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PREDICTING NUTRIENT DISTRIBUTION PATTERNS IN SOME COASTAL LAGOONS IN GHANA USING MIKE 3 MODEL

BY

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DECLARATION

This dissertation is the result of research work undertaken by Kwame-Biney Michael in the Department of Marine and Fisheries Sciences, University of Ghana under the supervision of Professor Kwasi Appeaning Addo, Dr. Edem Mahu and Dr. Joseph Ansong. I do hereby declare that the dissertation consists entirely of my own work and that no part of it has been previously published or submitted for a degree or diploma elsewhere.

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ABSTRACT

The study assesses the levels of phosphate, nitrate and ammonia in water and sediments from the Mukwe, Sakumono II, Gao and Laloi lagoons situated within the central coast of Ghana alongside other physicochemical parameters (pH, Dissolved Oxygen, Total Dissolved Solids and Temperature). Data collected over a six-month period was used in calibrating and predicting nutrient concentrations in the Sakumono II and Gao lagoons using the MIKE 3 model. High pH measurements beyond USEPA and Ghana's EPA permissible limits of 6.5 to 8.5 and 6.0 to 9.0, respectively, were recorded in the Sakumono II and Mukwe lagoons whiles Gao and Laloi recorded pH values within these permissible limits. With the exception of the Laloi lagoon which had an average dissolved oxygen value of 5.1mg/l, dissolved oxygen concentration in all the other lagoons were lower than the EPA and WHO permissible limits of 5.0mg/l to 6.5mg/l and 5.0mg/l to 6.0mg/l, respectively. Total Dissolved Solid measurements in all the lagoons were above the EPA permissible limit of 500mg/l. Phosphate, nitrate and ammonia concentrations in all the four lagoons were generally above Ghana's EPA and USEPA permissible limits. Discharge rates measured were highest for the Laloi lagoon and lowest for the Gao lagoon, which may be linked to the width and depth of the lagoons. Sediment nutrient concentrations were used together with the instantaneous sediment discharge formula to calculate the rate of discharge of sediment nutrient for the four lagoons. The results indicated that sediment nutrient concentration has a positive correlation with sediment discharge rate. Apart from few discrepancies in the results which was caused by poor rainfall data and non-point discharges, the correlation analysis indicated that MIKE 3 model was able to generally predict nutrient concentrations and show the distribution patterns in the Sakumono II and Gao lagoons. Average sediment nutrient concentrations recorded for phosphate during the dry and rainy season for Sakumono II, Mukwe, Gao and Laloi lagoons were (0.121 and 0.128mg/kg), (0.146 and 0.113mg/kg), (1.42 and 1.22mg/kg) and (0.112 and 0.103mg/kg) respectively. The average sediment nutrient concentrations recorded for ammonia during the dry and rainy season for Sakumono II, Mukwe, Gao and Laloi lagoons were (37.18 and 25.85 mg/kg), (41.49 and 37.46mg/kg), (4.58 and 4.31mg/kg) and (41.74 and 40.93mg/kg) respectively. The average sediment nutrient concentrations recorded for nitrate during the dry and rainy season for Sakumono II, Mukwe, Gao and Laloi lagoons were (14.54 and 11.55mg/kg), (15.15 and 15.41mg/kg), (3.83 and 3.46mg/kg) and (13.22 and 11.77mg/kg) respectively. Average sediment discharge rates recorded in the Sakumono II, Mukwe, Gao and Laloi lagoons for ammonia, nitrate and phosphate were (0.00000399 m^3/s, 0.00000133m^3/s and 0.0000000143m^3/s), (0.0000377m^3/s, 0.0000126m^3/s and 0.00000131m^3/s), (0.000021m^3/s, 0.0000073m^3/s and 0.0000000746m^3/s) and (0.00001624m^3/s, 0.0000537m^3/s and 0.0000000465m^3/s) respectively.

DEDICATION

I dedicate this work to my parents and the Horizon Team. 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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LIST OF ABBREVIATIONS

APHA- American Public Health Association.

GWLF Model- Generalized Watershed Loading Functions Model.

AGNPS Model- Agricultural Non-Point Source Model.

DWSM- Dynamic Watershed Simulation Model.

ROMS- Regional Ocean Modelling Systems.

TMDL- Total Maximum Daily Load.

USAID- United States Agency for International Development

GIS- Geographic Information System.

CSV- Comma Separated Value.

GPS- Geographic Positioning System.

ESRI- Environmental Systems Research Institute.

EWFD- European Water Framework Directive.

EHI- Estuarine Health Index.

TSI- Trophic State Index.

TDS- Total Dissolved Solids

WQI- Water Quality Index.

WRC- Water Resource Community.

WRI- Water Research Institute.

NEEAP- National Estuarine Eutrophication Assessment Program.

IGICWMF- Integrated Government Industry Community Water Management Framework.

DPSIR- Driving force Pressure State Impacts Response.

EPA- Environmental Protection Agency.

USEPA- United States Environmental Protection Agency.

WHO- World Health Organization.

FAO- Food and Agriculture Organization.

CHAPTER ONE

INTRODUCTION

1.1 **Background**

Coastal environments support over 75 percent of the world's population with consistently expanding demand and evolution duress (Paerl, 2006). These coastal environments comprise several ecosystems including lagoons, estuaries, wetlands, salt marshes and mangroves. Lagoons serve as intermediate water basins linking inland waterbodies to the sea, processing most of the riverine and coastal watershed discharge worldwide (Hobbie, 1987). Their biological conditions are shaped by catchment and ocean processes (Plew *et al*., 2015). They are regarded as part of the productive, resourceful and dynamic aquatic ecological communities within the coastal environment (Catianis *et al*., 2018). Despite being among the most productive habitats on earth, they have also been classified as the most impacted by man, mainly through land-based activities. For example, the productive nature of lagoons is linked to the fact that they process much of the world's riverine and coastal watershed discharges associated with nutrients mainly from agricultural activities (Miththapala, 2013).

Excessive nutrient input into coastal systems presents serious consequences such as algal blooms, hypoxia, acidification of coastal waters among others, which alter their structure and functioning, thus threatening food security (Ayivor & Gordon, 2012).

Export of nutrients into lagoons may occur naturally via upwelling and geological weathering. However, increasing human activities has led to export of exceedingly high levels of nutrients into coastal environments (Kennish, M. J., 2011). Several studies have shown that nitrogen (N) loading has multiplied 10 times over the last 50 years (Bricker *et al*., 2003; Whitall *et al*., 2007). It is therefore not surprising that several coastal ecosystems are experiencing hypoxia and acidification of bottom waters with subsequent adverse impacts due to excessive flux of nutrients into the coastal environment (Bricker *et al.*, 2008). Studies conducted in the Chesapeake Bay, USA shows that excess nutrients led to hypoxia in some parts of the estuary (Boesch *et al.,* 2001). In addition, Rabalais et al (2002) concluded that the reduction in amount of nitrogen and phosphorus was necessary for increasing the levels of oxygen in the Gulf of Mexico. In Australia, studies in the Gippsland Lake revealed that, nutrient input from anthropogenic sources led to hypoxia during the spring and summer period, which further resulted in phosphorus release from the sediment (Zhu *et al.,* 2017).

According to MPCA (2008), every lagoon needs some amount of nutrient to be healthy, however an excess supply of nutrients may lead to algal blooms as well as promote growth of bacteria and other microorganisms. When these algae die, they decompose using oxygen, which can cause anoxic conditions leading to fish kills. Some other types of algae produce harmful toxins, which are poisonous when consumed by humans (CDC, 2016; Ansa *et al.*, 2011).

Nitrogen is important for the growth of plant and animal tissues. Plants and animals also use nitrogen to synthesize protein (Arneson & MacAvoy, 2006). The earth's atmosphere is made up of about 78% of dinitrogen gas. which enters into lagoons in various forms (MPCA, 2008). Nitrogen is cycled through the atmosphere, biosphere and lithosphere via biological and chemical processes (National Atmospheric Deposition Program, 2016). Nitrogen fixing bacteria transforms atmospheric dinitrogen gas into organic nitrogen compounds that enter the hydrological cycle (Jiménez *et al*,, 2011). Nitrogen in lagoons can either be in a dissolved or particulate form. For example, nitrogen is present as organic nitrogen in the tissue of organisms (MPCA, 2008). Nitrate is also another form of nitrogen and it can be found in the atmosphere and water (National

Atmospheric Deposition Program, 2016). High nitrate levels are poisonous to humans and animals (Jones *et al.*, 2015). Nitrate is often transported into lagoons through fertilizer application, septic tanks and city drains (MPCA, 2008). When nitrogen enters the water column, it binds with bottom sediments and it is transported through bedload transport or it can also be transported in the water column when it binds with suspended sediments (Tang & Maggi, 2018).

Ammonia occurs in lagoons as inorganic nitrogen in a reduced form. The occurrence of different forms of nitrogen in a lagoon depends on the water pH. In marine waters, when pH is close to average seawater pH (which is 8.0), nitrogen mainly occurs as ammonium (Rezagama *et al.*, 2017). Ammonia in water is toxic (Levit & Bozeman, 2010). Ammonia in the water column may be adsorbed onto mineral particulate matter and found in suspension or buried in bottom sediments. Some part of ammonia goes into mineralization and is biologically accessible for the organisms in the water column (Jones *et* al.,2015).

Phosphorus is an essential nutrient in the water column and helps in the conversion of sunlight into usable energy. In addition, phosphorus is important for cell growth as well as reproduction (MPCA, 2008). Phosphorus is one of the abundant elements on Earth and also in igneous rocks (Minerals Educational Coalition, 2019). It is also known to build up in sediments (MPCA, 2008). Inorganic phosphorus helps in plant growth and can cause algal bloom in lagoons if not controlled (Goucher & Maas, 2014). When phosphorus is in the sediment, it is not available for algae to use but chemical and biological processes can cause phosphorus in sediment to be released back into the water column. An example is bottom-feeding fish or organisms that rework sediment can stir up bottom sediment making phosphorus available in the water column again (Søndergaard, 2007). Nutrient behavior in a lagoon is based on two factors. First the geology and discharge rate of the lagoon and secondly the land use within the catchment of the lagoon (USEPA, 2006;Olson, 2012).

When nutrients bind to bedrock sediments, they remain at the bottom of the lagoon until they are reworked back into the water column (Søndergaard, 2007). When nutrient bind with suspended sediment they float in the water column depending on the discharge rate of the lagoon (Sullivan, 1999).

Technological advancement has resulted in the use of computational models to analyze huge datasets and also simulate sediment-nutrient flow patterns and concentrations in order to better understand water quality (Gao & Li, 2014). Many models exist for nutrient pattern studies but they are differnet in terms of parameters required and the scale of work they can be used for (Mispan et al., 2015)

Studies by Mills *et al*., (1985) employed the use of the Generalized Watershed Loading Functions model (GWLF model) to study nutrient behavior and movement patterns in the Delaware river watershed in New York, America. Two years of data was collected for phosphorus, nitrogen and suspended solid from March 1980 to March 1982. At the end of the study, the GWLF model was able to show monthly nutrient fluxes in the river without extensive calibration. In addition, validation studies showed that the model had high predictive accuracy. However, the model underestimated peak monthly nutrient fluxes by 22% and could also not be used to estimate the effects of land-based flows on the river.

In Nebraska, two watersheds were studied using the Agricultural Non-Point Source Model (AGNPS model). The AGNPS model is a single storm event model that can simulate nitrogen, phosphorus and ammonia fluxes in lagoons and lakes. It can also simulate sediment transport, surface movement of pesticides from nonpoint and point sources from a single rainfall event. The model revealed that about 30% of nutrients and total sediment load entering the Prairie Creek watershed was from three different sub-watersheds. Other elements of nitrogen and phosphorus were distributed uniformly over the watershed. Areas producing many of these nutrients matched closely with areas that had high sediment contributions. The study demonstrated that estimated values from the AGNPS model was the same as measured values. In addition, the model performed satisfactorily in simulating nutrient-sediment flow patterns just as several other current models (example MIKE SHE). The limitation with AGNPS is that it relies on a lot of data before simulation can be possible (Young *et al*., 1989)

Another model than can be used in nutrient-sediment distribution and dissolved oxygen use is the QUAL2E, an enhanced stream water quality model. In some regions of America such as Pennsylvania, Maryland, Virginia and Delaware, low dissolved oxygen values as a result of nutrient loading is a common problem in aquatic systems therefore it is required that Total Maximum Daily Loads of nutrients assessments (TMDLs) are developed for waters that are not meeting dissolved oxygen standards (Vellidis *et al*., 2013). The QUAL2E is one of the common models used to determine TMDLs in the U.S because of its ability to calculate daily nutrient loads and run simulations to perfection (USGS, 2005). The limitation with the QUAL2E model is that it is a one dimensional model and also it cannot simulate unsteady flows in aquatic systems or systems receiving different inputs of pollutants (Vellidis *et al*., 2013).

In this project, the MIKE Eco Lab module under the MIKE 3 model was used to predict nutrient distribution patterns in some coastal lagoons in Ghana. The MIKE 3 was developed by DHI (DHI, 2007) and is DHI's fully integrated windows graphical user interface for setting up simulations. MIKE 3 can be used to simulate water quality and other ecological related studies in lagoons, estuaries or lakes. MIKE 3 also has the ability to calculate and make predictions concerning issues of nutrient enrichment and sediment transport in aquatic ecosystems. The advantage MIKE 3 model has over GWLF, AGNPS and QUAL2E models is its ability to simulate eutrophication and other water quality variables at the same time. Again it can simulate nutrient flows and pattern distribution during events like storms, high winds, rainfall and defined spills (DHI, 2017). Considering the nature of this study, which is spatio-temporal and the high possibility of events like rainfall and storms is high, MIKE 3 model becomes the suitable choice to use.

1.2 Problem Statement

Globally, nutrient enrichment has become an environmental issue in coastal ecosystems (Mindy & Suzie, 2006). Increase in population, urbanization and negative land use practices (farming and livestock rearing) causes the production of excess nutrients in the ecosystem (Paerl, 2006). Excess nutrient in these coastal ecosystems can lead to eutrophication which presents adverse consequences to ecosystem structure and functioning (Denmark, M. I 2014).

There is growing evidence that most lagoons in Ghana are deteriorating at a high rate. This is shown in studies by Gordon & Ntiamoa-Baidu (1970), Biney (1982), Mensah & Biney (2008) and Leeuwen *et al.,* (2018). These lagoons are being polluted through nutrients coming from sources such as livestock rearing, farms, and discharges from homes. The rate of nutrient pollution of these lagoons is expected to worsen in the coming years with regional and local programmes promoting the use of fertilizers such as the USAID West African Fertilizer and the Planting for Food and Jobs programmes respectively (USAID, 2016;MoFA, 2017). With the increasing usage of fertilizers and the effect of climate change on lagoons such as sedimentation, freshwater withdrawal from ground and surface water sources (Anthony *et al.*, 2009) it is necessary to understand their impact on the coastal environment.

This study provides information on the current state of the Mukwe, Sakumono II, Gao, and Laloi lagoons with respect to physico chemical parameters, nutrients, i.e. their distribution and levels in the water and sediment column and discharge rates into the coastal marine environment using Geographic Information System (GIS) approach and MIKE 3.

1.3 Aim of the Study

The aim of this research is to use GIS techniques to assess water quality and map out polluted sections based on nutrient concentrations in the Sakumono II, Mukwe, Gao and Laloi lagoons located on the central coast of Ghana and to use the MIKE 3 model to predict nutrient patterns in the Sakumono II and Gao lagoons.

1.4 Specific Objectives

1. Carry out a physicochemical characterization of Sakumono II, Mukwe, Gao and Laloi lagoons.
2. Determine the spatio-temporal distribution of nitrate, phosphate, and ammonia in the water column and sediments of each lagoon
3. Estimate sediment discharge rate and water discharge rate from each lagoon.
4. Predict nutrient levels in the Sakumono II and Gao lagoons using the MIKE 3 model.

1.5 Justification

Coastal Lagoons in Ghana are under a lot of stress due anthropogenic activities (Biney, 1982; Armah *et al.*, 2010). These activities include nutrient inputs from farm runoffs and domestic sewage effluents (Karikari *et al.*, 2009). Communities such as Tema and Kpone are classified as hotspots for industrial and economic development (Quantum Power Ghana Gas limited, 2013). This is as a result of the Tema Port and the Asogli Power Plant which have led to increased population regime shift because of the job opportunities which have caused increased human activities in the environment (Ghana Statistical Service, 2014).

The Mukwe, Sakumono, Gao and Laloi lagoons are within the Tema and Kpone environs. These lagoons are important economically and serve as a habitat to some mangrove species as well as other organisms (Attuquayefio & Gbogbo, 2001; Nartey *et al*., 2012;Badu Bortely, 2012). Even though these lagoons are important, they are being polluted with organic and inorganic substances, which is affecting their normal biological functioning. There is there therefore a need to use current techniques and models to understand the fate and behaviour of these nutrients

The Eco Lab module under the MIKE 3 model is an effective tool for predicting and monitoring eutrophication in aquatic ecosystems (DHI, 2011). It has a user friendly interface and can make very good predictions when calibration is done properly (DHI, 2017). It can simulate nutrient fluxes and distribution pattern during events like storms, high winds and rainfall (DHI, 2019). Therefore, considering the nature of this study which is spatio-temporal, the MIKE 3 model becomes a good choice to use.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Interest in coastal lagoons has increased in recent years. This is because coastal lagoons have numerous benefits and provide important ecosystem services for human sustenance. These services include transport of people and goods to different towns and villages, fishing and extraction of natural resources such as mangroves from the lagoons. The human dependency has resulted in the loading of nutrients from farms municipal waste and industrial waste, which affects the lagoon systems negatively. This has increased stress on these coastal ecosystems, thereby, resulting water quality and habitat modification issues.

This chapter reviews the literature on several themes including coastal ecosystems, coastal lagoons, importance and threats facing coastal lagoons and the use of numerical models to study sediment and nutrients flow patterns. In addition, this chapter reviews some relevant work done in the area of water and sediment quality of lagoons in Ghana from available literature as well as the current state of these lagoons

2.2. Coastal Ecosystems

Coastal ecosystems are regions where land and water link to create a unique environment in structure, diversity and energy flow (USAID, 2014). Coastal ecosystems are located along continental margins supporting biological productivity (Burke *et al*., 2001). Coastal ecosystems provide various components that help balance the aquatic and terrestrial environment. These components are broadly divided into animal components, plant components, and their habitats. Some of the animal components include aquatic invertebrates, phytoplankton (primary producers), micro algae and macro algae. Examples of plant components include submerged aquatic plants, seagrasses, and mangroves. Habitats under ecosystem components include biological habitat (living and dead plants and corals) and physical habitat (water, sediment, and rocks) (Paice & Chambers, 2016).

Coastal ecosystems provide many services. These services are classified as provisional services, cultural services, regulating services and supporting services. Provisional services refer to ecosystems providing food, water, wood, and fuel for the benefit of humans. Cultural services include spiritual, recreational and educational use of ecosystem components. Regulating services deals with ecosystem components regulating climate, flood, and diseases. Supporting services refers to ecosystem components helping in soil formation and primary production (Arico *et al*., 2005).

Based on the importance of ecosystem services, Abson & Termansen (2011) concluded that provisional and cultural services are directly used by humans in everyday activities. Coastal ecosystems include lagoons, mangroves, wetlands, estuaries, salt marshes amongst other habitats.

2.3. Coastal Lagoons

Coastal lagoons are waterbodies separated from the ocean by reef, barrier-island or spit and are linked intermittently or fully to the open sea by one or more tidal inlets. Coastal lagoons may be either brackish or marine depending on tidal processes, geomorphology or human intervention (Kennish & Pearl, 2010).

The formation of coastal lagoons in different parts of the world, usually follows the same principle. That is, coastal barriers separate flooded basins landward from the coastal ocean (Kennish, 2016). There have been some theories concerning the formation of coastal lagoons. Some of these theories include De Beautmonts (1845) theory that the building up of bars and shoals forms island barriers that cause flooded basins to separate from coastal oceans. Gilbert (1885) suggested barrier formation was rather due to the prograding of spits, which ends up creating shallow embayment which transitions into coastal lagoons. McGee (1890) modified a coastal lagoon formation model, which suggested coastal lagoons were created from the rising sea (eustatic sea level changes) that floods lowland areas. Finally, Oertel (2005) conducted studies that further proved that the models of Gilbert (1885) and McGee (1890) were indeed right and therefore those were the main processes by which coastal lagoons form.

Coastal lagoons are formed on low lying coasts like the Atlantic and Gulf coasts of the United States of America (Kennish, 2016). Coastal lagoons are rare around the Atlantic coastlines in general (Beer & Joyce, 2013). Coastal lagoons 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) (Kennish & Pearl, 2010). 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 (about 5.3% of the coastline) (Kennish & Pearl, 2010).

In Europe, there are regulations that classify coastal lagoons as transitional waters and put them under the European Water Framework Directive (Funfak *et al*., 2014). This Framework seeks to prevent the destruction of lagoons, enhance water quality and estuarine health index of coastal lagoons. The European Water Framework Directive does this by putting better strategies to conserve and reduce pressure on coastal lagoons (Aliaume *et al*., 2007).

In Asia, especially Vietnam, 300,000 people depend on coastal lagoons for food and job security. Statistics show that over 100,000 people directly depend on aquaculture and many others who depend on the lagoon indirectly (FAO, 2005). To conserve and protect the status of the lagoons, the Integrated Management of Lagoon Activities project was created by FAO. This project is geared at sustaining the lagoon in order to help promote the livelihood of the people in Asia (FAO, 2005).

