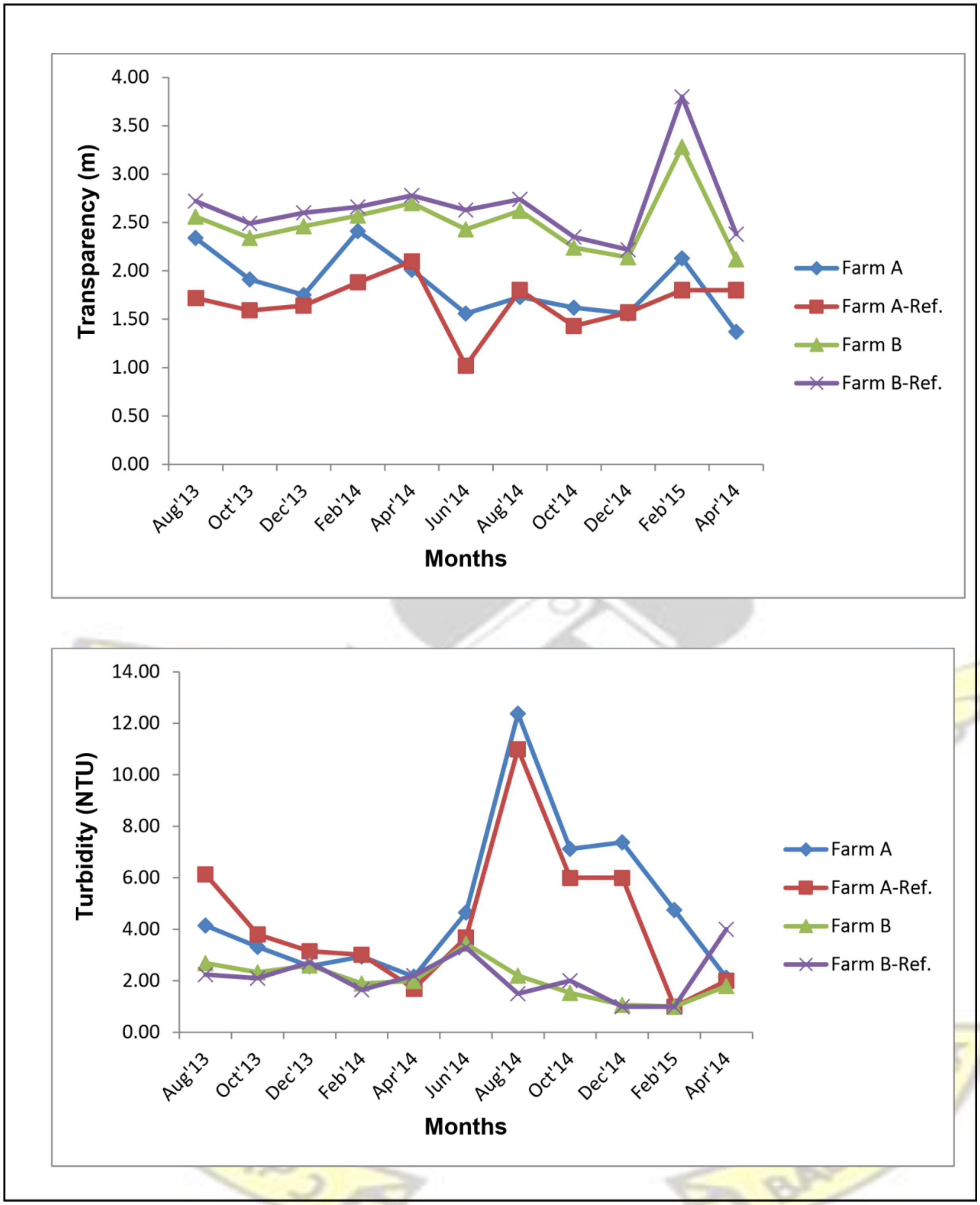


Figure 3. 21: Temporal variation of transparency and turbidty in the farms and the reference sites.

3.6.6 Dissolved Oxygen and Temperature Profiles

The mean DO concentration variations in the surface waters of Farm A and B and their reference sites are illustrated in Figure 3.23. DO concentration in the surface water varied between 4.58 and 9.33 mg/L for Farm A with the reference site varying between 5.32 and 9.29 mg/L. The Farm B DO levels ranged from 5.52 to 8.40 mg/L and the reference site varying from 5.51 to 8.72 mg/L.The DO levels encountered in Farm A were most of the time higher than Farm B (Figure 3.23).

The DO profiles are shown in Figures 3.24 and 3.25. The DO profiles were characterised by upper oxygenated water and deeper lower DO waters. The upper oxygenated water in Farm A ranged from 6.64 mg/L at 1m depth to 4.09 mg/L at depth 5m in December 2014 and oxygen saturation varied between 88.5 and 54%, respectively. However, the DO dropped to 0.53 mg/L at depth 9m. Concentration of DO in February 2015 at depth 1m was 4.41mg/L all the way to the bottom at 9 m was 3.18 with saturation of 40.6 %. The reference site also had oxygen concentration of 8.5 mg/L and a saturation of 115.5 % at 1m depth and 6.25 mg/L and 4.02 mg/L of DO at depths 5 m and 9 m respectively in February 2015. In Farm B, DO levels ranged from 8.05 mg/L at 1m through 7.35 mg/L at 5 m depth to 0.53 mg/L at 19 m depth in December 2014. The reference site had similar DO condition as the farm, with oxygen saturation of 105 % at 1 m depth and 1.06 mg/L at depth 19 m. In February 2015, though relatively lower values of DO were recorded at upper layers, the DO levels were consistent till depth 19 m for both the farm and the reference site. The oxygen levels encountered during the monitoring period is suitable for tilapia production and ecosystem use.

Generally, temperature decreased from the surface to the bottom in both farms and the reference sites. Temperature profiles are presented in Figures 3.26 and 3.27. The temperature in Farm A dropped from 29.9 to 29.0 °C from 1m to 9m depth in December 2014 and from 27.5 to 27.1 °C in February 2015 over similar depth. The temperatures in the reference sites decreased from 30.9 °C (1m) to 29.1 °C (9 m depth) in December 2014 and from 27.9 °C to 27.1 °C at the 9 m depth in February 2015. The differences in temperature from the surface to the bottom ranged from 0.4 to 2.5 °C for Farm A. For Farm B, temperature decreased from 30.1 to 29.0 at depth 9 m in December 2014 while, dropping from 27.6 °C to 27.4 °C in February 2015 at depth 9 m. At the reference site, temperature dropped from 29.5 °C to 29.0 °C and from 27.6 °C to 27.4 °C, respectively in December 2014 and February 2015 at depth 9 m. Even at the highiest depth of 38 m, the temperature change between the surface and the bottom was 2 °C.

3.6.7 Total Phosphate (TP) and Chlorophyll-a

Temporal variations of TP and Chlorophyll-a concentrations in the study area are illustrated in Figure 3.22. TP values ranged from 19.3 μg/L in December 2013 to 267.5 μg/L in February 2014 at Farm A and from 17.0 to 370 μg/L at the reference site. In Farm B, concentrations varied from 21.6 to 311.3 μg/L and from 3.0 to 380 μg/L at the reference site. Concentrations of chlorophyll-a ranged from 1.78 μg/L in December 2014 to 6.60 μg/L in October 2013 at Farm A and from 1.46 to 8.93 μg/L at the reference site. Farm B levels of Chlorophyll-a ranged from 1.19 to 7.05 μg/L and from 1.07 to 6.18μg/L at the reference site. No clear correlation was found between chlorophyll-a and total phosphate.

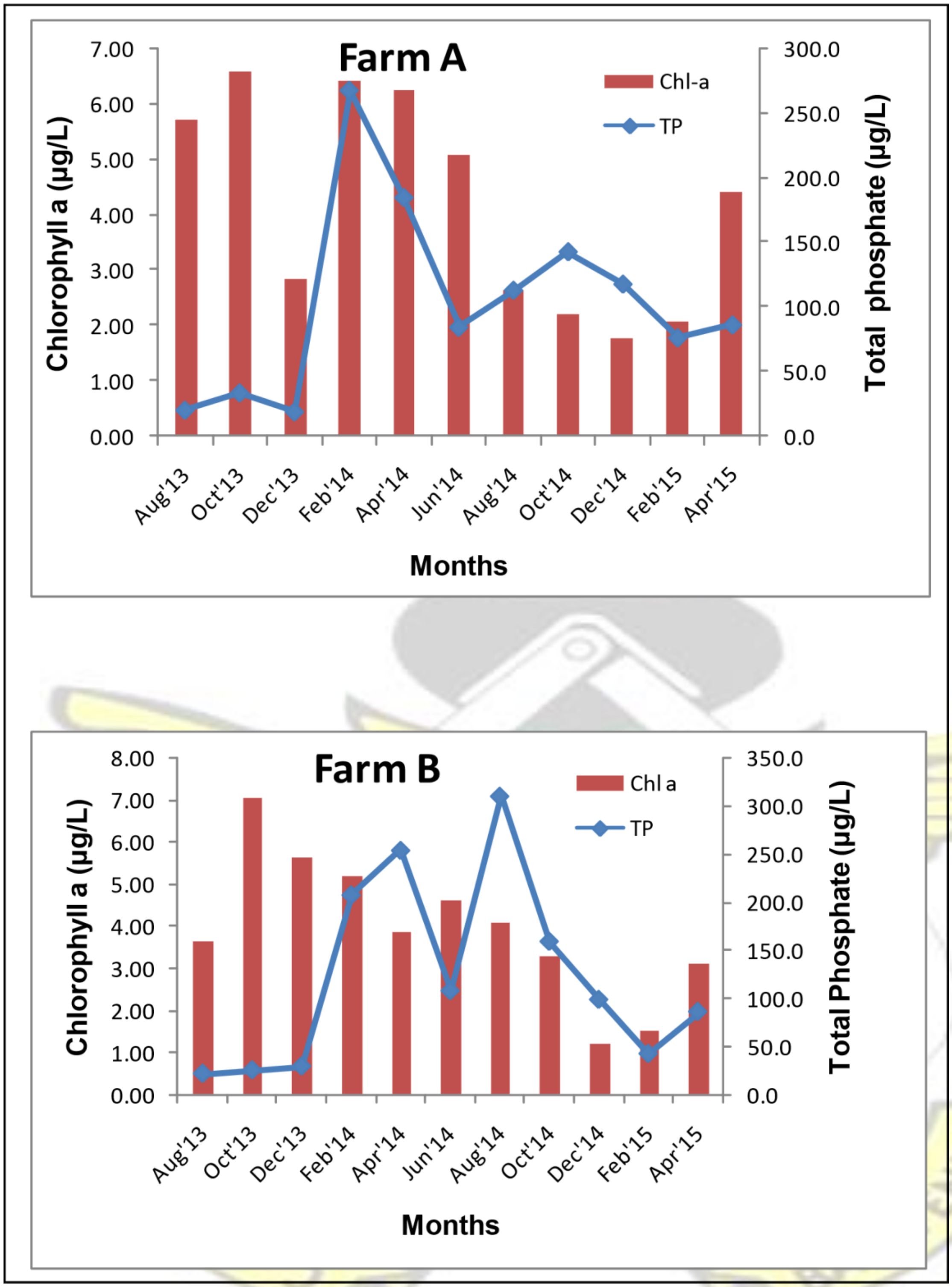


Figure 3. 22: Mean concentrations of chlorophyll a (Chl a) and total phosphate (TP) of surface waters in Farm A and B

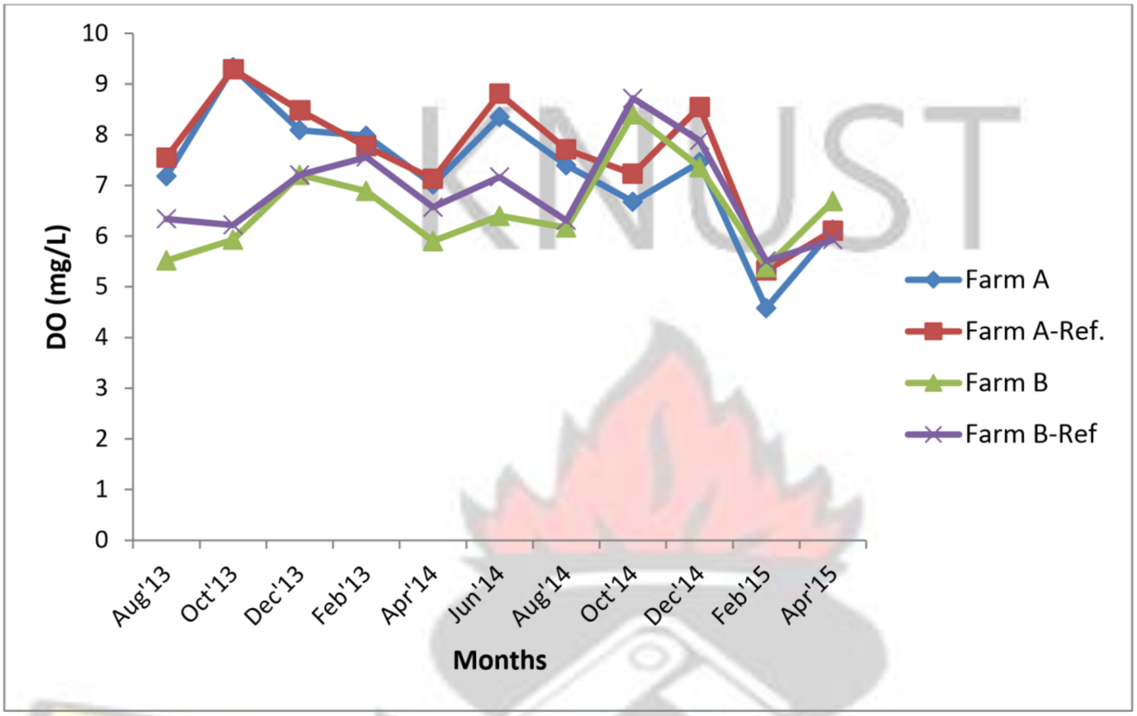


Figure 3. 23: Temporal variation of mean DO in surface waters of Farm A and B and their reference sites.

