MORPHOMETRIC AND PHYSICO-CHEMICAL CHARACTERIZATION OF THE WEIJA RESERVOIR: IMPLICATIONS FOR WATER RESOURCE MANAGEMENT AT THE CATCHMENT SCALE

BY

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DECLARATION

I hereby declare that; this thesis is a result of an original research work done under the supervision of Dr. Daniel Nukpezah and Dr. Philip-Neri Jayson-Quashigah with the exception of references to the work of other people which have been duly cited and that this work has neither in whole nor in part been presented for the award of another degree in this University or elsewhere.

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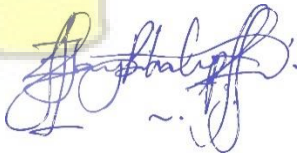

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(Supervisor) (Supervisor)

DEDICATION

Firstly, I dedicate this thesis to the Lord God Almighty for His abundant love and mercies and to my mother, Madam Mabel Kpanga for her immense support throughout my education.

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My sincerest gratitude goes to the Almighty God for His unchanging and unending Grace and guidance throughout the course of my post-graduate education and also in my research work.

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ABSTRACT

The Weija Reservoir, one of Ghana's water resources has been increasingly threatened by pollution in recent years as a result of fast population changes that have coincided with the formation of human settlements. In recent years, activities like as irrigation, nutrient pollution, sand mining, and encroachment on the Reservoir and along its boundary have had major impacts on the Reservoir, causing shortage in water supply. The aim of the study was to combine GIS and measurements of physico-chemical variables along a depth profile to map out the bathymetry and to model nutrient level in the Reservoir. Per that, a 3D (DEM) model of the Reservoir was constructed. Measurements were taken at a total of twenty-five thousand, two hundred and eleven data points with their corresponding coordinates and depths were recorded and processed using ArcGIS to obtain the current surface area and water holding capacity of the Reservoir of 19,330,988.38m^2 (19.33km^2) and 96,900,899.14m^3 respectively.

In order to assess the temperature variation and dissolved oxygen (DO) distribution along a depth profile, water and sediment samples for physicochemical analysis were obtained from the six sampling points. An echo sounder was then used to determine the depths at which the samples were taken and with a water depth sampler, the samples were taken along the depth profile at 1m intervals till the bottom of the Reservoir was reached. Measurements were taken along the depth profile in order to have a proper representation of the Reservoir. The physico-chemical parameters and nutrient in the samples were determined. A steady decrease in temperature was observed with increasing depth but analysis of variance (ANOVA) indicated that there was no significance in temperature with respect to depth. There was decrease in DO level along the depth profile and ANOVA showed that there was significant difference in DO distribution along the depth profile.

This indicated that, the least change in temperature along the depth profile can cause a drastic change in DO which will lead to the thermocline effect.

Total phosphorus, chlorophyll a content and Secchi depth were measured from the Reservoir and with the use of Carlson's Trophic State Index, the TSI for total phosphorus, chlorophyll a and Secchi depth was calculated. Average TSI (TP) was 79.33 making the Reservoir eutrophic. It was also observed that TSI (TP) = TSI (SD) > TSI (CHL) with TSI (SD) having an average value of 68.61 over the study period and TSI (CHL) having an average value of 38.29. This relationship indicates that, the Reservoir is eutrophic as result of heavy siltation rather than phytoplankton abundance.

The Utermöhl method for analysis was adopted in this study for analyzing the phytoplankton samples collected. Five (5) Classes were identified and the order of dominance was; Chlorophyceae (green algae) > Bacillariophyceae (diatoms) > Cyanophyceae (blue-green algae) > Euglenophyceae (euglenoids) > Dinophyceae (dinoflagellates). The Chlorophyceae were the most prevalent class (40.38%). Bacillariophyceae (30.77%), Cyanophyceae (23.08%), Euglenophyceae (3.85%), and Dinophyceae (1.92%) followed in declining order of abundance.

These findings provide insight on the extent of anthropogenic contamination in the Reservoir and how it affects the distribution and treatment of water as the Reservoir provides water to the populace.

Keywords: Digital Elevation Model, Thermocline Effect, Trophic State Index, Phytoplankton, Eutrophication, Depth Profile, Pollution

1.0 INTRODUCTION

1.1 Background

Reservoirs, or man-made lakes, are crucial aquatic ecosystems that offer critical environmental and economic functions (Asante, Quarcoopome & Amevenku, 2008). They store water for use in power generation, agriculture, industry, and residential use. Most Reservoirs contribute considerably to national food and nutritional security levels, as well as the lives of populations along their coasts, in the tropics (Karikari, Akpabey & Abban, 2013). Many Reservoirs, including Volta, Vea, Barekese, Kpong, and Weija, have been built in Ghana during the previous four to five decades by damming rivers (Asante *et. al.*, 2008). In Ghana, the requirement for comprehensive and integrated water resource management is much greater, necessitating immediate attention to the condition of our water bodies. This dilemma has emerged as a result of Ghana's growing population and the upstream nations that share the Volta River with Ghana. As a result, several sectors of the economy are now experiencing severe water shortages. Pollution and land degradation are also putting a strain on an already stressed resource base. According to reports, 44 percent of the country's water requirements are for residential consumption, 54 percent for agriculture, and 3 percent for industry (Nee-Whang, 1999).

The Weija Reservoir, one of Ghana's water resources has been increasingly threatened by pollution in recent years as a result of fast population changes that have coincided with the formation of human settlements lacking adequate sanitary facilities (Anim, Odame, Duodu, Ahialey, & Serfor-Armah, 2011). The Weija Reservoir was built in 1977 by an Italian firm, Messrs Tahi to replace an older Reservoir that had been swept out by Ghana Water Company Limited (GWCL) damming River Densu in 1968, primarily to meet the need for potable water supply. It is the country's second largest water Reservoir after the Volta Reservoir. The Weija Reservoir covers an area of about

9,000 square hectares and serves over 2.5 million people in Accra East and West. The effective storage capacity the Weija Reservoir is around 133 million m^3, computed as Reservoir volume at the maximum design level of 143 million m^3 and therefore serves as a main source of water supply for millions of inhabitants in Accra East and West (Anonymous, 2007; Anonymous, 2015). Over the years, human activities along the banks and within the Reservoir have had an impact on the quality of water. In recent years, activities like as irrigation, nutrient pollution, sand mining, and encroachment on the Reservoir and along its boundary have had major impacts on the Reservoir, causing shortage in water supply. A number of environmental issues have been highlighted as a result of this (Tagoe & Mantey, 2017). Nutrient enrichment is one of such issues and can come from both point and non-point sources. Water treatment plants are examples of point sources; non-point sources include diffuse inputs from the atmosphere and agriculture, such as land runoff and animal waste.

Excess phosphate and nitrate accelerate algal and plant development in natural environments, contributing to eutrophication and lowering oxygen levels. Algal blooms resulting from eutrophication reduce light penetration, affecting plant growth and die-offs in littoral zones, as well as diminishing the success of predators that require light to pursue and trap food. Furthermore, during the day, high rates of photosynthesis associated with eutrophication can deplete dissolved inorganic carbon and elevate pH to severe levels. Elevated pH can thus 'blind' organisms that rely on dissolved chemical signals for life by compromising their chemosensory capacities. When these dense algal blooms die, microbial breakdown substantially depletes dissolved oxygen, resulting in a hypoxic or anoxic 'dead zone' devoid of enough oxygen to support most life (Lehtiniemi, 2005). Warmer temperatures as a result of climate change have also led to the occurrence harmful algal blooms (HABs) in tropical waters. Generally, toxigenic cyanobacteria such as *Anabaena*,

Cylindrospermopsis, *Microcystis*, and *Oscillatoria (Planktothrix)* tend to dominate nutrient-rich freshwater systems due to their superior competitive abilities in conditions of high nutrient concentrations, low nitrogen-to-phosphorus ratios, low light levels, reduced mixing, and high temperatures (Downing *et al*., 2001; Paerl & Huisman, 2009; Paerl & Paul, 2012). *Cylindrospermopsis raciborskii* is particularly known for its invasiveness and ability to endure a wide range of temperature and light regimes and to employ a variety of feeding methods. It has been said to have benefited massively from the climate change phenomenon with regards to its ability to invade temperate areas (Antunes, Leão, & Vasconcelos, 2015).

The Reservoir is typically susceptible to different types of deterioration as a result of pollution caused by anthropogenic activities such as, dumping of residential waste, industrial effluents, and agricultural runoffs which cause the nutrient enrichment and heavy metal pollution (Ansah, Nukpezah, & Hogarh, 2018; Asante *et. al*., 2008). The presence of these pollutants poses serious health risks to the citizenry and therefore affected water needs to be treated before use which in turn leads to an increase in the cost of treatment of water. Water consumption is limited by the quantity and quality of accessible water, both of which are impacted by many types of pollution, whether chemical, biological, or physical (Ayisi, Quarshie & Cobbina, 2013). Good quality water, available in sufficient amounts, supports cleanliness and public health, and hence social development. This necessitates the treatment of water from natural sources to fulfill the needed quality requirements prior to consumption in order to avoid any potential health and environmental hazards. Based on that the government spends thousands of Ghana cedis to treat polluted sources of water and make them accessible for household, industrial, and agricultural use (Ayisi, Quarshie & Cobbina, 2013).

1.2 Problem Statement

Water supply Reservoirs such as the Weija Reservoir in numerous locations of Ghana guarantee an adequate and sustainable source of raw water throughout the year for treatment to deliver potable water to major cities and towns. The fresh water collected straight from these Reservoirs to meet the requirements of rapidly increasing metropolitan populations, however, varies in quality due to pollution (DFID, 1999). As a result of population growth and urbanization, portions of the Reservoir have been encroached upon, reclaimed, and used for residential and agricultural purposes, influencing the Reservoir with various activities such as the release of waste effluent from homes, farms and industries, which releases nutrients and other pollutants into the Reservoir. These human activities in the catchment of the Reservoir have a high potential to have a major influence on its physicochemical properties (Ameko, Achio, Okai–Armah & Afful, 2012)

The major causes of water pollution include indiscriminate dumping of domestic, industrial, and municipal solid and liquid wastes, inefficient land use, bad agricultural practices, and environmental deterioration which cause eutrophication of the Reservoir, leading to high algal content which has been a persistent water quality problem in the Reservoir for a long time (Darko & Ansa-Asare, 2009). According to research by Bosque-Hamilton et al. (2004), the Reservoir contained a lot of aquatic weeds as demonstrated by nutrient dominance. These situations drastically increase the cost of water treatment. In a study conducted by Boah, Twum & Pelig-Ba (2016), they indicated that, in 2014, the total cost of water treatment from the Reservoir was GHC 29,240,832.52.

Over the years, the water quality of the Reservoir has worsened, and 80% of the phytoplankton detected in the Weija Reservoir are bloom-forming blue-green algae. Algal blooms, low clarity, and fast volume loss in the Reservoir have all been recorded as symptoms of water quality issues.

The eutrophication of the Weija Reservoir has ramifications for the cost of potable water treatment (Oduro-Koranteng, 2003; Akuffo, 1989). Research indicates that eutrophication caused by excessive amounts of nutrient input into the Weija Reservoir has resulted in high water treatment costs as well as a drop in daily production capacity from 70 to 42 million gallons. Aside from the usual expense of water treatment, an additional $200,000 is paid each month to guarantee that the water being provided meets water quality requirements (Nukpezah, 2012). The assessment of water quality in the Weija Reservoir is critical since it is one of the primary sources of water for consumption and agriculture in Ghana.

A lot of research has been conducted in order to enhance the quality of water in the Weija Reservoir (Ansa-Asare, 2001; Ameka et al., 2000; Ansa-Asare & Asante, 1998; Biney, 1987, 1982; Amuzu, 1975; Ansah, Nukpezah, & Hogarh, 2018) which involved the use of conventional approaches in the estimation of the per capita nutrient input of the Reservoir such as taking samples mainly from the mixed layer and using the results obtained to estimate the entire per capita nutrient input of the Reservoir. The issue with these approaches is that they not based on studies in Ghana and therefore do not accurately represent the actual situation on the ground. Based on this, a new methodological approach for assessing Reservoir volume and depths, as well as estimating nutrient input into the Reservoir at different depths of the Reservoir, is provided. This would offer the evidentiary foundation for targeted intervention to address the problem of pollution and nutrient input in the Reservoir by utilizing an ad hoc approach in problem identification.

Earlier studies during the creation of the Reservoir in 1977 have established some of the morphometric parameters. However, in the face of climate change, land use change, encroachment of the Reservoir leading to heavy siltation, etc. some of these parameters such as surface area and volume might have changed. It is important to establish the key current morphometric parameters

as this influence water quality. Also, although past studies have suggested the Reservoir to be eutrophic, a quantitative measure of Trophic State Index (TSI) such as Carlson's TSI would provide a baseline that enables comparison with future state of the Reservoir and help track changes in water quality and make appropriate policy interventions for improvement

This study will help in developing a contextual understanding of cause-and-effect relationships, identifying key gaps in understanding in order to prioritize research and monitoring, identifying key pressures and drivers that if addressed would provide the greatest conservation benefit and aid the government of Ghana in attaining its national vision for the water and sanitation sector which is 'sustainable basic water and sanitation service for all by 2025' which ties into the United Nations broader vision of 'ensuring availability and Sustainable Management of Water and Sanitation for all by 2030', the sixth sustainable development goal of the organization.

1.3 Significance of Study

The issue of water quality and sustainable development in Ghana cannot be fully addressed unless the problem of pollution and water quality of one of its major sources of potable drinking water, the Weija Reservoir is addressed. This is due to the fact that the development of a country is dependent on the health of its people, which is in turn dependent on the quality of water available. An understanding of the water quality state of the Reservoir will aid in the improvement of its quality management techniques. This study will help critically assess the current state of water quality in the Reservoir and its implications on cost of treatment and water supply. It will also help ascertain the pollution problems that may confront the Reservoir and provide a scientific basis for findings which will aid authorities in determining the most appropriate responses and remedies to the situation and mitigate its inherent impacts on the populations that rely on the Reservoir as well

reduce the cost of treatment of the water. The results and recommendations are also expected to enhance the sustainable management of natural resources in the Weija Reservoir. This approach to diagnostic study of our major Reservoirs will contribute to effective water resources management.

1.4 Research Questions

1. What is the contribution of internal loading to the state of the Weija Reservoir?
2. What is the relationship between temperature and DO along a depth profile?
3. What is the current nutrient status of the Reservoir?
4. What is the current water holding capacity of the Reservoir?

1.5 Objectives

The overall objective of the study was to combine GIS and measurements of physico-chemical variables along a depth profile to map out the bathymetry and to model nutrient level in the Reservoir.

The specific objectives will be to:

1. Construct a 3D (DEM) model of the Reservoir to determine the current water holding capacity.
2. Determine the temperature variation along a depth profile.
3. Determine the dissolved oxygen (DO) distribution in the Reservoir along a depth profile

4. Determine the nutrient distribution in the Reservoir along a depth profile

5. Determine the Trophic State Index (TSI) of the Reservoir

6. Identify algal species of the Reservoir.

2.0 LITERATURE REVIEW

2.1 Status of Fresh Water in Ghana

Fresh surface water resources in Ghana include the Volta River System, the South-Western River System, and the Coastal River System (Ministry of Water Resources, Works and Housing, 2007). As stated by Ministry of Water Resources, Works and Housing (2007) in the Ghana National Water Policy (2007), surface water resources in Ghana are mostly derived from three river mainstem releases, including the Coastal River, the South-Western, and the Volta systems. The Volta River systems include the Red, Black, and White Volta rivers, as well as the Oti River. The South-Western River systems are made up of the Bia Tano, Ankobra, and Pra rivers. Coastal river systems include the Tordzie/Aka, Densu, Ayensu, Ochi-Nakwa, and Ochi-Amissah. These river systems account for 70%, 22%, and 8% respectively of the total land area of about 240,000 km2. Lake Bosumtwi is also Ghana's only natural freshwater lake. This is a forest-zone meteoritic Crater Lake with a surface size of 50 km^2 and a maximum depth of 78 m (WRC, 2012). Groundwater resources on the other hand are composed of three geological formations, with the basement complex (metamorphic rocks and crystalline igneous), the consolidated sedimentary formations, and the Cenozoic and Mesozoic sedimentary rocks accounting for 54%, 45% and 1%, respectively (Ministry of Water Resources, Works and Housing, 2007). Aquifer depths typically varied from 10 to 60m, with yields seldom reaching 6m^3 per hour. The Cenozoic and Mesozoic formations that are common in Ghana's extreme south eastern and western regions are also limestone aquifers with depths ranging from 120 to 300 meters. The limestone aquifers provide an output of roughly 184 cubic metres per hour on average (Ministry of Water Resources, Works and Housing, 2007; WRC Ghana 2007).

Reservoirs, dams, and impoundments were built for water supply, irrigation, hydroelectric power generation, and ecological support (Yeleliere, Cobbina & Duwiejuah, 2018). One of the world's largest man-made lakes is the Akosombo dam, which covers an area of around 8500 km^2 and has a water volume capacity of 148 km^3 (Mensah 2010; WRC Ghana 2015). Approximately 20 kilometres downstream of Akosombo, a comparably smaller impoundment with a covering area of roughly 40 km^2 has been built at Kpong (WRC 2012; WRC Ghana 2015). Another impoundment developed for the sake of generating energy was the Bui hydroelectric project in the Black Volta, which has a capacity of 400 MW. Other large impoundments in Ghana are the Barekese and Owabi supplies (consumptive water for Kumasi Metropolis), the Weija (supply water for Accra), and the Nawuni (supply water in and out of Tamale Metropolis) on the rivers Densu, Volta, and Offin (WRC 2012; WRC Ghana 2015).

Ex situ (withdrawal use) and *in situ* or in-stream use are the two primary kinds of freshwater resource consumption, which can also be referred to as consumptive and non-consumptive use, respectively as stated by Yeleliere *et. al.* (2018). In Ghana, municipal usage (water supply) accounts for 37% of total consumption, agricultural use (livestock watering and irrigation) accounts for 48%, and industrial use accounts for 15%. Consumptive water demand for surface water resources alone is expected to exceed 5 billion m^3 by 2020, accounting for 12% of total surface water resources (WRC, 2005). The statement provides information on the water usage pattern in Ghana, indicating that there is a high demand for surface water in various sectors of the country. Per the consumptive water demand for surface water resources at the time, it was predicted the demand will exceed 5 billion cubic meters by 2020, which was estimated to account for 12% of total surface water resources. There is an increase in the population, year on year and as the population increases, the demand for water also increases so therefore it can be inferred that,

if the consumptive demand for water was pegged at over 5 billion cubic meters in 2020, then currently, in 2023, the demand will be higher and this will be a recurring pattern for years to come. This highlights the need for efficient water management and sustainable water resource usage practices in the country. Conversely, water transport, inland fisheries, hydropower generation, tourism, and ecosystem support services are among the principal non-consumptive uses of water.

Growing populations and our persistent exploitation of this valuable resource to suit our basic requirements have jeopardized and corrupted the potential usage of freshwater resources (Yeleliere *et. al*., 2018). According to Nsubuga, Namutebi and Nsubuga-Ssenfuma (2014), climate change, as well as fiscal factors, combined with environmental pollution from waste (both municipal and industrial waste), leaching of toxic chemicals from fertilizers and pesticides used in agriculture, have exacerbated concerns about the potential use of this freshwater resource for our needs. A direct rise in pollution reduces the amount of operational water. Until the recent problem of localized pollution caused by the discharge of sewage into water bodies from industrial and domestic activities, leaching of fertilizers and pesticides used in agriculture, with the most recent and alarming canker being illegal artisanal mining denoted 'galamsey,' the quality of naturally occurring surface waters and groundwater was generally good (Yeleliere *et. al*., 2018). Furthermore, the use of chemicals in fishing, along with increasing population increase, has rendered our water supplies completely uncontrollable. Untreated sewage discharged from municipal garbage has resulted in major water contamination in most metropolitan areas. Lagoons and rivers near industrial regions are slowly dying as a result of the discharge of untreated municipal waste from household and industrial wastewater, which generates odor and nutrient enrichment, resulting in algal bloom (Nsubuga, Namutebi & Nsubuga-Ssenfuma, 2014) of which

the Korle Lagoon situated in Accra is a prime example of contaminated waterbodies in Ghana (WRC, 2015)

2.2 Fresh Water Pollution of Lakes and Reservoirs in Ghana

Bawakyillenuo (2020) states that freshwater pollution in Ghana has an influence on livelihoods, health, transportation services, and drinkable water for home use. Population growth, urbanization, a negative attitude toward the environment, unsustainable traditional agricultural practices, and industrial activity are the main causes of freshwater contamination in Ghana (Ampomah, 2017; Bawakyillenuo, 2020). Despite the known benefits and uses of freshwater, these resources are becoming increasingly polluted at an alarming rate, for example, high nutrient levels, high faecal coliform numbers, low levels of dissolved oxygen, organic and inorganic waste elements in water resources, jeopardizing their life-supporting qualities (Bawakyillenuo, 2020). Approximately 60% of Ghana's water bodies are contaminated, with the majority of them in catastrophic condition (Ampomah, 2017). There are several issues regarding fresh water pollution of lakes and Reservoirs in Ghana, including: improper disposal of sewage and industrial waste is a major contributor to fresh water pollution, leading to the contamination of lakes and Reservoirs, excessive use of chemicals such as pesticides and fertilizers in agriculture contributes to fresh water pollution, as these chemicals run off into nearby water bodies during heavy rainfall, mining activities that have resulted in heavy metal contamination of fresh water sources, improper disposal of solid waste, including plastics and other non-biodegradable materials, which has become a common issue in Ghana that contributes to fresh water pollution and lastly, climate change and its resulting changes in precipitation patterns which have led to changes in the quality and quantity of fresh water

resources. These are issues need to be addressed and can be done through effective waste management practices, increased public awareness, and better regulation and enforcement of environmental protection laws in the country.

2.2.1 Point and Non-Point Sources of Fresh Water Pollution in Ghana

There are two major methods for surface water to become polluted. Because surface water percolates through the soil and becomes groundwater, every pollutant in the surface water finds up in the groundwater and vice versa. There are two types of sources: point sources and non-point sources (Boateng, 2018). Pollutants that enter water bodies from a single recognized source are referred to as point sources because the source of pollution is easily known, the types of pollutants are easily determined, for example, mine tailings discharge or industry discharge while non-point source pollution refers to water contaminants that originate from several sources rather than a single discharge point (Boateng, 2018). These contaminants cannot be anticipated until experiments are carried out to determine their presence. For instance, urban runoff water or landfill leachate (Boateng, 2018). It is therefore an undeniable reality that Ghana's fresh water resources are under serious jeopardy, since water resources are running dry and becoming increasingly limited by the day.

2.2.2 Major Sources of Fresh Water Pollution in the Regions of Ghana

According to Mantey (2017), illegal mining operations have contaminated fresh water sources in Ghana. The principal water bodies in the Western Region, the rivers Pra, Daboase, and Ankobra, have become contaminated. Birim, the principal water body in the Eastern Region, has been contaminated. As a result, water treatment plants in Kyebi were forced to close owing to river contamination that was beyond remediation. This difficulty has pushed the Ghana Water Company to build boreholes that would serve smaller populations (Mantey, 2017). Also, Fresh water bodies

around the settlements of New Juaben and Koforidua have become contaminated as a result of fishing activity. In addition to the above, the Densu River in the Greater Accra Region, which gets its water from Western Accra surrounding the Weija dam, has become contaminated as a result of industrial waste and farming activities. Some water bodies in the Central Region, notably around Cape Coast, have been contaminated as a result of galamsey activities. The situation is similar, if not worse, in Brong Ahafo, where citizens have been obstructing the path of the river at regular intervals, preventing water from flowing into some regions of the Region (Mantey, 2017). The scarcity of water in Sunyani, as at the time the study was done, was caused by farming operations, in which locals obstructed the river channel to irrigate farmland. The Ashanti Region is also plagued by pollution. According to Mantey (2017), illegal mining operations have contaminated the Enu River, which supplies Konogo inhabitants in the Ashanti Region. Sand winning is the most common activity that pollutes water bodies in the Northern Region, although galamsey activities pollute water bodies in some areas. The Nawuni River in Ghana's northern area has been subjected to significant sand winning activities, which have permanently changed the river's hue (Mantey, 2017). It is very disturbing to see that the pollution of our Reservoirs has reached epic levels such that treatment plants have been forced to close down because the water sources have been viewed as beyond remediation. As a nation we need to come to the realization that our mismanagement of our freshwater resources will have significant and long-lasting effects on the environment and the communities that depend on these water sources. Some of which include; loss of potable water, in the sense that when freshwater bodies become contaminated to the point of being beyond remediation, they may no longer be safe for human consumption or for other uses, such as agriculture and industry, there will be severe health impacts upon consumption, leading to increased rates of waterborne illnesses and diseases, death and displacement of organisms that are

adapted to specific water conditions, thereby altering the balance of the ecosystem and in the long run, ecosystem degradation. These impacts highlight the importance of preventing freshwater pollution and managing water resources in a sustainable manner.

2.2.3 Effects of Fresh Water Pollution in Ghana

2.2.3.1 Illegal Mining

According to Ackah (2019), the practice of galamsey activities in the country, with their crude and inefficient techniques, poses one of the most serious threats to public health. It incorporates water usage methods and alluvial mining processes that pollute rivers, streams, and lakes. Toxic substances, such as mercury, are discharged into these bodies of water, with long-term health consequences for populations for centuries. The use of these heavy metals to contaminate surface and subsurface water has serious health consequences that will become apparent in the near future (Ackah, 2019). Galamsey practices expose Ghanaians to gaseous mercury, which is absorbed into the bloodstream by drinking and breathing. Once in the vascular system, it can cross the blood-brain barrier and build up in the brain, causing damage to the central nervous system. Millions of Ghanaians live along the banks of these rivers and collect raw water, which is extensively polluted with pollutants such as mercury and arsenic, for domestic use (Ackah, 2019).

The use of mercury has increased dramatically as exploration has moved from alluvial to surface mining. Waste mercury is typically allowed to wash off into surrounding rivers or local soils, with a particularly negative impact on the ecosystem. An analysis of the health effects of mercury uses in a galamsey village discovered that 90% of villagers (galamsey and non-galamsey) registered a faint metallic taste and salivation issues. Twenty percent also have physical tremors, and 65 percent have trouble sleeping. Mercury levels in biological samples revealed that between 86 and 91 percent of the population had been exposed to mercury (Rambaud, Casellas, Sackey, Ankrah,

Potin-Gautier, Tellier, Bannerman & Babut, 1999). A second related analysis in a separate region of Ghana that looked at the impact of mercury usage on total river systems discovered that: river sediments were greatly polluted and were brought so far downstream that some coastal areas were almost as contaminated as inland areas; fish are also strongly impaired, so that in the specific area studied, ingestion of a mere 45g of fish per day was enough to surpass the World Health Organization's (WHO) weekly tolerance of 300 g and consumption of specific types of vegetables could exceed the weekly mercury intake set by the WHO/Food and Agriculture Organization's expert committee (Babut, Sekyi, Potin-Gautier, Tellier, Bannerman, Casellas, & Rambaud, 2001). The Tano River, which supplies water to more than 60% of the Brong Ahafo region's population, is being harmed by illegal miners. Communities such as Dormaa Akwamu, Kenyase, and Nkaseim face similar dangers.

2.2.3.2 Agricultural Activities

Agricultural activities have an impact on water quality because they release nutrients (as a result of soil management and fertilizer application) and other chemicals (e.g., pesticides) into the water environment, cause biological contamination (e.g., from microbiological organisms in manure), and cause soil to erode and wash away from farmland. The major effect of agriculture on fresh water bodies will be the excessive use of agrochemicals such as fertilizers and pesticides. Pesticides such as 1,1,1-trichloro-2,2-bis (4-chlorophenyl) ethane (DDT) and 1,2,3,4,5,6-hexachlorocyclohexane (HCH), which are environmentally persistent and banned in developed countries (Fianko, Donkor, Lowor & Yeboah, 2011). Fianko *et, al.* (2011) state that since most farms have grown in size and are now commercialized, the difficulties of maintaining crops free of damage have grown. Hand-tilling weeds, for example, has been inefficient. As a result, the planet has seen a steady increase in the amount and quantity of agrochemicals used. The use of

agrochemicals has been crucial in the agricultural crop yield. Water samples from rivers in Ghana's Ashanti and Eastern Regions were found to contain the pesticides, lindane and endosulfan, similarly, mean pesticide concentrations in water samples for lindane and endosulfan in Ghana's Oda, Kowire, and Atwetwe rivers were 19.4 and 12.4 g/L (Oda), 16.4 and 17.9 g/L (Kowire), and 20.5 and 21.4 g/L (Atwetwe), respectively (Acquaah, 1997). Ntow, (2005) also observed the Volta Lake to be slightly polluted with lindane, DDT, DDE, and endosulfan. Pesticides can leach from the root zone or be washed off the land's surface by rain or irrigation water, ultimately ending up in nearby fresh waterbodioes as well as groundwater sources (Gooddy, Chilton & Harrison, 2002)

2.2.3.3 Domestic Waste

It is a well-known truth that practically all water contaminants are harmful to humans as well as other creatures. For example, sodium is known to promote cardiovascular illness, but nitrates are linked to blood issues. Some pollutants are cancers, while others, such as DDT, are known to be hazardous to people and can potentially disrupt chromosomes. Others, such as PCBs, cause liver and nerve damage, skin eruptions, vomiting, fever, diarrhea, and prenatal anomalies. This is all as a result of improper disposal and treatment of domestic waste located at landfills and dumpsites as well open defecation and indiscriminate waste disposal by residents. A study conducted by Nartey, Hayford & Ametsi, (2012), on water samples that were collected from four water bodies, namely; Densu, Lafa, Bale Rivers and the Gbegbe lagoon (Glefe) that run through certain waste dump sites in Ghana's Accra metropolitan region indicated that Helminth egg counts, coliform and faecal coliforms were all high in water samples, indicating that the bodies of water were contaminated with bacteria and diseases. Organic waste, as well as coliform bacteria produced from these waste dumps, were found to be the predominant contributors of contaminants in the water bodies. Because of the high amounts of microbes, the water bodies are dangerous for both primary and

secondary interactions. The presence of these coliforms could be responsible for the transmission of infectious diseases which include typhoid fever, dysentery, salmonellosis, cholera and gastroenteritis (EPA, 2002).

2.2.3.4 Industrial Waste

Waste discharges are a result of fast population increase, industrialization, and the associated technology, and the pace at which these pollutants are dumped into surface waterways is significantly larger than the carrying capabilities of the water bodies. Shivayogimath, Kalburgi, Deshannavar & Virupakshaiah, 2012). In Ghana, one of the primary sources of stream pollution is the discharge of industrial effluents, which causes water-borne illnesses such as cholera (Abdalla, Oppong-Kyekyeku, Donkor & Adiyiah, 2016). The tremendous rate at which industrial wastewaters are discharged into lakes and Reservoirs is such that the water bodies into which these wastewaters are discharged may no longer function as excellent quality water sources due to natural self-purification. High nutrient levels often cause dissolved oxygen depletion and the release of hazardous compounds such as heavy metals, which can bio-accumulate in microorganisms in the water are consequences (Morrison, Fatoki, Persson, & Ekberg, 2001). Microorganisms in fresh water bodies have the ability to collect persistent organic pollutants such as heavy metals, Polycyclic Aromatic Hydrocarbons (PAH), and Polychlorinated Biphenyl (PCB) in the environment (POPs) (Abdalla *et, al*., 2016). When these pollutants enter the body, they may not only affect the procreative capacity of these bacteria, but they may also have an influence on human health (Wagtech, 2015).

2.3 Limnology of Reservoirs

Limnology is the study of inland water bodies, including their physical structure, water cycle, chemical structure, biological structure, nutrient cycling and material budget, pollution, and deterioration. The physical structure of a lake is concerned with basin morphometry, water cycle and hydrodynamics, turbidity and light penetration, thermal stratification, and sediment deposition (Balasubramanian, 2015).

2.3.1 Some Factors Affecting the Limnology of Reservoirs

2.3.1.1 Morphometry

A lake's morphometry covers the basin's topography, bathymetry, area of water spread, and shoreline arrangement. The morphometric features of a lake influence sediment-water interactions (mixing, re-suspension, nutrient availability, littoral zone extent), productivity (amount of biomass created), and lake species. The following are the morphometric parameters: (1) Surface area (2) Mean depth (3) Volume (4) Maximum length (5) Mean width (6) Shoreline Length (7) Shoreline Development (8) Fetch (Balasubramanian, 2015). Lake morphometry can play a significant role in shaping the mixing patterns in a Reservoir, and can impact the physical, chemical, and biological characteristics of the Reservoir. Factors like mean and maximum depth affect mixing in terms of the amount of light penetration, water temperature, and water circulation. Deeper lakes tend to have less mixing and stratification compared to shallower lakes. The depth can also impact resuspension by affecting the water velocity and the amount of turbulence in the water column. Deeper lakes tend to have lower water velocities and less turbulence, which can reduce resuspension thus the deeper the lake, the lower the lower the rate of resuspension. The presence of developed shorelines thus shorelines with developments deviating from one and not having a circular shape can increase erosion and sedimentation in a lake, as well as alter water flow patterns

and water quality. The surface area of a lake can has a significant impact on the ecology, physical processes and water balance. A larger surface area can increase the amount of evaporation, which can affect the water balance and water temperature of the lake. Again, a larger surface area can increase the exposure of the lake to pollutants from the surrounding environment, such as fertilizers, sewage, and industrial waste. This can impact the water quality of the lake, including reducing its oxygen levels and increasing its nutrient levels, which can lead to the proliferation of harmful algae and bacteria. Fetch is the distance over which wind blows across a water body, and it can have a significant impact on a lake in several ways. The fetch of a lake determines the size of the waves that can be generated by the wind. Larger fetch can result in higher, more persistent waves, which can erode shorelines and impact water quality by mixing and resuspending bottom sediments. It can also affect water circulation patterns, including the distribution of temperature and dissolved substances thus longer fetch can result in more uniform water circulation and temperature, while shorter fetch can result in more localized circulation patterns. It can again influence the amount of light that penetrates into the water, which affects the growth and distribution of aquatic plants and animals. Longer fetch can result in lower light penetration, which can limit the growth of aquatic plants and reduce the productivity of the lake. Lastly, it can impact water quality by influencing the rate of water exchange with the surrounding environment, which can affect the balance of nutrients, pollutants, and dissolved oxygen in the water.

The size of a lake is measured in surface area, which is usually represented in acres or squared meters. Lake surface area can be used to forecast the effects of wind on a lake. During windy circumstances, lakes with a larger surface area are vulnerable to bigger waves (UF/IFAS, 2001). This is crucial because stronger waves may mix water at higher depths, reaching all the way to the lake's bottom in some cases. The capacity to induce mixing at the lake's bottom is critical because

it can result in silt re-suspension and/or disturbance of submerged aquatic vegetation. As a result, other lake properties, such as water clarity and nutrient availability, may be impacted. The surface area of a lake also determines its diluting capacity (UF/IFAS, 2001). Dilution capacity refers to a lake's ability to dilute materials, whether they are naturally occurring from the watershed or caused by a human-caused spill. Lakes with a larger surface area have a better potential for dilution than lakes with a smaller surface area. A lake with a higher dilution capacity is less likely to be influenced by fertilizers or other elements introduced by human activities thus changes in Reservoir surface area may reflect changes in diluting capacity and hence water quality.

A lake's mean depth is its average water depth. Due to early studies of algae, aquatic invertebrates, and fish populations revealed that shallow lakes are usually more productive than deep lakes, mean depth is crucial. This is because light can easily penetrate and reach the bottom for photosynthetic purposes. The ability for waves to alter bottom sediments is also heavily influenced by mean depth (Jeppesen, Søndergaard, Jensen, Havens, Anneville, Carvalho, Coveney, Deneke, Dokulil, Foy & Gerdeaux, 2005). This indicates that lakes with larger mean depths typically do not have as much bottom sediment mixing because wave action is less likely to reach the bottom.

Maximum depth (Zmax) is the location where water is deepest and is measured in feet (ft) or meters (m). It influences stratification and the proportion of water in which algae can grow (Jeppesen *et, al*., 2005). Most water in shallow lakes may have enough light or algae to grow, but in deeper lakes, much of the deep water does not have enough light for algae. The deeper the lake the lower the rate of light penetration.

The entire amount of water in a lake basin is known as volume, and it is commonly represented in acre-feet or cubic meters. Lake volume is an essential factor in lake management since it affects a lake's diluting capacity (UF/IFAS, 2001). Lakes with bigger water volumes have a better potential

to dilute items entering the lake basin. Lake volume is also important to consider when assessing nutrient loads since it might affect algal populations in a lake (Algesten, Sobek, Bergström, Ågren, Tranvik & Jansson, 2004). The loss of volume reduces the dilution capacity and increases the potential for eutrophication due to increased nutrient concentration.

Fetch is the longest uninterrupted distance over which the wind blows across the lake. The fetch is significant because it influences the depth at which waves can mix water and/or bottom sediments in a lake (Von Einem & Grane´li, 2010). The longer the maximum length, the stronger the waves, and the greater the possibility of bottom sediment mixing or disturbance therefore, he longer the fetch and stronger the wind speed, the higher the rate of mixing.

Hydraulic Residence Time (HRT), is the amount of time that water remains in a lake. Longer hydraulic residence periods result in greater carbon: phosphorus (C:P) ratios, which means that they are more nutrient-limited than shorter hydraulic residence times lakes. This is because less water from the watershed enters lakes with a high residence period, the phosphorus in the water is used up and not restored as rapidly (Dewey, 2018). Based on this, it can be deduced that Hydraulic Residence Time can therefore regulate primary production since it affects nutrient availability.

Shoreline length is the linear measurement of a water body's complete circumference. This distance denotes the whole area of lake front available for activities such as home construction and lake edge impacts. Shoreline length is significant because it quantifies the amount of interaction between a body of water and the surrounding land (UF/IFAS, 2001). Based on this, it can be inferred that the longer the shoreline length, the more the lake is exposed to shoreline erosion by virtue of the human activities occurring on the shore. Shoreline length can be determined by tracing around the water body on a map using a piece of string. The length of string will be compared with the map's scale to convert the measurement to the actual shoreline length.

The length of a lake's shoreline in relation to a circle of the same area is referred to as shoreline development. In other words, lakes with longer, irregularly shaped shorelines have greater shoreline development, whereas circular lakes have less shoreline development (UF/IFAS, 2001). The shoreline development value of a complete circle is 1.0. The number rises as the morphology of the shoreline gets more uneven. Shoreline development values in irregularly shaped Reservoirs with several embayment (coves) can surpass 3. Lakes with very uneven shorelines contain more near shore shallows for rooted plant development, as well as more shoreline for buildings and shoreline erosion, both of which may boost lake productivity (Rosenberger, Hampton, Fradkin & Kennedy, 2008). This is to say, the more the shoreline development deviates from 1, the greater the exposure to erosion which will in tend lead to an increase in productivity in the lake. Again, increased shoreline development can lead to an increase in water temperature by means of a decrease in vegetation which can lead to a decrease in water quantity as a result of evaporation. The formula for calculating (LD) = $L/2 \sqrt{\pi} A0$, where L = Shoreline length & A_0 = surface area of the lake.

