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THE ECOLOGICAL STATUS OF THE KETA LAGOON USING PHYSICOCHEMICAL AND BIOLOGICAL INDICATORS OF WATER QUALITY.

BY

PRISCILLA DANSO

10805316

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DECLARATION

This dissertation is the result of research work undertaken by Priscilla Danso in the Department of Marine and Fisheries Sciences, University of Ghana under the supervision of Dr. Edem Mahu and Mr Kweku Amoako Atta deDgraft-Johnson. I do hereby declare that the dissertation consists entirely of my work and that no part of it has been previously published or submitted for a degree or diploma elsewhere.

Signature: …………………… ………27/09/21……..…

Priscilla Danso Date

(Student)

Signature…… ……..… ………27/09/21………..

Dr. Edem Mahu Date

(Supervisor)

Signature……… ……..… ……27/09/21……………

Mr Kweku Amoako Atta deGraft-Johnson Date

(Co-supervisor)

ABSTRACT

The Keta Lagoon and its catchment areas are under the influence of intensive agriculture which depend heavily on agrochemical usage. It is necessary that, the quality of water in the lagoon is assessed to broaden our understanding of how the lagoon and its associated biota are responding to agro-related activities in its watershed. This study carried out a comprehensive assessment of the ecological status of the lagoon using physicochemical parameters (temperature, DO, turbidity, pH, nitrate, phosphate, silicate, ammonia), Trophic State Index and diversities of benthic macroinvertebrates and phytoplankton communities. The lagoon was partitioned into five zones (A to E) to depict the intensity of human impact as reflected through farming along the bank of the lagoon. Zone A is the area in close proximity to Anloga, Zone B, covers the mid-section of the lagoon and falls between Anloga and Woe, Zone C is main Woe area, Zone D represents the area between Woe and Afedome and finally Zone E which represents the area beyond Afedome extending towards Keta.

The average physicochemical parameters reported during the study showed that Zones A and B recorded the highest levels of pH, 9.6 ± 0.16 which was above the acceptable range levels by Ghana's EPA and USEPA (6.0 to 9.0). The least pH level was recorded for Zone C at 8.5 ± 0.03 which was within the acceptable range of pH. Dissolved oxygen levels measured was highest in Zone D (8.1 ± 0.26 mg/l) and least in Zone A (6.5 ± 0.13 mg/l), all within Ghana EPA and USEPA as well as the World Health Organization tolerable limits. Zones A recorded the higest nitrate values of 3.4 ± 0.03mg/l and least in Zone E, 1.9 ± 0.02 mg/l. All zones recorded nitrate levels that were above the Ghana and US EPA permissible ranges. Ammonia was highest in Zone A (0.12 ± 0.02 mg/l) and least in Zone E (0.03 ± 0.02 mg/l), and Phosphate levels was highest in Zone A (0.26 ± 0.01mg/l) and least in Zone E (0.13 ± 0.01 mg/l). Both phosphate and ammonia measured were within the permissible limits.

The Trophic State Index based on Chlorophyll-a estimation indicated that the lagoon was hypereutrophic (61.3-64.9). However, Zone A recorded the highest TSI value (64.9) and the least TSI was recorded by Zone E (61.3). Zones A, B and C (4.9-6.5) were in poor ecological conditions. D (3.0-3.8) was in fair ecological conditions. Zone E was in good ecological conditions. The mean Plankton Index of Biotic Integrity (P-IBI) for the entire lagoon, however, was 3.96 and that shows a mesotrophic lagoon with diverse populations of phytoplankton.The total number of macrobenthic species counted in the Keta lagoon was 1018 which consisted of 83% mollusks and 17% polychaetes as the major taxa. Generally, Macrobenthic assemblage richness, evenness and diversity were 1.2, 0.8 and 1.7 respectively for the lagoon.

The trends of physicochemical parameters (temperature, DO, turbidity, pH, nitrate, phosphate, silicate, ammonia), Trophic State Index, diversities of benthic macroinvertebrates and phytoplankton communities showed that the lagoon is in the state of deterioration with time.

DEDICATION

I dedicate this work to my family and friends. There is no doubt in my mind that without their continuous support and love I could not have completed this work.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Coastal areas are defined as the interface or transition areas between land and sea, including large inland lakes and lagoons (Prasetya, 2006). They comprise coastal floodplains, coastal forests called mangroves, lagoons, estuaries, marshes, and tide-flats, as well as beaches, dunes, and coral reefs (Mensah, 2020). They may also cover marine fisheries because the bulk of the world's marine fish harvest is caught or reared in coastal waters (FAO, 2020). Coastal areas serve as habitats that are highly relevant in terms of providing ecosystem services such as shelter, breeding areas, and nursery grounds for a wide variety of organisms (Prasetya, 2006). They sustain complex interactions of marine and terrestrial habitats supporting high biodiversity and complex life cycle and food chain linkages.

Furthermore, these coastal environments provide regulating ecosystem services such as protection from coastal hazards like storms and surges, coastal flooding, and erosion (Prasetya, 2006). Natural resources from coastal regions are essential components for human well-being, for example, they provide critical inputs for industries, space for ports and shipping, opportunities for recreational activities and other raw materials such as salt and sand (Santos *et al.*, 2020). They additionally serve as home to a large and growing proportion of the world's population with constantly expanding human demands (Breitburg *et al.*, 2018).

People are drawn to coastal regions due to the intrinsic benefits derived from them. The high concentration of people in coastal regions has no doubt produced many economic benefits, including improved transportation links, industrial and urban development, revenue from tourism, and food production (Zinov'ev & Sole, 2004). However, the combined effects of booming population growth with economic and technological development are threatening the ecosystems (Klasen & Lawson, 2007).

Although there are several and complex reasons for coastal environmental decline (such as climate change), population growth plays a significant role in the main threats to coastal ecosystems (Creel ,2003). These threats include habitat loss or conversion (Neumann et al., 2015a) and habitat degradation mainly caused by human activities such as agriculture or aquaculture leading to eutrophication, pollution and consequent changes in sediment (Neumann et al., 2012).

Today, approximately 3 billion people which is about half of the world's population are said to live within 200 kilometers of the coastline (Neumann et al., 2015a). It is projected that by 2025, this figure is likely to double (Mcmichael *et al.*, 2020). Therefore, addressing population issues can help to achieve a balance between reaping the economic benefits of coastal resources and preserving them for the future generation.

This is a concern because population growth and activities associated with it are gradually degrading the coastal ecosystems. For instance, in the 20th century, half of the world's wetlands disappeared together with about 50 percent of mangroves (UNFCCC-COP, 2018). Currently, 60 percent of the world's coral reefs are seriously degraded, and beyond recovery in some cases (Verweij, 2013). About 30 million Africans live within flood hazard zones of which 2 million are likely to be flooded. For example, Senegal, Nigeria and Cote d'Ivoire are ranked among the top 20 African countries in terms of population exposure to floods (Mbaye, 2020). In Ghana, high population growth along the coast has increased pollution from industry, agriculture, and urban areas just like many other countries (Songsore, 2009). This has led to the degradation of the various habitats in the coastal ecosystem (Botello et al., 2020).

Coastal lagoons as part of the coastal ecosystem also have numerous benefits (Whitfield & Elliott, 2011). Globally, they are mostly identified as one of the productive, dynamic and resourceful aquatic ecological communities within the coastal environment (Davies-Vollum et al., 2019). Coastal lagoons act as nurseries for migratory fish that colonize them as eggs, larvae, or juvenile fish. They provide essential goods and services, such as fisheries, tourism, aquaculture and urban development (Guidetti & Danovaro, 2018).

Lagoons like many other coastal ecosystems are stressed by anthropogenic pressures which lead to geomorphological, hydrodynamic, abiotic, and biological imbalances (Songore, 2009). These imbalances are likely to affect the proper functioning of these systems (Pranovi *et al.*, 2006). Examples of such cases are that of Mandinga, Alvarado and the Terminos Lagoons along the coastline of the Gulf of Mexico, where chlorinated hydrocarbons were identified in the lagoons due to agriculture purposes (Botello et al., 2020).

Some lagoons in the United States have undergone significant ecosystem decline as a result of human population growth and their ecological impacts (Bricker et al., 2008). For example, in 2018, the Indian River Lagoon system of Florida was overly enriched with nitrogen and phosphorus at an elevated level that declined the quality of the water and resulted in habitat loss (Barile, 2018). In West Africa, lagoons have been receptacles for sewage effluent and household waste transported by runoff water (Powell *et al.*, 2019, Barile, 2018, Ayache *et al.*, 2009). For instance, several studies on the Ebrie lagoon in Cote d'Ivoire showed that these lagoons are polluted with heavy metals and industrial waste (Kouadio, 2021).

Other activities by man such as infrastructure development and resource extraction impact coastal lagoons (DeGraft-Johnson *et al.*, 2010). However, this study draws attention to runoff into lagoons in Ghana and how that has changed the ecological status of these lagoons. When lagoons receive large amounts of nutrients from agricultural runoff, they result in adverse conditions (Morrison & Ministry of Fisheries, 2009). These include increased phytoplankton abundance, which causes harmful algal blooms (NOAA, 2017). High nutrient inputs can also alter vegetative communities by lending a competitive advantage to some species of macroalgae (Randall et al., 2019).

Harmful algal blooms may impact benthic habitats to varying degrees and result in large-scale mortality and prevalence of disease (Anderson, 2009). In some cases, the bacterial decomposition of these phytoplankton blooms depletes dissolved oxygen levels to such an extent that most marine life cannot survive, creating anoxic or "dead zones" in the coastal lagoons (Welch, 2021). Both nutrient and sediment loading from agricultural activities can lead to increased turbidity and reduced light availability thereby, reducing primary production, which in turn impacts negatively on the ecosystem (Lemley et al., 2017). Sediment may also physically smother sensitive habitats and impair the larval development of fishes (Wenger et al., 2014)

In Ghana, several lagoons face similar threats (Ansa-Asare *et al.*, 2009, Zaremba & Smoleński, 2000). One of such lagoons is the Keta lagoon, which is located on the eastern coast of Ghana. The Keta Lagoon is the largest lagoon in Ghana covering an area of 126.13 in length with open water estimated to cover an area of 300 km^2 which varies with the season (Davidson *et al.*, 2019). It is separated from the sea by a narrow coastal ridge which is 2.5 km at its widest point and 0.92 km at the narrowest point and surrounded by many settlements. The towns include Anloga, Woe, Keta and Kedzi to the south, Aborlove Nolopi, Anyako and Afiadenyigba to the north, Kodzi, Alakple and Tregui to the west and Denu and Adina to the east (Gyampoh *et al*., 2020). It is among the lagoons that are protected under the Ramsar convention globally (Davidson *et al*., 2019). The lagoon comprises of several small islands and a complex of lagoons with varying salinity .The dominant vegetation includes swamps, scrublands, and mangrove forests, which are heavily exploited by resident communities for fuel woods and commercial fishing. The wetland supports the livelihood activities of hundreds of thousands of people (Tufuor et al., 2015). Fishing, sand winning and vegetable farming are the main occupation of the people (Aniah et al., 2019).

The southern occupants of the lagoon are famous for the production of large quantities of onions, shallots and okro. Other crops grown include pepper, cassava, tomatoes and maize. Lagoon fisheries have been the major source of livelihood for many people in the area. The species caught are mainly tilapias which are sold locally. Salt mining has also been a substantial industry, particularly during the dry periods of the year. Mangrove exploitation for fuelwood is another important source of income .

However, there has been a rise in agricultural activities in the Municipality and is evident in the surface area farmland covered by the year 2018, which has increased by about 135.11 km^2 (Peters, 2019). These increased activities may be understood to keep up with the high population growth in the area, nevertheless, the Keta lagoon has been degraded by the intensification of farming activities around its catchment (Peters, 2019). In recent times, there has been a major decline in fish species diversity and fish catches in the Keta lagoon (Lamptey, 2014). The fishes caught are very small in size and some are matured at these small sizes (Entsua-Mensah, 2002, C. Addo, 2014, Lamptey, 2014). This has been attributed to; overexploitation of the fisheries due to the increased resident population and the degradation of water quality conditions in the lagoon caused by agricultural practices (Entsua-Mensah, 2002, Lamptey, 2014).

This project therefore seeks to carry out a comprehensive ecological assessment of the Keta lagoon by looking at the current physiochemical conditions, phytoplankton and benthic species composition to increase our understanding of how the ecological status of the lagoon has changed through time as a result of increasing human activities (i.e farming) along its bank.

1.2 Hypothesis

Expansion in agricultural activities around the Keta lagoon due to population growth has resulted in large export of nutrients into the lagoon. This has led to adverse effects such as poor water quality that affects the fisheries and other organisms in the lagoon. This research tested the following hypothesis:

1. Some areas of the lagoon are fast degrading than others because the intensity of farming activities varies along the lagoon.
2. The ecological state of the lagoon has not changed over the past decade.

1.3 Aim of the Study

This study aimed to assess the ecological status of the Keta lagoon using water quality parameters and the diversity of phytoplankton and benthic macroinvertebrate communities.

1.4 Specific Objectives

1. To determine the physicochemical conditions within the different zones of the lagoon through measurements of temperature, dissolved oxygen (DO_2), pH, salinity, nitrate, phosphate, ammonia and silicate.

2. To determine the Trophic State within the different zones in the lagoon using the parameters in (1) above.
3. To estimate phytoplankton and benthic macroinvertebrates diversity within the different zones of the lagoon.
4. To assess any change in ecological status within the different zones of the lagoon over the past decade by comparing present data to previous data.

1.5 Justification

A significant number of coastal lagoons in Ghana have been lost through the impacts anthropogenic activities regardless of their numerous importance (Davies-Vollum et al., 2019). For example, studies by Boadi & Kuitunen, 2013, Biney, 1982 and Apau & Appiah, 2012 showed that lagoons such as the Korle, Chemu and Kpeshie have lost their ecological integrity due to pollution of their catchment areas. Others such as the Songor, Skumo and Keta also face similar threats (Fianko & Dodd, 2019, Nartey et al., 2012, Sackey, 2014).

This study focuses on the Keta lagoon due to its enormous benefits yet increasing rate of deterioration over the last decade (Lamptey, 2014). The Keta lagoon is considered the most important coastal wetlands for birds in Ghana and supports over 72 resident and migratory bird species estimated to be over 100,000 individuals (Issaka et al., 2019). The sandbar between the lagoon and the adjacent sea provides safe nesting grounds for the threatened olive ridley

(Lepidochelys olivacea), leatherback turtle (Dermochelys coriacea), and the green turtle (Chelonia mydas)(ICA, 2021). The lagoon contributes significantly to the economic well-being of the people by providing livelihood through fishing and agriculture (Brinks, 2017). However, while the use of the land for farming has been a great source of livelihood for the surrounding communities, it has also led to an increased export of nutrients into the lagoon. Past research has shown that the ecological state of the Keta lagoon is deteriorating due to the high influx of nutrients that are being washed from land into the lagoon ((Sorensen *et al.*, 2003, Bhadury & Sen, 2020, Lamptey *et al.*, 2013).