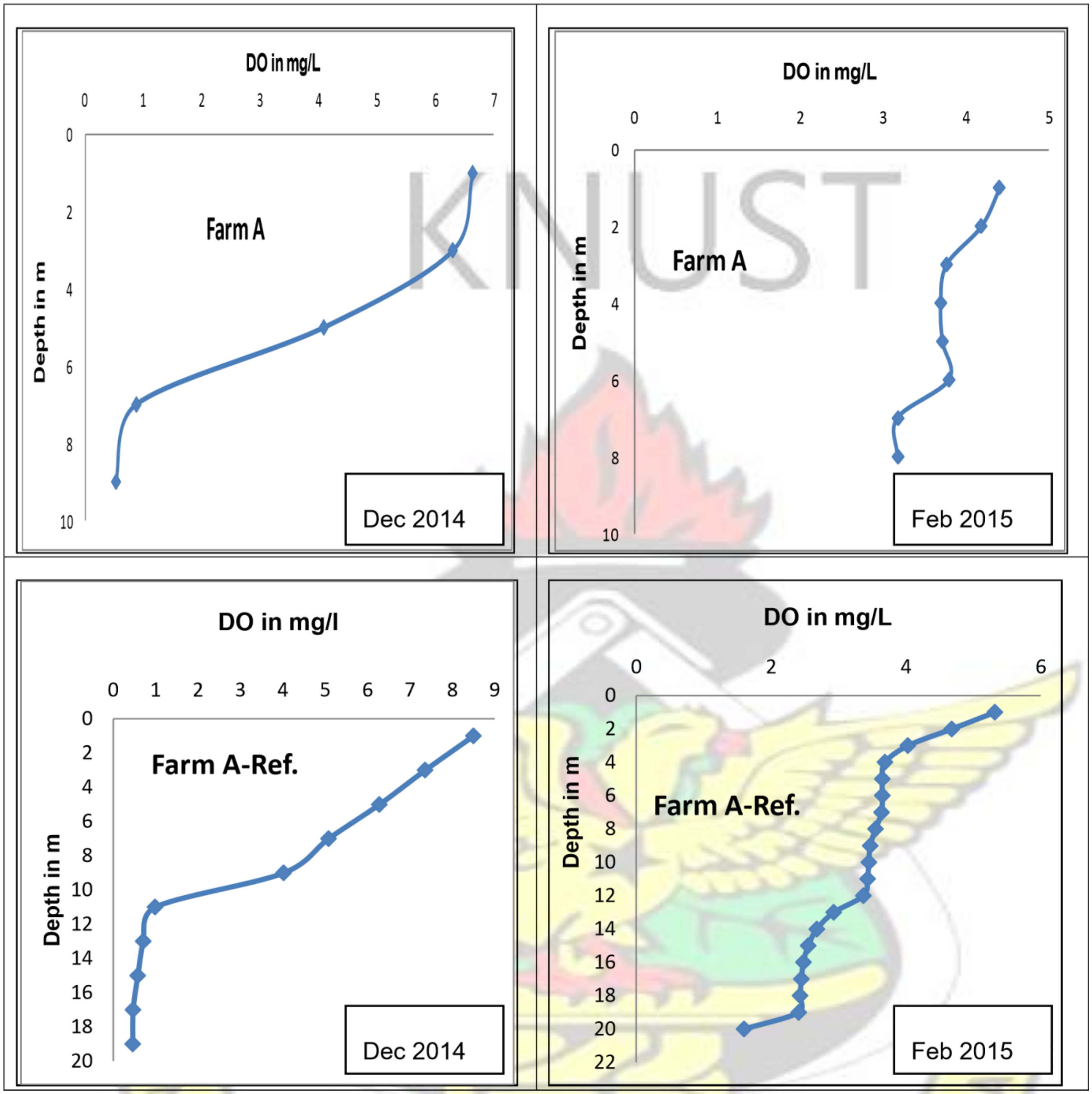


Figure 3. 24: DO profiles in Farm A and the reference site

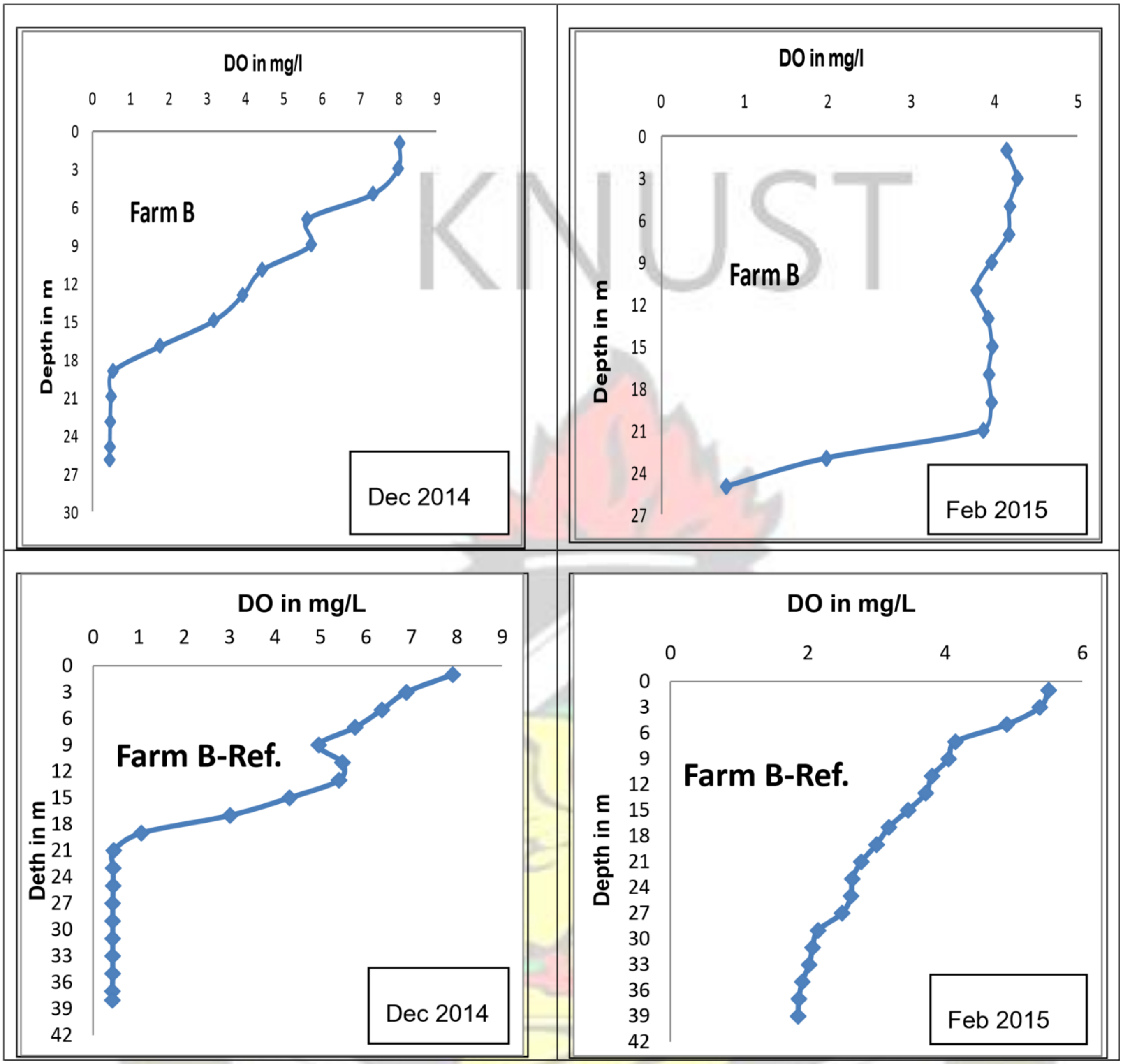


Figure 3. 25: DO profiles in Farm B and the reference site

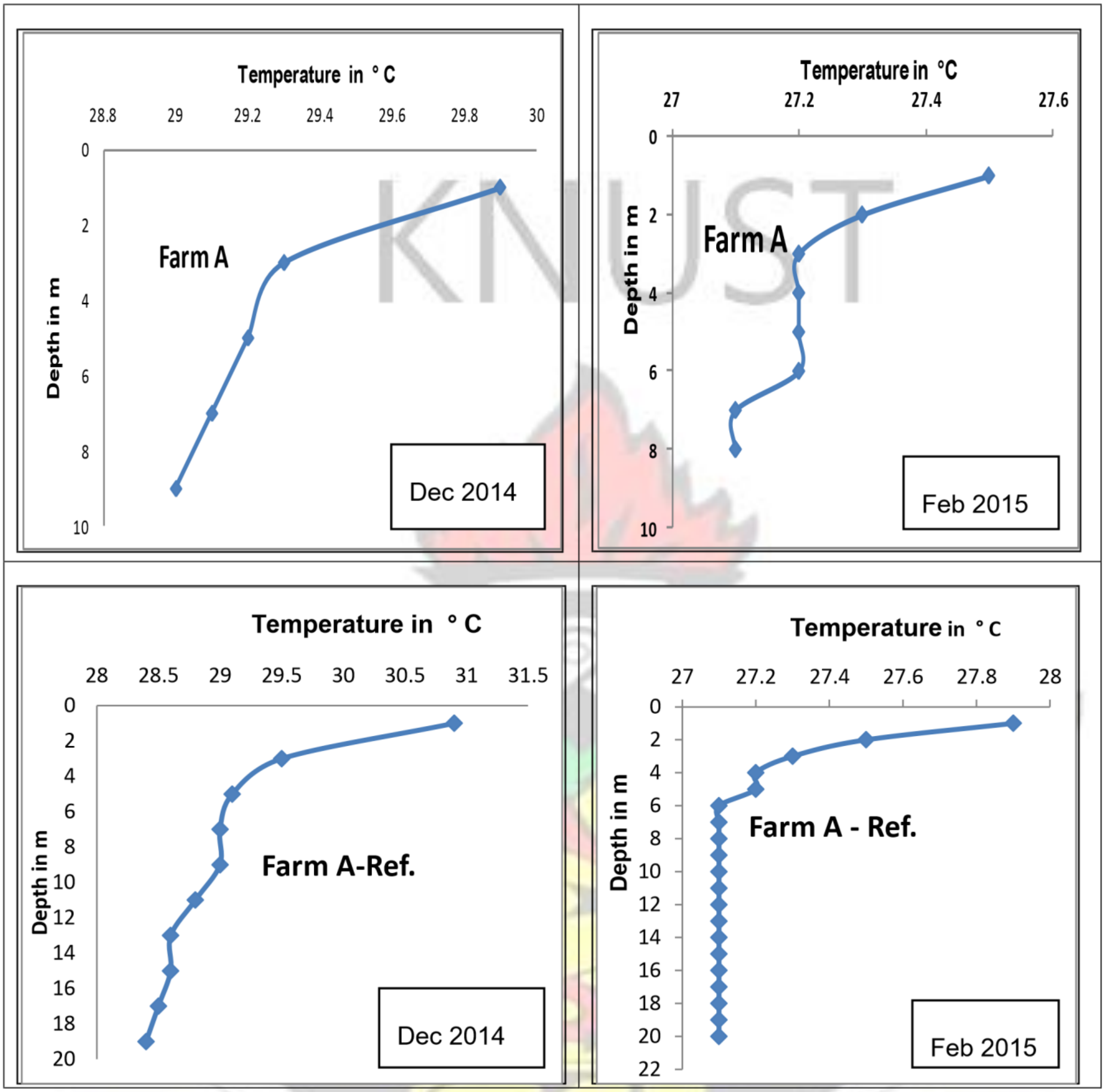


Figure 3. 26: Temperature profiles in Farm A and the reference site

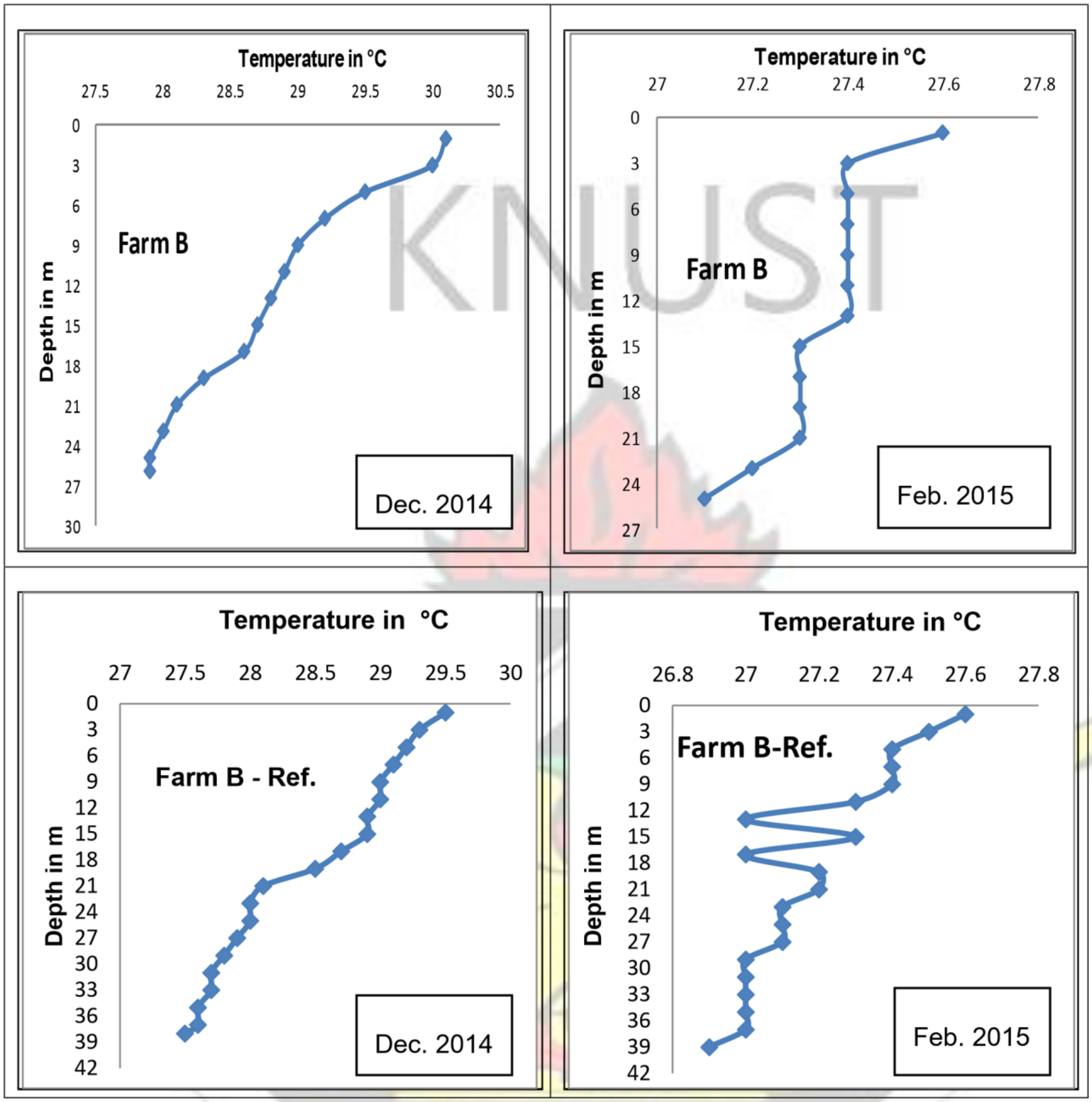


Figure 3. 27: Temperature profiles in Farm B and the reference site

3.6.8 Other Physical and Chemical Parameters

Tables 3.4 and 3.5 present the mean, standard deviation, minimum and maximum of some physical and chemical parameters at the study area. Surface water temperatures were found to be uniform at all sampling sites and exhited temporal variations. The consistant pH values for Farm A surface water ranged from 6.5 to 8.5 and 6.3 to 8.7 for the reference site. The Farm B pH levelsvaried from 6.4 to 8.7 for the surface water as the reference site varied between 6.6 and 8.6. The pH variations were observed to be uniform. Conductivity ranged from 55.6 to 119 µS/cm with a mean of 67.0 ± 12.3 and from 56.0 to 194 µS/cm with a mean of 74.9 ± 26.0 at Farm A surface and reference site, respectively. The surface water conductivity values recorded for Farm B varied from 55.3 to 88.7µS/cm and the control (57.5 – 83.30µS/cm) with a mean of 62.3 ± 5.5. The total hardness and total alkalinity of the sampling sites varied temporally and were both consistant (Tables 3.5 and 3.6). Low sulphate and COD concentrations were encountered at both the surface and bottom waters of all sampling sites. The surface waters of Farm A had a mean of 3.2 ± 1.4 mg/L with the reference site having a mean of 3.4 ± 2.0 mg/L. The bottom waters recorded a mean of 3.6 ± 1.7 mg/L and 3.1 ± 1.2 mg/L for the farm and reference site, respectively. Similar values of sulphate found in Farm A were observed at Farm B. The mean COD for Farm A surface (16.7 ± 9.3 mg/L); reference (19.3 ± 9.5 mg/L) and the Farm B surface (15.2 ± 7.0 mg/L); the reference (14.8 ± 6.8 mg/L). No significant differences ($p > 0.05$) were found for these physical and chemical parameters between the farms and the reference sites.

Table 3. 4: Mean concentrations and ranges (in parenthesis) of surface, bottom and reference sites for some physico-chemical parameters in fish Farm A

Parameter	Farm A Surface	Surface reference	Farm A Bottom	Bottom reference
Temperature	28.4	28.2	28.1	27.8
(° C)	(26.2-30.4)	(26.5-30.8)	(26.2-29.6)	(26.3-28.9)

pH	-	-	-	-
	(6.5-8.5)	(6.3-8.7)	(6.5-8.1)	(6.6-8.1)
Conductivity	67.0	74.9	66.9	63.2
(µS/cm)	(55.6-119)	(56-194)	(53.8-132)	(57.3-89.7)
Total hardness	23.9	25.1	23.6	22.7
(mg/L)	(18.8-35.4)	(20.6-49.0)	(19.0-32.4)	(20.4-24.8)
Alkalinity	30.8	30.9	30.2	29.7
(mg/L)	(23.2-42.2)	(24.0-47.4)	(23.6-39.4)	(23.6-35.4)
COD	16.7	19.3	16.7	21.6
(mg/L)	(2.96-44.6)	(6.27-41.4)	(3.15-30.7)	(6.27-44.6)
Sulphate	3.2	3.4	3.6	3.1
(mg/L)	(1.0-9.0)	(1.25-7.62)	(1.0-10.4)	(1.0-5.0)

Table 3. 5: Mean concentrations and ranges (in parenthesis) of surface, bottom and reference sites for some physico-chemical parameters in fish Farm B

Parameter	**Farm B Surface**	**Surface reference**	**Farm B Bottom**	**Bottom reference**
Temperature	28.8	28.5	27.9	27.7
(° C)	(27.0-30.5)	(26.9-30.0)	(24.1-30.0)	(26.6-28.8)
pH	-	-	-	-
	(6.4-8.7)	(6.6-8.8)	(4.2-8.5)	(6.62-8.50)
Conductivity	63.7	62.3	64.0	62.2
(µS/cm)	(55.3-88.7)	(57.5-83.3)	(43.2-83.3)	(57.8-73.9)
Total hardness	23.1	23.6	23.3	24.1
(mg/L)	(19.0-34.6)	(19.8-32.4)	(18.8-36.0)	(19.8-31.6)
Alkalinity	30.5	30.2	30.4	30.2
(mg/L)	(21.4-39.4)	(23.8-36.6)	(22.0-36.6)	(23.8-36.8)

COD	15.2	14.8	17.9	18.5
(mg/L)	(2.15-33.8)	(3.03-22.3)	(2.8-44.6)	(3.18-44.6)
Sulphate	3.2	2.9	3.2	3.3
(mg/L)	(0.86-17.0)	(1.0-5.1)	(0.71-10.3)	(1.0-6.4)

3.6.9 Metal Concentrations in the Water Column

Metal concentrations in the water column at both the surface and the bottom in Farms A and B are presented in Tables 3.6 and 3.7, respectively. The following metals; Pb, Cu, Cd and Se were not detected in the surface and the bottom waters of both farms. However, the mean concentrations of Zn, Fe and Mn detected at different layers of the farms and the reference sites were within the permissible limits recommended by USEPA (1986). The concentrations of metals in the water were found in the following order: Fe > Mn > Zn > Cu = Pb = Se = Cd. There seems to be no significant differences between the farms and the reference sites with respect to metals. However, there was a correlation between Fe and Zn (r = 0.664, $p < 0.01$), Fe and Mn (r =0.509, $p < 0.01$) and Zn and Mn (r =0.0.315, $p < 0.01$) in Farm B.

Table 3. 6: Mean and range of metal concentrations in water of Farm A in mg/L.

Metals	Farm A Surface	Surface control	Farm A Bottom	Bottom control	*Permissible limits
Pb	ND	ND	ND	ND	0.05
Zn	0.003	0.003	0.003	ND	1.0
	(0.0-0.04)	(0.0 – 0.03)	(0.0 – 0.05)		
Cu	ND	ND	ND	ND	1.0
Cd	ND	ND	ND	ND	0.01
Fe	0.091	0.047	0.112	0.145	1.0
	(0.0 - 0.50)	(00 – 0.13)	(0.0 – 1.16)	(0.0 – 0.54)	

Mn	0.037	0.036	0.041	0.063	0.05
	(0.0 – 0.17)	(0.0 - 0.16)	(0.0 – 0.163)	(0.0 – 0.359)	
Se	ND	ND	ND	ND	-

*Permissible llimits according to USEPA (1986) ND: not detected

Detection limits for Pd = 0.005 mg/L, Cu = 0.02 mg/L, Cd = 0.002 mg/L, Se = 0.001 mg/L

Table 3. 7: Mean and range of metal concentrations in water of Farm B in mg/L

Metals	**Farm B Surface**	**Surface control**	**Farm B Bottom**	**Bottom control**	***Permissible limits**
Pb	ND	ND	ND	ND	0.05
Zn	0.009	0.027	0.007	0.017	1.0
	(0.0 – 0.226)	(0.0- 0.336)	(0.0 – 0.11)	(0.0 – 0.12)	
Cu	0.001	ND	ND	ND	1.0
Cd	ND	ND	ND	ND	0.01
Fe	0.085	0.182	0.178	0.294	1.0
	(0.0 - 0.992)	(0.0 – 2.10)	(0.0 - 3.03)	(0.0 – 1.70)	
Mn	0.029	0.039	0.114	0.161	0.05
	(0.0 – 0.255)	(0.0 – 0.318)	(0.0 – 2.06)	(0.0 – 0.83)	
Se	ND	ND	ND	ND	-

*Permissible limits according to USEPA (1986) ND: not detected

Detection limits for Pd = 0.005 mg/L, Cu = 0.02 mg/L, Cd = 0.002 mg/L, Se = 0.001 mg/L

3.6.10 CCME and GWQI

The CCME water quality model results for both Farms A and B are shown in Figure 3.28, while that of GWQI is presented in Figure 3.29. The water quality index for the wet and dry seasons ranged between a score of 90 and 93 which is very favourable for tilapia production (Figure 3.27). The adapted GWQI showed fairly good water quality (Class II) for the monthly assessment both for the farm and the control areas (Figure 3.28).

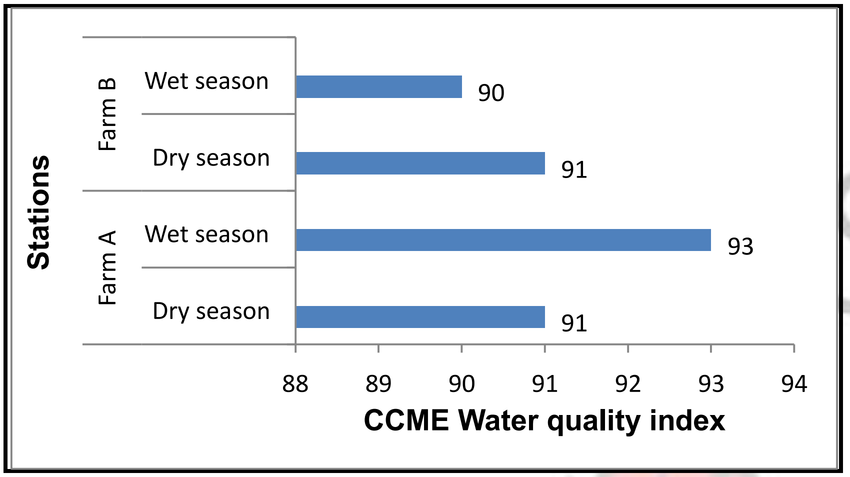


Figure 3. 28: CCME water quality index of cage tilapia farms A & B at different seasons (dry and wet) in the Lake Volta, Ghana

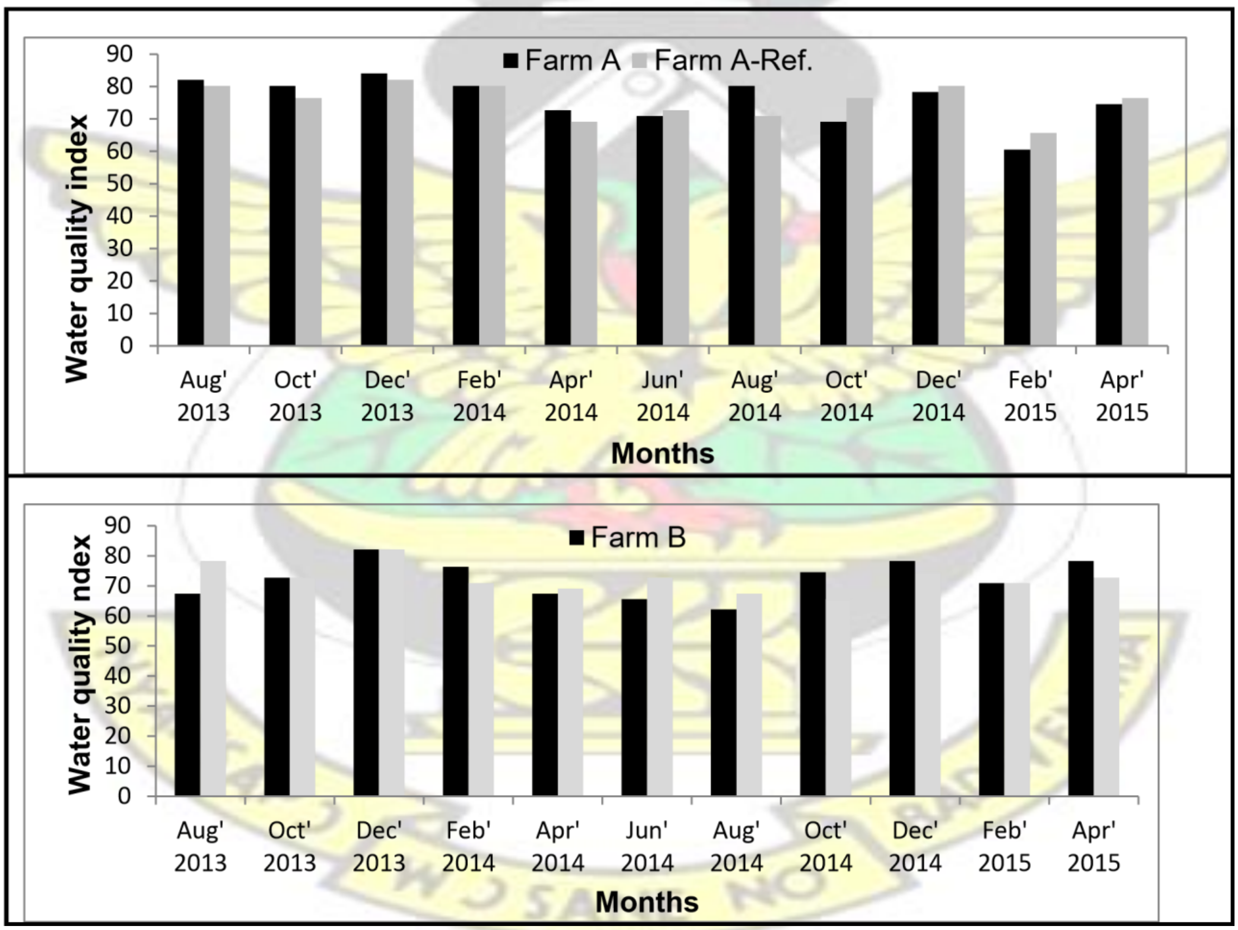


Figure 3. 29: Temporal variation of Ghana water quality index for Farms A& B and their reference sites in Lake Volta, Ghana

3.6.11 Sediment Particle Size and ORP

The sediment collected from all sampling sites were classified as sandy clay loam with prevalence of sand; Farm A (range 31.5 to 65.2 %), with its reference site ranging from 34.2 to 65.5 %. For Farm B (range 32.0 to 75.3 %); and the reference (47.9 to 81.2 %). The silt varied from 16.7 to 30.6 in Farm A; 10.7 to 31.2 in Farm B. The highest clay content was measured in Farm B (26.0 ± 4.57 %) (Table 3.10). The mean values recorded for moisture was 47.5 % for Farm A; 62.7 % for the reference and 60.4 % and 63.3 %, respectively for Farm B and its reference.

Sediment oxidation-reduction potential (ORP) which was measured to determine whether decreased DO levels had occurred, ranged from 28.0 to 197 mV at Farm A (Table 3.8) and 14.2 to 200 mV in Farm B (Table 3.9). The pH of the sediments varied between 4.00 and 7.06 at Farm A, and 4.38 to 5.396 at the reference site. At Farm B, the pH ranged from 3.93 to 7.23 and 4.35 to 6.39 at the reference site. Moisture, sand, silt and clay were significantly different ($p < 0.05$) between the farms and the reference sites, but gravel and ORP did not show any significance.

3.6.12 Metal Concentrations in Sediments

The results of themetal for the sediment analysis are shown in Table 3.8 for Farm A and Table 3.9 for Farm B. Unlike the water column, the bottom sediment showed appreciable amounts of metals with the exception of Cd which was not detected in the farms and their reference sites. Iron (Fe), which had the highest concentration had a mean of 13,766 and 9,733 mg/kg for Farm A and the reference site, respectively. The Farm B recorded a mean of Fe concentration of 38,659 mg/kg and 37,917 mg/kg for the reference site. The metal concentrations encountered in Farm B were higher than in Farm A. The order of abundance of these metals in the bottom sediment was: Fe > Mn > Zn > Cu > Pb >Se > Cd. Over all, the metals in the sediments were below the threshold effect concentration (MacDonald *et al.,* 2000). Significant differences existed in Farm B and the reference sites regarding the following metals; Zn, Cu, Mn and Pb. Pearson analysis showed relatively strong correlations between Pb and Se (r = 0.510, $p < 0.01$), Zn and Cu (r = 0.760, $p < 0.01$), Zn and Mn (r = 0.591, $p < 0.01$) and Mn and Cu (r = 0.617, $p < 0.01$) in Farm A. However, Farm B metals exhibited similar but weak relationships.