2.3.1.2 Physico-Chemical Parameters

The temperature of lake water affects (a) biological activity and growth, (b) the types of organisms that may exist, (c) water chemistry, (d) chemical processes, and (e) water balance computations (Balasubramanian, 2015). Temperature changes in lake water are caused by seasonal and daily variations in air temperature, water intake and outflow from catchments, and artificially generated thermal pollution (Balasubramanian, 2015). In lakes, three types of strata are defined based on temperature distribution. Epilimnion refers to the upper layer of water in a lake that is consistently warm and well-mixed. The bottom layer of water in a lake that is consistently cold and mostly undisturbed is referred to as Hypolimnion. Metalimnion is the intermediate layer of water that

marks the transition between the top and bottom layers and where temperature fluctuates significantly with depth. The temperature of lake water determines the kind of organisms that may dwell in it. At increasing temperatures, the rate of chemical reactions normally rises, which has an effect on biological activity. (Balasubramanian, 2015). Lakes create strata called Thermoclines due to the odd relationship between water temperature and density. These are strata with radically different temperatures in relation to depth. Due to the fact that water has a very high specific heat capacity, a lake helps to regulate the temperature and climate of the surrounding region. During the day, a lake may cool the area next to it with local breezes, resulting in a cool breeze.

Temperature-depth relationships in tropical and temperate water bodies vary based on several factors such as water column stability, mixing, solar radiation, and seasonality. In tropical water bodies, temperatures tend to be more stable and exhibit little vertical mixing, with a strong thermocline separating warm surface waters from colder deep waters. As a result, solar radiation warms the surface waters, creating a thermocline that stratifies the water column and limits the mixing of warm and cold waters (De Crop & Verschuren, 2019). This stability results in a relatively constant temperature with depth in the surface layer, with a more rapid drop in temperature in the thermocline.

Temperate water bodies, on the other hand, exhibit more pronounced seasonal and vertical temperature variations. During the warmer months, the surface waters are heated, leading to vertical mixing that brings warmer surface waters into contact with colder deep waters. This mixing helps to distribute the heat throughout the water column and maintain a relatively homogeneous temperature profile with depth. During the colder months, the surface waters cool and the mixing decreases, leading to a more stratified water column (De Crop & Verschuren, 2019).

In general, the temperature-depth relationships in tropical and temperate water bodies are influenced by a complex interplay of physical, biological, and chemical factors, and are important for understanding the functioning and productivity of these water bodies.

Dissolved oxygen refers to oxygen molecules that are dissolved in water and is an important indication of water quality. The existence of aquatic life is dependent on a suitable supply of oxygen dissolved in water. When it falls below the levels required to maintain aquatic life, it causes a major water quality degradation. DO concentrations in 100% saturated fresh water range from 7.56 mg/L (or 7.56 parts oxygen in 1,000,000 parts water) at 30°C to 14.62 mg/L at 0°C (MPCA, 2009). The primary reason of low dissolved oxygen (DO) is excessive algal growth driven by phosphorus. Another component that might aid in algal development is nitrogen. The process of algal death and decomposition uses dissolved oxygen. As a result, there may be inadequate dissolved oxygen available for fish and other aquatic organisms (MPCA, 2009). Higher water temperatures cause more molecular vibrations, which reduces the amount of space available between water molecules (Wilson, 2010). As salinity rises, so does the inability of water to contain DO (Wilson, 2010). Due to their ionic charges, the salts compete more effectively for intermolecular spaces. The quantity of DO in water is also affected by altitude owing to the different densities of O_2 available for dissolution. DO concentrations will be lower at higher elevations because atmospheric O_2 is less dense than at sea level because atmospheric O_2 is denser (Wilson, 2010).

In tropical water bodies, the strong thermocline that separates warm surface waters from colder deep waters creates a stable water column that limits vertical mixing. This stability leads to a well-defined oxygen-depletion layer, where the surface waters are rich in DO, while the deep waters are oxygen-deficient. The warmer surface waters and the lower solubility of oxygen at higher

temperatures also result in lower DO concentrations in the surface layer. One the other hand, in temperate water bodies, the more pronounced seasonal and vertical temperature variations result in more vigorous mixing and vertical exchange of water masses. This mixing helps to distribute DO throughout the water column, leading to relatively uniform DO concentrations with depth. During the warmer months, the increased respiration rates of aquatic organisms and decomposition of organic matter can lead to DO depletion in the surface waters, particularly in shallow and eutrophic (nutrient-rich) water bodies.

Phosphorus (P) is a nutrient that is required by all living creatures. Phosphorus, for example, is contained in DNA (the genetic material of living things), is used to construct cell membranes, and is used to generate energy at the cell level (as ATP, adenosine triphosphate) (Walker, Younos & Zipper, 2007). Phosphorus enters lakes and Reservoirs through a variety of sources, including point-source discharges, terrestrial runoff, decomposing organisms, and phosphorus-containing rocks. Natural supplies of phosphorus to lakes and Reservoirs include waste products from aquatic creatures and wildlife, as well as decomposing plant and animal tissues (Wetzel 2001, Brönmark & Hansson 2005). Phosphorus can be found in the water column, within the bodies of aquatic species, or adhering to particles (such as silt) in the water. Organic phosphorus absorbed in plant and animal tissues can be converted into soluble inorganic phosphates by bacteria and used by primary producers. Similarly, particulate-bound phosphates (phosphates bound to particles) can be utilized by primary producers if the phosphorus dissociates from the particle and becomes soluble in the water column (Walker *et, al*, 2007). Phosphorus can sink to the bottom sediment as a component of fecal waste, a dead organism, or as a sinking particle connected to another sinking particle. Phosphorus may become buried and inaccessible to the system once it reaches the bottom of a lake or Reservoir. Rooted plants may transfer phosphorus from the sediment into their tissues,

where it can be released back into the water after death (Horne & Goldman, 1994). Phosphorus in sediment can be released back into the system by chemical processes; for example, with pH levels over 8, phosphate can dissociate from its particle and become soluble in water (Walker *et, al.*, 2007). Bottom-feeding fish and species that live in bottom sediments, such as worms and other aquatic invertebrates, can disrupt the sediment and release phosphorus back into the water column (Brönmark & Hansson, 2005).

Nitrogen in lakes and Reservoirs can come from natural sources such as plant and animal decomposition, waste products from aquatic life in the water, urine and feces of wildlife in the catchment, or (in typically tiny amounts) mineral dissolution of rocks. Nitrogen entering lakes and Reservoirs is frequently of direct human origin, such as sewage treatment plant discharges or leachate from septic systems, as well as fertilizer runoff (Walker *et, al.*, 2007). Nitrogen may be found in a variety of forms in fresh water. Most algae and other primary producers may use inorganic nitrogen forms such as nitrates (NO_3^-), nitrites (NO_2^-), ammonia (NH_3), and ammonium ions (NH^{4+}). Nitrate level above 0.2 mg/L NO_3-N in lakes likely to boost algal development and signal probable eutrophic conditions (Anku, 2001). Nitrate concentrations more than 10 mg/L pose a potentially major public health risk. Concentrations ranging from 11 to 40 mg/L have been linked to methaemoglobinemia (blue babies) in infants under the age of six months. Ammonium is found in low amounts in natural waterways and is a prevalent contaminant in sewage and industrial effluents (Anku, 2001).

pH refers to a substance's alkalinity or acidity, which is measured on a scale ranging from 1.0 to 14.0 (Spellman and Drinan, 2000). The concentration of hydrogen ions [H^+] in water is measured by the pH. As [H^+] grows, pH lowers, and the solution becomes more acidic; conversely, as [H^+] declines, pH rises, and the solution becomes more alkaline (Spellman and Drinan, 2000). As pH

levels move away from the optimum, animal systems are stressed, and hatching and survival rates are reduced. The higher the death rates, the further a number is from the optimal pH range. The more sensitive a species is to pH fluctuations, the more impacted it is. Aside from biological consequences, high pH levels generally enhance the solubility of elements and compounds, making harmful substances more mobile and elevating the danger of absorption by aquatic life (Fondriest Environmental Inc., 2013). Minor pH shifts can have long-term consequences. A little adjustment in water pH can improve the solubility of phosphorus and other nutrients, making them more available for plant development (Fondriest Environmental Inc., 2013). Aquatic plants and algae grow with more readily available nutrients, increasing the need for dissolved oxygen. This results in a eutrophic lake that is rich in nutrients and plant life but deficient in dissolved oxygen concentrations.

The entire quantity of material dissolved in a water sample is often quantified as total dissolved solids (TDS). TDS is the total amount of organic and inorganic dissolved material that has been ionized and unionized in a water sample. TDS in freshwater systems is commonly composed of inorganic salts, trace quantities of organic matter, and dissolved minerals (Anku, 2001). TDS is a key indication of water quality. The mobility and transformation of metals and ionisable compounds are affected by dissolved solids, which affects ionic strength. TDS is also a significant indication of whether water is suitable for drinking, irrigation, or industrial usage. Excess dissolved solids in drinking water are unpleasant due to potential physiological impacts, unattractive mineral tastes, and increased expenses due to pipe corrosion and the need for extra treatment. The concentration of total dissolved solids influences the water balance in aquatic organisms' cells. This, in turn, inhibits the organism's capacity to maintain correct cell density, making it difficult to maintain its position in the water column. Excess dissolved minerals, gases, and organic

elements should be removed since they can induce physiological consequences and generate aesthetically unappealing color, taste, and odors (Anku, 2001; Spellman & Drinan, 2000).

2.3.1.3 Self-Purification Processes

Lakes naturally purify themselves through self-purification processes, which assist to preserve water quality and enhance water conditions. Through physical, chemical, and biological phenomena as mixing, sedimentation, oxidation-reduction reactions, and the actions of lower and higher species, these processes take place (Gu, 1985). Pollutants and organic materials in the water are dispersed and diffused by physical processes including mixing and turbulence. Adsorption and oxidation-reduction reactions are two examples of chemical processes that remove or change organic materials and contaminants. Decomposition of organic matter and pollution removal are both carried out by biological processes, including those of microbes and higher species (Tian, Wang & Shang, 2011). The kind and quantity of pollutants, the physical and chemical characteristics of the water, the existence of pollution-degrading microbes and higher species, and other variables all affect how well self-purification processes work in lakes.

Settling of solids is a crucial step in the lake's self-purification process. It happens when silt and organic debris from the water column settle to the lake's bottom where microorganisms may decompose them. This procedure aids in lowering the level of organic matter in the water, which can lead to eutrophication, a reduction in oxygen levels, and other issues in the lake. Pollutants that are affixed to or dissolved in the particles can be eliminated with the aid of settling (Chapman, 1992). The size, density, and water velocity of the particles, as well as the existence of turbulence and mixing, as well as other elements that may affect particle movement, all influence the pace of settling. Reducing the sediment intake can help facilitate effective settling.

Mixing is an important process in lake self-purification as it helps to distribute dissolved oxygen and nutrients throughout the water column and maintain a stable thermal structure in the lake. Mixing occurs when wind and other physical forces create turbulence in the water, causing different water masses to mix with one another. This process helps to remove pollutants that are attached to or dissolved in the water, as well as reducing the concentration of harmful substances, such as excess nutrients, that can contribute to eutrophication and oxygen depletion in the lake (Magee & Wu, 2017). The rate of mixing in a lake depends on a variety of factors, including the lake's size and shape, the intensity of wind and other physical forces, and the presence of physical barriers, such as bottom sediment, that can reduce mixing. Effective mixing can be promoted by increasing the input of oxygen and nutrients into the lake, reducing the concentration of pollutants, and promoting physical mixing in the water column. The natural purification process is sped up by a quick mixing of the entering waste material and the receiving water.

Any natural body of water undergoes a wide range of biological activities, which eventually result in the purification of the water. Feeding on solid matter by microscopic organisms, particularly bacteria, transform more complex molecules into simpler ones. This process eventually reaches a stage where the complex material transforms into minerals, water, and carbon dioxide (complete mineralization of harmful substances into innocuous form). Some of the larger solid material particles are also consumed by huge creatures. Additionally, larger species consume the bacteria that break down waste. Additionally, these bigger creatures will consume smaller ones. It is obvious that any body of water's natural food cycle plays a crucial role in the process of self-purification. It is also necessary to underline the significance of photosynthesis in the process of self-purification. Under the influence of sunshine, algae and other green plants create oxygen and consume carbon dioxide. As a result, the technique tends to increase the amount of oxygen in

contaminated waterways. Additionally, any extra carbon dioxide that is dissolved in the water as a result of the purification process will be used by green plants' photosynthetic processes.

River and lake characteristics vary, which has an impact on how each of them handles pollution. Three zones make up the purification process: the zone of degradation/decomposition, the septic zone, and the recovery zone. The impact of the wind direction causes rivers to flow turbulently whereas lakes move slowly. The rate of mixing of contaminants in rivers is pronounced near the point of waste deposition, also known as the decomposition zone, due to significant turbulence. Pollutants are transported farther downstream depending on the flow velocity before sedimentation, hence river turbidity rises as pollutants are suspended in the river for a longer period of time. Aquatic plants eventually perish as a result of diminished sun light penetration and reduced photosynthetic capacity. As a result, the amount of dissolved carbon dioxide (CO_2) that would normally be used by aquatic plants in the river starts to increase. However, because lakes have slow water flow, contaminants (such as sludge, dead algae, organic debris, etc.) accumulate in vast amounts at the bottom of the lake, where microbial organisms start to decompose them (Whitehead & Lack, 1982). The amounts of dissolved oxygen rapidly decrease as the Biochemical Oxygen Demand (BOD) increases. As water in a lake's pelagic zone exchanges with the profundal zone's low-DO water, overturns aid in the purifying process. Water from the profundal zone that rises as a result of the overturn exchanges gases with the atmosphere at the top through a process called aeration, and the cycle repeats itself from time to time. This is significant because it aids in reducing stratification in lakes, which in turn reduces the thickness of the impermeable thermocline layer and allows dissolved oxygen to permeate deeper into the water. The turbulence and flow velocity are relatively important factors in the aeration process in rivers. The contaminants are entirely deposited at the bottoms of both rivers and lakes in the septic zone, making the water

cleaner and aerating it more effectively. The rate of decomposition is accelerated, and the lakes' concentration of dissolved oxygen reaches its lowest. Organic compounds continue to be broken down by anaerobic bacteria as they accumulate. In addition, sunlight can now reach the water, which causes algae to proliferate and BOD levels to drop. The recovery zone is the last stage, where algae proliferate and aquatic plants start to thrive, using dissolved CO_2 while releasing oxygen into the water. The concentration of the DO increases when it exceeds the BOD due to the BOD and DO's inverse connection that started in the septic zone (McGhee & Steel, 1991).

Similar mechanisms for self-purification exist in rivers and lakes alike, although rivers and lakes differ substantially in the way their waters travel. While lakes flow is languid and dependent on wind direction, rivers flow is turbulent because of their increased velocity. Lakes also undergo overturns, which is a significant method for self-purification. In essence, aeration in lakes happens as a result of overturns, allowing poor-quality (low oxygen content) profundal zone water to rise and exchange gases with the atmosphere, whereas aeration in rivers happens as a result of flow velocity and turbulence.

2.4 Eutrophication

Lake eutrophication is produced by an excess of nutrients, primarily phosphorus. Excess phosphorus inputs to lakes are typically caused by sewage, industrial wastes, and runoff from agricultural, construction, and urban areas. Municipal and industrial discharges are examples of point sources of nutrients, whereas nonpoint sources of nutrients, such as runoff from agricultural or urban lands, are examples of nonpoint sources of nutrients and are the drivers of eutrophication. Excessive fertilizer or manure application, which promotes phosphorus accumulation in soils, is a significant driver of nonpoint nutrient intake. Phosphorus-rich soils wash into lakes, where part of

it dissolves and supports the growth of phytoplankton and aquatic plants. Erosion of soil particles into streams and lakes is a major cause of eutrophication in areas with high soil phosphorus concentrations (Carpenter, 2005; Bennett, Carpenter, & Caraco, 2001). Algal blooms are a typical observable result of eutrophication. Algal blooms may be either a nuisance to individuals who wish to utilize the water body or they can become dangerous algal blooms that cause significant ecological deterioration in water bodies. After the algae is degraded by microbes, the water body may become depleted of oxygen (Glibert & Burford, 2017; Schindler & Vallentyne, 2004).

2.4.1 Eutrophication Process and its Causes

Increased nutrient concentrations promote the development of aquatic plants, including both macrophytes and phytoplankton. As more plant material becomes accessible as a food source, the number of invertebrates and fish species grows. As the process progresses, the biomass of the water body grows and biological diversity declines. With more severe eutrophication, bacterial decomposition of surplus biomass leads in oxygen consumption, which can lead to hypoxia, which begins at the bottom sediment and moves deeper into the water. In the summer, hypoxic zones are widespread in deep water lakes owing to stratification into the cold oxygen-poor hypolimnion and the warm oxygen-rich epilimnion (Schindler & Vallentyne, 2008; Smith, Tilman & Nekola, 1999). Phosphorus is a required nutrient for plants, and it is the limiting element for plant development in the majority of freshwater habitats. Because phosphorus binds to soil particles strongly, it is mostly transferred via erosion and runoff. The extraction of phosphate into water is sluggish once it has been translocated to lakes, which contributes to the difficulty of reversing the consequences of eutrophication (Schindler, 2012; Khan & Mohammad, 2014). When macrophytes and algae die in productive eutrophic lakes, rivers, and streams, they disintegrate, and the nutrients in that organic matter are transformed into inorganic form by microbes. Because the breakdown process uses

oxygen, the concentration of dissolved oxygen decreases (Jeppesen *et, al*, 2005). Depleted oxygen levels, in turn, may result in fish deaths and a variety of other impacts that reduce biodiversity. Nutrients may get concentrated in an anoxic zone, generally in deeper waters walled off by stratification of the water column, and may be made available again only during fall turn-over in temperate climates or under turbulent flow conditions. Increased development of aquatic vegetation, phytoplankton, and algal blooms disturbs the ecosystem's regular functioning, generating a range of difficulties such as a shortage of oxygen, which is required for fish and shellfish survival (Bartram, Wayne, Ingrid, Gary & Olav, 1999). Dense algae development in surface waters can obscure deeper water and impair the survival of benthic shelter plants, affecting the whole ecosystem. Eutrophication also reduces the value of rivers, lakes, and recreational opportunities. When eutrophic conditions interfere with drinking water treatment, health concerns might arise. Phosphorus levels in water are well correlated with algal concentrations and lake trophic status. Studies in Ontario's Experimental Lakes Area have revealed a link between phosphorus input and the rate of eutrophication. Later phases of eutrophication result in blooms of nitrogen-fixing cyanobacteria that are only restricted by the phosphorus concentration (Higgins, Paterson, Hecky, Schindler, Venkiteswaran & Findlay, 2017)

2.4.2 Conceptual Model of Eutrophication

The introduction of extra nutrients into aquatic environments begins the eutrophication conceptual paradigm. Agricultural runoff, sewage discharge and industrial effluents are all common sources (Howarth *et, al*., 1996). These anthropogenic contributions considerably contribute to water body nutrient enrichment. The stage of nutrient enrichment begins when nutrients accumulate in the water. Increased nutrient levels increase primary production, resulting in rapid growth of aquatic plants and algae, especially phytoplankton (Paerl *et, al.*, 2016). This phase leads to the formation

of algal blooms, which is a sign of eutrophication. Blooms are composed of intense concentrations of algae, which frequently form surface scums or mats (Huisman *et, al.*, 2018). The ensuing decomposition of dead algae consumes dissolved oxygen in the water as algal biomass builds. This causes oxygen depletion, which can lead to hypoxia or anoxia, both of which are harmful to aquatic life (Diaz & Rosenberg, 2008). Water quality deteriorates further, as shown by decreased clarity, unpleasant odors, and, in certain cases, the buildup of hazardous algal toxins (Paerl & Otten, 2013). Rapid algal growth. and consequent depletion of oxygen affect aquatic species such as fish, invertebrates, and other wildlife (Smith & Schindler, 2009). Native species often get outcompeted by invasive species, resulting in biodiversity loss. The final component of the conceptual model emphasizes the relevance of eutrophication mitigation and management measures. These techniques seek to minimize nutrient inputs by implementing improved agricultural practices, updating sewage treatment systems, and regulating runoff. Ecological restoration strategies like as biomanipulation and nutrient removal technology can also assist minimize the effects of eutrophication.

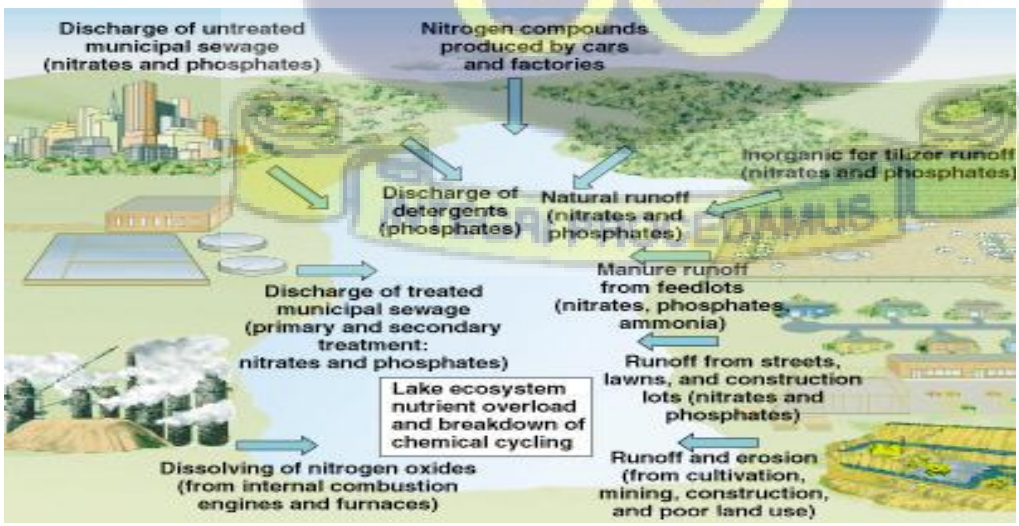

Figure 2.1 *Conceptual Model of Eutrophication*

Adopted from *(Nukpezah, 2020)*

2.4.3 External Nutrient Loading

External nutrient loading is the process through which nutrients, such as nitrogen and phosphorus, are added to a water body from sources that are external to the water body. Examples of such sources include agricultural runoff, sewage discharge, and atmospheric deposition. Increased nutrient levels can result in eutrophication, which is an overabundance of nutrients in the water body and can alter the aquatic ecology by increasing algae growth and decreasing oxygen levels (US Environmental Protection Agency, 2020; Howarth, Sharpley & Walker, 1996). This process takes place when nutrients from the land are not effectively absorbed or handled by the land and reach the water body, causing an increase in the development of algae and other aquatic plants that might result in eutrophication. Water quality might suffer, oxygen levels can drop, and aquatic life may be harmed as a result of eutrophication (Sharpley, 1994; Howarth & Marino, 2006). The land use and human activities in the immediate region, together with climatic and hydrological conditions, can all have a significant impact on the pace and volume of external nutrient loading.

2.4.4 Internal Nutrient Loading

Internal phosphorus (P) loading refers to the flow and recycling of P between sediment in a lake and the water column. Phosphorus and nitrogen are delivered into a lake environment via a variety of point and non-point sources, where they accumulate in the sediment (Dubey & Dutta, 2020; Liang, Liu, Zhen & He, 2015; Wongaree, 2019; Yang, Wei, Xu, Zhang, Li & Wan, 2019). Various factors affect this process, including chemical processes such as redox potential and pH, biological processes like mobilization and mineralization, as well as physical processes such as diffusion and sediment mixing. (Kowalczewska-Madura et al., 2019; Yang et al., 2013). In other words, internal loading is obtained from ancient external loading that sinks in sediments (Nürnberg, LaZerte, Loh & Molot, 2013). Phosphate (PO_4^{3-}) is adsorbed or precipitated with ferric (Fe^{3+}) iron

oxyhydroxides (FeOOHP) in the surface sediment under aerobic and oxygenated conditions. Initially, freshly precipitated Fe-OOH is a very low molecular weight colloid particle composed of iron and hydroxyl ions that polymerize (form chains). When PO_4^{3-} is coupled with Fe-OOH, it is mainly eliminated from recycling routes and in a form that algae cannot take up. As hypolimnetic dissolved oxygen depletes, anaerobic bacteria can create energy from organic detritus by using Fe-OOH as an alternative electron acceptor (James, 2016). The bacterially driven reduction of Fe-OOH to soluble Fe^{2+} breaks the connection between Fe-OOH and PO_4^{3-}, leading in the diffusion of Fe^{2+} and PO_4^{3-} into the sediment pore water and, subsequently, into the anoxic hypolimnion. As the summer advances, the slow process of diffusion at the sediment-water interface can cause significant soluble PO_4^{3-} and Fe^{2+} buildup in the anoxic hypolimnion. By the conclusion of the summer stratification, soluble P concentrations above the sediment surface may surpass 1mg/L, with concentration gradients extending up into the metalimnion (James, 2016).

2.4.5 Models for Assessing Nutrient Enrichment in Waterbodies

Assessing nutrient enrichment in waterbodies involves evaluating the level of nutrient inputs (e.g., nitrogen and phosphorus) relative to the natural background concentration. This can be done using a variety of models and methods. These include;

Total Maximum Daily Load (TMDL) model: This model evaluates the total amount of a pollutant that a waterbody can receive without exceeding water quality standards.

Water Quality Index (WQI) model: This model uses multiple water quality parameters to provide a single value that summarizes the overall water quality of a waterbody (Apostol & Christaki, 2002).

Trophic state indices: These indices, such as the Carlson Trophic State Index (TSI) and the Total Phosphorus Index (TPI), provide a relative measure of water quality based on the concentration of nutrients and other water quality parameters (Carpenter, Caraco, Correll, Howarth, Sharpley & Smith, 1998).

Nutrient Loading Model (NLM): This model predicts the effect of nutrient inputs on the water quality of a waterbody by simulating nutrient cycling processes and determining the resulting changes in water quality parameters (Smith, Schindler & Lytle, 1992).

Environmental Assessment (EA) model: This model evaluates the impact of multiple pollutants, including nutrients, on the overall water quality of a waterbody and assesses the potential for adverse effects on aquatic biota and human health (USEPA, 2003).

2.4.5.1 The Carlson Trophic State Index

Carlson's Trophic State Index (TSI) is an ecological index used to quantify the nutrient status of a water body, with reference to its trophic state or level of eutrophication (Carlson, 1977). It was developed by Robert Carlson (1977) and is widely used by water resource managers and scientists to assess nutrient enrichment in lakes and other water bodies. Secchi's disc transparency, chlorophyll-a, and phosphorus measurements are used in this procedure (Devi Prasad & Siddaraju, 2012). Trophic state is defined as the total weight of biomass in a body of water at a given location and time. It is the biological reaction of water bodies to nutrient inputs. Devi Prasad & Siddaraju, (2012) goes on to state that, nutrient effects can be influenced by factors such as seasonal variations, grazing of phytoplankton by zooplankton, and water mixing depth, among others.

The TSI is based on the relationship between chlorophyll-a (a pigment that is used as an indicator of phytoplankton biomass) and total phosphorus (TP) concentrations in a water body.

The index can be calculated using three parameters: log-transformed Secchi depth transparency, concentration of chlorophyll and total phosphorus in a lake. Thus;

TSI (SD) = 10 [6-ln SD/ln 2] …… (1)

TSI (CHL) = 10 [6-(2.04-ln CHL)/ ln 2] …… (2)

TSI (TP) = 14.42 ln (TP) + 4.15 … (3)

The above relations are then simplified into:

TSI (SD) = 60 -14.41 ln (SD; in meters) ……. (4)

TSI (CHL) = 9.81 ln (CHL; µg/L) + 30.6 …… (5)

TSI (TP) = 14.42 ln (TP; µg/L) + 4.15 ……. (6)

Carlson's trophic status index is mostly based on algal biomass, which includes three variables: chlorophyll a (CHL), Secchi disc depth (SD), and total phosphorus (TP). The TSI ranges from 0 to 100, with higher values indicating higher levels of nutrient enrichment and eutrophication. Oligotrophic water bodies have TSI values below 40, while mesotrophic water bodies have TSI values between 40 and 60, and eutrophic water bodies have TSI values above 60.

The TSI is a simple and widely used index for assessing the nutrient status of water bodies and can be used to monitor changes in the trophic state of a lake over time. Below is Table 2.1 which shows the trophic state indices and their corresponding attributes.

Table 2.1 The trophic state indices and their corresponding attributes.

TSI Values	Trophic Status	Attributes
<30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30 – 40	Oligotrophic	Hypolimnia of shallower lakes may become anoxic
40 – 50	Mesotrophic	Water moderately clear; increasing probability of hypolimnetic anoxia during summer
50 – 60	Eutrophic	Anoxic hypolimnia, macrophyte problems possible
60 – 70	Eutrophic	Blue green algae dominate, algal scums and macrophyte problems
70 – 80	Hyper-eutrophic	(Light limited productivity). Dense algae and macrophytes.
>80	Hyper-eutrophic	Algal scums, few macrophytes

(Devi Prasad, A. G. & Siddaraju, 2012)

2.4.6 Effects of Eutrophication

Eutrophication is the process by which an ecosystem is enriched with nutrients, causing an increase in the growth of plants and algae and a reduction in the quality of the water. It leads to the growth of harmful algal blooms. Excess nutrients can lead to an increase in toxic algae, which can harm other aquatic life, and may also pose a threat to human health if the toxins are ingested through drinking water or seafood. Again, it can lead to decreased dissolved oxygen levels. As plants and algae die, they decompose, consuming oxygen in the process, leading to decreased oxygen levels in the water, which can harm aquatic life (Yin *et, al.*, 2021; Zhang *et, al.*, 2021).

Eutrophication can have a significant impact on water supply. It can cause contamination of drinking water through harmful algal blooms can produce toxins that can contaminate drinking water supplies, making it unsafe for human consumption. Again, it leads to changes in water quality Increased nutrients in the water can alter the chemical composition of the water, making it less suitable for drinking or irrigation. Furthermore, eutrophication can lead to the growth of aquatic plants and algae, which can clog water intake systems, reducing the amount of water

available for treatment and supply in the long run. Lastly, eutrophication leads to increased treatment costs. Water treatment facilities may need to expend additional resources to remove excess nutrients and harmful algae from drinking water supplies, increasing the cost of providing clean water (Singh *et, al*., 2022; Zhang *et, al*., 2021; Li *et, al*., 2022).

With regards to fisheries, eutrophication can cause changes in fish populations. Increased primary productivity and shifts in community structure can alter the distribution and abundance of fish populations. In addition to the above, excess nutrients can lead to the growth of toxic algae, which can harm fish and other aquatic life (Song *et, al.,* 2021). Changes in water chemistry due to increased nutrients can reduce water quality, making it less suitable for aquatic life (Song *et, al.*, 2021). Finally, changes in the types and abundance of species as a result of eutrophication, can result in the loss of biodiversity in an ecosystem, including in fish populations.

Healthwise, harmful algal blooms can produce toxins that can contaminate drinking water supplies, making it unsafe for human consumption. Secondly, swimming or engaging in other water activities in eutrophic waters can expose individuals to toxic substances produced by harmful algal blooms. Consuming contaminated seafood can lead to food-borne illness (Hernández *et, al*., 2022; Hernandez *et, al*., 2021; Chen, *et, al*., 2021).

2.4.7 Eutrophication Management

Eutrophication management involves reducing nutrient inputs to bodies of water and restoring their ecological balance. Strategies for eutrophication management are not limited to but include improving the treatment of sewage and industrial wastewater to reduce the amount of nutrients released into bodies of water (Park *et, al.,* 2022), implementing best management practices in agriculture to reduce nutrient runoff, such as using cover crops and reducing fertilizer application, reducing the use of fertilizers, especially in urban areas, and properly disposing of pet and livestock

waste to reduce nutrient inputs to bodies of water (Wang *et, al*., 2021), restoring wetlands, riparian zones, and other habitats to improve water quality and reduce eutrophication (Kim *et, al*., 2022), regular monitoring and assessment of nutrient levels and water quality to track the effectiveness of management strategies and make necessary adjustments and educating the public about the impacts of eutrophication and the importance of reducing nutrient inputs to bodies of water (Chen *et, al*., 2021). Other innovative technologies such as constructed wetlands, biofilters, and aeration systems can also be used for eutrophication management (Jiang *et, al*., 2022). Effective eutrophication management requires the cooperation and collaboration of various stakeholders, including government agencies, industry, agriculture, and the general public.

Managing internal load in bodies of water involves reducing the release of nutrients into the water and restoring their ecological balance. Some of these strategies include; sediment removal, hypolimnetic withdrawal, aeration and circulation.

Only the most recent sediments, which are the richest in organic matter and contain the most mobile types of nutrients (particularly phosphorus) and are frequently polluted with heavy metals, are re-moved (Bartoszek & Koszelnik, 2015). These deposits produce leachate that contains massive quantities of nitrogen and phosphorus, much above the values measured in the water column (Łopata, Augustyniak, Grochowska, Parszuto & Tandyrak, 2020). The fundamental constraint of this technology is the high expense of sediment extraction and disposal. Their storage is linked to the damage of neighbouring places. Technical infrastructure, such as sludge clarity tanks, leachate purification equipment, or hydro transport equipment, is also required (Grochowska, Augustyniak, Łopata & Tandyrak, 2020). It should be highlighted that the removed sediments must not be left on the lake's edge; rather, they must be managed appropriately. If they are left on the shore, they may create secondary contamination of the lake.

With regard to Hypolimnetic Withdrawal, the accumulation of nutrients and pollutants such as iron (II) and ammonia in the hypolimnion layer and lake bottom is caused by the anoxic redox cycling of iron and phosphorus and the breakdown of settled organic matter. This therapy is useful in stratified lakes and small Reservoirs where anaerobic hypolimnion limits fish habitat and promotes the release of P, harmful metal ions, and hydrogen sulphide from sediments. The hypolimnetic withdrawal technique involves re-directing hypolimnetic water to the outflow, which is commonly a river (Bartoszek & Koszelnik, 2015). The treatment is carried out by laying a pipe down the lake's bottom, with an intake at the lowest point. The output pipe is often located below lake level and functions as a siphon (Nürnberg, 2019). Typically, this is performed by damming the surface outflow and replacing it with water pulled from the hypolimnion and as a result, the hypolimnion retention time and the possibility of anaerobic conditions developing are reduced, as is the availability of nutrients for the epilimnion layer (Klapper, 2003; Lewtas, Paterson, Venema & Roy, 2015). In the majority of instances, the hypolimnetic dissolved oxygen level rose, resulting in a decrease in anoxic conditions and duration (Bartoszek & Koszelnik, 2015). Another possible benefit is that hypolimnetic water removal may restrict cyanobacteria's access to Fe (II), which is now known to be a precursor to the formation of blue green algae blooms (Molot, Watson, Creed, Trick, McCabe, Verschoor, Sorichetti, Powe, Venkiteswaran & Schiff, 2014).

There is also hypolimnetic aeration. This is often accomplished by the use of specialized aerators that pump pure oxygen or fine air bubbles into the hypolimnion layer without producing destratification (Singleton & Little, 2006). Aeration decreases internal P loading chiefly by deactivating Fe-P redox processes at the sediment–water contact, or benthic zone. Whereas Fe and P interactions occur throughout the short-term cycle of P in lakes and do not store permanently in lake sediments, such a long-term decrease can be achieved by reducing nutrient external-load;

nevertheless, phosphorus improvements do not always occur with aeration (Katsev, Tsandev, L'Heureux, & Rancourt, 2006).

The main idea behind circulation is to increase the dissolved oxygen level by oxygenating the whole water column, which leads to the oxidation of chemical compounds. This is accomplished by the use of pumps, jets, and dispersed air (Bartoszek & Koszelnik, 2015). Complete circulation minimizes the internal loading of phosphorus and trace elements, as well as the complexification of iron and manganese, which speeds up precipitation. Complete circulation may potentially diminish algal growth by increasing mixed depth, decreasing available light, and exposing mixed algal cells to rapid variations in hydrostatic pressure. According to Pastorok *et, al*. (1982), as cited by Bartoszek & Koszelnik (2015), artificial circulation efficiency is determined by four indicators: dissolved oxygen content, ammonium, the pH of the epilimnion, and trace metals iron and manganese. In the majority of the instances analyzed, the trace metal concentration fell while the dissolved oxygen content increased.

The land use in the watershed determines the external P-loading to surface waters. The features and level of urban growth as well as the effectiveness of wastewater treatment facilities are the main determinants of the P-loading from point sources. Different parameters have an influence on diffuse P-loading. Due to the efficient integration of phosphorus into biomass, fast turnover and recycling of nutrients within the systems, and little usage of fertilizer, forests and other natural ecosystems exhibit low area-specific P-transport to lakes. P-transport from agricultural regions can be many times greater than transfer from natural environments, depending on the crops and fertilization techniques used (Reynolds & Davies, 2001; Kronvang, Iversen, Jørgensen, Paulsen, Jensen, Conley, Ellermann, Laursen, Wiggers, & Jørgensen, 2001; Hobbie & Likens, 1973; Sharpley, Smith, Jones, Berg & Coleman, 1992). A key component of lake restoration is reducing

external nutrient input. Reductions are achieved through altering land use, agricultural and forestry methods, as well as urban and sewage nutrient load reductions from wastewater plants and domestic activities (Marttila *et al.*, 2020; Tong *et al.*, 2020). By creating buffer strips and taking other steps to prevent erosion, some strategies target nutrients in general, whilst others focus on specific nutrients (N, P, or both), such as by reducing emissions or treating specific water sources. Dual-nutrient loading reductions (i.e., targeting both N and P) have been demonstrated to further enhance water quality, even though P is often the most cost-effective target for nutrient abatement techniques (Paerl *et al.*, 2016).

2.5 Stratification and Stratification Effects

In a body of water, stratification is the process of layering the water according to temperature and density, with the warmest and lightest water at the top and the coldest and densest water at the bottom. Stratification can alter the distribution of light and nutrients, causing changes in primary productivity and the makeup of aquatic communities. It can also cause the buildup of pollutants and other harmful substances in the bottom layer, impairing water quality and posing a threat to aquatic life (Schindler *et, al*. 1977). Finally, stratification can limit the mixing of water and nutrients, leading to reduced oxygen levels and increased nutrient buildup in the bottom layer.

In general, as the temperature of the water increases, its density decreases, and vice versa. This relationship is due to the fact that as water warms, its molecules have more kinetic energy and move further apart, resulting in a decrease in density. Conversely, as water cools, its molecules have less kinetic energy and move closer together, resulting in an increase in density. In lakes, this temperature-density relationship can lead to thermal stratification, where the water in the lake is layered based on temperature and density, with the warmest and lightest water at the top and the

coolest and densest water at the bottom (Kitanidis, 1997). This stratification creates two distinct layers in the lake, known as the epilimnion and hypolimnion, which can limit the exchange of water and other substances between the surface and bottom of the lake.

The majority of liquids get denser (heavier) when they cool. Only up to a certain degree can water likewise quickly get denser as its temperature decreases. At 3.94°C, water has its highest density. From then, it gradually loses density until it hits the freezing point at 0°C. At this stage, ice begins to form, and its density rapidly drops. Since ice is significantly lighter than liquid water, it develops on the top of lakes rather than at their bottom (Ginn *et, al.*, 2010; Downing *et, al.*, 2001).

The thermal stratification of lakes is a further significant effect of the temperature/density relationship of water. Fluids of different densities must be mixed, and the quantity of energy needed depends on the density difference. In the case of lakes, wind is the main source of this energy. Therefore, it is crucial to pay close attention to the changes in water density that occur along with rapidly dropping water temperatures.