All past studies carried out on the Keta lagoon used single-shot methods such as water quality analysis (Lamptey *et al.*, 2013), macrobenthic fauna (Lamptey & Armah, 2008), fish diversity (Lamptey, 2014) and primary production and chlorophyll a (Addo, 2014) to analyze the ecological state of the keta lagoon. This study sought to assess the current ecological state of the lagoon by analysing the physical, chemical and biological conditions to evaluate any change in the ecology of the lagoon and its water quality over the last decade. Specifically, the current study assessed the ecological status of the lagoon using the trophic state index, phytoplankton index and microbenthic invertebrate diversity.

CHAPTER TWO

2.0 LITERATURE REVIEW

In recent years, there has been an increased interest in coastal lagoons. This is due to the numerous benefits provided by these lagoon systems and their ability to provide important ecosystem services for human sustenance (Carabine et al., 2015). Examples of such services are movement of people and goods to different towns, cities and villages, fishing, and extraction of natural resources such as mangroves from these systems. Agricultural practices and municipal or industrial waste disposal has caused loading of nutrients from farmlands and the influx of chemicals into lagoons. These factors put a lot of strain on coastal lagoons, thereby, resulting in modification of both water quality and habitat (Prosser et al., 2019). This chapter reviews the literature on several themes such as coastal lagoons, their importance and threats. The use of phytoplankton, benthic organisms (species richness and evenness), chlorophyll-a and nutrients (Phosphate, Nitrate and Ammonia silicate) analyses to assess the ecological state of the aquatic ecosystem. Additionally, this chapter reviews some relevant work done on the water quality of lagoons in some parts of Ghana, especially the Keta Lagoon from the available literature.

2.1 Coastal Lagoons

A coastal lagoon is a "shallow coastal water body separated from the ocean by a barrier, connected at least intermittently to the ocean by one or more restricted inlets" (Kjerfve, 1994). They are formed and maintained through sediment transport processes. Sediment carried by rivers, waves, currents, wind, and tides accumulates in the river and tidal deltas, on marshes and flats where submerged aquatic vegetation slows currents (Uri *et al.*, 2009, Nichols & Boon, 1994, Neumann *et al.*, 2015b). The sedimentation process can eventually fill in lagoons. Lagoon barriers require continuous sediment deposition to maintain them because they are constantly eroded by waves and wind (Boumans, 1994, Nichols & Boon, 1994).

The quantity and quality of water in a lagoon are influenced by the rate at which the lagoon loses or gains water from evaporation, precipitation, groundwater input, surface runoff, and exchange with the ocean (Rajasekar & Philominathan, 2013, Allen *et al.*, 1981). Lagoon and ocean exchange is driven by tides and wave action and is often the largest component of lagoon water balance. Through exchange with the atmosphere, sediment, and ocean heat is also lost and gained (Nøhr Glud *et al.*, 1994, Jørgensen *et al.*, 1984)

Coastal lagoons can be classified as brackish or marine depending on factors such as tidal processes, human intervention or geomorphology (Rodríguez Climent, 2014, Kennish, 2015). They can be formed on low-lying coasts like the Atlantic and Gulf coasts of the United States of America. Around the Atlantic coastlines, coastal lagoons are rare in general (Beer & Joyce, 2013).They can be mostly found along the coast of Africa (about 17.9% of the coastline) and on the coast of North America (about 17.6% of the coastline) (Hans, 1994). However, they are less prominent along the coasts of Asia (about 13.8% of the coastline), the coast of South America (about 12.2% of the coastline), the coast of Australia (about 11.4% of the coastline) and along the coast of Europe as well (about 5.3% of the coastline)(Hans, 1994).

In Europe, coastal lagoons are classified based on some regulations under the European Water Framework Directive (Brack et al., 2017) .This Framework and regulations seek to prevent the destruction of lagoons, enhance water quality and estuarine health index of coastal lagoons. It does that by establishing better strategies to conserve and reduce pressure on coastal lagoons (Chi & Commission, 2007).

In Asia, thousands of individuals depend on coastal lagoons for food and job security. In 2005, FAO, UN responded to the largest lagoon ecosystem disarray in Southern Asia. Where coastal lagoons were improved under the capacity development project in the FAO Integrated Management of Lagoon Activities (IMOLA) (FAO, 2005).

Lots of local fishing communities in Africa, depend on coastal systems especially lagoons for fish and other livelihood activities, making these lagoons vulnerable to nutrient inputs and environmental modification. The quality of the water and health of the organisms that reside in them are affected (Fewtrell & Bartram, 2001). In terms of food for the people, it is estimated that about 70 percent of animal protein comes from fishes that thrive in coastal ecosystems like lagoons (Kurien & López Ríos, 2013).

There is therefore a global quest to protect and conserve coastal lagoons for future genreations. For example, the World Bank through the Global Environment Facility co-financing was set up in order to support actions in Tanzania, Senegal and Guinea-Bissau geared towards the protection of marine and coastal lagoons and fish resources (Hewawasam, 2002).

In Ghana, a management strategy was formulated for coastal lagoons in 1991(Gordon et al., 2021). It documented the importance of lagoons along the coast of Ghana and the dependence of the local communities on the resources. Despite the effort that has gone into this document, its actions have not been realized, leaving several of the country's lagoons in a deteriorating state (Asmah et al., 2008).

2.2 Types of Coastal Lagoons

Coastal lagoons are the most dynamic and complex ecosystems in the coastal zone (Mahrad, 2020). The hydrobiology of a lagoon is dependent upon the geomorphology and local environmental conditions. Thus, classification of lagoons on a broad scale is found difficult (Copeland, 1967). Coastal lagoons, in general, have been classified into different groups by scientists. Ejaque (2016) classified the coastal lagoon into four categories namely (I) estuarine lagoon, (ii) open lagoon, (iii) partially closed lagoon and (iv) closed lagoon. Later Kjerfve (1994) had grouped the coastal lagoons into three types of namely (i) choked, (ii) restricted and (iii) leaky lagoons. The characteristics of these lagoons as contemplated by him are as follows.

Choked lagoons: Choked lagoons have a very narrow connection with the nearby sea, which normally possesses tidal oscillations reduced to 5% or when compared to the adjacent coastal tide. They are also characterized by slow flushing rate of water and sediment, high wind-induced wave action, dominant wind forcing and irregular stratification of different environmental parameters due to high solar radiation and surface runoff from catchment areas. In arid or semi-arid provinces, the choked coastal lagoons remain permanently or temporarily hypersaline (Mahapatro et al., 2015). These types of lagoons are found in association with river deltas or with the nearby shoreline. Examples of such chocked lagoons in the world are Lagoa dos Patos and Lagoa de Araruama Brazil, St. Lucia of South Africa, the Coorong of Australia, and Songkla Lagoon of Thailand.

Restricted lagoons: Restricted lagoons are large water bodies commonly found parallel to the shoreline. They possess two or more inlets connected with the nearby sea or ocean. Thus, this type of lagoon generally experiences good tidal circulation amplified by wind-generated wave action. They represent a well-mixed water mass and as such the chance of vertical stratification is low. A wide range of salinity from near limnetic to oceanic conditions is noticed in this type of lagoon. The Flushing rate is faster as compared to the chocked lagoons. The examples of such restricted coastal lagoons are; Laguna de Terminos of Mexico, and Lake Pontchartrain in the USA and Chilika lagoon of Odisha, India.

Leaky lagoons: Leaky lagoons are generally elongated in nature and found parallel to the shoreline. They have many inlet connections to the adjacent sea. The characteristic features of the Leaky lagoons are wider channels or inlets, strong tidal currents, strong littoral drift action, strong wind action and the salinity is somewhat similar to the nearby sea. They experience a quick flushing rate. Examples of such lagoons are Mississippi Sound in the USA, and Wadden Zee, the Netherlands. Another kind of classification i.e., according to the tidal amplitude was suggested by different researchers, those have been classified into five types. They are Isolated lagoons, Percolation lagoons, Silled lagoons, Sluiced lagoons and Lagoonal inlets (Möller et al., 2007).

Boughey in 1957 also classified lagoons to be either 'Open' or 'Closed'. With open lagoons, there usually are adequate mass of water which helps sustain stable efflux from upstream of the lagoon into the ocean. In Ghana, these lagoons are usually found on the western coast where rainfall is high (mean rainfall of 1250mm annually) and the rivers feed the lagoons. However, closed lagoons are usually separated by a sandbar from the sea. They are mostly found in areas with low precipitation such as along the eastern coast of Ghana (Ansa- Asare, 2008).

2.3 Importance of Coastal Lagoons

Coastal lagoons are important because they support rich biodiversity. Coastal lagoons support many fish species and provide breeding habitats for 85 percent of migratory birds (Holmlund & Hammer, 1999). They also provide habitat for many other organisms such as sea turtles, and submerged aquatic vegetation (Powel, 2017). In addition, Coastal lagoons support a wide range of human economic activities such as tourism, recreation, transportation, and fisheries.

Lands around coastal lagoons are highly desirable places for people to live and as such people have exploited coastal lagoons for settlements and also for resources such as mangrove and salt production (Aliaume *et al.*, 2007). A range of natural services that are highly valued by society are supported by coastal lagoons (Anthony *et al.*, 2009). They have provided different economic-based advantages in large coastal subdivisions of many countries. Coastal lagoons have provided fish protein, and created recreational and aesthetic services (Holmlund & Hammer, 1999).

2.4 Threats to Coastal Lagoons

Coastal lagoons are widely used and therefore expected to undergo negative effects or strains (Duijndam *et al.*, 2020) (Uri *et al.*, 2009). The extent of stress that occurs in coastal lagoons may sometimes depend on the type of the lagoon and the percentage of mouth closure, although many of these threats are common in all lagoon systems (Casey *et al.*, 1997). Coastal lagoons generally, are vulnerable to outflow from wastewater treatment facilities, surface runoffs, forestry and agricultural activities, turbidity as a result of coastal projects and direct destruction of habitat for infrastructure development (Kennish *et al.*, 2010).

A joint report from European Environment Agency confirmed the state at which lagoons are deteriorating with time due to pesticides and fertilizers to agricultural lands (Saysel *et al.*,, 2002).

In Africa, lagoons like the Lagos lagoon in Nigeria which is the largest of four lagoon systems off the Gulf of Guinea are heavily and dangerously polluted with large quantities of pollutants from manufacturing and municipal waste as well as runoff from agricultural activities (Nkwoji *et al.*, 2020). The quality of water in the Aghien lagoon of the Ivory Coast also is severely degraded and the degradation is due to increasing anthropogenic activities (Ahoutou *et al.*, 2021).

2.4.1 State of coastal lagoons in Ghana

Broadly, coastal lagoons in Ghana are facing problems from two different kinds of sources. The natural and anthropogenic input. Studies conducted on lagoons in Ghana revealed that most are degraded with nutrients (ammonia, potassium, nitrate, and phosphate) and heavy metals (Finlayson *et al.*, 1998, Addo, 2014, Boadi & Kuitunen, 2002) from anthropogenic activities.

In the Kpeshi lagoon, Accra for example, Apau (2014) assessed water quality and evaluated the level of pollution in it, by monitoring levels of physicochemical parameters. The study revealed that industrial activities are predominant around the Lagoon. Matter (inorganic and organic) was found to be the cause of pollution of the lagoon. Mean sulphate, nitrate and phosphate concentrations recorded were 11,852 mg/L ± 2,915.1, 2,905.71 mg/L ± 616.52 and 487.14 mg/L ± 257.02 respectively. Iron and aluminum (Al) recorded the highest concentration of 13.2 mg/L ± 3.5 and 13.6 mg/L ± 4.3 respectively. Fish stomach content analysis revealed calcium (Ca) and potassium (K) as having the highest concentration of 15,709 mg/kg ± 75.035 and 5,999.94 mg/kg ± 87.30 respectively. Comparing these results with the WHO guidelines, it emerged that the Lagoon is highly polluted (Apau et al., 2012).

In the Sakumo Lagoon also in Accra, Research by Nartey (2012) which involved sampling for nitrite, nitrate, phosphorus and ammonia examination showed very high levels of phosphate very in the lagoon and also nitrate levels were observed to be increasing as the years went by. Further studies in the same Sakumo lagoon by Agbemehia (2014) also showed that nitrate and ammonia concentrations in the lagoon were getting high due to increased land-based effluents with time. The study concluded that the Sakumo lagoon qualifies to be classified as a polluted lagoon due to high concentrations of nutrients (Nartey et al., 2012).

Bentum *et al* in 2011) also conducted a study in the Fosu Lagoon, Cape Coast. The study focused on metal contamination levels and showed that lead (Pb) had the greatest discrepancy and iron (Fe) had the least. However, Fe enrichment was minimal, while Copper (Cu) and zinc (Zn) were significantly high. The average pollution Load Index calculated showed that the lagoon was unpolluted with Fe, Cu, and Zn but moderately polluted with lead (Pb), which is dangerous to human health (Bentum et al., 2011).

Another study conducted in the Keta lagoon, volta region by Lamptey *et al* (2013) revealed that the lagoon was under stress due to agricultural practices around its catchment. The intensity of agriculture and the use of agrochemicals influence the lagoon and its catchment areas.The Water Quality Index of the Keta lagoon and its floodplains showed various degrees of poor water quality and therefore considered unsuitable for recreation. This calls for intensive physical and chemical treatment of the water according to WHO standards (Lamptey et al., 2013).

Water quality assessment in lagoon systems is very vital in sustaining ecological characteristics. Coastal lagoons are favorable habitats for primary producers (phytoplankton and aquatic plants) because of their relatively low flushing rates (Anthony et al., 2009). Nitrogen and phosphorus are dissolved nutrients that occur in limited quantities in natural aquatic environments (Brooks, 1997). Eutrophication of water bodies usually occurs when there is an increased amounts of nitrogen and phosphorus, which in turn reduces dissolved oxygen content and adversely affects aquatic life), (Brooks, 1997), (FAO, 2020)

2.5 Nutrient Loading

High input amount of substances (organic or inorganic) that are rich in phosphate, ammonia, nitrate or potassium into a water body results in nutrient loading or pollution. Nutrient input are mostly from different sources and are therefore difficult to be classified and hard to control (Walker, 2004). Studies have shown that human activities are the major drivers influencing the flux of nutrients into coastal lagoons (Peierls *et al.*, 1991, Smith *et al.*,1999).