Table 3. 8: Mean and range of metals, moisture, ORP and pH in sediment of Farm A

Parameter	**Farm**	**Control**	***TEC**
Moisture (%)	47.5 (16.0 – 81.0)	62.7 (35.0 – 82.0)	-

ORP (mV)	139 (28.0 – 197)	125 (67.0 – 193)	-
pH	- (4.00 – 7.06)	- (4.38 – 5.96)	-
Pb (mg/kg)	1.84 (0.00 -19.25)	1.40 (0.00 – 17.75)	35.8
Zn (mg/kg)	48.4 (0.00 – 326)	56.2 (0.00 – 105.3)	121
Cu (mg/kg)	15.2 (0.60 – 138)	19.5 (6.00 – 39.2)	31.6
Cd (mg/kg)	ND	ND	0.99
Fe (mg/kg)	13766 (236 – 228110)	9733 (237 – 24086)	188,400
Mn (mg/kg)	341 (20.26 – 2125)	567 (112 – 1086)	630
Se (mg/kg)	0.350 (0.00 – 1.25)	0.29 (0.00 – 0.71)	-

*TEC = Threshold effect concentration (MacDonald *et al.,* 2000) ND = Not detected Detection limit for Cd = 0.20 mg/kg

Table 3.
9: Mean and range of metals, moisture, ORP and pH in sediment of Farm B

Parameter	Farm	Control	*TEC
Moisture (%)	60.4 (21.0 – 91.0)	63.3 (26.0 – 88.0)	-
ORP (mV)	142 (14.2 – 200)	132 (67.1 – 184)	-
pH	- (3.93 – 7.23)	- (4.35 – 6.39)	-
Pb (mg/kg)	1.98 (0.0 – 15.0)	0.76 (0.0 – 10.5)	35.8
Zn (mg/kg)	133.0 (0.0 -949.0)	90.5 (24.9 – 208.0)	121
Cu (mg/kg)	35.7 (0.0- 74.3)	40.4 (7.25 – 67.5)	31.6
Cd (mg/kg)	ND	ND	0.99
Fe (mg/kg)	38659 (51 -474270)	37917 (4386 – 320024)	188,400
Mn (mg/kg)	1966 (47 -11283)	3136 (150 – 9185)	630
Se (mg/kg)	0.52 (0.00 – 1.77)	0.34 (0.00 – 0.75)	-

*TEC = Threshold effect concentration (MacDonald *et al.*, 2000) ND = Not detected Detection limit for Cd = 0.20 mg/kg

3.6.13 Total Organic Carbon (TOC), Total Organic Matter (TOM), Total Nitrogen (TN) and Total Phosphate (TP) in Sediments

The mean TOC, TOM, TN and TP variations are illustrated in Figures 3.31 and 3.32. The TOC values ranged from 1.10 to 2.39 % at Farm A and from 0.46 to 4.61 % at the reference site. TOC varied from 2.57 to 5.22 % at Farm B and from 3.90 to 7.00 % for the reference site. Significant differences were detected in TOC between the farm and the reference sites (ANOVA, $p < 0.05$). TOM values ranged from 1.89 to 4.11 % at Farm A and from 0.79 to 7.93 at the reference site. In Farm B, however, TOM values fluctuated from 4.42 to 8.98 % and from 6.70 to 12.03 % at the reference site. The variations of TOM were similar to those observed in the TOC. The highest monthly average level was observed at reference site in December 2013. TOM concentrations were significantly different from those at the reference sites (ANOVA, $p < 0.05$).

Total nitrogen content at Farm A ranged from 0.097 to 0.204 % and from 0.040 to 0.400 % at the reference site, TN values varied from 0.222 to 0.450 % and from 0.335 to 0.605 % at Farm B and the reference site, respectively (Figures 3.31 and 3.32). TN showed significant differences between the sampling sites (ANOVA, $p < 0.05$). Rather unfortunately, TP could not be measured on the sediment samples during the first year of the study. However, TP determinations were performed on the sediments from June 2014 to April 2015. The TP levels ranged from 0.013 to 0.265 % in Farm A and from 0.016 to 0.452 % at the reference site. In Farm B, TP content ranged from 0.100 to 0.605 % and from 0.024 to 0.325 % at the reference site. There was no significant difference between the sampling sites for TP. Relationship between TOC, TOM, TN and

Table 3.
TP have been shown by Pearson's correlation coefficients in Table 3.11 and 3.12.

10: Sediment particle size distribution and soil texture of Farms A and B

Farm	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Texture
Farm A	0.010±0.047 (0.0 – 0.37)	50.7±7.35 (31.5 – 65.2)	23.2 ± 3.16 (16.7 – 30.6)	26.0 ± 4.57 (17.6 – 40.7)	Sandy clay loam
Ref. A	0.095±0.302 (0.0 – 1.91)	51.9±8.89 (34.2 – 65.5)	21.6 ± 2.94 (16.5 - 26.9)	20.8 ± 3.05 (15.0 – 28.2)	Sandy clay loam
Farm B	0.138±0.87 (0.0 – 7.76)	57.3±8.96 (32.0 – 75.3)	20.0 ± 3.95 (10.7 – 31.2)	22.5 ± 5.57 (12.6 – 49.8)	Sandy clay loam
Ref. B	0.011±0.027 (0.0 – 0.10)	60.4±6.54 (47.9 – 81.2)	18.8±3.68 (3.78 -23.9)	20.8 ± 3.05 (15.01 – 28.2)	Sandy clay loam

3.6.14 Observation of Wild Fishes around Cages

Large numbers of wild fish species were visible around the cages in both farms. From personal observation the density of the wild fishes were much higher during feeding of the caged fish. No such observations were made at the reference sites.

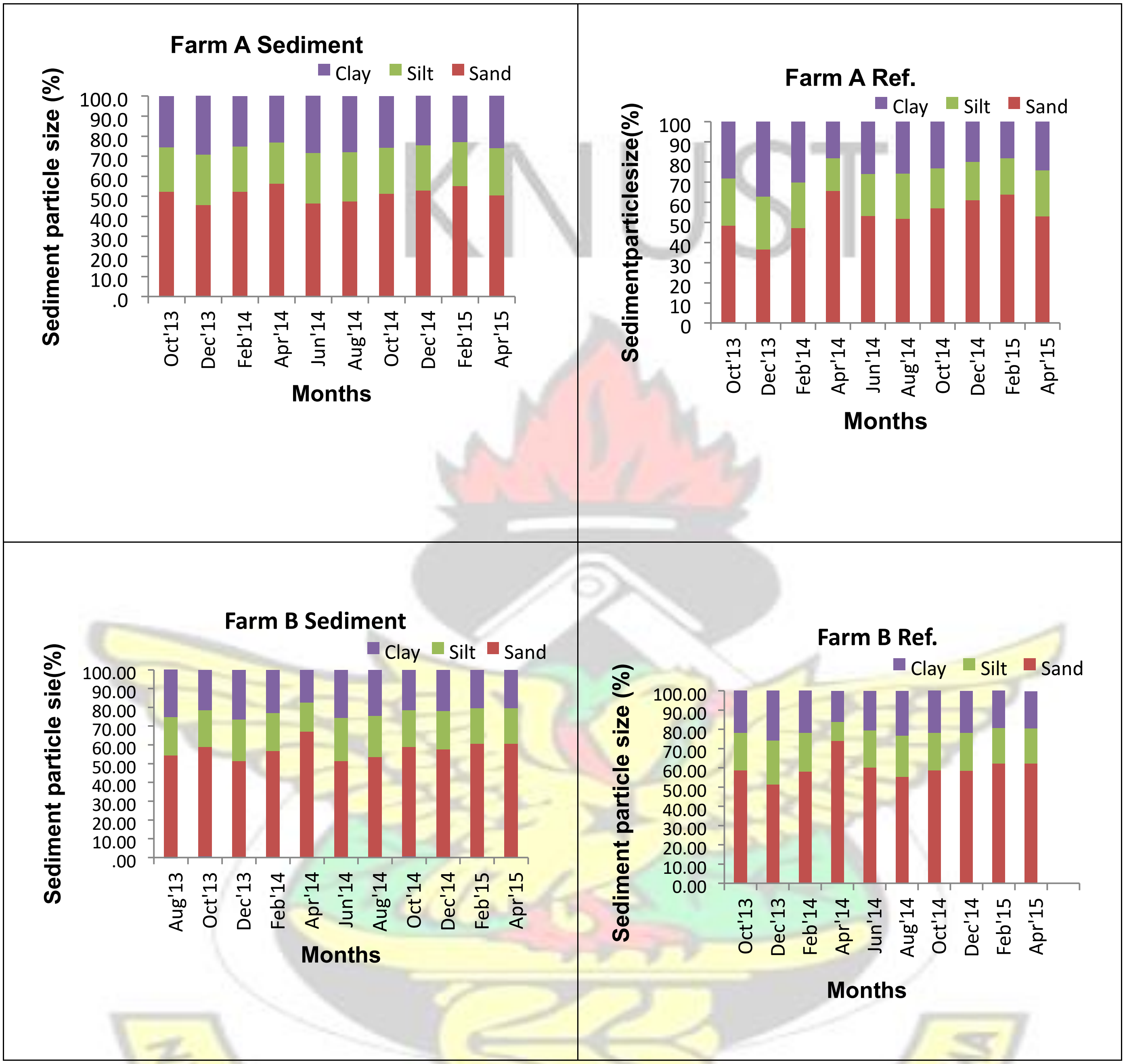


Figure 3. 30: Variation of particle size content in sediment of Farm A and B and their reference sites in Lake Volta during the monitoring period

11: Pearson correlation analysis between sediment variables in Farm A (N=96)

Table 3.

	TOC	TOM	TN	TP	ORP	pH
TOC	1					
TOM	1.000**	1				
TN	.988**	.988**	1			
TP	-.159	-.159	-.167	1		
ORP	-.088	-.095	-.094	-.345	1	
pH	-.284**	-.280**	-.292**	-.335*	.510**	1

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 3. 12: Pearson correlation analysis between sediment variables in Farm B (N=96)

	TOC	TOM	TN	TP	ORP	pH
TOC	1					
TOM	1.000**	1				
TN	.999**	.999**	1			
TP	-.122	-.123	-.120	1		
ORP	-.041	-.037	-.044	-.142	1	
pH	.136	.144	.145	.147	.063	1

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

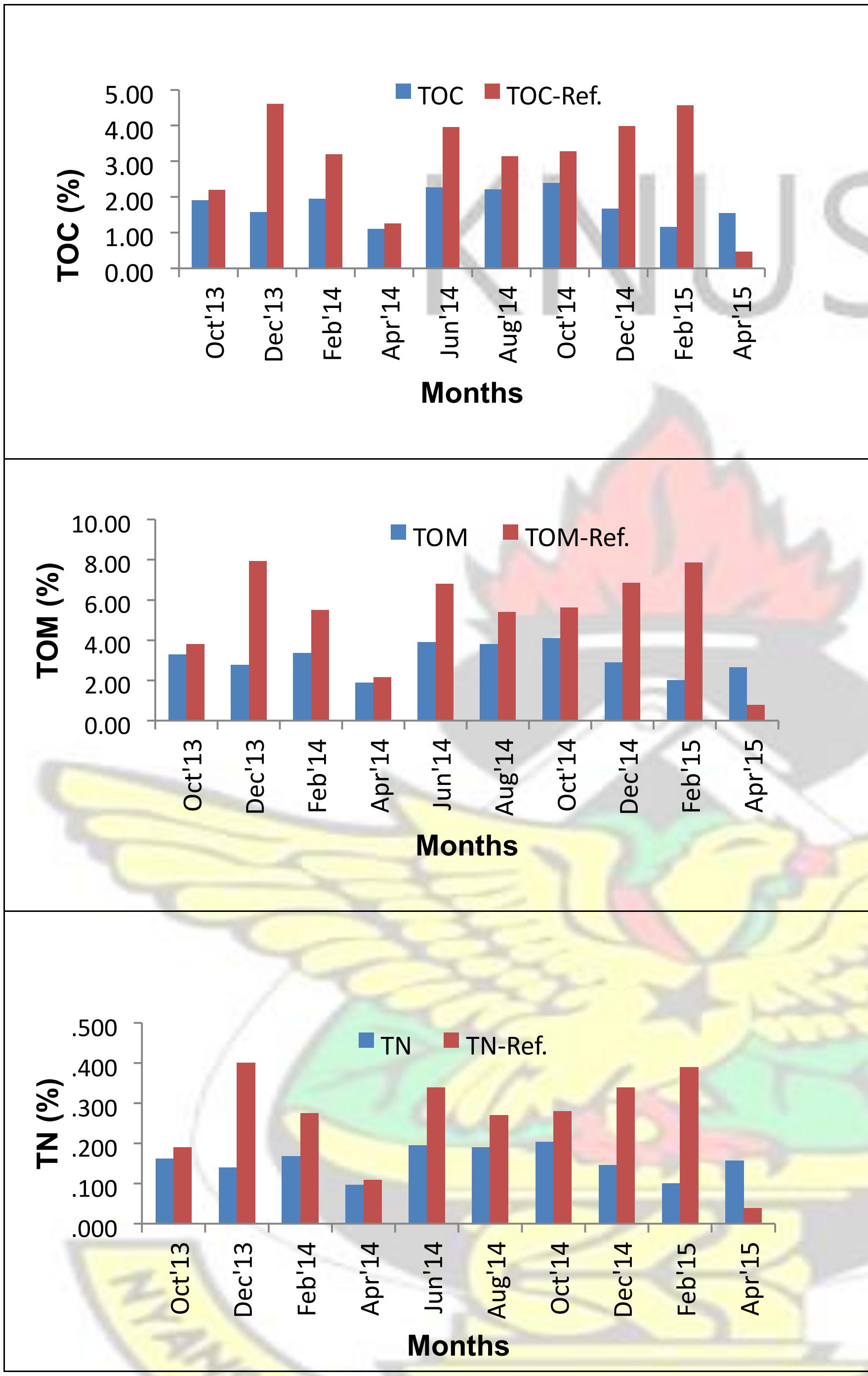

5.00
4.00
3.00
2.00
1.00
0.00
TOC (%)
TOC
TOC-Ref.
Oct'13
Dec'13
Feb'14
Apr'14
Jun'14
Aug'14
Oct'14
Dec'14
Feb'15
Apr'15
Months
10.00
8.00
6.00
4.00
2.00
0.00
TOM (%)
TOM
TOM-Ref.
Oct'13
Dec'13
Feb'14
Apr'14
Jun'14
Aug'14
Oct'14
Dec'14
Feb'15
Apr'15
Months
.500
.400
.300
.200
.100
.000
TN (%)
TN
TN-Ref.
Oct'13
Dec'13
Feb'14
Apr'14
Jun'14
Aug'14
Oct'14
Dec'14
Feb'15
Apr'15
Months

Table 3.

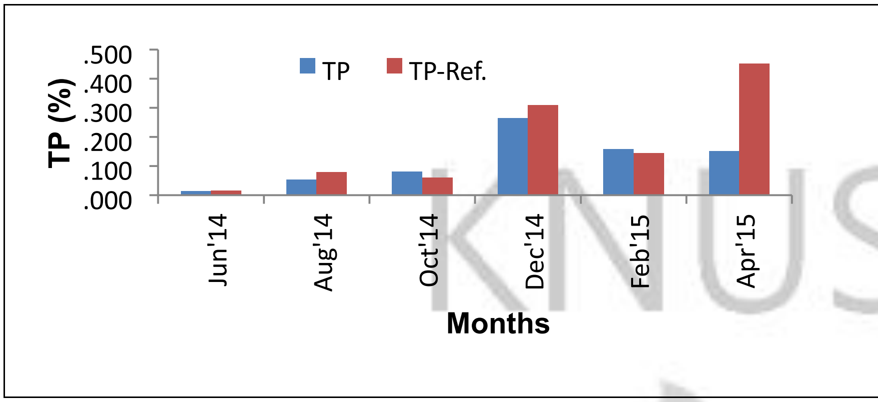


Figure 3. 31: Variations of TOC, TOM, TN and TP contents in sediment of Farm A and the reference site (TOC-Ref.,TOM-Ref., TN-Ref., TP-Ref.) in the Lake Volta

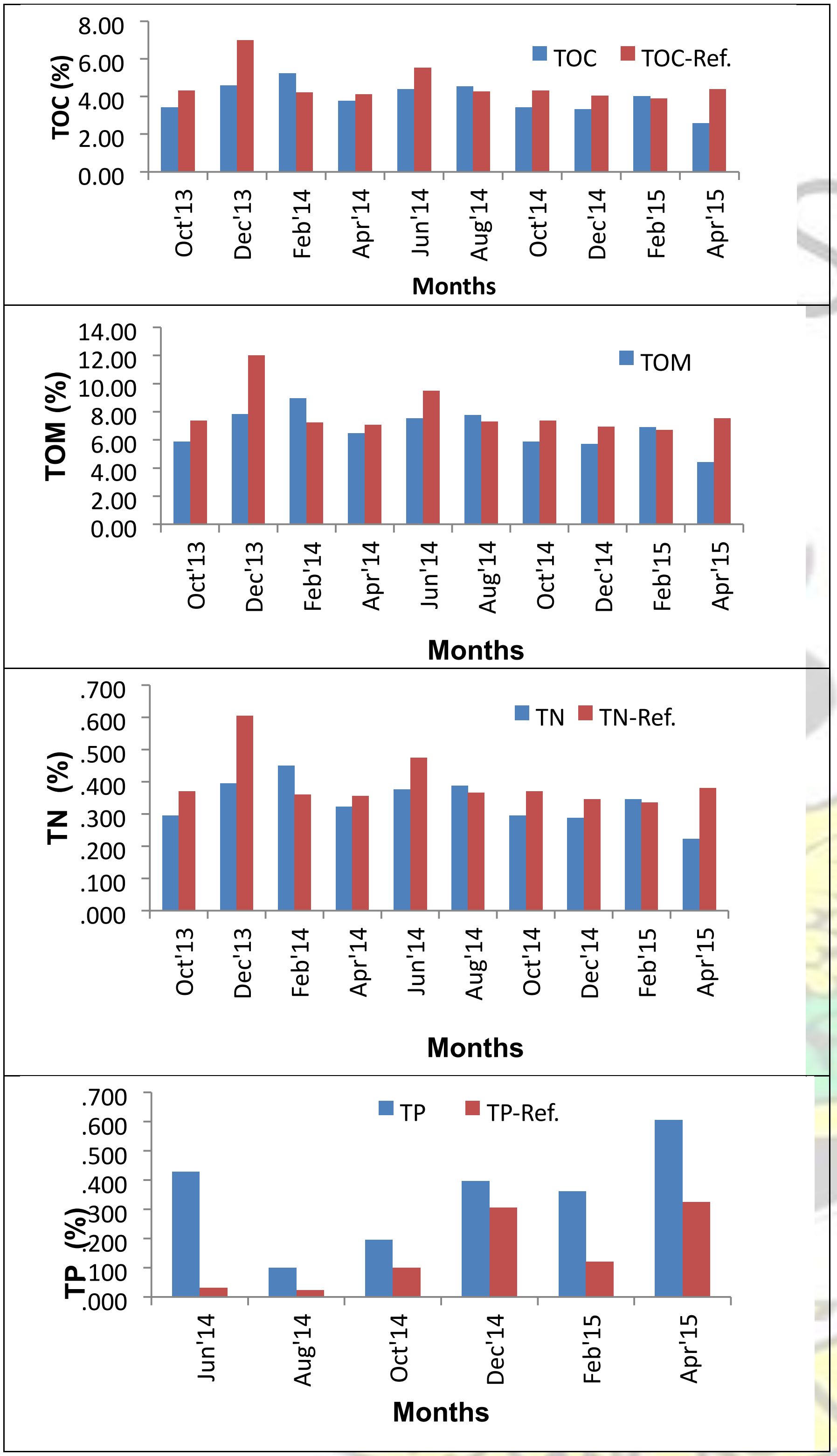


Figure 3. 32: Variations of TOC, TOM, TN and TP contents in sediment of Farm B and the reference site (TOC-Ref., TOM-Ref., TN-Ref., TP-Ref.) in the Lake Volta.

3.7 Discussion

3.7.1 Water Currents in the Fish Farms

Water current speeds are necessary for the dispersion of pollutants in a lake's environment (Wetzel, 2001). In lake environments or water bodies where cage culture is practiced, enough water currents are necessary for the dispersal of organic waste generated in fish cages. Recent studies have revealed that faster water currents can disperse waste over a larger area and distance (Sarὰ *et al.,* 2004). By implication locations with lower current speeds are likely to accumulate organic materials in the sediment, and likely show greater impacts of fish farming. The mean current velocity for the period of deployment was 0.037 m s^{-1} for Farm A and 0.062 m s^{-1} for Farm B. These currents were moderate and capable of dispersing nutrient from the cage farms. Alpaslanu and Pulatsü (2008) reported that 0.04 m s^{-1} was adequate to disperse waste produced by rainbow trout farming (*Oncorhynchus mykiss*) in cages in a Turkish reservoir. In Lake Malawi, Gondwe *et al.,* (2011) observed an average current velocity of 0.093 m s^{-1} which was adequate to facilitate the dispersion of waste discharged by tilapia cage fish farming. The water current in the fish farms were mostly wind driven on the surface of the lake. The residual flows were directed north-eastwards.

3.7.2 Water Temperature and DO Profiles

Water temperatures reflected the conditions of the weather and exhibited similarities at all the sampling sites. Water temperature profile at various depths in the fish farms and the reference sites fluctuated between 26.6 and 30.9 °C and indicated no clear thermal stratification in the water column with season weather fluctuation. The observed temperature range of 26.6 and 30.9 °C is important as it could affect the decomposition rate of organic waste discharging from fish cages (Gondwe *et al.,* 2011). Decomposition of fish wastes and excess food have the potential of reducing DO levels near cage site, but the DO reduction depends on water exchage rate, fish density and feeding rates. The temperature ranges observed for the farms and the reference sites were well within the optimum range for fish growth of 25–32 °C (Boyd, 1998). Earlier work on the lake reported a similar temperature range of 27.5 to 30.0 °C (Karikari *et al.,* 2013).

Dissolved oxygen is very important parameter for aquatic life the in water column. In many water bodies, DO has been used as the primary indication of localized pollution of cage culture operations. DO levels in the surface waters at the farms and their reference sites ranged from 4.58 to 9.33 mg/l and the % saturation varied between 61.5 and 125 %. The concentrations of DO found in the surface water in this study were above the "critical" farm value of 3.7 mg/l recommended by Abo and Yokoyama (2007) for sustainable aquaculture. The DO ranges in the present study were consistent with earlier oxygen values (7.3-8.1 mg/L) in the Lake Volta reported by Karikari *et al.,* (2013) and DO levels of 4.35 to 7.68 mg/L observed in a cage farm in Lake Malawi (Gondwe *et al.,* 2011). The surface DO did not show any clear temporal pattern, however, the patterns at the farms were similar to the reference sites (Figure 3.23). The mean surface DO concentrations of the reference sites were marginally higher than the farms DO most of the times, but these differences were not significant. These slightly lower DO levels in the farms may suggest little effects from the fish cages. The DO profile showed upper oxygenated waters and deeper near anoxic waters (Figures 3.24 and

3.25). Low DO concentrations such as 0.53 mg/l were observed in bottom waters. However, reasonable amounts of DO (3.17-5.41 mg/L) were observed at the depth of 13 m.

3.7.3 Nutrients and Other Physico-chemical Variables

The nutrients (NO_3-N, NO_2-N, NH_4-N and PO_4-P), chlorophyll-a, pH, turbidity, total hardness, alkalinity and conductivity concentrations were not significantly different (p > 0.05) between the farms and the reference sites. This suggests that increased concentrations of these variables were not detected at the cage site. Similar observation was made by Gondwe *et al.,* (2011) in a tilapia cage farm in Lake Malawi. Several studies have concluded that, there is no recognizable impact on water column parameters by fish farming at short spatial scales (Pitta *et al.*, 1999; La Rosa *et al.*, 2002; Nordvarg & Johansson, 2002; Soto & Norambuena, 2004). Some of the reasons might be due to the presence of currents and sufficient depths to distribute and dilute cage wastes harmful to the surrounding environment.