In Africa, most of the local fishing communities depends on lagoons and this makes lagoons vulnerable to nutrient inputs and environmental changes which affect both the water quality and the organisms that reside in them (Boisrobert & Virdin, 2008). With regards to food security, it is estimated that 70 percent of animal protein comes from fishes that thrive in coastal ecosystems like lagoons (Schönfeldt & Hall, 2012). Therefore, in the quest to protect and conserve coastal ecosystems and the resources in them, the Global Environment Facility co-financing was set up allowing the World Bank to support actions in Tanzania, Senegal and Guinea-Bissau geared towards protection of marine and coastal ecosystems and fish resources (Boisrobert & Virdin, 2008).

2.4 Coastal Lagoons in Ghana and Levels of Anthropogenic Pollution

2.4.1 Coastal Lagoons in Ghana

There are about ninety lagoons along the coast of Ghana and these lagoons cover less than 5 km^2 in surface area along the total coastal stretch (Armah, 2005). Studies by Biney, (1982), Max *et al*. (1999) and Tay *et al.*(2010) have shown that lagoons in Ghana have had an impact on the health and socio-economic welfare of societies that live nearby and communities beyond. During the off-season for marine fishing, lagoons play a significant role in artisanal fisheries (Mensah & Biney, 2008). Over the past decade, some studies by Gordon (1987), Biney (1982), Mensah & Biney (2008) and Leeuwen *et al* (2018) examined the state of these lagoons and how they have affected communities. Gordon (1987) reviewed literature from authors such as Mensah (1979) and Biney

(1982) on water quality in some lagoons in Ghana which included (Keta, Laloi, Sakumo II and Kpeshie lagoons). The study revealed that the Kpeshi and Sakumono II lagoon were polluted to some degree. The study further examined physicochemical parameters in some of these lagoons as well as their hydrography and hydrology and how it affects the functioning of these lagoonal systems as well as the ecosystem. Ntiamoa-Baidu & Gordon (1991) examined the role of coastal wetlands and some management plans to be adopted in Ghana. Mensah and Biney (2008) identified the impact of human activities on nutrient and trophic status and linked it to transparency in eight lagoons in Ghana. A model was used to predict the trophic status index in the lagoons. Leeuwen *et al* (2018) accessed water quality in Sakumo II and Klottey lagoons and suggested ways to help increase the flushing time of these lagoons.

2.4.2 Levels of Anthropogenic Pollution (Quantitative Studies)

Most studies conducted have revealed that most of lagoons in Ghana are heavily polluted with nutrients (ammonia, potassium, nitrate, and phosphate) and heavy metals (Gordon, 1987; Boadi & Kuitunen, 2002; Addo *et al.*, 2011). Apau *et al*. (2012) accessed water quality in the Kpeshi Lagoon, Accra. This study estimated the level of pollution in the Kpeshi lagoon by monitoring levels of physicochemical parameters. The study found that industrial activities are predominant around the Lagoon. Inorganic and organic matter 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.

Bentum *et al* (2011) also conducted a study in the Fosu Lagoon, Cape Coast. The study, which focused on metal contamination levels, revealed 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.

Lamptey *et al* (2013) conducted a study on the Keta Lagoon in the Volta region. The study showed that the Keta Lagoon was under duress from agricultural practices around its catchment. The Water Quality Index calculated for the lagoon revealed that water quality was poor and therefore marked as unfitting for drinking and recreation.

Research by Nartey *et al* (2011) in the Sakumono lagoon, Accra which included collecting samples for nitrite, nitrate, phosphorus and ammonia examination revealed that phosphate levels were very high in the lagoon and also nutrient levels were increasing as the years went by.

Agbemehia (2014) also assessed the effect of industrial waste loading into the Sakumono lagoon. The study revealed that nitrate and ammonia concentrations in the lagoon and land based effluents were higher than phosphate values. The study concluded that the Sakumono lagoon qualifies to be classified as a polluted lagoon due to high concentrations of nutrients. This calls for interventions in advocacy to save the lagoons in the country.

Currently, there have been some efforts to improve the quality of water resources in the country by the Water Resources Commission of Ghana (WRC). The WRC is made up of 15 members including the environmental protection agency and the Water Research Institute and it seeks to advise communities as well as researching into efficient ways of managing effluents before disccharge into inland and coastal ecosystems (Owusu *et al.*, 2016).

2.5. Classification of Coastal Lagoons

Boughey (1957) classified lagoons to be ‘Open’ or ‘Closed’. Open lagoons have an adequate mass of water which helps sustain stable efflux from up-stream 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. Seasonal rivers and streams feed the closed lagoons. Closed lagoons are separated from the sea by a sandbar. These lagoon types are found in areas with low precipitation such as along the eastern coast of Ghana (Mensah & Biney, 2008).

Lagoons can also be classified as chocked, restricted and leaky (Miththapala, 2013). Chocked lagoons are usually made up of a series of joined oval cells that are linked by a single close entrance channel along the coast and have high wave energy as well as strong littoral drift (Kjerfve, 1994). Chocked lagoons are known to have long flushing times, direct wind forcing, and intermittent stratification event due to high solar radiation (reference). In semi-arid regions, chocked coastal lagoons often end up being permanently or temporarily hypersaline (Kjerfve, 1994).

Restricted lagoons have multiple connections to the sea, temporarily preventing water mixing. However, there is good water mixing processes and a good amount of net transport of lagoon water to the adjacent ocean (Miththapala, 2013). In restricted lagoons, wind action has an important role. Surface current is formed due to the wind action, which can further cause mixing of water. Leaky lagoons have broad channels to the sea. They have an uninterrupted exchange of water with the adjacent sea and strong currents (Miththapala, 2013).

2.6 Importance of Coastal Lagoons

Coastal lagoons are of great importance because the productive ecosystem supports a rich biodiversity. In addition, they act as support or breaking areas for migratory birds and spawning grounds for fishes. Also, humans have exploited coastal lagoons for settlements and also for resources including mangrove and salt production (Aliaume *et al*., 2007). Coastal lagoons support a range of natural services that are highly valued by society (Gönenç and Wolflin 2005). They have offered different economic based advantages in large coastal subdivisions of many countries. Coastal lagoons have provided important food resources such as fish protein, and also offer recreational and aesthetic services (Vallejo, 1982).

2.7 Threats to Coastal Lagoons

According to Vallejo (1982), as far as a lagoon is used wisely and moderately, negative effects may be accommodated because it is only when demand intensifies that strain appears. The intensity of strain that occurs in coastal lagoons depends on the type of the lagoon and percentage of mouth closure, but many of these threats are common in most lagoons (GOMC, 2005). Generally, coastal lagoons 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 as a result of infrastructure development (Gustavon, 2010).

In recent years, pressures on coastal lagoons have exacerbated and this has affected water quality negatively (Aliaume *et al*., 2007). Kennish *et al*. (2014) identified twelve anthropogenic strains on lagoon ecosystems. These strains are eutrophication, organic or sewage waste, habitat loss or modification, erosion, chemical contaminants, sediment particulate inputs, overfishing, serious aquaculture, the introduction of invasive species, changes in hydrological regimes as a result of human interaction, climate change, coastal subsidence, and debris. Kennish and Pearl (2010) categorized anthropogenic strains into water quality degraders that are biological in nature, physical factors that affect habitat (dredging) and strains that change the biological community (overfishing and introduction of invasive species).

There is a concern that climate change will affect freshwater resources in the Mediterranean region (Atwood et al., 2009). This will further strain water and coastal lagoons because they have little volume as compared to the adjacent sea. Expected global changes include temperature differences and the amount of precipitation (Eisenreich, 2005).

An example of such a scenario is the disarray of coastal lagoons in southeastern Asia in year 2005 (FAO, 2005). It was identified that structures such as culverts were constructed in areas that restricted the lagoons tidal circulation and mangrove overharvesting as well as overfishing were high. These practices caused habitat modification and the situation threatened food security and job security of over 30000 people who depend on the lagoon (FAO, 2005).

2.8 Nutrient Loading

Nutrient loading or nutrient pollution results from the high amounts input of organic or inorganic substances rich in, phosphate, ammonia, nitrate or potassium into a waterbody. Nutrient input cannot be easily classified and it is hard to control because they come from different sources (Uscop, 2004).

Lagoons need some amount of nutrient to function effectively, but excess nutrient loading into coastal waterbodies leads to eutrophication (Justic *et al.*, 2009). Eutrophic waters can further cause anoxic conditions in coastal ecosystems (Paul & Meyer, 2001). The anoxic or hypoxia conditions in lagoons have increased exponentially in the world (Rosenberg, 2008). Excess inputs of organic and inorganic matter alter the balance in oxygen supply in the water column. This happens through physical forcing and oxygen depletion through the decomposition of organic matter (Smith *et al.*, 1992). Anoxic conditions in coastal lagoons are regulated by mixing processes and lagoon stratification (Hagy *et al.*, 2004). Anoxic conditions in the water column do not only affect organisms and their habitats but the biogeochemical processes that control nutrients variations in the lagoon. The alteration of biogeochemical processes leads to further oxygen depletion which causes fluctuations in biogeochemical cycles of phosphorus in lagoon sediments (Conley *et al.*, 2009). When oxygen levels in a lagoon become low, iron bound phosphorus in sediments releases dissolved inorganic phosphorus (Jensen *et al.*, 1995). Studies conducted by Conley *et al* (2002) revealed that the Baltic Sea in Europe produced an enormous amount of dissolved inorganic phosphorus internally than the inputs from rivers. The studies also revealed that the Baltic Sea is the largest coastal area globally to suffer from serious hypoxia because of anthropogenic activities. When lagoon sediments release dissolved inorganic phosphorus back into the water column, it boosts phytoplankton growth, which behaves like positive feedback as a result of increased hypoxia conditions (Conley, 1999).

Low oxygen levels in the lagoon (anoxic conditions), also affect nitrogen levels and anaerobic ammonium oxidation also known as anammox (Conley *et al.*, 2009). When fixed levels of nitrogen in lagoons are reduced, denitrification occurs (Seitzinger & Giblin, 1996). Denitrification is the reductive respiration of nitrate or nitrite to nitrogen (N_2) or nitrous oxide (N_2O). In addition, anammox conditions cause the removal or the reduction of fixed nitrogen (Dalsgaard *et al.*, 2003). Denitrification levels are controlled by nitrate and carbon levels (Conley *et al.*, 2009). Studies conducted by Seitzinger & Giblin (1996) revealed that there is a linear relationship between the denitrification rate and anoxic sediment conditions.

Further studies by Eyre & Ferguson (2009) also revealed that when coastal lagoonal systems as well as estuarine systems become anoxic, nitrogen levels would increase. This will further increase the availability of dissolved inorganic nitrogen and will potentially increase the risk of eutrophication (Webster & Harris, 2004).

Ammonia occurs in coastal environments through nitrogen reduction. The pH of the lagoon affects the occurrence of different types of ammonia. In coastal lagoons, 95% of ammonia compound is in the form of cations and is called ammonium (Rezagama *et al.*, 2017). Most of the ammonia in water is toxic and exist in a gaseous form as NH_3. Nitrate in lagoon systems are normally converted into ammonia when there is enough oxygen, and then assimilated into amino acids in organisms (Ozcoasr, 2019). 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 (Jones *et* al.,2015).

2.9 Point and Non-Point Source Pollution

Point source pollutants can be traced because they are from single identifiable sources. Some major point sources of water pollution includes wastewater treatment plants, industrial effluents, livestock feeding operations and septic facilities (Uscop, 2004). Point source discharges that are not regulated can result in nutrient loading, chemical pollution and input of toxic waste which can affect the coastal ecosystem and the organisms in them (NOAA, 2007).

Nonpoint source pollution is also known as diffuse pollution (Uscop, 2004). Nonpoint source pollution is a form of water pollution that results from numerous dispersed sources of pollutants. Nonpoint pollutants are normally transported through surface runoffs, atmospheric inputs spontaneous leaks of chemicals from industries and end up affecting surface and bottom waters (KDHE, 1997).

3.0 Flushing Time

Flushing time of a coastal lagoon also known as residence or turnover time 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). To assess problems relating to coastal lagoons and propose management solutions to them, there is a need to know about the flushing time (Zilitinkevich, 1995). The movement of water in coastal lagoons is influenced by tides and wind action (Zilitinkevich, 1995). When lagoons are polluted by point and nonpoint sources, it is important to know how much of the stress they can tolerate before they become seriously affected. This can be done through the calculation of the flushing time (Miroslav, 2008). Flushing time has many advantages especially to issues linked to water quality in lagoons and in coastal ecosystems as a whole. For an example setting up an aquaculture resource in a coastal system requires good tidal flushing mechanisms to cleanse water, boost dissolved oxygen levels and reduce nutrient inputs through the process (Dalgleish *et al*., 2007).

3.1 Discharge Rate

Discharge rate is the measure of the volume flow of water in an open channel with respect to time. It is expressed mathematically as the product of water velocity and cross-sectional area of water (USGS, 2012). Discharge rate has a unit of cubic feet per second (USGS, 2012). The common method of calculating discharge rate is the current meter method. This method calculates discharge rate by summing subsection areas of lagoon cross-section and respective average water velocities (Rantz, 1982). A current meter is a device that is used to calculate the velocity of flowing water (lagoon water) and its concept of operation is dependent on the correlation between the velocity of the water and the angular velocity of the meter blade (rotor). When the current meter is placed in a lagoon or a particular water body, the number of revolutions of the blade is counted within a particular time interval and then the velocity at that point is determined. The cross-sectional area of the lagoon and average water depth are multiplied together and then the value derived is multiplied by the water velocity from the current meter to obtain the discharge rate (Rantz, 1982).

Another method for calculating discharge rate is the moving boat technique. This technique is suitable for large lagoons and large estuaries. It has an advantage over the current meter because it can calculate different discharge rates within a large lagoonal system faster than the current meter method. The moving boat method also comes in handy when the water level fluctuates and flow conditions become erratic (Thandaveswara, 2000). With the moving boat method, a special form of current meter is attached to the boat to measure the velocity at an instant. This is done by aligning the boat to the preselected path that is normal to the lagoon flow. An echo sounder simultaneously measures the cross-sectional area of the lagoon and a special current meter measures both lagoon water and boat velocities. The water velocity from the current meter as well as the water depth and cross-sectional area from the echo sounder is then converted to discharge rate (Jerrydawang, 2013). In 1978 when the Yanuna, Delhi in India flooding occurred this method was also used to monitor flood in downstream and proved very useful during the study (Gupta, 2017).

Discharge rates of lagoons can also be determined with the float method. The float method is useful especially in the absence of a current meter (Montana, 2015). In using the float method, two cross-sections along a straight channel are selected for the measurement. The cross sections should be distant from each other so that the time it takes the float to pass through each cross section is measured accurately. Also, a travel time of about 20 seconds is recommended (Jerrydawang, 2013). The distance between the two cross sections multiplied by the travel time is equal to the velocity of the lagoon water. A coefficient between 0.6 to 0.85 is used to convert surface float velocity to vertical mean velocity. The discharge rate is calculated by multiplying the velocity by the product of the water depth and the width of the lagoon (Rantz 1982; Montana 2015). The discharge rate and the flushing time have a role to play in the water quality of a lagoon such that when a lagoon has a good discharge rate, sedimentation is little and also when a lagoon has good flushing time, water quality improves quickly (Miththapala, 2013).

3.2. Water Quality

Water Quality refers to the physical, chemical and biological properties of water that makes it suitable or unsuitable for use (Khalil *et al*., 2016). Coastal ecosystems worldwide are under threat as a result of anthropogenic activities (Kennish, 2011). However, this situation has exacerbated with coupled effects from climate change. This has led to awareness creation by scientists and coastal managers to try and manage the situation by monitoring water quality by using models (Catianis *et al*., 2018).

In North America, especially the United States of America, studies by Boesch *et al* (2001) revealed that point and non-point sources of nutrients including aeolian deposition caused poor water quality in lagoons. Therefore, in order to protect these ecosystems, the National Estuarine Eutrophication Assessment Program was developed to monitor and find solutions for better and successful management practices (Whitall *et al*., 2007). Studies by Driscoll *et al* (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.

In Europe, coastal lagoons are monitored closely and they fall under the European Water Framework Directive (WFD: 2000/60/EC). This framework helps put in measures that boost the status of lagoons and stop further deterioration of these watersheds (Aliaume *et al*., 2007). In southern Europe, the DITTY project was established to consciously develop scientific and workable strategies for sustainable use of available water resources in the region taking into account anthropogenic activities that negatively impacted the aquatic environment (Martínez & fernández, 2005). Five lagoons in Southern Europe (Portugal, Spain, France, Italy, and Greece) were chosen to pilot this program. These lagoons included Ria Formosa, Mar Menor de Murcia, Etang de Thau, Sacca di Goro and Gulf of Gera. Through the DITTY project, the Decision Support System Prototype that employs the use of GIS and mathematical models have helped solved problems in these lagoons (Aliaume *et al.*, 2007).

A report by Rome (2000) addressed health problems that were documented in Asia in the year 1997 as a result of poor water quality in lakes, rivers, and lagoons. It was discovered that these watersheds had poor water quality because of the discharge of pathogens and nutrients from point and non-point sources and this 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 (Rome, 2000).

In Malaysia, watersheds are known to play an important role when it comes to regional economic development especially for industrial, local, fisheries and agricultural uses (Mei *et al.*, 2016). However, some of these coastal resources, for example, the Muda Basin remains polluted because of 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 (Mei *et al*., 2016).

In Africa, the Ebri Lagoon in Ivory Coast, 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 Ebri lagoon has three inlets that refresh the lagoon water at an average rate of 18.5 times yearly 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 revealed that, 95% of total nitrogen and phosphorus loads from the capital city were mainly from domestic sources and 5% from the 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 (Chantraine *et al*., 1985). The study prejoected that if solutions are not provided, concentration levels could increase five times by 2050 and therefore suggested that pollution reduction strategies geared towards reduction of non-point sources of pollution will be beneficial in decreasing pollution.

3.3 Water Quality Index

Water Quality Index (WQI) is calculated from water quality parameters (eg. BOD, Chlorophyll a, phosphate, ammonia, nitrate, DO and pH) and is used to provide a single value information on the assessment (Singh, 2015). Water Quality Index is defined as an expression of the effect of diverse quality factors that gives an idea of the overall quality of water (Department of Environment, 2011). Water Quality Indices can be classified into Physicochemical Indices and Biological Indices. The Physicochemical Indices take into account the physical and chemical parameters of a sample of water, whilst the Biological Indices deal with the biological component of a sample of water (Fernández *et al*., 2012). The Water Quality Index may be derived using different equations. An example is the Hortons method, which calculates WQI as

$$WQI = {}^{\sum QnWn}/_{\sum Wn} \ldots \ldots \ldots \ldots \ldots \ldots Equation\ 3.3.1$$

Where Qn is the Quality rating of the nth water quality parameter and Wn is the unit weight of the nth water quality parameter. The quality rating, Qn is given by equation 3.3.2.

$$Qn = {}^{(Vn - Vid) \times 100}/_{(Sn - Vid)}..\ \ Equation\ 3.3.2$$

Where Vn is the estimated value of the nth water quality parameter at a given sample location, Vid is the ideal value for the nth parameter in pure water and Sn is the standard permissible value of the nth water quality parameter. The unit weight Wn is can be calculated from equation 3.3.3.

$$\text{Wn}={}^{K}/_{Sn} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots ..Equation\ 3.3.3$$

Where Sn is the standard permissible value of the nth water quality parameter and K is the constant of proportionality. The constant of proportionality can be calculated (Singh, 2015)

$$\text{K}={}^{1}/_{(\Sigma(1 \div Sn = 1,2, \ldots n)} \ldots \ldots \ldots ..Equation\ 3.3.4$$

3.4 Lagoon Sediments

Coastal lagoons are formed and shaped by sediments (Atwood et al., 2009). Therefore, sediment study is an integral part of lagoon studies (Petti & Bosa, 2018). Sediment analysis includes sediment nutrient analysis and grain size analysis and is examined as an essential part of water quality (Catianis *et al*., 2018).

Lagoon sediments harbor organic matter, which comes from phytoplankton production and drainage channels from land-based flows (Jorgensen, 1996: Payet & Obura, 2004)). A process of anaerobic and aerobic pathogenic activity regulates organic matter in surface sediment, consequently causing the release of inorganic nutrients such as nitrogen and phosphorus (Canfield *et al*., 1993). An excess of inorganic nutrients pollutes the water column causing eutrophication and hypoxia in the water column (Jessen *et al*., 2015). In eutrophic lagoons, blooms of algae can result in an inflow of reactive particulate materials to the surface sediment. Particulate flux may cause oxygen reduction due to consumption rates beyond circulation from the water column (Žilus, 2011). This shows the linear relationship between the water column and the sediment. In addition, sediments play a major role in the movement of chemical pollutants from up-stream to down-stream (Mensah & Biney, 2008).

Lagoon sediments are made up of a combination of particles of rocks comprising grades of gravel (0-20mm) or sand (0.08-2mm) as well as tiny subdivisions categorized as clay or silt (less than 0.07mm). Extremely fine divisions qualify as colloidal suspension. The fine fractions are classified as cohesive sediment. Cohesive sediment may include but not limited to particles of clay or silt, organic matter, diatoms, and dinoflagellates. On the other hand, non-cohesive sediments are made up of larger particles. Hence non-cohesive particles are not affected by flocculation and adsorption processes (Loucks & van Beek, 2017). The water quality in a lagoon is affected by fine grain sediments (Payet & Obura, 2004). For example, adsorbing capacities of suspended solids has a direct connection to the fate of pollutants in waters. Sediments are conveyed from one point to another by turbulent motion and advection. Therefore, the displacement of the cohesive sediments suspended in the water column is predicted through the type of deposition, settlement rate, and bed processes of consolidation, bioturbation, and resuspension (Loucks & van Beek, 2017).