Specific latent heat is the amount of heat energy required to change the phase of a substance (such as water) from one state to another (such as from solid to liquid or from liquid to gas) without a change in temperature. This process is known as phase change, and the heat energy absorbed or released during phase change is referred to as latent heat. In the context of lakes and their thermal stratification, the specific latent heat of water can have significant effects on the stability of the thermal stratification (Räty & Viitasalo, 2000). When water at the surface of the lake absorbs heat from the sun, it warms and expands, becoming less dense. This can cause it to rise and mix with the cooler, denser water at depth, disrupting the thermal stratification.

Similarly, when the water at the surface of the lake cools and releases heat, it contracts and becomes denser, sinking to the bottom and disrupting the thermal stratification. This mixing process, known as thermal convection, can be enhanced or suppressed by the specific latent heat of water, depending on the amount of heat energy required for the phase change (Chen & Clift, 2011). Overall, the specific latent heat of water can play an important role in determining the stability of thermal stratification in lakes.

Figure 2.3. is an image depicting the temperature profile in Reservoirs showing epilimnion, metalimnion, hypolimnion and the thermocline. The epilimnion is a layer of aerobic water near the surface that is warm and rich in dissolved oxygen (commonly above 7 ppm). Temperature and dissolved oxygen (DO) levels in this region are typically maintained by sunlight penetration and wind-induced mixing (Perks, 2006). The hypolimnion is the bottom part of the Reservoir that is typically anaerobic, cold, and poor in dissolved oxygen (commonly below 3 ppm) (Davis & Cornwell, 1998). Between the epilimnion and hypolimnion, there is a very thin layer of water called the thermocline where there is a rapid change in temperature and dissolved oxygen (Hasan, Alam & Chowdhury, 2014).

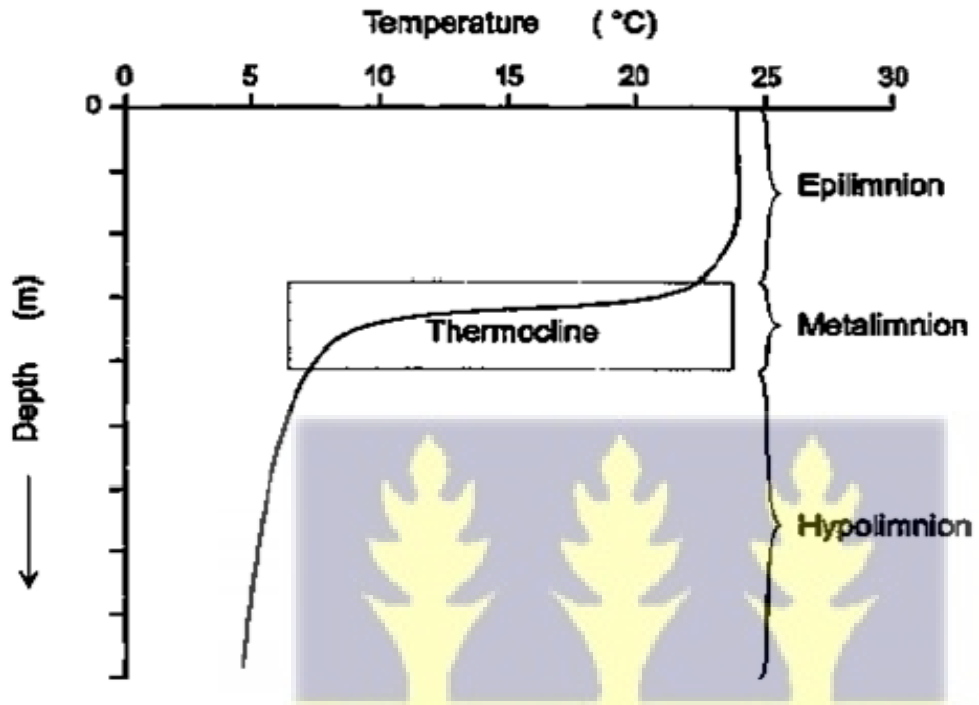

Figure 1.3. *Temperature profile in Reservoirs showing epilimnion, metalimnion, hypolimnion and the thermocline (Hasan, Alam & Chowdhury, 2014)*

Overturn in a lake refers to the mixing of water in the lake that occurs when the temperature-induced stratification breaks down. In a typical thermally stratified lake, the warmer, less dense water at the surface is separated from the colder, denser water at the bottom by a layer of water called the metalimnion. Overturn occurs when the energy input to the lake (such as wind or solar radiation) is sufficient to break down the stratification, resulting in mixing of the water in the lake (Keller & Hupfer, 2007; Hasan, Alam & Chowdhury, 2014). Overturn is a crucial occurrence because it improves the lake's ecology and water quality by distributing heat, nutrients, and oxygen across the lake. For instance, overturn can assist in preventing the accumulation of hazardous substances in the hypolimnion and in maintaining the wellbeing of the lake's fish and other aquatic organisms.

Small temperature changes can have significant impacts on the thermocline in tropical waters, which is often more persistent than in temperate waters. The thermocline acts as a barrier between the warm, nutrient-poor surface waters and the cooler, nutrient-rich deeper waters. A shift in the thermocline can result in changes in water mixing, water chemistry, and nutrient availability, which can affect the distribution and productivity of aquatic species.

In tropical waters, small temperature changes can cause the thermocline to become shallower or deeper, altering the distribution of heat and nutrients in the water column. This can result in changes to the water chemistry, including the pH and dissolved oxygen levels, which can have consequences for the health of aquatic species. In contrast, in temperate waters, the thermocline is typically less persistent and can be easily disrupted by changes in temperature. This can result in increased mixing of the water column, leading to a homogenization of water chemistry and temperatures (Naqvi, 2010). It is therefore important to monitor and understand the effect of temperature changes on the thermocline in tropical and temperate waters, as these changes can have significant impacts on aquatic ecosystems and the services they provide.

Stratification of the water column is caused by the thermocline, which serves as a barrier between the warmer, nutrient-poor surface waters and the cooler, nutrient-rich deeper waters. The distribution and productivity of aquatic species may be impacted by changes to the distribution of heat, nutrients, and dissolved oxygen as a result of this (Naqvi, 2010). Additionally, it can stop the nutrient enrichment that results in the formation of algae in the surface waters from bottom waters mixing with the surface waters. Harmful algal blooms (HABs) that pose threats to aquatic ecosystems and human health may develop from this. Once again, it limits the interchange of oxygen between the surface and bottom waters, which causes the depletion of oxygen in the latter (Naqvi, 2010). Death may ensue from this. The pH, dissolved oxygen levels, and nutrient levels

of the water may all be affected by the thermocline, which may also have an effect on the distribution and health of aquatic animals. As certain aquatic organisms are specialized to surviving in varying water temperatures and chemistries, the thermocline can also have an impact on their dispersal. The distribution of species may alter as a result of changes in the thermocline, which may have an effect on how well the food web and ecosystem operate.

3.0 METHODOLOGY

3.1 Study Area

Weija Reservoir, lies between geographical coordinates 5º 33′ 0″N and 5º 40′ 0″ N and 0º 20′ 0″W and 0º 24′ 0″ W (Anon, 2016). The Weija Reservoir, located approximately 17 kilometres west of Accra, is virtually at the mouth of the 116-kilometre-long River Densu, which originates in Ghana's Eastern Region in the Atewa-Atwiredu mountain range. The existing Reservoir supplies water to Accra's western suburbs, as well as agricultural and fishery programs (Asante *et, al*., 2008). The Weija Reservoir is 14 km long, 2.2 km wide and has total surface area of 38 km2 with mean depth of 5 m (Vanden Bossche & Bernacsek, 1990). The normal surface elevation is estimated at 14.37 km with maximum of 15.24 km (Nukunya & Boateng, 1979). The Reservoir region is low-lying, with undulating terrain and isolated hills. The climate is tropical, with temperatures averaging 27°C. Rainfall is mild, with a seasonal average of 65.5 millimeters. The Reservoir's catchment area is in the coastal savanna zone, where rainfall is seasonal, with two rainfall maxima in June and September, and dry intervals between December and March. The catchment's primary economic activity are fish and crop farming. Maize, cassava, sugarcane, and vegetables are major crops (Asante *et, al*., 2008).

3.2 Reconnaissance Visit and Selection of sampling sites

In May 2022, a reconnaissance assessment was conducted around the Weija Reservoir to determine its entrance points, the main activities that were taking place there, and any possible sources of contamination. Visited locations were Upper Weija, Machigani, Tetegu, Gbawe, and Kalabule Dam. Per the study, three (3) entry points were selected which served as the sample stations: Upper Weija (UW), Machigani (M) and Kalabule Dam (K). Within each sample station, two (2) sampling points were selected for purposes of the study. A Global Positioning System

(GPS) was used to record the coordinates of all the selected sampling stations. Figure 3.1 shows a map of the study area with the coordinates of the selected sites presented in Table 3.1 below.

Figure 2.1 *Map of Sample Sites in Study Area*

Table 3.1 **Coordinates (C) of the Sampling Sites**

SS/Coordinates	C1 (Point A)	C2 (Point B)
SS1 (Upper Weija)	N 05° 34.425' W 000° 20.757'	N 05° 34.939' W 000° 20.782'
SS2 (Machigani)	N 05° 33.247' W 000° 22.403'	N 05° 33.268' W 000° 22.099'
SS3 (Kalabule dam)	N 05° 33.362' W 000° 22.940'	N 05° 33.459' W 000° 22.861'

3.3 Determination of Morphometric Parameters

In order to obtain the Bathymetry (Digital elevation model) of the Weija Reservoir, data measurements were taken at a total of twenty-five thousand, two hundred and eleven points with their corresponding coordinates and depths were recorded. Access to the Reservoir was reached

using a hand paddled canoe. Five hundred (500) of the points were obtained using a depth echo sounder which measures the time it takes for a pulse of sound to travel from the measurement platform to Reservoir floor and back and as a result, calculates the depth of water at that point. The points were taken on the sampling days in June and July. The points were written a book for later recording onto Microsoft Excel. The other twenty-four thousand, seven hundred and eleven were obtained using the Garmin EchoMAP SV fish finder which recorded all the points and stored them on an external secure digital (SD) card for extraction upon arrival on the University of Ghana Campus.

The written data (500 points with corresponding depths) obtained with the echo sounder was then manually inputted into Microsoft Excel. The data obtained using the fish finder was loaded from the SD card into Microsoft Excel as well. The data was then converted from latitude and longitude to decimal degrees which could be accessed and used by ArcGIS application. The data was then loaded into ArcGIS and cleaned removing outliers that were not in the specified domain.

The Natural Neighbour interpolation method was employed for the purpose of this research. This method was chosen because it is an excellent general-purpose interpolation approach with the advantage of not requiring the specification of parameters such as radius, number of neighbours, or weights, and it handles huge numbers of sample points effectively. Natural neighbour interpolation works well with clustered scatter points in general. This approach can handle big input point datasets effectively. Local coordinates specify the degree of effect any scatter point has on output cells when utilizing the Natural Neighbour approach. This method resulted in the development of the DEM of the Reservoir.

With the area and volume toolset of the ArcGIS application, surface area and volumetric representations of the data was obtained after interpolation and development of the DEM. The Z-

factor which was the various corresponding depths of the points was applied to ensure accuracy of surface area and volume calculations. After this process, an output text file was created by the application which stored the parameters used to generate the results as well the calculated surface area and volume measurements. With that, the volume and surface area of the Reservoir was obtained from the DEM.

Shoreline length was determined by tracing around the water body on a map using a piece of string. The length of string was then compared with the map's scale to convert the measurement to the actual shoreline length. With the shoreline determined, the formula, $(LD) = L/2 \sqrt{\pi A_0}$, was used to calculate the shoreline development where L = Shoreline length & A_0 = surface area of the lake.

3.4 Determination of Physico-Chemical Parameters

Water and sediment samples for physicochemical analysis were obtained from the six sampling points (Figure 3.1) in June 2022, July 2022, August 2022, September 2022, October, 2022 and November 2022. A hand paddled canoe was used to reach the sampling sites. A Secchi disc with black and white quadrants of radius of 20cm was used to measure the Secchi depth. The Secchi depth is related to water clarity and is a measure of how deep light can penetrate into the water. It was lowered into the lake at the various points until it was no longer seen. The corresponding depth (m) was recorded and later used in the calculation of the Trophic State Index (TSI). Monthly sampling of water at the 3 stations was done to determine DO concentration, temperature variation and nutrient distribution along a depth profile at 1 m interval from the surface to the Reservoir bottom for 6 months (June through November, 2022).

3.4.1 Water Samples

The current state of the Reservoir was determined by taking water samples and key physico-chemical parameters and testing them. The sampling sites were chosen based on the level of activity observed at locations around the Reservoir. Three (3) sampling stations were selected with six (6) sampling points selected at random in each of the three sampling stations. The coordinates of all the selected sample points were recorded using a Global Positioning System (GPS).

At the sites, clean plastic bucket was used to fetch water by hand from mixed layer at the various sampling points. With the aid of the HORIBA U-50 series multi parameter water quality checker, the physico-chemical parameters, pH, temperature, dissolved oxygen (DO), total dissolved solids, salinity and conductivity of the samples from the mixed layer were be measured in-situ. After, the physico-chemical parameters had been recorded in a book, the samples were transferred into 250ml bottles and placed on ice in an ice-chest to be transported to the Ecological Laboratory of the University of Ghana for nutrient analysis.

An echo sounder was then used to determine the measurement of the various depths at which the samples were taken and with a water depth sampler, the samples were taken along the depth profile at 1m intervals till the bottom of the Reservoir was reached. Sampling this way allowed for plotting of results that established the presence and extent of stratification (thermal and chemical) within the water column. The physical parameters, pH, temperature, dissolved oxygen (DO), total dissolved solids, salinity and conductivity were be measured in-situ using the HORIBA U-50 series multi parameter water quality checker. For nutrient analysis, samples were collected using the water depth sampler and poured into 250ml bottles. Water samples were placed on ice soon

after collection and transported to Ecological Laboratory within 24 hours of collection for nutrient analysis.

Turbidity was measured using a turbidimeter (HACH ®; 2100P Turbidimeter). The cuvette was rinsed with distilled water and filled with the sample. The procedure was repeated for each sample and the blank. The cuvette was placed into the instrument's light cabinet and covered with the light shield. After stabilization, turbidity value was read and recorded in Nephelometric Turbidity Units (NTU).

For orthophosphate, a total of 25 ml of sample and blank was measured and placed into a beaker. PhosVer® 3 Phosphate Reagent Powder Pillow was poured into the samples and mixed right away. A two- minute reaction time was permitted. The presence of phosphate was indicated by a blue coloring of the mixture. To zero the spectrophotometer, the blank was placed in the cell holder. The prepared sample was placed in the cell holder, and phosphate-phosphorus levels were measured at 890 nm as mg/l PO_4^{3-} .

Nitrates determination was done via nitration of salicylic acid according to standard methods described by Robarge et al. (2008) with slight modifications. Water samples were filtered through a Whatman No 42 filter paper prior to analysis. Ten milliliters (10 ml) of sample were transferred into a test tube where 5 ml of 5% w/v salicylic acid in concentration sulfuric acid was added. A reaction time of 10 minutes was allowed after which 2 ml of 2M NaOH was added. This was swirled for 5 minutes and the absorbance were read with a UV-vis spectrophotometer (Spectroquant Pharo 300) at 410 nm and a pathlength of 16 mm. Calibration standards of concentrations 5, 10, 15, 20, 25 and 30 mg/L were taken through same process as samples. Absorbances recorded were used to generate a linear relationship between absorbance and

concentration. Concentration of NO_3^- was determined using the calibration curve generated based on sample absorbances

3.4.2 Sediment Samples

At the bottom of the Reservoir, an Ekman Grab was lowered to the bottom of the Reservoir and used to take sediment samples. The sediment samples were then transferred into labelled zip-lock bags which were placed in an ice-chest for transportation to the Ecological Laboratory. At the lab, the physico-chemical parameters, pH and electrical conductivity were determined. Organic matter content as well as total phosphorus (TP) and total nitrogen (TN) were determined also.

To determine pH and electrical conductivity, sediment samples were air-dried at temperatures ranging 25°C to 30°C. Dried sample was ground using a wooden pestle and mortar and sieved using a 2mm mesh sieve. Sieved samples (10g) were weighed into a previously cleaned 50 ml beaker. Twenty milliliters of distilled water were added and the soil-water mixture was stirred for 15 minutes using a stirring rod. A previously calibrated pH meter and EC meter were used to determine the pH and Electrical Conductivity of the liquid suspending above the soil layer.

Total Phosphorus in sediment was determined using Murphy and Riley's molybdenum blue method of phosphate determination with modifications proposed by Watanabe and Olsen (1965). Sediment samples were air-dried at temperatures ranging 25°C to 30°C. Dried sample was ground using a wooden pestle and mortar and sieved using a 2mm mesh sieve. Sieved samples were kept in air-tight plastic bags for further analysis. One gram (1 g) of sieved sample was quantitatively transferred into a digestion flask with the help of an analytical balance. Twenty milliliters (20 ml) of a ternary acid mixture (HNO_3, H_2SO_4 and $HClO_4$) in the ratio 3:2:1 was added. The soil-acid mixture was digested using a block digester (behrotest® K8) at 200oC for 60 minutes. Acid digestates obtained were filtered into a 100 ml volumetric flask and made to the mark with distilled

water. Acid digestates of sediments were used for color development. One milliliter (1 ml) of digestate was pipetted into a 50 ml volumetric flask containing about 25 ml distilled water. Three drops of p-Nitrophenol solution were added followed by the dropwise addition of 4M NH4OH until the solution turned yellow permanently. Eight milliliters (8 ml) of a solution containing ammonium molybdate [$(NH_4)6Mo_7O_{24}$], antimony potassium tartrate [$K_2Sb_2(C_4H_2O_6)2$], sulfuric acid (H_2SO_4) and ascorbic acid ($C_6H_8O_6$) is added and allowed for a full blue color development.

The concentration of Phosphorus in sample was directly proportional to the intensity of blue color developed. Color intensity (absorbance) was measured using a UV-vis spectrophotometer (Spectroquant Pharo 300) at 720 nm with a pathlength of 16 mm. Absorbances of calibration standards (5, 10, 15, 20, 25 and 30 mg/L) prepared are also measured. This is used to generate a calibration curve of the equation, y = mx + b where, y represents the absorbance and x the concentration in mg/L. By substitution, the unknown value (x; the concentration of P in digestate) is determined by solving for x as; x = (y-b)/m. Values of x obtained (concentration of P in digestate) are used to calculate for the concentration of Phosphorus in the sediment using the following expression:

Total P (mg/kg) =((S-B) ×V)/(m×a)

Where;

S = sample reading (x of sample)

B = blank reading (x of reagent blank)

V = volume of digestate prepared (100 ml)

m = mass of sediment digested (1 g)

a = aliquot of digestate pipetted (1 ml)

Analysis of Total Kjeldahl Nitrogen in Sediment was done using standard methods described by the Food and Agriculture Organization of the United Nations, FAO (2021). One gram (1 g) of air-dried sample ground to pass a 2mm mesh sieved was weighed and transferred into a digestion flask. About 0.2g of catalyst (K_2SO_4 and Selenium powder) was added followed by 20 ml of concentrated sulfuric acid. Sample was heated with a block digester at 430°C for 60 minutes. Samples were allowed to cool, filtered, transferred into a 100 ml volumetric flask and made to the mark with distilled water. Five milliliters (5 ml) of digestate were then transferred into a distillation flask where 5 ml of 40 % w/v NaOH was added. Sample was distilled using a Kjeldahl's distillation unit where ammonia is trapped into a 250 ml conical flask containing 5 ml of 2% boric acid (containing bromocresol green + methyl red indicator). Distillation was done for some few minutes to obtain about 50 ml of distillate.

Distillate obtained was titrated against 0.01 M HCl until an equilibrium is reached. Titre values obtained are used to calculate for the concentration of nitrogen using the following expression:

$$\% N=((T-B) \times N \times 0.014 \times V)/(m \times a) \times 100$$

Where:

T and B = sample and blank titre values obtained respectively

N = molarity of HCl used

V = volume of digestate (100 ml)

m = mass of sample digested

a = aliquot of digestate distilled (5 ml)

3.5 Measurement of Trophic State Indices (TSI)

Carlson's Trophic State Index was employed as a convenient way to quantify the relationship among nutrient levels (measured by total phosphorus), algal biomass (measured by chlorophyll a) and Reservoir clarity (measured by Secchi disk transparency). The index was computed using the relation as developed by Carlson (1977):

TSI (SD) = 10 [6-ln SD/ln 2] …… (1)

TSI (CHL) = 10 [6-(2.04-ln CHL)/ ln 2] …… (2)

TSI (TP) = 14.42 ln (TP) + 4.15 … (3)

The above relations are then simplified into:

TSI (SD) = 60 -14.41 ln (SD; in meters) ……. (4)

TSI (CHL) = 9.81 ln (CHL; µg/L) + 30.6 ……. (5)

TSI (TP) = 14.42 ln (TP; µg/L) + 4.15 ……. (6)

For Chlorophyll-a Analysis, a vacuum pump was set up with a filtering funnel fitted on it. Filtration of the water samples was then done with 12.5cm filter paper which was put into the filtering funnel. The sample bottles were vigorously shaken before the filtration process. A measure of 500ml of the samples from the 3 sampling stations were filtered until the filter paper was stained and no water was visible. The filter papers were then folded and placed into well labelled Petri dishes with tight-fitted lids. The Petri dishes were then wrapped with aluminum foil and stored in the freezer until the time of analysis which was within 14 days of sample collection. For the analysis, the folded filter papers were each put in 15ml test tubes containing 10ml of 96% ethanol. The tubes were capped and wrapped with aluminum foil to protect them from light. The tubes were then

placed in the freezer for 24hrs in order to improve the process of extraction. The tubes were then shaken and the content filtered through a 12.5cm filter paper after the 24hr period had elapsed. This was done to separate the filter paper and other sediments from the extract. The supernatant was then poured into a 1cm path cuvette. The absorption at 750 (A 750), 655 (A 655) and 649 (A 649) nm were measured using a spectrophotometer.

The concentration of chlorophyll-a was computed using the relation:

$$\text{Ch-a } (\mu g/L) = \frac{13.7\,(A\,655 - A\,750) - 5.76\,(A\,649 - A\,750)v}{V * I}$$

v = volume (n^{-1}) of extract

V = volume (L) of sample filtered

I = path of length of spectrophotometer cuvette in cm

Total Phosphorus determination was done by taking an aliquot of the sample containing 1 to 20µg of orthophosphate were pipetted into 50ml volumetric flasks. The pH was then adjusted by adding few drops of P-nitrophenol indicator, then a few drops of 4M NH_4OH until the solution turned yellow. 8ml of reagent B where B was blank reading (x of reagent blank). It was then added and mixed with distilled water until the required volume was obtained. A blank with distilled water and 8ml of reagents B was then prepared. The spectrophotometer was calibrated using P solution as stated below. P standard (Phosphate solution of known concentration) containing 25µg was obtained by pipetting 5ml of the standard P solution (5ppm) into a 50ml volumetric flask. The intensity of the color at the wavelength of 712nm was measured using a standard spectrophotometer.

$$\text{mg P kg}^{-1}\text{ soil} = \frac{\text{Sample Reading} - \text{Blank Reading} \times \text{Volume of extractant}}{\text{Weight of soil} \times \text{Volume of aliquot}}$$

3.6 Estimation of Nutrient Level during the sample period (Av. Nutrient over sampling period per Reservoir volume)

The nutrient level during the sample period was estimated by taking the average of the amount of nutrient (nitrates and orthophosphate) recorded along the depth profile and across each month in each sample point.

Estimation of Nitrates Level

Average of Nitrates ($NO_3 - N$) over sample period (mg/L) =

$$\frac{\text{Sum of means of } (NO3 - N) \text{ of every month along the depth profile (mg/L)}}{\text{Number of Months}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Nitrates Level over sample period per Reservoir volume (mg)

= Average Nitrates Level over Sample Period (mg/L) × estimated volume of Reservoir (L) …. (2)

Estimation of Orthophosphate Level

Average of Orthophosphates (PO_4^{3-}- P) over sample period (mg/L) =

$$\frac{\text{Sum of means of } (PO43-- P) \text{ of every month along the depth profile (mg/L)}}{\text{Number of Months}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Orthophosphates Level over sample period per Reservoir volume (mg)

= Average Orthophosphate Level over Sample Period (mg/L) × estimated volume of Reservoir (L) ……. (2)

3.7 Algal Species Composition

Depth integrated phytoplankton samples were taken at each of the 3 sample sites. The samples were uniform mixtures of water in the mixed layer to the lower limit of the photic zone as determined by Secchi disk. Samples were taken in the months of June and October, with June representing the wet season and October, the dry season.

A millilitre of Acid-Lugol's solution was added immediately, on site to 25ml of each sample. The Lugol's solution enters the phytoplankton cell more quickly, leaving the organisms better preserved in the sample. The iodine increases the specific weight of the cell resulting in faster settling. Again, the solution was used because it makes detection of the phytoplankton easier by enhancing the contrast between the organisms and the surrounding fluid. The iodine stains the starch aiding recognition of algal groups such as Chlorophyta which use this as a storage compound. The samples were placed on ice soon after collection and transported to the MPhil Laboratory of the Department of Marine and Fisheries Sciences within 24 hours of collection where identification was done.

The Utermöhl method for analysis was adopted in this study for analyzing the phytoplankton samples collected. The method assumes that there is a Poisson distribution of the cells within the counting chamber and relies on the sedimentation of aliquots of water samples in the counting chambers (Edler & Elbrächter, 2010). For 24 hours, the inverted microscope and other equipment (such as sedimentation chambers) were allowed to acclimate to the same room temperature (Brierley *et, al.*, 2007). This facilitates the dispersal of the algal cells in the sedimentation chambers in a random manner. In the sedimentation chambers, it also lessens the development of convection currents and air bubbles (Edler & Elbrächter, 2010). The samples were gently shaken by a combination of alternate horizontal rolling and vertical tumbling of the sample bottles to allow the

contents to be homogenously mixed (Brierley *et, al.*, 2007). The homogenous mixing was done to allow random distribution to be achieved in the settling chambers when aliquots are transferred. After homogenous mixing, aliquots of 1 ml were taken from the samples and transferred into 25 mL Hydro-Bios Kiel plankton chambers and diluted with 24 mL of distilled water for microscopic study. Care was taken during the transfer to help attain random distribution of the algal cells. The chambers were closed with thick cover slips to prevent the formation of air bubbles within them. Sedimentation was carried out in the counting chambers with a settling time of four hours per cm height of the chamber. The sedimentation chambers were placed on a flat horizontal surface away from intense vibration, light and heat sources as suggested by Brierley *et, al.* (2007).

Identification of phytoplankton taxa was done with the aid of the BDS 300 inverted microscope located in the MPhil Laboratory of the Department of Marine and Fisheries Sciences. The BDS 300 inverted microscope has an objective system for magnification from x100 to x400.

Appropriate literature including Bellinger & Sigee (2010), APHA (1992) and http://www.algaebase.org/ were employed to help with the identification of the phytoplankton taxa.

3.8 Data Analysis

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

Stata software version 11 was used in the determination of statistical differences between the physicochemical parameters between the months and along the depth profile. A significance level

of 0.05 was used for this study. Analysis of Variance (ANOVA), was used to establish whether stratification is significant with respect to depth and Multiple Comparisons Test (MCT) was used to establish significance among the individual depths.

4.0 RESULTS

4.1 Morphometric Characterization

4.1.1 Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) was used to determine the deepest and shallowest portions of the Reservoir. As shown in Figure 4.1, the deep regions of the Reservoir were represented by the red and yellow colors while the shallow represented by the green and blue colors. The deep red color indicated the deepest region while the deep blue region indicated the shallowest region. The depth ranges from shallowest to deepest as determined by the DEM was from 0.03m to 8.47m.

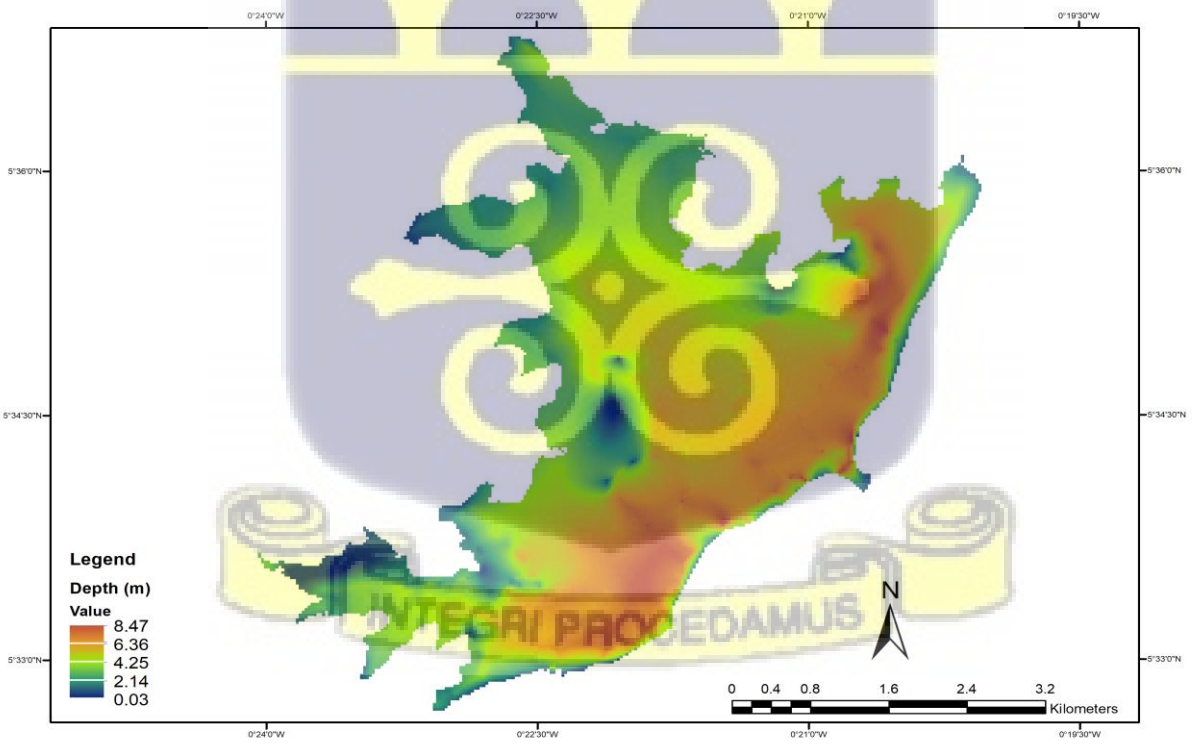

Figure 3.1 *Digital elevation model of Weija Reservoir*

4.1.2 Depth, Volume and Other Morphometric Parameters

Based on the DEM, the maximum depth of the Reservoir was determined to be 8.47m. The mean depth was determined to be 4.88m. The surface area and the volume of the Reservoir were 19,330,988.38m^2 (19.33km^2) and 96,900,899.14m^3 (9.69×10^{10}L) respectively.

The shoreline length was determined to be 24200m (24.2km). Shoreline length is significant because it quantifies the amount of interaction between a body of water and the surrounding land. Therefore, with a shoreline of 24200m, it can be inferred that there is a lot shoreline for occurrence of human activities for example, building of settlements which exposes the shoreline to erosion and the Reservoir to external nutrient loading and increased rate of evaporation during high temperatures due to the removal of vegetation which has a shading effect. Per this, the quality and quantity are at risk.

The shoreline development was determined to be 1.55. Shoreline development is the ratio of the length of the shoreline to the circumference of a circle whose area is equal to that of the lake. A perfect circle has a shoreline development value of 1.0. As per the value obtained, it can be deduced that since, it deviates from 1 and is irregular to some extent, there is more shoreline for available for the building of houses and also an increased exposure to shoreline erosion. With this, the Reservoir is susceptible to an increase in the productivity of the lake which would eutrophication in the long run.

4.2 Physico-Chemical Characterization

4.2.1 Water Samples (Mixed Layer)

Temperature Variation in the Mixed Layer over the 6-Month Study Period

The results obtained are presented in Figure 4.2. The readings varied between a minimum of 26.06°C to a maximum of 29.77°C. There were slight variations in the water temperatures recorded at the various sites during the study period. Temperature was highest in October across all the sample sites while in August; the lowest temperature values was recorded. Figure 4.2 shows the temperature variations at the sites over the study period.

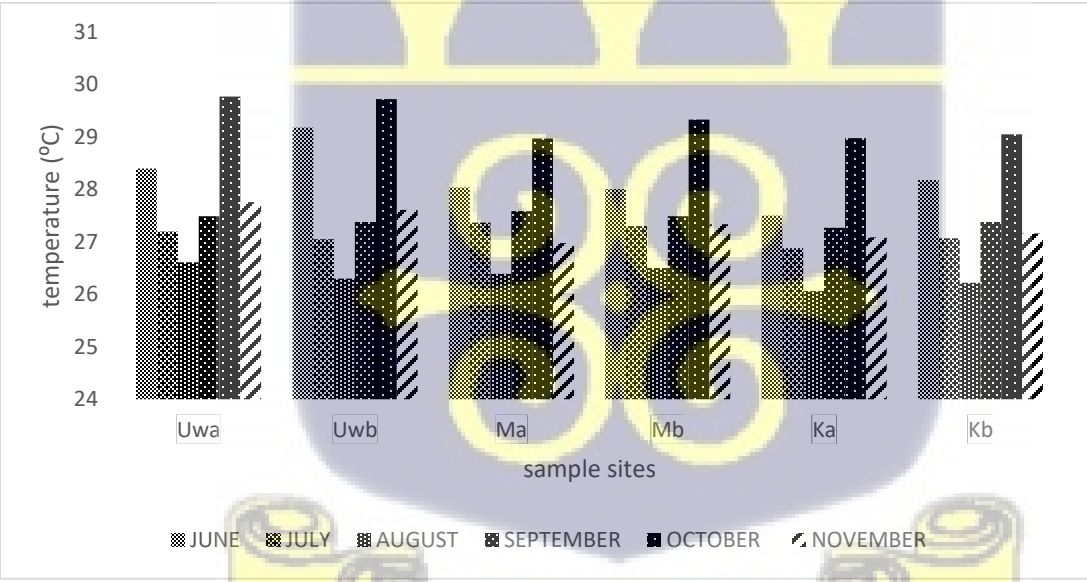

Figure 4.2 *Temperature variation in the mixed layer over the 6-month study period*

DO Variation in the Mixed Layer over the 6-Month Study Period

Results obtained for dissolved oxygen concentrations over the study period are shown in Figure 4.3 The mean values of DO record varied from a minimum 2.63 mg/L at Machigani Point B (Mb) in June to a maximum of 9.47 mg/L at Upper Weija Point A (UWa) in the month of September.

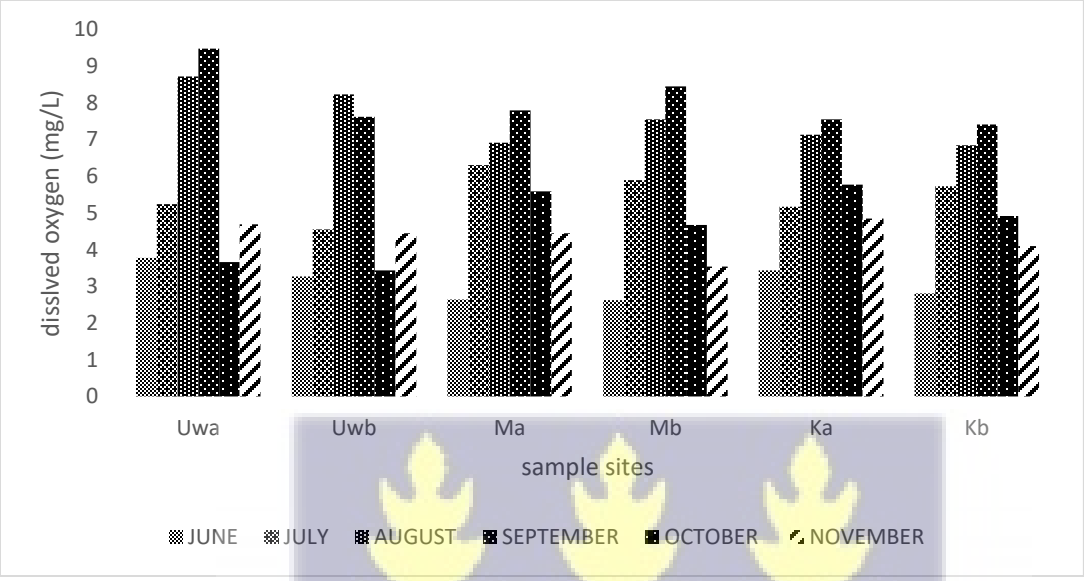

Figure 4.3 *DO Variation in the mixed layer over the 6-month study period*

Electrical Conductivity (E.C) Variation in the Mixed Layer over the 6-Month Study Period

Results obtained for electrical conductivity over the study period are shown in Figure 4.4 From June to November, conductivity levels fluctuated between a minimum of 296 µS/cm in October at Upper Weija Point B (UWb) and a maximum of 514 µS/cm in June at Kalabule Dam Point A (Ka). Averagely June recorded the highest E.C values while October recorded the lowest.