There was no significant difference found between the farm sites and the reference sites in TP and chlorophyll a concentrations (p > 0.05). The highest chlorophyll-a value was 8.93 µg/L, recorded at the reference site of Farm A. The highest chlorophyll-a value observed by a previous study on the Lake Volta was 19.0 µg/L (Karikari *et al,*. 2013). A limit of 10 µg/L in chlorophyll-a has been suggested as an environmental quality standard in the Northern European waters, in order to avoid eutrophication (Basaran *et al.,* 2010). There is no such standard in Ghana or in the subregion. Phosphorus has been reported as a critical nutrient in determining eutrophication status of reservoirs (Marinho & Huszar, 2002). The highest TP values occurred in February / April 2014 and dropped sharply in June 2014 in both farms. The drop corresponded with the highest rainfall (227.1 mm) in June and the lowest water level (72.7 m) in the same period (Figures 3.8 and 3.10). In the same month a considerable decrease in transparency in all the farms and a reasonable increase in turbidity were recorded (Figure 3.21). Since phosphorous is a limiting factor to phytoplankton it is possible the drop in TP was due to uptake by phytoplankton which also reduced transparency and increased turbidity. The combination of the rains and the lowest water level must have been a factor. The TP varied temporally.

3.7.4 Water Quality Indices

The resultsobtained from CCME water quality index for both Farms A and B was an indication of good water quality, favouring all year round tilapia production.The GWQI showed fairly good water quality in Class II category, rendering the water suitable for ecosystem use. This further suggests that the lake water could be used forwater supply, irrigation, recreation and cage culture or tilapia production.

3.7.5 Metals in Water Column and Sediment

Several researchers have mentioned the build up of metals in sediment due to aquaculture activities (Chou *et al.,* 2002; Mendiguchia *et al.,* 2006; Sutherland *et al.,* 2007). For example, Fe and Zn are used as additives in fish diet. Copper is usually employed as an antifouling agent for treating cage nets. In this study metals such as Pb, Zn, Cd and Se were not defectedin the water column. Zinc (Zn), Fe and Mn values found in the water column were very low and were below the permissible limits recommended by USEPA (1986). Similar low values of heavy metal were reported by Ansa-Asare *et al*., (2012) on the lake. The results is also consistent with, a freshwater satellite Lake in Kenya where Pd and Zn were not detected in the water column and Fe, Mn and Cu levels were very low (Mwamburi, 2009). The low levels of heavy metals may be partly due to the fact that little or no waste water from agricultural, industrial or sewage is discharged into the lake. There were no significant differences in metals concentrations among the farms and the reference sites in the water column.

The heavy metal levels observed in the sediments in this study were all lower than the threshold effects concentration (MacDonald *et al.,* 2000). The variation in the content of the lakes sediment was shown in the metal distribution. Franc *et al.,* (2005) reported that high sand and low organic contents in sediment reflectlow metal concentrations. The high metal concentrations observed in Farm B over Farm A may be attributable to relatively higher organic matter content in the sediment at Farm B, a large scale fish farm. According to Tsai *et al.,* (2003), the level of metals in sediment increases with a corresponding increase in organic materials. Very high concentrations of Fe were found in the sediments and according to Basaran (2010), apart from the feeds used in aquaculture, natural background concentrations of heavy metals may also play an important role in accumulation process of Fe and Zn in sediments. Fe usually has high natural background levels which are thousand times high in sediments. Comparing the accumulation of heavy metals in water column and sediments, it can be said that heavy metals accumulate more in sediments than water, since the sediment act as a major depository for all contaminants and dead organic matter (Nguyena *et al.,* 2005; Davis *et al.,* 2006 and Saeed and Shaker, 2008).

3.7.6 Sediment Quality

The particle size analysis showed that the texture of the sediment was sandy clay loam at all the sampling sites (Figure 3.30). The sand content in the sediments analysed had a range of 31.5 – 81.2 %. The larger the diameter of sediment particles, the higher the ability of the environment to recover from the impact caused by waste accumulation (Cabrera *et al.,* 2004). With the sand pre-dominating the sediment, the monitoring sites will have the potential to recover from any waste accumulation. Measurement of ORP is done to determine organic enrichment of the sediment. In undisturbed sediment, ORP value is about 300 to 400 mV (Winsby *et al*., 1996). A positive redox indicates the presence of oxygen in sediments and negative redox potential value is generally indicative of enriched organic matter. According to Collman and Holland (2000), sediment redox transition from oxic to suboxic condition occur between 150 and 300 mV, while transition from suboxic to anoxic is between 0 and -150 mV. In the current study the mean (range, 125 – 142 mV) ORP for the farms and the reference sites were all positive values (Tables 3.8 and 3.9), indicating the presence of oxygen in the sediment and therefore low organic enrichment.

Table 3. 13: Sediment particle size distribution and soil texture of Farms A and B

Farm	Gravel	Sand	Silt	Clay	Texture

Farm A	0.010 (0.0 – 0.37)	50.7 (31.5 – 65.2)	23.2 (16.7 – 30.6)	26.0 (17.6 – 40.7)	Sandy clay loam
Ref. A	0.095 (0.0 – 1.91)	51.9 (34.2 – 65.5)	21.6 (16.5 - 26.9)	20.8 (15.0 – 28.2)	Sandy clay loam
Farm B	0.138 (0.0 – 7.76)	57.3 (32.0 – 75.3)	20.0 (10.7 – 31.2)	22.5 (12.6 – 49.8)	Sandy clay loam
Ref.B	0.011 (0.0 – 0.10)	60.4 (47.9 – 81.2)	18.8 (3.78 -23.9)	20.8 (15.01 – 28.2)	Sandy clay loam

The amount of TOC, TOM, TN and TP sediment is useful in the determination of sediment contamination. It is estimated that for a zone to be considered as uncontaminated, the content of organic matter in the sediment must range from 0.5 to 5 %, whereas the sediments with more than 15 % organic matter are typical in contaminated zones (Mendez, 2002). US EPA (2002) recommended assessment categories for TOC in sediments. For low impact, TOC should be less than 1 %; for intermediate impact, TOC should range 1 to 3 %, and for high impact the TOC in sediments should be greater than 3%. However, these thresholds are still under evaluation. The sampled analysed had a TOM of 1.89 - 4.11 % for Farm A and 4.42 – 8.98 % for Farm B (Figures 3.31 and 3.32). The results of the organic matter indicated that the sampled sites ranged from uncontaminated to slightly contaminated sediments due to organic matter. Alpaslan and Pulatsü (2008) observed organic matter values of 13.12–15.57 % at the cage-station sediments in Kesikköprü Reservoir in Turkey.

Organic matter level of 39-69 % was determined in the rainbow trout cage culture of oligotrophic Passage Lake, Canada (Cornel and Whoriskey, 1993).

The mean TOC was 1.10 - 2.39 % for Farm A and 2.57 - 5.22 % for Farm B. According to USEPA (2002) categorization, the organic carbon levels in the analysed sediments were of intermediate impact. Troell and Berg (1997) reported total carbon content of between 2.8 % and 4.49 % in sediment of tilapia cages in tropical Kariba Lake which is similar to the present study. Temporetti *et al.,* (2001) determined TOC levels of 0.2 % to 5.3 % in salmonid cultured sediment. Additionally, Alpaslan and Pulatsü (2008) reported TOC levels of 5.4-8.59 % in a rainbow trout cultured reservoir. The accumulation of organic matter beneath cages differed from farm to farm and mainly depended on local conditions such as hydrological, geomorphogic featuresand production capacity. Accumulation rates are therefore, different for different farms (Maldonado *et al.,* 2005). The accumulation of TOM and TOC in the present study were low compared to others elsewhere and showed significant differences in the sites. However, it was not clear that the tilapia cage culture influenced the accumulation of TOM and TOC in the reference sites, since TOM and TOC values were relatively higher at the reference sites.

Total nitrogen (TN) levels of the sediment in the farm sites were different from the reference sites and were determined as between 0.097- 0.204 % for Farm A and 0.22-0.45 % for Farm B (Figures 3.29 and 3.30). The levels presented are similar to the values of Troell and Berg (1997) ranging from 0.22 to 0.40 % in the tilapia cages in a tropical Lake and of Alpaslan and Pulatsü (2008) (0.26 % and 0.44 %) reported in a rainbow trout cage system. Temporetti *et al.* (2001) recorded TN levels of 0.1-0.8 % in salmonid cage system. In this study the maximum phosphorus level was 0.265 % for Farm A and 0.605 % for Farm B. Troell and Berg (1997) observed phosphorus maximum value of 0.26 % in tilapia cage farm in a tropical Kariba Lake.This value is similar to Farm A TP value. The maximum TP determined in a reservoir in Turkey where rainbow trout culture is performed was 0.13 % (Alpaslan and Pulatsü, 2008). However, TP ranged from 0.2-5.3 % in salmonids cage farm in Alicura Reservoir, Argentina (Temporetti *et al.,* 2001). There were perfect correlations among TOM, TOC and TN, suggesting they have a common source (Tables 3.11 and 3.12).

3.7.7 Effects of Wild Fishes Aggregation in the Vicinity of Cages

In the aquatic environment floating structures are well-known to be effective in the attraction of fish (Freon & Dagorn, 2000; Castro *et al.,* 2002). Fish cage structure attract wild fish, the uneaten feed that escapes through the cages and fouling organisms may facilitate the attraction effect (Bjordal & Skar, 1992). For the period of the study, huge numbers of wild fish species were seen around the cages in Lake Volta. This phenomenon has been observed in other parts of the world. However, it was not within the scope of this study to estimate the number of fishes. Four Mediterranean farms had remarkably large aggregations (between 30,000–88,000) of fish (Dempster *et al.,* 2004). In contrast, few wild fishes were observed in the reference site. A study of a sea- cage fish farm in Canary Islands recorded a total of 15,204 fishes composed of 15 families and 23 fish taxa.The wild fish around the cage farm were about 50 times more than the two control locations (Tuya *et al.,* 2006).The consumption of cage waste by wild fishes around the cages significantly modifies the dispersion of wastes beneath and around the cages by increasing their area of deposition as wild fish move around the fish farm (Sarὰ *et al*, 2004).

3.8 Conclusion

The knowledge of environmental impacts of cage culture is vital to the protection and management of aquatic resources. The results obtained revealed that the production systems of the tilapia cage culture that were studied in the Lake Volta did not significantly impact the composition of the water quality in the neighbourhood of the cages. However, the farms seemed to have moderate effect on sediment quality with respect to organic matter which is difficult to attribute solely to impact from cages since data on pre-farm sediment quality was non-existent. The minimal impact of the cage aquaculture could be attributed to possible dispersion of cage waste by the water currents, the probable consumption of waste by schools of wild fishes that congregated around the cages, especially during feeding of caged fish, and reduction of nutrients by dilution.

The results showed that concentration of heavy metals in the water column and sediment were low and within torelable levels suggesting no impacts from feed additives. The water quality indices (CCMEQI and GWQI) indicated that the lake water quality is good and suitable for tilapia production and other ecosystem use such as irrigation, recreation and water supply. With expansion in cage operations in the lake, waste generation will continue to increase and that will produce considerable pollution into the lake's environment. For sustainable development of cage culture in Lake Volta, it would be useful for stakeholders to determine the maximum capacity with the least effect and design a long term programme to monitor water and sediment quality.

CHAPTER 4:

AN ESTIMATION OF NITROGEN, PHOSPHORUS, AND CARBON WASTES INPUTS FROM CAGE FARMS ON THE VOLTA LAKE IN GHANA INTO THE ENVIRONMENT

4.1 Introduction

Lake Volta is the largest man-made lake in the world by surface area (8,502 km^2) and the world's third largest lake by volume (approximately 150 billion m^3) (Lakepedia, 2016). In Ghana, fish is a very popular and an important food item. The consumption of fish and fish products has increased over the years, while capture fishery production continue to fall short of current demand. One of the most recent solutions is the establishment of aquaculture cages in the Lake Volta, to increase fish production for the local communities and potentially for export. Cage culture cultivation has proven to be so successful that over the last decade it has expanded significantly and now there are large-scale aquaculture establishments on the lake (Kassam, 2014).

Concerns have been expressed elsewhere about the increasing levels of nutrient wastes discharged into the aquatic environment due to cage culture expansion (Whitmarsh *et al.,* 2006; Redmond *et al.,* 2010; Azevedo *et al.,* 2011). Composition of nutrient releases from cage aquaculture can be divided into two groups; dissolved waste and particulate organic. Dissolved inorganic nutrients such as NH_3 and PO_4 are released through excretion and C as CO_2 is released through respiration. Particulate organic C, N and P are released through defaecation and loss of feed (Olsen *et al.,* 2008). The different parts of the ecosystem are affected differently by the waste components (Olsen *et al.,* 2008). Uneaten feed and the larger faeces particles sink into the bottom of the lake, while bacterial decomposition of organic material such as uneaten feeds release ammonia into the lake waters (De La Vega 2001).

Minimising the environmental impact is a positive step to sustainability of the aquaculture environment. Reducing environmental impacts of culture operations requires estimation of the amount of waste associated with production. There are two methods for estimating material lost to the environment: direct, through sampling and analysis of the water column and of sedimenting particulate material; and indirect, using a mass balance approach (Beveridge, 2004). The direct monitoring and estimation of waste outputs is even more difficult, costly and likely inaccurate (Dominique *et al.,* 2003). According to Kelly *et al.,* (1996) inherent physical constraints related to this type of operation suggest that (nutrient) mass balance estimates of waste production are likely to provide more robust estimates of waste output than direct monitoring of waste output. The accurate estimation of waste loading from cage culture using nutrient mass balance require accurate information on the chemical composition of feed used, the chemical composition of the fish produced, the juveniles stocked as well as the mortalities (Sowles and Churchil 2004). The effect of cage aquaculture on the Lake
Volta and its surroundings is mostly unexplored, being a relatively recent development. A good knowledge on the impacts of nutrient loading from cage aquaculture will assist in sustainable development of the sector considering its rapid expansion on the lake.

In this study, carbon, nitrogen and phosphorus loads from cage culture were investigated to elucidate the effects on the lake's environment to enhance sustainable cage culture in the Volta Lake.

4.2 Material and Methods

4.2.1 Study Sites

The two Farms A and B selected for these studies have been described in sections 3.22 and 3.23 of Chapter 3. Both farms practice intensive fish farming with tilapia (*Oreochromis niloticus*) as the main species for production. Farm A is a medium scale farm with annual production of 106 tonnes while Farm B is a large scale farm with annual production of 2,300 tonnes. Feeding in both farms is done by hand and the feeds are extruded diet manufactured in Ghana by Raanan Fish Feeds. The feed is grouped into starter (48 % crude protein for fry up to about 4 g), pre-grower (40 % crude protein for fingerlings from 5 g up to about 40 g), grower (33-38 % crude protein and for fish from about 50 g to about 250 g) and finisher (30 % crude protein for 250 g fish and above).

4.2.2 Study Approach

The data on feed used, harvests and mortality for the 2014 production year from the two farms were used. Estimation of N, P and C wastes from cages into the environment was undertaken using simple input-output mass balance according to Sowles and Churchill (2004). This method of estimating nutrient loading from fish farm is useful because it accounts for inputs and outputs in more detail. This method has been used extensively in estimating nutrient loads in open waters including Lake Malawi which is a high current environment where empirical measurements may not be possible (Gondwe *et al.,* 2011). This method could also be used in open waters of Lake Volta. A second inputoutput mass balance according to Beveridge (2004) was used. In this second model, the input through stocked fish and the output through mortality were not considered. It was assumed that the input through fingerlings would be balanced by the output through mortality. However, the food conversion ratio (FCR) was considered.

4.2.3 Input-output Mass Balance Method

The input-output mass balance method of estimating nutrient loading into the environment requires the accurate and detail chemical composition and weights of the different inputs (feed and juveniles) and outputs (mortality removal and harvest).

Loading is calculated as the input minus output as given by Sowles and Churchill (2004). Data such as feed input, juveniles, mortalities and harvest were obtained from the production records of the farms. However the composition of nitrogen, phosphorous and carbon in feed and fish were analysed as in sections 4.2.4 and 4.2.5.

4.2.4 Proximate Analysis of Feed

Three types of feeds (one pre-grower and two grower) produced by Raanan fish feed West Africa limited and one pre-grower fish feed from the Netherlands that is widely used by the fish farmers were selected and analysed for their proximate compositions.

The feed types were Tilapia grower 33, Tilapia grower 38, Tilapia pre-grower 40 and Coppens pre-grower. The feed samples were collected from the farm into a transparent polyethylene bags and transported to CSIR Water Research and Soil Research

Laboratories for analysis. In the laboratory the following: moisture, ash, phosphorus, nitrogen, carbon and protein analyses were performed on the feeds following AOAC, 2012 procedure already explained in sections 3.3.4 to 3.3.10 of Chapter three.

4.2.5 Proximate Analysis of Fish

The body composition of the fish from Farm A and B were determined from the analysis of six tilapia collected from cages. The adult tilapia used for the determination weighed between 500 and 1000 g. The juveniles weighed 2 to 30 g, while the mortalities were between 250 and 500 g for Farm B. The live fish samples were removed from the cages placed in a container with ice and transported the Council for Scientific and Industrial Research (CSIR) Food Research laboratory. In the laboratory the full body was homogenized and chemical analysis evaluated on the following: moisture, ash, nitrogen, phosphorous, carbon and crude protein according to the procedures outlined in Association of Official Analytical Chemists (AOAC, 2012). From Farm A the grown out were weighing between 150 and 300 g, juveniles 2 to 20 g and mortalities (dead fish) 100 and 250 g.

The mass balance equations employed are as follows:

$$N\ (kg) = (F \times N_{fd} + J \times N_{jv}) - (H \times N_{hv} + M \times N_{mo}) \quad (4.1)$$

$$P\ (kg) = (F \times P_{fd} + J \times P_{jv}) - (H \times P_{hv} + M \times P_{mo}) \quad (4.2)$$

$C\,(kg) = (F \times C_{fd} + J \times C_{jv}) – (H \times C_{hv} + M \times C_{mo})$ (4.3) Where:

F, J, H and M are fresh weights (kg) of feed used, juveniles stocked, fish harvested and total mortalities, respectively as documented in farm records. N_{fd}, N_{jv}, N_{hv}, and N_{mo} are nitrogen content in feed, juveniles, harvests and mortality, respectively expressed as % fresh weight. P and C loadings are expressed in the same manner as N contents in the N loading equation above.

The second output-input mass balance method used was after Beveridge (2004) as follows:

$Nut_{env} = Nut_{food} – Nut_{fish}$

Where total nutrient losses to the environment Nut_{env}, were computed as being equivalent to the difference between the nutrients added in the food, Nut_{food}, and those assimilated by the fish which were subsequently harvested, Nut_{fish}. This is based on available or analysed data on N, P and C (nutrient) content of feeds, FCR (Food conversion ratio) values and N, P, C content of fish. Accordingly, the equations for N, P and C loadings into the environment are expressed as follows:

$$N_{env} = (N_{feed} * FCR) – N_{fish} \quad (4.4)$$

$$P_{env} = (P_{feed} * FCR) – P_{fish} \quad (4.5)$$

$$C_{env} = (C_{feed} * FCR) – C_{fish} \quad (4.6)$$

Where N_{env}, P_{env} and C_{env} are N, P, C losses to the environment. N_{feed}, P_{feed} and C_{feed} are N, P, C content in feed. N_{fish}, P_{fish} and C_{fish} are N, P, C content in fish. FCR is the food conversion ratio.

4.2.6 Data Analysis

To determine whether significant differences existed between the two methods, data obtained were subjected to independent sample T-test. Using both the Levene test for equality of variance and equality of means with the decision criteria such that if $p < 0.05$, both variance and means were considered significant.Regression analysis was used to establish relationships between monthly feed supplied and nutrient losses. Statistical analyses were executed using SPSS version 21. All graphs were executed by Microsoft excel.

4.3 Results

4.3.1 Feed Composition

Table 4.1 presents the analysis of the nutritional compositions of the type of tilapia feeds predominantly used in the study area. Four types of feed were analysed which covered the various stages of production, pre-grower, grower and termination. The mean percent composition per wet weight of feed for N ranged between 5.60 and 6.61 %, P ranged from 1.33 to 1.40 %, while C fluctuated between 41.94 and 42. 89 %. There was a strong linear relationship between feed supply and N, P and C losses from the cages which suggest that wastes generated in the cages can be directly related to the amount of feed supplied (Figure 4.1).