But the connection between sediment transport, nutrient input (loading), eutrophication, and anoxia conditions is more complicated in coastal and lagoon systems (Cloern, 2001). This results from the distinctiveness and highly variable nature of the lagoon systems. Climatic and topographic variation in these waterbodies alters their physiological, biological and chemical processes, thus facilitating organic material production and changes in oxygen levels as well as nutrients (Paerl, 2006). The complex relationship between hydrologic discharge, that is flushing, mixing processes, thermal and salinity stratification, wind and tidal mixing and residence time, as well as spring tides, regulates the recurrence and spatial-temporal degree of anoxia conditions in coastal lagoons (Paerl, 2006). Therefore, to really understand the connection between sediment-nutrient transport and nutrient inputs, sophisticated computational models are needed to analyze huge datasets and simulate the flow in such systems to predict sediment flow and estuary nutrient concentrations (Gao & Li, 2014).

3.5 Numerical Models for Sediment Flow Dynamics

Numerical models are constantly being improved so the programs and scripts to mimic actual situations in the environment. These models require calibration of their input parameters to represent variations and conditions in the watershed (Mispan *et al*., 2015). Some models that can calculate nutrient influx rates and simulate sediment-nutrient patterns include Generalized Watershed Loading Functions model (GWLF), QUAL2E, AQUATOX, Dynamic Watershed Simulation Model (DWSM), Agricultural Non-Point Source model (AGNPS), Regional Ocean Modelling System (ROMS) and MIKE Zero.

3.5.1 The Generalized Watershed Loading Functions (GWLF) Model

The GWLF model is famous for the prediction of monthly loading of sediment and nutrient levels (Nguyen *et al*., 2019). These include nitrogen and phosphorus. In addition, this model can be used for watersheds that are less monitored (Haith & Shoemaker, 1987). The model relies on the Universal Soil Loss Equation (USLE) for erosion calculations. The GWLF model simulates nutrient flow by using the loading function method where flow volumes and sediment loads are linked to particulate or dissolved concentrations (Mispan *et al*., 2015). The model also uses land cover and land use changes procedures to simulate Best Management Practices (BMPs) (ASAE, 2004). Runtime process of the model is from some seconds to few minutes. Some of the limitations associated with the GWLF model include (1) non-present client support services and calibration difficulties (Mispan *et al*., 2015) and (2) its inability to calculate denitrification loss and its inability to assume linear trends of landcover change over time instead it can only fixed areas of land cover (Brodersen *et al*.,2013).

The GWLF model has been employed in studies of nutrient behavior and movement patterns in the Delaware River watershed in New York by Mills *et al* (1985), America. Some of the limitations of the GWLF model is

3.5.2 The QUALE2E Model

The QUAL2E model can be used to simulate dissolved oxygen levels, algae generation predictions as well as levels of nutrient loading. The QUAL2E is a one-dimensional model used for water quality analysis. QUAL2E model can also be used to simulate ammonia, nitrate, inorganic and natural phosphorus levels in lagoons(Mispan *et al*., 2015). It can be used to simulate diurnal variations in temperature and dissolved oxygen levels. Runtime process of the QUAL2E model is in seconds (USGS, 2005). Some limitations associated with this model is its efficiency when it comes to spatial predictions (Vellidis *et al*., 2013). In the United States of America, the QUAL2E model is adopted for the assessment of the Total Maximum Daily Loads of nutrient because it has the ability to do these calculations and simulations to perfection (USGS, 2005).

3.5.5 The AQUATOX Model

The AQUATOX model is famous for chemical concentrations, nutrient loading, temperature variations simulations and the prediction of the fate of various pollutants. It is also helpful when it comes to the prediction of nutrients in vertically stratified lakes (Haith & Shoemaker, 1987). The AQUATOX model can also be used in environmental predictions of possible situations that involve water quality, physical environment and aquatic life (Haith & Shoemaker, 1987). AQUATOX employs the use of differential mathematical equations to show changes in estimations of variables (Mispan *et al*., 2015). The runtime process of this model ranges from seconds to a few minutes (Clough, 2014). A study by Bontje (2010) employed the use of AQUATOX to analyze toxic effects and nutrient stress in aquatic ecosystems. Some of the limitations of the AQUATOX model is its inability to represent its process by mechanical constructs (USEPA, 2014). For example AQUATOX becomes difficult to use in situations where fine scale hydrodynamics are to be recorded.

3.5.6 The Dynamic Watershed Simulation Model (DWSM)

The Dynamic Watershed Simulation Model (DWSM) is a storm model that can be used for surface and subsurface runoff predictions, soil erosion, and soil entrainment simulations as well as flood waves simulations (Mispan et al., 2015). DWSM is a one-dimensional model and is normally used for runoff simulations after a rainfall event or series of rainfall events. The model has five components. These include hydrology, soil erosion, sediment transport, and nutrient and pesticide transport (Borah *et al*., 1999)

One of the advantages of using the DWSM model is its ability to simulate events with few aligned parameters (Mispan et al., 2015). The runtime processes of the DWSM is in minutes (Deva K Borah et al., 1999). The DWSM has few limitations, which include the absence of drain and base flow simulation capabilities and as a results causes under prediction of flow portions as well as runoff volumes from larger watersheds (Borah *et al*., 1999). Many studies have relied on the Dynamic Watershed Simulation Model. An example of such a study is the Illinois State Water Survey (ISWS), which employed the DWSM to access the upper Sangamon River basin in the United States. The model was able to predict peak flows in the basin as well as the peak flows in other basins with 38 and 112 square miles (Borah *et al*., 2004)

3.5.7 The Agricultural Non-Point Source (AGNPS) Model

The Agricultural Non-Point Source (AGNPS) model is a single storm event model developed by Young et al. (1987, 1994). Unlike the DWSM, the AGNPS model can only simulate one event at a time. These events are grouped as surface overflow, soil disintegration, sediment transport, nutrient transport, pesticides from point and nonpoint sources (Grunwald, 2017).

AGNPS can mimic sediment flow rates in sediment-adsorbed stages. Nutrient yield in the sediment-adsorbed stage is experimentally determined using sediment yield, nutrient concentration (N or P), and an enhancement proportion (Youthful *et al*., 1987). Nutrients on surface runoff can be modelled by replicating an extraction coefficient of nutrients N and P. The mean concentration of dissolvable nutrients can be calculated using sediment surface within overflow, and aggregate overflow. The AGNPS model utilizes a nitrate rot component when reproducing nitrate transport through waterway channels AGNPS is spatially spread yet temporally lumped with algorithms that can reasonably strong with runtime gauges in minutes; it is suitable for modelling nutrient loadings and transport (Mispan et al., 2015). Several studies have employed the use of the AGNPS model. An example is the sediment simulation studies conducted at Glonn watershed in Germany by (Grunwald & Norton, 1999). The model was able to predict surface flows correctly but it was discovered that calibration of the model is important for a better agreement between measured surface runoff values and the predicted surface runoff values from the model (Grunwald & Norton, 1999).

3.5.8 The Regional Ocean Modelling Systems (ROMS)

The Regional Ocean Modelling System (ROMS) was developed from the S-Coordinate Rutgers University Model (SCRUM) (Song & Heidvogel,1994). ROMS is an open source hydrostatic ocean model that is used to simulate internal ocean waves, sea-ice interaction, as well as sediment flow patterns and it has an extensive package of model test problems online (Venâncio *et al*., 2012). The ROMS has the ability to calculate sediment flow dynamics which includes dispersion, resuspension, and deposition of sediment (or organic matter that are bonded to sediments) from point and nonpoint sources. The advantage ROMS has over DWSM, GWLF, AGNPS, AQUATOX, and QUAL2E models is its ability to simulate sediment flows during events like storms (Blaas, 2002). The runtime process of ROMS is dependent on the parameters selected in the input file. Therefore, the model can run from minutes to hours. The downside of ROMS is that it cannot predict nutrient concentrations in the water column. Therefore, there is a need to employ mathematical equations to establish a link between nutrient concentrations in the water column and nutrient concentrations in the sediment before using ROMS for simulations. ROMS has been used in a lot of sediment transport flow monitoring programs an example include the study of sediment transport on the Southern Californian shelves (Blaas *et al*., 2007). The study revealed that waves caused resuspension of sediment in the basin (Hs>1m). The model simulation also revealed that the current in the basin hardly transported the sand particles but the current was able to carry the silt out of the erosion area in plumes.

3.5.9 MIKE Zero Model

The MIKE Zero platform is the windows user graphical interface which gives assess to MIKE 11 MIKE 3 and MIKE 21 flow models as well as other DHI packages (DHI, 2012). The MIKE model can be used to model rivers, estuaries, channels, coastal waters and deep seas (DHI, 2017). Models under the MIKE Zero platform have the ability to simulate sediment flows during events like storms, waves and rainfall. The runtime process of MIKE is dependent on the CPU/GPU of the computer being used and parameters selected in the input file and therefore, the model can run from minutes to days. The downside of the MIKE Zero model is its inability to run without connection to the license key, which requires internet (DHI, 2017). MIKE has been used in a lot of sediment transport flow monitoring programs. An example is the study of sediment transport in the Var river, France by (Zavattero *et al*., 2016).The study revealed the rates of sediment transport along the Var river and it further analyzed the impacts on the river aquifer exchange areas.

CHAPTER THREE.

METHODOLOGY

3.1. Study Area

The 565 km coastline of Ghana, which stretches from Elubo to Aflao within the Gulf of Guinea has been zoned into the Western, Central and Eastern coasts (Ly, 1980). The Western coast extends from Elubo to the Ankobra estuary, covering 95 km of the shoreline and is composed of fine sand and rocks with gentle sloping beaches (Gordon, 1987). The Central coast extends from the Ankobra estuary to Prampram covering a total stretch of about 321 km long (Ly, 1980). The Eastern cost extends from Prampram to Aflao, covering a stretch of about 149 and is characterized by a sandy shoreline and lots of erosion (Ly, 1980; Gordon, 1987; Duvall et al., 2017).

There are about ninety lagoons along the coastal stretch of Ghana and these lagoons cover less than 5 km^2 in surface area along the total coastal stretch (Armah, 2005). The study was conducted in the Sakumono II, Mukwe, Gao and Laloi lagoons located in the Greater Accra Region of Ghana (Figure. 1). The study sites are located within the Central coast of Ghana and were selected based on their socio economic and ecological importance. For example the Gao and Mukwe lagoons are known to be home to some important mangrove species as well as wetlands (Attuquayefio & Gbogbo, 2001) and the Laloi lagoon has been documented to have rich biodiversity (Badu Bortely, 2012).

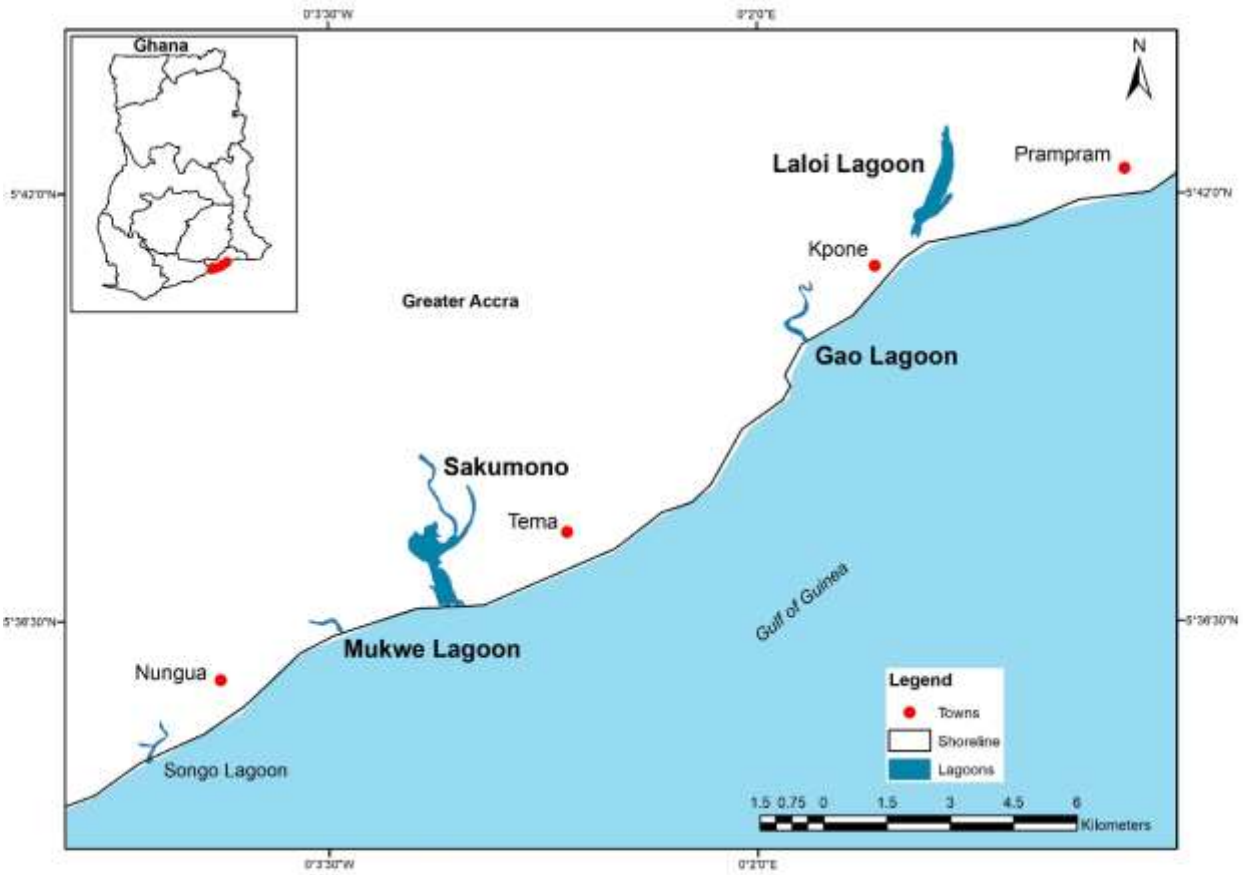


Figure 3.1. 1: A map of the Ghana coast showing the locations of the Sakumono II, Mukwe, Gao and Laloi lagoons.

3.1.1 Mukwe Lagoon

3.1.1.1 Introduction

Located at latitude 5.608978°N and longitude 0.055784°W, is the Mukwe lagoon which lies within the central coast of Ghana in the southern part of the Nungua township, a suburb of Tema in the Greater Accra region (Attuquayefio & Gbogbo, 2001). The Mukwe lagoon covers an area of approximately 0.043 km^2. Studies conducted in the past shows that the lagoon connected to the sea by a sluice, which allowed the lagoon to exchange water with the open sea depending on rainfall patterns and tides (Attuquayefio & Gbogbo, 2001). Currently, the lagoon has an open connection with the sea during both dry and rainy season.

3.1.1.2 Hydrology

The lagoon is fed by the Lafa stream that passes through the Nungua Township. The stream has an unrestricted flow into the lagoon even though some parts of the stream has been diverted into farms for irrigational purposes. Irrigation practices and disposal of wastes substances into the stream has resulted in the pollution of the Mukwe lagoon. Pollutants include high levels of phosphate and other nutrients as well as plastic bottles and Styrofoam (Addo et al., 2012). Plate 3.1.1.1 shows a picture of the Mukwe lagoon polluted with plastics and styrofoams.

Plate 3.1.1. 1: A picture of the Mukwe lagoon polluted with plastics and Styrofoam.

3.1.1.3 Land Use

Land use around the Mukwe watershed area includes farming, animal rearing, recreation and occasionally fishing. The farmed products include but not limited to cabbage, carrots and pepper. The farmers use fertilizer that washes into the Mukwe lagoon (Addo et al., 2012). In addition, there is a small-scale free-range livestock production. These include cattle and goats. These animals graze on the grassland close to the lagoon. There is not much fishing in the lagoon because of the level of pollution (Gbogbo & Oppong, 2008).

3.1.1.4 Vegetation

The stream that feeds the Mukwe lagoon is invaded by aquatic plants (*Typha domingensis*). Some mangroves species, herbaceous plants and low-lying grass characterize the margins of the Mukwe lagoon. An example of the mangrove plants is *Avicennia africana*. Other plants present include *Cyperus articulates* and *Azadirachta indica* (Gbogbo & Oppong, 2008).

3.1.2 The Sakumo II lagoon

3.1.2.1 Introduction

The Sakumo II lagoon also known as Sakumono lagoon is located on the eastern part of Accra between Teshie-Nungua and Tema at latitude 5.625989°N and longitude 0.038258°W. The lagoon covers an area of about 35 km^2 depending on the season (dry or wet) (Nartey *et al*., 2012). The total catchment area of the lagoon is about 276 km^2 (Gordon, 1987). The Sakumo II lagoon is one of the RAMSAR sites in Ghana and serves as a feeding area for water birds (Agbemehia, 2014). The lagoon connects to the sea through a culvert and a sluice. A major road runs over the culvert (Nartey et al., 2012).

3.1.2.2 Hydrology

Two main streams have direct connection to the lagoon. These include the Mamahum- Onkahe on the western side of the lagoon) and the Dzorwulu-Gbagbla Ankonu. During the dry season, the part of the stream connecting to the Sakumo II lagoon dries up (Agbemehia, 2014). In 1953 a sluice was constructed to prevent flooding of the coastal road (Nartey *et al*., 2012). Though the lagoon has free connection to the open sea, there is little inflow of seawater except during spring tides. The direction of the flow is dependent on the tide (Leeuwen *et al*., 2018). There is little freshwater inflow into the lagoon due to farmers channeling stream for agricultural purposes. 1however, the lagoon is flooded during rainy seasons. Also, some factories and residence close to the lagoon use the stream connecting to the lagoon as a waste drain, polluting the lagoon in the process (Leeuwen *et al*., 2018). Plates 3.1.2.1 shows a picture of the Sakumono II lagoon (estuarine end) during the dry season and plate 3.1.2.2 shows a picture of Sakumono lagoon II (estuarine end) during the raining season

Plate 3.1.2. 1: A picture of Sakumono II lagoon (estuarine end) during the dry season.

Plate 3.1.2. 2: A picture of Sakumono II lagoon (estuarine end) during the raining season.

3.1.2.3 Land Use

Land use activities along the Sakumo II lagoon include settlement, industrial development, fishing, recreation and rearing of animals. There is a high tendency of chemical pollution resulting from industrial development around the Sakumo II lagoon including that from a textile company and some food processing companies (Agbemehia, 2014). Studies have shown that in the past there used to be intensive fishing in the Sakumo II lagoon (Gordon & Ntiamoa-Baidu, 1970). This included but not limited to crab collection and tilapia. Studies by Gbogbo & Oppong (2008) proposed that the decline in fishing activities in the Sakumo II lagoon is due to the level of pollution coupled with low flushing making the lagoon unsuitable for fishes to thrive. In addition, cattle farmers prefer to allow their cattle to graze close to the lagoon where there is availability of grass since urbanization has decreased the pasture available for cattle in the Sakumono town. Cow dung along the margins may pose threat of pollution to the lagoon especially during rainfall when it washes to the waterbody (Hamilton, 2011).

3.1.2.4 Vegetation

The lagoon is characterized by freshwater marsh and coastal savanna grassland. Some specific vegetation found include the succulent forbs and the *imperata cylindrical* as well as *paspalum vaginatum* (coastal savanna grassland). Currently there are no mangrove communities along the Sakumono lagoon (Gbogbo & Oppong, 2008).

3.1.3 The Gao Lagoon

3.1.3.1 Introduction

The Gao lagoon is located in the kpone area of Tema, close to the Asogli Power Plant at latitude 5.672731°N and longitude 0.042183°E (Quantum Power Ghana Gas limited, 2013). The Gao lagoon is relatively bigger than the Mukwe lagoon and is influenced by tidal regimes. Tidal patterns coupled with the waves from the adjacent sea influences the marine and fluvial sediments that occur around the bank of the lagoon (Quantum Power Ghana Gas limited, 2013)

3.1.3.2 Hydrology

The main sources of freshwater feeding the Gao lagoon is the Gyrokorgyor stream which flows between Manhean and Kpone (Quantum Power Ghana Gas limited, 2013). During the rainy season, when there is a lot of water discharge, a freshwater body from the Tema Free Zone Port feeds the lagoon (Ghana Statistical Service, 2014). There are many industries close to the lagoon and as a result of that, chemicals are washed from the industries into the Gao lagoon (Gordon, 1987). This pollutes and destroys aquatic life in the lagoon. The Gao lagoon has free connection to the open sea and its flow is influenced by the tide (Gordon, 1987). Plate 3.1.3.1 shows a picture of the Gao lagoon.

Plate 3.1.3. 1: A picture of Gao lagoon.

3.1.3.3 Land Use

Land use in the Gao lagoon area include settlement, fishing, industrial developments and farming (Ghana Statistical Service, 2014). Studies conducted in the past by Gordon (1987) show high tendency of chemical pollution resulting from industrial development around the lagoon including an oil refinery, the Asogli Power Plant, oil reserves, fuel tanker sites and agro industrial companies (Quantum Power Ghana Gas limited, 2013).

Currently, there has been a decline in fishing activities in the Gao lagoon due to chemical pollution coupled with climatic regime (Ghana Statistical Service, 2014). The upstream side of the lagoon is dry during most part of the year, thus restraining fishing to the midstream and the estuarine part of the lagoon. During the rainy season, however, there are some fishing activities upstream (Ghana Statistical Service, 2014). On the western side of the lagoon, there are vegetable farms and, therefore, it is possible for nutrient to wash into the lagoon when there is rainfall.