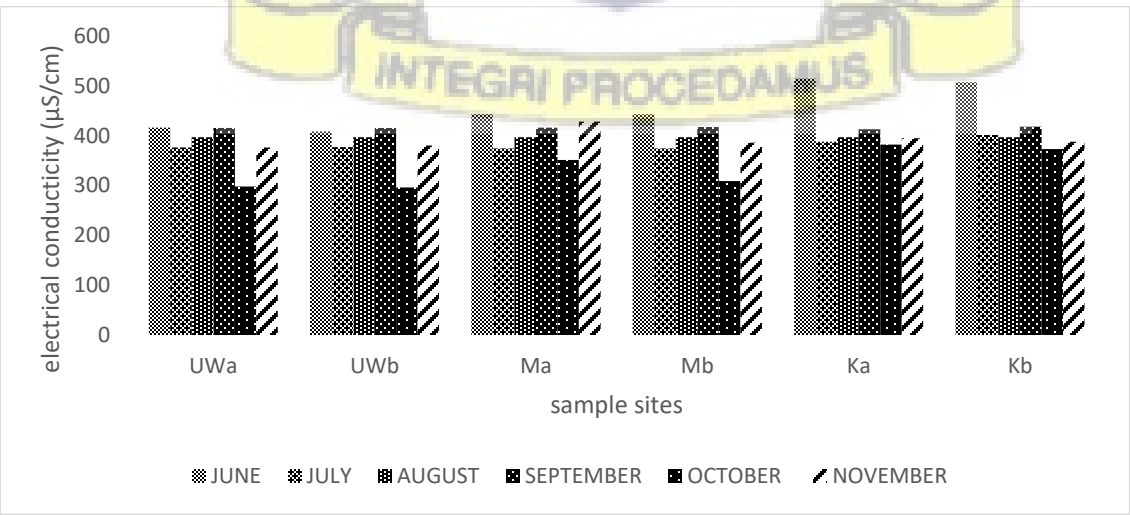

Figure 4.4 *E.C Variation in the mixed layer over the 6-month study period*

Salinity Variation in the Mixed Layer over the 6-Month Study Period

Results obtained for salinity over the study period are shown in Figure 4.5. It was observed that salinity remained constant with a value of 0.2ppt over the entire study period with the only exceptions being the month of October at Upper Weija Points A and B (UWa & UWb) and Machigani Point b (Mb) with a value of 0.1ppt

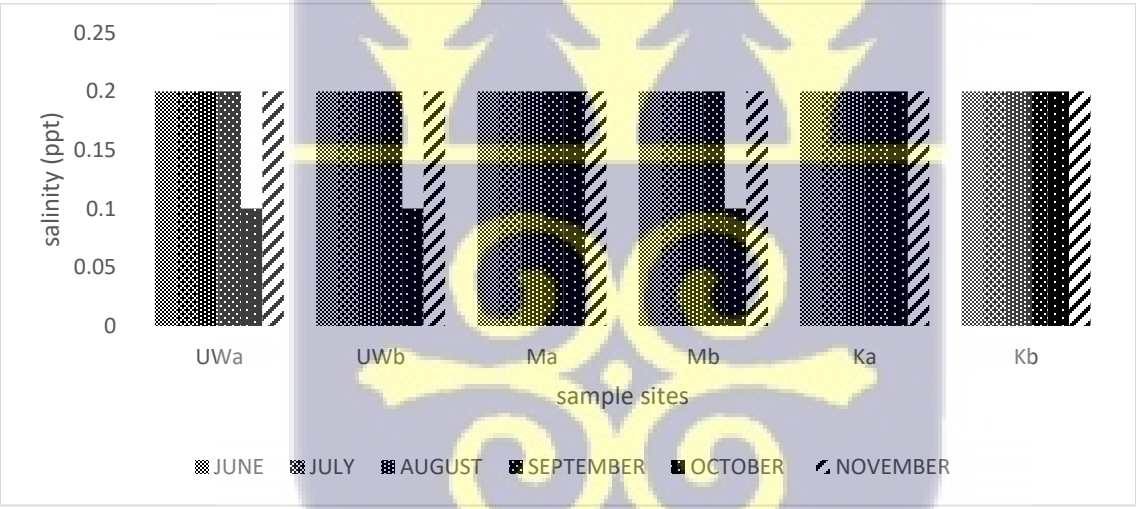

Figure 4.5 *Salinity variation in the mixed layer over the 6-month study period*

pH Variation in the Mixed Layer over the 6-Month Study Period

The pH values of water from the various sites are presented in Figure 4.6. The values ranged from a minimum of 2.63 Mb in June to a maximum of 8.91 at UWb in July. The least values of 2.64 and 2.63 were recorded at Ma and Mb in the month of June. This indicates that the water was highly acidic during that period.

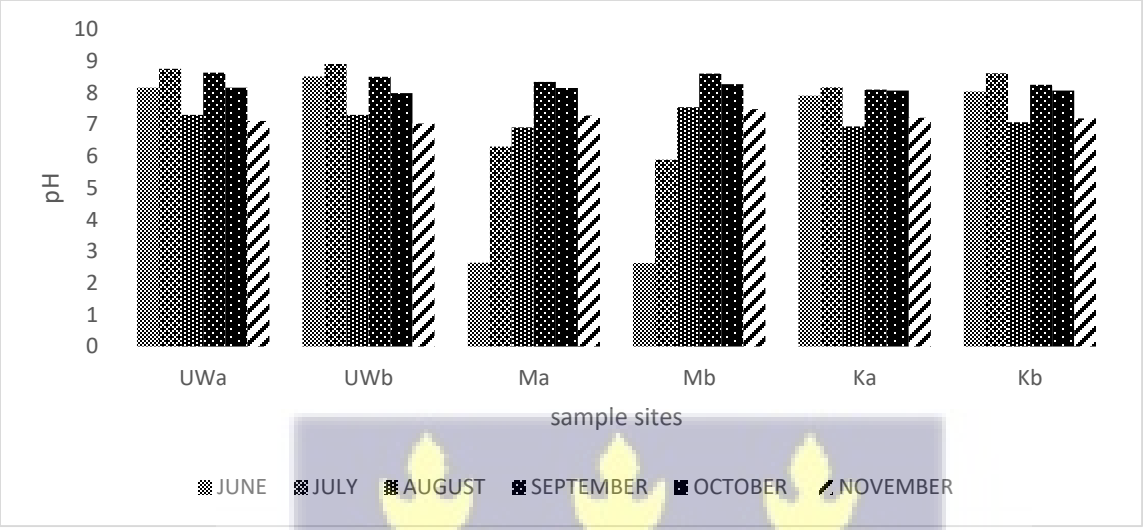

Figure 4.6 *pH variation in the mixed layer over the 6-month study period*

Total Dissolved Solids (TDS) Variation in the Mixed Layer over the 6-Month Study Period

Results for TDS measured over the period are shown in Figure 4.7. The values ranged from a minimum of 175 mg/L at UWb in November to a maximum of 329 mg/L at Ka in June. Other than these, all the other sites had moderate Total Dissolved Solids concentrations.

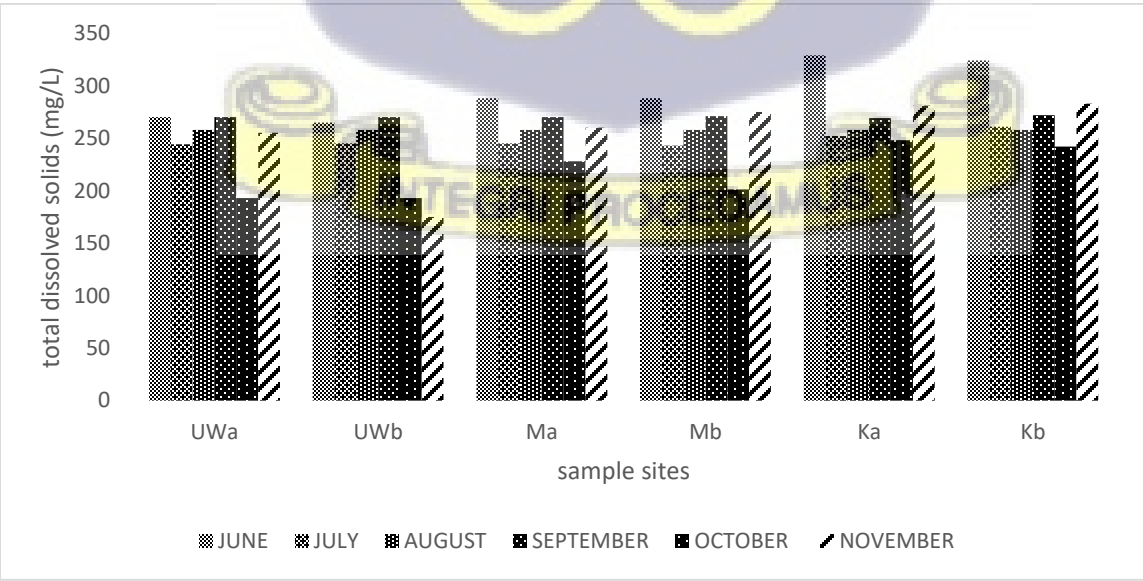

Figure 4.7 *Total Dissolved Solids (TDS) variation in the mixed layer over the 6-month study period*

Turbidity Variation in the Mixed Layer over the 6-Month Study Period

Figure 4.8 shows turbidity values obtained. The values were generally low ranging from 6.05 NTU at UWb in July to a maximum of 14.08 NTU at Ma in August. The other sites had similar mean turbidity readings. Averagely, Ma recorded the highest turbidity values over the study period.

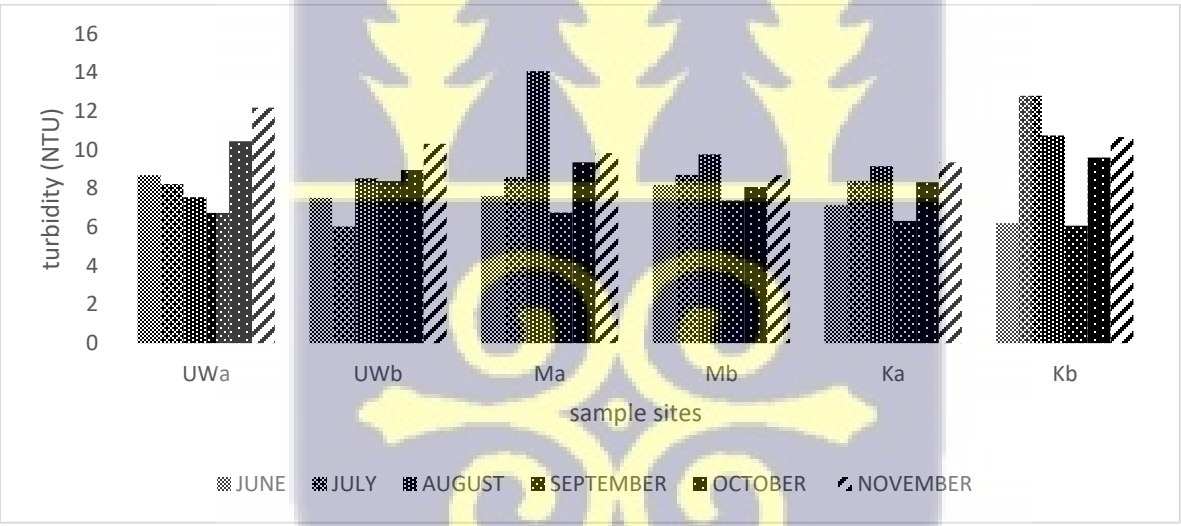

Figure 4.8 *Turbidity variation in the mixed layer over the 6-month study period*

Orthophosphate Variation in the Mixed Layer over the 6-Month Study Period

Results obtained are presented in Figure 4.9. The values were generally high, all above the natural background levels of freshwater bodies (i.e., 0.02 mg/L) with the exception of Kb in the month of September with concentration of 0.02mg/L. The values recorded ranged from a minimum of 0.02 mg/L at Kb in September to a maximum of 0.18 mg/L at UWb in September as well.

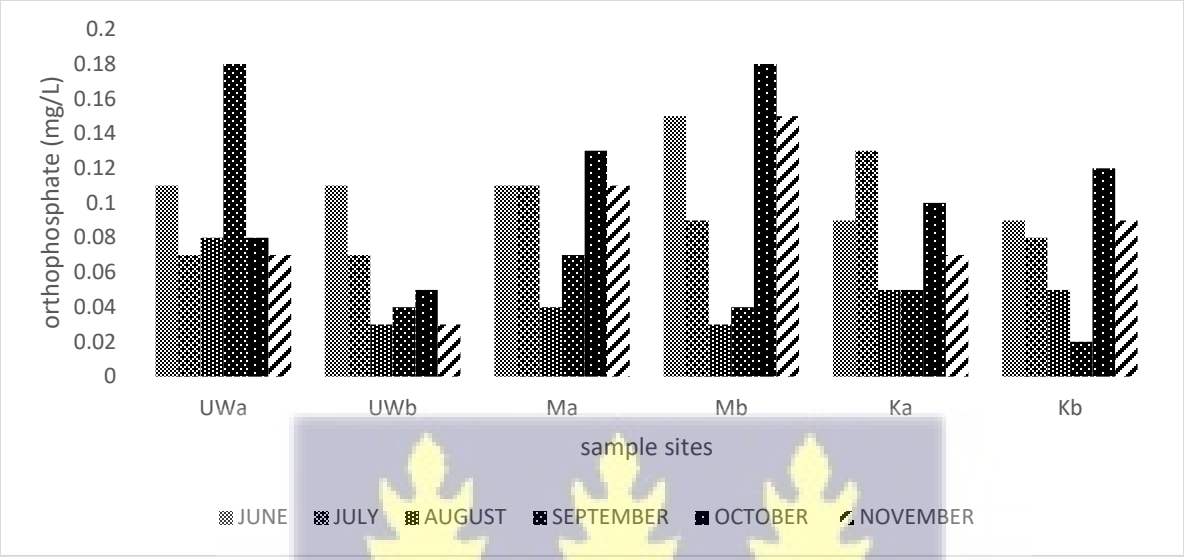

Figure 4.9 *Orthophosphate variation in the mixed layer over the 6-month study period*

Nitrate Variation in the Mixed Layer over the 6-Month Study Period

Nitrate results obtained in the water the study is presented in Figure 4.10. The values ranged from a minimum of 59.58 mg/L at UWb in August to a maximum of 147.22 mg/L at UWa in November. There was no clear trend in the concentrations obtained at the various sites. However, the recorded concentrations were very high.

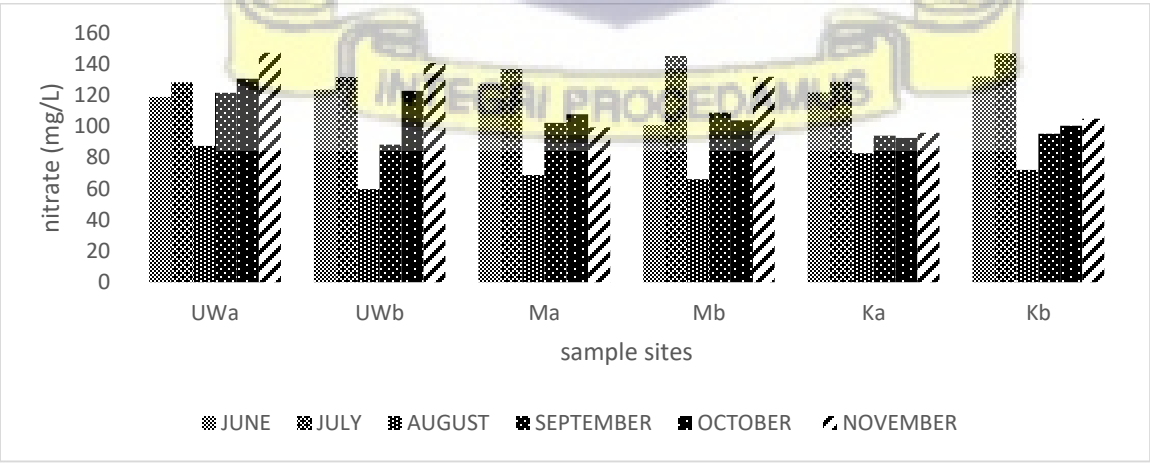

Figure 4.10 *Nitrate variation in the mixed layer over the 6-month study period*

4.2.2 Water Samples (Depth Profile)

Temperature Variation Along a Depth Profile

Temperature Variation in Upper Weija Point A (UWa)

In this research, water temperature in Upper Weija Point A (UWa) varied across the months at each depth. From Figure 4.11 October recorded the highest temperature along the depth profile from 0m to 6m. On the other hand, the month of August recorded the least temperature across the depth profile. The highest temperature recorded in June was 29.81°C at a depth of 1m while the lowest was 29.24°C recorded at 6m. The second highest recorded along the depth profile was June, followed by November, September then July.

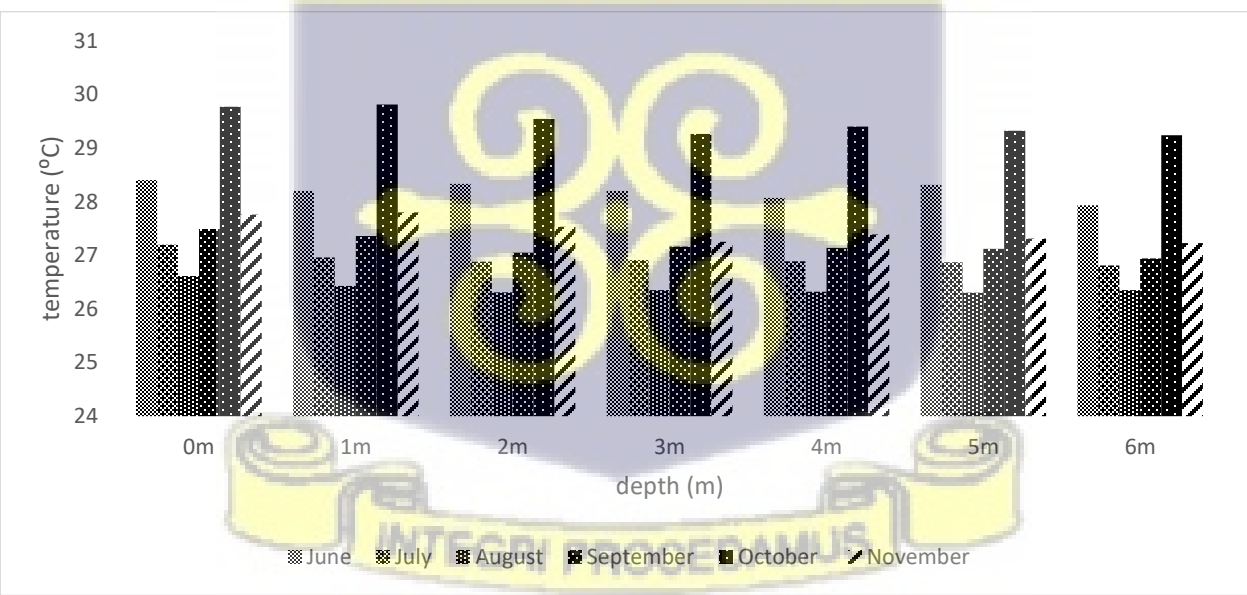

Figure 4.11 *Temperature variation in Upper Weija point A (UWa)*

Temperature Variation in Upper Weija Point B

Temperature in Upper Weija Point B (UWb) varied across the months at each depth. From Figure 4.12 October recorded the highest temperature along the depth profile from 0m to 6m just like

UWa. On the other hand, the month of August recorded the least temperature across the depth profile. The highest temperature recorded in June was 29.72°C at the water surface (0m) while the lowest was 29.17°C recorded at 5m. The second highest recorded along the depth profile was June, followed by November, September then July. The only difference was that, at 3m, July recorded a higher temperature than September even though the temperature difference was small.

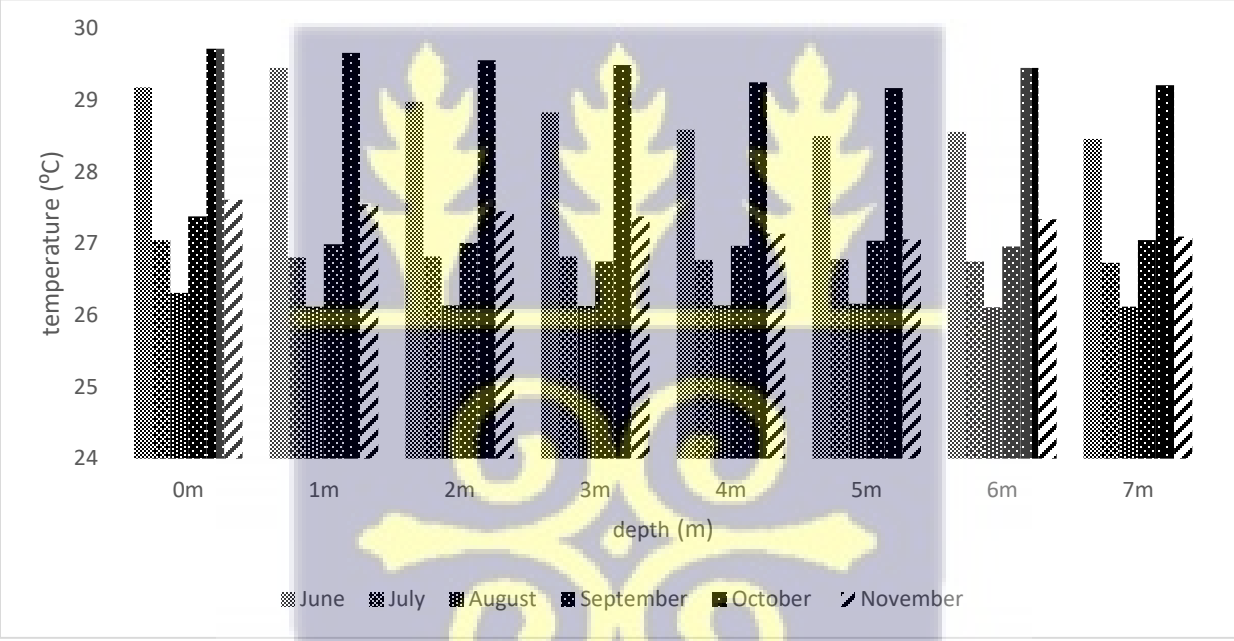

Figure 4.12 *Temperature variation in Upper Weija point B (UWb)*

Temperature Variation in Machigani Point A (Ma)

Temperature in Machigani (Ma) varied across the months at each depth. From Figure 4.13, it was observed that, generally the temperatures were quite high as compared to Upper Weija. October and June recorded the highest and 2nd highest temperature along the depth profile respectively. The month of August recorded the least temperature along the depth profile with the exception of the

4m depth where November recorded the lowest. The highest temperature recorded in June was 28.97°C at the water surface while the lowest was 28.27°C recorded at 6m.

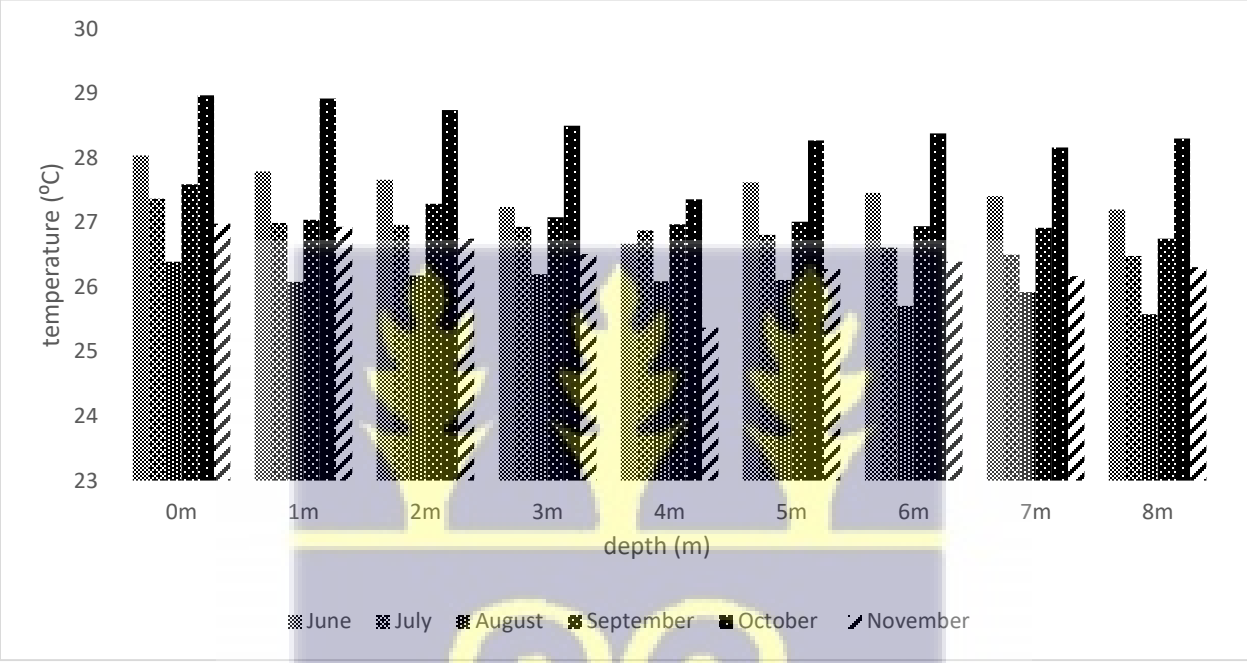

Figure 4.13 *Temperature variation in Machigani point A (Ma)*

Temperature Variation in Machigani (Point B)

During the study period, temperature in Machigani (Mb) varied across the months at each depth. From Figure 4.14, it was observed that, generally the temperatures were quite high as compared to Upper Weija. October and June recorded the highest and 2nd highest temperature along the depth profile respectively. The month of August recorded the least temperature along the depth profile with the exception of the 4m depth where November recorded the lowest. The highest temperature recorded in June was 29.41°C at the 1m depth while the lowest was 28.48°C recorded at 7m.

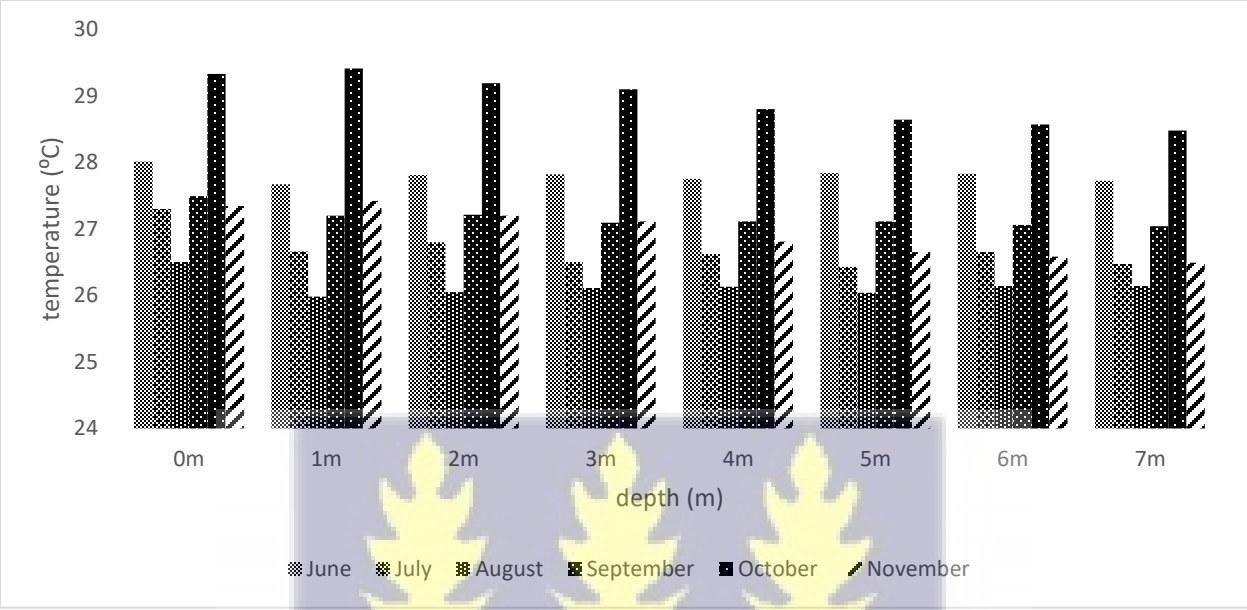

Figure 4.14 *Temperature variation in Machigani point B (Mb)*

Temperature Variation in Kalabule Dam Point A (Ka)

Temperature in Kalabule Dam (Ka) varied across the months at each depth. October and June recorded the highest and 2nd highest temperature along the depth profile respectively. The month of August recorded the least temperature along the depth profile. The highest temperature recorded in June was 28.98°C at the water surface while the lowest was 28.07°C recorded at 4m as shown in Figure 4.15.

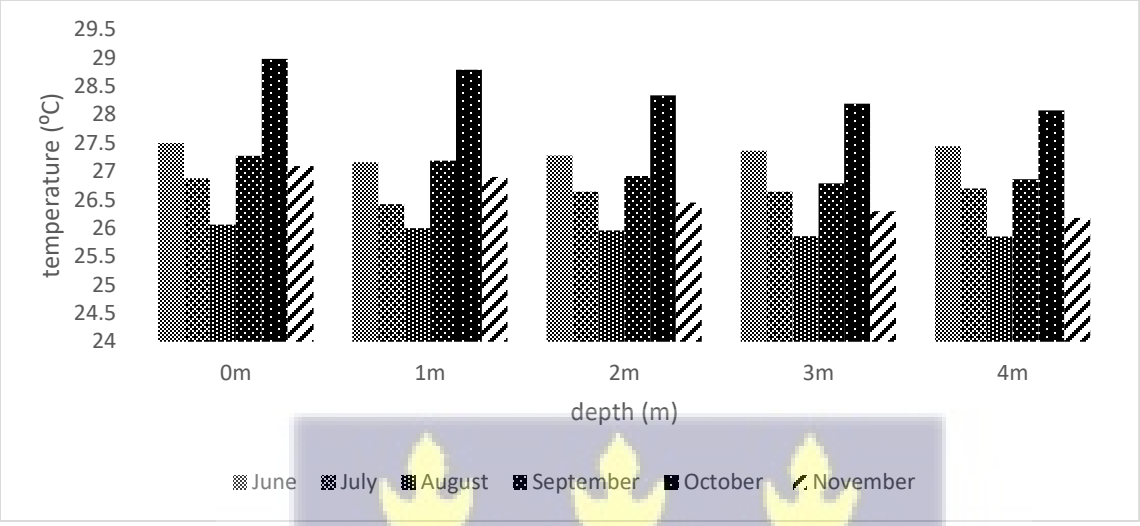

Figure 4.15 *Temperature variation in Kalabule Dam point A (Ka)*

Temperature Variation in Kalabule Dam Point B (Kb)

Temperature in Kalabule Dam (Kb) varied across the months at each depth as shown in Figure 4.16. Another observation was that there was a steady drop in temperature for every month along the depth profile. October and June recorded the highest and 2nd highest temperature along the depth profile respectively with September and July following closely. The month of August recorded the least temperature along the depth profile. The highest temperature recorded was 29.05°C in the month of June at the water surface while the lowest was 25.75°C recorded at 6m in the month of August.

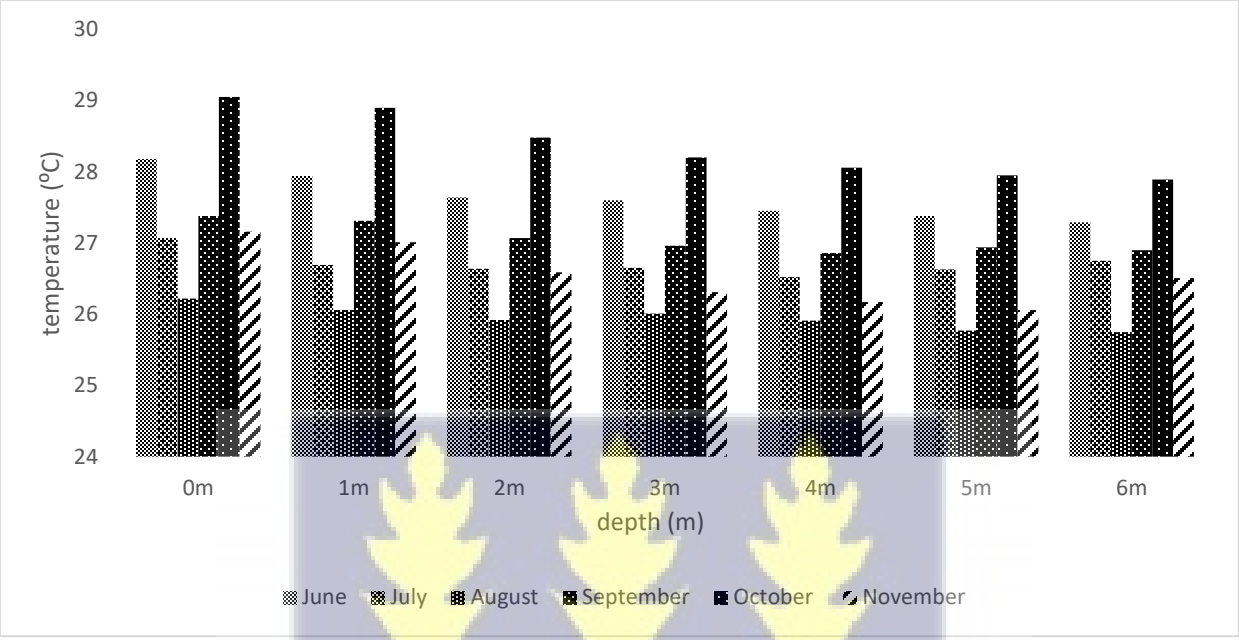

Figure 4.16 *Temperature variation in Kalabule Dam point B (Kb)*

Dissolved Oxygen (DO) Variation along a Depth Profile

DO Variation in Upper Weija Point A (UWa)

Figure 4.17 shows the DO variation along the depth profile of Upper Weija point A (UWa). The highest DO value of 9.47mg/L was recorded at the surface in September. There was a steady decrease along the profile till the 4m depth where another increase occurred, from 5.15mg/L to 5.32mg/L. August the recorded the 2nd highest values along the profile followed by November, October, July and June with the exception of the surface (0m) where July recorded the 3rd highest value with 5.24mg/L.

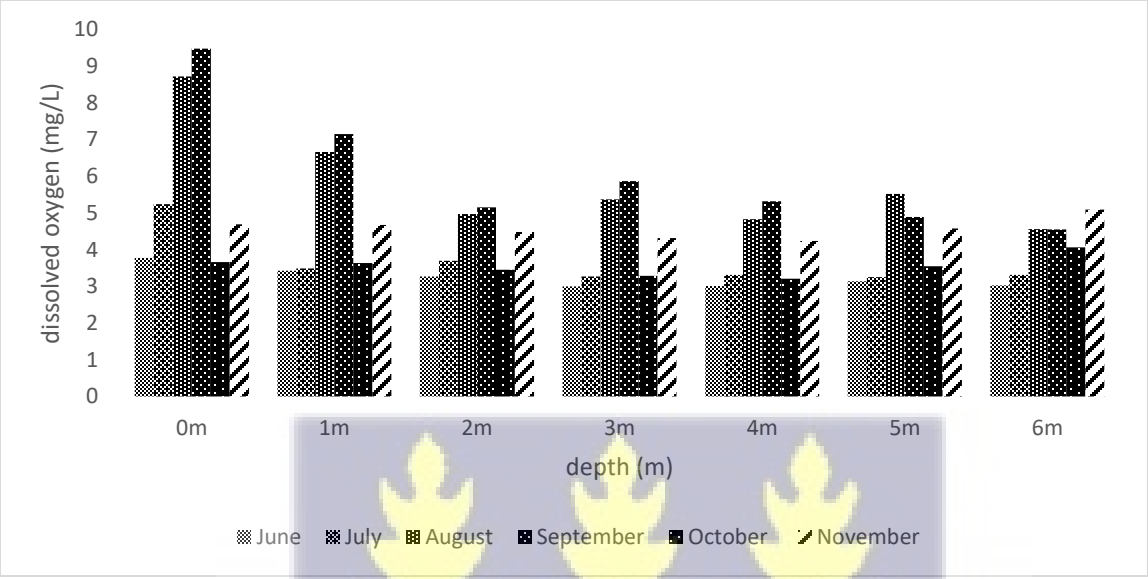

Figure 4.17 *DO variation in Upper Weija point A (UWa)*

DO Variation in Upper Weija Point B (UWb)

Figure 4.18 shows the DO variation in Upper Weija point B (UWb) along the depth profile over the 6-month study period. August recorded the highest DO level of 8.23mg/L at 0m. August remained the highest recording along the depth profile. The lowest value recorded was 2.23mg/L in the month of September at 7m. It was observed that the levels of DO kept fluctuating along the depth profile across all months. None of the months neither recorded a steady increase nor decrease in the DO levels along the depth profile.

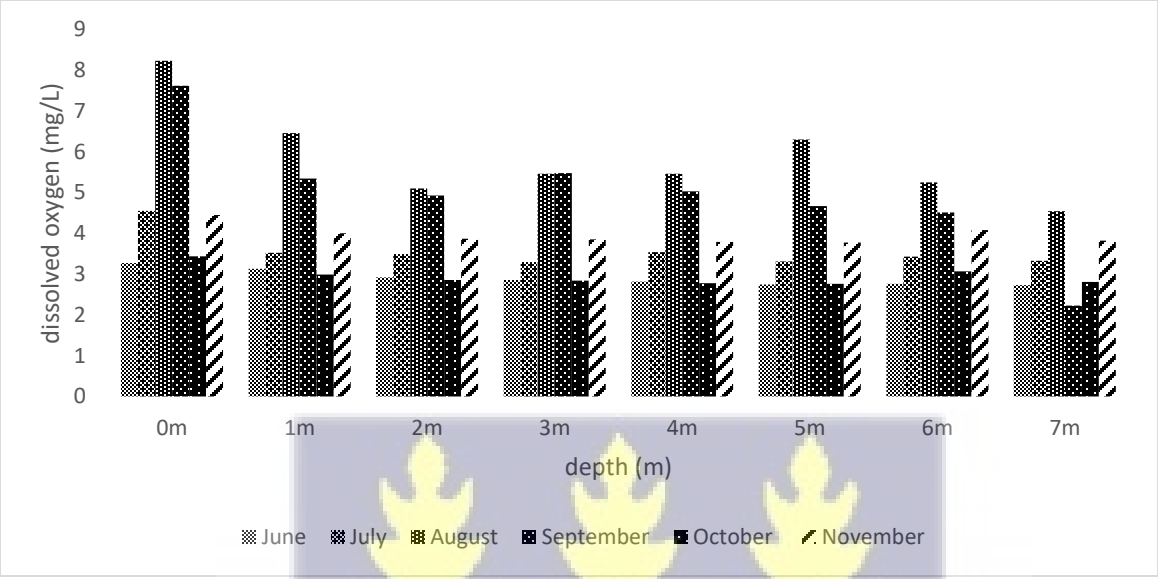

Figure 4.18 *DO variation in Upper Weija point B (UWb)*

DO Variation in Machigani Point A (Ma)

Figure 4.19 shows the variation of DO along the depth profile of Machigani point A (Ma). For the month of June, the values recorded remained within a range of 2.46mg/L and 2.71mg/L at 7m and 8m respectively. Only the month of July maintained a steady decrease in DO levels from 6.3mg/L at 0m, the highest in the month to 2.76mg/L at 8m. The levels within the months were not uniform, they were fluctuating along the profile.

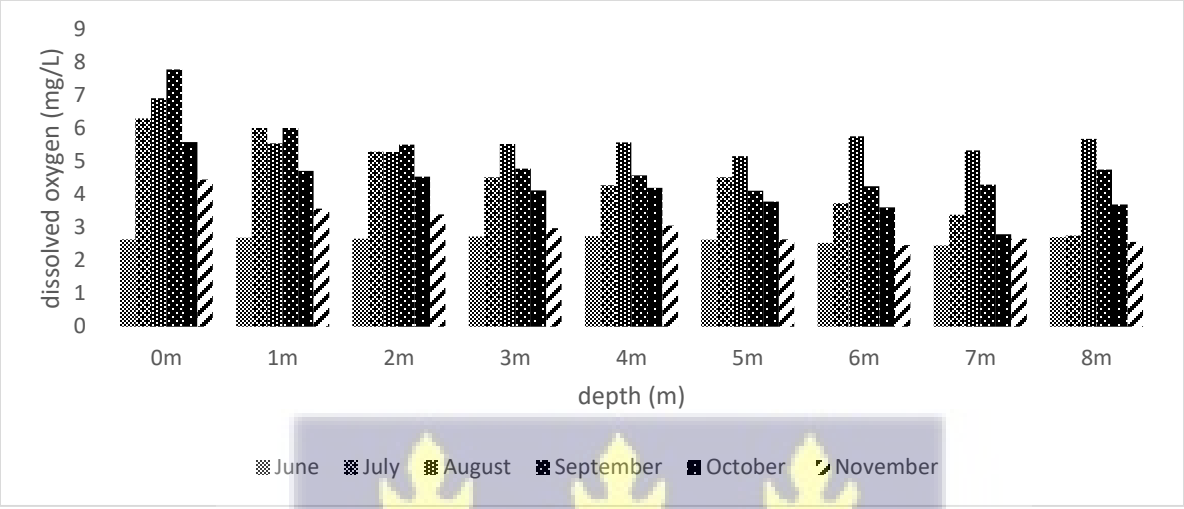

Figure 4.19 *DO variation in Machigani point A (Ma)*

DO Variation in Machigani Point B (Mb)

Figure 4.20 shows the DO variation across the 6-month study period in Machigani point B (Mb). The highest DO recorded was in the month of September with 8.45mg/L at 0m while the lowest recorded was 1.51mg/L in November at 7m. Variations in the DO values for the month of June were small. The range was between 2.46mg/L at 7m and 2.64mg/L at 1m. With the exception of October and November that had a steady decrease along the depth profile, the values recorded in the other months were fluctuating along the profile.