For every lagoon to function effectively, an amount of nutrient is needed, nonetheless, excess nutrient loading into coastal water bodies leads to eutrophication (Rabalais *et al.*,2009). Eutrophic waters can further cause anoxic conditions in coastal ecosystems (Paul & Meyer, 2008).

2.6 Indicators of nutrients loading

Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. While aquatic life is dependent on these photosynthesizers (Langley et al., 2015), excess nutrients, however, can overstimulate aquatic plant and algae growth leading to eutrophication.

When an aquatic ecosystem is exposed to an increased nutrient concentration from point and non-point sources, the state is known as eutrophication. It is characterized by an increase in phytoplankton and algal biomass in the water column that results in decreased levels of dissolved oxygen in water. Dissolved oxygen is used up during organic decomposition or bacterial respiration depriving fish and invertebrates of available oxygen in the water (Guidetti & Danovaro, 2018).

2.6.1 Phytoplankton and Chlorophyll-a

Phytoplankton is an excellent indicator of ecological change. They are highly sensitive indicators of nutrient input (Pinckney et al., 2001). Eutrophication is characterized by increased phytoplankton biomass, with the composition of the phytoplankton community becoming more uniform (Guidetti & Danovaro, 2018). Certain species disappear, while opportunistic species of phytoplankton begin to dominate (McQuatters-Gollop et al., 2019). Species diversity is reduced because of the competitive exclusion between species, whereas with a slight increase in eutrophication levels, competition is relaxed, resulting in increased diversity. With a further increase in the level of eutrophication, diversity drops again because of species reduction due to stress (Sahraoui et al., 2012). Eutrophication tends to favor small and fast-growing organisms, which usually means that the proportion of the dominant taxa to the total biomass is relatively low. This means that the biodiversity values are higher than when large-sized taxa dominate (Bužančić et al., 2016). In highly eutrophicated systems, the trophic chain usually lacks higher links, and autotrophic processes exceed heterotrophic, which significantly affects the balance of the system (Winder & James, 2010).

Phytoplankton total biomass, together with chlorophyll *a* was used as indicators of ecological change in a study conducted by Pearl *et al* in 2007. The study revealed that the phytoplankton community structure is impacted by nutrients inputs, chlorophyll a and seasonal hydrological cycles.

Studies done by Addo *et al* (2014) on the Keta Lagoon showed that the Trophic Status Index based on Chlorophyll estimation indicated that the lagoon was hypereutrophic. The high primary productivity was attributable to the high concentration levels of nutrients especially nitrate (95.31 mgl-1, 79.44 mgl-1) and phosphate (0.007 mgl-1, 0.005 mgl-1) for Anloga and Woe sites respectively contributed from farmlands situated around the lagoon through leaching. This was evident in decreased dissolved oxygen levels (Addo *et al.*, 2014).

Seasonal variation in plankton community structure (phytoplankton and zooplankton), chlorophyll a and some Physico-chemical properties of Rabigh Lagoon, Eastern site of the Red Sea, Saudi Arabia were studied in 2015 by Toujliabah and Elbassat. The study aimed to estimate the environmental health of Rabigh Lagoon as well as renewing the ecological database for the investigated area. The ecological parameters comprise some physical and chemical parameters as Temperature, Secchi Disc, pH, DO, S%, Nutrients "Nitrite, NO2-N; Nitrate, NO3-N; Ammonia, NH3-N; total nitrogen, T-N; Reactive phosphate, PO4-P and total phosphorus, T-P. A total of 103 species belonging to five phytoplanktonic groups were identified. The highest group was Bacillariophyceae (45.05%) then Cyanophyceae (33.83%) followed by Dinophyceae (20.99%). Chrysophyceae (0.07%) and Chlorophyceae (0.05) were considered a rare group. Chlorophyll a showed a range between 12.33 µg l-1 during spring and 5.49 µg l-1 during summer. The analysis showed that Rabigh Lagoon is a mesotrophic ecosystem (Touliabah & Elbassat, 2017).

Uttah *et al* (2008) used a bio-survey of Phytoplankton as indicators of water quality for recreational activities in a river in Calabar, Nigeria. In total, 331 phytoplankton individuals were identified from sixty-six species in sixty genera and six taxonomic groups. The most abundant taxon was Bacillariophyceae 212 (64.05%), followed by Cyanophyceae 42 (12.69%), Chlorophyceae 40 (12.08%); Dinophyceae 16 (4.83%); Chrysophyceae 12 (3.63%) and Xanthophyceae 9 (2.72%). Similarly, the diatoms were highest in species richness (54.55%) followed by Cyanophyceae (18.18%), Chlorophyceae (12.12%), Dinophyceae (6.06%), Chrysophyceae (4.55%), and Xanthophyceae (4.55%).

It was concluded that there was no observation of any preponderance of harmful phytoplankton in the Calabar River during the study. The river thus showed no evidence of stress beyond its carrying capacity, and there was no evidence of any harmful environmental conditions that are detrimental to recreational activities in the Calabar River (Uttah et al., 2010).

Phytoplankton monitoring as bioindicators was also used to assess the health of the Nasarawa reservoir in Nigeria by Yusif (2020). This was to evaluate the relationship between phytoplankton and reservoir environmental variables. Phytoplankton and water samples from Nasarawa reservoir (Nigeria) were collected and analyzed for ten months (February 2018 to November 2018). A total of 38 genera belonging to five major families such as Bacillariophyceae (42%), Chlorophyceae (24%) Cyanophyceae (13%), Deemidiaceae (18%) and Euglenophyceae (3%) were recorded. Four Phytoplankton classes; Bacillariophyta, Chlorophyta Cyanophyta, and Desmidiaceae showed positive close relation with dissolved oxygen, pH, transparency, and total dissolved solids. The overall phytoplankton density in the reservoir was higher in the dry season than in the wet season. Palmer pollution index was employed to study the water quality of the reservoir. The total score was calculated to be 25, showing evidence of high organic pollution. A conclusion was derived that, the presence of organic pollution indicators *Closterium* sp, *Navicula sp, Nitzschia* sp, *Synedra* sp, *Chlamydomonas* sp, *Cyclotella* sp and *Anacystis* sp is a warning sign of the deteriorating condition of the water quality in the reservoir (Yusuf, 2020).

2.7.2 Benthic macroinvertebrates

Benthic macroinvertebrates are also commonly used as indicators of the biological condition of lagoons. They are reliable indicators because they spend all or most of their lives in water, are easy to collect and differ in their tolerance to pollution (Iyiola, 2020). Evaluating the abundance and variety of benthic macroinvertebrates in a waterbody gives us an indication of the biological condition of that waterbody. Generally, lagoons in healthy biological conditions support a wide variety and a high number of macroinvertebrate taxa, including many that are intolerant of pollution. Samples yielding only pollution–tolerant species or very little diversity or abundance may indicate a less healthy waterbody. Biological condition is the most comprehensive indicator of waterbody health (Saad Abdelkarim, 2020). When the biology of a lagoon is healthy, the chemical and physical components of them are also typically in good condition (Barhoumi *et al.*,2016).

A study was conducted by Aggrey-Fynn in Domini and Amansuri Lagoons in the Western Region of Ghana in 201. The physicochemical and ecological health conditions were assessed using ecological indices e.g, richness and diversity of macroinvertebrate fauna along environmental gradients. The invertebrate richness and diversity ranged from J'= 0.68-0.81 and H'= 0.74-1.45 respectively in Amansuri while that of Domini were J'= 0.01-0.02 and H'= 0.01-0.03 respectively. The conclusion was that reduction in invertebrate composition, richness and diversity would imply a change or deterioration in environmental conditions of the lagoon (Galyuon et al., 2011).

A study on benthic macroinvertebrates was done by Lamptey (2008), on the Keta Lagoon of Ghana. The study concluded that the macrobenthic fauna was low in density and species diversity and numerically dominated by bivalves and capitellid polychaetes. Salinity, pH, and turbidity in that order were the major significant variables structuring the macrobenthic faunal assemblage in the Keta Lagoon (Galyuon et al., 2011).

2.7.3 Anoxic conditions

Excess inputs of matter (organic and inorganic) can alter the balance in oxygen supply in the water column. This happens through oxygen depletion from the decomposition of organic matter (Davies-Colley et al., 1995). Anoxic conditions in coastal lagoons are regulated by mixing processes and lagoon stratification (Adam et al., 2020). Anoxic conditions in the water colum affects both organisms and their habitats as well as the biogeochemical processes that control nutrient variations in the lagoon system. The alteration of biogeochemical processes leads to further oxygen depletion and this can fluctuate biogeochemical cycles of phosphorus in lagoon sediments (Viaroli et al., 2005).

Nitrogen and ammonia levels are affected when oxygen levels are low, in the lagoon (anoxic conditions)(Zilius et al., 2012). Denitrification occurs when fixed levels of nitrogen in lagoons are reduced (Seitzinger & Giblin, 1996).

2.7.4 Relationship between ammonia and nitrate

When there is enough oxygen in lagoon systems, nitrate is normally converted into ammonia and then assimilated into amino acids in organisms (Yuan et al., 2016). Ammonia in the water column is adsorbed onto mineral particulate matter and can either be found in suspension or buried into the sediment. Some part of ammonia goes into mineralization and is biologically accessible for use (Kang et al., 2015). Seitzinger & Giblin (1996) conducted a study that revealed that there is a linear relationship between the denitrification rate and anoxic sediment conditions (Seitzinger & Giblin, 1996).

Further studies by Eyre & Ferguson (2009) revealed that when dissolved oxygen levels decreases in a lagoonal system, nitrogen increases. This will further increase the availability of dissolved inorganic nitrogen and will potentially increase the risk of eutrophication (Lillebø et al., 2005).

2.7 Flushing Time of lagoon systems

Flushing time of a coastal lagoon is the time required for the volume of water in a lagoon or a parcel of water to be removed effectively through its open channels into the sea (Choi & Lee, 2004). It is also known as residence or turnover time. Flushing time has a lot of advantages especially to issues that are linked to water quality in lagoons and in coastal ecosystems as a whole. Low flushing time makes a lagoon a favorable habitat for primary producers (Phytoplankton and aquatic plants) (Nixon, 1995). Nonetheless, as nutrients levels that are transported into the lagoon keep increasing, primary production exceeds the demands of consumers (secondary producers) and this could lead to uncontrolled growth of phytoplankton and macroalgal blooms and subsequent hypoxia thus, reduced penetration of light (McGlathery et al., 2007).

2.8 The Rate of discharge

The measure of the volume flow of water in an open channel with respect to time usually describes the rate of discharge of a system. It is expressed mathematically as the product of water velocity and cross-sectional area of water (USGS, 2014). The discharge rate and the flushing time play a major role in the water quality of a lagoon. Water quality improves quickly when a lagoon has a good discharge rate and flushing time.

2.9 Water Quality

The physical, chemical and biological properties of water that make it suitable or unsuitable for use is termed water quality. (Wang et al., 2017). The quality of coastal lagoons worldwide are under threat as a result of anthropogenic activities (Kennish, 2011). The situation has aggravated with coupled effects from climate change. This has increased the awareness and interest of a lot of scientists and coastal managers to try and manage the situation by monitoring water quality (Catianis et al., 2018).

Studies by Ongley (2001) showed that point and non-point sources of nutrients including aeolian deposition causes poor water quality in lagoons. Therefore, to protect these ecosystems, the National Estuarine Eutrophication Assessment Program was developed in the North-eastern of China to monitor and find solutions for better and successful management practices (Lee et al., 2012) (Whitall *et al.*, 2007). Studies by Driscoll (2003) investigated annual nitrogen loads in 10 watersheds in the United States. The study established that the Casco Bay received 449.5 kg of nitrogen, the Great Bay received 667.8 kg, the Merrimack River received 825 kg, the Massachusetts Bay received 7408.6kg, and the Buzzards Bay received 104 kg. The Narragansett Bay received 2101.7 kg, the Long Island Sound received 977.5kg, the Raritan Bay received 2110.6kg, the Chesapeake Bay received 919.6 kg and the Pamlico Sound received 1808.4 kg of nitrogen load. Massachusetts Bay recorded the highest level of nitrogen pollution because of high emission levels in the area (Eshleman & Sabo, 2016).

As a result of poor water quality in lakes, rivers, and lagoons Asia suffered a severe health problems in the year 1997 which was documented by Corrales (1995). It was discovered that the quality of water in these watersheds were poor because of the discharge of pathogens and nutrients from point and non-point sources and that led to algal blooms and fish kills. Therefore, to solve water quality problems in some parts of Asia, some countries like China, India, and Pakistan came up with new ideas and management strategies for water quality management and resource planning (Corrales, 1995).

In Asia, watersheds are known to play an important role when it comes to regional economic development especially for industrial, local, fisheries and agricultural uses (Chen *et al.*, 2020). However, some of these coastal resources, for example, the Muda Basin remain polluted because of a lack of interest from stakeholders and as a result, studies were conducted to investigate if Water Resource Management can be a tool to enhance the quality of the Basin. It was discovered that for a better management strategy, it will require an Integrated Government Industry Community Water Management Framework (Chen et al., 2016).

In Cote d'Ivoire, the Ebrie lagoon which is the largest coastal lagoon in West Africa (Affian *et al.*, 2009), was assessed using the Driving Force-Pressure-State-Impacts Response (DPSIR) Framework (Scheren *et al.*, 2004). The Ebrie lagoon has three inlets that refresh the lagoon water and these rivers are the Comoe, the Agneby and the Mé River (Chantraine *et al.*, 1985). Studies conducted by Scheren *et al.*, (2004), revealed that local and industrial activities in the Capital City (Abidjan), as well as other agricultural activities along a wider catchment area of the lagoon, was leading to its deterioration. The study also showed that 95% of total nitrogen and phosphorus loads from the capital city were mainly from domestic sources and 5% from industries. The inlets (the Comoe, Agneby and Mé River) also contributed to some amounts of nutrients pollution. Thus 42% from land-based runoff and 13% from atmospheric deposition (Scheren et al., 2004). The study projected that if solutions are not provided, concentration levels could increase five times by 2050 and therefore suggested that pollution reduction strategies geared towards the reduction of non-point sources of pollution will be beneficial in decreasing pollution (Scheren et al., 2004).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study area

This study was conducted in the Keta Lagoon, located in the Volta Region of Ghana (Figure 3.1). The study site is located within the Eastern coast of Ghana and was selected based on its socio-economic and ecological importance. The Keta lagoon is the largest lagoon in Ghana and known for its rich biodiversity (Ofori- Danson, 2014). It is located within longitudes 0°48'E and 1°01'E, and latitudes 5°48'N and 6°03'N.

The maximum length and width of the lagoon is approximately 25 and 13.5 km respectively (Lamptey & Armah, 2008). The lagoon covers an estimated surface area of 340 km^2 with average water depths ranging from 0.47 to 0.94 m during the wet season and 0.14 to 0.56 m in the dry season (Lamptey & Armah, 2008). The lagoon and its catchment forms part of the extensive Volta delta system, which has been defined as the land below the 5 m contour (Addo *et al.*, 2018). The open water of the lagoon and its associated wetlands covers an area of about 702 km^2 (Xorse, 2013).