3.1.3.4 Vegetation

The Gao lagoon is characterized by different mangrove species. Some of these species include *Avicennia germinans* and *Rhizophora mangle*. Studies by Quantum Power Ghana Gas limited (2013) show that the *Avicennia germinans* constitute about eighty percent of the mangrove species of the lagoon and the plants species around the lagoon include *Sesuvium portulcastrum* and *Paspalum vaginatum*.

3.1.4 The Laloi Lagoon

3.1.4.1 Introduction

The Laloi lagoon lies within latitude 5.42.30°N and longitude 0.04.35°N with a total catchment area of 0.695 km^2 (Gordon *et al.*, 1998). The Laloi lagoon is located at Prampram and it enters the sea at Kpone, which lies in the Tema Export Processing Zone (Ghana Statistical Service, 2014). Laloi lagoon and its environs is considered a protected area since turtles come around to lay their eggs (Gordon, 1987). The Laloi lagoon is also known as the Eldon saltpan (Attuquayefio & Gbogbo, 2001).

3.1.4.2 Hydrology

The main source of freshwater feeding the Laloi lagoon comes from the Dekyidor stream in Prampram. During the rainy season, the lagoon volume increases causing it to extend towards the low-lying areas close to the lagoon (Ghana Statistical Service, 2014). Relatively the Laloi lagoon is bigger than the Sakumo II, Mukwe and the Gao lagoons. Plate3.1.4.1 shows a picture of Laloi lagoon.

Plate 3.1.4. 1: A picture of Laloi lagoon.

3.1.4.3 Land Use

Land use in the Laloi area include farming, settlement, recreational centers, fishing and salt mining. There are few vegetable farms about 100 m from the lagoon. Since these farms are located up-land, there is a tendency of nutrient loading into the lagoon when it rains (Badu Bortely, 2012). In addition, there are few houses and recreational centers close to the Laloi lagoon. These recreational centers are free for public access all year round except when there is a social activity in town. During Christmas a lot of people use these facilities (Attuquayefio & Gbogbo, 2001; Ghana Statistical Service, 2014). The Laloi lagoon plays an important economic role in the community by serving as a source of fish production for domestic purposes and for income. The main economic activity carried out in the Laloi lagoon is salt mining and fishing (Entsua-mensah, 1998). According to studies by Gbogbo & Oppong (2008), the lagoon is rich in biodiversity because it is less polluted. The lagoon has periodic connection to the sea depending on the tide and climatic conditions. Fishing on Tuesdays is prohibited in the Laloi lagoon. Salt mining is practiced in the lagoon because of its high saline content (Attuquayefio & Gbogbo, 2001)

3.1.4.4 Vegetation

The Laloi lagoon is characterized by both mangrove and rushes community. These include the *Avicennia Africana, Sesuvium portulacastrum and Philoxerus vermicularis*. There is also the presence of aquatic plants that are salt resistant (Attuquayefio & Gbogbo, 2001).

3.2 Field methods

Sampling was done from August 2018 to February 2019. Each of the study sites was visited once every month during the six months period. Tide predictions were made using tide tables from the tides for fishing platform online. Water samples were collected from the freshwater system feeding the lagoon (source) as well, upstream, midstream, and estuarine part of the lagoon.

3.2.1 Water Sampling Method

The physicochemical parameters measured were nutrients, (ammonia, nitrates and phosphates), Dissolved oxygen, salinity, pH, conductivity, temperature, Total Suspended Solids and Total Dissolved Solids. Sub-surface water samples were collected at fixed points cutting across upstream, midstream, downstream of the lagoons and the adjacent sea from each site and stored in 250 ml tight plastic bottles for nutrient analysis. Samples were kept on ice and transported to the laboratory for analysis. In transporting to the laboratory, samples were kept at a constant temperature in an airtight container with ice cubes. Temperature, pH, dissolved oxygen, salinity, TSS and TDS were measured in-situ using Multi-parameter Probe (HI 98194 Hannah Instrument, Woonsocket, Rhode Island USA). The HACH Spectrophotometer was used for the nutrient analysis of the water samples following the American Public Health Association Procedures (APHA, 1992; USEPA, 2006).

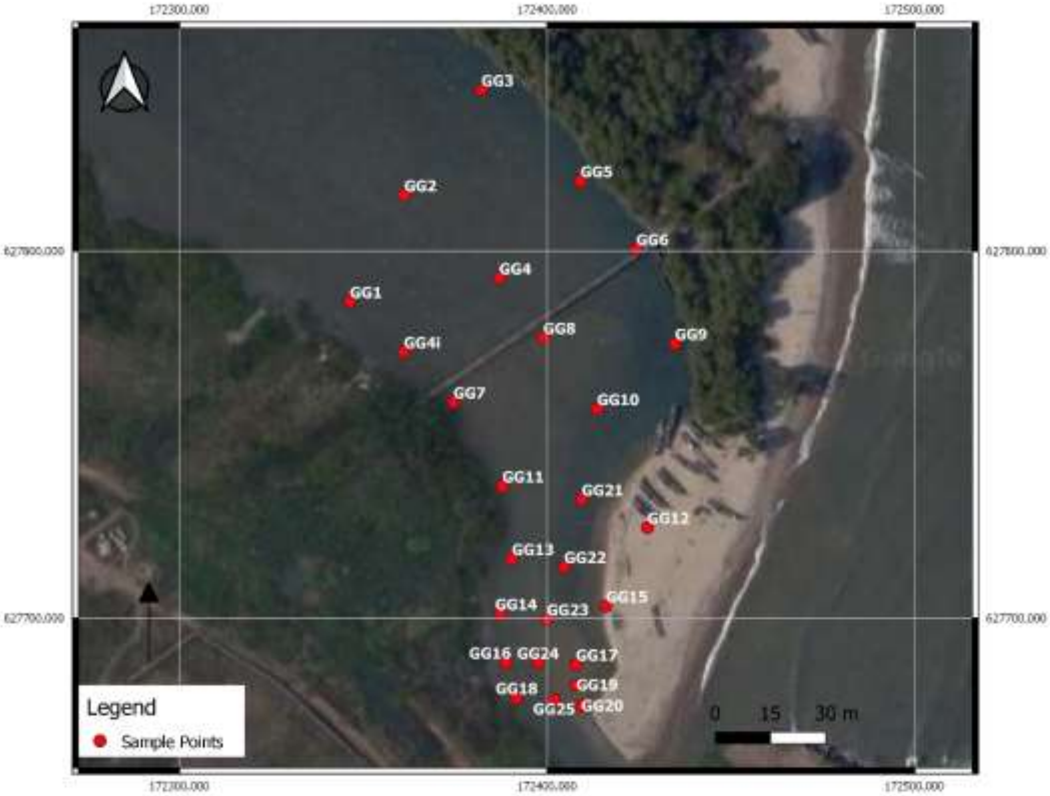


Figure 3.2.1 shows sampling stations in the Gao lagoon.

Figure 3.2.2 shows sampling stations in the Mukwe lagoon.

Figure 3.2.3 shows sampling stations in the Sakumono II lagoon (estuarine side).

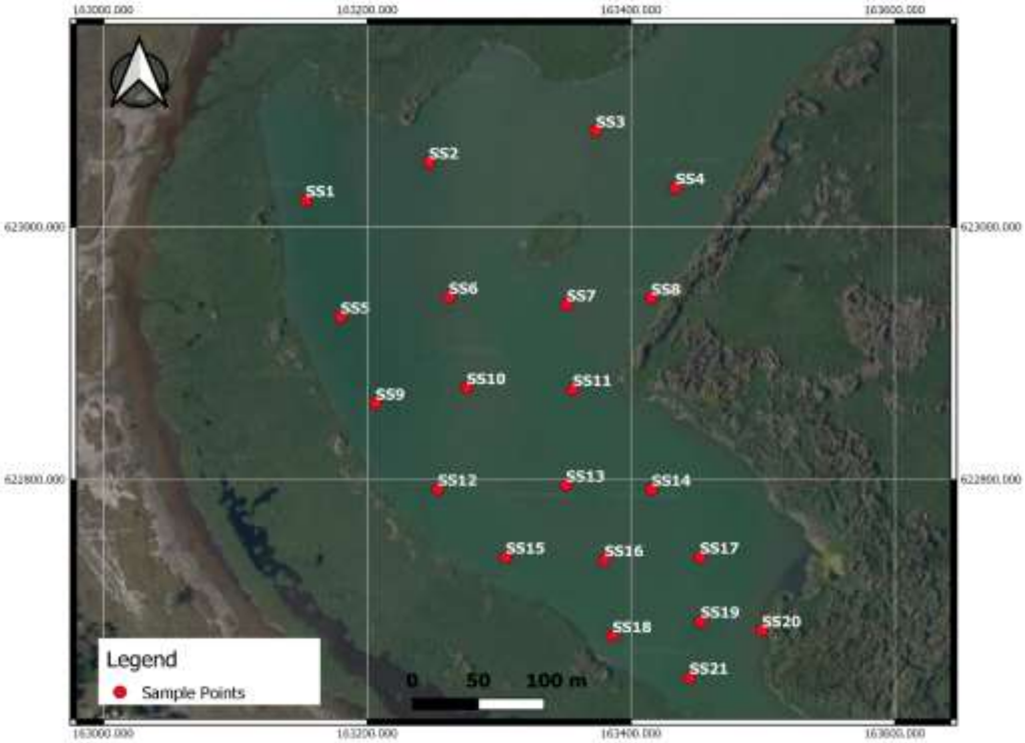


Figure 3.2.4 shows sampling stations in the Sakumono II lagoon (main basin)

3.2.2 Sediment Sampling

A corer was used for the sediment sampling. A UTEC corer with both sides open was placed vertically in the lagoon and pressed to about 2 cm deep. The sediment samples were then stored in transparent Ziploc bags and transported on ice to the laboratory for analysis. Sediment samples were taken from all the four lagoons. Sediment samples were analysed nitrate, phosphate and ammonia following the United States Environmental Protection Agency Procedures (USEPA, 1997; USEPA, 2006).

3.3 Laboratory methods

3.3.1 Water Quality Analysis

Analysis was done using the HACH DR2800 Spectrophotometer following APHA (1998) procedures after the samples were allowed to thaw to room temperature. Analytical blanks (reagent blank and cell blank) were prepared and used to calibrate the spectrophotometer. The full analysis was conducted using reagent blanks which were made by treating aliquot of distilled water as a sample. Distilled water was used to fill spectrophotometer cells and measurements were taken to find the difference between the sample and reference cells in cell blank assessment. Care was taken not to contaminate glassware by rinsing the bottles, vials, pipettes and other shared instruments during the measurements and analyses of the water samples.

3.3.1.1 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 procedures of APHA (HACH, 2005). After that, samples were transferred into the cuvette and measured. The spectrophotometer was zeroed using the blank sample.

3.3.1.2 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. In a similar manner, a blank sample with distilled water was also prepared. Both samples and blanks were treated adhering to procedures of APHA. After the actual samples were transferred into the cuvette and measured. The spectrophotometer was zeroed using the blank sample.

3.3.1.3 Ammonia Determination Using Salicylate

At a wavelength of 655 nm, Ammonia analysis was conducted using the HACH 385N, Ammonia Salic 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 treated adhering to procedures of APHA. The actual samples were transferred into the cuvette and measured in the spectrophotometer which was zeroed using the blank sample. Appropriate dilution factors were incorporated into the programme of the spectrophotometer to obtain final readings for ammonia concentrations.

3.4 Data Analysis

Variations from averaged values of both in-situ and laboratory analyses of samples were represented on bar display charts using Microsoft Office Excel 2016 and Python. Data was organized into tables and graphs being generated as pictorial representation of the data obtained for the study period.

3.5 Data Interpolation

Nutrient data for all the lagoons for the six months period was interpolated using the ARCMAP tool. Comma-separated value (CSV) files was created from measured phosphorus, nitrate, ammonia and the respective GPS locations. Shapefiles were created for each lagoon following the ArcMAP user manual (Sisk, 2014). A spatial distribution map of each nutrient was created for the six months using natural neighbor option following ESRI and ArcMAP procedures (Garnero & Godone, 2013). A python script was used to show the distribution and nutrients patterns in the lagoon using spatial maps from ArcMap. Appendix D shows python script used in the interpolation.

3.6 Model Descriptions

The MIKE ECOLAB module, which is part of the MIKE Zero package, was used for nutrient pattern predictions. Calculated discharge rates, fluxes as well as measured nutrients was computed into the model following MIKE DHI guidelines (DHI, 2017). Shapefiles created from ArcGIS were converted into xyz formatted file in order to generate a mesh in MIKE Zero model. A bathymetric grid was developed from depth measurements on the field and xyz shapefile following DHI mesh generation procedures (DHI, 2007). Figure 3.6.1 shows a diagram of the process of mesh generation following DHI guidelines.

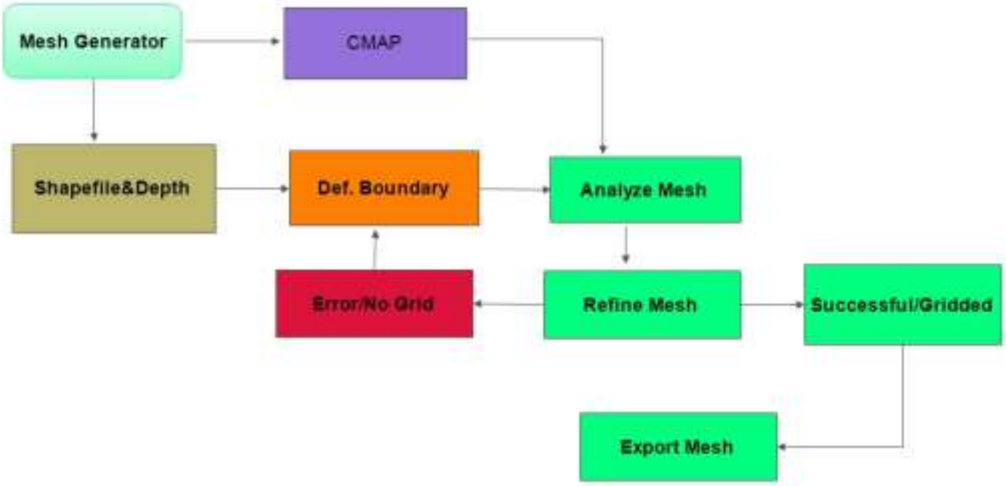


Figure 3.6. 1: A diagram showing the process of mesh generation following DHI guidelines

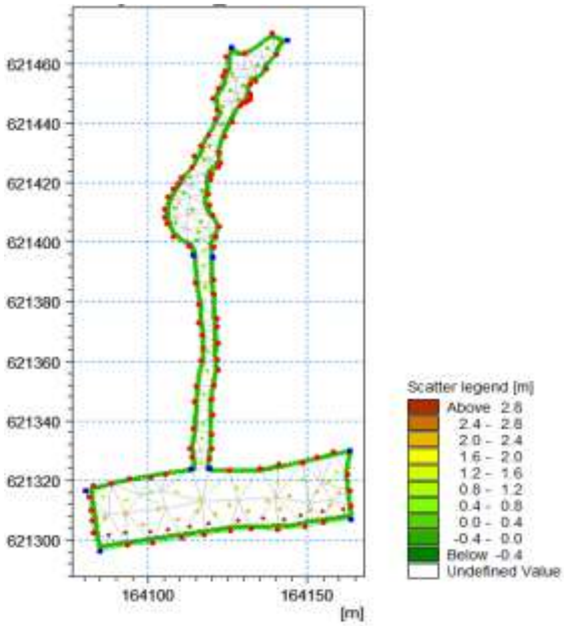


Figure 3.6. 2: A diagram of a successfully gridded mesh of the Sakumono II lagoon (estuarine side)

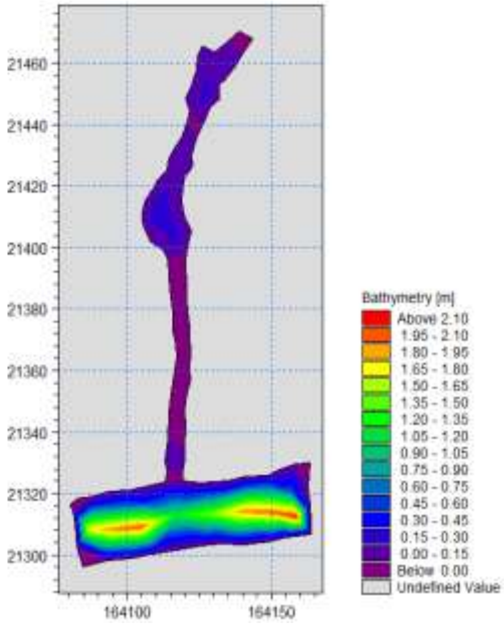


Figure 3.6. 3: A diagram showing bathymetric grid generated from a gridded mesh of the Sakumono II lagoon (estuarine side)

A time series file (dfs0) was created for the model to run and make predictions for six months (Mpo, 2014). The dfs0 file, measured nutrient data (from upstream or source), Shapefiles in the form of xyz formatted file was well as boundary conditions generated from rainfall data, discharge rates, fluxes, nutrient data and gridded mesh were used to run the model (DHI, 2019). Four flow points in the form of a shapefile were created with the help of ArcGIS to help in model predictions, following the DHI guidelines (DHI, 2019). These flow points were selected randomly from the measured sampled points with known latitudes, longitudes and measured nutrient values. After running the model, correlation analysis was done to check whether the predicted model values and measured field values had a positive or negative correlation and also to check the differences between the two set of data.

CHAPTER FOUR

RESULTS

4.1 Introduction

In conformity with the objectives of this research, this chapter provides results on the physiochemical characterization of Sakumono II, Mukwe, Gao and the Laloi lagoons and the rate of water and sediment discharges. This chapter also provides spatio-temporal distributions of nitrate, phosphate and ammonia levels in the water column as well as the sediment of each lagoon. Finally, this chapter also shows results for nutrient prediction simulations for the Sakumono II lagoon and the Gao lagoon.

4.2 Sakumono II lagoon

Unlike the other lagoons in this study, the Sakumono II lagoon has been divided into two main basins (main basin and the estuarine basin) because of different morphodynamics of both basins and also because of a barrier created by invasive weeds that prevent easy exchange of water in both basins (Leeuwen *et al.,* 2018).

Figure 4.2.1 shows phosphate levels in the Sakumono II lagoon (main basin) for six months of research. The highest phosphate level measured during the period of study was in February 2019 at a concentration of 9.6 mg/l. The lowest phosphate level recorded was in August 2018 at a concentration of 0.18 mg/l. Some parts of the lagoon were not assessable (bushy) during the period of study and these areas have been represented with a white color.

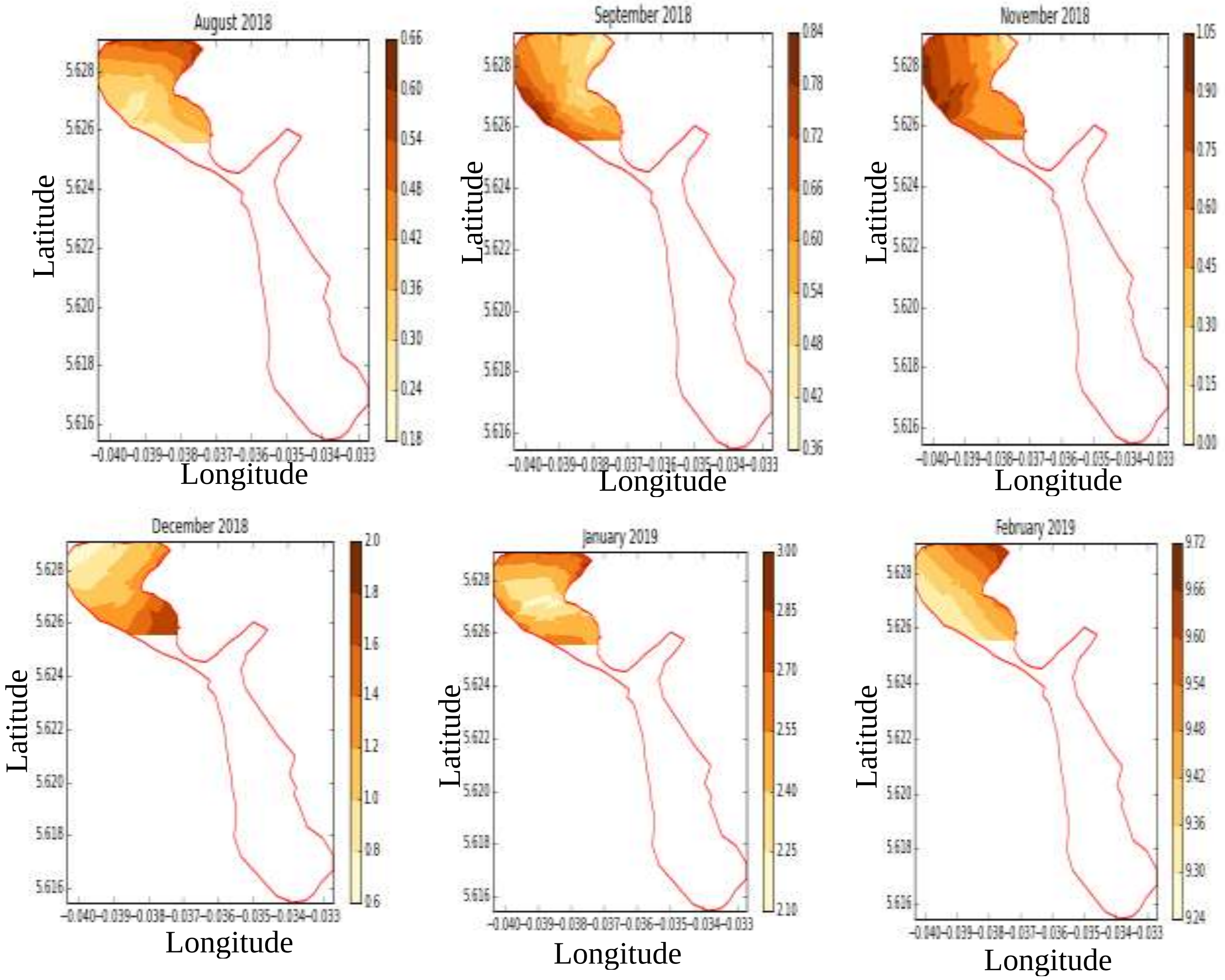


Figure 4.2. 1 – Phosphate levels in the Sakumono II lagoon (main basin)

Table 4.2.1 shows phosphate levels in the Sakumono lagoon (estuarine basin) for six months of research. The highest phosphate level measured during the period of study was in February 2019 at a concentration of 9.8mg/l. The lowest Phosphorus level recorded was in August 2018 at a concentration of 0.1mg/l.