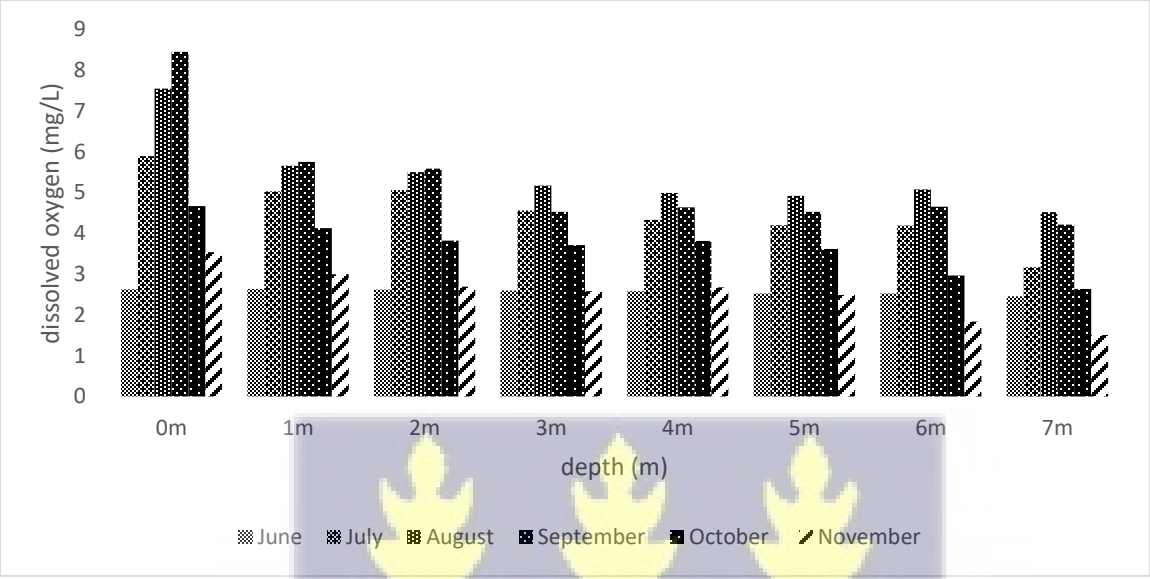

Figure 4.20 *DO variation in Machigani point B (Mb)*

DO Variation in Kalabule Dam Point A (Ka)

Figure 4.21 shows the DO variation in Kalabule Dam point A (Ka). Generally, across all the months with the exception of August and September, the deeper along the depth profile, the lower the DO value. August and September gradually decreased until the 3m depth where increases were observed. September recorded the highest value of 7.55mg/L while November recorded the lowest value of 2.35mg/L

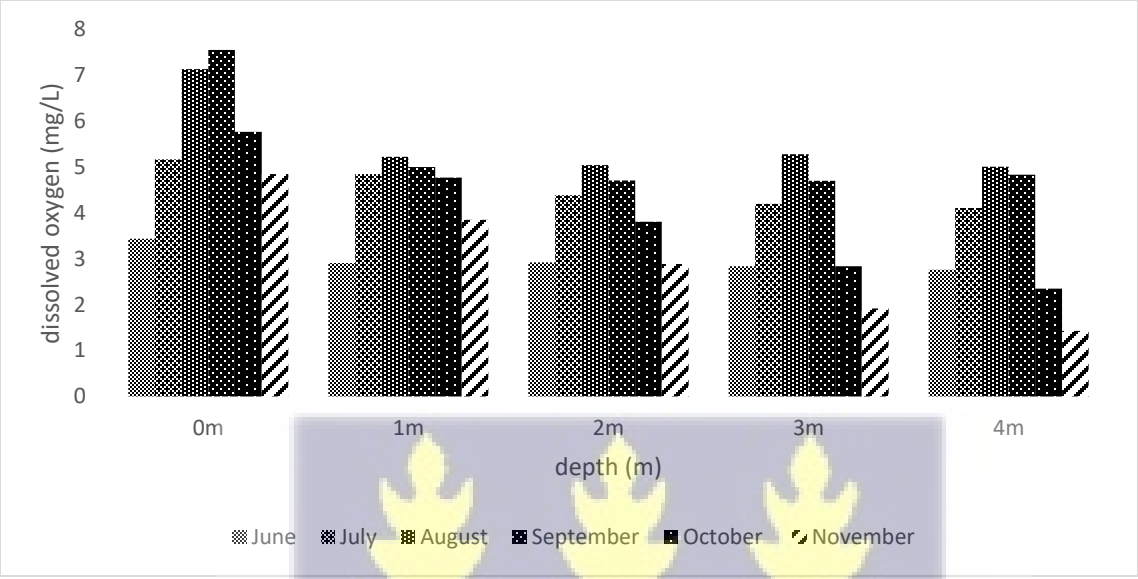

Figure 4.21 *DO variation in Kalabule Dam point A (Ka)*

DO Variation in Kalabule Dam Point B (Kb)

Figure 4.22 shows the DO variation in Kalabule Dam point B (Kb). At depths 0m and 6m, September recorded the highest DO values of 7.41mg/L and 4.73mg/L respectively. August was in a range from 4.33mg/L to 6.84mg/L at depths 6m and 0m respectively. It was also observed that the decrease along the depth profile in August steady from 1m to 6m with the exception of 0m to 1m which showed a sharp decrease from 6.84mg/L to 5.36mg/L. The month of October also showed a steady decrease from 0m to 6m. July showed a different pattern where there was a decrease from 5.73mg/L at 0m to 4.95mg/L and 4.24mg/L at 1m and 2m respectively till the 3m depth with corresponding DO of 4.17mg/L. From depths 4m to 6m, slight increases are recorded from 4.24mg/L to 4.33mg/L and finally to 4.39mg/L.

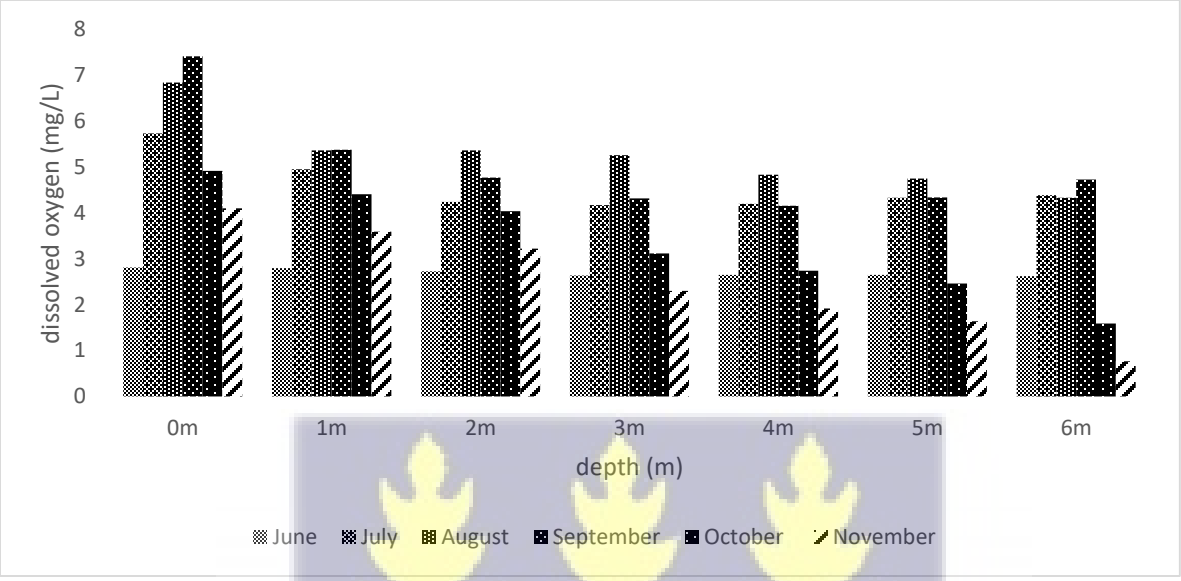

Figure 4.22 *DO variation in Kalabule Dam point B (Kb)*

Comparison of Average Temperature and Average DO over the 6-Month Period

Figure 4.23 shows the comparison of the average temperature and the average DO over the six-month study period. From the depth of 0m to 8m, the average temperature had a range of 26.77 ºC to 27.63 ºC. The average temperature at a depth of 0m had a steady decrease continually to 4m a sharp increase at 5m which decreased at a steady rate to 8m depth. DO was observed to have had a steady decrease from 0m to 7m then a sharp increase at 8m.

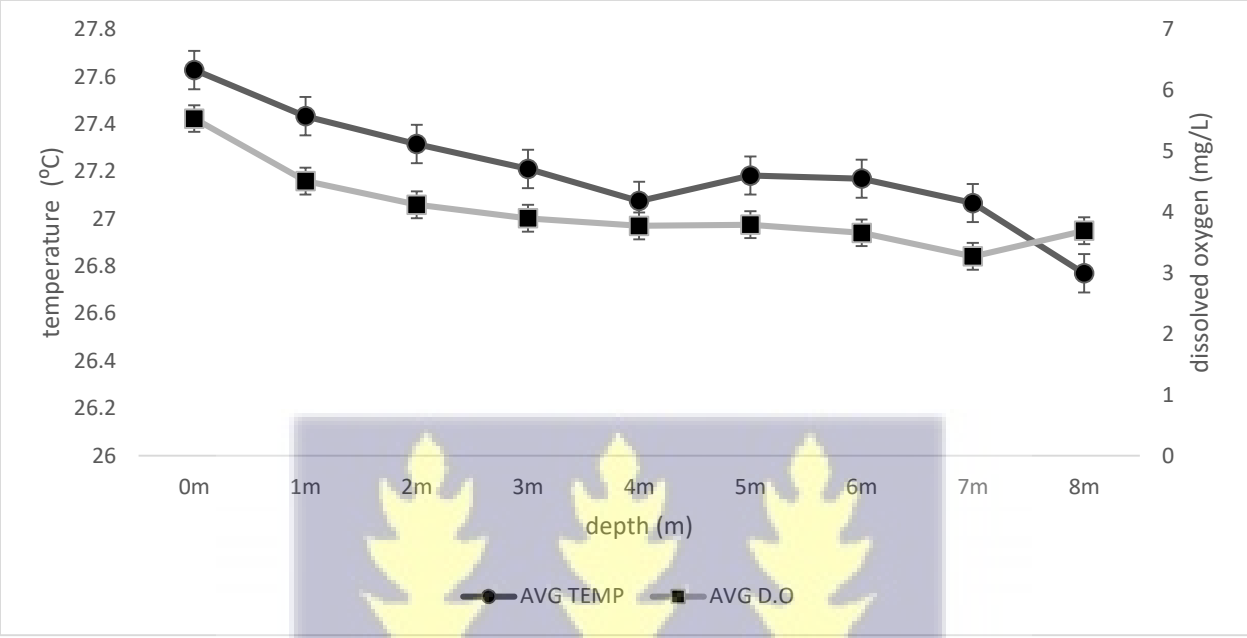

Figure 4.23 *Comparison of average temperature and average DO over the 6-month period along the depth profile across the six (6) sampling sites*

Electrical Conductivity along a Depth Profile

Appendix 1 shows the Electrical Conductivity Variations along the Depth Profile of Sample Points A & B of Upper Weija over the 6-month Study Period. In June, the highest E.C. values of 426 µS/cm and 421µS/cm were recorded at deepest areas of both UWa and UWb, at 6m and 7m respectively. The differences in the KKB E.C values were very minimal with respect to depth at the sample locations. This was not the case for the sample months. The lowest E.C value recorded was 296 µS/cm in the month of October at 2m and 0m depths at Upper Weija Points A (UWa) and B (UWb) respectively.

Appendix 2 shows the Electrical Conductivity Variations along the Depth Profile of Sample Points A & B of Machigani over the 6-month study period. In June, the highest E. C. values of 492 µS/cm and 475 µS/cm were recorded at deepest areas of both Ma and Mb, at 7m and 8m respectively. The differences in the E.C values were very minimal with respect to depth at the sample locations. The lowest E.C value recorded was 334 uS/cm in the month of October at 3m depths at Machigani A (UWa) and 309 µS/cm at 2m and 3m at Machigani B (UWb) respectively.

Appendix 3 shows the Electrical Conductivity Variations along the Depth Profile of Sample Points A & B of Kalabule dam over the 6-month Study Period. In June, the highest E. C. values of 516 µS /cm and 507 µS /cm were recorded at 4m at Ka and 0m at Kb. The other months had a range of 252 µS/cm to 473 µS/cm. The lowest E.C value recorded was 252 µS/cm in the month of October at 4m depths at Kalabule Dam Point A (Ka) and 342 µS /cm at 3m at Kalabule Dam Point B (Kb).

Salinity along a Depth Profile

Appendix 4 shows the salinity variations along the Depth Profile of Sample Points A & B of Upper Weija over the 6-month Study Period. Salinity values in all the months were 0.20ppt at both points (UWa) and (UWb) from depths 0m 6m and 0m to 4m respectively with the exception of the month of October which had a value of 0.10ppt at both points (UWa) and (UWb) from depths 0m 6m and 0m to 4m respectively.

Appendix 5 shows the salinity variations along the Depth Profile of Sample Points A & B of Machigani over the 6-month Study Period. Salinity values in all the months were 0.20ppt at both points (Ka) and (Kb) from depths 0m to 8m and 0m to 3m respectively with the exception of the month of October at point B (Kb) which had the highest value of 0.20ppt at depths 0m to 4m and the lowest value of 0.10ppt at 5m to 7m.

Appendix 6 shows the salinity variations along the Depth Profile of Sample Points A & B of Kalabule over the 6-month Study Period. The salinity values in all the months were 0.20ppt at both points A (Ka) and B (Kb) from depths 0m to 4m and 0m to 6m respectively.

Generally, there were no significant changes in these parameters with depth suggesting that there is no chemocline and stratification not induced by salinity changes and changes in electrical conductivity.

pH Along a Depth Profile

Table 4.1 shows the pH variations along the Depth Profile of Sample Points A & B of Upper Weija over the 6-month Study Period. The highest pH value was recorded in July at points A (UWa) and B (UWb) with a value of 8.91 and 8.97 at 6m and 1m respectively. The lowest pH value was recorded in November at both points A (UWa) and B (UWb) with a value of 7.01 and 7.03 at 5m and 0m respectively. The pH was generally between the acceptable ranges (6.5-8.5) per WHO standards with July being the exception with values slightly above the range.

Table 4.1 **pH Variations along the depth profile of sample points A & B of Upper Weija over the 6-month study period**

		Upper Weija					
		June	**July**	**August**	**September**	**October**	**November**
	Depth (m)	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
UWa	**0**	8.16±0.01	8.76±0.01	7.30±0.01	8.63±0.01	8.16±0.01	7.11±0.01
	1	8.19±0.01	8.83±0.01	7.27±0.01	8.60±0.01	8.19±0.01	7.14±0.013
	2	8.21±0.01	8.85±0.01	7.21±0.01	8.54±0.01	8.19±0.01	7.14±0.02
	3	8.10±0.01	8.87±0.01	7.17±0.01	8.51±0.01	8.17±0.01	7.12±0.01
	4	8.04±0.01	8.88±0.01	7.14±0.02	8.49±0.01	8.10±0.01	7.05±0.01
	5	8.19±0.01	8.89±0.02	7.11±0.01	8.47±0.01	8.06±0.01	7.01±0.01
	6	8.11±0.01	8.91±0.01	7.07±0.01	8.46±0.01	8.13±0.01	7.08±0.01
	Depth (m)	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
UWb	**0**	8.51±0.02	8.91±0.05	7.30±0.04	8.50±0.04	7.99±0.03	7.03±0.03
	1	7.98±0.03	8.97±0.05	7.21±0.04	8.57±0.04	8.02±0.03	7.06±0.03

	2	8.48±0.02	8.95±0.05	7.16±0.04	8.52±0.04	8.00±0.03	7.04±0.03
	3	8.44±0.02	8.96±0.05	7.1±0.04	8.51±0.04	8.02±0.03	7.06±.0.03
	4	8.38±0.02	8.95±0.05	7.08±0.04	8.51±0.04	8.01±0.03	7.05±0.03
	5	8.31±0.02	8.95±0.05	7.07±0.04	8.52±0.04	8.01±0.05	7.05±0.03
	6	8.23±0.02	8.95±0.05	7.06±0.04	8.52±0.04	8.08±0.03	7.12±0.03
	7	8.21±0.02	8.96±0.05	7.06±0.04	8.11±0.04	8.04±0.04	7.08±0.03

Table 4.2 shows the pH variations along the Depth Profile of Sample Points A & B of Machigani over the 6-month Study Period. The highest pH value was recorded in September at points A (Ma) and B (Mb) with a value of 8.37 and 8.63 at 2m and 1m respectively. The lowest pH value was recorded in June at both points A (Ma) and B (Mb) with a value of 2.53 6m and 5m to 6m respectively. June and July recorded low pH with that of June being extremely low. This shows that in June and July the Reservoir was quite acidic but became normal between September and November.

Table 2.2 **pH Variations along the depth profile of sample points A & B of Machigani over the 6-month study period**

		Machigani					
		June	**July**	**August**	**September**	**October**	**November**
	Depth (m)	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
Ma	**0**	2.64±0.02	6.3±0.03	6.91±0.01	8.34±0.02	8.15±0.03	7.28±0.02
	1	2.69±0.02	6.01±0.03	5.55±0.01	8.4±0.01	8.11±0.03	7.24±0.02
	2	2.66±0.02	5.30±0.03	5.29±0.01	8.37±0.02	8.13±0.03	7.26±0.02
	3	2.73±0.02	4.52±0.03	5.53±0.01	8.33±0.02	8.03±0.03	7.16±0.02
	4	2.74±0.02	4.28±0.03	5.58±0.02	8.25±0.01	8.02±0.03	7.15±0.02

	5	2.63±0.02	4.52±0.03	5.16±0.01	8.20±0.01	7.94±0.03	7.07±0.02
	6	2.53±0.02	3.74±0.03	5.76±0.02	8.17±0.01	7.96±0.03	7.09±0.02
	7	2.46±0.02	3.39±0.03	5.33±0.02	8.13±0.01	7.90±0.03	7.03±0.02
	8	2.71±0.02	2.76±0.03	5.68±0.02	7.80±0.01	7.87±0.03	7.00±0.02
	Depth (m)	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
Mb	**0**	2.63±0.02	5.89±0.02	7.55±0.01	8.6±0.02	8.27±0.02	7.49±0.01
	1	2.64±0.02.	5.03±0.02	5.66±0.01	8.62±0.02	8.22±0.02	7.44±0.01
	2	2.62±0.02	5.06±0.02	5.50±0.01	8.61±0.02	8.17±0.02	7.39±0.01
	3	2.60±0.02	4.56±0.02	5.17±0.01	8.55±0.02	8.15±0.02	7.37±0.01
	4	2.58±0.02	4.33±0.02	4.99±0.01	8.50±0.03	8.15±0.04	7.37±0.02
	5	2.53±0.02	4.20±0.02	4.92±0.01	8.50±0.02	8.04±0.03	7.26±0.01
	6	2.53±0.02	4.19±0.02	5.08±0.01	8.39±0.02	7.97±0.02	7.19±0.01
	7	2.46±0.02	3.17±0.02	4.52±0.01	8.36±0.02	7.86±0.03	7.08±0.01

Table 4.3 shows the pH variations along the depth profile of sample points A & B of Kalabule over the 6-month study period. The highest pH value was recorded in July at points A (Ka) and B (Kb) with a value of 8.49 and 8.66 at 4m and 1m respectively. The lowest pH value was recorded in August at both points A (Ka) and B (Kb) with a value of 6.99 at 0m, 1m, 3m, and 4m and a value of 6.87 at 6m respectively. The other months has a pH range of 7.02 to 8.25 which fall within of the WHO standards for surface water.

Table 4.3 **pH Variations along the depth profile of sample points A & B of Kalabule Dam over the 6-month study period**

		Kalabule Dam					
		June	**July**	**August**	**September**	**October**	**November**
	Depth (m)	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
Ka	**0**	7.91±0.14	8.17±0.14	6.94±0.14	8.1±0.14	8.07±0.14	7.21±0.14
	1	7.91±0.14	8.43±0.14	6.99±0.14	8.08±0.14	7.97±0.14	7.11±0.14
	2	7.93±.14	8.45±0.14	6.98±0.15	8.04±0.14	7.88±0.14	7.02±0.15
	3	7.87±0.14	8.45±0.14	6.99±0.14	8.03±0.14	7.62±0.14	7.16±0.15
	4	7.85±0.14	8.49±0.14	6.99±0.14	8.05±0.14	7.5±0.14	7.14±0.15
	Depth (m)	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
Kb	**0**	8.04±0.14	8.61±0.14	7.07±0.28	8.25±0.15	8.07±0.28	7.19±0.25
	1	8.08±0.14	8.66±0.14	7.07±0.28	8.25±0.16	8.1±0.28	7.22±0.25
	2	8.04±0.14	8.64±0.14	7.07±0.28	8.21±0.16	8±0.28	7.12±0.25
	3	7.91±0.14	8.59±0.14	7.06±0.28	8.17±0.16	7.8±0.28	7.14±0.25
	4	7.92±0.14	8.55±0.14	7.03±0.28	8.15±0.16	7.76±0.28	7.08±0.25
	5	7.92±0.14	8.58±0.14	6.99±0.28	8.1±0.16	7.72±0.28	7.24±0.25
	6	7.93±0.14	8.54±0.14	6.87±0.28	7.63±0.15	7.53±0.28	7.15±0.25

4.2.3 Distribution and variation of Key Physico-Chemical Parameters along a depth profile

Average Temperature Variation over the 6-month Study Period

Fig 4.24 shows the average temperature variation over the six-month study period. The temperature recordings in each of the month were steady at 0m to 1m which each of them gradually decreasing to a depth of 4m and gradually increasing before showing a slight decrease towards the end from 7m to depth of 8m. The highest average temperature values were recorded in September followed by June, with the lowest recordings taken in August. Generally, it was observed that temperature was reducing with increasing depth. This indicates that temperature profile creates a stable thermal stratification, which can lead to a separation of the water column into distinct layers with different temperature, nutrient, and oxygen levels.

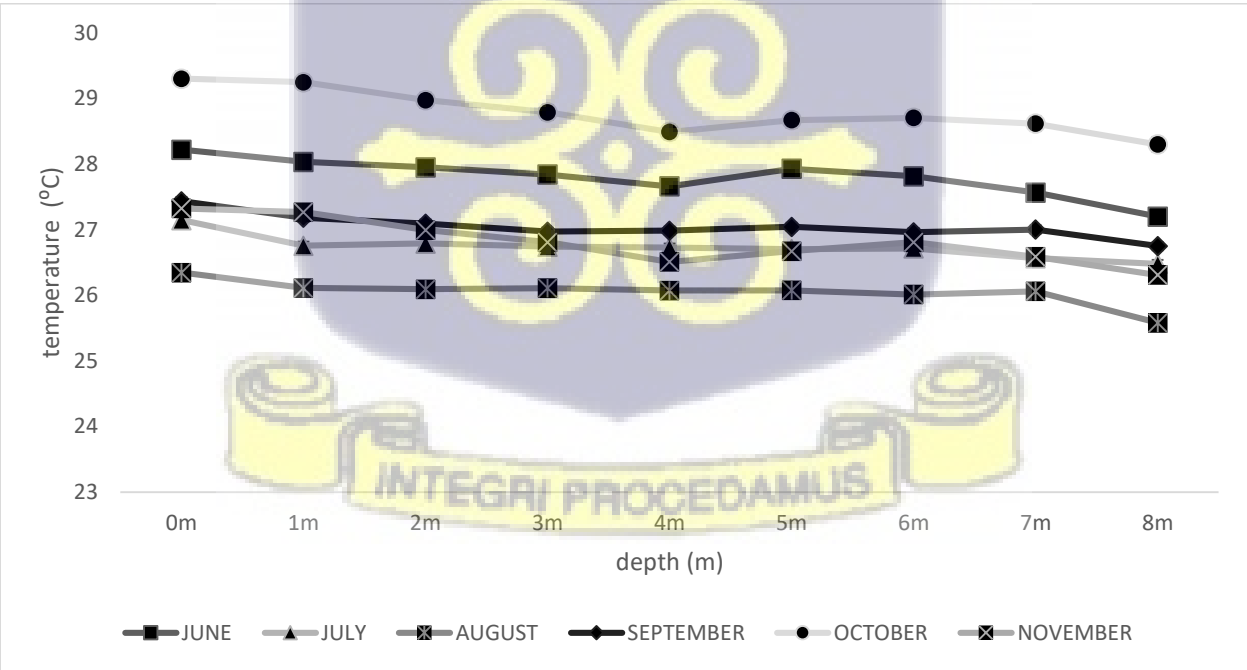

Figure 4.24 *Average temperature variation over the 6-month study period across the six (6) sample points.*

Average DO Variation over the 6-month Study Period

Figure 4.25 shows the DO variation over the six-month study period. At depths 0m and 8m, September recorded the highest DO values of 8.05mg/L and 4.75mg/L and August was in a range from 7.56mg/L to 5.68mg/L at 0m and 8m respectively, although a sharp decrease was observed that from 0m to 1m. There was a slight decrease along the depth profile in July and October from 0m to 1m remaining steady to a slight increase at 8m depth with the exception of the months June and November which remained steady throughout. A gradual decrease in DO along the depth profile was observed which can have serious implications. Per this data, it can be deduced that the deeper waters could be hypoxic (low oxygen) or anoxic (no oxygen), which can result in stress or death of aquatic species that require oxygen to survive.

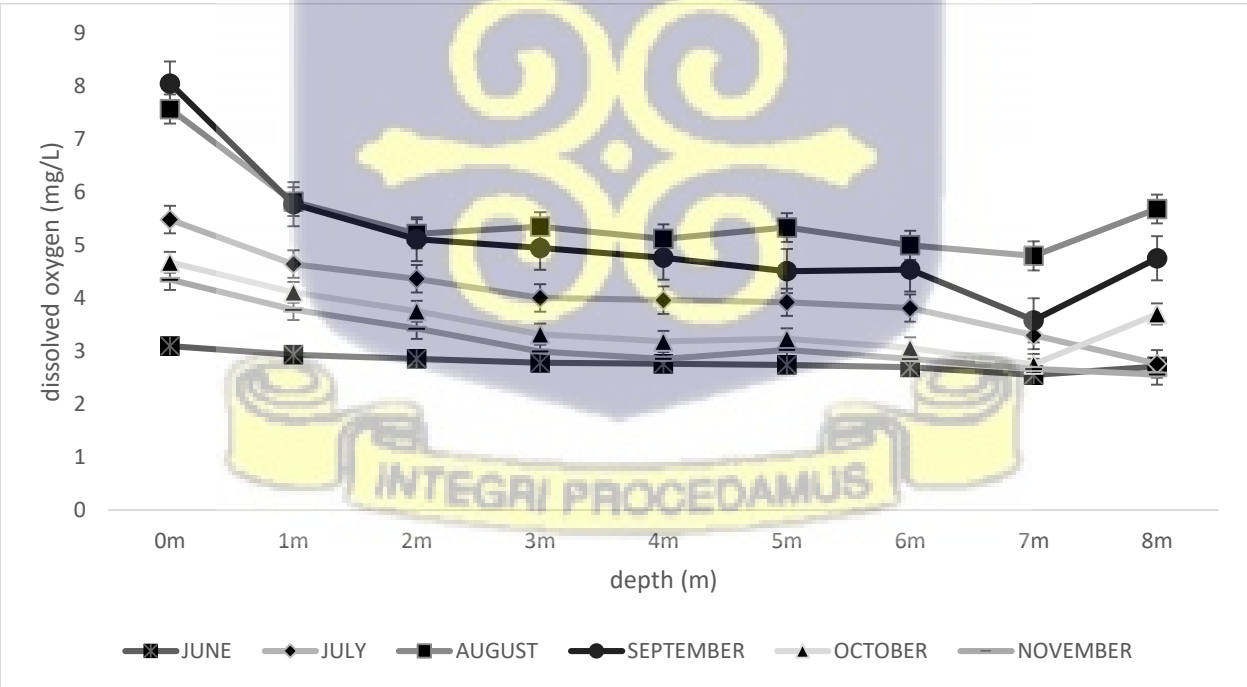

Figure 4.25 *Average DO variation over the 6-month study period across the six (6) sample points*

Nutrient Distribution along the Depth Profile of the Weija Reservoir

Average Orthophosphate Distribution over the 6-month Study Period

Figure 4.26 shows the average orthophosphate over the six-month study period. The recording of orthophosphate was steady from 0m to 2m with a slight sharp increase to 3m which decrease to 4m and continued to remain steady until an extreme sharp increase from 6m to 7m decreasing sharply to 8m with a value of 0.63mg/L. The other months showed the recording remained steady ever slightly increasing and decreasing from 0m to 8m with the exception of July which recorded a sharp increase from 7m depth to 8m depth at 0.38mg/L. No clear trend was observed along the depth profile but orthophosphate concentration was highest towards the water-sediment interface (6m – 8m). This could be as a result of the release of orthophosphate from the sediments under anoxic conditions which was earlier suggested per the decrease in along the depth profile. Under low DO, more nutrients will be released and this will be accumulated in the hypolimnion so when there is an overturn, all the nutrients will be released into the water column which will cause eutrophication.

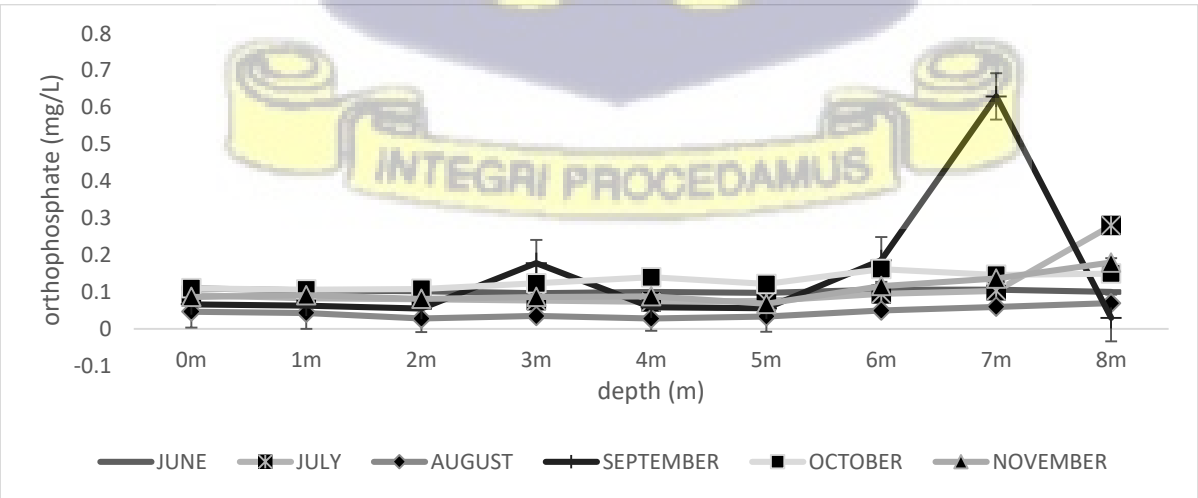

Figure 4.26 *Average orthophosphate distribution over the 6-month study period across the six (6) sample points*

Average Nitrate Distribution over the 6-month Study Period

Figure 4.27 shows the average nitrate distribution over the 6-month study period at 0m to 8m. Recordings of nitrate within the month of June to October had a range of 72mg/L to 136.16mg/L with the exception of November. The recordings in November ranged from 119.95mg/L to 1083.61mg/L at 0m to 8m respectively with a slight increase from 6m to 7m depth to a sharp increase to 8m. Generally, there was increase in nitrate concentration along the depth profile, even though the increases were not in uniformity. This could also be as a result of nutrient release under hypoxic or anoxic conditions. Just like orthophosphate, the accumulation at the hypolimnion and later release into the water column during overturn can lead to eutrophication.

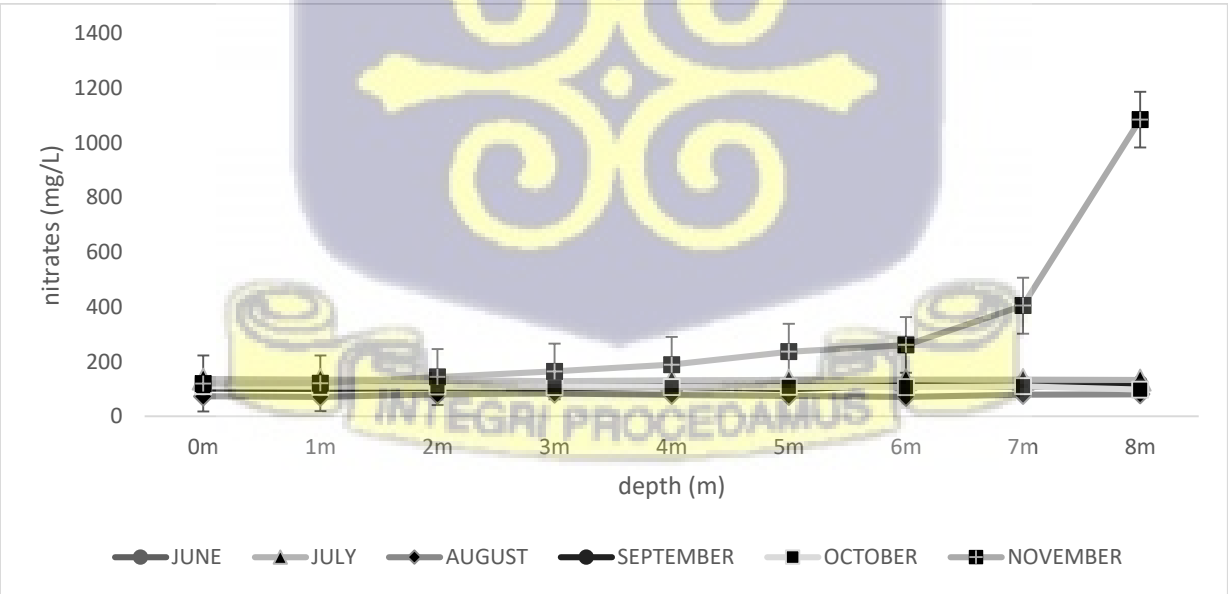

Figure 4.27 *Average nitrate distribution over the 6-month study period across the six (6) sample points*

Comparison of Average Orthophosphate and Average Nitrate Distribution over the 6-Month Period

Figure 4.28 shows the comparison of average orthophosphate and average nitrate distribution over the six-month period. The average orthophosphate ranged from 0.08mg/L to 0.24mg/L at 0m to 8m whilst average nitrate distribution ranged from 108.73mg/L to 271.23mg/L at 0m to 8m. The recordings of the average orthophosphate were steady from 0m to 2m with a slight increase and decrease from 2m to 6m and sharp increase and decrease from 6m to 8m. The recordings of the average nitrate distribution had a steady flow and increased slightly at 7m to 8m. It is also observed as orthophosphate decreases slightly at 2m, nitrate remains steady until an interception at 3m. Between 3m and 6m, nitrate content maintains a steady and gradual increase, while orthophosphate reduces from 0.09mg/L at 3m to 0.07mg/L at 5m. Again, there is a sharp increase in nitrates between 7m and 8m but a sharp decrease in orthophosphate as the water-sediment interface (8m) is approached.

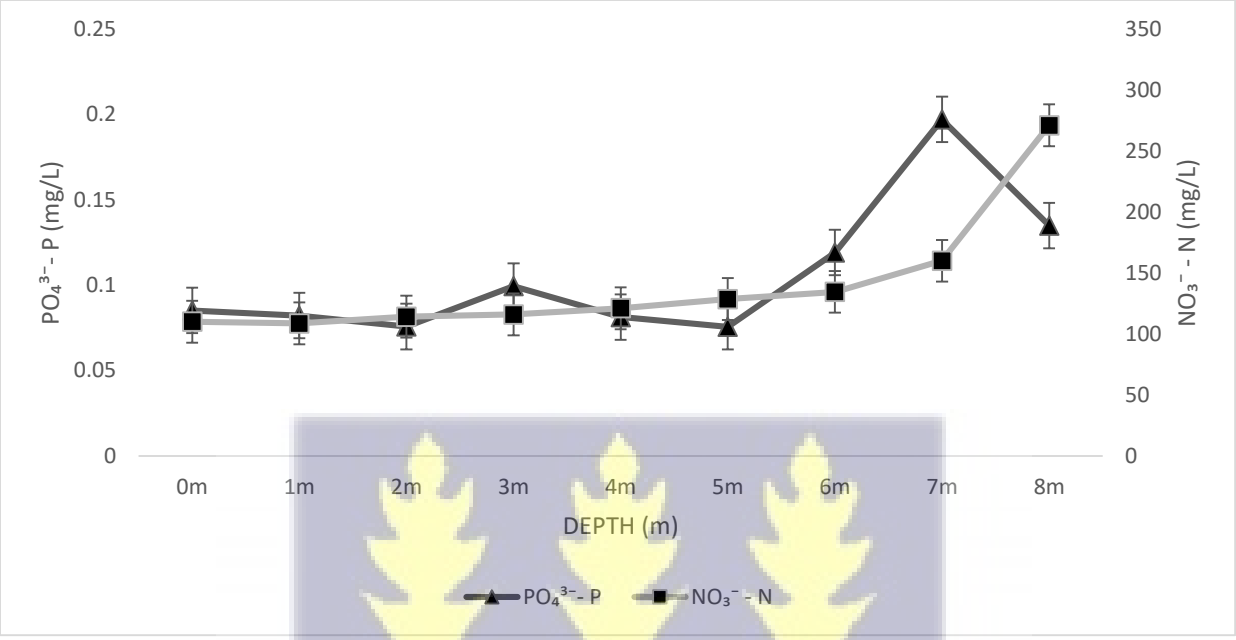

Figure 4.28 *Comparison of Average Orthophosphate and Average Nitrate Distribution over the 6-Month Period*

Statistical Analysis (Water Samples)

With the aid of multivariate analysis, it was observed that generally, there was significant difference with respect to the depths and months of each sample location.

For Kalabule Dam, there was high significance for all parameters except nitrogen with respect to depth with significance levels of 0.00 for all of them. Nitrogen recorded a significance level of 0.65 indicating that there were no significant variations in nitrates concentration. With respect to the sampling months, all parameters recorded significant levels of 0.00 indicating that there was a significant difference for all the parameters with respect to the months. Using the Multiple Comparisons Test (MCT), the specific depths that showed significance in Kalabule Dam were determined in relation to the various parameters studied. With regards to temperature, there was significance among the individual depths with the exception of 2m and 3m, 2m and 6m, 3m and

4-, 5- and 6-meter depths, 4m and 5- and 6-meter depths and 5m and 6m. This indicates that the interactions among these depths showed no significance ($p>0.05$) with respect to temperature. For dissolved oxygen (DO), generally, changes in DO with depth was significant with the exception of 3m and 4m, 4m and 5m and 5m and 6m. This indicates that major DO changes that affect the Reservoir occur at the water surface or close to the water surface and the water-sediment interface or close to the water-sediment interface. Also, the interactions between the water-sediment interface (6m) and the other depths showed very high significance levels of 0.00. This can be as a result of high amounts of phosphates in the sediments as compared to the water column leading to the release of high orthophosphate amounts at the water-sediment interface under anoxic conditions in the hypolimnion as compared to the other depths.