Streamflow around the Keta lagoon is seasonal and corresponds to the seasonal variation in rainfall (Agyare et al., 2015). Apart from the Volta River, the Todzie river also flows into the Keta lagoon through the Avu lagoon which is just around the northwest border of the Keta lagoon (Finlayson et al., 1998). The Belikpa river also discharges directly into the Keta lagoon (Ampadu, 2017).

In time past, the people of Keta were mainly fishermen and grew a few vegetables for domestic consumption and coconuts for sale. In the 1930s the coconut production collapsed because of the

Cape St. Paul disease, and the rapidly increasing population compelled the people to give up the old agricultural systems and develop manure-intensive horticulture based on vegetable production which continues to expand and exert pressure on the lagoon up to now (Appeaning Addo et al., 2020).

Typical vegetable production systems of the Keta area are shallots, pepper, okra, tomatoes, carrots, which are grown all year round based on irrigation with groundwater from small wells using the rope and bucket method. This system is highly dependent on the application of organic manure (Lamptey *et al.*, 2013).

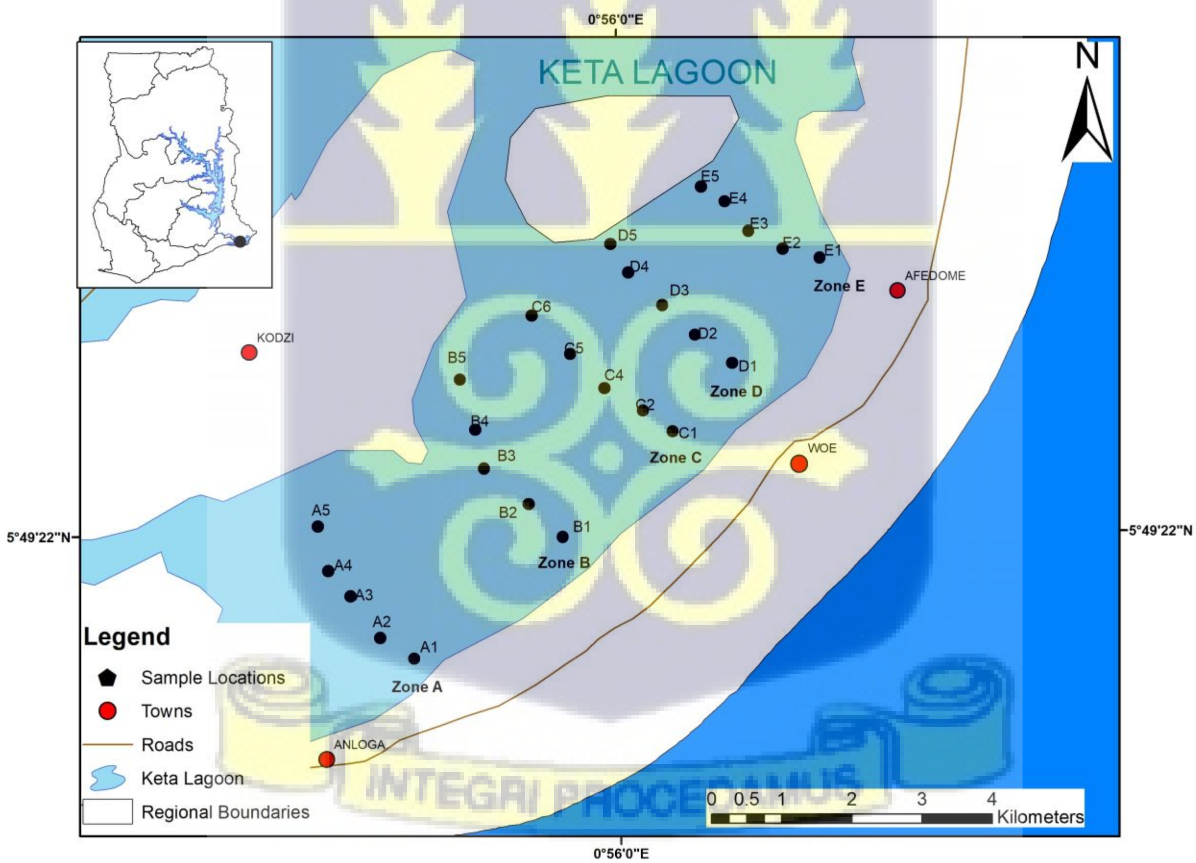

Fig 3.1 A Map of the Keta Lagoon showing the various sampling areas.

3.2 Field Methods

The entire lagoon was sampled for four (4) months between October 2020 to July 2021. The lagoon was divided into five broad zones (A to E) to cover a large extent of the lagoon to avoid bias. Zone A represented Anloga, Zone B represented the area that covers the mid-section between Anloga and Woe. Zone C represented the Woe area, Zone D represented the area between Woe and Afedome and Zone E, represented the area of Afedome towards the Keta area. Zone A to D are areas of intense agricultural activities with intensity increasing from A to D. Zone E is comparatively low on agricultural activities. Each zone is about 2 km or more away from the other. The various zones were further on sub-zoned along a vertical transect comprising of 5 sampling sites. In all, 25 sites were sampled for water and sediment within the entire lagoon over the four months.

3.3 Water Sampling

3.3.1 Physicochemical parameters

The physicochemical parameters (Dissolved oxygen, salinity, pH, conductivity, temperature, Total Suspended Solids and Total Dissolved Solids) were measured in situ using Multi-parameter Probe (Horiba U-52 G).

3.3.2 Nutrients sampling

Sub-surface water samples were collected from each of the sites and stored in 500 ml tight plastic bottles for nutrient (Phosphate, Nitrate, Ammonia and Silicate) analysis (Plate 3.1).

3.3.3 Chlorophyll a sampling

Chlorophyll a samples were taken and stored in 500ml plastic bottles and kept in black polyethylene bags to avoid photosynthesis.

3.3.4 Phytoplankton sampling

Phytoplankton samples were taken using a plankton net of 20 µm and stored in dark brown plastic bottles. Samples were preserved with 20% formaldehyde for later identification and counting.

3.4 Benthic sampling

The Ekman grab was used to obtain the benthic samples. Samples were then washed thoroughly on 0.5 mm mesh-sized sieves and stored in containers with 20% formaldehyde. Samples were stained with rose bengal before laboratory procedures began.

All the samples were kept at a constant temperature in an airtight container with ice cubes before transported to the laboratory.

Plate 3.1: Sampling on the Keta lagoon.

Laboratory Analysis

3.5 Nutrient Analysis

Analysis was done using the HACH DR2800 Spectrophotometer following APHA (1998).

3.5.1 Phosphate Determination Using the Ascorbic Acid Method

At a wavelength of 880 nm, phosphate analysis was carried out. In a reaction tube, 10 ml of samples were measured, and one (1) PhosVer3 Phosphate powder pillow was added to the reaction tube and left to dissolve completely after which the solution was shaken for 30 seconds. A blank sample with distilled water was also prepared. Both samples and blanks were treated adhering to the guidelines of APHA (HACH, 2005). After that, samples were transferred into the cuvette and measured. The spectrophotometer was zeroed using the blank sample.

3.5.2 Nitrate Determination Using Cadmium

At a wavelength of 500 nm, nitrate analysis was carried out. In a reaction tube, 10 ml of the samples were measured, and one (1) NitrateVer5 reagent powder pillow was added to the reaction tube and left to dissolve completely after which the solution was shaken for 30 seconds. Similarly, a blank sample with distilled water was also prepared. The procedures outlined in the American Public Health Association Procedures were adhered to, when handling both samples and blanks (APHA, 1998; USEPA, 2006). After that, the actual samples were transferred into the cuvette and measured. The spectrophotometer was zeroed using the blank sample (APHA, AWWA, 2017).

3.5.3 Ammonia Determination Using Salicylate

At a wavelength of 655 nm, Ammonia analysis was conducted using the HACH 385N, Ammonia Salicylate Test. A 10 ml aliquot of the lagoon water was measured into a reaction tube and diluted with distilled water. Ammonia salicylate powder pillow was added to the samples and a blank. The reaction tubes were shaken vigorously after their stoppers had been inserted until completely dissolved. A three-minute reaction was allowed to occur in the bottles. Ammonia cyanurate reaction powder pillows were added to the samples and allowed to dissolve completely after the three minutes was consumed. A five-minute reaction was allowed to occur during which a green coloration was seen and observed. Both samples and blanks were handled according to the procedures of the American Public Health Association Procedures. The samples were transferred into the cuvette and measured in the spectrophotometer which was zeroed using the blank sample. (APHA, 1998; USEPA, 2006). In order to obtain final readings for ammonia concentrations, an appropriate dilution factors were incorporated into the program of the spectrophotometer(APHA, AWWA, 2017).

3.6 Chlorophyll a analysis

Chlorophyll-a analysis was done using the standard procedure for the determination of chlorophyll-a by Alain Aminot (2002). Samples were gently mixed and filtered through a glass-fiber filter (by CHMLAB GROUP, 47 mm) placed on a filter holder with forceps. Samples were filtered at a residual pressure of 0.7 bar using the filter pump. The filter paper was removed carefully from the filter with forceps and kept in cleaned labeled Petri dishes. Extraction of the chlorophyll-a pigment was then carried out by dissolving the filter paper in 10ml of 90 %

acetone. The sample extracted was carefully transferred into the cuvette and the absorbance was measured at wavelengths of 750 nm, 664 nm, 647 nm, and 630 nm against a 90% blank (Plate 3.2) (Aminot & Rey, 2000). The chlorophyll-a concentration was then calculated using the formulae below;

Chl-a(μg/L)=(11.85*E664) -(1.54*E647) -(0.08*E630)

Concentration of Chl-a(mg/L) = [Chl-a * v]/V*L (2)…………………………..eqn 1(Aminot & Rey, 2000).

Where;

v = Volume of acetone 90%, L

V = Volume of the water sample, L

L = Light path of cuvette, cm

E664 = Value of absorbance at wavelength 664 nm

E647 = Value of absorbance at wavelength 647 nm

E630 = Value of absorbance at wavelength 630 nm

3.7 Trophic State Index

The Trophic State Index is a classification system designed to rate water systems based on the amount of biological productivity. (USEPA, 2007). Carlson's index was proposed by Robert Carlson in 1977. The index uses algal biomass as the basis for the trophic state classification. Three variables, chlorophyll pigments, Secchi depth and total phosphorus was used to estimate the trophic state. The range of the index is from approximately zero (depicting an extremely good condition) to 100 (an extremely degraded condition). The index has an advantage over the use of the raw variables of phosphorus and chlorophyll value in terms of time consumption. It is relatively simple and easy to calculate.

Three equations are used; Secchi depth, TSI (SD), chlorophyll pigments, TSI (CHL) and total phosphorus, TSI (TP);

Carlson's Trophic State Index (TSI)=[TSI (TP)+TSI(CHL)+TSI(SD)]/3

Where; TSI (TP)=14.42In Total Phosphorus (µg/L) +4.15

TSI(CHL)=9.8InChlorophyll-a(µg/L)+30.6

TSI(SD)=60-14.41In Sechhi depth(Meters)……………………………………eqn 2

(Carlson, 1996).

3.8 Phytoplankton Analysis

Phytoplankton analysis was carried out using procedures outlined in the Phytoplankton Manual by Hotzel &Croome (1999). The samples were shaken gently and inverted thoroughly for at least 30 seconds so that it is well mixed before subsampling to avoid subsampling errors. Subsamples were immediately transferred into a counting chamber (Utermohl chamber) of 5ml, 10ml and 25ml. This was to ensure that each of the phytoplankton cells present in each sample will be identified. Cells were made to settle on the floor of the Utermohl chamber. The floor of the chamber was mounted and observed under an inverted microscope for identification and counting to estimate the phytoplankton population (Plate 3.2). Dense samples were diluted with distilled water and the dilution factor was taken into account in the estimate. The identification was done using The Phytoplankton Manual by Snejana Moncheva (2010), de Vlaming (2006), (Hötzel & Croome, 1999.) were followed during laboratory work and identification.

Plate 3.2: Chlorophyll-a analysis and Phytoplankton identification in the lab.

3.9 Benthic sample

To remove the formaldehyde and other fine sediments (lesser than 0.5 mm), benthic samples were thoroughly washed with water. Washed samples were spread evenly on a sorting tray, with a white background. The stained matter was picked using a fine forceps and placed into storage vials containing 30% alcohol for short-term preservation. Stained matter or organisms identified were placed into broad taxa, including polychaetes and mollusk (Eleftheriou & McIntyre, 2007; Rumohr, 2009). Acceptable taxonomic keys such as Nickles (1950), (Fauchald, 1977) and Barnes (1994), articles and manuals such as Tebble (1955), Rupert & Fox (1988), Branch & Branch (1998), (Rouse & Pleijel, 2021), Ardovini & Cossignani (2004) and Martin & Davis (2001) were used as guides.

3.9.1 Diversity and Ecological health Indices

3.9.1.1 Benthic macroinvertebrates

Benthic diversity indices which serve as an indication of community health on spatial and temporal scales were measured using the following indices (Bevilacqua et al., 2011).

3.9.1.2 Margalef's species richness (d)

Species richness is the total number of different species present (without taking into account the proportion and distribution of each species) within the sample. Margalef index (Margalef, 1958) is represented by the equation;

$$d = \frac{S-1}{\ln N} \text{ ....eqn 3}$$

where S = the total number of species, and

N = the total number of individuals in the sample.