Table 4.2 1 – Phosphate levels in Sakumono II lagoon (estuarine basin).

SITE CODE	LAT	LONG	AUG	SEP	NOV	DEC	JAN	FEB
S1	5.614461°N	-0.031466°W	0.1±0.2 mg/l	0.7±0.1 mg/l	0.67±0.01 mg/l	1.9±0.1 mg/l	2.9±0.1 mg/l	9.2±0.2 mg/l
S2	5.614429°N	-0.031434°W	1.7±0.1 mg/l	0.95±0.02 mg/l	0.88±0.01 mg/l	1.72±0.01 mg/l	2.72±0.01 mg/l	9.4±0.2 mg/l
S3	5.614361°N	-0.031492°W	1.55±0.02 mg/l	0.66±0.04 mg/l	0.55±0.01 mg/l	2±1.0 mg/l	3±1.0 mg/l	9.4±0.1 mg/l
S4	5.614244°N	-0.031530°W	1.5±0.2 mg/l	0.66±0.03 mg/l	0.55±0.02 mg/l	1.64±0.02 mg/l	2.64±0.02 mg/l	9.6±0.1 mg/l
S5	5.614183°N	-0.031519°W	1.5±0.1 mg/l	0.8±0.2 mg/l	0.6±0.1 mg/l	3.22±0.03 mg/l	3.22±0.01 mg/l	9.56±0.02 mg/l
S6	5.614148°N	-0.031586°W	1.51±0.03 mg/l	0.8±0.1 mg/l	0.6±0.1 mg/l	6±1.0 mg/l	7±1.0 mg/l	9.56±0.02 mg/l
S7	5.614106°N	-0.031550°W	1.7±0.2 mg/l	0.83±0.03 mg/l	0.73±0.0.2 mg/l	6.5±0.2 mg/l	7.5±0.1 mg/l	9.6±0.1 mg/l
S8	5.614053°N	-0.031628°W	1.7±0.2 mg/l	0.8±0.2 mg/l	0.6±0.1 mg/l	6.9±0.1 mg/l	7.9±0.1 mg/l	9.66±0.2 mg/l
S9	5.614013°N	-0.031553°W	1.7±0.1 mg/l	0.88±0.02 mg/l	0.66±0.01 mg/l	6.9±0.1 mg/l	7.9±0.1 mg/l	9.66±0.2 mg/l
S10	5.613969°N	-0.031524°W	1.9±0.1 mg/l	0.93±0.1 mg/l	0.7±0.2 mg/l	7.8±0.1 mg/l	8.8±0.1 mg/l	9.4±0.2 mg/l
S11	5.613958°N	-0.031567°W	2.1±0.1 mg/l	0.98±0.1 mg/l	0.7±0.1 mg/l	7.8±0.1 mg/l	8.8±0.1 mg/l	9.3±0.1 mg/l

Figure 4.2.2 shows nitrate levels in the Sakumono II lagoon (main basin) for the six months period under study. The highest nitrate level measured during the period was in August 2018 at a concentration of 9.7 mg/l. The lowest Nitrate level recorded was in September, which was at a concentration of 3.1 mg/l. Some parts of the lagoon were not assessable during the period of study and these areas have been represented with a white color.

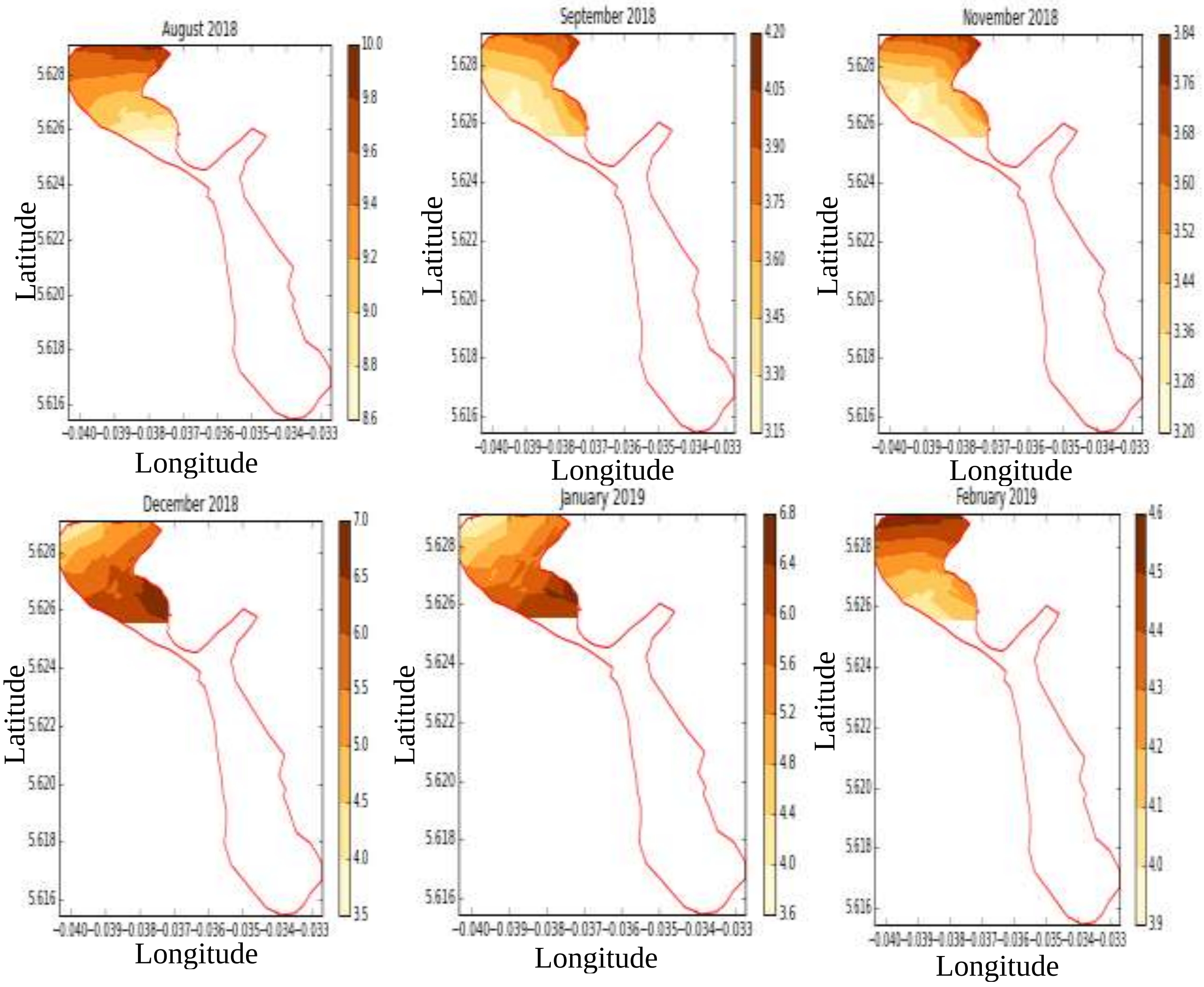


Figure 4.2. 2 – Nitrate levels in Sakumono II lagoon (main basin).

Table 4.2.2 shows Nitrate levels in the Sakumono lagoon (estuarine basin) for six months of research. The highest Nitrate level measured during the period of study was in August 2018 at a concentration of 9.54mg/l. The lowest Nitrate level recorded was in January and February 2019 at a rate of 2mg/l.

Table 4.2 2 – Nitrate levels in Sakumono lagoon (estuarine basin).

SITE CODE	LAT	LONG	AUG	SEP	NOV	DEC	JAN	FEB
S1	5.614461°N	-0.031466°W	8±1.0mg/l	3.16±0.01 mg/l	3.06±0.01 mg/l	6.63±0.01 mg/l	6.63±0.01 mg/l	4±1.0 mg/l
S2	5.614429°N	-0.031434°W	9.54±0.02 mg/l	3.34±0.02 mg/l	3.14±0.01 mg/l	7.240±0.01 mg/l	7.24±0.01 mg/l	4.2±0.1 mg/l
S3	5.614361°N	-0.031492°W	9.2±0.1 mg/l	3.32±0.01 mg/l	3.22±0.02 mg/l	7.24±0.01 mg/l	7.24±0.02 mg/l	4.21±0.02 mg/l
S4	5.614244°N	-0.031530°W	9.2±0.1 mg/l	3.21±0.01 mg/l	3.11±0.01 mg/l	5.87±0.02 mg/l	5.87±0.01 mg/l	3.2±0.1 mg/l
S5	5.614183°N	-0.031519°W	9.3±0.1 mg/l	3±1.0 mg/l	3±1.0 mg/l	5.27±0.02 mg/l	5.22±0.01 mg/l	3.2±0.1 mg/l
S6	5.614148°N	-0.031586°W	9.5±0.2 mg/l	3.12±0.02 mg/l	3.12±0.01 mg/l	3.22±0.01 mg/l	3.12±0.02 mg/l	2.1±0.1 mg/l
S7	5.614106°N	-0.031550°W	9.5±0.1 mg/l	3.12±0.01 mg/l	3.12±0.01 mg/l	3.22±0.01 mg/l	3.12±0.01 mg/l	2.1±0.1 mg/l
S8	5.614053°N	-0.031628°W	9.5±1.0 mg/l	3±1.0 mg/l	2.9±0.2 mg/l	3.07±0.01 mg/l	3.07±0.01 mg/l	2±1.0 mg/l
S9	5.614013°N	-0.031553°W	9±0.1 mg/l	3±1.0 mg/l	2.9±0.1 mg/l	2.13±0.02 mg/l	2.13±1.0 mg/l	2.03±0.02 mg/l
S10	5.613969°N	-0.031524°W	8.5±0.1 mg/l	3±1.0 mg/l	2.84±0.01 mg/l	2.47±0.01 mg/l	3.10±1.0 mg/l	2.03±0.01 mg/l
S11	5.613958°N	-0.031567°W	8.5±1.0 mg/l	3±1.0 mg/l	2.78±0.01 mg/l	2.3±0.2 mg/l	3.16±1.0 mg/l	2.03±0.01 mg/l

Figure 4.2.3 shows ammonia levels in the Sakumono II lagoon (main basin) for six months of research. The highest ammonia level measured during the period of study was in February 2019 at a concentration of 12.23 mg/l. The lowest Ammonia level recorded was in August 2018 at a

concentration of 0.3 mg/l. Some parts of the lagoon were not assessable during the period of study and these areas have been represented with a white color.

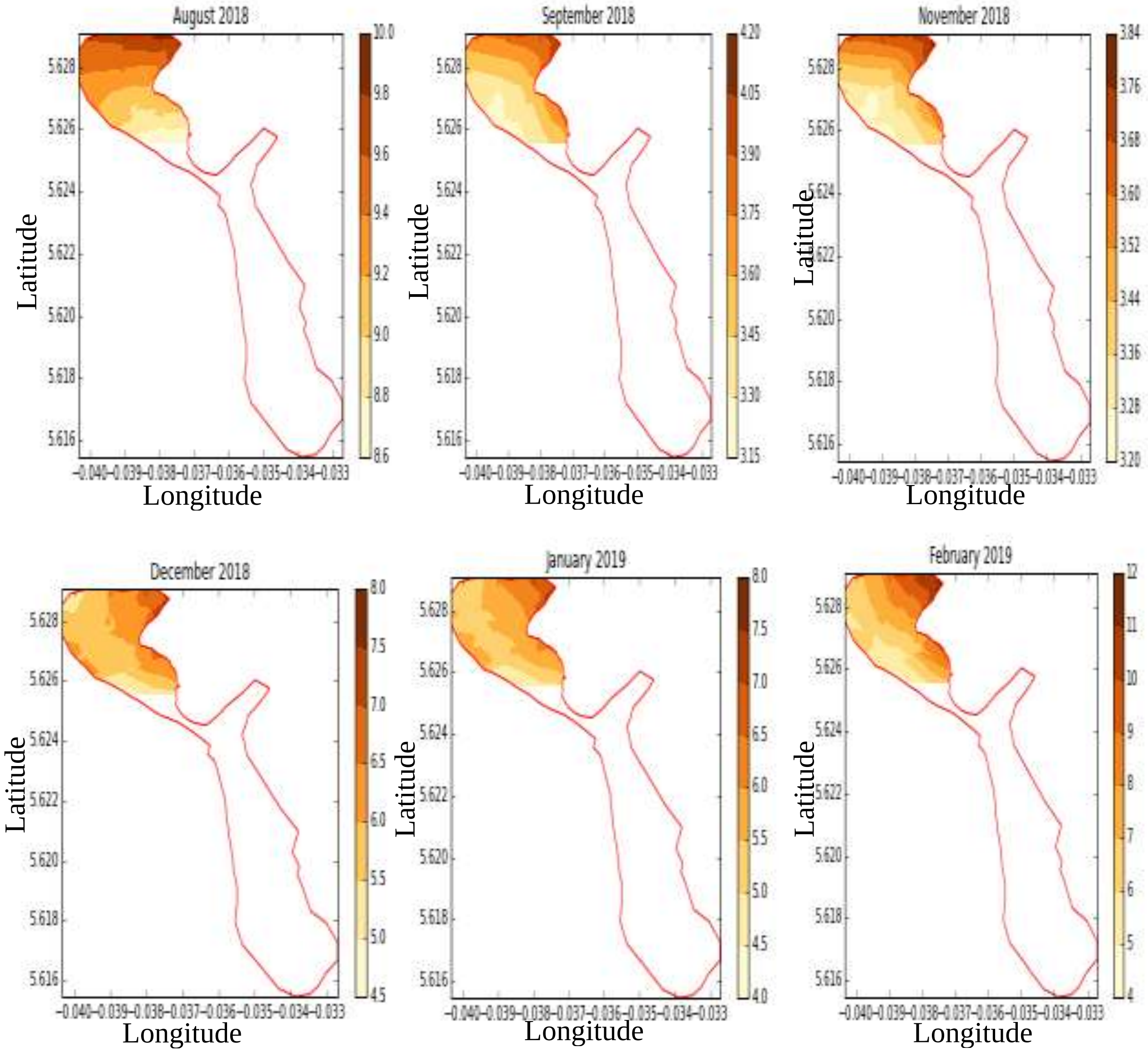


Figure 4.2. 3 – Ammonia levels in Sakumono II lagoon (main basin).

Table 4.2.3 shows Ammonia levels in the Sakumono lagoon (estuarine basin) for six months of research. The highest Ammonia level measured during the period of study was in February at a concentration of 34mg/l. The lowest Ammonia level recorded was in August at a concentration of 0.23mg/l.

Table 4.2 3 – Ammonia levels in Sakumono II lagoon (estuarine basin).

SITE CODE	LAT	LONG	AUG	SEP	NOV	DEC	JAN	FEB
S1	5.614461°N	-0.031466°W	0.7±0.3 mg/l	0.8±0.01 mg/l	0.7±0.1 mg/l	1.5±0.1 mg/l	1.2±0.1 mg/l	4.34±0.01 mg/l
S2	5.614429°N	-0.031434°W	1.42±0.2 mg/l	2.34±0.01 mg/l	2.02±0.02 mg/l	5.65±0.02 mg/l	5.23±0.01 mg/l	6.62±0.02 mg/l
S3	5.614361°N	-0.031492°W	1.02±0.2 mg/l	2.31±0.02 mg/l	2.02±0.01 mg/l	5.63±0.01 mg/l	5.21±0.02 mg/l	6.62±0.02 mg/l
S4	5.614244°N	-0.031530°W	0.23±0.3 mg/l	3.31±0.01 mg/l	3.21±0.01 mg/l	5.63±0.01 mg/l	5.33±0.01 mg/l	6.03±0.01 mg/l
S5	5.614183°N	-0.031519°W	0.23±0.4 mg/l	3.44±0.01 mg/l	3.24±0.01 mg/l	6.42±0.01 mg/l	6.12±0.01 mg/l	6.01±0.03 mg/l
S6	5.614148°N	-0.031586°W	3.34±0.3 mg/l	8.41±0.02 mg/l	6.41±0.02 mg/l	27.5±0.1 mg/l	23.4±0.1 mg/l	21±1.0 mg/l
S7	5.614106°N	-0.031550°W	4.47±0.3 mg/l	8.56±0.01 mg/l	6.56±0.03 mg/l	27.5±0.1 mg/l	23.4±0.2 mg/l	26±1.0 mg/l
S8	5.614053°N	-0.031628°W	4.47±0.5 mg/l	12.6±2.0 mg/l	5.6±0.2 mg/l	27.5±0.2 mg/l	23.4±0.2 mg/l	26.7±1.0 mg/l
S9	5.614013°N	-0.031553°W	4.44±0.5 mg/l	12.4±1.0 mg/l	5.6±0.1 mg/l	27.3±1.0 mg/l	24.1±1.0 mg/l	33.02±1.0 mg/l
S10	5.613969°N	-0.031524°W	3.46±0.2 mg/l	12.1±1.0 mg/l	4.3±0.1 mg/l	27±1.0 mg/l	19.56±1.0 mg/l	24.1±2.0 mg/l
S11	5.613958°N	-0.031567°W	3.4±0.3	11.65±1.0	3.2±0.1	24±1.0	19.2±1.0	21.3±1.0 mg/l

Table 4.2.4 shows the means of sediment nutrient levels for ammonia, nitrate and phosphorus in mg/kg in the Sakumono II lagoon in both dry and rainy seasons during the study period.

Table 4.2 4 – Mean sediment nutrient levels in Sakumono II lagoon during period of study.

			NUTRIENT (DRY SEASON) (December to February)			NUTRIENT (RAINY SEASON) (August to November)		
SITE CODE	LAT	LONG	NH3 mg/kg	N03 mg/kg	%TP mg/kg	NH3 mg/kg	N03 mg/kg	%TP mg/kg
S1	5°66'27.85''N	0°6'29.62''W	39.1	15.08	0.127	27.9	12.05	0.134
S2	5°37'31.61"N	0° 2'24.67"W	38.4	15.2	0.123	26.5	12.01	0.134
S3	5°37'26.10"N	0° 2'16.15"W	38.32	14.5	0.122	26.3	11.3	0.128
S4	5°36'50.5"N	0°01'53.3W	35.4	14.21	0.12	25.12	11.26	0.124
S5	5°36'48.0"N	0°01'53.5"W	34.7	13.7	0.113	23.43	11.13	0.121

Table 4.2.5 shows the average of various discharge rates of sediments per day in the Sakumono II lagoon for the study period.

Table 4.2 5 – Sediment discharge rate in the Sakumono II lagoon per day.

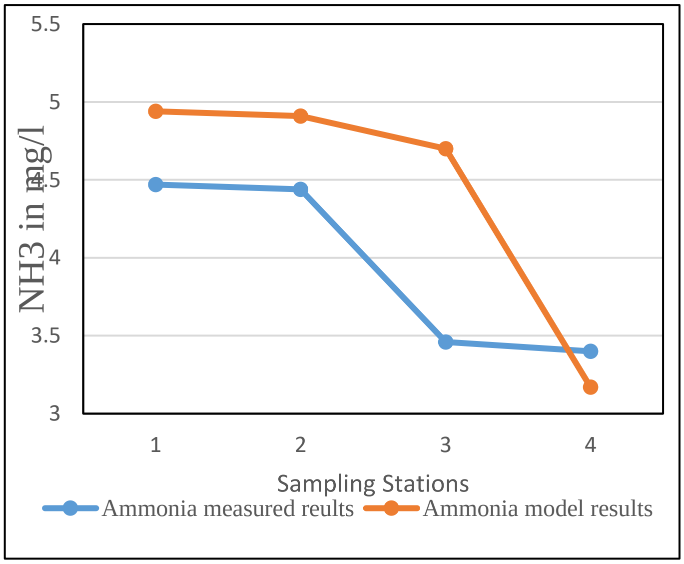
NUTRIENT	SEDIMENT DISCHARGE RATE
NH3	0.00000399 m^3/s.
NO3	0.00000133 m^3/s.
P04	1.43E-08 m^3/s.