In Machigani, there was high significance for temperature and DO with respect to depth. The significance level recorded was 0.00 for both parameters. With regards to the nutrients, orthophosphate recorded a significance level of 0.09 while nitrate recorded a significance level of 0.83 indicating that there was no significance for nutrients with respect to the depths. A 0.00 significance level was recorded for all four (4) parameters with respect to the sampling months showing there was high significance for temperature, DO, orthophosphate and nitrate with respect to the months. Multiple Comparisons Test indicated that, for temperature, there was significance among the depth interactions except, 1m and 2- and 3-meter depths, 2m and 3- and 5-meter depths, 3m and 5-, 6- and 7-meter depths, 4m and 5-, 6- and 7-meter depths and 5m and 6- and 7-meter depths. For DO, there was very high significance of 0.00 between the water surface (0m) and the other depths (from 1m to 7m). There was also high significance between the water-sediment interface (7m) and the other depths (0m to 5m). It was observed that the significant difference in levels kept increasing until the interaction with 6m which was not significant. With regards to

orthophosphate, all depth interactions were not significant with the exception of the water-sediment interface (7m) interaction with depths 2m, 3m, 4m and 5m with significant levels of 0.17, 0.10, 0.003 and 0.25 respectively. There was no significance for nitrate.

In Upper Weija, there was high significance for temperature, DO and orthophosphate with significance levels of 0.023, 0.00 and 0.00 respectively with respect to depth. For nitrate, there was no significance (0.87) with respect to depth. Also, there was no significance for temperature with respect to the sampling months. Significance level was 0.10. On the other hand, there was high significance with levels of 0.00 for DO, orthophosphate and nitrate with respect to the sampling months. For temperature, it was observed that the water surface (0m) interaction with 2m, 3m and 4m were significant and also interactions between 3m and depths 5 and 6 meters were significant. The other depth interactions were not significant with respect to temperature. For DO, there was very high significance of .00 between the water surface (0m) and the other depths (from 1m to 7m). The other interactions were not significant. With regards to orthophosphate, all depth interactions were not significant with the exception of the water-sediment interface (7m) interaction with the other depths (from 1m to 7m) respectively. There was no significance for nitrate as.

4.2.4 Sediment Characterization

Organic Matter Content in Sediment

Fig 4.29 shows the organic matter content over the 6-month study period. Recordings of organic matter within the month of June to October had a range of 8.01% to 13.72% The recordings in November ranged from 9.95% to 11.70%. Averagely site UWb recorded the highest percentage over the study period.

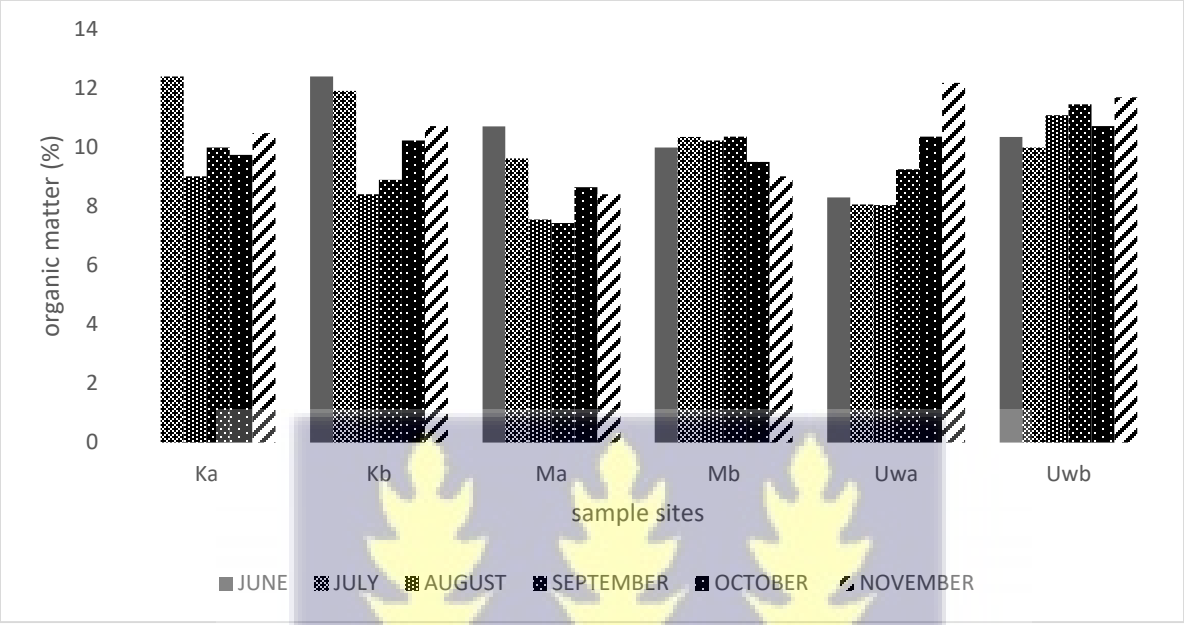

Figure 4.29 *Organic matter content in sediment taken from the six (6) sample sites over the 6-month study period*

Total Nitrogen Content in Sediment

Fig 4.30 shows the nitrogen content over the 6-month study period. The data did not show any trend generally with the exception of site Ma which recorded a steady increase in percentage total nitrogen content from June with a value of 0.45% to November with a value of 0.72%.

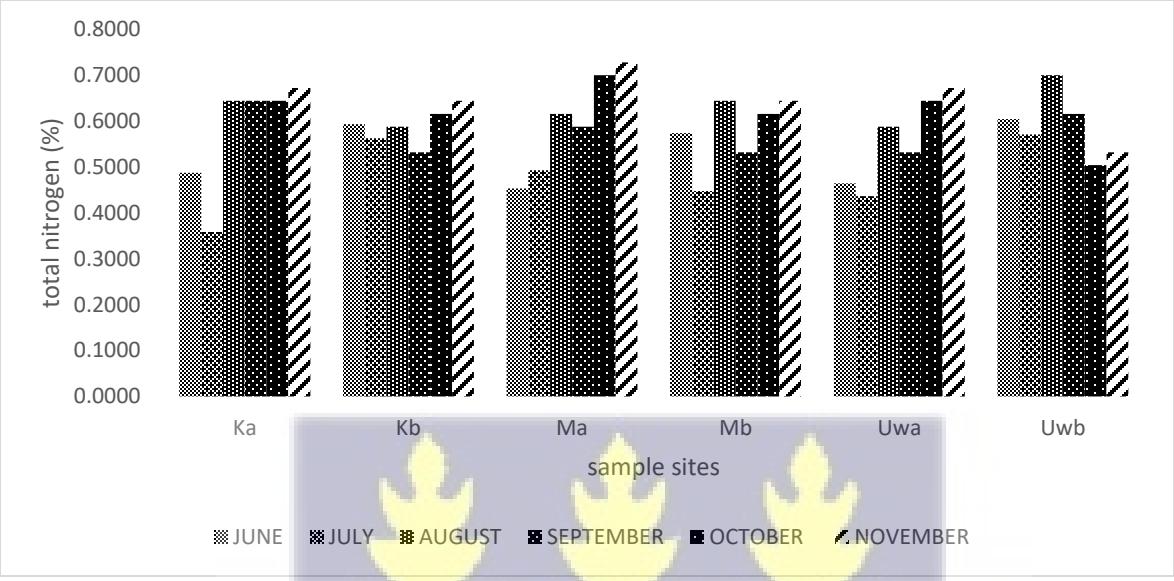

Figure 4.30 *Total nitrogen content in sediment taking from the six (6) sample sites over the 6-month study period*

Total Phosphorus Content in Sediment

Fig 4.31 shows the total phosphorus content in the sediment samples over the 6-month study period. The data did not show any trend generally as well. Site UWb recorded the highest total phosphorus content in all months except October. Aside that, the graph shows some level of uniform distribution of total phosphorus across the six months.

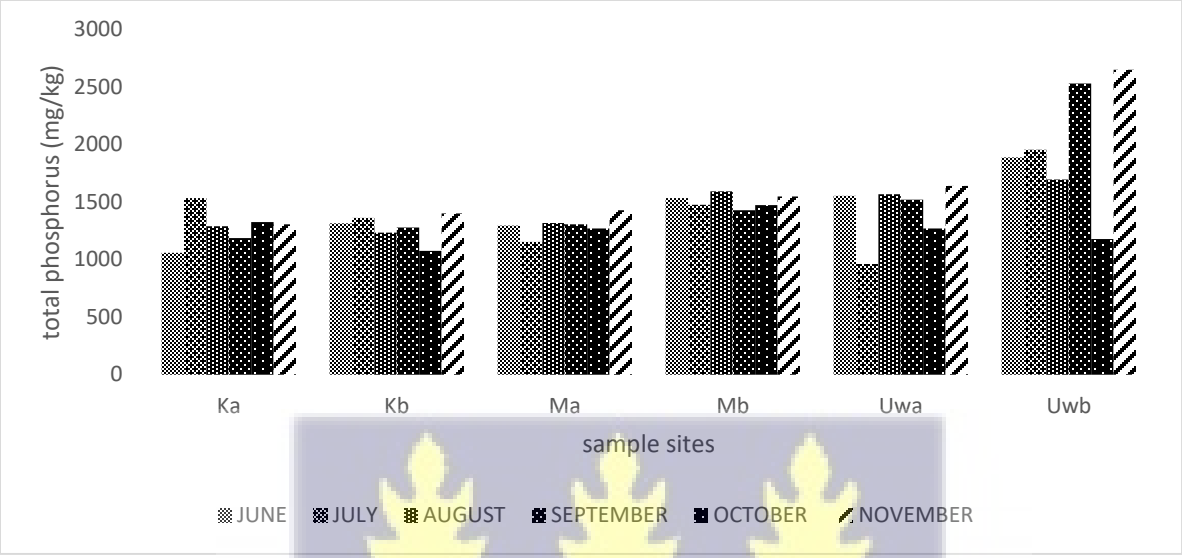

Figure 4.31 *Total phosphorus content in sediment taken from the six (6) sample points over the 6-month study period*

pH Variation in Sediment

Fig 4.32 shows the pH variation in the sediment samples over the 6-month study period. The same trend was observed for sample points Ka, Kb, Ma and Mb. From June to August there is a uniform pH level, then in September, there is a slight dip in levels. In October, there is a sharp increase from September, with a gradual increase in the pH level November.

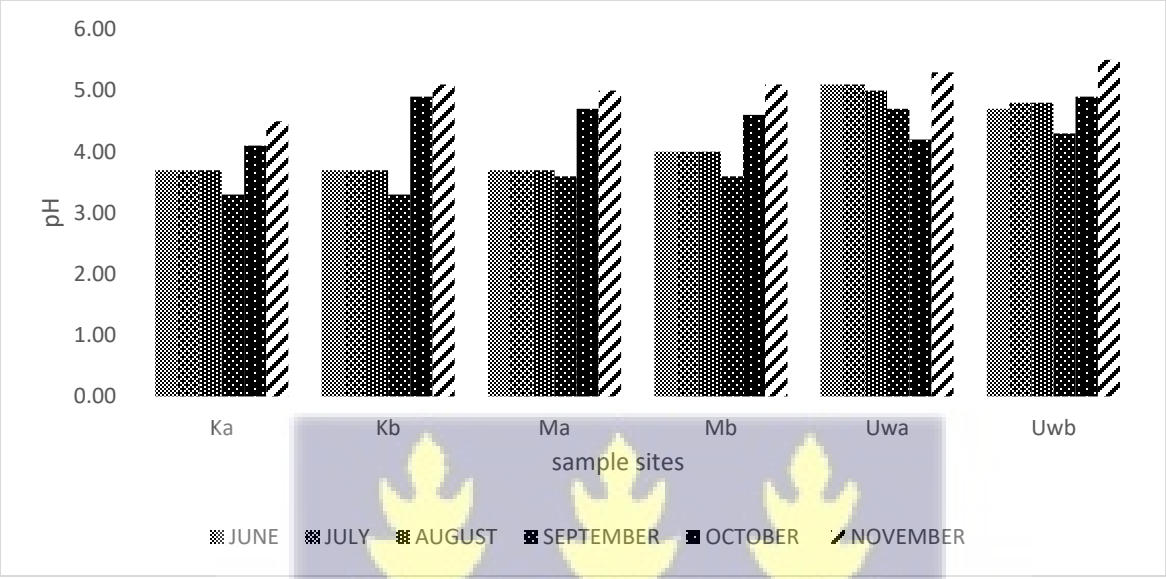

Figure 4.32 *pH variation in sediment taken from the six (6) sample points over the 6-month study period*

E.C Variation in Sediment

Fig 4.33 shows the E.C variation in the sediment samples over the 6-month study period. August recorded both the highest and the lowest E.C values over the study period. The values were 4.42dS/m and 1.13dS/m. At Ma, there was a steady reduction across the months, from June to November. No trend was observed in this dataset.

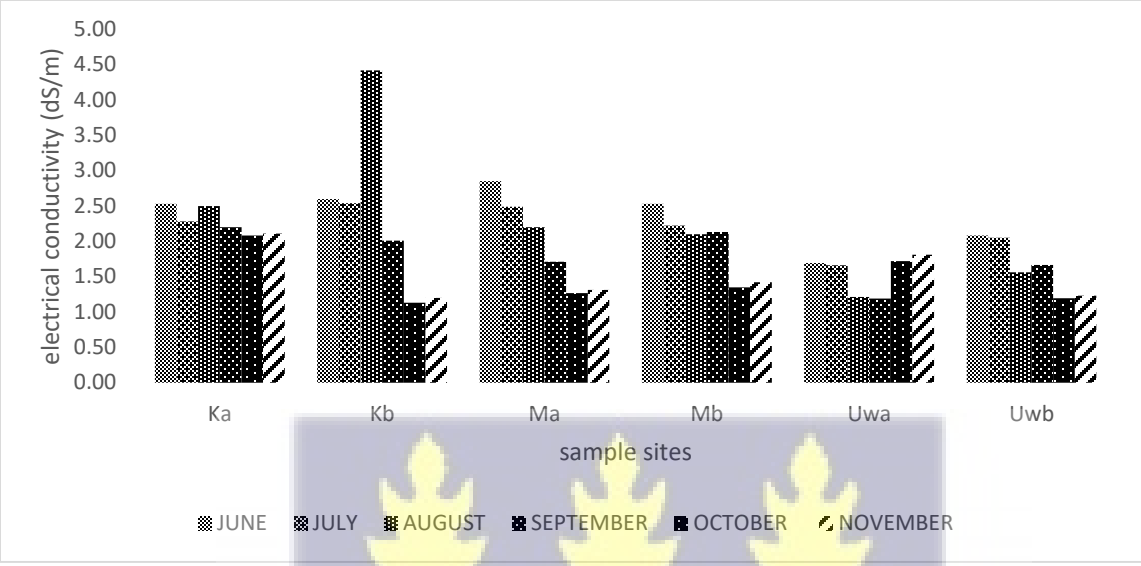

Figure 4.33 *Electrical conductivity (E.C) variation in sediment taken from the six (6) sample sites over the 6-month study period*

Statistical Analysis (Sediment Samples)

0.05 significance level was used for this study so the *p*-value of 0.107 indicates that there was no significant difference in organic matter content in the various sample locations with respect to time. This was consistent with the profile plot above. An insignificant interaction effect means that the effect of one factor does not depends on the level of the other factor. The effect of Sample location on recorded Organic matter is independent of the respective months in which the study was done. Similarly, the *p*-values for the main effects are insignificant. From Table 4.4, the p-value with respect to the months was 0.329 which indicates that there was no significant difference in the organic matter content across the study months. With a p-value of 0.128 there was no significant difference among the sample locations as well.

Generally, the high organic matter content recorded in the Reservoir could be attributed to the abundance of aquatic macrophytes and aquatic fauna in the Reservoir. Abundance of these aquatic organisms means a lot of decomposition will occur when the organisms die.

Table 4.4 **Statistical ANOVA Table for Organic Matter**

Dependent Variable: Organic Matter

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2980925574.467[a]	17	175348563.204	1.777	0.118	0.627
Intercept	354774350990.559	1	354774350990.559	3594.727	0.000	0.995
Months	615521945.340	5	123104389.068	1.247	0.329	0.257
Sample location	456375668.228	2	228187834.114	2.312	0.128	0.204
Date and Sample Location	1909027960.900	10	190902796.090	1.934	0.107	0.518
Error	1776473718.111	18	98692984.340			
Total	359531750283.13	36				
Corrected Total	4757399292.578	35				

a. R Squared = 0.627 (Adjusted R Squared = 0.274)

From Table 4.5, the *p*-value of 0.929 indicates that there was no significant difference in nitrogen content in the various sample locations with respect to the months of study. The effect of Sample location on recorded total nitrogen is independent of the respective months in which the study was done. With a p-value of 0.713 there was no significant difference among the sample locations as well. On the other hand, the p-value with respect to the months was 0.007 which indicates that there was high significant difference in the total nitrogen content across the study months. The significant differences were observed between June and August, June and November, July and the

months of August, October and November as seen in the Pairwise Comparisons Table in Appendix 2

Generally, the high nitrogen content recorded in the Reservoir sediments could be attributed to anthropogenic activities such as discharge of domestic waste into the Reservoir as well as other activities including fishermen bathing in the Reservoir. Another major contributor could be fertilizer from farms around the Reservoir which is transported into the Reservoir as a result of run-off.

Table 4.5 **Statistical ANOVA Table for Total Nitrogen**

Dependent Variable: Total Nitrogen

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	12446096.450[a]	17	732123.321	1.621	0.159	0.605
Intercept	1229418088.684	1	1229418088.684	2722.883	0.000	0.993
Sample Location	311353.050	2	155676.525	0.345	0.713	0.037
Months	10322993.411	5	2064598.682	4.573	0.007	0.560
Sample Location * Months	1811749.990	10	181174.999	0.401	0.929	0.182
Error	8127241.607	18	451513.423			
Total	1249991426.741	36				
Corrected Total	20573338.057	35				

a. R Squared = 0.605 (Adjusted R Squared = 0.232)

From Table 4.6, the *p*-value of 0.068 indicates that there was no significant difference in total phosphorus content in the various sample locations with respect to the months of study. The effect of sample location on recorded total nitrogen is independent of the respective months in which the

study was done but with a p-value of 0.00 there was high significant difference among the sample locations. The p-value with respect to the months was 0.018 which indicates that there was high significant difference in the total phosphorus content across the study months. This shows that the months as well as the sample location played a major role in the significant changes in the phosphorus content of the Reservoir. The significant differences were observed between June and October, July and the months of September and October, August and October and October and November as seen in the Pairwise Comparisons Table in Appendix 3. As shown in Appendix 4, there was significant differences among all the sample locations.

Table 4.6 **Statistical ANOVA Table for Total Phosphorus**

Dependent Variable: Total Phosphorus

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1341557.580[a]	17	78915.152	4.457	0.001	0.808
Intercept	73251063.487	1	73251063.487	4137.404	0.000	0.996
Sample Location	620551.365	2	310275.683	17.525	0.000	0.661
Months	328139.503	5	65627.901	3.707	0.018	0.507
Sample Location and Date	392866.711	10	39286.671	2.219	0.068	0.552
Error	318682.722	18	17704.596			
Total	74911303.789	36				
Corrected Total	1660240.302	35				

a. R Squared = 0.808 (Adjusted R Squared = 0.627)

4.3 Trophic State Indices (TSI) of Weija Reservoir

Trophic State Index (Secchi Depth)

Table 4.5 shows the Secchi depth values in meters for all six (6) sampling points from June to November. In June, the Secchi depth values recorded, ranged from 0.4m to 0.7m. Upper Weija Point B (UWb) recorded the lowest while Machigani Point B (Mb) recorded the highest. In July, Kalabule Dam's Points A and B, Machigani's Points A and B and Upper Weija's Points A and B recorded 0.6m, 0.7m and 0.5m respectively. Depth of 0.7m was recorded for all sampling points in the month of August except Upper Weija Point B (UWb) which recorded a slight increase with 0.8m. In September, Kalabule Dam's points A and B plus Machigani Point A and Upper Weija Point B recorded equal values of 0.7m with Machigani Point B and Upper Weija Point A recording 0.8m and 0.9m respectively. October and November recorded varying values ranging between 0.3m being the lowest and 0.5m being the highest.

Averagely, October and November recorded the lowest Secchi depth values with 0.4m while the month of September recorded the highest value of 0.75m.

Tables 4.7 and 4.8 shows the trophic state index of the Reservoir using the Secchi depth. The values recorded for this section of the study ranged from 64.15 in September to 73.20 in October and November. June, July and August recorded 68.61, 67.36 and 65.14 respectively.

Table 4.7 **Secchi depth in meters (m) from June to November at the six (6) sample points**

Code/Month	June	July	August	September	October	November
Ka	0.60±0.10	0.60±0.15	0.70±0.10	0.70±0.14	0.50±0.09	0.50±0.11
Kb	0.60±0.12	0.60±0.07	0.70±0.03	0.70±0.06	0.40±0.13	0.40±0.09
Ma	0.60±0.06	0.70±0.11	0.70±0.07	0.70±0.12	0.50±0.06	0.50±0.13
Mb	0.70±0.09	0.70±0.05	0.70±0.05	0.80±0.08	0.40±0.19	0.40±0.14
UWa	0.40±0.04	0.50±0.09	0.70±0.04	0.90±0.05	0.30±0.02	0.30±0.08
UWb	0.40±0.16	0.50±0.19	0.80±0.09	0.70±0.10	0.30±0.04	0.30±0.17
Average	0.55±0.10	0.60±0.11	0.70±0.06	0.75±0.09	0.40±0.09	0.40±0.12

Table 4.8 **Trophic State Index (Secchi Depth) of the Weija Reservoir from June to November**

MONTH	TSI (SD)
June	68.61
July	67.36
August	65.14
September	64.15
October	73.20
November	73.20

Trophic State Index (Chlorophyll a)

Table 4.9 shows the chlorophyll a values from June to November in the six (6) sampling points. The chlorophyll a values recorded in June, ranged from 1.52µg/L to 3.9µg/L. Kalabule Dam Point

A (Ka) recorded the lowest while Machigani Point B (Mb) recorded the highest. In July, Kalabule Dam's Points A and B, Machigani's Points A and B and Upper Weija's Points A and B recorded 1.87µg/L, 2.45µg/L, 3.90µg/L, 1.65µg/L, 2.39µg/L and 1.52µg/L respectively. Similar values to the month of July were recorded in August but the sampling points varied. In September, Upper Weija Point B recorded the lowest value of 1.53µg/L while Kalabule Dam Point B recorded the highest value of 2.53µg/L. October recorded 1.80µg/L, 2.14µg/L, 1.65µg/L, 2.47µg/L, 2.27µg/L and 2.34µg/L for Kalabule Dam's Points A and B, Machigani's Points A and B and Upper Weija's Points A and B respectively while November recorded varying values ranging between 1.52µg/L and 2.45µg/L.

The average chlorophyll a values recorded for the duration of the study were between 1.94µg/L and 2.36µg/L.

Table 4.9 **Chlorophyll a in microgram per liter (µg/L) from June to November at the six (6) sample points**

Code/Month	June	July	August	September	October	November
Ka	1.52±0.24	1.87±0.54	1.87±0.39	2.15±0.12	1.80±0.32	1.87±0.44
Kb	2.27±0.16	2.45±0.65	2.45±0.21	2.53±0.26	2.14±0.56	2.45±0.61
Ma	1.60±0.35	3.90±0.47	3.90±0.78	2.18±0.39	1.65±0.13	2.18±0.54
Mb	3.90±0.47	1.65±0.36	1.65±0.36	1.60±0.11	2.47±0.19	2.47±0.38
UWa	2.45±0.19	2.39±0.24	2.39±0.48	1.70±0.17	2.27±0.41	2.39±0.27
UWb	2.39±0.26	1.52±0.77	1.52±0.45	1.53±0.22	2.34±0.24	1.52±0.48
Average	2.36±0.28	2.30±0.51	2.30±0.45	1.94±0.21	2.11±0.31	2.15±0.45

Table 4.10 shows the trophic state index of the Reservoir using chlorophyll a. The TSI (CHL) values computed ranged from 37.10 in September to 39.02 in June. July and August recorded 38.77 while 37.93 and 38.12 were values obtained in October and November respectively.

Table 4.10 **Trophic State Index (Chlorophyll a) of the Weija Reservoir from June to November**

MONTH	TSI (CHL)
June	39.02
July	38.77
August	38.77
September	37.10
October	37.93
November	38.12

Trophic State Index (Total Phosphorus)

Table 4.11 shows the total phosphorus levels. Averagely, June recorded the lowest total phosphorus level with 155.16µg/L and July recorded the highest value of 275.50µg/L.

In June, the levels recorded, ranged from 53.39µg/L to 394.20µg/L. Both minimum and maximum levels occurred at Kalabule Dam Point A (Ka) and Upper Weija Point A (UWa) respectively. In July, the levels recorded ranged from 40.74µg/L to 445.73µg/L in Kalabule Dam Points A (Ka) and Upper Weija Point B (UWb) respectively. Upper Weija Point A recorded the lowest level of 40.74µg/L in the month of August just like Kalabule Dam Point A in the previous month. 357.47µg/L was the highest level recorded in August at Machigani Point A (Ma). In September, Kalabule Dam's points A and B, Machigani Point A and B and Upper Weija Points A and B

recorded 162.78µg/L, 62.78µg/L, 237.47µg/L, 201.14µg/L, 423.59µg/L, 212.56µg/L and 216.65µg/L respectively. October and November recorded varying minimum and maximum levels, 126.04 to 327.27 in October and 149.71 to 297.06 in November. The highest level recorded in November was the lowest in the high levels in comparison to the other months

Table 4.11 **Total Phosphorus in microgram per liter (µg/L) from June to November at the six (6) sample points**

Code/Month	June	July	August	September	October	November
Ka	53.39±0.35	40.74±0.29	77.06±0.44	162.78±0.61	327.27±0.77	297.06±0.75
Kb	39.10±0.28	117.47±0.54	155.84±0.61	62.78±0.39	106.45±0.52	135.84±0.58
Ma	115.43±0.54	457.06±0.82	357.47±0.78	237.47±0.70	230.94±0.70	172.98±0.63
Mb	197.88±0.66	290.12±0.74	122.37±0.55	201.14±0.67	126.04±0.56	149.71±0.60
UWa	394.20±0.80	301.96±0.75	40.74±0.29	423.59±0.80	139.10±0.58	250.94±0.72
UWb	130.94±0.58	445.63±0.81	215.43±0.68	212.16±0.68	307.67±0.76	211.76±0.68
Average	155.16±0.53	275.50±0.66	161.48±0.56	216.65±0.64	206.25±0.65	203.05±0.66

Table 4.12 shows the trophic state index of the Reservoir. The TSI (TP) values determined ranged from 75.78 in June to 83.93 in July.

Table 4.12 **Trophic State Index (Total Phosphorus) of the Weija Reservoir from June to November**

MONTH	TSI (TP)
June	75.78
July	83.93
August	76.35
September	80.52

October	79.82
November	79.60

Table 4.13 shows Trophic State Index quantifying the relationship among nutrient levels which was measured by total phosphorus, algal biomass, measured by chlorophyll a and Reservoir clarity which was measured by Secchi disk transparency.

Table 4.13 **Trophic State Index of the Weija Reservoir from June to November**

MONTH	TSI (TP)	TSI (CHL)	TSI (SD)
June	75.78	39.02	68.61
July	83.93	38.77	67.36
August	76.35	38.77	65.14
September	80.52	37.10	64.15
October	79.82	37.93	73.20
November	79.60	38.12	73.20

Figure 4.34 shows the relationship among all three trophic state indices over the six-month period. It is observed that TSI (SD) ranges from 64.15 in July to 73.20 in October and November. This to say the latter recorded the highest value in relation to Secchi depth over the study period. Averagely the TSI (SD) over the period was 68.61 and in accordance with Table 2.1, the Reservoir is eutrophic. TSI (CHL) remained constant, after a slight increase from June until August where a slight a decrease into September was observed. From there, it was gradual rise until the month of November with 38.12. The average TSI (TP) for the 6-month period of the study was 79.33. In

accordance with Table 2.1, the Reservoir is hyper-eutrophic and is attributed with, light limited productivity as well as dense algae and macrophytes.

It was also observed that TSI (TP) = TSI (SD) > TSI (CHL). This relationship indicates that, the Reservoir is eutrophic but its eutrophic state cannot be attributed to algae dominance but rather non-algal particulates that are limiting light attenuation.

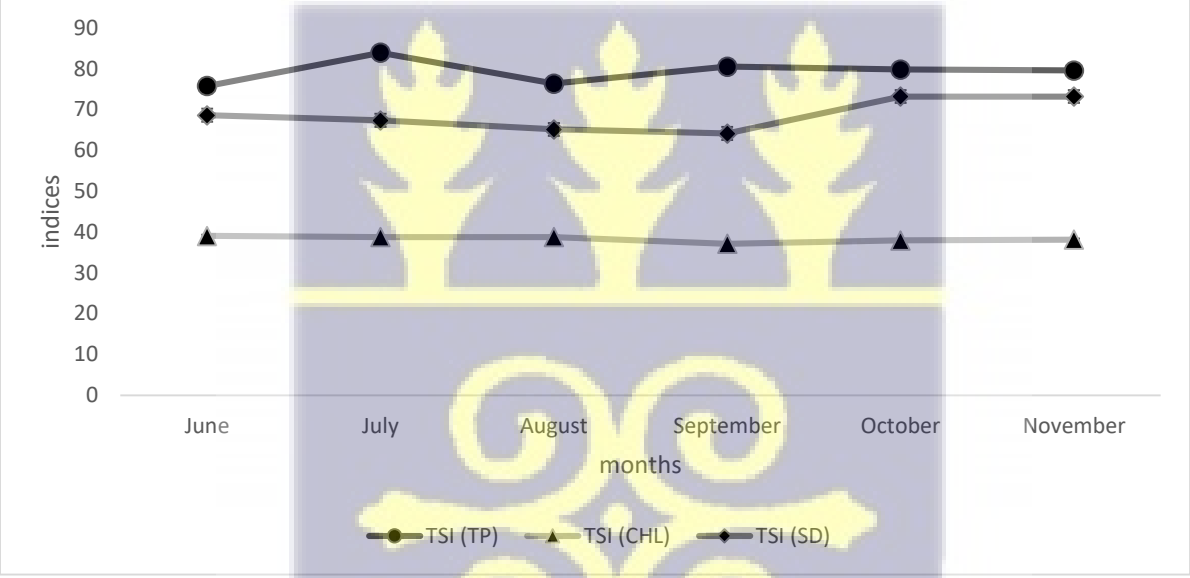

Figure 4.34 *Trophic State Index of Weija Reservoir from June to October*

4.4 Estimated Nutrient Levels in the Weija Reservoir

Nitrates Level

The nitrates level in the Weija Reservoir was estimated at 11,784,118,344,415mg (11,784,118.34kg / 12,989.77tons). Levels of this magnitude in the Reservoir could lead to serious cases of eutrophication or even hyper-eutrophication.

Orthophosphates Level

The orthophosphates level in the Weija Reservoir was estimated at 9,302,486,317.44mg (9,302.47kg / 9.3tons). Levels of this magnitude in the Reservoir could lead to serious cases of eutrophication or even hyper-eutrophication

4.5 Algae Species Composition

A total of 52 genera belonging to 6 algae classes were reported. The algal composition included 16 genera of Bacillariophyceae, 21 genera of Chlorophyceae, 12 genera of Cyanophyceae, a Dinophyceae genus, and two genera of Euglenophyceae as shown in Table 4.14. As a result, the sequence of dominance is among the classes of algae is Chlorophyceae (green algae) > Bacillariophyceae (diatoms) > Cyanophyceae (blue-green algae) > Euglenophyceae (euglenoids) > Dinophyceae (dinoflagellates). The abundance of Chlorophyceae is an indication that the Reservoir is eutrophic and the presence of relatively high number Cyanophyceans indicates that the Reservoir is polluted.

Table 4.14 **Composition of Various Algal Classes within the Weija Reservoir**.

No.	Class	Genera	% Genera Composition in Reservoir
1	Bacillariophyceae	16	30.77
2	Chlorophyceae	21	40.38
3	Cyanophyceae	12	23.08
4	Dinophyceae	1	1.92
5	Euglenophyceae	2	3.85
	Total	**52**	**100**

The Chlorophyceae were the most prevalent class (40.38%). Bacillariophyceae (30.77%), Cyanophyceae (23.08%), Euglenophyceae (3.85%), and Dinophyceae (1.92%) followed in declining order of abundance as shown in Figure 4.35.

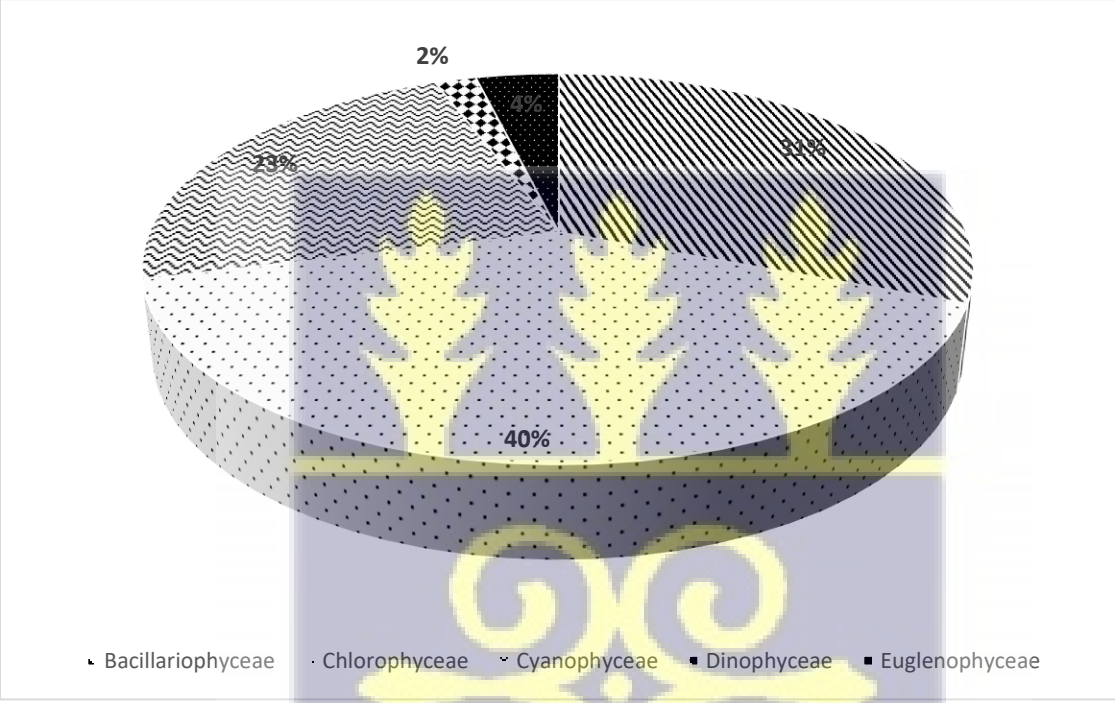

Figure 4.35 ***Percentage Contribution of the Various Algae Classes to the Reservoir***

Table 4.15 **List of Algae in the Weija Reservoir in June and October, 2022**

Algal Group		**Sample Points**											
		June						**October**					
	Class	**Ka**	**Kb**	**Ma**	**Mb**	**UWa**	**UWb**	**Ka**	**Kb**	**Ma**	**Mb**	**UWa**	**UWb**
Bacillariophyceae	*Asterionella*	+	+	+	+	+	+	+	+	+	+	+	+
	Aulacoseira	+	+	+	+	+	+	+	+	+	+	+	+
	Coconeis	+	+	+	+	+	+	+	+	+	+	+	+
	Cyclotella	+	+	+	+	+	+	+	+	-	-	+	+
	Cymbella	+	+	+	+	+	+	+	+	+	+	+	+
	Diatoma	+	+	-	-	-	-	+	+	-	-	-	-
	Eunotia	+	+	+	+	+	+	+	+	+	+	+	+
	Fragilaria	+	+	+	+	+	+	+	+	+	+	+	+
	Melosira	+	+	+	+	+	+	+	+	+	+	+	+
	Navicula	+	+	+	+	+	+	+	+	+	+	+	+
	Nitzschia	+	+	+	+	+	+	+	+	+	+	+	+
	Pinnularia	+	+	+	+	+	+	+	+	+	+	+	+
	Rhizosolenia	+	+	+	+	+	+	+	+	+	+	-	-
	Surrirella	+	+	+	+	+	+	+	+	+	+	+	+
	Synedra	+	+	+	+	+	+	+	+	+	+	+	+
	Tabellaria	+	+	+	+	+	+	+	+	+	+	+	+

	Actinastrum	+	+	+	+	+	+		+	+	+	+	+	+
	Ankistrodesmus	+	+	+	+	+	+		+	+	+	+	+	+
	Chlorella	+	+	+	+	+	+		+	+	+	+	+	+
	Closterium			+	+	+	+				+	+	+	+
	Coelastrum	+	+	+	+	+	+		+	+	+	+	+	+
	Gonatozygon	+	+	+	+	+	+		+	+	+	+	+	+
	Hydrodictyon	+	+	+	+	+	+		+	+	+	+	+	+
	Microspora	+	+	+	+	+	+		+	+	+	+	+	+
	Mongeotia	+	+	+	+	+	+		+	+	+	+	+	+
Chlorophyceae	*Oedogonium*	+	+	+	+	+	+		+	+	+	+	+	+
	Oocystis	+	+	+	+	+	+		+	+	+	+	+	+
	Pandorina	+	+	+	+	+	+		+	+	+	+	+	+
	Pediastrum	+	+	+	+	+	+		+	+	+	+	+	+
	Scenedesmus	+	+	+	+	+	+		+	+	+	+	+	+
	Spirogyra	+	+	+	+	+	+		+	+	+	+	+	+
	Straurastrum	+	+	+	+	+	+		+	+	+	+	-	-
	Tetraedron	+	+	+	+	+	+		+	+	+	+	+	+
	Tribonema	+	+	+	+	+	+		+	+	-	-	-	-
	Ulothrix	+	+	+	+	+	+		+	+	+	+	+	+
	Volvox	+	+	+	+	+	+		+	+	+	+	+	+
	Zygnema	+	+	+	+	+	+		+	+	+	+	+	+

	Anabaena	+	+	+	+	+	+		+	+	+	+	+	+
	Anabaenopsis	+	+	+	+	+	+		+	+	+	+	+	+
	Anacystis	+	+	+	+	+	+		+	+	+	+	+	+
	Aphanocapsa	+	+	+	+	-	-		+	+	+	+	-	-
	Arthrospira	+	+	+	+	-	-		+	+	+	+	-	-
	Gomphosphaeria	+	+	+	+	+	+		+	+	+	+	+	+
Cyanophyceae	*Merismopedia*	+	+	+	+	+	+		+	+	+	+	+	+
	Microcystis	+	+	+	+	+	+		+	+	+	+	+	+
	Oscillatoria	+	+	+	+	+	+		+	+	+	+	+	+
	Planktolyngbya	+	+	+	+	+	+		+	+	+	+	+	+
	Planktothrix	+	+	+	+	+	+		+	+	+	+	+	+
	Spirulina	+	+	+	+	+	+		+	+	+	+	+	+
Dinophyceae	*Peridinium*	+	+	+	+	+	+		+	+	+	+	+	+
Euglenophyceae	*Euglena*	+	+	+	+	+	+		+	+	+	+	+	+
	Phacus	+	+	-	-	+	+		+	+	-	-	+	+

KEYS: (+) Present; (-) Absent; (Ka) Kalabule Dam Point A; (Kb) Kalabule Dam Point B; (Ma) Machigani Point A; (Mb) Machigani Point B; (UWa) Upper Weija Point A; (UWb) Upper Weija Point B

4.6.1 Class Bacillariophyceae

A total of sixteen (16) genera were identified within the study period, comprising *of Asterionella, Aulacoseira, Coconeis, Cyclotella, Cymbella, Diatoma, Eunotia, Fragilaria, Melosira, Navicula, Nitzschia, Pinnularia, Rhizosolenia, Surrirella, Synedra* and *Tabellaria*

4.6.2 Class Chlorophyceae

A total of twenty-one (21) genera of Chlorophyceae were identified within the study period comprising of genera such as *Scenedesmus, Pediastrum, Chlorella, Ulothrix* and *Ankistrodesmus*. *Ulothrix*.