Table 4. 1: Mean ± SD proximate composition of selected extruded feed types used inNiletilapia (*Oreochromis niloticus*) production in Volta Lake, Ghana

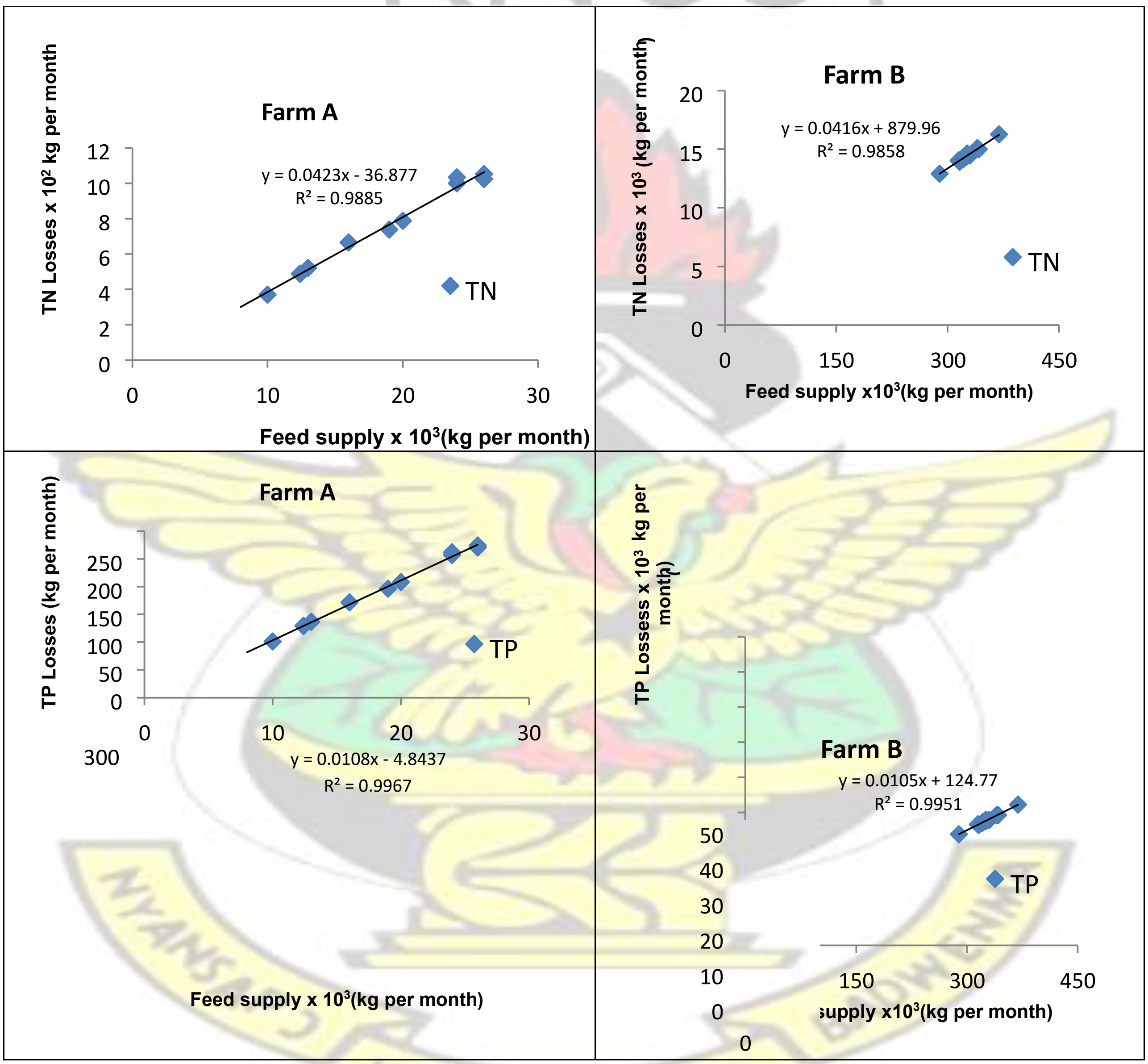
Feeed type	% Moisture	% Ash	% N	% P	% C	% Protein
Feed A	8.45±0.23	7.70±0.52	6.61±0.10	1.39±0.15	42.7±0.98	41.2±0.23
Feed B	8.72±0.30	7.39±0.11	5.60±0.42	1.40±0.15	42.9±1.58	33.2±0.35
Feed C	8.67±0.44	8.37±0.02	6.21±0.12	1.38±0.06	42.8±1.46	38.5±0.28
Feed D	8.39±0.29	8.87±0.55	6.58±0.13	1.33±0.09	41.9±1.44	39.7±0.97

Feed A =Coppens; Feed B =Raanan 33; Feed C =Raanan 38; Feed D =Raanan PG-40

The linear relationship were for N (r^2= 0.988), P (r^2= 0.996) and C (r^2= 0.973), and the slopes for the linear regressions were 0.010 for N and then 0.042 and 0.249 for P and C, respectively at Farm A. The linear relationship at Farm B were for N (r^2= 0.985), P (r^2= 0.995) and C (r^2= 0.972), and the slopes for the linear regressions were 0.041 for N then 0.010 and 0.254 for P andC, respectively.

4.3.2 Fish Composition

The chemical composition of the tilapia fish is shown in Table 4.2. The mean N content in the fish collected from Farm A were 1.84, 2.99 and 2.89 % for juvenile, adult and dead fish,respectively. The P content was 0.52, 0.41 and 0.39 % for juvenile, adult and dead fish, respectively. The C content was a bit low (13.9 %) in juvenile but quite high in adult fish (27.3 %) and dead fish (27.5 %). Similarly, the protein content was low for juvenile fish (11.5 %) and high for adult fish (18.7 %) and 18.1 % for mortality fish. The moisture content ranged from 70.4 % to 85.2 %. The chemical composition of tilapia collected from Farm B was similar to that of Farm A.



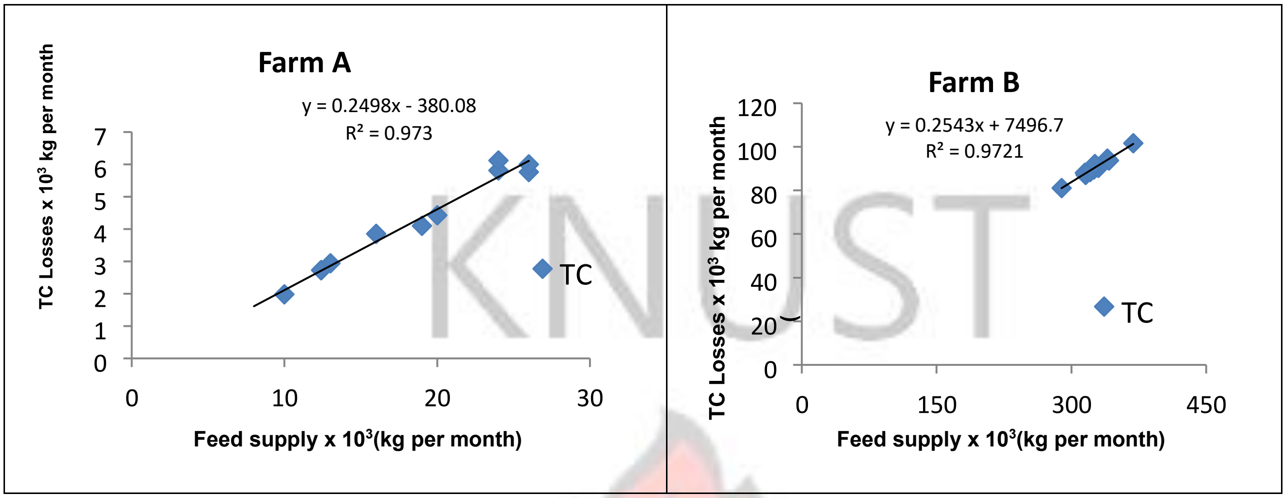


Figure 4. 1: Relationship between feed supply and modeled TN, TP and TC losses fromFarmsA and B tilapia cages in Lake Volta, Ghana

Table 4. 2: Mean±SD percentage composition of moisture, ash, N, P, C and protein in Nile tilapia fish (*Oreochromis niloticus*) fresh weight of juveniles, harvest /adult and mortality reared in cages in Lake Volta, Ghana

PARAMETER	**JUVINILLE**		**HARVEST/ADULT**		**MORTALITY**	
	Farm A	Farm B	Farm A	Farm B	Farm A	Farm B
Moisture %	85.2±0.75	83.7±1.41	70.4±1.31	70.7±0.83	70.5±2.18	74.3±1.42
Ash %	3.37±0.18	2.61±0.40	2.27±0.17	3.56±1.38	1.96±0.26	2.94±0.15
N%	1.84±0.28	1.63±0.16	2.99±0.12	2.98±0.06	2.89±0.18	2.25±0.14
P%	0.52±0.03	0.52±0.07	0.41±0.03	0.44±0.25	0.39±0.03	0.51±0.03
C %	13.9±0.66	13.7±0.82	27.3±1.15	25.7±1.32	27.5±0.95	22.8±0.87
Protein %	11.5 ±0.50	10.2±0.40	18.7±0.81	18.6 ±0.35	18.1±0.95	14.1±0.41

4.3.3 Comparison of the two Mass Balance Methods

Table 4.3 shows the means and associated standard deviation for N, P, and C discharges from Farm A and B determined by the two methods.Using the criteria stated in Section

4.2.6, there were no significant differences between the means and variances ($p > 0.05$). This suggests that anyone of the two methods could be conveniently used for the estimation of nutrient loading in a cage farm.

Comparing the two different methods used for the estimation of the nutrients released into the Lake Volta's environment, the methods produced seemingly different nutrient loads (Table 4.4) for Farm A. This is because in Sowles and Churchil's model, input through stocked fish and output through mortality are considered and the nutrient losses in mortality from the cages were considerable. However, Farm B recorded very comparable values (Table 4.4). This is also because the nutrient contribution of input and output in Solwes and Churchill's model were negligible. Moreover, the input through fingerlings was balanced by the output through mortality. Nutrient estimates of 71.7 % of N, 80.8 % of P, and 64.8 % of C were discharged from Farm B cages into the environment.

Table 4. 3: Comparison of means ± standard deviations of N, P and C loadings of FarmAand B using two methods

	Farm A (n=11)	**Farm B (n=12)**
Nitrogen (kg)		
Solwes & Churchill's method	742.56 ± 254.6	14442.56 ± 806.34
Beveridge's method	856.64 ± 251.5	14486.54 ± 818.5
Phosphorus (kg)		
Solwes & Churchill's method	194.45 ± 64.8	3545.53 ± 202.4
Beveridge's method	209.83 ± 64.1	3554.49 ± 205.0

Carbon (kg)		
Solwes & Churchill's method	4224.73 ± 1516.4	90345.78 ± 4960.4
Beveridge's method	5292.32 ± 1509.9	90830.21 ± 5042.3

Equality of variance and means are not significantly different (Independent-sample t test, $p > 0.05$)

4.3.4 Nutrient Load Estimation

Tables 4.5 and 4.6 show the nutrient balance of the component that is discharged during tilapia production from feeding through ingestion and the fraction not included in the harvested biomass, but are released into the environment in various forms of waste. From the nutrients estimation, it was observed that a nutrient load of 583 kg of C, 93.5 kg of N and 22.8 kg of Pper tonne of tilapia produced,is released into the environment with a C: N: P ratio of 25.6: 4.1: 1.0 (Tables 4.5). From Farm B, it was seen that for every tonne of tilapia produced, a nutrient load of 474 kg of C, 75.60 kg of N and 18.55 kg of P was discharged into the environment with a C: N: P ratio of 25.6: 4.1: 1.0 (Table 4.6). About 64.8 % of C, 71.7 % of N and 80.8 % of P were not used by the tilapia. From the estimation, and with the production of 2300 tonnes fish/year, from Farm B, the waste generated and discharged into the lake's environment would be 1090 tonnes of C, 174 tonnes of N and 42.6 tonnes of P which have the potential to cause harm to both the environment and the fish farms.

Table 4.4: Estimates of nutrient (N, P, C) load into the Lake Volta, comparing two inputoutput mass balance methods at both Farms A and B.

Nutrient loading	Input-output Mass balance method	Input-output Mass balance method
	After Sowles and Churchill (2004)	After Beveridge (2004)
FARM A		

Total N (%)	65.4	75.8
Total P (%)	78.4	84.7
Total C (%)	53.9	68.1
FARM B		
Total N (%)	71.5	71.7
Total P (%)	80.6	80.8
Total C (%)	64.5	64.8

Table 4. 5: Estimate of nutrient balance (C, N and P) and total environmental loading, kilogrammeper tonne of Nile tilapia (*Oreochromis niloticus*) in Farm A

Nutrient balance	**Carbon**	**Nitrogen**	**Phosphorus**
Feed input	855.7 (100 %)*	123.4 (100 %)	26.9 (100 %)
Uneaten feed	134.4 (16.0 %)	26.3 (21.0 %)	5.69 (21.0 %)
Feed consumption	721.3 (84.0 %)	97.1 (79.0 %)	21.2 (79.0 %)
Feed retention	273.0 (31.9 %)	29.9 (24.2 %)	4.10 (15.3 %)
Indigestible fraction (faeces)	171.8 (20.1 %)	19.0 (15.4 %)	11.7 (43.5 %)
Soluble excretion	276.4 (32.3 %)	48.3 (39.1 %)	5.37 (20.0 %)
Total environment load	582.7 (68.1 %)	93.5 (75.8 %)	22.8 (84.7 %)

*The percentage in parentheses indicates the fraction of each in relation to the feed input.

Nutrient balance	**Carbon**	**Nitrogen**	**Phosphorus**

Feed input	731.00 (100 %)*	105.40 (100 %)	22.95 (100 %)
Uneaten feed	109.4 (15.0 %)	21.2 (20.0 %)	4.64 (20.0 %)
Feed consumption	621.6 (85.0 %)	84.2 (80.0 %)	18.3 (80.0 %)
Feed retention	256.58 (35.1 %)	29.83 (28.4 %)	4.41 (19.2 %)
Indigestible fraction (faeces)	139.8 (19.1 %)	15.4 (14.6 %)	9.53 (41.6 %)
Soluble excretion	224.8 (30.8 %)	39.0 (37.0 %)	4.38 (19.1 %)
Total environment load	474.00 (64.8 %)	75.60 (71.7 %)	18.55 (80.8 %)

Table 4. 6: Estimate of nutrient balance (C, N and P) and total environmental loading,kilogrammeper tonne of Nile tilapia (*Oreochromis niloticus*) in Farm B

*The percentage in parentheses indicates the fraction of each in relation to the feed input.

4.3.5 Feed Input and Fish Production

Figure 4.3 presents monthly feed input and fish production at fish Farms A and B in the Asuogyaman District in the Eastern Region from January to December 2014. Both fish production and fish feed input dropped from February to March for Farm A. There was an increase in April and a feed decrease in May. Thereafter, there was a steady increase in both feed input and fish production until October. Both feed input and production dropped in November and finally increased in December. Fish production ranged between 4.57 and 15.95 tonnes per month, while the feed used fluctuated from 8.0 to 26 tonnes. The total amount of feed utilized in 2014 was 210.8 tonnes and the corresponding fish production was 106 tonnes. There was no harvest in May 2014. Generally, the fish production was closely related to the feed applied.

In Farm B, both fish production and fish feed input decreased in February and gradually increased from March until June where after they decreased slightly and finally increased in December. Fish production ranged from 166 to 220 tonnes per month and the use of fish feed varied between 289 and 369 tonnes per month (Figure 4.3). The total amount of feed used and fish production in Farm B during 2014 was 3,910 and 2,299 tonnes, respectively.

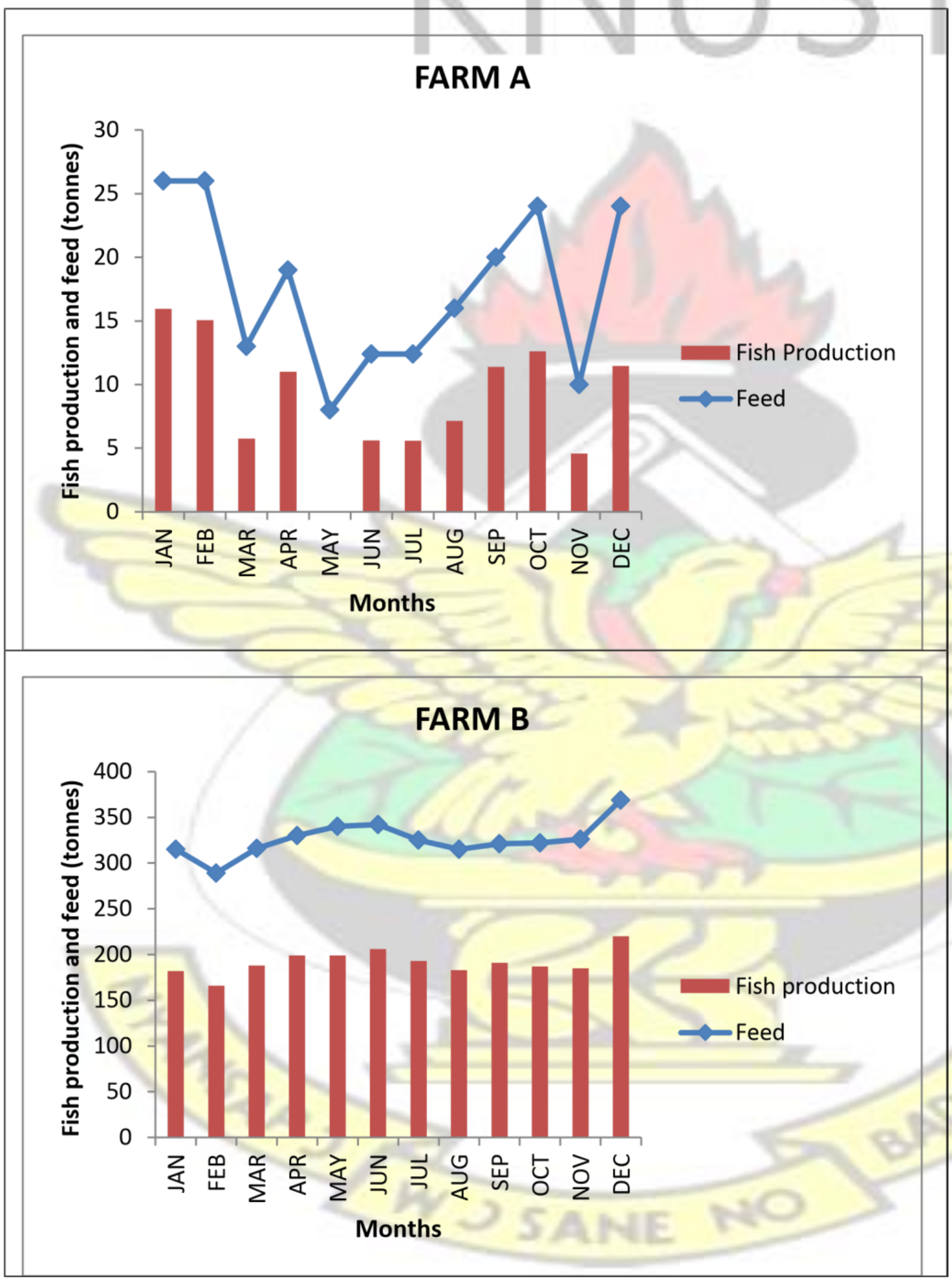


Figure 4. 2: Monthly fish production and fish feed used in cage Farms A and B in 2014

4.3.6 Monthly Loading Estimates in the two Farms

In both farms under consideration, the monthly estimates of TN, TP and TC discharges from aquaculture farms fluctuated with feed inputs (Figure 4.5). In May, there was no fish harvest in Farm A (Figure 4.5). It was observed that an increase in feed input resulted in high nutrient loading into the environment. However, a decrease in feed input gave a corresponding minimal nutrient discharges.

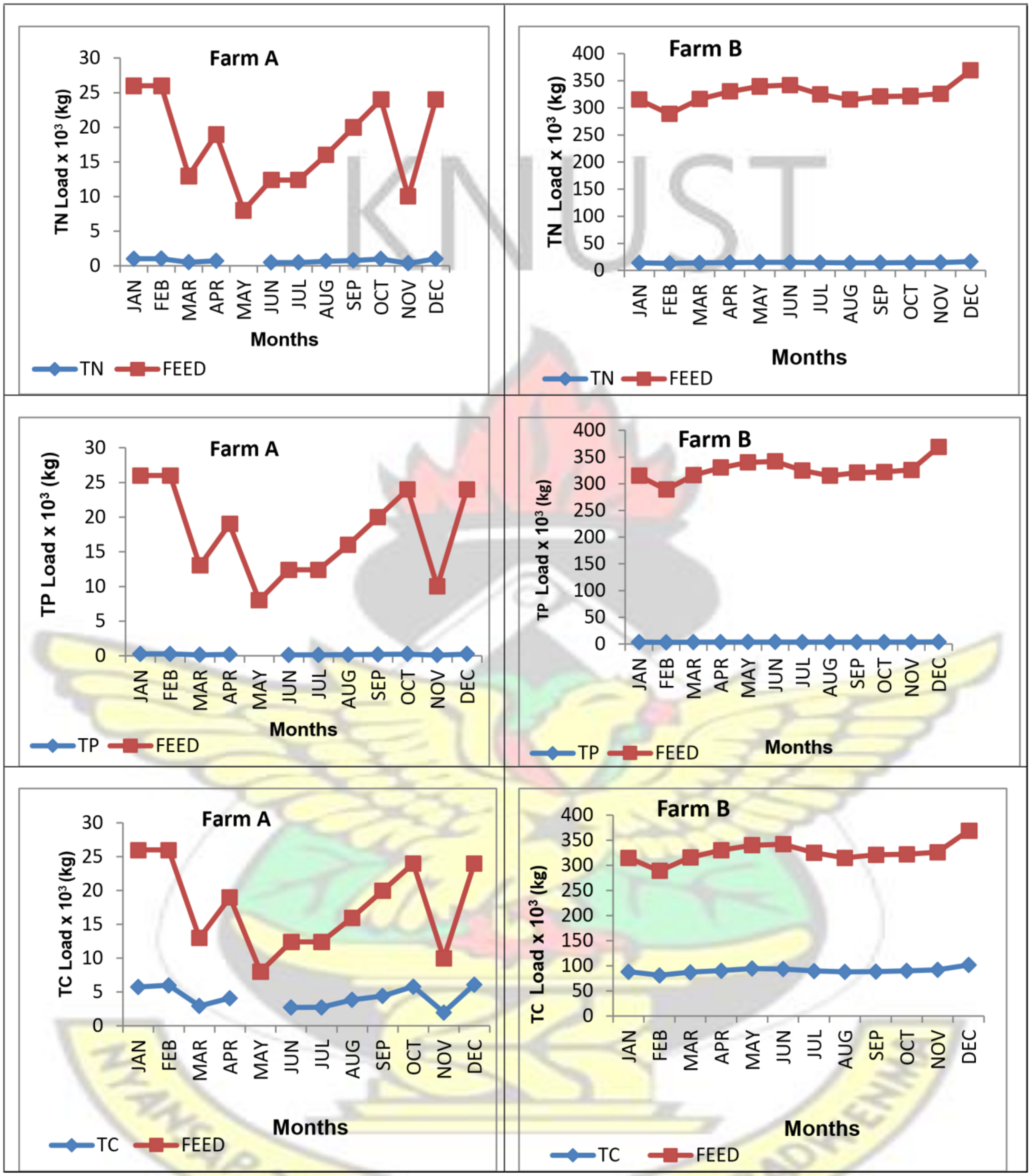


Figure 4. 3: Monthly loading estimates of TN, TP and TC into the Volta Lake from cage Farms A and B

Comparing waste loadings from the two farms (Table 4.7), the TC (582.7 kg), TN (93.5 kg), and TP (22.8 kg) loadings from Farm A is higher with higher FCR ranging from 1.63 to 2.26 and an average of 2.0. However, Farm B with FCR range of 1.66 to 1.76 and an average of 1.70 recorded lower TC of 474 kg, TN of 75.6 kg and TP of 18.6 kg per tonne.

Table 4. 7: Comparison of waste of C, N and P loading between cage fish Farms A and B (kg t^{-1} fish produced)

Farm	**TC**	**TN**	**TP**
Farm A	582.7	93.5	22.8
Farm B	474	75.6	18.6

4.4 Discussion

4.4.1 Nutrient Discharge from Cage Farms

The results from the present study showed that considerable amounts of nutrients, C, N and P were discharged from the cage culture operations into the lake's environment that has the potential to cause pollution to the water, sediment and organisms in the ecosystem. The nutrient discharges from the farmswere; for Farm A, 68.1 % of C; 75.8 % of N and 84.7 % of P. For Farm B, 64.8 % of C; 71.7 % of N and 80.8 % of P. The environmental impact of wastes discharged from cages depends largely, on the farming location and the characteristic of the receiving environment, mostly its ecological context, depth and hydrodynamic regime (Doglioli *et al.,* 2004; Pusceddu *et al.,* 2007).

These factors will ultimately influence the dilution of pollutants (Doglioli *et al.,* 2004).