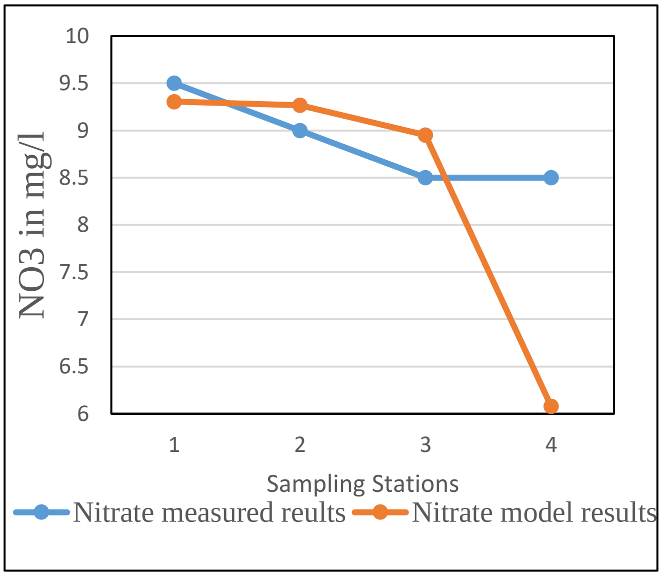
Table 4.2.6 shows the mean water discharge rate in the Sakumono lagoon during the dry season and the rainy season.

Table 4.2 6 – Mean discharge rate of Sakumono II lagoon during study period.

Dry Season	Rainy Season
0.002m^3/s	0.04m^3/s

Figure 4.2.4 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of August 2018 for the Sakumono II lagoon (estuarine basin). Plotted values of ammonia and nitrate had a positive correlation of 0.76 and 0.68 respectively. Phosphate results showed a negative correlation of -0.92.





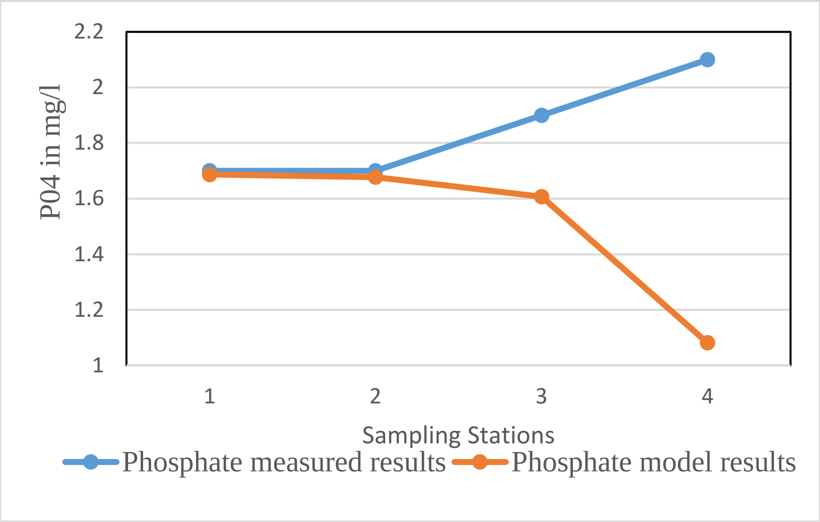
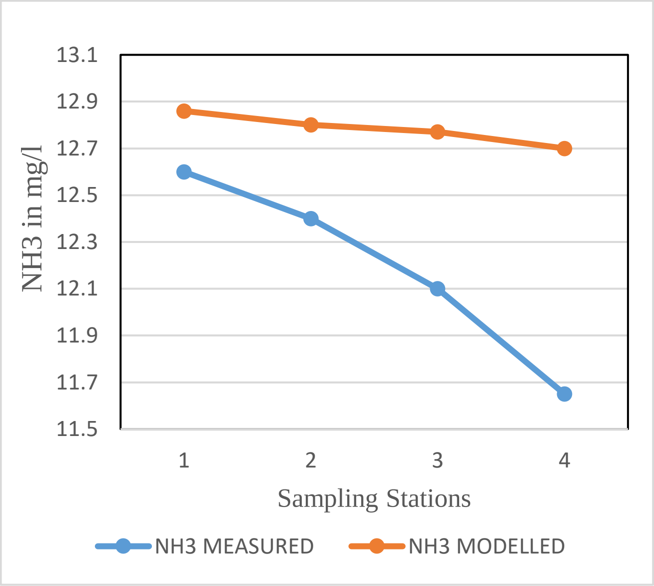
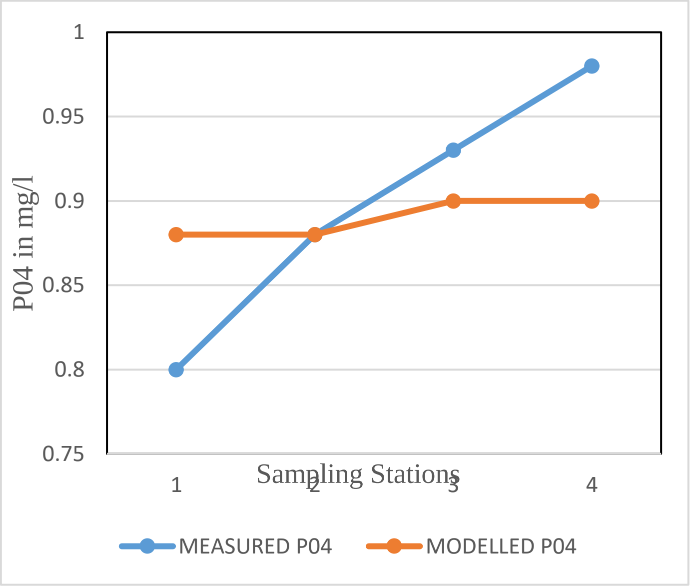


Figure 4.2. 4 Graph of measured nutrient levels against predicted model results in the month of August for the Sakumono II lagoon.

Figure 4.2.5 Shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of September for the Sakumono II lagoon (estuarine basin). Plotted values of Ammonia, Nitrate and Phosphate had positive correlations of 0.97, 0.68 and 0.86 respectively.





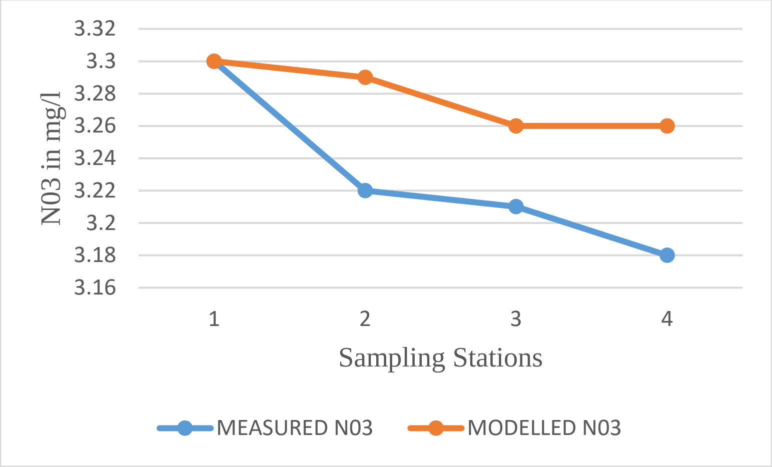
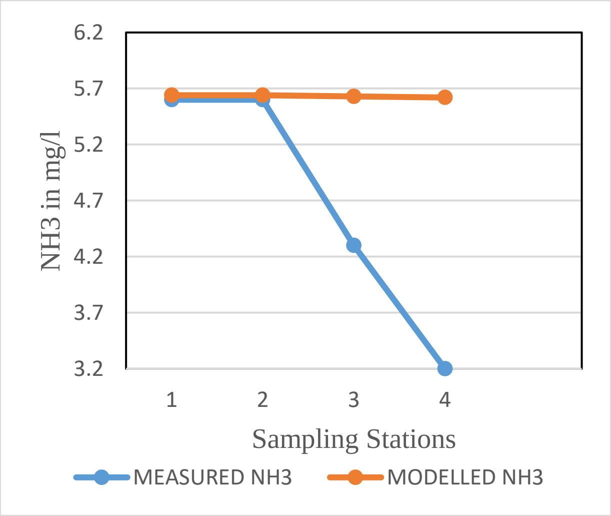
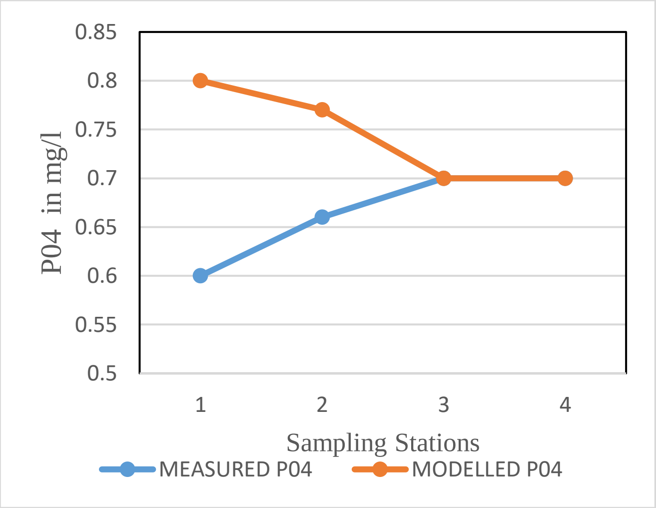


Figure 4.2. 5 Graph of measured nutrient levels against predicted model results in the month of September for the Sakumono II lagoon.

Figure 4.2.6 Shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of November for the Sakumono II lagoon (estuarine basin). Plotted values of Ammonia and Nitrate had a positive correlation of 0.93 and 0.95. Phosphate had a negative correlation of -0.91.





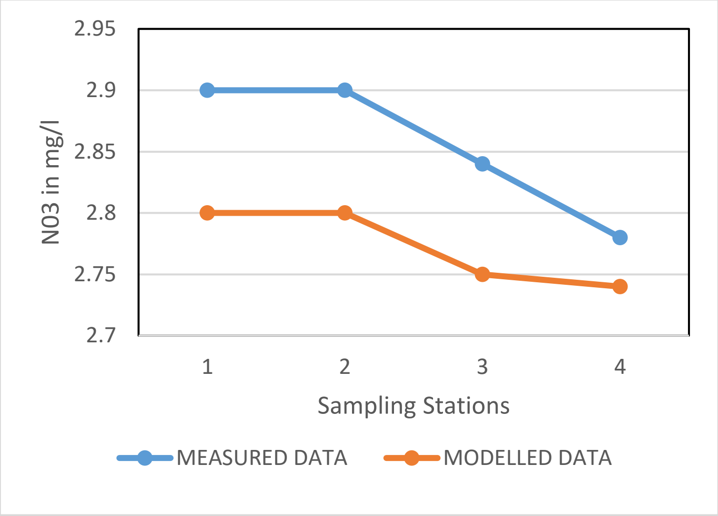
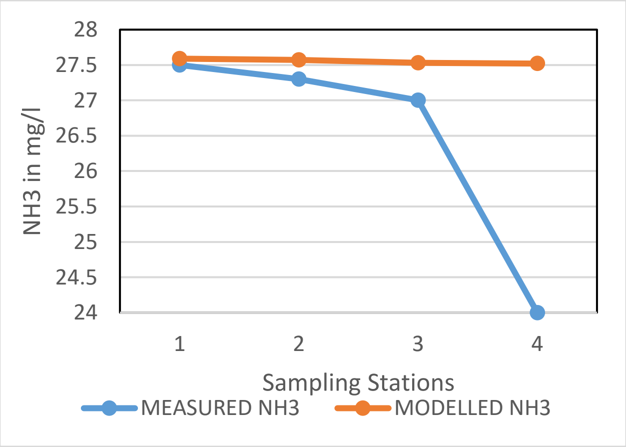
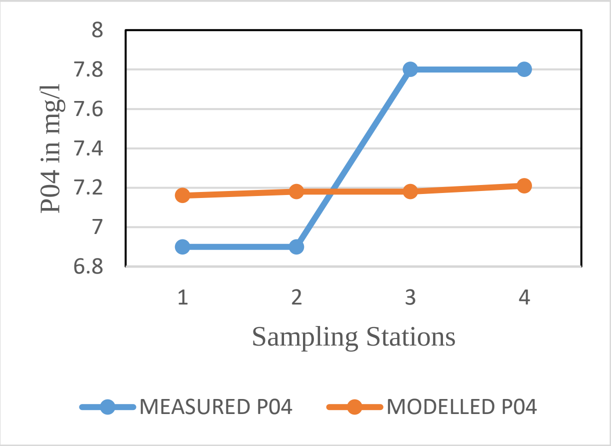


Figure 4.2. 6 Graph of measured nutrient levels against predicted model results in the month of November for the Sakumono II lagoon.

Figure 4.2.7 Shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of December for the Sakumono II lagoon (estuarine basin). Plotted values of ammonia and phosphate had positive correlations of 0.74 and 0.70 respectively. Nitrate had a negative correlation of -0.73.





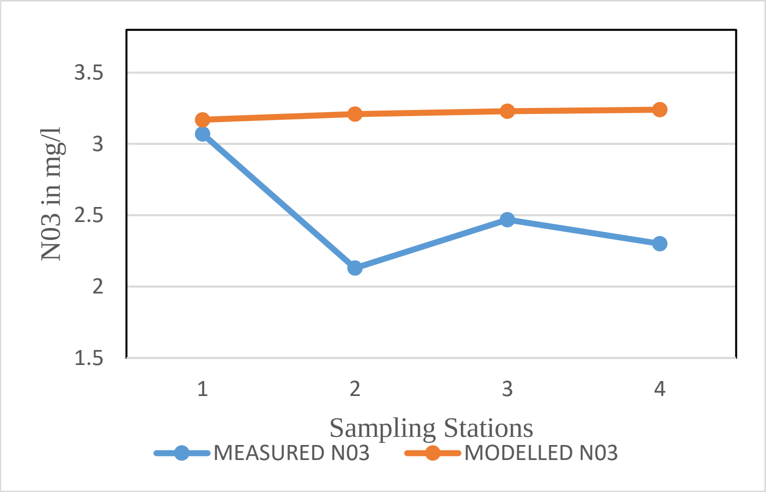
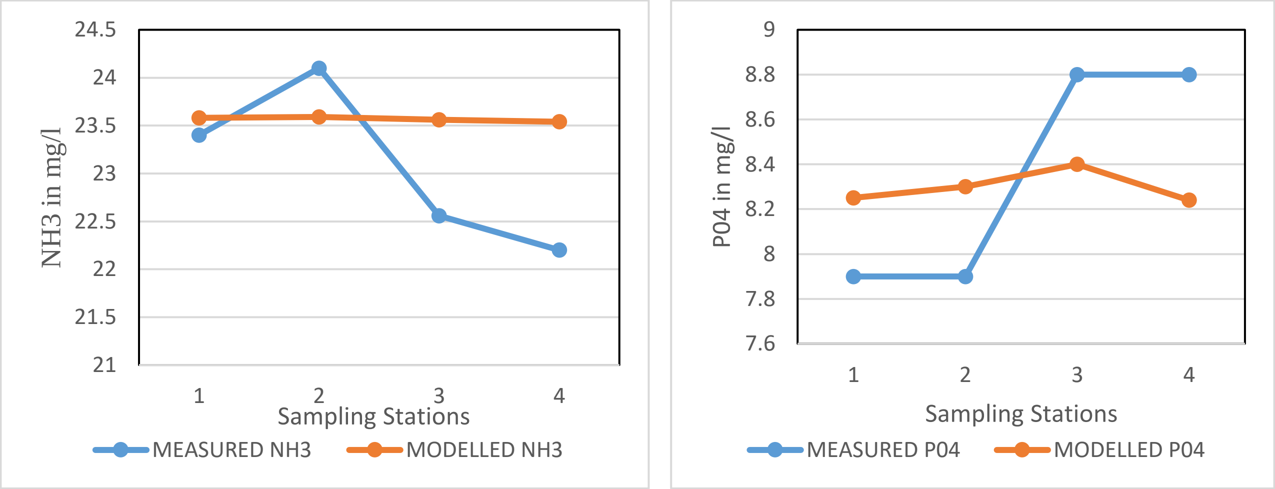


Figure 4.2. 7 Graph of measured nutrient levels against predicted model results in the month of December for the Sakumono II lagoon.

Figure 4.2.8 Shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of January for the Sakumono II lagoon (estuarine basin). Plotted values of ammonia, phosphate and nitrate had positive correlations of 0.96, 0.30 and 0.23 respectively.



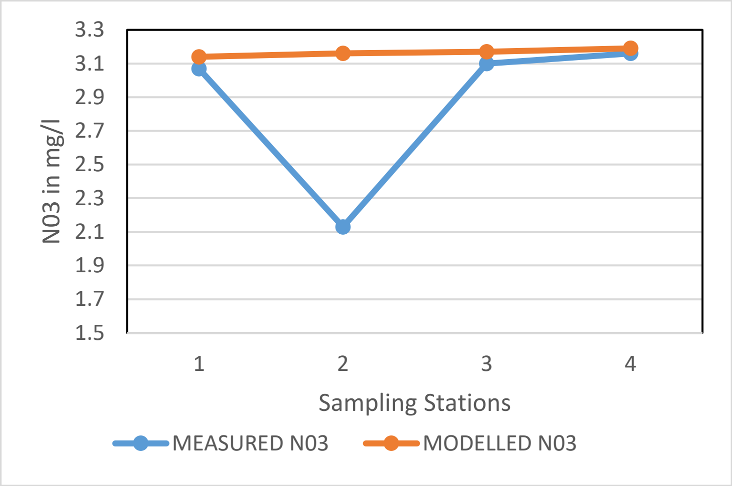
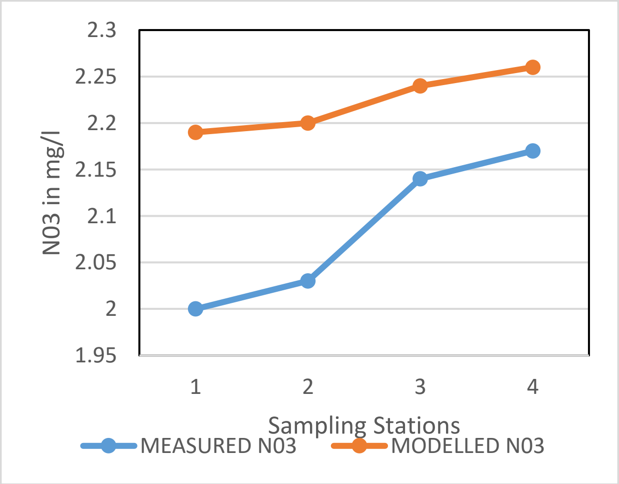
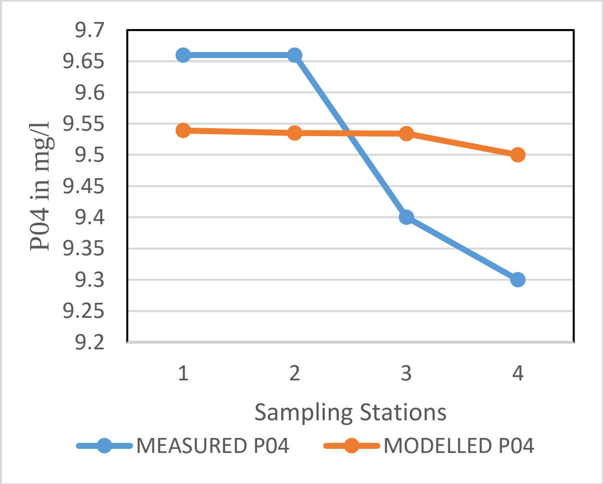


Figure 4.2. 8 Graph of measured nutrient levels against predicted model results in the month of January for the Sakumono II lagoon.

Figure 4.2.9 Shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of February for the Sakumono II lagoon (estuarine basin). Plotted values of ammonia, phosphate and nitrate had positive correlations of 0.83, 0.79 and 0.99 respectively.





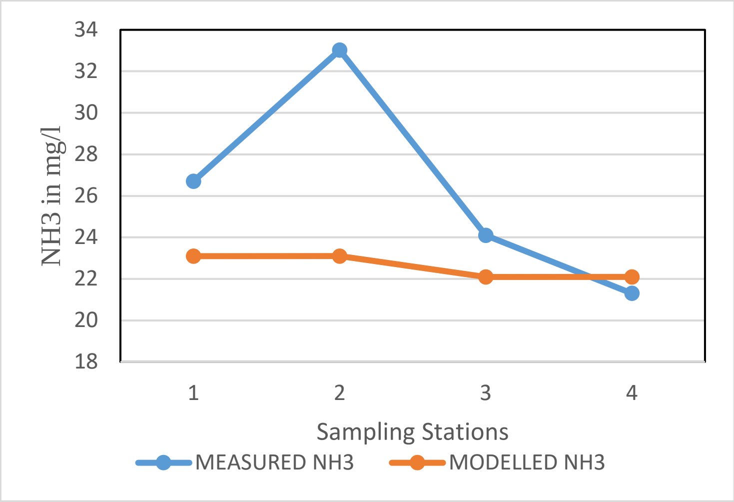


Figure 4.2. 9 Graph of measured nutrient levels against predicted model results in the month of February for the Sakumono II lagoon.

4.3 Mukwe lagoon

Spatial maps were developed for the Mukwe lagoon based on the metadata on nutrients collected from the period of August 2018 to February 2019. Sediment discharge rates and water discharge rates were also calculated.

Figure 4.3.1 shows phosphorus levels in the Mukwe lagoon for six months of research. The highest phosphorus level measured during the period of study was in September at a concentration of 16.9 mg/l. The lowest Phosphorus level recorded was in August at a concentration of 0.4 mg/l. On the average, the highest phosphorus levels were recorded in February.