4.6.3 Class Cyanophyceae

A total of twelve (12) genera of the Cyanophycean taxa was identified in June and December of 2022 consisting of *Anabaena, Anabaenopsis, Anacystis, Aphanocapsa, Arthrospira, Gomphosphaeria, Merismopedia, Microcystis, Oscillatoria, Planktolyngbya, Planktothrix* and *Spirulina*

4.6.4 Class Dinophyceae

Peridinium sp. was the only member of this class identified in the study period

4.6.5 Class Euglenophyceae

Two members of this class namely; *Euglena* and *Phacus* were identified within the study period.

5.0 DISCUSSION

5.1 Morphometry

Surface Area and Water Holding Capacity of Reservoir

The Weija Dam was erected over the Densu River in Weija in 1977 to meet the ever-increasing need for hydroelectric power and water for household, industrial, and agricultural reasons. The Reservoir was built largely to supply household and industrial water to the western section of the Greater Accra metropolitan region, but it is also utilized for agriculture and fishing (Ansah-Asare & Asante, 1998). Anonymous (1997) stated that the maximum designed surface area and volume of the Reservoir was 20.5km^2 and 143,115,000m^3 respectively. However, in this study, surface area and the volume of the Reservoir were 19,330,988.38m^2 (19.33km^2) and 96,900,899.14m^3 respectively. The surface area of the Reservoir has reduced by 5.71% while that of the volume has reduced by 32.29% as per the initial design for the Reservoir. Per the effective storage capacity, the Weija Reservoir which is estimated at around 133 million m^3, the volume of the Reservoir has reduced by 27.14%. The reduction of the surface area could be as a result of the land use land cover changes that have occurred around the Reservoir over the years. Most of the vegetation around the area has been converted into settlements. This is corroborated by a study conducted by Adjei, Adjei, Obuobie & Odai (2019) and Attua, Ayamga & Pabi (2014). In the same study conducted by Adjei, Adjei, Obuobie & Odai (2019) it was indicated that between 1986 and 2018, the land use and land cover surrounding the Weija Reservoir changed substantially. The majority of the shrubs and grassland used to protect the lake have been converted to habitation and barren ground, which is expected to have an impact on the Reservoir's sustainability. Between 1986 and 2018, the settlement and bare ground area around the Weija Reservoir more than doubled, while shrub and grassland areas nearly vanished. With regards to the volume, the 32.29% reduction could

have been caused by evaporation where high temperatures and low rainfall can cause water to evaporate from the surface of the Reservoir, reducing its overall volume. Also, trees and vegetation in the catchment that can bring about a cooling effect are lacking. Changes in precipitation patterns and increased temperatures as a result of climate change can be a major factor to changes in the volume of the Weija Reservoir. Another cause could be water abstraction for treatment and distribution to the citizenry in the sense that if water is being withdrawn from the Reservoir at a higher rate than it is being replenished, the volume of the Reservoir will shrink. Iradukunda & Bwambale (2021) states that sediments accumulate in Reservoirs over time, displacing available storage volume if the water in the Reservoir is carrying a high amount of sediment, it can deposit on the bottom of the Reservoir, reducing the overall volume of the Reservoir and its surface area. Nukpezah (2012) also stated, with the spotlight being on the Weija Reservoir, that high sedimentation rates reduced lake and Reservoir volume which caused issues with water quantity and availability for irrigation, among other home and commercial uses.

The shoreline length measured 24200m in length (24.2km). Shoreline length is important because it measures how much a body of water interacts with the surrounding land. With a shoreline of 24200m, it can be concluded that there is a lot of shorelines available around the Reservoir for human activities, such as settlement construction, which exposes the shoreline to erosion and the Reservoir to external nutrient loading and increased rate of evaporation during high temperatures due to the removal of vegetation that has a shading effect. As a result, both the quality and quantity are in jeopardy. Also, the calculated shoreline development was 1.55. The ratio of the length of the coastline to a circle whose size is the same as the lake's is known as shoreline development. The shoreline development value of a complete circle is 1. Based on the value obtained, it may be inferred that, the level of irregularity of the shoreline was another contributing factor to the

reduction in surface area and volume of the Reservoir. There has been more shoreline accessible for the construction of settlements which has also led to a greater exposure to shoreline erosion. As erosion occurs, more sediments are washed into the Reservoir, resulting in high sedimentation which in turn reduces the effective capacity of the Reservoir.

5.2 Physico-Chemical Characterization

Temperature Variation in the Mixed Layer and Along the Depth Profile

Primary production in Reservoirs is influenced by temperature, which also has an impact on other aquatic physiological and metabolic activities including eating and mobility as well as the dispersion of the organisms (Singh, 2015; Lewis, 2000; Dhanam et al., 2016). There were no significant differences at the sample points. The significant differences were observed across the months. Many freshwater biomes studied indicated that seasonal variations in phytoplankton are strongly controlled by water temperature. Temperature values were relatively high in the mixed layer. This could be attributed to climate change resulting from rising air temperatures, which increase heat transfer to the water surface, decreased ice cover and snowpack, which results in longer and warmer exposure of the water surface to the sun and increased atmospheric carbon dioxide (CO_2), which has a warming effect on surface waters. Studies conducted by Hall *et, al.* (2018), Magnuson (2000) and Buxton *et, al.* (2018) showed significant relationships between climate change and high Reservoir temperatures. Also, the shoreline development of 1.55 gives a lot of room for encroachment which will lead to the removal of vegetation which is necessary for cooling the Reservoir and its catchment. Vegetation helps regulate water temperature by providing shade and reducing the amount of solar radiation that is absorbed by the water. The loss of vegetation can increase the water's albedo, or reflectivity, leading to increased solar radiation and

warming of the water. It is also important to note that trees and other vegetation transpire water into the atmosphere, which cools the water through evaporation. The loss of vegetation can reduce the cooling effect of evapotranspiration, leading to increased water temperature. These were the findings obtained from a study conducted by Robinson (2006).

Along the depth profile, generally there was no significance in temperature with the exception of a few depths in specific sample points. A steady decrease in temperature was observed with increasing depth. Temperature variations remained uniform throughout the study period. The changes in temperature with increasing depth at the various sample points were minimal. The decreasing temperature with increasing depth in the Reservoir can be attributed primarily to the process of stratification, where the water column is divided into different layers. This stratification is maintained by differences in water temperature, which in turn is affected by factors such as solar radiation, air temperature, wind, and mixing processes. A study conducted by Kipp & Weitkamp (2003) supports the deductions made based on the findings in this study.

DO Distribution in the Mixed Layer and Along the Depth Profile

Dissolved oxygen controls an aquatic ecosystem's health and protects aquatic life (Chang, 2002). Aquatic habitats acquire dissolved oxygen from the atmosphere and photosynthesis. Dissolved oxygen levels decrease as a result of things like aerobic bacteria respiration, dead sediments decomposing, and so on (Mulani et, al., 2009). Diverse rates of decomposition of dead macrophytes and other organic waste that enter the Lake, as well as the varied vegetative cover that determines water aeration, may be the cause of significant variances in DO levels during the sample months. Dissolved oxygen values were relatively low in the mixed layer from June 2022 to November 2022 and this could be attributed to the lake being eutrophic as shown in Figure 4.34. The eutrophication process leads to an increase in nutrients, such as nitrogen and phosphorus, leads

to an increase in primary productivity and growth of aquatic plants and algae. This in turn led to in an increase in organic matter and a decrease in DO levels recorded. Studies have confirmed the relationship between low DO levels and eutrophication in lakes and other aquatic systems. A study published in the Journal of Environmental Quality in 2019 found that eutrophication was a major driver of low DO levels in a large number of lakes in the United States (Batt et al., 2019). Another study published in the Journal of Limnology in 2020 found that eutrophication was a significant factor in the development of hypoxia in a lake in northern Italy (Di Bella et al., 2020).

With respect to DO distribution along the depth profile, a gradual decrease in DO along the depth profile was observed. It can be deduced that the deeper waters could be hypoxic (low oxygen) or anoxic (no oxygen), which can result in stress or death of aquatic species that require oxygen to survive. Generally, DO levels were low during the study period plus, levels were lower with increasing depth. In the absence of oxygen, organic matter will undergo anaerobic degradation, which can produce toxic substances and release nutrients and into the water column that will exacerbate the eutrophication situation in the Reservoir. The reduction in DO with increasing depth could be attributed decomposition rates of organic matter, leading to higher demand for oxygen. Stevenson (2015) stated that low dissolved oxygen (DO) levels are often associated with the hypolimnion (lower layer) in a lake or Reservoir because the hypolimnion is typically the layer with the lowest mixing and circulation, leading to reduced oxygen replenishment from surface waters. This statement was buttressed by Spencer & Forward (2002). The hypolimnion is also the layer where organic matter accumulates and undergoes decomposition, leading to higher oxygen demand. As a result, low DO levels in the hypolimnion can limit the survival and growth of aquatic life. The low levels of DO record pose a major risk to the quality of water in the Reservoir.

Temperature-DO Relationship Along the Depth Profile

It was observed that there was correlation between temperature and DO, in that, both parameters decreased with increasing depth even though the rate of decrease for temperature was relatively lower than that of DO. Generally, there was no significance in temperature variations with respect to depth but there was significance in DO variation with respect to depth. This indicates that, the least change in temperature along the depth profile can cause a drastic change in DO which will lead to the thermocline effect. The thermocline effect in the Reservoir can have significant implications on the physical, chemical, and biological processes that occur within its ecosystem. The thermocline can create a barrier that limits the exchange of oxygen between the surface and deeper waters, leading to low oxygen levels in the hypolimnion and potentially affecting the survival of aquatic species, it can restrict the mixing of nutrients between the surface and deeper waters, affecting the rate of nutrient cycling and the productivity of the lake ecosystem. Again, the thermocline can also restrict the penetration of light, which is necessary for photosynthesis, and limit the growth of phytoplankton and other aquatic plants. It can also lead to the formation of "dead zones" where the lack of mixing and low oxygen levels can lead to the buildup of harmful substances, such as nutrients and pollutants, and affect the quality of the water.

Nutrient Distribution Along the Depth Profile

Along the depth profile, no distinct trend was seen, however the orthophosphate content was greatest near the water-sediment interface (6m – 8m). Also, generally, increases in nitrates were observed along the depth profile. This may be the result of the sediments' release of orthophosphate and nitrates in anoxic conditions, as shown earlier by the decline in DO along the depth profile. When DO is low, more nutrients are released. These nutrients build up in the hypolimnion, where they are stored until an overturn releases them all into the water column, causing eutrophication.

In this study, estimated nitrates level in the Reservoir over the study period was 11,784,118,344,415mg (11,784,118.34kg / 12,989.77tons) and estimated orthophosphates level in the Reservoir was 9,302,486,317.44mg (9,302.47kg / 9.3tons). The Reservoir's high nutrient content might cause severe eutrophication or possibly hyper-eutrophication which will in turn cause rapid growth of algae, which will lead to the formation of algal bloom. This can lead to decreased water quality, reduced oxygen levels, and the death of fish and other aquatic life (Anderson & Giblin, 1996). The decomposition of dead algae can deplete the dissolved oxygen levels in the water, leading to anaerobic conditions that are harmful to aquatic life. Eutrophication can reduce the value of a Reservoir for human use. Studies done by Schindler (1977) and Weathers & Smart (2011) show that high nutrient content in water bodies can lead to eutrophication, which can result in lower water quality. This can increase the cost of water treatment, as more resources may be needed to remove pollutants and harmful substances from the water before it can be safely used for drinking, irrigation, or other purposes. The high amounts of nutrients currently present in the Reservoir will require a lot funds to be pumped into its treatment before the water is distributed to the citizenry. Excess amounts of nutrient in the Reservoir reduces the quality of the water in the Reservoir.

5.3 Sediment Characterization

The high amounts of total phosphorus in the sediments of the Reservoir could be attributed to excessive phosphorus loading from the agricultural activities as well discharge of domestic waste into the Reservoir. The Reservoir sediments have the ability to retain phosphorus therefore the more phosphorus is released into the Reservoir as a result of anthropogenic activities, the more the sediments are able to retain. Also, high phosphorus in sediments with low DO at the sediment-

water interface creates redox condition for release of nutrients under anoxic conditions. From Appendix 11 as well, the p-value to determine whether or not organic matter has an effect on total nitrogen for the regression analysis was greater than 0.05, therefore, organic matter has an effect on total phosphorus. The analysis indicates that for every unit change in organic matter, phosphorus will increase by a coefficient of 0.0046. Per this finding, organic matter content is also a major contributing factor to the total phosphorus amounts recorded.

The nitrogen content of the sediments in the Reservoir may be as a result of the presence of nitrogen fixing algae (blue-green algae) such as *Anabaena, Oscillatoria, Aphanocapsa*. The nitrogen fixing capabilities are well documented in studies done by Fay & Fogg (1962), Fogg (1942) and Cameron (1958). The presence of these cyanophycaeae as shown in Table 4.15, coupled with run-off from neighbouring containing excess fertilizer can be the major source of nitrogen in the Reservoir. Studies done by Hill & Bolgrien (2011), Wollheim, Vörösmarty, Bouwman, Green, Harrison, Linder, Peterson, Seitzinger & Syvitski (2008) and Shen, Zhong, Huang & Chen, (2015) indicate that increasing Nitrogen loading of lakes from agricultural lands is connected with human Nitrogen application to crops in the form of fertilizers and manures. Several studies have found that applying fertilizer N at levels higher than crop N removal rates increases Nitrogen losses to surface water bodies (Zhang, Wang, Liu, Lei, Liu, He, Zhai, Ren, Liu, 2015; Choi, Lee & Ro, 2003; Zhou, Gu, Schlesinger & Ju, 2016).

5.4 Trophic State Index of Weija Reservoir

The average TSI (TP) for the 6-month period of the study was 79.33. In accordance with Table 2.1, the Reservoir is hyper-eutrophic and is attributed with, light limited productivity as well as dense algae and macrophytes. It was also observed that TSI (TP) = TSI (SD) > TSI (CHL) with

TSI (SD) having an average value of 68.61 over the study period and TSI (CHL) having an average value of 38.29. This relationship indicates that, the Reservoir is eutrophic but its eutrophic state cannot be attributed to algae dominance but rather non-algal particulates limiting light attenuation. The eutrophication of the Reservoir could then be attributed to high sedimentation as per the shoreline development of 1.55 determined in this study. Even though in general the Reservoir can be described as eutrophic in accordance with indices in Table 2.1, there were some slight variations in the values obtained month on month for the 6-month period. Continuous input of nutrients from nearby crop fields and other anthropogenic activities in the Reservoir and its catchment, which boosts the growth of phytoplankton and other aquatic plants in the Reservoir has also contributed to its current state. According to Kuma & Ashley (2008), leached agrochemicals used by farmers in the immediate vicinity of the Reservoir are immediate sources of contamination. Overfishing of algae-feeding fish deprives the water of a critical component of its natural purifying process. Inadequate or non-existent human waste management conditions persist in rapidly increasing metropolitan townships. This observation is found to be true per the Trophic Status findings as well as the high nitrogen values recorded in this study. Carvalho & Kirika (2003) states that the quantity of phosphorus in an aquatic water body is the most important factor in determining its trophic status. Any change in the phosphorus content of a freshwater environment might affect its trophic status. They also add that the decrease in nutrient input decreases phosphorus content in lakes, which affects phytoplankton growth. The average total phosphorus TSI over the duration of the study was 79.33, accounting for the Reservoir being hyper-eutrophic based solely on this parameter. The results obtained in this study buttress the point raised by Carvalho & Kirika (2003) about the phosphorus content being directly proportional to the trophic status of the Reservoir.

5.5 Algae Species Composition

In June and October 2022, 52 genera from five (5) algae classes were observed and recorded in Weija Reservoir. Except for *Aphanocapsa* and *Arthrospira* (Cyanophyceae), which were missing in Upper Weija in both months, algae groups were uniformly distributed in the sample locations in both months. *Straurastrum* (Chorophyceae) was missing in Upper Weija in October, as was *Tribonema* (Chorophyceae) in both Machigani and Upper Weija. For both months, Machigani was devoid of *Phacus* (Euglenophyceae). This dominance of Chlorophytes in this study correlates to usual trends in tropical water bodies documented by Adesalu, 2010; Kadiri & Omozusi, 2002. The presence of Cyanophyceans such as *Microcystis* and *Anabaena*, as well as other phytoplankton such as *Actinastrum*, *Oscillatoria*, and *Closterium*, indicates that the Reservoir is polluted. Phytoplankton species identified belonged to four major groups, blue-green algae, green algae, diatoms and flagellates. The blue-green algae were the most dominant species and accounted for 81.2% of the total phytoplankton in the area in a study done by Oduro-Koranteng (2003). This is in contrast to the findings in this study. A total of five (5) classes were identified and among them, the green algae were the dominant ones with the diatoms being the second most dominant and finally, the blue-green algae being the third most dominant. Changes in water temperature, pH, nutrient levels, and other environmental factors over the years could have altered the conditions for growth of different algal species, leading to changes in dominance. Also, as the algae compete in the Reservoir for nutrients and light, the relative success of different species can change. Predation by zooplankton and other consumers can impact the populations of different algal species, leading to changes in their relative dominance. All the above factors could have contributed to the change in dominance from 2003 and till date. Anthropogenic activities such as runoff from agricultural activities, swimming and cleaning in and around the Reservoir all

contribute to rising abundance of these organisms (Anago, Esenowo, & Ugwumba 2013). Egborge (2006) published a similar study on Cyanophyceans showing pollution which corroborate the results obtained in this study.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main purpose of the study was to combine GIS and measurements of physico-chemical variables along a depth profile to map out the bathymetry and to model nutrient level in the Reservoir. Based on that, a 3D (DEM) model of the Reservoir was constructed and the current surface area and water holding capacity was determined. The Trophic State Index (TSI) of the Reservoir was also calculated and algal species composition was identified.

It was found from the study that, the surface area and water holding capacity of the Reservoir had reduced in comparison to its original state when it was constructed. Reduction in water holding capacity by 27.14% due was most likely to sedimentation and climate change. This was supported by the high TSI (SD) but low TSI (CHL) measured. In terms of quality, Reservoir is eutrophic due to high TSI (TP) of 79.33 measured.

There were significant differences among the study areas namely, Kalabule Dam, Machigani and Upper Weija with respect to temperature, DO levels and nutrient content along the depth profile. There was no significance in temperature variations with respect to depth but there was significance in DO variation with respect to depth. This indicated that, the least change in temperature along the depth profile could cause a drastic change in DO leading to the thermocline effect. The trophic state index calculated showed that the Reservoir was highly eutrophic and this correlated with the high nutrient content recorded during the study.

The study also showed that there has been a change in algal species dominance in the Reservoir over the last 20 years. The dominance of chlorophytes and presence cyanophyceans indicated that the Reservoir was heavily polluted.

These results throw light on the level of pollution of the Reservoir as a result of anthropogenic activities and its effect on water treatment and distribution since the Reservoir serves as a source of water to the citizenry.

6.2 Summary of Key Findings Relative to the Study Objectives

Table 3 **Summary of Key Findings Relative to the Study Objectives**

No.	Key Objectives	Summary of Findings
1.	Construct a 3D (DEM) model of the Reservoir to determine the current water holding capacity.	a. Surface area was 19,330,988.38m^2 (19.33km^2) b. Water holding Capacity was 96,900,899.14m^3 c. Shoreline length was 24200m (24.2km) d. Shoreline Development was 1.55
2.	Determine the temperature variation along a depth profile.	a. There was no significant change in temperature with respect to depth. b. A steady decrease in temperature was observed with increasing depth.
3.	Determine the dissolved oxygen (DO) distribution along a depth profile	a. There was significance in DO distribution along the depth profile b. There decrease in DO level along the depth profile was observed.
4.	Determine the nutrient distribution along a depth profile	a. Orthophosphate content was greatest near the water-sediment interface and significant along the depth profile. b. Increases in nitrates were observed along the depth profile but were not significant c. Estimated nitrates level in the Reservoir over the study period was 11,784,118,344,415mg (11,784,118.34kg / 12,989.77tons) d. Estimated orthophosphates level in the Reservoir over the study period was 9,302,486,317.44mg (9,302.47kg / 9.3tons)
5.	Measure the Trophic State Index (TSI) of the Reservoir	a. The average TSI (TP) for the 6-month period of the study was 79.33. b. The average TSI (SD) for the 6-month period of the study was 68.61 c. The average TSI (CHL) for the 6-month period of the study was 38.29 d. The relation; TSI (TP) = TSI (SD) > TSI (CHL) showed that the eutrophic state of the Reservoir was a result of heavy siltation

6.	Identify algal species and compare with prior studies to establish if there are changes in species composition, if any.	a. Five (5) Classes were identified: Chlorophyceae (green algae), Bacillariophyceae (diatoms), Cyanophyceae (blue-green algae), Euglenophyceae (euglenoids), Dinophyceae (dinoflagellates) b. Order of dominance was; Chlorophyceae (green algae) > Bacillariophyceae (diatoms) > Cyanophyceae (blue-green algae) > Euglenophyceae (euglenoids) > Dinophyceae (dinoflagellates) c. Study also showed that there has been a change in algal species dominance in the Reservoir over the last 20 years

6.3 Recommendations

Arising from the results of the study the following recommendations;

Recommendations for Further Studies

1. With respect to the physico-chemical parameters, this study focused on the southern entry points of the Reservoir so further studies can be done from the other entry points to be able to get a holistic overview of the state of the Reservoir.
2. A study on the relationship between the expanding human habitats and socio-economic activities around the Reservoir and nutrient load of the Reservoir should be done in order to identify the various drivers and pressures that have led to its current state.
3. Further studies should be done determine the algae abundance and composition along the depth profile so as to determine whether there is a correlation between the nutrients along the depth and the algae present at those depths.

General Recommendations

1. The environmental department of the Weija Gbawe district assembly should increase environmental education for community inhabitants around the Reservoir. Communities must be made aware that environmental protection is a shared responsibility.
2. The Weija Gbawe district assembly should ensure that there are proper systems in place for waste disposal, collection and management in communities surrounding the reservoir.
3. The Weija Gbawe district assembly should undertake periodic clearing of aquatic weeds in the Reservoir since they contribute to the high organic matter content of the Reservoir when they decompose.
4. Buffer zone policies need to be enforced by the government through empowering of local authorities by providing the necessary resources needed, in order to reduce the rate of encroachment on the shores of the Reservoir.

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APPENDICES

APPENDIX 1

Table Showing Electrical Conductivity Variations along the Depth Profile of Sample Points A & B of Upper Weija over the 6-month Study Period

		UPPER WEIJA					
		JUNE	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**
	Depth (m)	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**
UWa	**0**	416±3.113	376±2.206	397±1.651	415±5.163	298±3.53	376±5.567
	1	417±1.076	376±2.484	398±2.947	417±7.200	297±3.01	372±6.043
	2	417±0.151	376±3.687	400±3.873	418±5.163	296±1.51	371±3.551
	3	418±1.447	376±4.613	399±4.151	418±4.238	297±3.01	378±5.043
	4	419±2.373	376±5.706	400±5.354	418±5.534	300±3.48	375±2.519
	5	417±2.651	376±2.669	401±6.280	416±6.460	304±3.36	379±5.396
	6	426±3.854	377±0.169	399±7.373	417±6.738	297±2.81	372±4.843
	Depth (m)	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**
UWb	**0**	408±6.667	377±8.020	397±4.117	415±2.212	296±4.225	380±1.062
	1	408±7.143	378±4.496	399±4.593	443±7.355	300±5.368	384±6.205
	2	409±4.651	376±6.004	400±2.101	421±6.974	300±4.987	384±5.824
	3	410±6.143	379±3.496	400±3.593	422±9.958	298±7.971	382±8.808
	4	413±3.619	378±4.972	399±1.069	418±8.117	299±6.130	383±6.967
	5	415±4.496	379±7.849	399±3.946	419±9.926	299±7.939	383±8.776
	6	421±5.943	378±7.296	399±3.393	419±3.736	297±1.749	381±2.586
	7	421±6.776	378±8.129	399±4.226	420±8.307	299±6.320	383±7.157

APPENDIX 2

Table Showing Electrical Conductivity Variations along the Depth Profile of Sample Points A & B of Machigani over the 6-month Study Period

				MACHIGANI			
		JUNE	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**
	Depth (m)	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**
	0	443±0.962	374±6.343	397±3.151	416±7.406	351±5.850	428±2.143
Ma	**1**	443±6.105	375±1.851	399±6.643	419±4.369	352±3.813	427±2.976
	2	448±5.724	374±5.343	398±7.119	419±3.869	341±2.887	418±5.734
	3	452±5.708	375±5.819	397±3.996	420±3.813	334±4.184	411±5.476
	4	465±1.867	376±2.696	398±3.443	422±5.850	337±5.110	414±6.773
	5	456±8.676	376±2.143	398±4.276	422±3.813	341±5.387	412±1.680
	6	481±2.486	378±2.976	401±7.034	422±2.887	348±6.591	425±2.606
	7	492±7.057	381±5.734	406±6.776	424±4.184	379±7.517	456±2.884
	8	449±2.867	381±5.476	403±8.073	432±5.110	344±8.610	421±4.087
	Depth (m)	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**
Mb	**0**	443±3.252	374±2.262	397±9.593	417±5.232	309±6.623	386±5.049
	1	444±8.395	374±7.405	399±5.403	419±4.679	311±7.549	388±4.123
	2	444±8.014	376±7.024	400±8.879	419±5.512	309±8.642	385±5.420
	3	445±7.998	376±7.008	399±4.387	421±8.270	309±5.605	386±6.346
	4	448±4.157	375±3.167	401±7.879	421±8.012	310±5.105	387±6.623
	5	450±10.996	377±9.976	400±8.355	420±9.309	323±5.049	406±7.827
	6	462±4.776	376±3.786	399±5.232	420±4.216	330±7.086	407±8.753
	7	475±9.347	380±8.357	398±4.679	423±5.142	346±5.049	424±9.846

APPENDIX 3

Table Showing Electrical Conductivity Variations along the Depth Profile of Sample Points A & B of Kalabule Dam over the 6-month Study Period

		KALABULE DAM					
		JUNE	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**
	Depth (m)	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**
Ka	**0**	514±1.925	388±3.225	397±4.461	413±4.215	382±5.020	395±7.310
	1	514±4.068	391±5.368	404±6.604	419±6.358	376±0.830	384±3.120
	2	514±3.687	387±4.987	403±6.223	420±5.977	363±7.306	376±9.596
	3	507±6.671	383±7.971	399±9.207	421±8.961	361±4.814	373±7.104
	4	516±4.830	385±6.130	401±7.366	420±7.120	252±7.306	265±9.596
	Depth (m)	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**	**E.C. (µS/cm)**
Kb	**0**	507±7.306	401±6.114	397±9.596	418±4.804	373±2.087	388±4.739
	1	484±4.814	407±8.606	398±6.072	719±2.767	372±3.383	385±6.036
	2	465±7.306	411±5.082	398±2.949	420±1.841	354±4.309	370±0.943
	3	503±3.782	401±1.959	397±2.396	421±3.137	342±4.587	358±1.869
	4	504±0.659	397±1.406	400±3.230	422±4.063	351±5.790	367±2.147
	5	499±0.106	395±2.239	404±5.988	423±4.341	384±6.716	404±3.351
	6	501±0.939	390±4.997	404±5.730	424±5.544	464±7.809	473±4.276

APPENDIX 4

Table Showing Salinity Variations along the Depth Profile of Sample Points A & B of Upper Weija over the 6-month Study Period

		UPPER WEIJA					
		JUNE	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**
	Depth (m)	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**
UWa	**0**	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	1	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	2	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	3	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	4	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	5	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	6	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	Depth (m)	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**
UWb	**0**	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	1	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	2	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	3	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	4	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	5	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	6	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	7	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00

APPENDIX 5

Table Showing Salinity Variations along the Depth Profile of Sample Points A & B of Machigani over the 6-month Study Period

		MACHIGANI					
		JUNE	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**
	Depth (m)	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**
	0	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
Ma	**1**	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	2	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	3	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	4	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	5	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	6	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	7	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	8	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	Depth (m)	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**
Mb	**0**	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	1	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	2	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	3	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	4	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.10±0.00	0.20±0.00
	5	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	6	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	7	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00

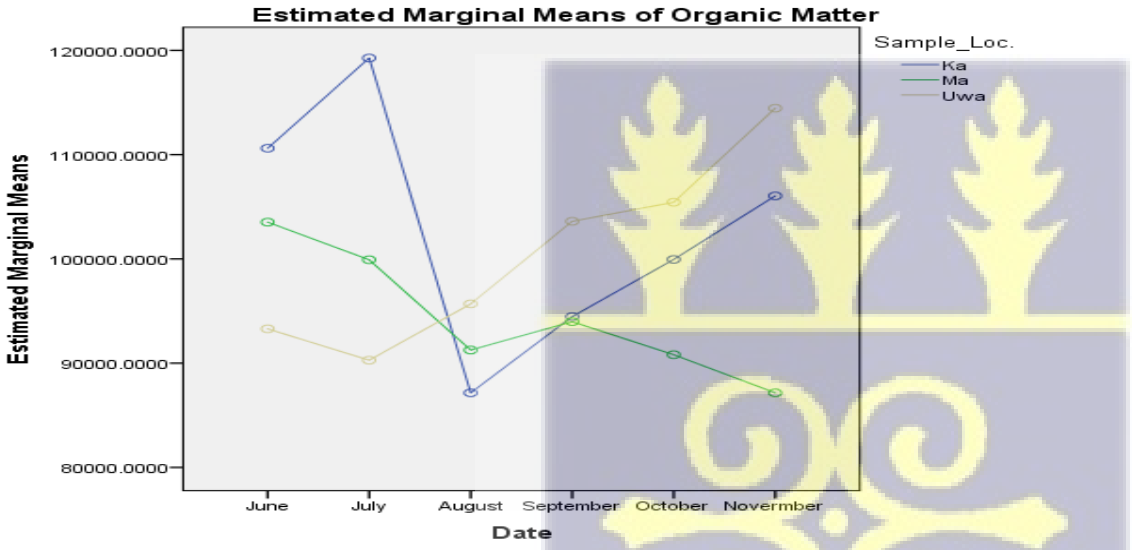
APPENDIX 6

Table Showing Salinity Variations along the Depth Profile of Sample Points A & B of Kalabule Dam over the 6-month Study Period

		KALABULE DAM					
		JUNE	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**
	Depth (m)	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**
Ka	**0**	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	1	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	2	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	3	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	4	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	Depth (m)	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**	**Sal. (ppt)**
Kb	**0**	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	1	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	2	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	3	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	4	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	5	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00
	6	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00	0.20±0.00

APPENDIX 7

Plot Profile for Organic Matter Content



APPENDIX 8 Statistical Pairwise Comparison Table for Total Nitrogen

Dependent Variable: Total Nitrogen

(I) Date						
(I) Date		Mean Difference			95% Confidence Interval for Difference[b]	
June	(J) Date	(I-J)	Std. Error	Sig.[b]	Lower Bound	Upper Bound
June	July	263.608	387.949	.505	-551.443	1078.659
July	August	-1003.333*	387.949	.019	-1818.384	-188.283
	September	-443.333	387.949	.268	-1258.384	371.717
	October	-910.000*	387.949	.031	-1725.051	-94.949
	Novermber	-1190.000*	387.949	.007	-2005.051	-374.949
July	June	-263.608	387.949	.505	-1078.659	551.443
August	August	-1266.941*	387.949	.004	-2081.992	-451.891
	September	-706.941	387.949	.085	-1521.992	108.109
	October	-1173.608*	387.949	.007	-1988.659	-358.557
	Novermber	-1453.608*	387.949	.001	-2268.659	-638.557
August	June	1003.333*	387.949	.019	188.283	1818.384
September	July	1266.941*	387.949	.004	451.891	2081.992
	September	560.000	387.949	.166	-255.051	1375.051
	October	93.333	387.949	.813	-721.717	908.384
	Novermber	-186.667	387.949	.636	-1001.717	628.384
September	June	443.333	387.949	.268	-371.717	1258.384
October	July	706.941	387.949	.085	-108.109	1521.992
	August	-560.000	387.949	.166	-1375.051	255.051
	October	-466.667	387.949	.245	-1281.717	348.384
	Novermber	-746.667	387.949	.070	-1561.717	68.384
October	June	910.000*	387.949	.031	94.949	1725.051
Novermber	July	1173.608*	387.949	.007	358.557	1988.659

	August	-93.333	387.949	.813	-908.384	721.717
	September	466.667	387.949	.245	-348.384	1281.717
	Novermber	-280.000	387.949	.480	-1095.051	535.051
Novermber	June	1190.000*	387.949	.007	374.949	2005.051
Based on	July	1453.608*	387.949	.001	638.557	2268.659
estimated	August	186.667	387.949	.636	-628.384	1001.717
marginal	September	746.667	387.949	.070	-68.384	1561.717
means	October	280.000	387.949	.480	-535.051	1095.051
*. The mean difference is significant at the .05 level.						
b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						

APPENDIX 9 Statistical Pairwise Comparison Table for Total Phosphorus in Sample Months

Pairwise Comparisons

Dependent Variable: Total Phosphorus

(I) Date	(J) Date	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
June	July	-127.236	76.821	.115	-288.632	34.160
	August	-8.405	76.821	.914	-169.801	152.991
	September	83.713	76.821	.290	-77.683	245.109
	October	174.868*	76.821	.035	13.472	336.264
	Novermber	-43.528	76.821	.578	-204.924	117.868
July	June	127.236	76.821	.115	-34.160	288.632
	August	118.831	76.821	.139	-42.565	280.227
	September	210.949*	76.821	.013	49.553	372.345
	October	302.104*	76.821	.001	140.708	463.499
	Novermber	83.708	76.821	.290	-77.688	245.104
August	June	8.405	76.821	.914	-152.991	169.801
	July	-118.831	76.821	.139	-280.227	42.565
	September	92.118	76.821	.246	-69.277	253.514
	October	183.273*	76.821	.028	21.877	344.669
	Novermber	-35.123	76.821	.653	-196.519	126.273
September	June	-83.713	76.821	.290	-245.109	77.683
	July	-210.949*	76.821	.013	-372.345	-49.553
	August	-92.118	76.821	.246	-253.514	69.277
	October	91.154	76.821	.251	-70.241	252.550
	Novermber	-127.241	76.821	.115	-288.637	34.154
October	June	-174.868*	76.821	.035	-336.264	-13.472
	July	-302.104*	76.821	.001	-463.499	-140.708

	August	-183.273*	76.821	.028	-344.669	-21.877
	September	-91.154	76.821	.251	-252.550	70.241
	Novermber	-218.396*	76.821	.011	-379.792	-57.000
Novermber	June	43.528	76.821	.578	-117.868	204.924
	July	-83.708	76.821	.290	-245.104	77.688
	August	35.123	76.821	.653	-126.273	196.519
	September	127.241	76.821	.115	-34.154	288.637
	October	218.396*	76.821	.011	57.000	379.792

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

APPENDIX 10 Statistical Pairwise Comparison Table for Total Phosphorus in Sample Locations

Pairwise Comparisons

Dependent Variable: Total Phosphorus

(I) Sample_Loc.	(J) Sample_Loc.	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Ka	Ma	-121.438*	54.321	.038	-235.562	-7.314
	Uwa	-318.612*	54.321	.000	-432.736	-204.487
Ma	Ka	121.438*	54.321	.038	7.314	235.562
	Uwa	-197.173*	54.321	.002	-311.297	-83.049
Uwa	Ka	318.612*	54.321	.000	204.487	432.736
	Ma	197.173*	54.321	.002	83.049	311.297

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

APPENDIX 11 Two-Way ANOVA Table for Water Analysis at Kalabule Dam

Tests of Between-Subjects Effects[a]							
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Temperature	48.439[b]	41	1.181	44.083	.000	.984
	DO	138.108[c]	41	3.368	49.162	.000	.985
	Phosphorus	.426[d]	41	.010	18.437	.000	.962
	Nitrogen	27872.519[e]	41	679.818	13.566	.000	.949
Intercept	Temperature	47616.241	1	47616.241	1776725.400	.000	1.000
	DO	1000.465	1	1000.465	14601.427	.000	.998
	Phosphorus	.737	1	.737	1307.798	.000	.978
	Nitrogen	724047.918	1	724047.918	14448.535	.000	.998
Depth	Temperature	3.194	6	.532	19.864	.000	.799
	DO	41.596	6	6.933	101.180	.000	.953
	Phosphorus	.140	6	.023	41.522	.000	.893
	Nitrogen	210.181	6	35.030	.699	.652	.123
Period	Temperature	38.400	5	7.680	286.569	.000	.979
	DO	77.404	5	15.481	225.937	.000	.974
	Phosphorus	.071	5	.014	25.032	.000	.807
	Nitrogen	25127.055	5	5025.411	100.283	.000	.944
Depth * Period	Temperature	1.461	30	.049	1.817	.054	.645
	DO	15.074	30	.502	7.333	.000	.880
	Phosphorus	.214	30	.007	12.657	.000	.927
	Nitrogen	579.166	30	19.306	.385	.995	.278
Error	Temperature	.804	30	.027			
	DO	2.056	30	.069			
	Phosphorus	.017	30	.001			
	Nitrogen	1503.366	30	50.112			
Total	Temperature	52639.893	72				

	DO	1309.105	72				
	Phosphorus	1.119	72				
	Nitrogen	820815.143	72				
Corrected Total	Temperature	49.243	71				
	DO	140.163	71				
	Phosphorus	.443	71				
	Nitrogen	29375.885	71				

a. Location = Kalabule Dam

b. R Squared = .984 (Adjusted R Squared = .961)

c. R Squared = .985 (Adjusted R Squared = .965)

d. R Squared = .962 (Adjusted R Squared = .910)

e. R Squared = .949 (Adjusted R Squared = .879)