3.9.1.3 Pielou's evenness (J')

Pielou's evenness (Pielou's, 1969) used the ratio of the expected number of species against the recorded number of species as an index of evenness, with the assumption that all species were accounted for in the sample. This aids in qualifying organism distribution among sampled assemblages. The higher the attained value, the more evenly individuals are spread among the species. Species evenness is dependent on species richness and species diversity. The evenness measure is a ratio of the observed diversity to the maximum possible in a sample having the same number of species. Equation used was (Pielou's evenness (1966):

$$J' = \frac{H'}{H'max} = \frac{H'}{\log S} \text{......................................eqn 4}$$

where H’ = the Shannon-Wiener diversity index S = the total number of species

3.9.1.4 *Shannon-Wiener’s diversity index (H’)*

The Shannon-Wiener diversity index (also referred to as the Shannon diversity), characterizes the state of an assemblage per the species richness and species abundance. It assumes all species are represented in the sample and that individuals are randomly sampled from an independently large population. The community diversity is defined by the obtained value; 0 to 1.5 for poor, 1.5 to 2.5 for moderate and > 2.5 for highly diverse. The Shannon-Wiener diversity value often falls between 1.5 and 3.5 but can exceed 4. The index increases as the community richness and evenness increases (Magurran, 2004). The equation used is:

$$H' = -\sum_{i=1}^{S} pi \ \ln pi \quad \text{.............................eqn 5}$$

Where; pi = the proportion of individuals found in species i

ln = natural logarithm, s = the total number of species

3.9.1.5 *Index of Biotic Integrity (IBI)*

Phytoplankton assessment was done using the Index of Biotic Integrity (IBI). The index has been proven to be an important tool for assessing ecosystem quality (Gammon and Simon 2000). The degree of sensitivity to environmental factors of organisms was used in developing the biotic integrity index. It has been developed for different aquatic environments in different countries and regions (Wang *et al*., 2005; Kane *et al*., 2009; Bae *et al*., 2010; Zalack *et al*., 2010; Maulood *et al*., 2011; Wu *et al*., 2012a, 2012b; Al-Janabi *et al*., 2016; Ersanli and Gönülol 2003; Lacouture *et al*., 2006). A discriminant analysis was made with the primary data (Phytoplankton count) to obtain plankton metrics data. Multivariate statistical analysis was then used to evaluate the metrics to determine levels of the phytoplankton population. (Blanco *et al.*, 2007; Martinez-Crego *et al.*, 2010). The Plankton Index of Biotic Integrity was calculated as the sum of selected metrics scores according to Kane (2004), Kane et al., (2009) and Teng et al., (2014) (Houssou et al., 2020);

$P-IBI=\sum_{i=1}^{n}(Pi)$……………………………………….eqn 6

With Pi the score of metric i. The IBI value range was divided into four equal parts corresponding to 'Very good', 'good', 'fair' and 'poor' (Houssou et al., 2020). For metrics that decrease with degradation, the equation used was; (Houssou et al., 2020)

$Pi = {}^{\text{metric value}}/_{95\%\ \text{percentile}}$…………………………………eqn 7

For the metrics that increase with degradation, the equation was;

$\mathbf{Pi} = \frac{\text{maximum value-minimum value}}{\text{maximum-5\% percentile}}$……………………………………...eqn 8

3.10 Data Analysis

Differences from average values from both in-situ and laboratory analyses of water quality and benthic and phytoplankton diversities were represented on bar display chat using Microsoft office excel 2016, Minitab and the R software. Data were organized into tables and graphs, being generated as a pictorial representation of data obtained for the four months of the study perio

CHAPTER FOUR

4.0 RESULTS

This chapter gives results on the following, based on the objectives of this research,

1. the physicochemical conditions within the different zones of the lagoon through measurements of temperature, dissolved oxygen, pH, salinity, nitrate, phosphate, ammonia and silicate.
2. Trophic State within the different zones in the lagoon using the parameters in (1) above.
3. Estimate of phytoplankton and benthic macroinvertebrates diversity within the different zones of the lagoon.
4. Assessing any change in ecological status within the different zones of the lagoon.

4.1 Water quality analysis (Physico-chemical parameters).

Generally, there was not much variation in pH within the various zones for each month. However zones A and B in the month of April recorded the highest pH level (9.6. ± 0.16). The pH of the lagoon increased from October, through to April and decreased in July (Figure 4.1.1). Zone B in the month of October measured the least pH value (7.6 ± 0.17). Temperature on the other hand, showed variations within the zones for each month (Figure 4.1.2).

The highest level of temperature was recorded for zone D in the month of April (32.9 ± 0.72 °C) and least for zone E (27.7 ± 0.37 °C). DO was also measured for the various zones, highest level was recorded for zone C (8.4 ± 0.21mg/l) in the month of April and least for zone B (6.0 ± 0.60 mg/l) in the month January. On the whole, DO levels measured showed an increased trend from October through to April (Figure 4.1.3). Much variations was seen in salinity within the zones (Figure 4.1.4), highest salinity was recorded for zone E (26.0 ± 0.5 ppt) in April and least in zone C (16.5 ± 2.7 ppt).

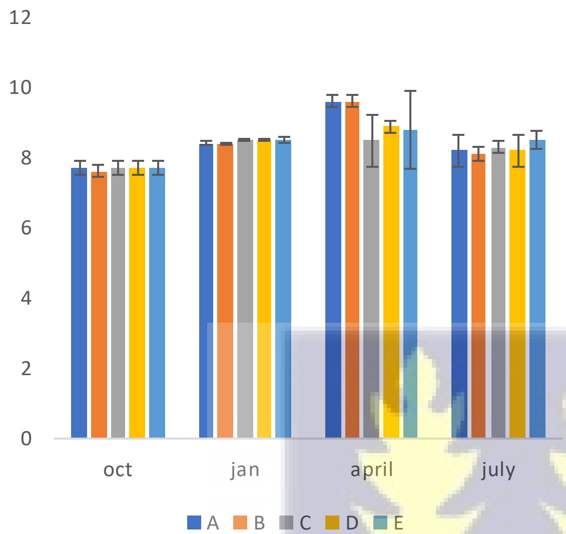

Figure 4.1: pH levels of the Keta lagoon for the sampling months.

Figure 4.2: Levels of temperature of the Keta lagoon for the sampling months

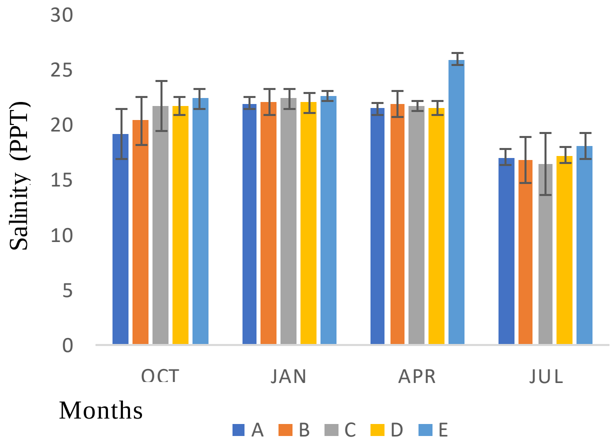

Figure 4.3: Levels of salinity of the Keta lagoon for the sampling months.

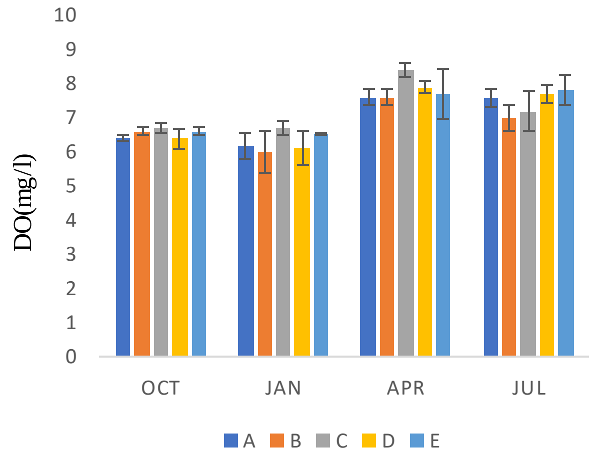

Figure 4.4: DO levels of the Keta lagoon for the sampling months.

4.2 Nutrient Analysis

Nitrate levels in the Keta lagoon for the sampling months showed much variation (Figure 4.2.1). The highest level of nitrate was recorded by zone A (3.8± 0.44 mg/l) in the month of April and least by Zone C (1.6 ± 0.98 mg/l). On the average, high values of nitrates were recorded for the various zones in the month of April compared to the other months. Ammonia levels were generally high in zones A, B and C in all in the sampling months (Figure 4.2.2). The highest level was recorded in Zone A (0.12 ± 0.01 mg/l) in the month of October and least in zone C (0.03± 0.05 mg/l). Phosphate levels varied within the zones during the sampling months. Highest value of phosphate was recorded for zone D (0.31 ± 0.03 mg/l) in the month July. Least phosphate levels recorded was 0.1 ± 0.04 mg/l in the month of January (Figure. 4.2.3) and for Zone D.

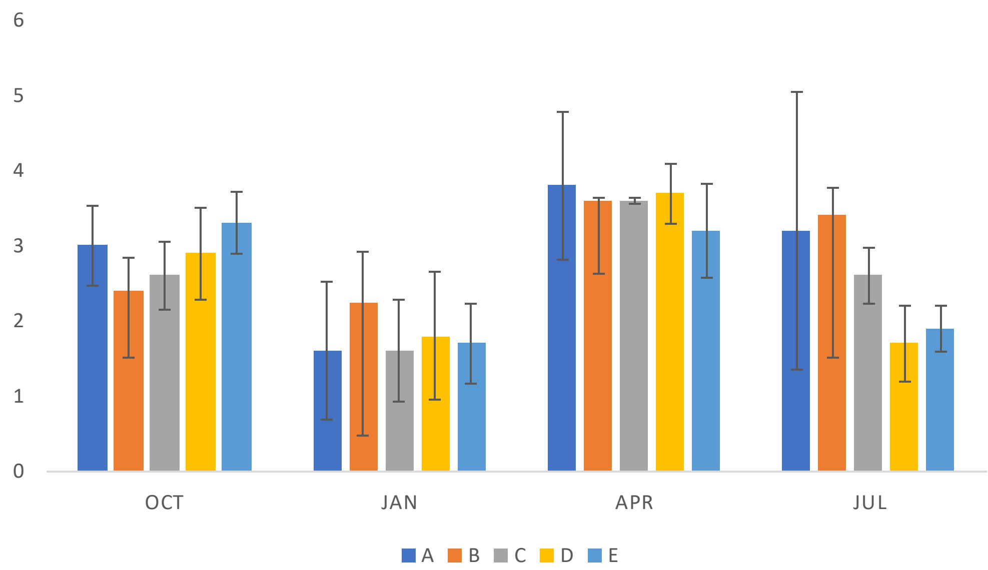

Figure 4.5: Levels of nitrates in the Keta lagoon for sampling months

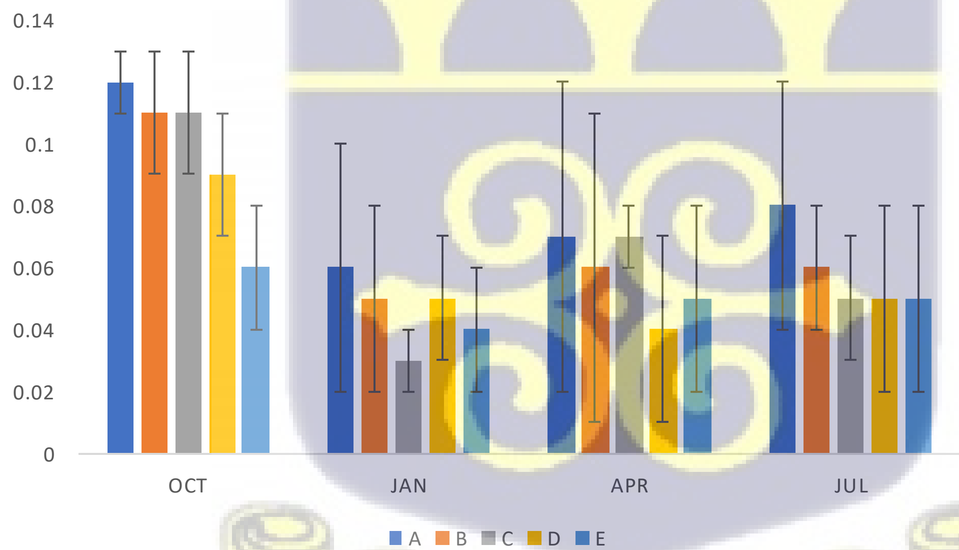

Figure 4.6 Levels of ammonia in the Keta Lagoon for the sampling months.

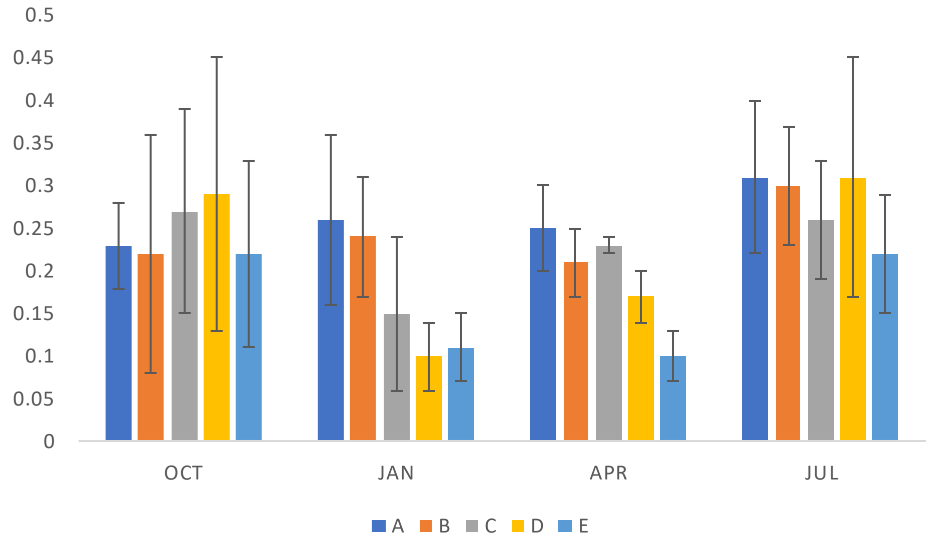

Figure 4.7 Levels of Phosphate in the Keta Lagoon for the sampling months.

4.3 Trophic State Index

Using measurements obtained from chlorophyll-a, sechi disc depth and nutrients, trophic state index was calculated for the various zones of the Keta Lagoon (Figure 4.3.1). Highest TSI was recorded for zone A (64.9) and the lowest for zone E (61.3).

Figure 4.8: Trophic State Index of the various zones of the lagoon.

4.4 Phytoplankton Index

Phytoplankton species encountered and identified within the samples taken include diatoms, blue-green algae and cyanobacteria (Plate 4.1). The total counts of phytoplankton was used to estimate P-IBI scores for each zone in the months October, January, April and July (Figure 4.4.1).

A score value less than 1 depicts an excellent ecological condition of water, based on phytoplankton populations. Values of 1 to 3 indicate good condition, while 3 to 4 show fair ecological condition, values above 4 show poor condition of water based on enormously high phytoplankton population. Zones A, B, C and D were areas of poor ecological condition throughout the months. Zone E fluctuated from good to fair conditions throughout the months of the study. Futhermore, phytoplankton and silicate for the various zones were analysed (Figure 4.4.2). Generally, it was observed that phytoplankton population was high where silicate levels are high.

Plate 4.1: Some phytoplankton found at the study sites, Cyclotella spp (A), Tabellaria spp(B) and Euglena(C).