The Farm B site is located in the open lake, and it is characterized by an average depth of about 30 m and an average current speed of 0.062 m s^{-1}, while Farm A site has 20 m and 0.037 m s^{-1} average depth and current speed, respectively. Despite the high biomass and the high nutrient release, these sites did not produce any significant effect on the chemistry of the water column and the sediment quality. The water quality results of the fish farm sites were comparable to the reference sites during this investigation. These results agree with many other authors who reported no significant effects of fish farms on water column parameters (La Rosa *et al.,* 2002; Soto and Norambuena, 2004; Pitta *et al.,* 2005). One of the reasons could be due to high dilution.

Lower concentrations of dissolved N and P in water than expected despite high nutrient loadings from cage farm are indicative of removal of these nutrients, likely as a result of immediate sedimentation of solid waste and uptake of dissolved forms by algae and bacteria and/or adsorption to particles and eventual removal by sedimentation. Schindler (1978) and Levine and Schindler (1992) reported that experimentally added phosphate was quickly taken upby seston and thus rendered susceptible to removal by sedimentation. Nitrogen transformations in the water would contribute to the lower than expected ammonia concentrations observed in the water. In this study considerable amount of increase in nitrate in the water column suggests that part of the ammonia excreted as fish waste was converted into nitrate. McDonald *et al.,* (1996) also reported a faster increase in nitrate/nitrite, relative to ammonium, for lakes with aquaculture operations as compared with lakes with no aquaculture operations, indicating that most of the nitrogenous load from excretion and uneaten feed was nitrified and mineralized relatively quickly in the aerobic, well mixed water column.

Table 4. 8: Comparisons of modelled N and P discharge from cage fish farms in freshwater lakes (kg t^{-1} fish produced)

Country	TN	TP	Species cultured	Reference
Poland	100	23	Rainbow trout	Penczak *et al.*,(1982)
Denmark	83	11	Rainbow trout	Warrer-Hansen (1982)
Findland	73.3	18.3	-	Sumari (1982)
Ireland	124.2	25.6	Rainbow trout	Foy & Rosel (1991)
France	97.9	18.6	Brown trout	Merceron *et al.*, (2002)
Japan	30.9-86.0	14.8-26.4	Common carp	Jahan *et al.*, (2002)
Thailand	112	33	Red tilapia	Sumafish (2003)
Thailand	65	46	Giant gourami	Sumafish (2003)
China	120-160	25-35	Channel catfish & Bluntsnout bream	Guo *et al.*, (2009)
Malawi	106	43	Tilapia	Gondwe *et al.*, (2011)
Brazil	45	14.3	Nile tilapia	Neto & Ostrensky (2013)
Ghana	75.6-93.5	18.6-22.8	Nile tilapia	Present study

TN: total nitrogen; TP: total phosphorus

Table 4.8 summarises nitrogen and phosphate discharges from cage culture in freshwater lakes or reservoirs from this study and other similar cage fish farms. The TN and TP loadings of 75.6–93.5 kg and 18.6–22.8 kg in our study were reasonable with FCR ranging from 1.7–2.0. The higher TN and TP loadings observed in other countries reflect higher FCR of the fish farms. For example, the relatively higher TN and TP loadings of 120-160 kg and 25-35 kg, respectively from China were based on FCR ranging from 2.5 to 3.56. Another considerably higher TN of 106 kg and TP of 43 kg from Malawi correspond with FCR of 2.1 to 3.9 (average of 2.7). The low TN and TP releases from cage farm in Brazil were based on a low FCR of 1.35. Lower FCR could be achieved with improvement in feed utilization. In the present study, Farm B with 2,300 tonnes of fish biomass discharged lower nutrient levels onto the environment, reflecting a better FCR of 1.7. However, Farm

A with far lesser biomass of 106 tonnes released higher nutrients levels with relatively higher FCR of 2.0.

Philips *et al.,* (1985) estimated 79 % and 85 % loss of N and P, respectively which corresponded to 104 kg N fish per tonne produced. Enell (1987) found 74 % of nitrogen and 82 % of phosphorus in freshwater cage farms which was lost to the environment, an equivalence of 86 kg N per tonne of fish produced. According to Holby and Hall (1991), 77 % of phosphorus was lost to the environment. Hakanson (2005) estimated that the production of 1 tonne of fish in cages brings 50-75 kg of N and between 10-20 kg of P to the environment. Neto & Ostrensky (2013) indicated that 65 % of N and 72 % of P corresponding to about 45 kg of N and 14 kg of P per tonne of fish produced in cages. These values match with those estimated in this study (About 75.8 % loss of N and 84.7 % loss of P, equivalent to 93.5 kg of N and 22.8 kg of P per tonne of fish produced at Farm A and about 72 % loss of N and 81 % loss of P, equivalent to 76 kg of N and 19 kg of P per tonne of fish produced in Farm B). The similarity of the results among studies is largely due to similar species, comparable feed formulation and FCR values (Gavine *et al.,* 1995).

The nutrient load discharged into the lake's environment from feeding losses of about 20 % for Farm B and 21 % for Farm A were estimated based on Neto & Ostrensky (2013). Approximately 20 % of fish feed is reported lost from cages before it is ingested (Pearson and Gowen, 1990). Beveridge (2004) also assumed 20 % feeding losses for tilapia. Tilapia is said to take a longer time to eat compared to most farmed fish species and therefore allowing a considerable amount of uneaten feed to sediment and a portion of the feed dispersed from the cages (Guerrero, 1980; Jauncey, 1998). Figures 4.4 and 4.5 show the nutrient balance model of N and P released into the environment in various forms of waste per tonne of tilapia production at Farms A and B. In general, nutrient loading is due to poor feed quality, poor farming and management practices and poor digestibility (Islam, 2005).

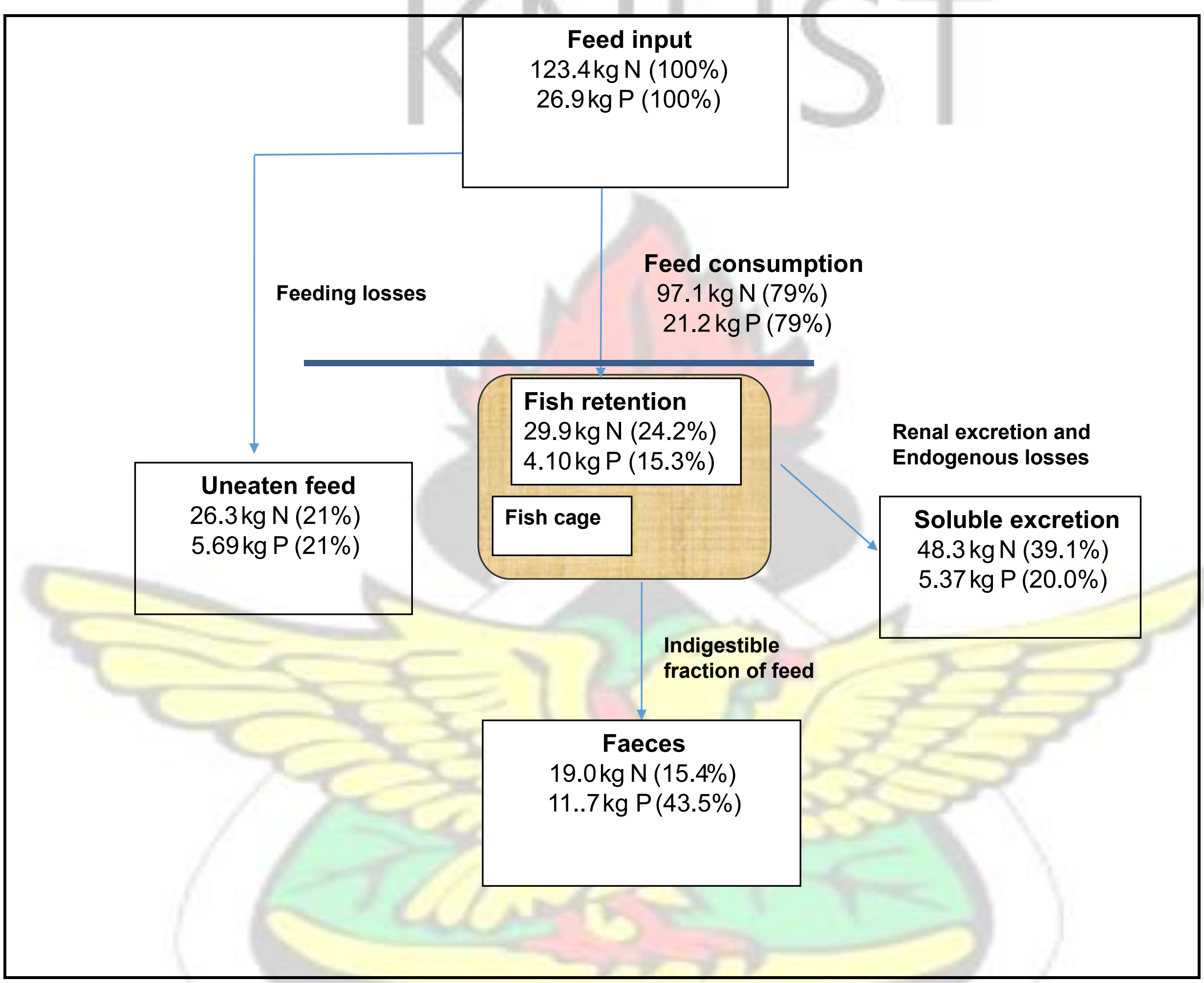


Figure 4. 4: A simple mass balance model of nitrogen and phosphorus for 1 tonne of intensive cage tilapia production (Farm A).

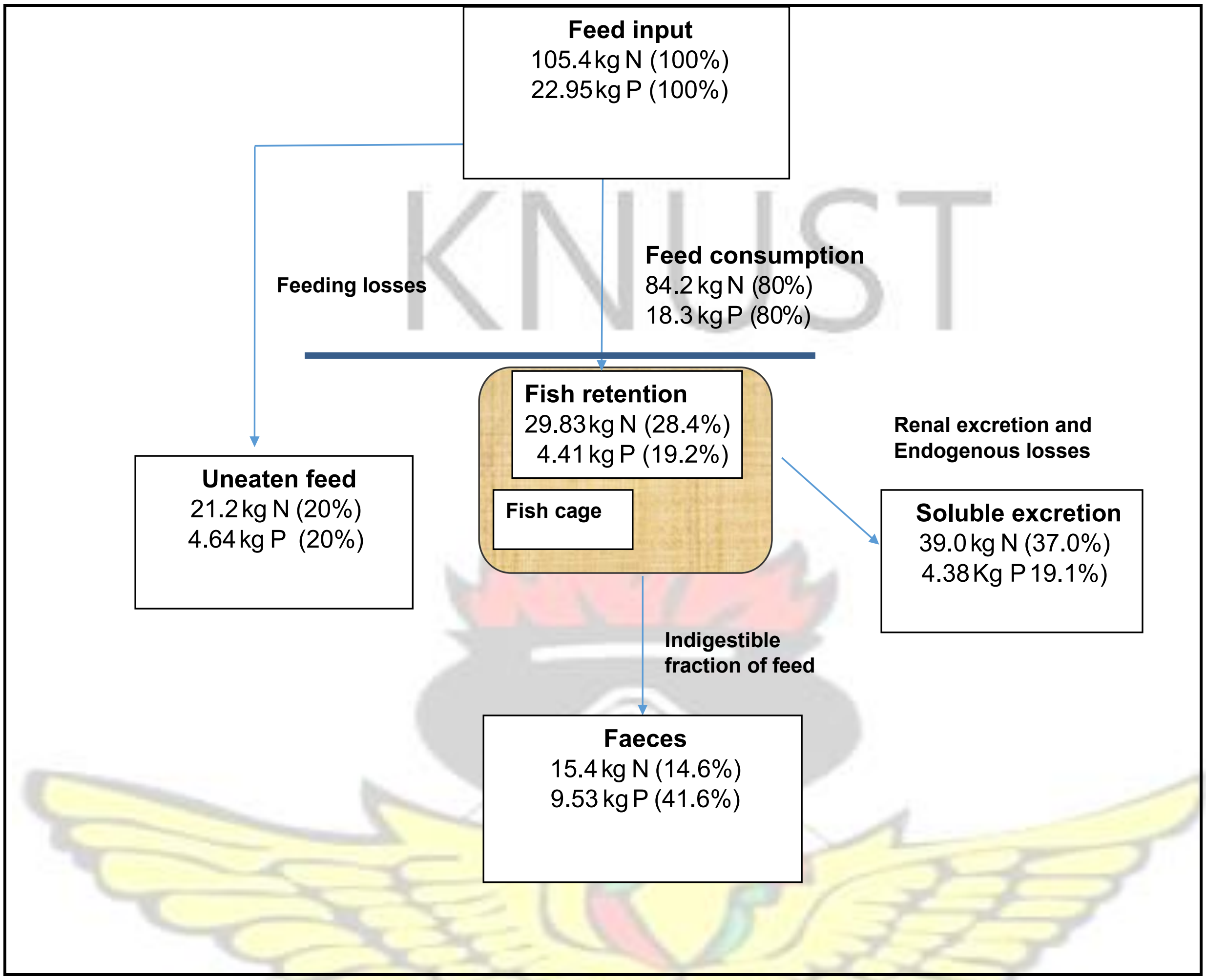


Figure 4. 5: Simple mass balance model of nitrogen and phosphorus for 1 tonne of intensive cage tilapia production (Farm B).

4.4.2 Effects of Nutrient Discharges on Sediment Quality

Analysis of the nutrient concentration such as TOC, TOM, TN, and TP of the sediment is a matter of determining the prospective inputs of the cages (La Rosa *et al.,* 2004; Schendel *et al.,* 2004). The results obtained from the nutrients analysis in the sediment (Chapter 3 of this thesis) did not indicate any appreciable change in the quality of the sediment as a result of the nutrient discharges from the cages. Karakassis *et al.,* (2000) reported negative redox potential values and increased TOM and TN at cage sites than undisturbed sites. However, in this study, positive values (range: 125-142 mV) of redox potential were recorded at the farms and the reference sites, suggesting oxic conditions in the sediment. Cage culture does not always result in changes in sediment chemistry or in macrobenthic community ecology (Cornel and Whoriskey, 1993; Johannessen *et al.,* 1994). The released nutrient from the cages may have been reduced by nutrient losses through the outflow at the dam (about 43.56 km^3 per annum i.e about one-third of the lake's volume). Mhlanga *et al.,* 2014, during their investigation of phosphorus concentration from cages in Lake Kariba, reported nutrient losses via the outflow at the dam.

It was observed in this study that the amount of nutrient wastes (C, N and P) being lost from the cages into the surrounding environment in Lake Volta was directly proportional to the feed supplied (Figure 4.1). This suggests that the nutrient discharges from the cages are expected to increase considerably as the production levels increase and more feed is supplied with time. It has been reported that wastes are dispersed more rapidly into far distances in fast moving waters than water with low current velocity (Sarὰ *et al.,* 2004). In areas where the current speed is much slower, there is enrichment of organic matter in the sediment directly beneath the cages (Canal-vergés *et al.,* 2010. Gondwe *et al.,* (2011) reported that waste discharged by cages in Lake Malawi was dispersed by mean current speed of 9.3 cm/s. Alpaslanu and Pulatsü (2008) also showed that 4 cm/s was sufficient to cause the dispersion of waste produced in cage farms in a Turkish reservoir. The nutrients emanating from fish cage farms in Lake Volta may be dispersed from the vicinity of the cages due to current speeds recorded in the farms (ranging from 1.70 cm/s to about 11.0 cm/s).The current speeds were fast enough to facilitate rapid dispersion of pollutants from the cages. Some studies have observed that wild fish can consume up to 80% of the organic particles sinking from fish pens (Vita *et al*., 2004; Felsing *et al*., 2005; Sudirman *et al.,* 2009). During the monitoring it was observed that at feeding times a lot of wild fish congregated around the cages to make use of the uneaten feed. In Lake Volta like other lakes, it is possible that, fraction of the lost feed and the faeces were consumed by wild fish, thereby reducing the environmental impact.

4.5 Conclusions

The nutrient loadings estimated in this study from the two farms in the Volta Lake constitute about the first assessment of discharges of C, N and P resulting from operations of Nile tilapia cage aquaculture in Ghana, using actual farm management and environmental data. The nutrient budget for the cage farms indicated that as high as 64.8-68.1 % of C, 72.0-75.8 % of N, and 81.0-84.7 % of P of the total feed input were released into the lake's environment for each tonne of fish produced, and only 31.9-35.0 % of C; 24.2-28.3 % of N and 15.3-19.2 % of P were harvested as fish biomass. These represent 257-273 kg C, 29.8-29.9 kg N, and 4.10-4.41 kg P per tonne of fish produced.

The tilapia cage culture provided considerable nutrients inputs that have potential to cause eutrophication in lakes. The nutrient discharges from the cages did not have any appreciable impact on the lake's environment at the current production levels. Sufffcient current velocity, dilution, consumption of waste by wild fish and nutrient losses through the outflow at the dam may be considered as the major reasons for no impact in the study area.

The two mass balance methods employed in the determination of the nutrient loads in this study were not significantly different ($p > 0.05$) in estimating loads from the same farm. This indicates that both methods are reliable and capable of estimating wastes from aquaculture activities. The model is a useful tool for the farmer and the regulating agency for the prediction of environmental impacts from aquaculture farms.

CHAPTER 5: PREDICTING THE ECOLOGICAL CARRYING CAPACITY OF TILAPIA CAGE CULTURE IN LAKE VOLTA USING PHOSPHORUS MASS BALANCE MODEL

5.1 Introduction

Lake Volta, a multipurpose water body supports a range of interests including wild capture fisheries, transportation, tourism, water supply, hydropower as well as residential uses. Currently, cage fish farming of tilapia is fast expanding on the lake. Population growth and increased demand for fish require efficient management of water resources used for the production of food (Tacon and Halwarth, 2007).

Large quantities of waste (uneaten food and fish faeces) are produced as a result of intensive cage fish culture (Beveridge, 2004). Usually the particulate organic wastes settle at the bottom of the lakes and bacterial decomposition of organic material such as unconsumed feeds release ammonia into the lake waters (Dela Vega, 2001). Reservoirs have the ability to accommodate and suppress nutrients but when limits are exceeded may lead to ecosystem breakdown and collapse (Wiens, 2006).

It is in the best interest of all users of a water resource to mitigate user conflicts and maintain ecological integrity. Proper management is prudent to avoid perturbations of these delicate, heavily used and ecologically important systems. An Ecosystem Approach to Aquaculture (EAA) is one way to preserve the anthropogenic and ecological resources of this system (Soto, *et al.,* 2008). EAA acknowledges equity among human uses while maintaining ecological sustainability (Ross *et al.,* 2013). An EAA can be applied using carrying capacity. Carrying capacity has been classified into four types of carrying capacity appropriate for aquaculture (Inglis *et al.,* 2000):

i. Physical — "total area of culture farms that can be accommodated in the available physical space", that is identification of potential zones or sites for actual development.
ii. Production — "the stocking density of fish at which harvests are maximized", which depend upon the technology, production system and the investment required.
iii. Ecological — "the stocking or farm density which does not cause unacceptable ecological impacts", to processes, services, species, populations or communities

in the environment. iv. Social — “the level of farm development that does not cause unacceptable social impacts.”

Lake water total phosphorus (TP) concentration is a strong predictor of numerous indicators of lake water quality and overall ecosystem composition, because of the strong associations between TP concentrations and lake ecology; numerous studies have attempted to determine the factors that exert the greatest impact on lake water TP concentrations. A lot of works have typically predicted lake TP concentrations based on input values for the areal phosphorus loading rate, mean lake depth, fractional phosphorus retention and areal hydraulic loading. Phosphorus losses within lakes are most commonly conceptualized as a function of the areal hydraulic loading rate or mean lake depth and a particle settling velocity (Peters, 1986).

Reservoirs have the capacity to accommodate and suppress nutrients effects and when limits are exceeded may lead to ecosystem breakdown and collapse (Wiens, 2006). It is believed that negative effects of cage fish farming can lead to changes in trophic states.

The estimation of ecological carrying capacity of a specific site and also full analyses of a lake environment are essential to sustain culture, protect environment or the ecosystem and reduce risks of eutrophication that may occur (Ross *et al.,* 2013). A phosphorus mass balance model for freshwater lakes first established by Vollenweider (1968) and further developed by Dillon and Rigler (1974) is widely used and tested for estimating phosphorus levels in lakes. Beveridge (2004) highlighted that Dillon and Rigler (1974) and OECD (1982) models have been known to produce favourable results when applied to lakes and reservoirs in different areas, as well as otherwaters with cage fish culture.For example, Dillon and Rigler model has been successfully used to estimate the ecological carrying capacities for rainbow trout in Kesikköprü Dam Lake in Turkey, tilapia cage culture of Lake Kariba in Zimbabwe and on a large reservoir of Ilha Soteira in Brazil, (Pulatsü, 2003; Mhlanga *et al.,* 2013; David*et al*., 2015).

The study is aimed at estimating the ecological carrying capacity of important areas for aquaculture development in Lake Volta using phosphorus loads from tilapia cage farms as well as other field water quality, and farm production data. This is done as a basis for planning, decision making and integrated management of sustainable aquaculture in the lake.

5.2 Material and Methods

The Lake Volta is a tropical man-made lake that was created by damming River Volta in 1964 to provide hydroelectric power. Geographically, it lies between longitude 1° 30° W and 0° 20° E and Latitude 6° 15´ N and 9° 10´ N (Figure 3.1). At a maximum level, the lake has a volume of 149 km^3, a surface area of about 8500 km^2 and its length is 400 km. The average is 19 m.

Currently, there are 467 cage farms with about 4,733 cages on the lake. These farms annual production totalled to about 33,500 tonnes, (MoFAD, 2014). For the purposes of estimating the ecological carrying capacity, two farm areas were chosen and these farms have already been described in detail in chapter 3 of this thesis. In this study, phosphorus mass balance models were used to estimate the ecological carrying capacities of the two aquaculture sites.Hydrographic, morphometry and water quality data were used in the models. Phosphorus assimilation capacity (as an indicator of ecological carrying capacity) was converted to potential of tilapia production by considering the amount loaded per tonne of fish produced separately for the two cage aquaculture sites. The result of the mass balance model (Dillon and Rigler, 1974) was used to estimate the maximum fish production allowable in each area per year. Proximate analyses of feed and fish and the production data collected from the farms were used as parameters within the model and water flow and volume movement within and out with the study areas were used as forcing functions.

During field monitoring, water depths at all sites were taken using echosounder (Plastimo Echotest II). The water level of the reservoir reduced consistently from August 2013 until the end of sampling in April 2015. Variation of TP content at reference sites of both farms were compiled for the surface waters of the lake for the study period. These values were taken to indicate the TP levels at (reference sites) pre-farm conditions, since environmental impact assessment (EIA) data for the farms were not readily available. The maximum allowable TP was chosen, to ensure that the lake or the study areas would not change in trophic status as defined by the OECD (1982). Consequently, a threshold of 100 µg/L TP was used as an absolute maximum allowable concentration.