APPENDIX 12 Multiple Comparison Test Table for Water Analysis at Kalabule Dam

Multiple Comparisons[a]																					
LSD			Temperature					DO					Phosphorus							Nitrogen	
						95% Confidence Interval					95% Confidence Interval				95% Confidence Interval					95% Confidence Interval	
Location	Depth		Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Kalabule Dam	0	1	.2058*	.06683	.004	.0693	.3423	1.0525*	.10686	.000	.8343	1.2707	.0033	.00969	.733	-.0165	.0231	2.7431	2.88999	.350	-3.1591	8.6452
		2	.4092*	.06683	.000	.2727	.5457	1.4667*	.10686	.000	1.2484	1.6849	-.0033	.00969	.733	-.0231	.0165	1.1574	2.88999	.692	-4.7447	7.0596
		3	.4975*	.06683	.000	.3610	.6340	1.8442*	.10686	.000	1.6259	2.0624	-.0125	.00969	.207	-.0323	.0073	2.0718	2.88999	.479	-3.8304	7.9739
		4	.5642*		.000	.4277	.7007	2.0608*	.10686	.000	1.8426	2.2791	-.0158	.00969	.113	-.0356	.0040	.4745	2.88999	.871	-5.4276	6.3767
		5	.6150*	.08185	.000	.4478	.7822	2.1150*	.13088	.000	1.8477	2.3823	-.0033	.01187	.781	-.0276	.0209	-3.5880	3.53950	.319	-10.8166	3.6407
		6	.5550*	.08185	.000	.3878	.7222	2.4050*	.13088	.000	2.1377	2.6723	-.1633*	.01187	.000	-.1876	-.1391	-1.0417	3.53950	.771	-8.2703	6.1870
	1	0	-.2058*	.06683	.004	-.3423	-.0693	-1.0525*	.10686	.000	-1.2707	-.8343	-.0033	.00969	.733	-.0231	.0165	-2.7431	2.88999	.350	-8.6452	3.1591
		2	.2033*	.06683	.005	.0668	.3398	.4142*	.10686	.001	.1959	.6324	-.0067	.00969	.497	-.0265	.0131	-1.5856	2.88999	.587	-7.4878	4.3165
		3	.2917*	.06683	.000	.1552	.4282	.7917*	.10686	.000	.5734	1.0099	-.0158	.00969	.113	-.0356	.0040	-.6713	2.88999	.818	-6.5734	5.2308
		4	.3583*	.06683	.000	.2218	.4948	1.0083*	.10686	.000	.7901	1.2266	-.0192	.00969	.057	-.0390	.0006	-2.2685	2.88999	.439	-8.1707	3.6336

		5	.4092*	.08185	.000	.2420	.5763	1.0625*	.13088	.000	.7952	1.3298	-.0067	.01187	.578	-.0309	.0176	-6.3310	3.53950	.084	-13.55596	.8976
		6	.3492*	.08185	.000	.1820	.5163	1.3525*	.13088	.000	1.0852	1.6198	-.1667*	.01187	.000	-.1909	-.1424	-3.7847	3.53950	.293	-11.01133	3.4439
	2	0	-.4092*	.06683	.000	-.5457	-.2727	-1.4667*	.10686	.000	-1.6849	-1.2484	.0033	.00969	.733	-.0165	.0231	-1.1574	2.88999	.692	-7.0596	4.7447
		1	-.2033*	.06683	.005	-.3398	-.0668	-.4142*	.10686	.001	-.6324	-.1959	.0067	.00969	.497	-.0131	.0265	1.5856	2.88999	.587	-4.3165	7.4878
		3	.0883	.06683	.196	-.0482	.2248	.3775*	.10686	.001	.1593	.5957	-.0092	.00969	.352	-.0290	.0106	.9144	2.88999	.754	-4.9878	6.8165
		4	.1550*	.06683	.027	.0185	.2915	.5942*	.10686	.000	.3759	.8124	-.0125	.00969	.207	-.0323	.0073	-.6829	2.88999	.815	-6.5850	5.2193
		5	.2058*	.08185	.018	.0387	.3730	.6483*	.13088	.000	.3810	.9156	.0000	.01187	1.000	-.0242	.0242	-4.7454	3.53950	.190	-11.97440	2.4833
		6	.1458	.08185	.085	-.0213	.3130	.9383*	.13088	.000	.6710	1.2056	-.1600*	.01187	.000	-.1842	-.1358	-2.1991	3.53950	.539	-9.4277	5.0295
	3	0	-.4975*	.06683	.000	-.6340	-.3610	-1.8442*	.10686	.000	-2.0624	-1.6259	.0125	.00969	.207	-.0073	.0323	-2.0718	2.88999	.479	-7.9739	3.8304
		1	-.2917*	.06683	.000	-.4282	-.1552	-.7917*	.10686	.000	-1.00099	-.5734	.0158	.00969	.113	-.0040	.0356	.6713	2.88999	.818	-5.2308	6.5734
		2	-.0883	.06683	.196	-.2248	.0482	-.3775*	.10686	.001	-.5957	-.1593	.0092	.00969	.352	-.0106	.0290	-.9144	2.88999	.754	-6.8165	4.9878
		4	.0667	.06683	.326	-.0698	.2032	.2167	.10686	.052	-.0016	.4349	-.0033	.00969	.733	-.0231	.0165	-1.5972	2.88999	.585	-7.4994	4.3049
		5	.1175	.08185	.161	-.0497	.2847	.2708*	.13088	.047	.0035	.5381	.0092	.01187	.446	-.0151	.0334	-5.6597	3.53950	.120	-12.88883	1.5689
		6	.0575	.08185	.488	-.1097	.2247	.5608*	.13088	.000	.2935	.8281	-.1508*	.01187	.000	-.1751	-.1266	-3.1134	3.53950	.386	-10.34220	4.1152

	4	0	-.5642*	.06683	.000	-.7007	-.4277	-2.0608*	.10686	.000	-2.2791	-1.8426	.0158	.00969	.113	-.0040	.0356	-.4745	2.88999	.871	-6.3767	5.4276
		1	-.3583*	.06683	.000	-.4948	-.2218	-1.0083*	.10686	.000	-1.2266	-.7901	.0192	.00969	.057	-.0006	.0390	2.2685	2.88999	.439	-3.6336	8.1707
		2	-.1550*	.06683	.027	-.2915	-.0185	-.5942*	.10686	.000	-.8124	-.3759	.0125	.00969	.207	-.0073	.0323	.6829	2.88999	.815	-5.2193	6.5850
		3	-.0667	.06683	.326	-.2032	.0698	-.2167	.10686	.052	-.4349	.0016	.0033	.00969	.733	-.0165	.0231	1.5972	2.88999	.585	-4.3049	7.4994
		5	.0508	.08185	.539	-.1163	.2180	.0542	.13088	.682	-.2131	.3215	.0125	.01187	.301	-.0117	.0367	-4.0625	3.53950	.260	-11.2911	3.1661
		6	-.0092	.08185	.912	-.1763	.1580	.3442*	.13088	.013	.0769	.6115	-.1475*	.01187	.000	-.1717	-.1233	-1.5162	3.53950	.671	-8.7448	5.7124
	5	0	-.6150*	.08185	.000	-.7822	-.4478	-2.1150*	.13088	.000	-2.3823	-1.8477	.0033	.01187	.781	-.0209	.0276	3.5880	3.53950	.319	-3.6407	10.8166
		1	-.4092*	.08185	.000	-.5763	-.2420	-1.0625*	.13088	.000	-1.3298	-.7952	.0067	.01187	.578	-.0176	.0309	6.3310	3.53950	.084	-.8976	13.5596
		2	-.2058*	.08185	.018	-.3730	-.0387	-.6483*	.13088	.000	-.9156	-.3810	.0000	.01187	1.000	-.0242	.0242	4.7454	3.53950	.190	-2.4833	11.9740
		3	-.1175	.08185	.161	-.2847	.0497	-.2708*	.13088	.047	-.5381	-.0035	-.0092	.01187	.446	-.0334	.0151	5.6597	3.53950	.120	-1.5689	12.8883
		4	-.0508	.08185	.539	-.2180	.1163	-.0542	.13088	.682	-.3215	.2131	-.0125	.01187	.301	-.0367	.0117	4.0625	3.53950	.260	-3.1661	11.2911
		6	-.0600	.09452	.530	-.2530	.1330	.2900	.15113	.065	-.0186	.5986	-.1600*	.01370	.000	-.1880	-.1320	2.5463	4.08706	.538	-5.8006	10.8932
	6	0	-.5550*	.08185	.000	-.7222	-.3878	-2.4050*	.13088	.000	-2.6723	-2.1377	.1633*	.01187	.000	.1391	.1876	1.0417	3.53950	.771	-6.1870	8.2703
		1	-.3492*	.08185	.000	-.5163	-.1820	-1.3525*	.13088	.000	-1.6198	-1.0852	.1667*	.01187	.000	.1424	.1909	3.7847	3.53950	.293	-3.4439	11.0133

		2	-.1458	.08185	.085	-.3130	.0213	-.9383*	.13088	.000	-1.20256	-.6710	.1600*	.01187	.000	.1358	.1842	2.1991	3.53950	.539	-5.0295	9.4277
		3	-.0575	.08185	.488	-.2247	.1097	-.5608*	.13088	.000	-.8281	-.2935	.1508*	.01187	.000	.1266	.1751	3.1134	3.53950	.386	-4.1152	10.3420
		4	.0092	.08185	.912	-.1580	.1763	-.3442*	.13088	.013	-.6115	-.0769	.1475*	.01187	.000	.1233	.1717	1.5162	3.53950	.671	-5.7124	8.7448
		5	.0600	.09452	.530	-.1330	.2530	-.2900	.15113	.065	-.5986	.0186	.1600*	.01370	.000	.1320	.1880	-2.5463	4.08706	.538	-10.8932	5.8006

APPENDIX 13 Two-Way ANOVA Table for Water Analysis at Machigani

Tests of Between-Subjects Effects[a]							
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Temperature	71.090[b]	47	1.513	15.596	.000	.939
	DO	154.767[c]	47	3.293	6.962	.000	.872
	Phosphorus	.215[d]	47	.005	6.123	.000	.857
	Nitrogen	896135.870[e]	47	19066.721	1.088	.386	.516
Intercept	Temperature	70880.010	1	70880.010	730831.625	.000	1.000
	DO	1551.784	1	1551.784	3280.930	.000	.986
	Phosphorus	.857	1	.857	1147.349	.000	.960
	Nitrogen	1832035.091	1	1832035.091	104.547	.000	.685
Depth	Temperature	4.890	7	.699	7.203	.000	.512
	DO	33.367	7	4.767	10.078	.000	.595
	Phosphorus	.010	7	.001	1.922	.087	.219
	Nitrogen	62027.548	7	8861.078	.506	.826	.069
Period	Temperature	64.084	5	12.817	132.151	.000	.932
	DO	105.639	5	21.128	44.671	.000	.823
	Phosphorus	.192	5	.038	51.359	.000	.843
	Nitrogen	546660.688	5	109332.138	6.239	.000	.394
Depth * Period	Temperature	2.117	35	.060	.624	.927	.313
	DO	15.761	35	.450	.952	.555	.410
	Phosphorus	.013	35	.000	.500	.983	.267
	Nitrogen	287447.634	35	8212.790	.469	.990	.255
Error	Temperature	4.655	48	.097			
	DO	22.703	48	.473			
	Phosphorus	.036	48	.001			
	Nitrogen	841128.398	48	17523.508			
Total	Temperature	70955.755	96				

	DO	1729.254	96				
	Phosphorus	1.108	96				
	Nitrogen	3569299.359	96				
Corrected Total	Temperature	75.745	95				
	DO	177.470	95				
	Phosphorus	.251	95				
	Nitrogen	1737264.268	95				

a. Location = Machigani

b. R Squared = .939 (Adjusted R Squared = .878)

c. R Squared = .872 (Adjusted R Squared = .747)

d. R Squared = .857 (Adjusted R Squared = .717)

e. R Squared = .516 (Adjusted R Squared = .042)

APPENDIX 14 Multiple Comparison Test Table for Water Analysis at Machigani

Multiple																				
LSD			Temperature					DO					Phosphorus					Nitrogen				
						95% Confidence Interval					95% Confidence Interval					95% Confidence Interval				95% Confidence Interval	
Location	Depth		Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Machigani	0	1	.2683*	.12714	.040	.0127	.5240	1.0533*	.28076	.000	.4888	1.6178	.0017	.01116	.882	-.0208	.0241	-1.7825	54.04243	.974	-110.4421	106.8771
		2	.2892*	.12714	.027	.0335	.5448	1.3200*	.28076	.000	.7555	1.8845	.0125	.01116	.268	-.0099	.0349	-11.0879	54.04243	.838	-119.7475	97.5717
		3	.4267*	.12714	.002	.1710	.6823	1.4458*	.28076	.000	.8813	2.0103	.0150	.01116	.185	-.0074	.0374	-23.5764	54.04243	.665	-132.2360	85.0832
		4	.7292*	.12714	.000	.4735	.9848	1.4867*	.28076	.000	.9222	2.0512	.0200	.01116	.079	-.0024	.0424	-35.1042	54.04243	.519	-143.7638	73.5554
		5	.5417*	.12714	.000	.2860	.7973	1.5367*	.28076	.000	.9722	2.1012	.0108	.01116	.336	-.0116	.0333	-46.3889	54.04243	.395	-155.0485	62.2707
		6	.5825*	.12714	.000	.3269	.8381	1.6608*	.28076	.000	1.0963	2.2253	.0058	.01116	.603	-.0166	.0283	-60.7982	54.04243	.266	-169.4578	47.8614
		7	.6575*	.12714	.000	.4019	.9131	2.1933*	.28076	.000	1.6288	2.7578	-.0150	.01116	.185	-.0374	.0074	-72.9861	54.04243	.183	-181.6457	35.6735
	1	0	-.2683*	.12714	.040	-.5240	-.0127	-1.0533*	.28076	.000	-1.6178	-.4888	-.0017	.01116	.882	-.0241	.0208	1.7825	54.04243	.974	-106.8771	110.4421
		2	.0208	.12714	.871	-.2348	.2765	.2667	.28076	.347	-.2978	.8312	.0108	.01116	.336	-.0116	.0333	-9.3054	54.04243	.864	-117.9650	99.3542
		3	.1583	.12714	.219	-.0973	.4140	.3925	.28076	.169	-.1720	.9570	.0133	.01116	.238	-.0091	.0358	-21.7939	54.04243	.689	-130.4535	86.8657

	4	.4608*	.12714	.001	.2052	.7165	.4333	.28076	.129	-.1312	.9978	.0183	.01116	.107	-.0041	.0408	-33.3217	54.04243	.540	-141.9813	75.3379
	5	.2733*	.12714	.037	.0177	.5290	.4833	.28076	.092	-.0812	1.0478	.0092	.01116	.415	-.0133	.0316	-44.6064	54.04243	.413	-153.2660	64.0532
	6	.3142*	.12714	.017	.0585	.5698	.6075*	.28076	.035	.0430	1.1720	.0042	.01116	.710	-.0183	.0266	-59.0157	54.04243	.280	-167.6753	49.6439
	7	.3892*	.12714	.004	.1335	.6448	1.1400*	.28076	.000	.5755	1.7045	-.0167	.01116	.142	-.0391	.0058	-71.2036	54.04243	.194	-179.8632	37.4560
2	0	-.2892*	.12714	.027	-.5448	-.0335	-1.3200*	.28076	.000	-1.8845	-.7555	-.0125	.01116	.268	-.0349	.0099	11.0879	54.04243	.838	-97.5717	119.7475
	1	-.0208	.12714	.871	-.2765	.2348	-.2667	.28076	.347	-.8312	.2978	-.0108	.01116	.336	-.0333	.0116	9.3054	54.04243	.864	-99.3542	117.9650
	3	.1375	.12714	.285	-.1181	.3931	.1258	.28076	.656	-.4387	.6903	.0025	.01116	.824	-.0199	.0249	-12.4885	54.04243	.818	-121.1481	96.1711
	4	.4400*	.12714	.001	.1844	.6956	.1667	.28076	.556	-.3978	.7312	.0075	.01116	.505	-.0149	.0299	-24.0163	54.04243	.659	-132.6759	84.6433
	5	.2525	.12714	.053	-.0031	.5081	.2167	.28076	.444	-.3478	.7812	-.0017	.01116	.882	-.0241	.0208	-35.3010	54.04243	.517	-143.9606	73.3586
	6	.2933*	.12714	.025	.0377	.5490	.3408	.28076	.231	-.2237	.9053	-.0067	.01116	.553	-.0291	.0158	-49.7104	54.04243	.362	-158.3700	58.9492
	7	.3683*	.12714	.006	.1127	.6240	.8733*	.28076	.003	.3088	1.4378	-.0275*	.01116	.017	-.0499	-.0051	-61.8982	54.04243	.258	-170.5578	46.7614
3	0	-.4267*	.12714	.002	-.6823	-.1710	-1.4458*	.28076	.000	-2.0103	-.8813	-.0150	.01116	.185	-.0374	.0074	23.5764	54.04243	.665	-85.0832	132.2360
	1	-.1583	.12714	.219	-.4140	.0973	-.3925	.28076	.169	-.9570	.1720	-.0133	.01116	.238	-.0358	.0091	21.7939	54.04243	.689	-86.8657	130.4535
	2	-.1375	.12714	.285	-.3931	.1181	-.1258	.28076	.656	-.6903	.4387	-.0025	.01116	.824	-.0249	.0199	12.4885	54.04243	.818	-96.1711	121.1481

	4	.3025*	.12714	.021	.0469	.5581	.0408	.28076	.885	-.5237	.6053	.0050	.01116	.656	-.0174	.0274	-11.5278	54.04243	.832	-120.1874	97.1318
	5	.1150	.12714	.370	-.1406	.3706	.0908	.28076	.748	-.4737	.6553	-.0042	.01116	.710	-.0266	.0183	-22.8125	54.04243	.675	-131.4721	85.8471
	6	.1558	.12714	.226	-.0998	.4115	.2150	.28076	.448	-.3495	.7795	-.0092	.01116	.415	-.0316	.0133	-37.2219	54.04243	.494	-145.8814	71.4377
	7	.2308	.12714	.076	-.0248	.4865	.7475*	.28076	.011	.1830	1.3120	-.0300*	.01116	.010	-.0524	-.0076	-49.4097	54.04243	.365	-158.0693	59.2499
4	0	-.7292*	.12714	.000	-.9848	-.4735	-1.4867*	.28076	.000	-2.0512	-.9222	-.0200	.01116	.079	-.0424	.0024	35.1042	54.04243	.519	-73.5554	143.7638
	1	-.4608*	.12714	.001	-.7165	-.2052	-.4333	.28076	.129	-.9978	.1312	-.0183	.01116	.107	-.0408	.0041	33.3217	54.04243	.540	-75.3379	141.9813
	2	-.4400*	.12714	.001	-.6956	-.1844	-.1667	.28076	.556	-.7312	.3978	-.0075	.01116	.505	-.0299	.0149	24.0163	54.04243	.659	-84.6433	132.6759
	3	-.3025*	.12714	.021	-.5581	-.0469	-.0408	.28076	.885	-.6053	.5237	-.0050	.01116	.656	-.0274	.0174	11.5278	54.04243	.832	-97.1318	120.1874
	5	-.1875	.12714	.147	-.4431	.0681	.0500	.28076	.859	-.5145	.6145	-.0092	.01116	.415	-.0316	.0133	-11.2847	54.04243	.835	-119.9443	97.3749
	6	-.1467	.12714	.254	-.4023	.1090	.1742	.28076	.538	-.3903	.7387	-.0142	.01116	.210	-.0366	.0083	-25.6941	54.04243	.637	-134.3537	82.9655
	7	-.0717	.12714	.576	-.3273	.1840	.7067*	.28076	.015	.1422	1.2712	-.0350*	.01116	.003	-.0574	-.0126	-37.8819	54.04243	.487	-146.5415	70.7777
5	0	-.5417*	.12714	.000	-.7973	-.2860	-1.5367*	.28076	.000	-2.1012	-.9722	-.0108	.01116	.336	-.0333	.0116	46.3889	54.04243	.395	-62.2707	155.0485
	1	-.2733*	.12714	.037	-.5290	-.0177	-.4833	.28076	.092	-1.0478	.0812	-.0092	.01116	.415	-.0316	.0133	44.6064	54.04243	.413	-64.0532	153.2660
	2	-.2525	.12714	.053	-.5081	.0031	-.2167	.28076	.444	-.7812	.3478	.0017	.01116	.882	-.0208	.0241	35.3010	54.04243	.517	-73.3586	143.9606

	3	-.1150	.12714	.370	-.3706	.1406	-.0908	.28076	.748	-.6553	.4737	.0042	.01116	.710	-.0183	.0266	22.8125	54.04243	.675	-85.8471	131.4721
	4	.1875	.12714	.147	-.0681	.4431	-.0500	.28076	.859	-.6145	.5145	.0092	.01116	.415	-.0133	.0316	11.2847	54.04243	.835	-97.3749	119.9443
	6	.0408	.12714	.749	-.2148	.2965	.1242	.28076	.660	-.4403	.6887	-.0050	.01116	.656	-.0274	.0174	-14.4094	54.04243	.791	-123.0689	94.2502
	7	.1158	.12714	.367	-.1398	.3715	.6567*	.28076	.024	.0922	1.2212	-.0258*	.01116	.025	-.0483	-.0034	-26.5972	54.04243	.625	-135.2568	82.0624
6	0	-.5825*	.12714	.000	-.8381	-.3269	-1.6608*	.28076	.000	-2.2253	-1.0963	-.0058	.01116	.603	-.0283	.0166	60.7982	54.04243	.266	-47.8614	169.4578
	1	-.3142*	.12714	.017	-.5698	-.0585	-.6075*	.28076	.035	-1.1720	-.0430	-.0042	.01116	.710	-.0266	.0183	59.0157	54.04243	.280	-49.6439	167.6753
	2	-.2933*	.12714	.025	-.5490	-.0377	-.3408	.28076	.231	-.9053	.2237	.0067	.01116	.553	-.0158	.0291	49.7104	54.04243	.362	-58.9492	158.3700
	3	-.1558	.12714	.226	-.4115	.0998	-.2150	.28076	.448	-.7795	.3495	.0092	.01116	.415	-.0133	.0316	37.2219	54.04243	.494	-71.4377	145.8814
	4	.1467	.12714	.254	-.1090	.4023	-.1742	.28076	.538	-.7387	.3903	.0142	.01116	.210	-.0083	.0366	25.6941	54.04243	.637	-82.9655	134.3537
	5	-.0408	.12714	.749	-.2965	.2148	-.1242	.28076	.660	-.6887	.4403	.0050	.01116	.656	-.0174	.0274	14.4094	54.04243	.791	-94.2502	123.0689
	7	.0750	.12714	.558	-.1806	.3306	.5325	.28076	.064	-.0320	1.0970	-.0208	.01116	.068	-.0433	.0016	-12.1879	54.04243	.823	-120.8475	96.4717
7	0	-.6575*	.12714	.000	-.9131	-.4019	-2.1933*	.28076	.000	-2.7578	-1.6288	.0150	.01116	.185	-.0074	.0374	72.9861	54.04243	.183	-35.6735	181.6457
	1	-.3892*	.12714	.004	-.6448	-.1335	-1.1400*	.28076	.000	-1.7045	-.5755	.0167	.01116	.142	-.0058	.0391	71.2036	54.04243	.194	-37.4560	179.8632
	2	-.3683*	.12714	.006	-.6240	-.1127	-.8733*	.28076	.003	-1.4378	-.3088	.0275*	.01116	.017	.0051	.0499	61.8982	54.04243	.258	-46.7614	170.5578

		3	-.2308	.12714	.076	-.4865	.0248	-.7475*	.28076	.011	-1.31320	-.1830	.0300*	.01116	.010	.0076	.0524	49.4097	54.04243	.365	-59.2499	158.0693
		4	.0717	.12714	.576	-.1840	.3273	-.7067*	.28076	.015	-1.27112	-.1422	.0350*	.01116	.003	.0126	.0574	37.8819	54.04243	.487	-70.7777	146.5415
		5	-.1158	.12714	.367	-.3715	.1398	-.6567*	.28076	.024	-1.22212	-.0922	.0258*	.01116	.025	.0034	.0483	26.5972	54.04243	.625	-82.0624	135.2568
		6	-.0750	.12714	.558	-.3306	.1806	-.5325	.28076	.064	-1.09770	.0320	.0208	.01116	.068	-.0016	.0433	12.1879	54.04243	.823	-96.4717	120.8475

APPENDIX 15 Two-Way ANOVA Table for Water Analysis at Upper Weija

Tests of Between-Subjects Effects[a]							
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Temperature	50.498[b]	47	1.074	.771	.807	.463
	DO	164.693[c]	47	3.504	18.459	.000	.954
	Phosphorus	3.261[d]	47	.069	8.681	.000	.907
	Nitrogen	32282.320[e]	47	686.858	5.257	.000	.855
Intercept	Temperature	64903.953	1	64903.953	46583.655	.000	.999
	DO	1490.079	1	1490.079	7849.315	.000	.995
	Phosphorus	1.046	1	1.046	130.920	.000	.757
	Nitrogen	1164998.543	1	1164998.543	8916.774	.000	.995
Depth	Temperature	25.917	7	3.702	2.657	.023	.307
	DO	32.307	7	4.615	24.312	.000	.802
	Phosphorus	.493	7	.070	8.807	.000	.595
	Nitrogen	404.202	7	57.743	.442	.870	.069
Period	Temperature	13.937	5	2.787	2.001	.098	.192
	DO	89.279	5	17.856	94.059	.000	.918
	Phosphorus	1.040	5	.208	26.031	.000	.756
	Nitrogen	27656.048	5	5531.210	42.335	.000	.834
Depth * Period	Temperature	8.301	35	.237	.170	1.000	.124
	DO	29.077	35	.831	4.376	.000	.785
	Phosphorus	2.253	35	.064	8.054	.000	.870
	Nitrogen	2037.633	35	58.218	.446	.992	.271
Error	Temperature	58.518	42	1.393			

	DO	7.973	42	.190			
	Phosphorus	.336	42	.008			
	Nitrogen	5487.404	42	130.652			
Total	Temperature	68672.936	90				
	DO	1791.481	90				
	Phosphorus	4.391	90				
	Nitrogen	1261344.213	90				
Corrected Total	Temperature	109.016	89				
	DO	172.666	89				
	Phosphorus	3.596	89				
	Nitrogen	37769.724	89				

a. Location = Upper Weija

b. R Squared = .463 (Adjusted R Squared = -.137)

c. R Squared = .954 (Adjusted R Squared = .902)

d. R Squared = .907 (Adjusted R Squared = .802)

e. R Squared = .855 (Adjusted R Squared = .692)

APPENDIX 16 Multiple Comparison Test Table for Water Analysis at Upper Weija

Multiple																					
LSD			Temperature					DO							Phosphorus					Nitrogen	
						95% Confidence Interval					95% Confidence Interval				95% Confidence Interval					95% Confidence Interval	
Location	Depth		Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Upper Weija	0	1	.8067	.48188	.102	-.1658	1.7791	1.0533*	.17787	.000	.6944	1.4123	.0033	.03650	.928	-.0703	.0770	1.4931	4.66641	.751	-7.9241	10.9103
		2	1.3050*	.48188	.010	.3325	2.2775	1.5775*	.17787	.000	1.2185	1.9365	.0192	.03650	.602	-.0545	.0928	-3.8542	4.66641	.414	-13.2714	5.5630
		3	1.5692*	.48188	.002	.5967	2.5416	1.5175*	.17787	.000	1.1585	1.8765	-.0433	.03650	.242	-.1170	.0303	2.0833	4.66641	.658	-7.3339	11.5005
		4	1.1175*	.48188	.025	.1450	2.0900	1.6483*	.17787	.000	1.2894	2.0073	.0117	.03650	.751	-.0620	.0853	-.4630	4.66641	.921	-9.8802	8.9542
		5	.2575	.48188	.596	-.7150	1.2300	1.5525*	.17787	.000	1.1935	1.9115	.0167	.03650	.650	-.0570	.0903	1.6782	4.66641	.721	-7.7390	11.0954
		6	.3350	.48188	.491	-.6375	1.3075	1.6183*	.17787	.000	1.2594	1.9773	.0050	.03650	.892	-.0687	.0787	1.3310	4.66641	.777	-8.0862	10.7482
		7	1.1517	.59019	.058	-.0394	2.3427	2.3499*	.21785	.000	1.9103	2.7896	-.2850*	.04470	.000	-.3752	-.1948	-3.8657	5.71517	.502	-15.3994	7.6679
	1	0	-.8067	.48188	.102	-1.7791	.1658	-1.0533*	.17787	.000	-1.4123	-.6944	-.0033	.03650	.928	-.0770	.0703	-1.4931	4.66641	.751	-10.9103	7.9241
		2	.4983	.48188	.307	-.4741	1.4708	.5242*	.17787	.005	.1652	.8831	.0158	.03650	.667	-.0578	.0895	-5.3472	4.66641	.258	-14.7644	4.0700
		3	.7625	.48188	.121	-.2100	1.7350	.4642*	.17787	.013	.1052	.8231	-.0467	.03650	.208	-.1203	.0270	.5903	4.66641	.900	-8.8269	10.0075

	4	.3108	.48188	.522	-.6616	1.2833	.5950*	.17787	.002	.2360	.9540	.0083	.03650	.820	-.0653	.0820	-1.9560	4.66641	.677	-11.3732	7.4612
	5	-.5492	.48188	.261	-1.5216	.4233	.4992*	.17787	.008	.1402	.8581	.0133	.03650	.717	-.0603	.0870	.1852	4.66641	.969	-9.2320	9.6024
	6	-.4717	.48188	.333	-1.4441	.5008	.5650*	.17787	.003	.2060	.9240	.0017	.03650	.964	-.0720	.0753	-.1620	4.66641	.972	-9.5792	9.2552
	7	.3450	.59019	.562	-.8460	1.5360	1.2966*	.21785	.000	.8569	1.7362	-.2883*	.04470	.000	-.3785	-.1981	-5.3588	5.71517	.354	-16.8925	6.1749
2	0	-1.3050*	.48188	.010	-2.2775	-.3325	-1.5775*	.17787	.000	-1.9365	-1.2185	-.0192	.03650	.602	-.0928	.0545	3.8542	4.66641	.414	-5.5630	13.2714
	1	-.4983	.48188	.307	-1.4708	.4741	-.5242*	.17787	.005	-.8831	-.1652	-.0158	.03650	.667	-.0895	.0578	5.3472	4.66641	.258	-4.0700	14.7644
	3	.2642	.48188	.586	-.7083	1.2366	-.0600	.17787	.738	-.4190	.2990	-.0625	.03650	.094	-.1362	.0112	5.9375	4.66641	.210	-3.4797	15.3547
	4	-.1875	.48188	.699	-1.1600	.7850	.0708	.17787	.692	-.2881	.4298	-.0075	.03650	.838	-.0812	.0662	3.3912	4.66641	.471	-6.0260	12.8084
	5	-1.0475*	.48188	.035	-2.0200	-.0750	-.0250	.17787	.889	-.3840	.3340	-.0025	.03650	.946	-.0762	.0712	5.5324	4.66641	.242	-3.8848	14.9496
	6	-.9700	.48188	.051	-1.9425	.0025	.0408	.17787	.820	-.3181	.3998	-.0142	.03650	.700	-.0878	.0595	5.1852	4.66641	.273	-4.2320	14.6024
	7	-.1533	.59019	.796	-1.3444	1.0377	.7724*	.21785	.001	.3328	1.2121	-.3042*	.04470	.000	-.3944	-.2140	-.0116	5.71517	.998	-11.5452	11.5221
3	0	-1.5692*	.48188	.002	-2.5416	-.5967	1.5175*	.17787	.000	-1.8765	-1.1585	.0433	.03650	.242	-.0303	.1170	-2.0833	4.66641	.658	-11.5005	7.3339
	1	-.7625	.48188	.121	-1.7350	.2100	-.4642*	.17787	.013	-.8231	-.1052	.0467	.03650	.208	-.0270	.1203	-.5903	4.66641	.900	-10.0075	8.8269
	2	-.2642	.48188	.586	-1.2366	.7083	.0600	.17787	.738	-.2990	.4190	.0625	.03650	.094	-.0112	.1362	-5.9375	4.66641	.210	-15.3547	3.4797

	4	-.4517	.48188	.354	-1.4241	.5208	.1308	.17787	.466	-.2281	.4898	.0550	.03650	.139	-.0187	.1287	-2.5463	4.66641	.588	-11.9635	6.8709
	5	-1.3117*	.48188	.009	-2.2841	-.3392	.0350	.17787	.845	-.3240	.3940	.0600	.03650	.108	-.0137	.1337	-.4051	4.66641	.931	-9.8223	9.0121
	6	-1.2342*	.48188	.014	-2.2066	-.2617	.1008	.17787	.574	-.2581	.4598	.0483	.03650	.193	-.0253	.1220	-.7523	4.66641	.873	-10.1695	8.6649
	7	-.4175	.59019	.483	-1.6085	.7735	.8324*	.21785	.000	.3928	1.2721	-.2417*	.04470	.000	-.3319	-.1515	-5.9491	5.71517	.304	-17.4827	5.5846
4	0	-1.1175*	.48188	.025	-2.0900	-.1450	-1.6483*	.17787	.000	-2.0073	-1.2894	-.0117	.03650	.751	-.0853	.0620	.4630	4.66641	.921	-8.9542	9.8802
	1	-.3108	.48188	.522	-1.2833	.6616	-.5950*	.17787	.002	-.9540	-.2360	-.0083	.03650	.820	-.0820	.0653	1.9560	4.66641	.677	-7.4612	11.3732
	2	.1875	.48188	.699	-.7850	1.1600	-.0708	.17787	.692	-.4298	.2881	.0075	.03650	.838	-.0662	.0812	-3.3912	4.66641	.471	-12.8084	6.0260
	3	.4517	.48188	.354	-.5208	1.4241	-.1308	.17787	.466	-.4898	.2281	-.0550	.03650	.139	-.1287	.0187	2.5463	4.66641	.588	-6.8709	11.9635
	5	-.8600	.48188	.082	-1.8325	.1125	-.0958	.17787	.593	-.4548	.2631	.0050	.03650	.892	-.0687	.0787	2.1412	4.66641	.649	-7.2760	11.5584
	6	-.7825	.48188	.112	-1.7550	.1900	-.0300	.17787	.867	-.3890	.3290	-.0067	.03650	.856	-.0803	.0670	1.7940	4.66641	.703	-7.6232	11.2112
	7	.0342	.59019	.954	-1.1569	1.2252	.7016*	.21785	.002	.2619	1.1412	-.2967*	.04470	.000	-.3869	-.2065	-3.4028	5.71517	.555	-14.9364	8.1309
5	0	-.2575	.48188	.596	-1.2300	.7150	-1.5525*	.17787	.000	-1.9115	-1.1935	-.0167	.03650	.650	-.0903	.0570	-1.6782	4.66641	.721	-11.0954	7.7390
	1	.5492	.48188	.261	-.4233	1.5216	-.4992*	.17787	.008	-.8581	-.1402	-.0133	.03650	.717	-.0870	.0603	-.1852	4.66641	.969	-9.6024	9.2320
	2	1.0475*	.48188	.035	.0750	2.0200	.0250	.17787	.889	-.3340	.3840	.0025	.03650	.946	-.0712	.0762	-5.5324	4.66641	.242	-14.9496	3.8848

	3	1.3117*	.48188	.009	.3392	2.2841	-.0350	.17787	.845	-.3940	.3240	-.0600	.03650	.108	-.1337	.0137	.4051	4.66641	.931	-9.0121	9.8223
	4	.8600	.48188	.082	-.1125	1.8325	.0958	.17787	.593	-.2631	.4548	-.0050	.03650	.892	-.0787	.0687	-2.1412	4.66641	.649	-11.5584	7.2760
	6	.0775	.48188	.873	-.8950	1.0500	.0658	.17787	.713	-.2931	.4248	-.0117	.03650	.751	-.0853	.0620	-.3472	4.66641	.941	-9.7644	9.0700
	7	.8942	.59019	.137	-.2969	2.0852	.7974*	.21785	.001	.3578	1.2371	-.3017*	.04470	.000	-.3919	-.2115	-5.5440	5.71517	.338	-17.0777	5.9897
6	0	-.3350	.48188	.491	-1.3075	.6375	-1.6183*	.17787	.000	-1.9773	-1.2594	-.0050	.03650	.892	-.0787	.0687	-1.3310	4.66641	.777	-10.7482	8.0862
	1	.4717	.48188	.333	-.5008	1.4441	-.5650*	.17787	.003	-.9240	-.2060	-.0017	.03650	.964	-.0753	.0720	.1620	4.66641	.972	-9.2552	9.5792
	2	.9700	.48188	.051	-.0025	1.9425	-.0408	.17787	.820	-.3998	.3181	.0142	.03650	.700	-.0595	.0878	-5.1852	4.66641	.273	-14.6024	4.2320
	3	1.2342*	.48188	.014	.2617	2.2066	-.1008	.17787	.574	-.4598	.2581	-.0483	.03650	.193	-.1220	.0253	.7523	4.66641	.873	-8.6649	10.1695
	4	.7825	.48188	.112	-.1900	1.7550	.0300	.17787	.867	-.3290	.3890	.0067	.03650	.856	-.0670	.0803	-1.7940	4.66641	.703	-11.2112	7.6232
	5	-.0775	.48188	.873	-1.0500	.8950	-.0658	.17787	.713	-.4248	.2931	.0117	.03650	.751	-.0620	.0853	.3472	4.66641	.941	-9.0700	9.7644
	7	.8167	.59019	.174	-.3744	2.0077	.7316*	.21785	.002	.2919	1.1712	-.2900*	.04470	.000	-.3802	-.1998	-5.1968	5.71517	.368	-16.7304	6.3369
7	0	-1.1517	.59019	.058	-2.3427	.0394	-2.3499*	.21785	.000	-2.7896	-1.9103	.2850*	.04470	.000	.1948	.3752	3.8657	5.71517	.502	-7.6679	15.3994
	1	-.3450	.59019	.562	-1.5360	.8460	-1.2966*	.21785	.000	-1.7362	-.8569	.2883*	.04470	.000	.1981	.3785	5.3588	5.71517	.354	-6.1749	16.8925
	2	.1533	.59019	.796	-1.0377	1.3444	-.7724*	.21785	.001	-1.2121	-.3328	.3042*	.04470	.000	.2140	.3944	.0116	5.71517	.998	-11.5221	11.5452

		3	.4175	.59019	.483	-.7735	1.6085	-.8324*	.21785	.000	-1.2721	-.3928	.2417*	.04470	.000	.1515	.3319	5.9491	5.71517	.304	-5.5846	17.4827
		4	-.0342	.59019	.954	-1.2252	1.1569	-.7016*	.21785	.002	-1.1412	-.2619	.2967*	.04470	.000	.2065	.3869	3.4028	5.71517	.555	-8.1309	14.9364
		5	-.8942	.59019	.137	-2.0852	.2969	-.7974*	.21785	.001	-1.2371	-.3578	.3017*	.04470	.000	.2115	.3919	5.5440	5.71517	.338	-5.9897	17.0777
		6	-.8167	.59019	.174	-2.0077	.3744	-.7316*	.21785	.002	-1.1712	-.2919	.2900*	.04470	.000	.1998	.3802	5.1968	5.71517	.368	-6.3369	16.7304

APPENDIX 17 Regression Analysis between Organic Matter and Total Phosphorus

Call:

lm(formula = Total_Phosphorus ~ Organic_Matter, data = Data1)

Residuals:

Min	1Q	Median	3Q	Max
-576.44	-191.77	-46.07	118.44	1108.16

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.004e+03	3.377e+02	2.974	0.00537	**
Organic_Matter	4.584e-03	3.348e-03	1.370	0.17981	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 345.1 on 34 degrees of freedom

Multiple R-squared: 0.05228, Adjusted R-squared: 0.02441

F-statistic: 1.876 on 1 and 34 DF, p-value: 0.1798