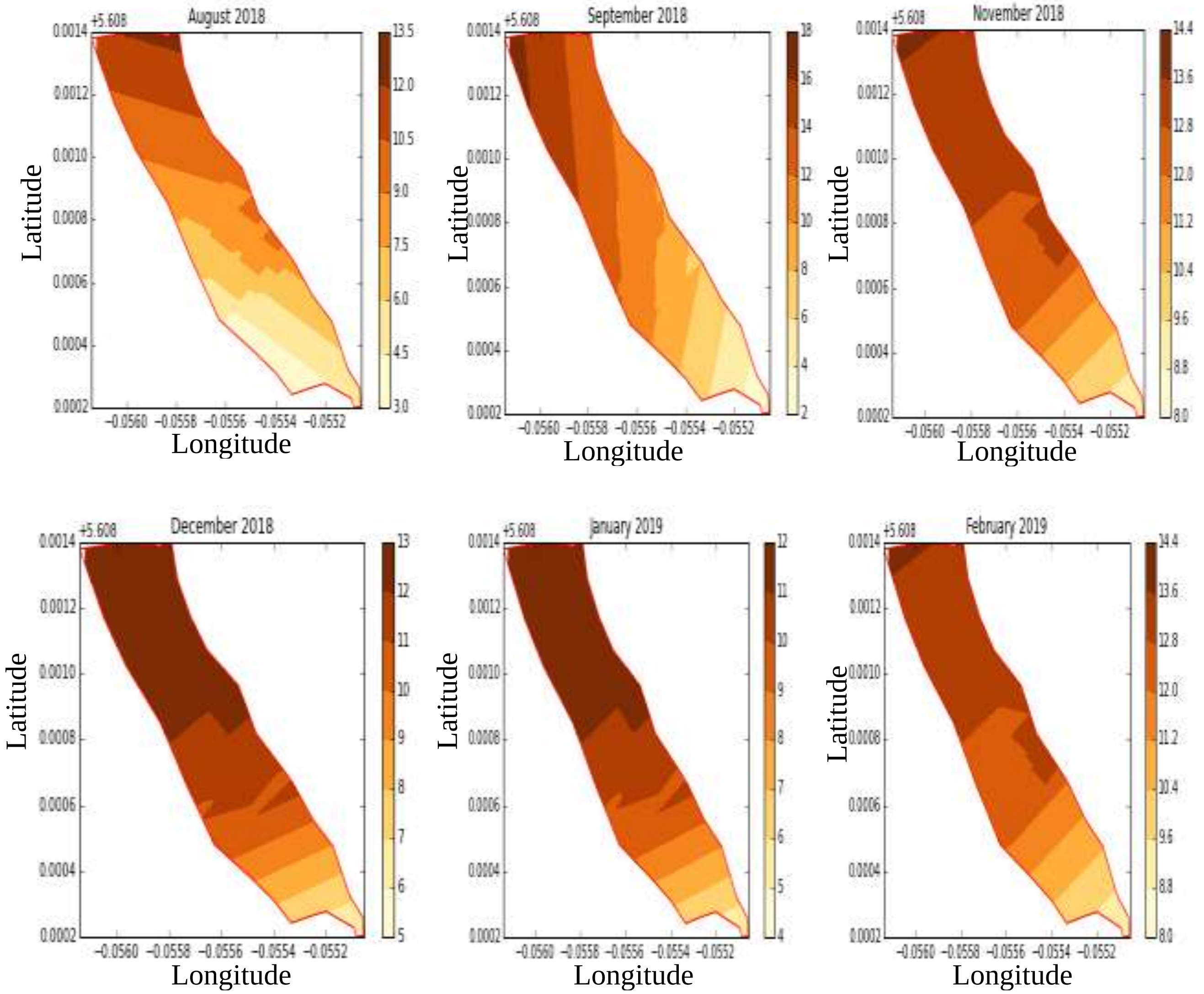


Figure 4.3. 1 – Phosphorus levels in the Mukwe lagoon for the study period.

Figure 4.3.2 shows nitrate levels in the Mukwe lagoon for six months of research. The highest nitrate level measured during the period of study was in August 2018 at a concentration of 19 mg/l. The lowest Nitrate level recorded was in December 2018 at a concentration of 2 mg/l

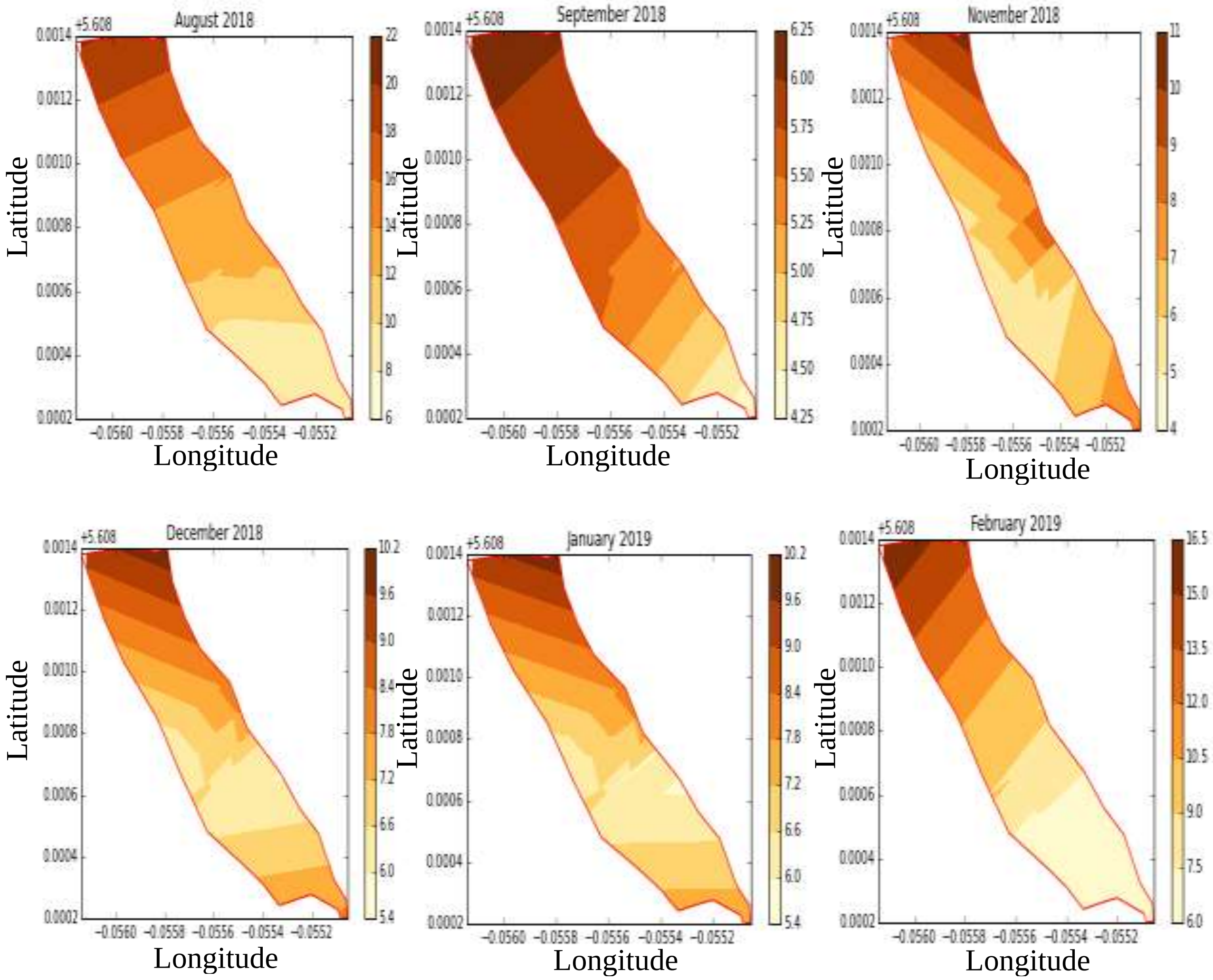


Figure 4.3. 2 – Nitrate levels in the Mukwe lagoon.

Figure 4.3.3 shows ammonia levels in the Mukwe lagoon for six months of research. The highest ammonia level measured during the period of study was in February 2019 at a concentration of 80.2 mg/l. The lowest ammonia level recorded was in September 2018 at a concentration of 0.7mg/l.

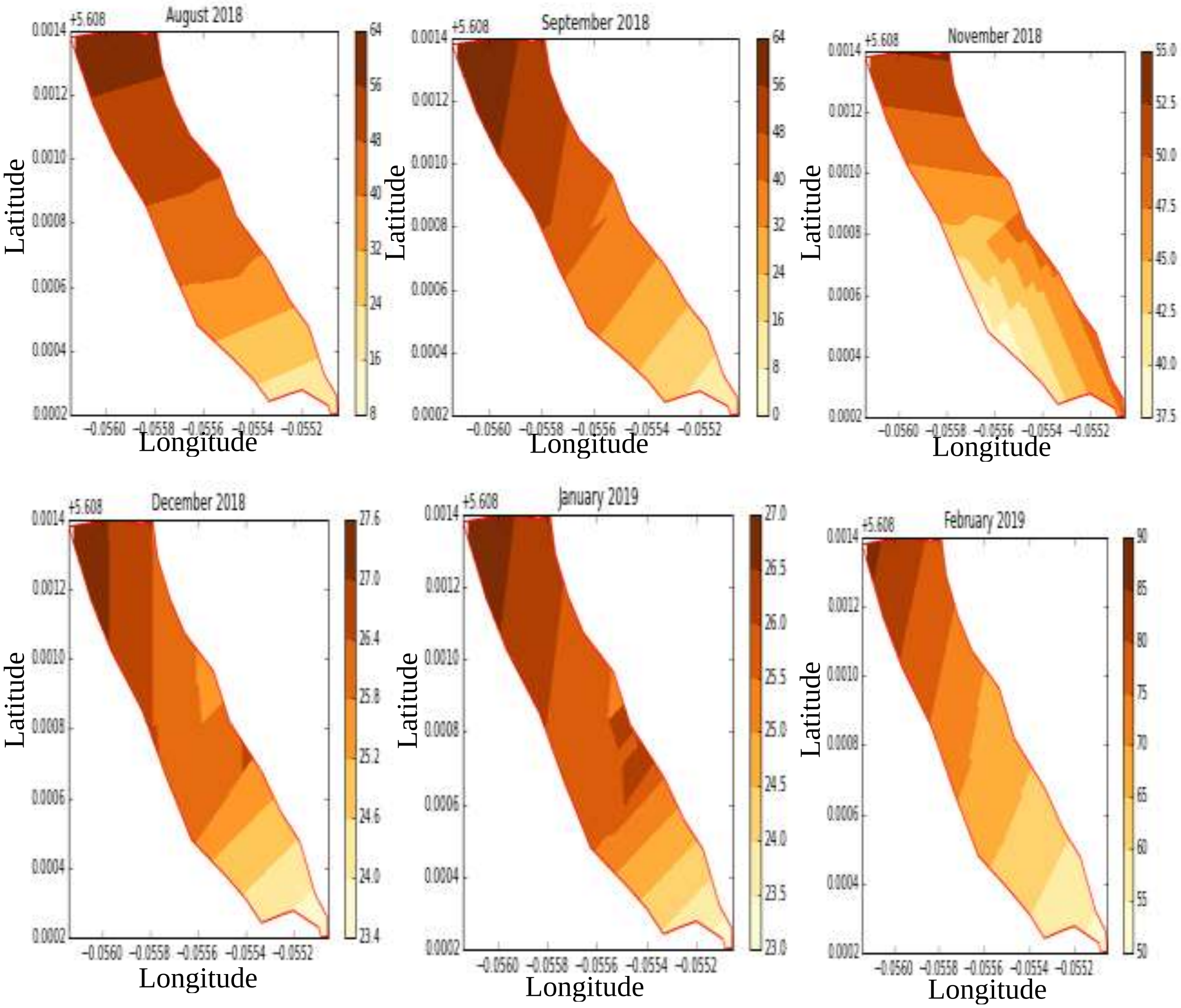


Figure 4.3. 3 – Ammonia levels in the Mukwe lagoon for the study period.

Table 4.3.1 shows the means of sediment nutrient levels for ammonia, nitrate and phosphorus in mg/kg in the Mukwe lagoon in both dry and rainy seasons during the study period.

Table 4.3. 1 – Mean sediment nutrient levels in the Mukwe lagoon during period of study.

			NUTRIENT (DRY SEASON)			NUTRIENT (WET SEASON)		
SITE	LAT	LONG	NH3 mg/kg	NO3 mg/kg	%TP mg/kg	NH3 mg/kg	NO3 mg/kg	%TP mg/kg
M1	5.609392	-0.056117	44.28	16.76	0.178	40.32	16.21	0.169
M2	5.608987	-0.055896	44.1	16.16	0.147	37.31	16.15	0.147
M3	5.608602	-0.055669	40.68	14.76	0.141	37.23	15.8	0.102
M4	5.608523	-0.055252	40.2	14.2	0.141	36.21	14.56	0.102
M5	5.608244	-0.055072	38.21	13.87	0.121	36.21	14.31	0.045

Table 4.3.2 shows the average of various discharge rates of sediments per day in the Mukwe lagoon for the study period.

Table 4.3. 2 – Sediment discharge rate in the Mukwe lagoon.

NUTRIENT	SEDIMENT DISCHARGE RATE
NH3	0.0000377 m^3/s
NO3	0.0000126 m^3/s
P04	0.00000131 m^3/s

Table 4.3.3 shows the mean water discharge rate in the Mukwe lagoon during the dry season and the rainy season.

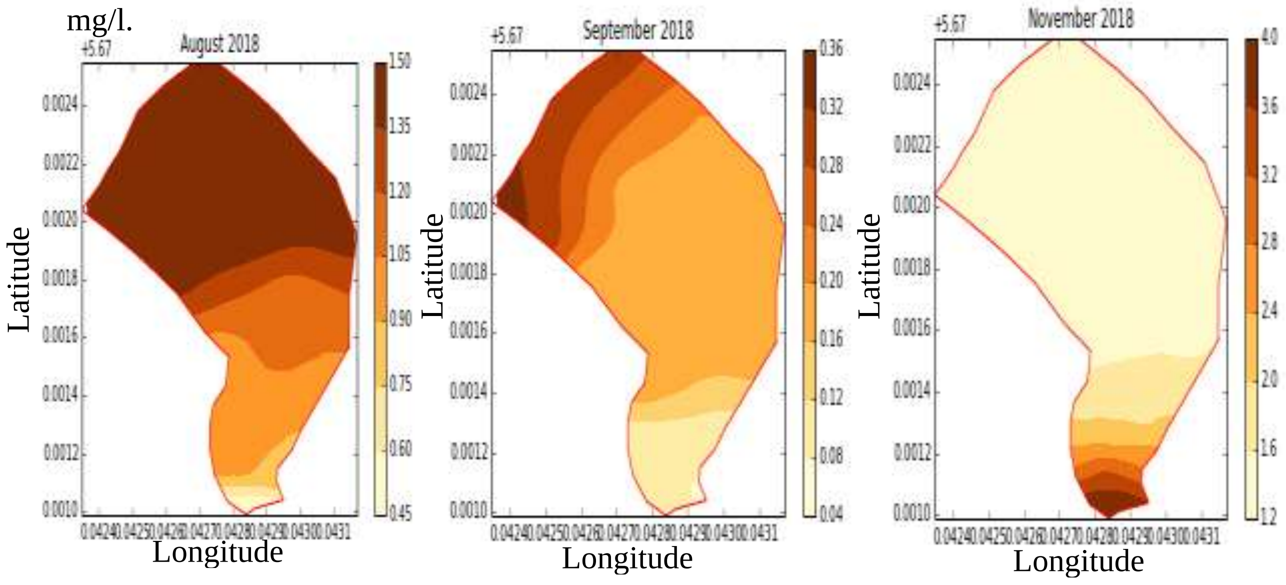
Table 4.3. 3- Mean discharge rate of Mukwe lagoon during study period.

Dry Season	Rainy Season
0.01m^3/s	0.08m^3/s

4.4 Gao Lagoon

Spatial maps were developed for the Gao lagoon based on the metadata on nutrients collected from the period of August 2018 to February 2019. Sediment discharge rates and water discharge rates were also calculated.

Figure 4.4.1 shows phosphorus levels in the Gao lagoon for six months of research. The highest phosphorus level measured during the period of study was in February 2019 at a concentration of 5.79 mg/l. The lowest phosphorus level recorded was in September 2018 at a concentration of 0.07 mg/l.



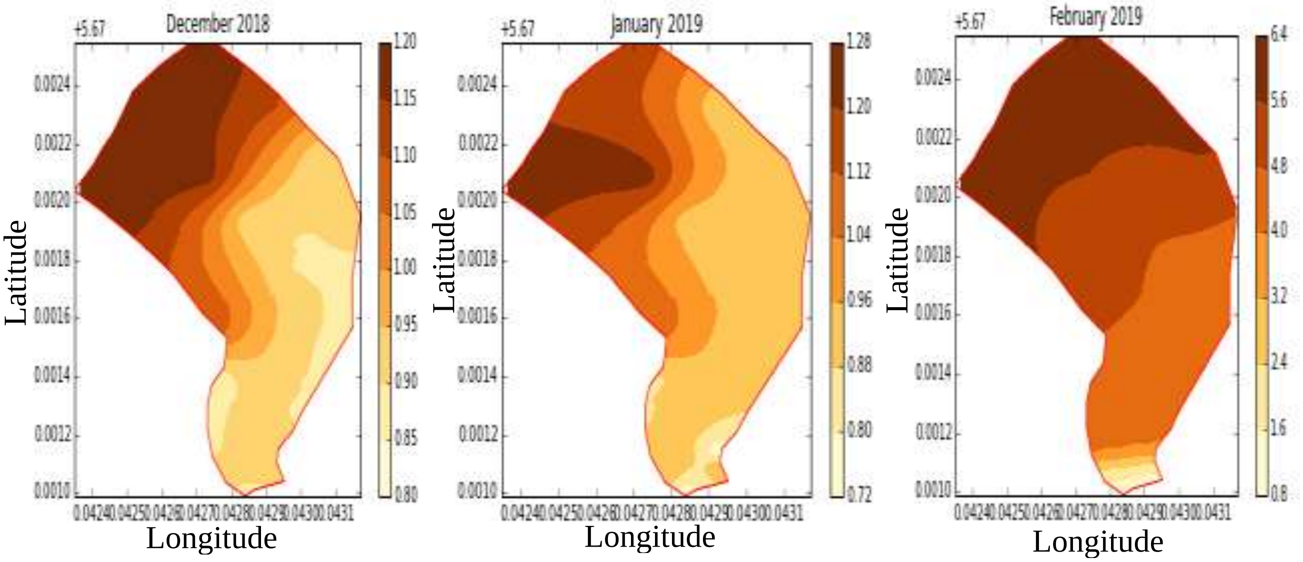
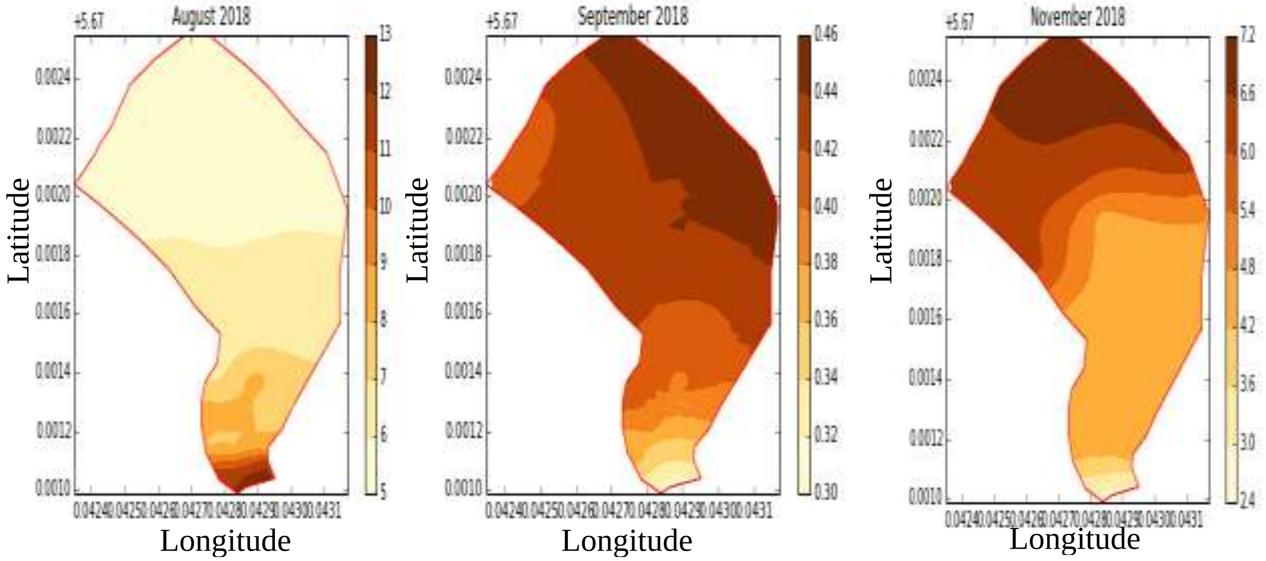


Figure 4.4. 1 – Phosphate levels in the Gao lagoon.

Figure 4.4.2 shows nitrate levels in the Gao lagoon for six months of research. The highest phosphate level measured during the period of study was in August 2018 at a concentration of 12 mg/l. The lowest nitrate level recorded was in September 2018 at a concentration of 0.2 mg/l.