5.2.1 Hydrological Data

The length and width of the selected areas of the lake was measured using Google earth map ruler tool. The depth of the water was measured with an echosounder. Using the calculated area (from length and width) and depth, the volume of the channels of the lake was estimated. The outflow ($m^3 s^{-1}$) was estimated via flow velocity measurements using drogues. The residence time or water retention time T_w, which is the average amount of time water spends in a lake was calculated as follows;

$$T_w = \frac{A \times 10^6 \times D_m}{Q \times S} \tag{5.1}$$

Where Q is outflow ($m^3 s^{-1}$), surface area, A (km^2), S, is seconds in a year (3600 x 24 x 365.25) and mean depth D_m (metres).

5.3 Dillon & Rigler (1974) Model Assumptions

- In this model, algal population densities are negatively correlated with water quality in general and growth and survival of fish stocks in particular.
- Phosphorus (P) is the limiting nutrient that controls phytoplankton abundance in most lakes and reservoirs.
- The lake (or discrete lake area) is well-mixed and at a steady state, and that fish cage farming is the major anthropogenic source of nutrients

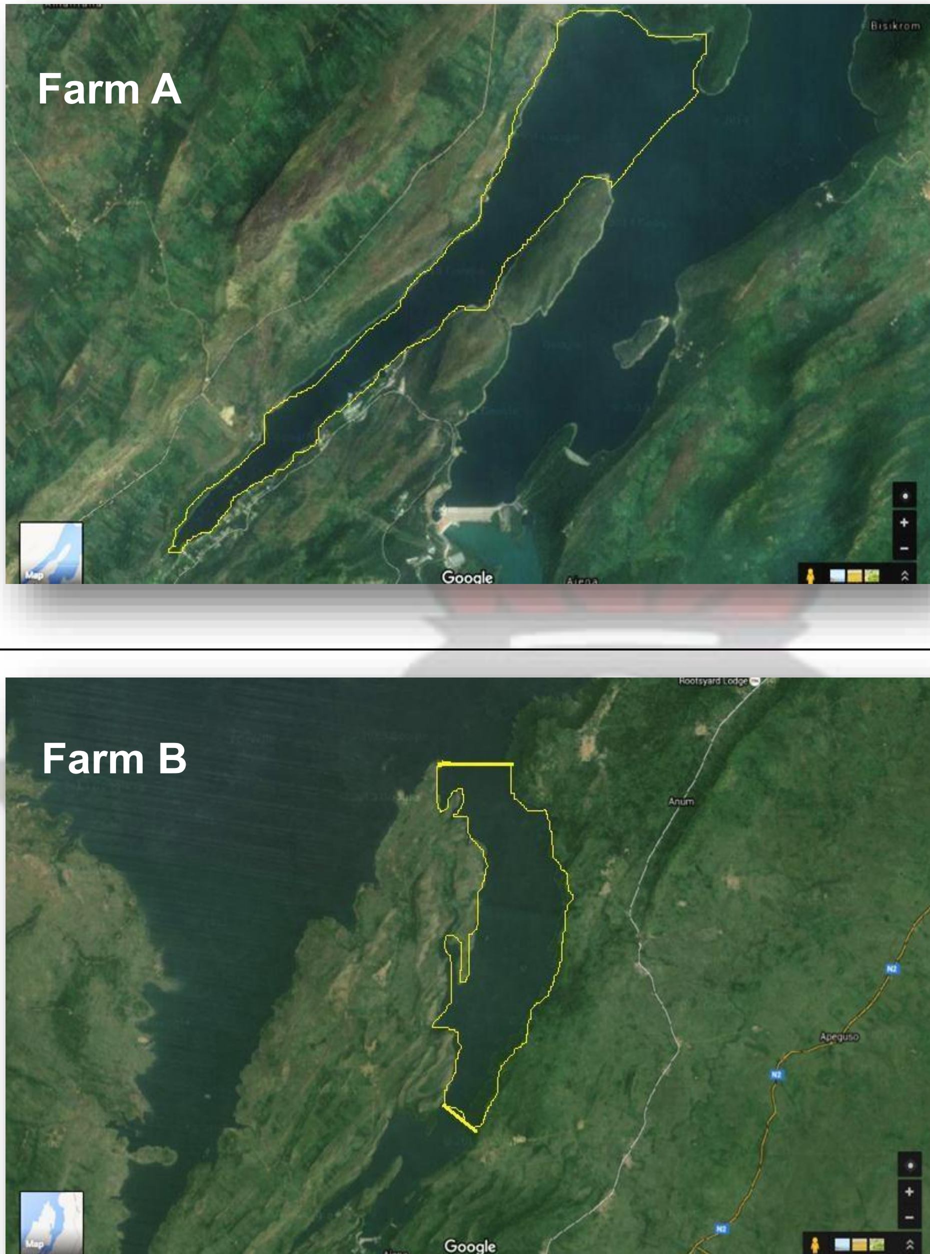


Figure 5. 1: Google image of sections of Lake Volta in Ghana showing discrete areas (marked yellow) where the farms were situated and for which the carrying capacities were determined.

5.3.1 Dillon and Rigler Model

The model is a modification of Vollenweider's original model (Vollenweider 1968) and states that "the concentration of total-P in a water body, [*P*], is determined by the P loading, the size of the lake (area, mean depth), the flushing rate (i.e. the fraction of the water body lost annually through the outflow) and the fraction of P lost permanently to the sediments” (Beveridge, 2004, pp.186). At steady state:

$$[P] = \frac{L(I-R)}{Z\square} \tag{5.2}$$

Where [*P*] is in µg/L total-P or TP; *L* = the total-P loading in gm^{-2} per year; Z= is the mean depth in m; *R* = the fraction of total-P retained by the sediments; and □ = the flushing rate in volumes per year.

The phosphorus mass balancd model for the evaluation of carrying capacity was described in a number of steps as follows:

1. Determination of the steady-state total-P concentration. In tropical lakes and reservoirs, [P] is be taken as the annual average total P concentration of surface waters and should be based on a number of samples taken during the year.

2. The development capacity of lake or reservoir for intensive cage culture is the difference between the productivity of the water body prior to exploitation and the final desired/acceptable level of productivity.

3. The capacity of the water body for intensive cage fish culture is the difference, □[P], between [P] prior to exploitation, $[P]_i$, and the acceptable [P] once fish culture is established, $[P]_f$.

□ [P] = $[P]_f$ - $[P]_i$ (5.3)

□P is related to P loadings from the fish cages, L_{fish}, the size of the lake, A, its flushing rate and the ability of the water body to handle the loadings.

□P = L_{fish} (1 - R_{fish})/ z□ (5.4)

L_{fish} =□ [P] z□/(1 - R_{fish}) (5.5)

The acceptable/desirable change in [*P*], □ [*P*] (µg/L) is determined as described in Step 2 above, and z can be calculated from hydrographic data obtained either from the literature or from survey work.

Z = V/A

Where *V* = volume of water body (m^3) and *A* = surface area (m^2). The flushing rate, □ (per year), is equal to Q_oV, where Q_o is the average total volume (m^3) flowing out of the lake/reservoir each year.

R_{fish} is the most difficult parameter to estimate. At least 45-55% of the total-P wastes from cage rainbow trout are likely to be permanently lost to sediments as a result of solids deposition. In the absence of any other data, these values are also used for cage tilapia and carp, and calculated as

R_{fish} = x + [(1 - x) R] (5.6)

Where x is the net proportion of total-P lost permanently to the sediments as a result of solids deposition (0.45-0.55) and R is proportion of dissolved total-P lost to the sediments i.e. phosphorus retention coefficient

$$R = 1/1 + 0.747\rho^{0.507} \quad (5.7)$$

ρ= Flushing rate (y^{-1})

4. Acceptable total-P loading, La is estimated by multiplying L_{fish} and lake surface area.
5. Intensive cage fish production (t y^{-1}) can be estimated by dividing L_a by the average total-P wastes pertonne of fish production.

An excel spreadsheet model was created for each of these formulae to allow for easy input of data and calculation of results. This will also allow for the utilization of these models for subsequent areas once more data is available.

5.4 Results

The characteristics of the areas in question of the Lake Volta and the fish farms are presented in Tables 5.1 and 5.2. The measured data of mean depth, area, volume, outflow and flushing rates of the studied sites selected are shown in Table 5.1. The surface areas of Farm A and B are 5.365 and 63.607 km^2, respectively. The mean depths were 20 and 30 m for Farm A and B sites. The mean depth presented variations during the sampling period as the lake level consistently continued to fall during the study period. The volume and outflow recorded for Farm A were 107.3 x 10^6 m^3 and 939 x 10^6 m^3, respectively with a flushing rate of 8.75 y^{-1} and a residence time of 0.1143 years. The Farm B area which is bigger had a volume of 1908 x 10^6 m^3, outflow of 7967 x 10^6 m^3 and a flushing rate and residence time of 4.175 y^{-1} and 0.2395 years, respectively.

Table 5.2 presents the data used for the estimation of phosphorus loads. Farm A utilized 210.8 tonnes of feed to produce 106.12 tonnes of fish per year with FCR of 1.99. The total phosphorus content in the feed and the fish were, respectively 1.35 % and 0.41 %. The total phosphorus loads to the environment was 22.77 kgt^{-1}. The feed used by Farm B to realise a production of 2,299 tonnes per year was 3,910 tonnes with FCR of 1.70. The total phosphorus content in the feed was 1.35 %, while in the fish, it was 0.44 %. The total phosphorus discharged to the environment from cages in Farm B was 18.55 kgt^{-1} and 42,665 kg y^{-1}, respectively.

Table 5.1: Morphometric and hydrodynamic data of selected sites of reservoir used for calculation of ecological carrying capacity.

Characteristics	**Units**	**Symbols**	**Farm A**	**Farm B**
Surface area	km^2	A_o	5.365	63.607
Lake volume	10^6 m^3	V_o	107.3	1908
Mean depth	m	Z	20	30
Total outflow [a]	10^6 m^3	Q	939	7967
Flushing rate[b]	y^{-1}	□□□Q/ V_o	8.75	4.175
Residence time[c]	y	T_w	0.1143	0.2395
Phosphorus retention coefficient[d]		R	0.308	0.393

a The volume of water discharged by the outlet to the main channel of the reservoir b The number of times water is totally renewed in one year. c The average amount of time water spends in the site. d The fraction of Total Phosphorus (TP) retained by sediment, estimated according to the method proposed by Larsen and Mercier (1976).

Table 5. 2: Measured data used for calculations of phosphorus loads per tonnne of tilapia produced in cages in 2014.

Characteristics	**Units**	**Farm A**	**Farm B**

Total feed	t y^{-1}	210.8	3,910
Annual production	t y^{-1}	106.12	2299
Phosphorus content in feed	%	1.35	1.35
Feed conversion ratio (FCR)		1.99	1.70
Phosphorus content in fish	%	0.41	0.44
Phosphorus load to environment	kgt^{-1}	22.77	18.55
Tot. Phosphorus load to environment	kgy^{-1}	2,416	42,665

Figure 5.2 shows the bimonthly average measured values of TP for surface waters in the reference sites of Farm A and B. The results which are considered as reference conditions indicated very high values of TP ranging from 73.0 to 380 µg/L for both farms, in the months of February to October 2014. However, lower and more typical levels of TP were obtained from August 2013 to December 2013 (range: 3.0-49.0 µg/L) and December 2014 to April 2015 (range: 46-97µg/ L). The TP levels encountered within the farms were not significantly different from the reference sites (ANOVA, $p > 0.05$). The high TP values obtained fell within both dry and wet seasons. Those values were not used in the model. For the reference (pre-culture) TP, the average of August to December 2013 and December 2014 to April 2015 levels were used in the Dillon and Rigler model.

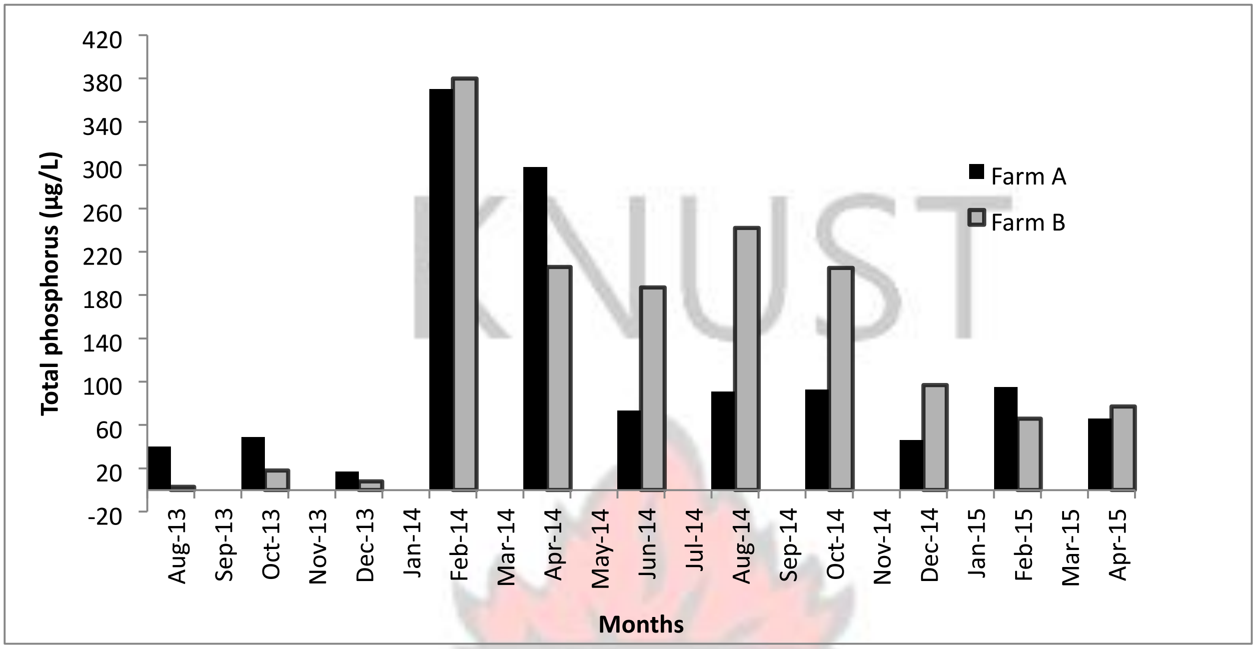


Figure 5. 2: Bimonthly average Total Phosphorus level (TP) for surface waters in the reference sites of Farms A and B from Aug. 2013 to April 2015

Applying Farm A results of this study and using the model equations in the earlier described steps:

1. The average phosphorus concentration of the lake water samples was $[P]_i$ = 46µg/Lat the reference site in the study period from August to December, 2013, since pre- culture operation value was not available.

2. A 100 µg/L is chosen as the value for maximum acceptable $[P]_f$ in tropical inland watebodies used for the culture of tilapia

3. Determine Δ [P];

$\Delta [P] = [P]_f - [P]_i$

= 100 – 46 = 54 µg/L

L_{fish} =□ [P] z□/(1 - R_{fish}) xwas

calculated to be 0.50

Thus, R is calculated from equation (5.7),

R= 0.308

Thus, using equation (5.6) R_{fish} is calculated as 0.65.

z = 20 m (Table 5. 1)

□= 8.75 y^{-1} (Table 5. 1)

L_{fish} = (54 x 20 x 8.75) / (1 - 0.65)

= 27,000 mg m^{-2} y^{-1}

Equivalent to 27.0 g m^{-2} y^{-1}

4. Since the area under operation (Farm A area) of the Lake has a surface area of 5.365 x 10^6 m^2, the total loading, L_a, is

L_a = 27.0g m^{-2} y^{-1}x 5.365 x 10^6 m^2

L_a = 27.0g y^{-1}x 5.365 x 10^6

L_a = 144.86 x 10^6 g y^{-1}

5. Having calculated the total acceptable P loading L_{fish}, this value is divided by the average total P waste to the environment per tonne fish production as a result of the cage culture to obtain the carrying capacity of the area.

The tonnage of fish of P loading from Farm A as calculated from chapter 4 of this thesis was 22.765 kg t^{-1} (Table 5.2). Therefore,

Carrying capacity of Farm A area of lake = 144.86x 10^6 g y^{-1}/ 22765 g t^{-1}

= **6,363 t y^{-1}**

The rest of the carrying capacity predictions were done with spreadsheet calculations. Some scenarios were considered since there were changes in the pre-culture TP and the mean depth as the lake water level continued to reduce during the monitoring period (Table 3.7). The ecological carrying capacities of the fish farms are shown in Tables 5.3 and 5.4. The carrying capacity was found to be sensitive to mean depth and pre-culture TP. Change in depth and TP, resulted in different carrying capacities. From both farms, it was observed from the scenarios that, the higher the mean depth, the bigger the carrying capacity (Figure 5.3). Conversely, the higher the pre-culture TP, the lower the carrying capacity (Figure 5.4). In Farm A, area (Table 5.3), at depth 20 m, the carrying capacity was 6,439 ty^{-1}, while at depth 25 m, the carrying capacity increased to 8,049 ty^{1}. However, when the pre-culture TP was varied from 46 µg/L to 69 µg/L, the carrying capacity reduced from 6,439 to 3,697 ty^{-1}. Similar results were obtained for Farm B area in Table 5.4. The predicted carrying capacity for Farm A, according to the scenarios ranged from 3,697 to 8,049ty^{-1}, while Farm B varied between 28,322 and 137,622 ty^{-1}.

However, scenarios 1 and 2 are of a magnitude higher and therefore scenario 3 and 4 are reasonable capacities that could be acceptable for the areas studied. The two farm areas recorded different ecological carrying capacities. The ecological carrying capacities estimated for the farms under consideration are far higher than the present production levels. Therefore, their carrying capacities have not yet been reached.

Table 5. 3: Ecological carrying capacity scenarios for Farm A area

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean depth (m)	20	25	20	25
$[TP]_f$ (µg/L)	100	100	100	100
$[TP]_i$ (µg/L)	46	46	69	69
TP loading (L_{fish}) (mg m^{-2} y^{-1})	27,324	34,156	15,686	19,608
Carrying capacity (ty^{-1}) of fish	6,439	8,049	3,697	4,621

Table 5. 4: Ecological carrying capacity scenarios for Farm B area

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean depth (m)	30	35	30	35
$[TP]_f$ (µg/L)	100	100	100	100
$[TP]_i$ (µg/L)	16.7	16.7	80.0	80.0
TP loading (L_{fish}) (mg m^{-2} y^{-1})	34,402	40,135	8,259	9,636
Carrying capacity (ty^{-1}) of fish	117,962	137,622	28,322	33,042

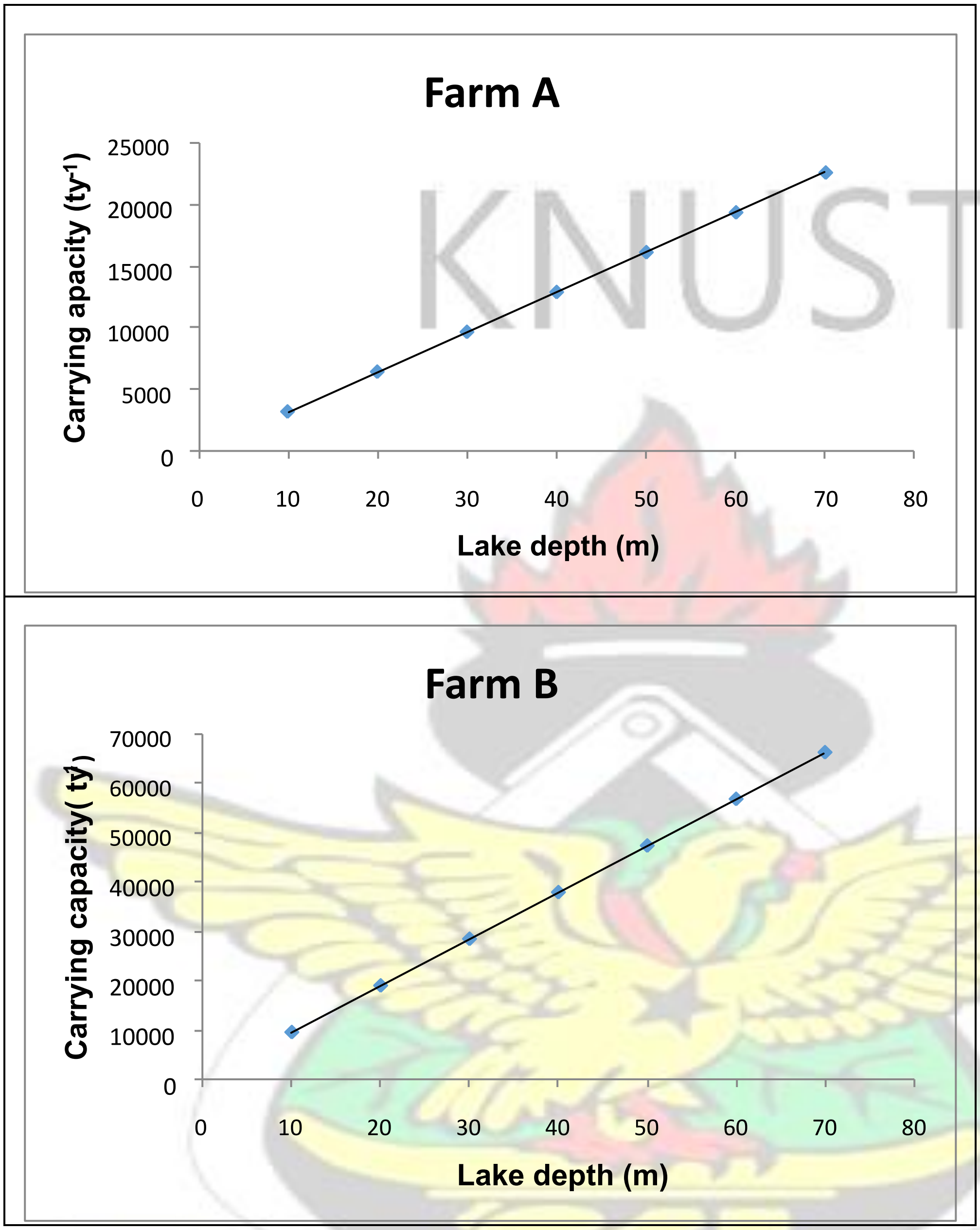


Figure 5. 3: Relationship between lake depth and carrying capacities of Farms A and B areas in L. Volta, Ghana.