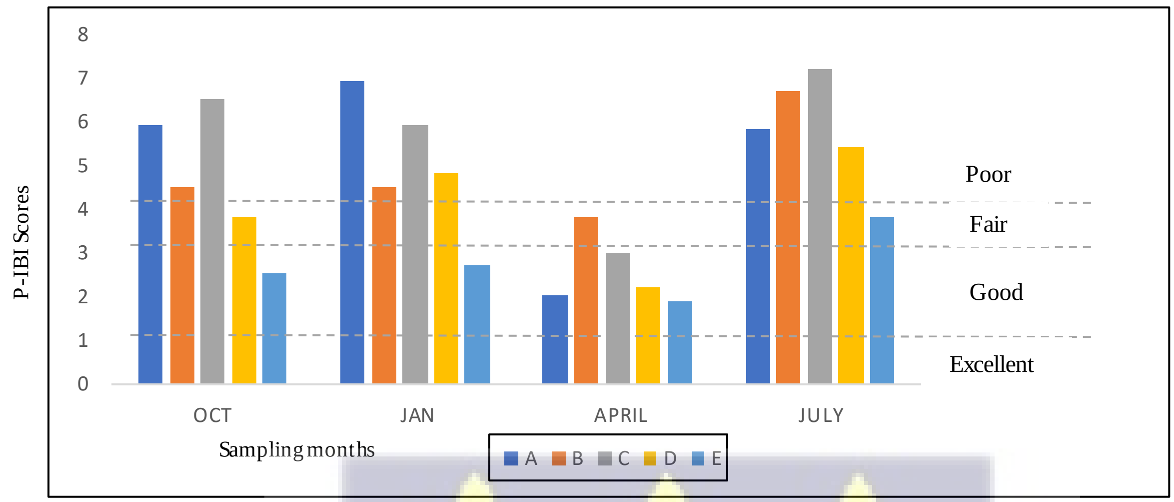

Figure 4.9 P-IBI Scores for each zone in the month

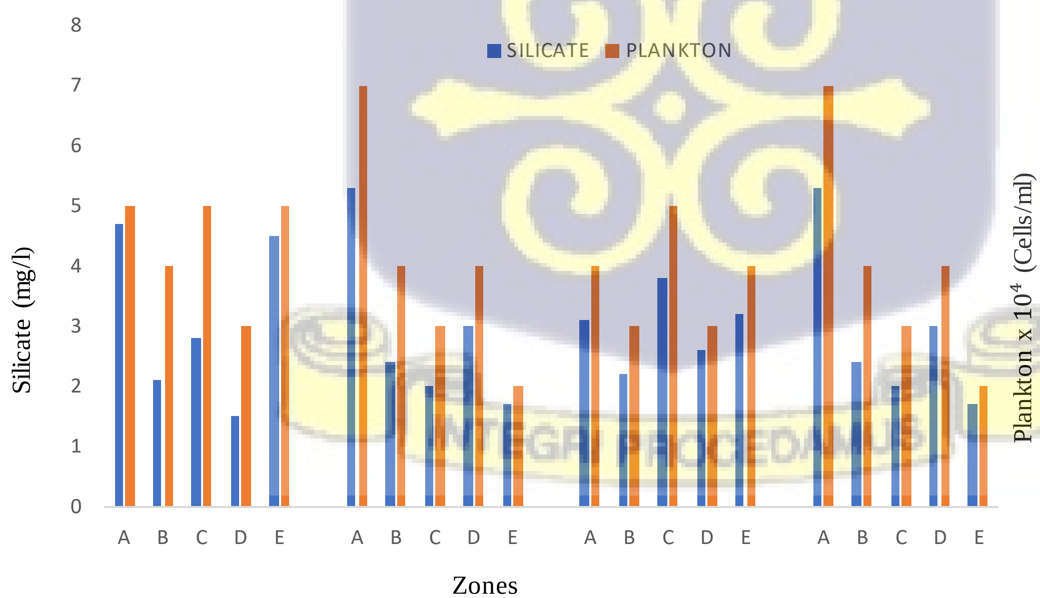

Figure 4.10: Levels of phytoplankton and silicate for each zone.

4.5 Benthic Macroinvertebrates

A total of 1018 individual species were counted. Major taxa obtained from the analyses were polychaetes and mollusks. Examples of the species encountered were *Tivella Sylid*, sites *Tellina nymphalis*, *Tivela tripla*, *Tympanotonus fuscatus*, *Tivela bicolor*, *etc.(*Plate 4.5.1*)*. The total counts of benthic organisms for each zone per sampling month was estimated.(Figure 4.5.1). Generally, benthic counts decreased from October to July for each zones. The highest benthic counts were obtained in Zone A for all the sampling months and least in zone E for July. The major taxa identified were estimated in percentage (Figure 4.5.2). Mollusks were 83% of the total species identified and polychaetes were a percentage of 17. Species diversity, richness and evenness were further cacultated using the counts obtained (Table 4.5.1). Zones A and B showed higher levels of diversity, evenness and richness.

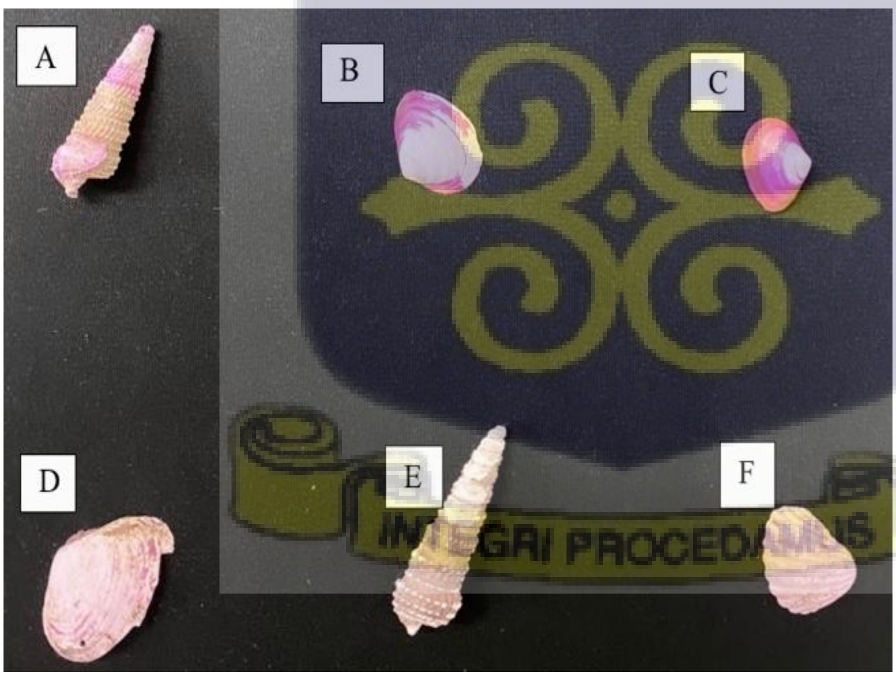

Plate 4.2: Some benthic organisms obtained from the Keta lagoon. Tympanotonus fuscatus (A), Tellina nymphalis (B), Tivela bicolor (C) and Tivela tripla (D).

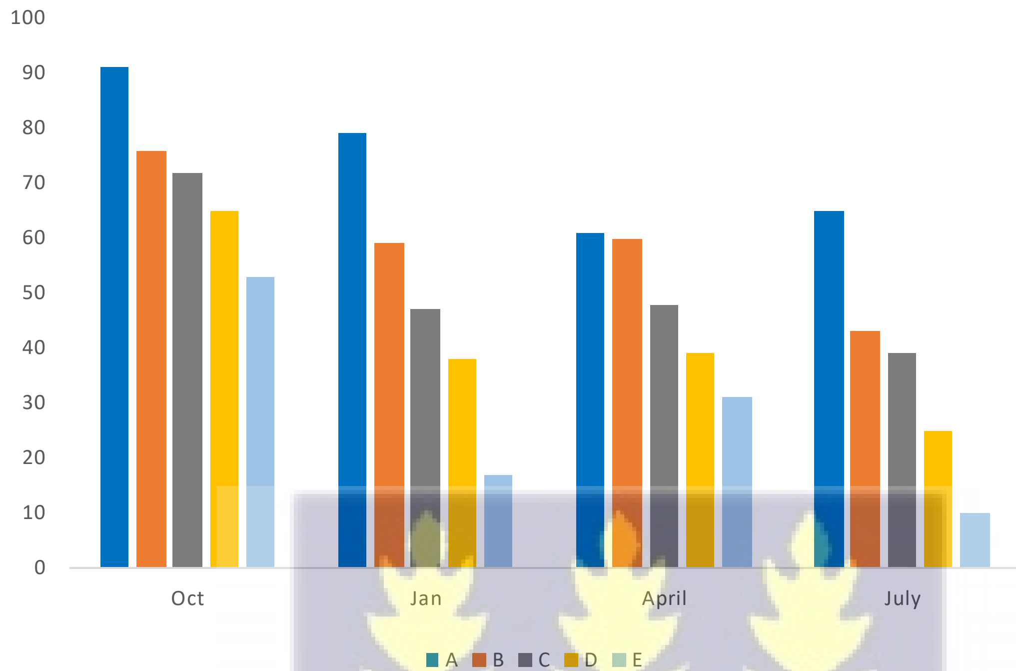

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Figure 4.11: Counts of benthic macroinvertebrates for each zone

Figure 4.12: Major taxa of benthic organisms in percentage.

Table 4.1: A table showing Species richness and diversity indices for each zone.

Indices	Zone A	Zone B	Zone C	Zone D	Zone E
Margalef's Richness (d)	1.3	1.3	1.2	1.0	1.0
Pielou's Evenness (J')	0.87	0.86	0.79	0.74	0.71
Shannon-Weiner (H')	1.8	1.8	1.7	1.5	1.5

4.6 Comparing this study to past ones

4.6.1 Water quality parameters

Water quality parameters obtained in this study was compared to past studies. The highest averaged pH was recorded for this study and least for the study done by Lamptey 2008 (Fig. 4.6.1).

Temperature was also compared to previous work done on the Keta lagoon by Lamptey 2013 and Lamptey 2008. Highest temperature was recorded in this study and least by Lampety 2008.

Salinity (Figure 4.6.3) and DO (Figure 4.6.4) levels in the lagoon for this study and that of study done by Lamptey, 2008 on the Keta lagoon were compared.The highest level of Salinity and DO were recorded for this study and the lowest for Lamptey, 2008.

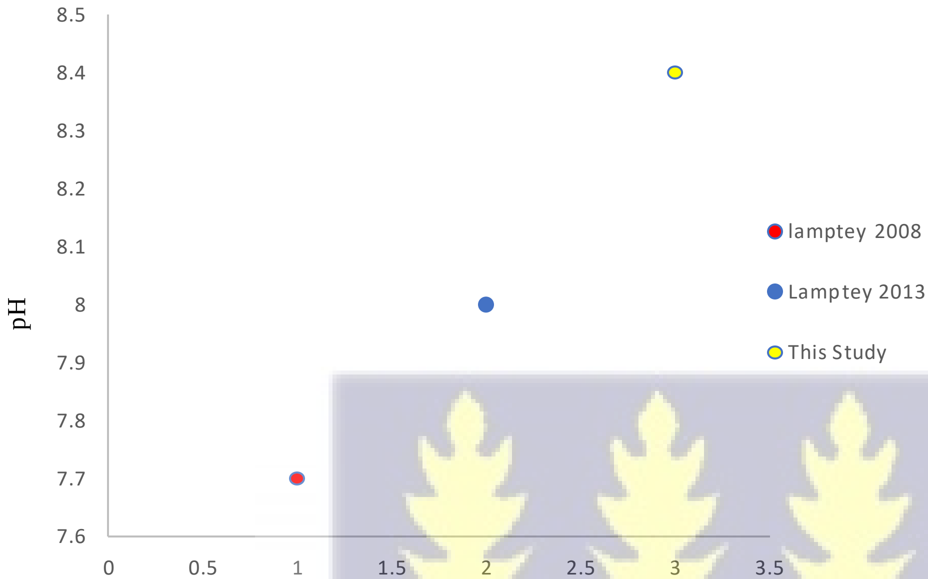


Figure 4.13: Shows levels of pH for this study and past studies

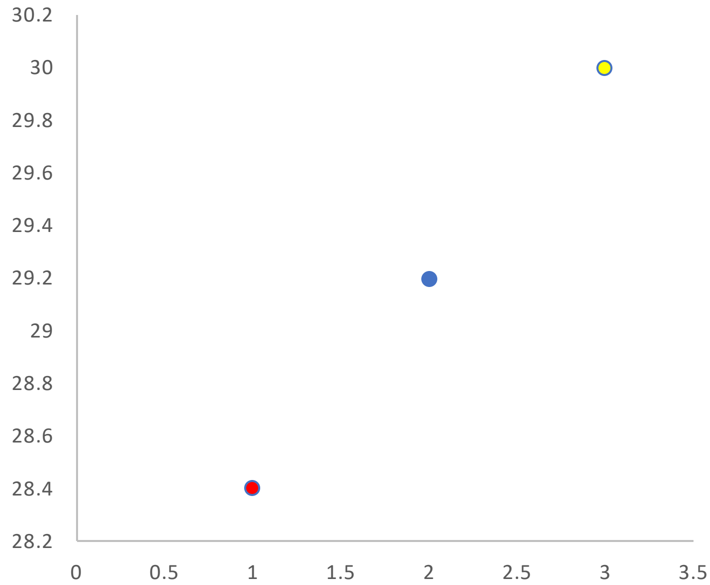
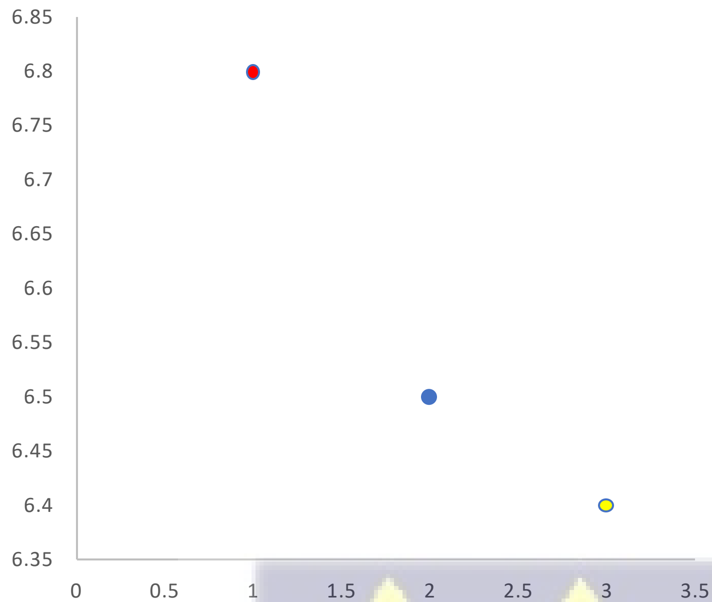


Figure 4.14: Shows temperature for this study and past studies.