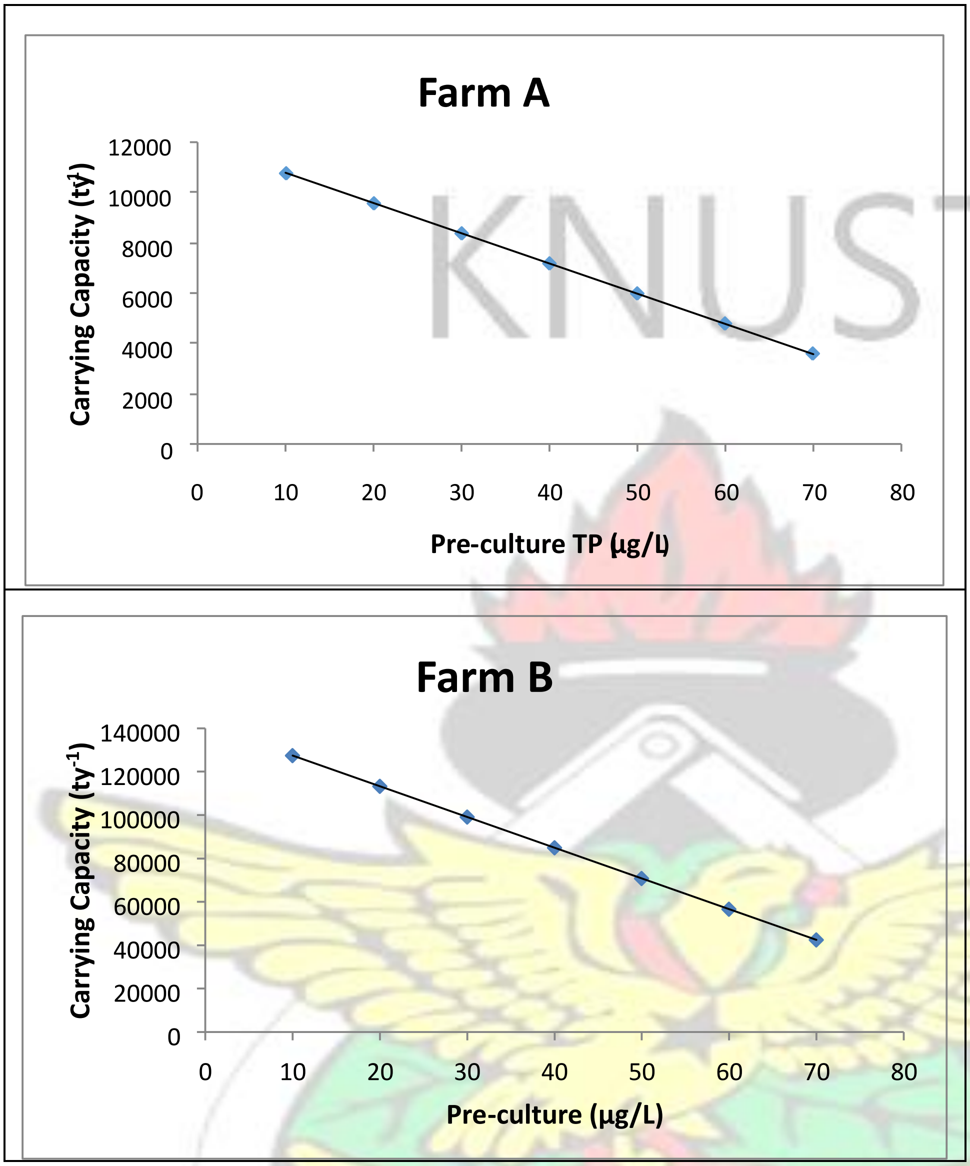


Figure 5. 4: Relationship between pre-culture TP and the carrying capacities of Farms A and B areas in L. Volta, Ghana

5.5 Discussion

The estimation of the ecological carrying capacity indicated that the farm areas in the same lake recorded different values due to different phosphorus loading, suggesting heterogeneity. Previous studies have approached aquaculture carrying capacity by using the model to address entire lake water body as one homogeneous unit. However, when handling a large lake system with diverse conditions such as bathymetry, local winds, currents and turnover rates, these may play a vital role in the fate of lake nutrients. Therefore, trophic status can vary throughout the lake. The spatial heterogeneity can result in a localized elevated TP concentration which is likely to produce algal blooms than the whole lake prediction (Oakley, 2015). In Lake Volta, cages are located in different segments of the lake. Cages located in different places in the lake will make different contributions to carrying capacity and so a zoned approach to ecological carrying capacity is more applicable. The analysis showed that even using simple mass balance model for estimating the ecological carrying capacity for selected portions of the lake, demands a lot of data and different expertise making it costly and difficult (David *et al.,* 2015). This suggests that implementing a whole lake's carrying capacity would require a huge variety of input data and multidisciplinary effort. Nonetheless, estimation of carrying capacity is necessary for aquaculture development and planning.

The model output which is the carrying capacity is most of the time a single value, but variation in conditions at different zones of lakes or reservoirs suggest that a range of values are necessary. In the current study, a range of values were considered. The range in carrying capacity estimation observed by using a range of input values of key variables such as lake depth and initial TP, demonstrated the importance of these inputs to the model. A clear relationship between change in carrying capacity and change in input values exists for the variables. Reduction of water level will reduce the inflow rate which will impact greatly on the carrying capacity. Increase in lake depth, increased the total permissible production or the carrying capacity. Conversely, as the initial TP increases, carrying capacity decreased. Oakley (2015) observed similar results and noted that, increase in FCR and the P content of feed decreased total permissible production. Other factors such as flushing rate which varies seasonally and year to year, final TP which depends on designated use of the system, derived from negotiation among stakeholders and sedimentation coefficient can impact on the carrying capacity of the lake.

The scenarios tested showed that the current production levels of tilapia of 450 and 4,200 tonnes, respectively for Farm A and B zones are nowhere near the ecological carrying capacity ranges for Farm A and B zones. Despite the rapid expansion of cage culture, the present biomass and impact to the lake's ecosystem is still acceptable. Cage aquaculture has the potential to continue on its current trend and increase without substantially altering the lakes ecosystem. David *et al.,* (2015) observed that there were concentrations of farms in areas with highest carrying capacities. In this study, the Farm B area which had the higher ecological carrying capacity was found to have concentration of 4 large farms. According to Costa-Pierce, (2002) overcrowding of cages at the most excellent locations can make the venture environmentally unsustainable, but then the acceptable practice is to separate the farms. The reason is overcrowding will facilitate pollution and easy spread of diseases. Individual cage farms may produce slight ecological impact but the effect of many overcrowding farms will be cumulatively important (White *et al.,* 2013). Therefore, the main challenge of aquaculture development and management is to reduce the concentration of farms in the same area. The concentration of many farms in few sites may cause excessive eutrophication (David *et al.,* 2015).

Table 5. 5: Trophic states for Phosphorus, chlorophyll-a and Secchi disk

Trophic state	Total phosphorus (μgL^{-1})	Chlorophyll a (μgL^{-1})	Secchi disk (m)

Ultra-oligotrophic	≤ 4	≤1	≥12
oligotrophic	≤ 10	≤ 2.5	≥ 6
Mesotrophic	≤ 35	≤ 8	≥ 3
Eutrophic	≤ 100	≤ 25	≥ 1.5
Hyper-eutrophic	> 100	> 25	< 1.5

(OECD, 1982)

Site selection is important for cage aquaculture development and the most excellent site must have the best flushing and dispersal of nutrients as well as high quality water resources. The sites in the present study were all between 50 to 150 m close to the shore of the lake. The winds were moderate and the waves were not damaging except occasionally. Limnological conditions found in the studied areas were generally good quality waters with slight differences among the sites. There was no major limitation for tilapia culture. The physical and chemical water characteristics of the Lake water indicated mesotrophic environment using OECD trophic state index (TSI) (Table 5.5).

The Lake Volta ranges of carrying capacity estimates are probably reasonable, despite the assumptions that favour a higher capacity. The model used was appropriate and has been used extensively by other researchers and is ideal for estimating fish cage culture carrying capacity. The model has utilized the best information available and hence represents the best guess scenarios for the Volta Lake's carrying capacities for the zones studied.

5.6 Conclusion

The main purpose of carrying capacity estimates is to sustain culture, protect environment or ecosystem and to reduce risk of eutrophication. One of the conditions to maintain environmental sustainability of cage culture in tropical reservoirs is to set limits for cage culture expansion (Costa-Pierce, 2002). In this study, Dillon and Rigler (1974) mass balance model was used to evaluate the ecological carrying capacity for tilapia culture in two already developed aquaculture areas located on Volta Lake. The results of this work indicated that the ranges of carrying capacities of the two zones studied on the lake have not yet been reached. Further cage culture of tilapia could be established in the lake without compromising the water quality and the ecosystem. These calculated ranges of values (from 3,697 to 4,697$ty^{-1}$for Farm A and from 28,322 to 33042ty^{-1} for Farm B zones) can be taken as an indicator of a possible ecologically sustainable aquaculture production level for Lake Volta. It should be noted that not all the modelled area will be suitable for fish production; therefore the actual carrying capacity would be less than the modelled value. With the government's proposal to increase aquaculture production from 10, 200 tonnes in 2010 to 100,000 tonnes by the end of 2016 (MoFA, 2012), and from the results of this study, this may be still within acceptable ecological limits, since there are other zones in the lake to accommodate the required expansion. However, monitoring of water quality should be undertaken periodically to accurately determine the current state of the lake in order to both confirm and refine predictions. Although, there may be challenges with the model, it has been recognized as a useful tool for guiding cage culture development in many reservoirs.

CHAPTER 6: CONCLUSIONS

6.1 Introduction

The study utilised four methods of assessing the environmental impacts of cage farming in Lake Volta. The first method was through questionnaire survey to generate data on fish farmer's current operations and activities, understanding challenges faced by the industry and assessing their environmental awareness towards sustainable cage development. The second method was using physical, chemical as well as chlorophyll-a analyses of water and sediment samples in the cage areas and also at reference sites further away from the cages both upstream and downstream to determine the extent of impact from wastes on the water column and the underlying sediments. The third method considered mass balance model using farm production data in combination with proximate analyses of feed and fish compositions to estimate the amount of waste (nutrient) discharges from cage farms into the lake's environment. The fourth method used Dillon and Rigler phosphorus mass balance model to estimate the ecological carrying capacity of selected zones in the LakeVolta with existing fish farms.

The previous chapters of this thesis have discussedpotential impacts of cage culture in the Lake Volta. The aim of this chapter is to review the main findings of the studies and make recommendations and further research needs for socioeconomic and environmental sustainability of cage culture in Ghana.

6.2 Summary of Main Findings

6.2.1 Characteristics of Cage Culture in LakeVolta

The cage farmers on the lake practice intensive farming using commercial floating feed and all-male fingerlings purchased from public, private and own hatcheries. The cage farms surveyed showed that 22.73 % of the farmers get their source of fingerlings from ARDEC, 36.36 % from public or commercial producers and 40.91 % from own hatcheries. Species cultured by all the farmers' was Nile tilapia (*Oreochromis niluticus*) which is an improved "Akosombo strain" a species indigenous to the Lake Volta.

It was observed that most of the farm owners were highly educated professional (Accountants, Auditors, Clearing agents, Businessmen), who have hired managers to operate the cage culture on their behalf. Most of the farm owners had alternative source of income. However, the managers of the farms posessed requisite education that can allow for further skill development.

Due to high financial capital required for the operation of the cage farms and lack of access to credits, the cage fish farming was mostly dominated by men in their mid forties, constituting about 63 % of farm owners in the study area. Some of the constraints to cage culture identified that needs immediate attention to facilitate the growth of cage culture and improve the potential were high cost of skilled labour, water quality, lack of credit facility to start and operate cage farming, high cost of feed and insufficient and irregular supply of fingerlings. Availability of high quality feed and fingerlings at a reasonable price would be a breakthrough for sustainable cage culture in Ghana. It was observed that insufficient availability of fingerling have necessitated the use of 2 g weight of fingerlings for stocking, instead of about 15 g (Beveridge, 2004).

Some social challenges faced by the industry were stealing, conflict between fish farmers and the fisher folks over fishng areas and access to water space. Technical assistance to cage farmers to help them come out with innovative idea and use best practice methodologies to make the business profitable and ultimately avoid the deterioration of the lake’s water was found to be inadequate and irregular.

The study indicated that the cage culture enterprise is economically and socially important, providing and maintaining employment and incomes in the riparian communities and fish for the whole country and thereby contributing to food security.

6.2.2 Water and Sediment Quality Monitoring

Investigation on the impact of cage fish farming activity on the water column in the cage farms indicated that oxygen, chlorophyll-a, turbidity, conductivity, pH, etc. was not affected by the farming activity. The concentrations of these parameters were not significantly different between the farms and the reference sites. Despite such huge discharges from fish cages which have the potential to influence concentrations of various parameters in the lake's environment. Nutrients (NO_3-N, NO_2-N, NH_4-N and PO_4-P) concentrations were not significantly different ($p > 0.05$) between the farms and the reference sites.

Low levels of metals were observed in the water column and the sediments, indicating that there was no effect of any feed additives on the lake's environment. The low effect of cage culture on the water and sediment quality in Lake Volta could be attributed to the possible dispersion of the wastes from the cages by water currents which had a mean of 0.037 and 0.062 m s^{-1} for Farm A and B, respectively. It was also due to the consumption of the particulate waste (uneaten feed and faeces) by schools of fish species from the wild which were found around the cages. It was confirmed that the effect of the cage culture on the water and sediment was minimal during the study period, as the farming expands; waste generation may increase and may exceed the assimilation capacity of the lake which may cause pollution. Therefore, continuous monitoring of the water and sediment is necessary to check any possible large scale impact.

The results for the CCME water quality model for both Farms A and B indicated that the water quality was good and does not differ much from the natural or desired levels. The CCME water quality index gave a ranged between a score of 90 and 93 which showed that tilapia production is very favourable and can be undertaken all year round. The GWQI also showed fairly good water quality (Class II) for the assessment of both the farm and the reference areasfor ecosystem use. Overall, the lake water is good for intended uses such as for water supply, irrigation, recreation and cage culture or tilapia production.

6.2.3 Nutrient Inputs from Cage Farms into the Lake's Environment

An estimation of waste emission by mass balance for two tilapia cage farms with FCR of 1.99 (Farm A) and 1.7 (Farm B) conducted indicated that high percentages of C, N and P were dischaged into the lake's ecosystem with the potential to cause harm.

In both farms studied, waste discharges fluctuated with feed input and FCR. The higher the FCR, the higher the waste input into the lake. The waste estimates was proportional to the annual production, suggesting that an increase in feed input would result in high nutrient loading into the environment.The tilapia cage culture provided considerable nutrients inputs that have potential to cause eutrophication in Lake Volta. However, the impact on water and sediment quality was not significant. The reasons to the low impact of waste on the lake may be varied. It could be due to phytoplankton uptake and dilution of the nutrient waste considerably by deep waters. Additionally, the discharged nutrient may have been lost through the outflow at the dam. It is also probable that portion of uneaten feed and the faeces were scavenged by wild fish species. Moreover, the water current speed was capable to facilitate rapid dispersion of waste. The environmental impact would therefore be reduced. Generally, the application of good feed quality and good farming and management practices can reduce the nutrient inputs into the water environment.

6.2.4 Estimation of Ecological Carrying Capacity

The estimation of the ecological carrying capacity indicated that the farm areas in the same lake recorded different values due to different phosphorus loading, suggesting heterogeneity. In Lake Volta, cages are located in different segments of the lake. Cages located in different places in the lake will make different contributions to carrying capacity and so a zoned approach to ecological carrying capacity is more applicable. In the current study, a range of input values were considered in the estimation of the carrying capacity such as depth and initial TP. Increase in lake depth increased the total permissible production or the carrying capacity. Conversely, as the initial TP increases, carrying capacity decreased. Other variables such as flushing rate, final TP and sedimentation coefficient can impact on the carrying capacity of the lake.

The ecological carrying capacity showed that the current production levels of tilapia are far below the ecological carrying capacity ranges for Farm A (from 3,697 to 4,697 ty^{-1}) and B (28,322 to 33042 ty^{-1} of fish) zones. It should be noted that not all the modelled area will be suitable for fish production; therefore the actual carrying capacity would be less than the modelled value. A careful and detailed water quality monitoring should be undertaken at each aquaculture site in order to both confirm and refine predictions.

6.2.5 Recommendations

The following recommendations are made based on the results and the experience of the current study:

1. Earlier workers on the Lake Volta have indicated that, the lake is oligotrophic. However, the results from this study showed that the lake is mesotrophic, judging from transparency, chlorophyll-a, and total phosphate concentrations and based on OECD (1982) trophic state classification. There is the need for stakeholders to confirm the trophic state in all the lake's strata looking at the primary production, nutrients and other parameters as part of the lake's water management.
2. It was confirmed that the effect of the cage culture on the water and sediment quality was minimal during the study period, however, as the cage farming expands; waste generation may increase and may exceed the assimilation capacity of the lake which may cause pollution. Therefore, continuous monitoring of the water and sediment quality is necessary to check any possible large scale impact.
3. Lake Volta is a multipurpose lake. In order to protect the lake for sustainable development, regulatory agencies concerned should establish environmental quality standards for chlorophyll-a and total phosphorus and enforce them to avoid future eutrophication and subsequent algal blooms.
4. It was evident from the study that technical assistance to cage farmers was irregular and inadequate. Fisheries commission and aquaculture institutions, including the Universities should provide regular technical assistance through workshops, hands–on etc. in the area of stocking density, feed management and FCR, culture techniques, water quality, record keeping etc. and to help reduce the cage farm's impact on the lake's environment.
5. Authorities should request the farmers to keep accurate information about their activities. A fish farm monitoring and reporting system should be set up at the

Fisheries Commission. This will make available credible farm data for research and planning purposes.

6.2.6 Thesis Limitations and Further Research Areas

There were limitations in the research work conducted for this thesis which emanated from limited resources and limited cooperation from other users of the lake.

In chapter 3 of this thesis, hydrological data such as depth and current speed of the selected sites were obtained using hand held echosounder for depth and drogues for current speed and direction of the lake water. Whilst, these equipment provide very reliable data, it was time consuming and impossible to conduct these measurements many times at all seasons and at different depths. It was realized during the study that there was no bathymetric information on the lake. Further research is needed to undertake acomprehensive hydrological study to collect data on bathymetry, current speed and direction data in different areas of the lake using Acoustic Doppler current profiler (ADCP), several times in each season.This will help provide good and credible data to help in waste dispersion models and other models of the lake.

Sediment traps were deployed within the fish farms and the reference sites to capture the particulate organic matter (the uneaten feed and fish faeces) in the determination of rate of sedimentation. We were successful in only few deployments. The indigenous fisherfolks removed all the sediment traps and made away with the buoy a number of times. Within the farms, the workers did not pay attention to the sediment traps and they were lost. Further research is required to deploy sediment traps within the farms and the reference sites to ascertain the sedimentation rate of the particulate organic matter to be able to determine the area of impact of cage operations.

In the determination of total phosphate, secchi (transparency) and chlorophyll-a in the water column in chapter 3, it was revealed that the average concentrations of these trophic state indicators pointed out that the Lake Volta is mesotrophic according to OECD (1982) trophic state classification. However, earlier workers have stated that the lake is oligotrophic. Therefore, there is the need for stakeholders to confirm the trophic state in all the lake's strata looking at the primary production and other parameters such as total phosphate, secchi, suspended solids, nutrients, chlorophyll-a and phytoplankton as part of lake water management.

A huge number of wild fishes were observed to aggregate around the cages especially during the feeding of caged fish at the time of the study. These schools of wild fish species are known to scavenge the feed that fall out from the cages to reduce the impact of waste around the cage area. Further research will be required to estimate the numbers of the wild fish and their species composition around the cages. This will help in the understanding of the role of wild fish in reducing the impact of cage operations and determine whether cage fish farming is an aggregating device for wild fish, thereby depleting the wild stock available to fishermen in the riparian communities.

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Appendix 1: Fish Farm Survey Questionnaire

SURVEY ON FISH CAGE CULTURE IN THE VOLTA LAKE
QUESTIONNAIRE ADMINISTRATION

This questionnaire is being administered to fish cage culture farmers in the Volta Lake to collate information on the sector for the purpose of determining the strengths and constraints encountered by farmers in the sector. All information is for research purpose and will be treated confidentially.

ELEVATION: **GPS Coordinates:**

Part A. Location/Address of Farm

1. Name of Fish farm…………………………………………………………………..Date…………………………….
2. Address of Farm/Business…………………………………………………………………………Tel…………………………
3. Location of cage…………………………………………………Name of town/village……………………………………
4. District………………………………………………………………Region………………………………………………………..

Part B. Fish Farmer Information

5. Name of farm owner……………………………………………………………………………………………
6. Level of education of farmer
   a. No formal education b. MSLC/JSS c. Vocational/Technical d. Secondary e. First degree and above
7. Age of farmer? ....
8. Gender of farmer/owner: 1. Male 2. Female
9. What is your main occupation/profession of farmer?...
10. Is fish farming your main source of income? 1.Yes 2.No
11. What other sources of income do you have?...
12. Name of respondent……………………………………………Role of respondent…………………………………..
13. Level of education of respondent
    a. No formal education b. MSLC/JSS c. Vocational/Technical d. Secondary e. First degree and above
14. When was the farm established? ……………………………………………………………………………………………
15. Do you have any formal training in fish farming? 1. Yes 2. No
16. Do you receive any technical assistance with your farm? 1. Yes 2. No
17. If you answered “No” to Q16 please go to Q21. If you answered “Yes” please go to Q18
18. What form of technical assistance do you receive?...
19. Who provides the technical assistance?
    1. Fisheries Directorate 2. NGO 3. Others (Pls. Specify)…………………………………………………
20. Is the assistance adequate? 1. Yes 2.No
21. How many employees work on the farm?...

Employees	Qualification	Role

Rearing cage(s):

Cage No.	Year constructed	Depth	Area(Size)	Construction cost

Part C. INPUTS

25. Where do you get your supply of fingerling?

a. ARDEC b. DoF c. Commercial fingerling producer (Pls. specify)…………………………………………… d

.Others (Please

specify)……

26. Do you always get enough and at the right time? 1.Yes 2. No

27. What size(s) of fingerlings do you order?...

28. How much do you pay per fingerling?...

29. What size of fingerlings do you stock and how many per cage?..

30. What type of feed do you use on your farm?

a. Locally formulated feed b. Imported formulated feed c. Prepares own feed d.Others (pls specify)………………………………………………………………………………………………………

31. Where do you buy the feed and what brand?..

32. What is the cost of feed?..

Feed brand	Protein content	Pellet size	Cost/Kg	Weight/bag

33. What quantity of feed do you apply per day?

Period after stocking (weeks)	Quantity	Average wt of fish (g)

Part D. PRODUCTION

34. How long does it take you to harvest after stocking?...

35. How often do you harvest your fish?..

36. What is total average weight of fish per cage at harvest?..

37. What is the size composition of your harvest?

Size composition	Size ranges	Weight/ %	Price /kg
3			
2			
1			
Regular			
Economy			
School boys			

Part E. MARKETING

38. Where do you sell your fish?

1. Farm gate 2. Local market Others (Specify)

……………………………………………….

……
…………………………………………………………….

38. How do you sell your fish?

1. Fresh 2. Frozen 3. Processed (smoked, dried, salted etc.)

39. Who are your main clients?

Part F. CONSTRAINTS

40. What do you consider as your main constraints? (e.g. water quality, marketing, stealing, credit etc)