Figure 4.15: Shows levels of Salinity for this study and past studies



4.6.2 Nutrients

Nutrients analysed from this study was compared to past studies done on the Keta lagoon. Nitrates, Ammonia and Phosphates levels were highest in this studies and least levels recorded by Lamptey (2008).

Figure 4.17: Shows Nitrate concentration levels.

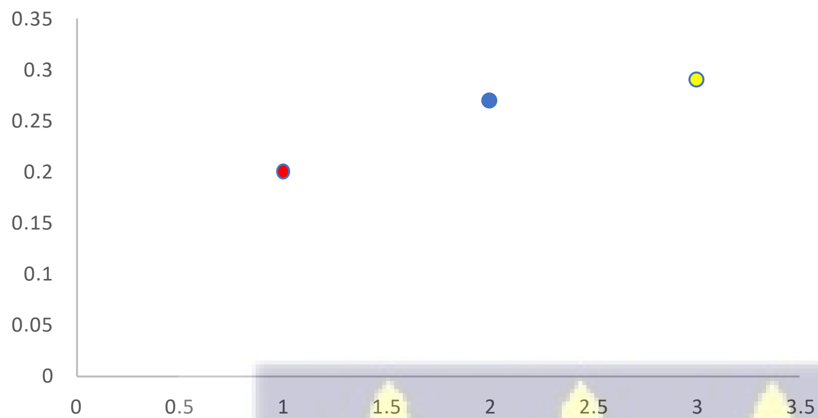


Figure 4.18: Shows Phosphate concentration levels.

4.6.3 *Benthic macroinvertebrates*

Major phylum obtained from this study was compared to work done by Lampety, 2008. Both studies reflected high levels of mollusks, followed by polychaetes. Mollusks constituted 60 % of the study done by Lamptey, 2008, followed by 33% polychaetes and 7% of other species (Figure 4.6.3.1). This study showed 83% of mollusks and 17% polychaetes. Species richness, evenness and diversity were compared. The study done by Lamptey, 2008 recorded values of 3.5, 2.2 and 5.8 for species richness, evenness and diversity respectively while this study recorded 1.2, 0.8 and 1.7 respectively. Diversity was high in 2008 during the previous studies than this current studies.

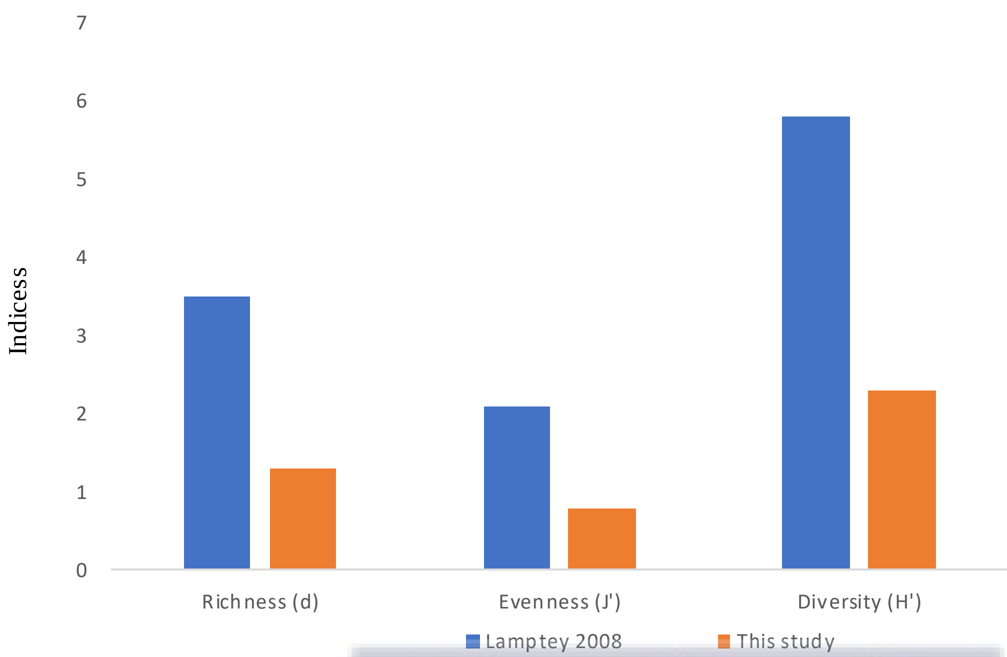


Figure 4.21: Compares species richness, evenness and diversity to past study

4.7 A Principal Component Analysis showing relationship between measured parameters

PCA ordination diagram for the relationship between the Physico-chemical parameters (Salinity, DO, Turbidity, CHL-a, Nitrate, Phosphate, Ammonia, Silicate) and benthic diversity and phytoplankton index (Figure 4.7.1). For the first component, nitrate, phosphate, ammonia, silicate, turbidity, Chl-a and phytoplankton index were in a strong positive correlation. For the second component, benthic diversity, salinity and DO were in a negative correlation.

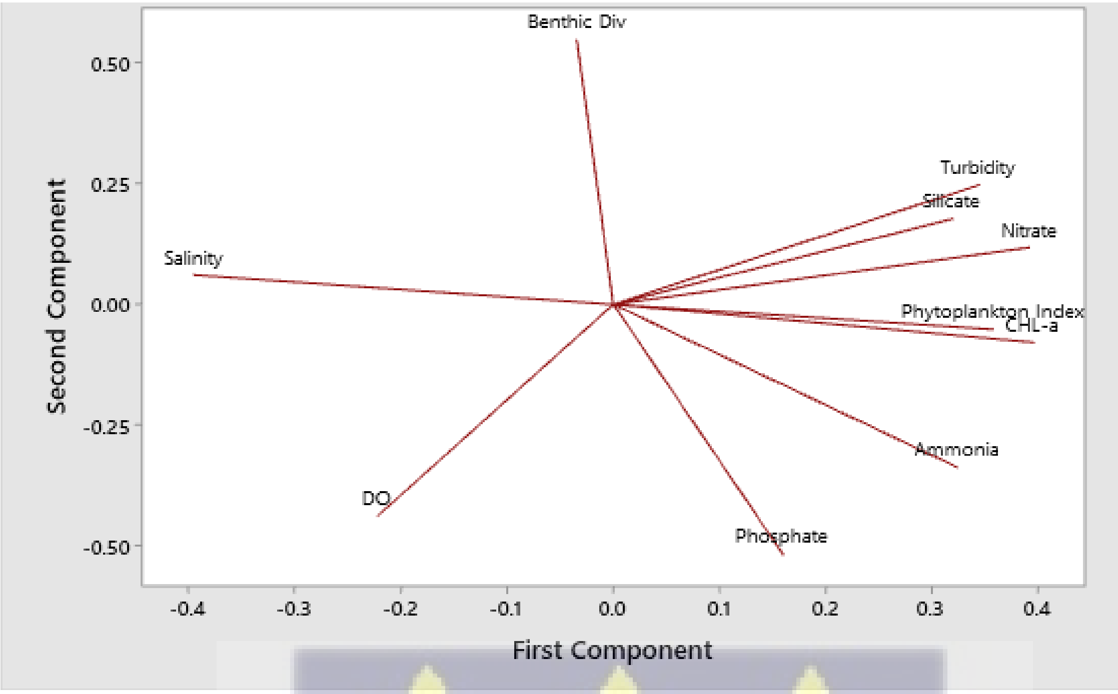


Figure 4.6.1: A Principal Component Analysis. Legend: First component = the axis, which maximizes the variance of points projected perpendicularly onto it. Second component = perpendicular to the first component and direction in which the variance of points projected onto is maximized.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Water Quality Parameters

5.1.1 pH

The acceptable pH values for Ghana's EPA is 6.0. (Taylor et al., 1999). Zones A and B recorded 9.6, which is above the acceptable range. Zones C, D and E measured pH value within the permissible levels. Zones A and B (Anloga and Woe areas) are areas with high agricultural activities along the lagoon compared to the other zones. The levels of pH in the various zones generally showed no significant difference statistically.

High pH values measured in the area may be caused by anthropogenic activities by the use of pesticides(through acid hydrolysis) and farming activities (transporting of excess fertilizers) around the catchment area of the lagoons. When there is surface runoff, chemicals in pesticides and fertilizers in the surrounding farms end up in the lagoon (Laar *et al*., 2011; Kwesi, 2017). Studies by Lamptey (2008), Lamptey (2013) and Avornyo (2017) on the lagoon reported pH values of 7.7, 8.0 and 8.3 respectively. Comparing the three past studies to this current study depicts a trend of increasing alkalinity with time. This can affect the normal biological function of the lagoon (USEPA 2006). The Keta lagoon is an open system (Karikari et al., 2009), and therefore characterized by having a considerable amount of fresh/seawater exchange which means the alkalinity of the sea may affect the pH of the lagoon.

5.1.2 Dissolved Oxygen (DO)

Dissolved oxygen is an indicator of water quality in a lagoonal system (Minnesota Pollution Control Agency, 2009, N. Sexauer & V. Karn, 2013). Organisms in lagoons depend on oxygen for survival and therefore, lower oxygen levels pose a threat to these organisms (Campanati et al., 2016). Dissolved oxygen levels measured in Zone A was 6.5 mg/l, B recorded 6.3 mg/l, C was 7.8 mg/l, D was 8.1 mg/l and E 7.5 mg/l.

Studies relating to water quality in the United States of America, classify the minimum required concentrations for dissolved oxygen in lagoonal water to be in the range of 5 mg/l to 6mg/l (EPA- Washington, 2009). This is also in line with the dissolved oxygen standard provided by the World Health Organization (Enderlein & Peter, 1996). Studies by Lamptey (2008), Lamptey (2013) and Avornyo (2017) reported DO values of 6.3mg/l, 6.1mg/l and 5.8 mg/l respectively in the Keta lagoon, which shows a trend of decreasing DO levels in the lagoon. However, this current study measured an average DO value of 7.2 mg/l which is an acceptable DO level both by Ghana's and USA EPA. High levels of DO can be attributed to the system being shallow with strong winds which increases the aeration at that particular point of time and levels of aerobic activities in the Keta lagoon catchment area.

5.1.3 Temperature

Averaged temperature values recorded in the lagoon for Zones A was 32.3°C, B was 31.9°C, recorded 30.4°C then D and E were 29.1 °C and 28.6 °C respectively. Fluctuations in temperature values may be caused by varying weather conditions and mixing processes at the time the measurement were taken. Ghana's EPA permissible limit for temperature is 29°C

(Agbemehia, 2014). Past studies conducted by Lamptey (2008), Lamptey (2013) and Avornyo (2017) in the Keta lagoon reported temperature values of 28.4°C, 29.2°C, and 29.3°C respectively. Comparing the temperature recorded for this study, which is 30.5 °C (which is above the EPA permissible limit) to previous ones, shows an increase in temperature in the lagoon with time. In an aquatic system, temperature is necessary for oxygen solubility, therefore if the temperature keeps increasing in the lagoon, oxygen levels will be expected to reduce.

5.1.4 Salinity

Mean salinity measured for zones A was 21.1 ppt, B was 22.3 ppt, C 22.6 ppt, D and E 17.2 ppt and 22.2 ppt respectively. Salinity affects dissolved oxygen levels in the water. The solubility of oxygen in water increases as salinity decreases and this is in line with levels of DO recorded in the lagoon. Past studies by Lamptey (2008) recorded mean salinity of 30.4 ppt and this study measured a mean value of 20.8 ppt this shows that salinity has decreased over time. Generally, Salinity was averagely low as compared to the previous levels rcorded and this can be attributed to more freshwater influx thus run off from Todzie River and from the Volta River.

5.2 Nutrients

5.2.1 Nitrate

Nitrate is transported in the water column when it bonds with suspended sediments (Tang & Maggi, 2018). Inputs of nitrates in lagoons occur through runoff of chemical fertilizers or animal manure from farmlands and waste from sewage (MPCA, 2008).. Zones A, B, C, D and E recorded averaged nitrate values of 3.4 mg/l, 2.9 mg/l, 2.4 mg/l., 2.6 mg/l and 1.9 mg/l respectively. Nitrate measurements for the Keta lagoon during the months of the study were within the range of 1.9mg/l to 3.4 mg/l, however zone A recorded the highest nitrate levels, and least in zone E.

Ghana's EPA tolerable limit for nitrate in an estuarine system or open lagoons is 0.1mg/l (Nartey *et al.*, 2012). This suggests that the lagoon has nitrate values above the permissible range. Previous studies in the Keta lagoon by Lamptey (2008), Lamptey (2013) and Avornyo (2017) recorded nitrate levels of 1.08 mg/l, 1.09 mg/l and 1.13 mg/l respectively. Comparing the measured level nitrate of this study to these past studies shows a considerable increase in nitrate levels over the years.

5.2.2 Phosphate

Phosphate is the limiting factor in the growth of algae which is known to control primary productivity in a lagoonal system (ANNET, 2014). High levels of phosphorus concentrations in a lagoon shows anthropogenic intervention (Addo *et al.*, 2011). Zone. A, B, C, D and E recorded phosphate levels of 0.26 mg/l, 0.22mg/l, 0.21 mg/l, 0.17 and 0.13 mg/l. Phosphate measurements for the lagoon were within the ranges of 0.13mg/l to 0.26 mg/l, although zone A recorded the highest level. Zone E recorded the least level of phosphate. EPA's (Ghana) maximum tolerable value for phosphate in the aquatic system is 2.0 mg/l (Nartey *et al.*, 2012). This suggests that phosphate levels in the lagoon were within the acceptable EPA range. Phosphate values recorded by Lamptey (2008), Lamptey (2013) and Avornyo (2017) were 0.2 mg/l, 0.27 mg/l and 0.28 respectively. These past studies show that the levels of phosphate in the lagoon is increasing with time.

5.2.3 Ammonia (NH_3)

Ammonia in water bodies are caused by anthropogenic activities. Nitrate in an estuarine system is converted into ammonia and then assimilated into amino acids by organisms (van der Hoek et al., 2018). Ammonia recorded for the various zones are 0.12 mg/l for zone A, 0.09mg/l for zone B, 0.10mg/l for zone C, 0.06 mg/l for zone D and 0.03mg/l for Zone E. Ammonia measurements for the lagoon were in the ranges of 0.03 mg/l to 0.12 mg/l with zone A recording the highest. Zone E recorded the least levels of ammonia.

Both Ghana's EPA and USEPA permissible limit for ammonia in an estuarine or lagoonal system is 1.5 mg/l and 0.02 respectively (Nartey et al., 2012, USEPA, 2014). This, therefore, suggests that the levels are above the USEPA permissible limits but within Ghana's EPA. Previous studies in the lagoon by Lamptey (2008), Lamptey (2013) and Avornyo (2017) recorded ammonia levels of 0.02mg/l, 0.07mg/l and 0.06 mg/l respectively. This indicates that the level of ammonia in the system is increasing with time. High nitrate values and relatively low ammonia levels indicate that dissolved oxygen levels available are enough to convert ammonia into nitrate (van der Hoek et al., 2018).

5.3 Trophic state index

The trophic status index (TSI) of the Keta Lagoon was based on the concentration of chlorophyll *a* and total phosphorus in the lagoon. Zone A recorded the highest TSI of 64.9. The least TSI was recorded for zone E. Averagely, TSI values obtained from the lagoon ranged from 61.3 to 64.9, and falls within the Carlson's Trophic status index range scale of 60- 100, which implies that the lagoon is eutrophic-hypereutrophic. The TSI obtained in this study is in line with the study done by Addo (2010) on the Keta lagoon. TSI calculated by Addo (2010) was 71.13, which falls within 60-100 of the Carlson's Trophic State index range (Addo, 2014). This state of the lagoon may be attributed to high nitrate and phosphate concentration brought into the lagoon from farmlands around it and resulting in increased primary productivity (Chao Song, 2018). However, when nutrient inputs continue to increase, the lagoon will become extremely rich in nutrients which can result in excessive algal blooms.

5.4 Phytoplankton

The phytoplankton assemblages consisted of four divisions. They included Euglenophyta (*Euglena*), Ochrophyta (*Navicula spp*, *Cyclotella*, *Gyrosigma*, *Surirella*, *Cymbella*), Heterokontophyta (*Tabellaria*, *Synedra*) and Cyanoprokaryota (*Phormidium*, *Anabeana*).

Euglenophyta is highly related to environmental pollution and their presence can induce significant algal bloom in a nutrient-rich condition (Annick *et al.*, 2016). They are therefore good indicators of environmental pollution. Diatoms, including *Navicula* and *Surirella* are also related to pollution from anthropogenic activities and are therefore eutrophication and organic pollution indicators (Jüttner *et al.*, 2003).

The ten candidate metrics selected for final P-IBI development achieved significant discrimination of nutrient pollution levels in the lagoon. Zones A, B and C (4.9-6.5) were in poor ecological conditions in October . In January and July, Zones A, B, C, and D (3.0-3.8) were in fair ecological conditions. Zone E (1.9-3.8) were in good ecological conditions.

Generally, Zones A, B, C and D showed poor ecological conditions. These areas are of high agricultural activities which require may require high fertilizer application, this may have caused an increase in phytoplankton population. Zone E had less phytoplankton population and this implies less nutrient input compared to the other zones.

The mean Plankton Index of Biotic Integrity (P-IBI) for the lagoon is 3.96, which shows a mesotrophic lagoon with diverse populations of phytoplankton. According to Codd *et al.*, (2005) when mesotrophic lagoons are not properly managed, algal blooms may occur (Houssou *et al.*, 2020). High nutrients influx in the presence of enough DO can cause algal bloom and anoxic conditions in the water (Anderson, 2002, Bellanger *et al.*, 2004).

5.5 Plankton and Silicate

From figure 4.4.2, levels of phytoplankton go high as silicate levels increase. With respect to the highest levels of silicate recorded in the zones of the lagoon showed; Zone A (4.6 mg/l) > Zone E (2.8) > Zone C (2.7) > Zone (2.5) > Zone B (2.3). Phytoplankton populations and silicate were observed to be highest in Zone A, just as was observed in the studies done by Ling Sun *et al.*, 2007, on a community lagoon in China. The results of the study showed that the biomass and ratio of diatoms species increases significantly when there is an increase in silicate levels (Chen et al., 2016).Diatoms require high silicate as much as nitrogen and phosphorus for their development (Baker *et al.*, 2007, Brack et al., 2017, Holligan & Lucas, 2021 & Nelson et al., 2005). Other planktonic groups such as chrysophytes and silicoflagellates also undergo silification.

5.6 Benthic macroinvertebrate

The total number of species counted in the Keta lagoon was 1018 which consists of 83% mollusks and 17% polychaetes as the major taxa. Species richness for zone A, B, C, D and E are 1.3, 1.3, 1.2, 1.0 and 1.0 respectively. Zone A and B showed the highest richness. Species evenness for the zones were 0.87, 0.86, 0.79, 0.74 and 0.71 respectively. Zone A recorded the highest level and E the least. Diversity was highest also in zone A and least in D and E. Generally, Macrobenthic assemblage richness, evenness and diversity was 1.2, 0.8 and 1.7 respectively for the lagoon. The species richness, as well as the scale and level of perturbation has a direct link with the number of samples taken and sample size (Magurran, 2004, Gotelli et al., 2017). Species richness, evenness and diversity were low compared to studies done by Lamptey, 2008. This can be as a result of excessive inputs of nutrients or physical disturbance of habitat (Lamptey & Armah, 2008).

Two major taxa were identified in the study, indicating low species diversity and evenness (USEPA, 2015). Higher diversity and evenness indicate better environmental conditions, while the opposite can indicate stresses on the system.

5.7 Principal component analysis (PCA)

The results of the PCA (figure 4.6.1) showed that phytoplankton and benthic diversities were influenced by the various physicochemical parameters. For the first component, nitrate, phosphate, ammonia, silicate, turbidity, Chl-a and phytoplankton index were in a strong positive correlation. Therefore, it is expected that phytoplankton and for that matter, Chl-a will increase as nitrate, silicate, ammonia and phosphate increase. Turbidity is also expected to increase as nutrients and Chl-a increase. For the second component, benthic diversity, salinity and DO were in a negative correlation. The presence of excess nutrients accelerates the growth of algae and higher forms of plant life, this will eventually lead to oxygen deficiency (hypoxia) condition that affects benthic organisms except for benthic groups that can withstand harsh conditions of the lagoon.

CHAPTER SIX

6.0 CONCLUSION

6.1 Conclusion

Physicochemical parameters (temperature, pH, dissolved oxygen, salinity, turbidity), nutrients concentration (nitrate, phosphate, ammonia and silicate), benthic and phytoplankton diversities were analyzed in this study from the Keta Lagoon. Sampling was done within the period of October 2020 to July 2021. The lagoon was divided into five zones based on the intensity of farming activities. Measurements obtained from the study were analyzed within the zones and also compared to previous studies to understand the trends over time.

Zone A, B, C and D showed generally high levels of water quality parameters (DO, temperature, turbidity, salinity, nitrate, phosphate, ammonia) in an order of A>B>C>D> E.

There was evidence that showed a general trend of water quality deteriorating as the years go by, comparing with studies conducted in previous years. For example, generally, DO levels are decreasing whereas ammonia, phosphate, nitrate, pH and turbidity are increasing with time. It is expected that the normal biological functioning of the lagoon system as well as the biodiversity will be affected. Measurements obtained from the study were further compared to standards by Ghana's EPA, USEPA and WHO acceptable ranges. Most of the measured results from the study (pH, nitrate, etc) were higher than the permissible limits of the earlier on mentioned institutions which suggests that the lagoon is polluted. Objectives 1 and 2 have been achieved.

Objectives 2 and 3 were achieved by calculating the Trophic State Index, Phytoplankton and benthic diversity. The Trophic state index and Phytoplankton diversity also showed that the lagoon had excess nutrients especially nitrates, phosphate and ammonia that support an abundance of aquatic plants. The benthic community was low in diversity and richness and dominated by bivalves 83% and polychaetes 17%. These benthic organisms appear to withstand the physical disturbance of the lagoon.

The Principal Component analysis determined the relationship between water quality parameters, nutrients levels, benthic diversity and Phytoplankton population. This showed that the increase in nutrients levels will in turn increase the population of Phytoplankton and reduce water quality and benthic community. Comparing the current status of the lagoon to the previous shows that the lagoon is deteriorating with time, confirming objective 5 of the study.

6.2 Recommendation

Based on the conclusion of the study, it is recommended that subsequent studies should be done over a longer period to understand the dynamics that exist in the lagoon system better. Also, researchers should liaise with community members to obtain information on the water level which will aid in deciding a better sampling strategy (for example when the water levels are low). Again, numerical models can be used to help understand the distribution patterns of nutrients and also to predict future nutrients concentration levels.

Further studies on the effects of pollutants on macrobenthic organisms should be investigated to determine their susceptibility to anthropogenic stress (nutrients or organic pollution).

There should be strict regulations on agricultural activities that can minimize nutrients loading around the catchment areas of the lagoon. This can be achieved through projects such as the OWSD project, which is focused on developing Android/ Interactive Voice Response (IVR) soil nutrient test kits in order to guide the application of fertilizers around the Keta Lagoon Complex in Ghana.

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APPENDIX

A table showing averaged physicochemical parameters for October 2020

Zone	pH	Temperature (°C)	Salinity (ppt)	DO (mg/l)	TDS (mg/l)	Conductivity (mS/cm)	Turbidity (NTU)
A	7.7 ±0.19	31.5 ±0.40	19.2 ±2.33	6.4 ±0.10	19.0 ±1.92	32.0 ±2.48	85.9 ±8.51
B	7.6 ±0.17	31.8 ±0.55	20.4 ±2.14	6.6 ±0.12	20.0 ±1.78	32.7 ±3.11	93.1 ±44.21
C	7.7 ±0.21	31.6 ±0.49	21.8 ±6.31	6.7 ±0.13	20.0 ±2.60	31.7 ±4.40	63.3 ±16.71
D	7.7 ±0.20	30.8 ±0.21	21.8 ±0.85	6.4 ±0.30	21.1 ±0.76	34.7 ±1.26	59.1 ±15.59
E	7.7 ±0.20	30.7 ±0.20	22.4 ±0.84	6.6 ±0.12	21.3 ±0.78	32.8 ±3.11	59.1 ±15.59

A table showing averaged physicochemical parameters for Jan 2021

Zone	pH	Temperature (°C)	Salinity (ppt)	DO (mg/l)	TDS (mg/l)	Conductivity (mS/cm)	Turbidity (NTU)
A	8.4 ±0.05	30.2 ±0.25	22.0 ±0.55	6.2 ±0.38	21.4 ±0.54	35.1 ±0.89	40.3 ±5.22
B	8.4 ±0.02	31.2 ±0.56	22.2 ±1.19	6.0 ±0.60	21.7 ±0.63	35.5 ±1.37	46.3 ±26.97
C	8.5 ±0.03	31.1 ±0.19	22.4 ±0.97	6.7 ±0.18	23.4 ±4.39	35.6 ±1.38	37.2 ±12.06
D	8.5 ±0.02	31.0 ±0.39	22.1 ±0.90	6.1 ±0.49	21.9 ±0.15	35.8 ±0.32	29.7 ±7.54
E	8.5 ±0.08	31.2 ±1.30	22.7 ±0.46	6.5 ±0.03	21.6 ±0.08	35.6 ±0.17	38.2 ±14.27

A table showing averaged physicochemical parameters for April 2021

Zone	pH	Temperature (°C)	Salinity (ppt)	DO (mg/l)	TDS (mg/l)	Conductivity (mS/cm)	Turbidity (NTU)

A	9.6 ±0.16	32.1 ±37.62	21.5 ±0.62	7.6 ±0.22	21.2 ±1.05	32.5 ±1.65	87.9 ±28.65
B	9.6 ±0.16	32.5 ±37.68	21.9 ±1.19	7.6 ±0.22	21.2 ±1.05	34.9 ±1.70	97.2 ±37.68
C	8.5 ±0.74	33.0 ±13.69	21.8 ±0.41	8.4 ±0.21	21.1 ±0.38	36.3 ±2.31	50.2 ±13.69
D	8.9 ±0.17	32.9 ±11.72	21.6 ±0.62	7.9 ±0.20	21.4 ±0.61	35.9 ±1.91	60.3 ±11.72
E	8.8 ±1.11	31.6 ±9.78	26.0 ±0.52	7.7 ±0.75	24.8 ±0.44	40.7 ±0.72	22.9 ±9.78

A table showing averaged physicochemical parameters for July 2021.

Zone	pH	Temperature (°C)	Salinity (ppt)	DO (mg/l)	TDS (mg/l)	Conductivity (mS/cm)	Turbidity (NTU)
A	8.2 ±0.45	28.5 ±0.31	17.1 ±0.73	7.6 ±0.26	16.9 ±2.49	28.1 ±1.10	32.7 ±22.82
B	8.1 ±0.19	29.2 ±0.44	16.8 ±2.11	7.0 ±0.38	17.0 ±1.94	27.2 ±3.42	59.5 ±29.67
C	8.3 ±0.16	28.9 ±0.16	16.5 ±2.75	7.2 ±0.57	16.7 ±2.49	27.0 ±4.12	63.0 ±10.40
D	8.2 ±0.45	28.6 ±0.31	17.3 ±0.73	7.7 ±0.27	17.7 ±0.70	28.5 ±1.12	29.2 ±21.82
E	8.5 ±0.27	27.7 ±0.37	18.1 ±1.21	7.8 ±0.45	16.6 ±3.26	29.3 ±1.69	28.5 ±19.21

A table showing total Phytoplankton count within the zones

ZONES	OCT	JAN	APRL	JUL

A	1329	1468	1210	1205
B	1001	1044	921	1412
C	1456	1245	716	1671
D	854	1045	512	1241
E	341	368	214	912

Abundance (No. of individuals) of species identified at the study sites.

Species	Abundance (Oct)	Abundance (Jan)	Abundance (April)	Abundance (July)
Tellina nymphalis	63	41	51	48
Tivella tripla	68	52	48	31
Tivella bicolor	41	27	32	21
Capitella spp	16	8	9	7
Pitaria tumens	11	6	4	2
Eisenia fetida	7	11	14	8
Tympanotomous fuscata	112	74	63	53
Syllidae grube	39	21	18	12
Total	**357**	**240**	**239**	**182**

Nitrate levels recorded in the Keta lagoon

ZONES	OCT	JAN	APR	JUL
A	3	1.6	3.8	3.2
B	2.4	2.24	3.6	3.4
C	2.6	1.6	3.6	2.6
D	2.9	1.8	3.7	1.7
E	3.3	1.7	3.2	1.9

Ammonia levels recorded in the Lagoon

ZONES	OCT	JAN	APR	JUL
A	0.12	0.06	0.07	0.08
B	0.11	0.05	0.06	0.06
C	0.11	0.03	0.07	0.05
D	0.09	0.05	0.04	0.05
E	0.06	0.04	0.05	0.05

Phosphate levels recorded in the Keta lagoon

ZONES	OCT	JAN	APR	JUL
A	0.23	0.26	0.25	0.31
B	0.22	0.24	0.21	0.3
C	0.27	0.15	0.23	0.26
D	0.29	0.1	0.17	0.31
E	0.22	0.11	0.1	0.22