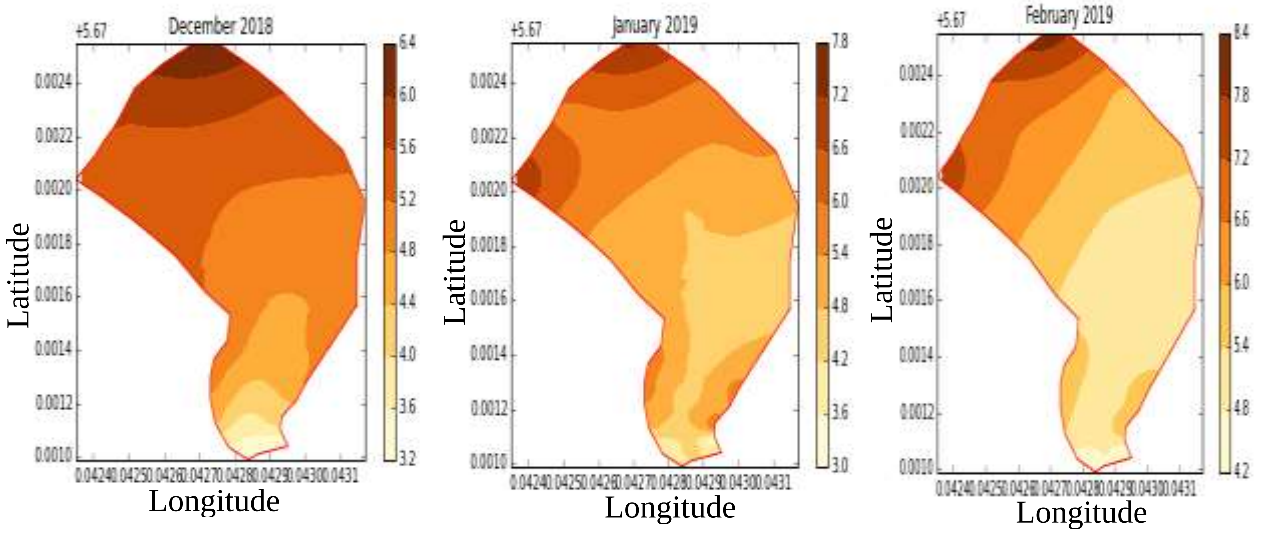
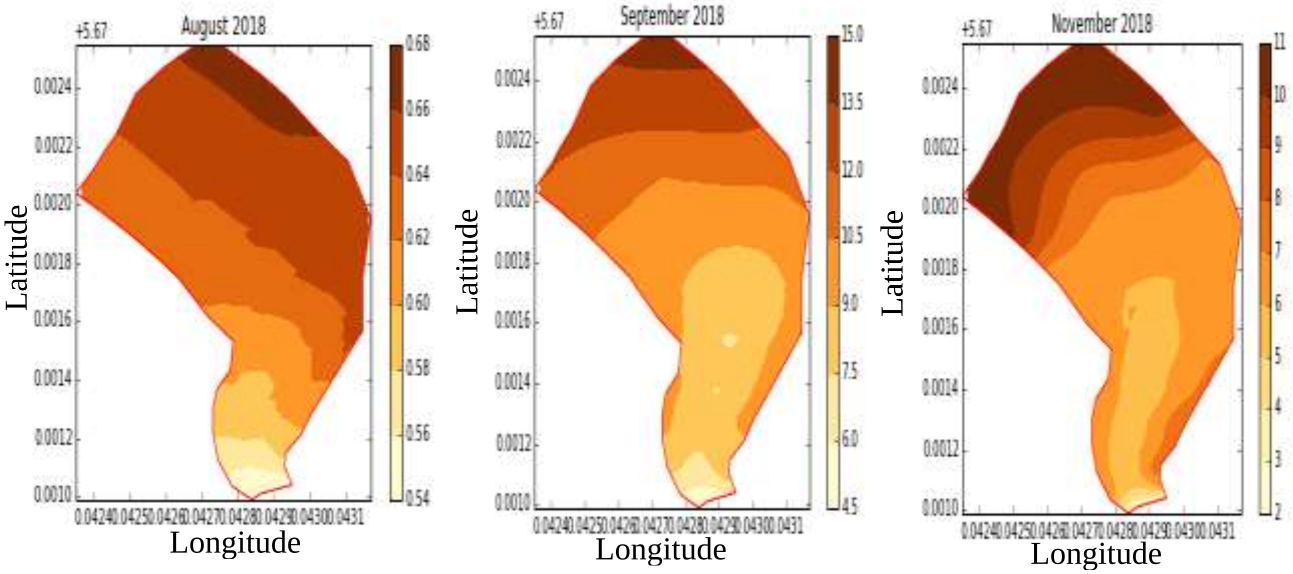


Figure 4.4. 2 – Nitrate levels in the Gao lagoon.

Figure 4.4.3 shows ammonia levels in the Gao lagoon for six months of research. The highest ammonia level measured during the period of study was in September 2018 at a concentration of 13.7 mg/l. The lowest ammonia level recorded was in August at a concentration of 0.5 mg/l.



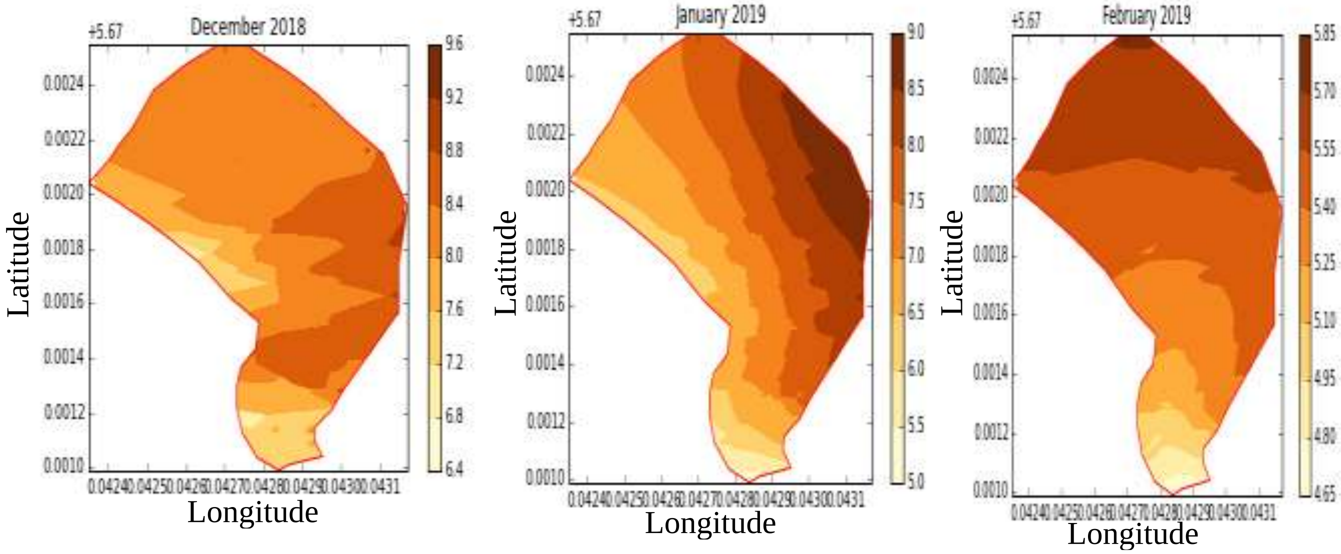


Figure 4.4. 3– Ammonia levels in the Gao lagoon.

Figure 4.4.4 shows the means of sediment nutrient levels for ammonia, nitrate and phosphorus in mg/kg in the Gao lagoon in both dry and rainy seasons during the study period.

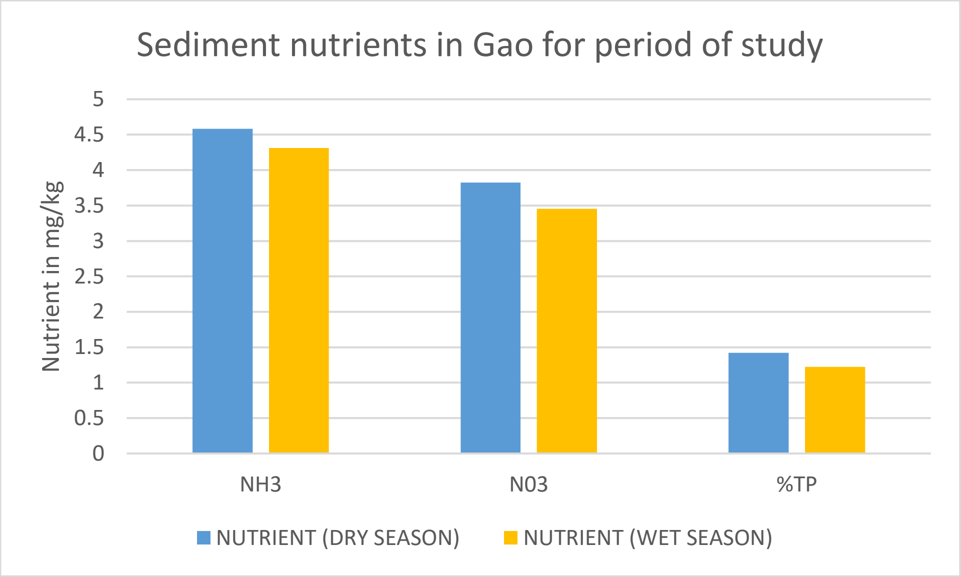


Figure 4.4. 4- A Graph of average sediment nutrient in Gao lagoon for study period.

Table 4.4.1 shows the average of various discharge rates of sediments per day in the Gao lagoon for the study period

Table 4.4. 1 – Sediment discharge rate in the Gao lagoon.

NUTRIENT	SEDIMENT DISCHARGE RATE
NH3	0.000021 m^3/s
N03	0.0000073 m^3/s
P04	0.0000000746 m^3/s

Table 4.4.2 shows the mean water discharge rate in the Gao during the dry season and the rainy season.

Table 4.4. 2– Mean discharge rate of Gao during study period.

Dry Season	Rainy Season
0.007m3/s	0.05m3/s

Figure 4.4.5 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of August for the Gao lagoon Plotted values of ammonia and phosphate had positive correlations of 0.99, 0.97 respectively. Ammonia had negative correlation of -0.61

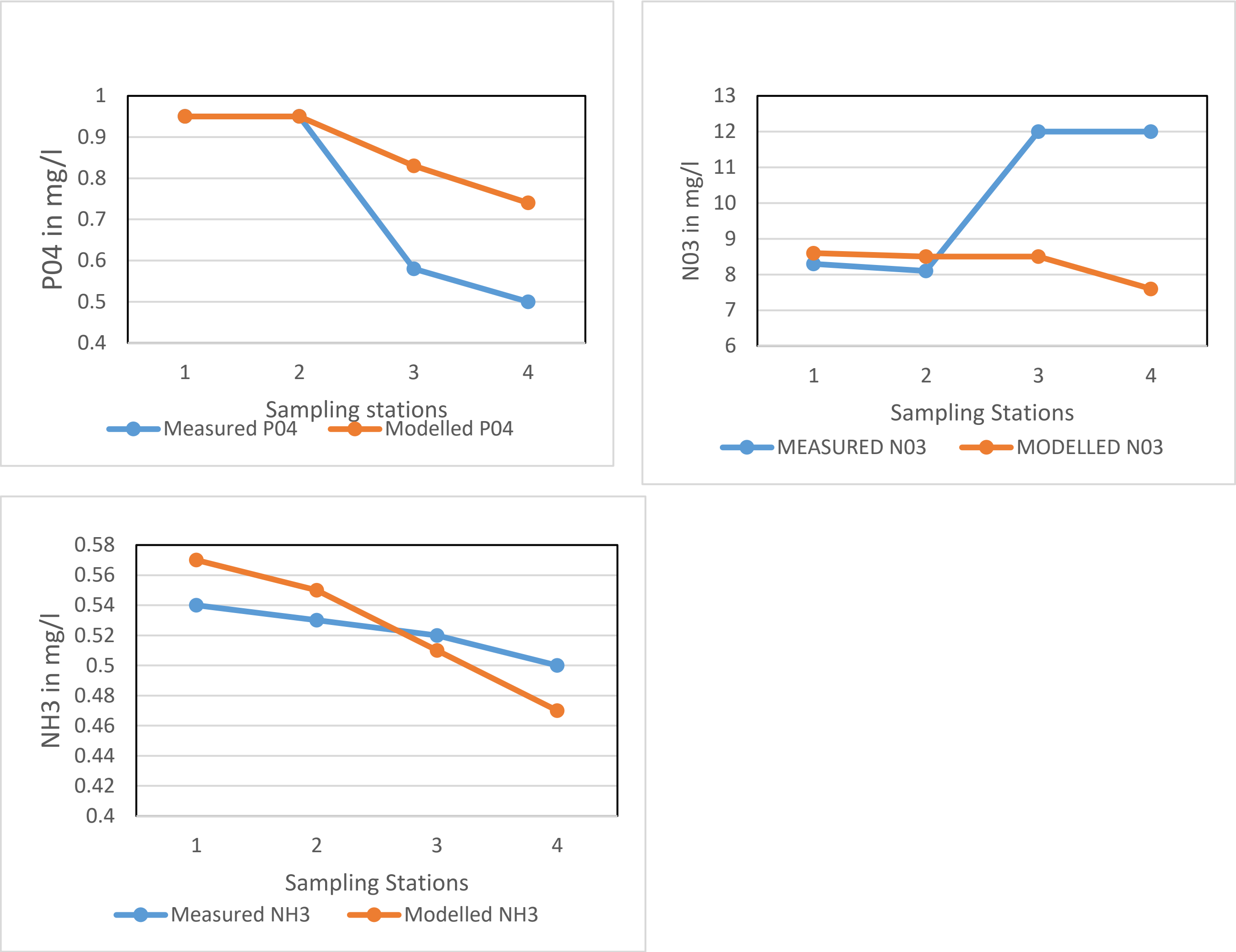


Figure 4.4. 5 Graph of measured nutrient levels against predicted model results in the month of August for the Gao lagoon.

Figure 4.4.6 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of September for the Gao lagoon Plotted values of ammonia, nitrate and phosphate had positive correlations of 0.99, 0.94 and 0.57 respectively

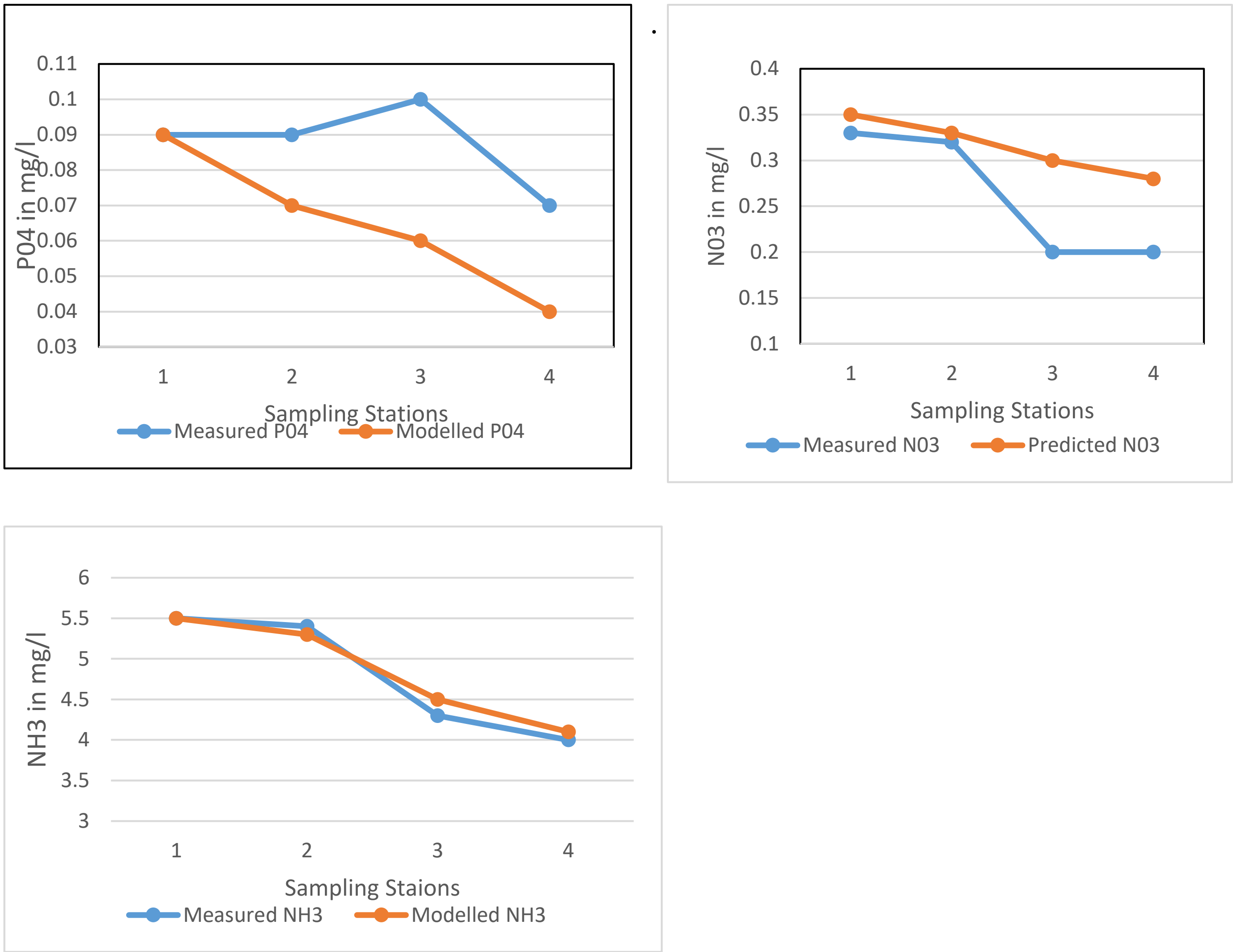


Figure 4.4. 6 Graph of measured nutrient levels against predicted model results in the month of September for the Gao lagoon.

Figure 4.4.7 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of November for the Gao lagoon Plotted values of ammonia, nitrate and phosphate had positive correlations of 0.98, 0.96 and 0.99 respectively.

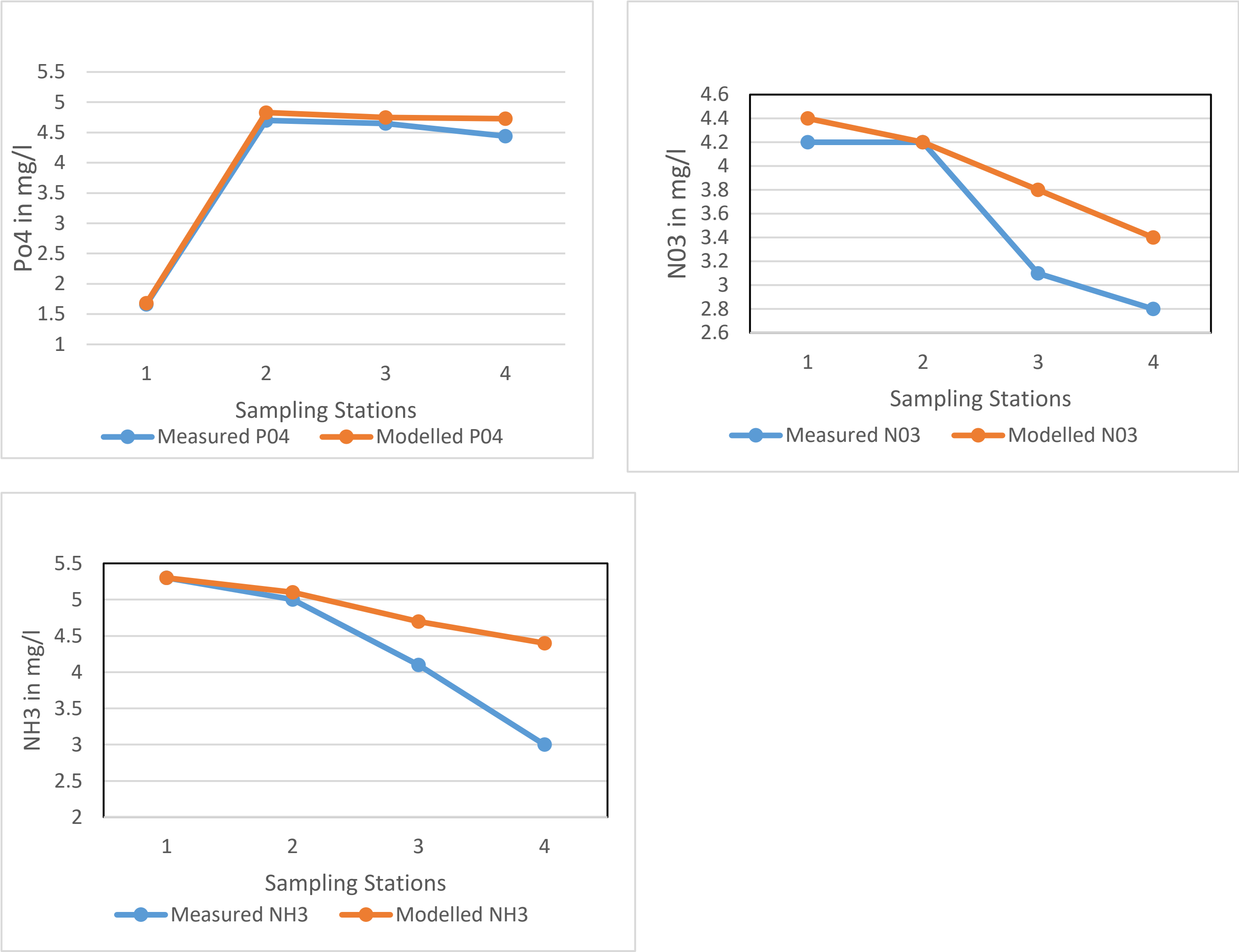


Figure 4.4. 7 Graph of measured nutrient levels against predicted model results in the month of November for the Gao lagoon.

Figure 4.4.8 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of December for the Gao lagoon Plotted values of ammonia, nitrate and phosphate had positive correlations of 0.91, 0.92 and 0.79 respectively

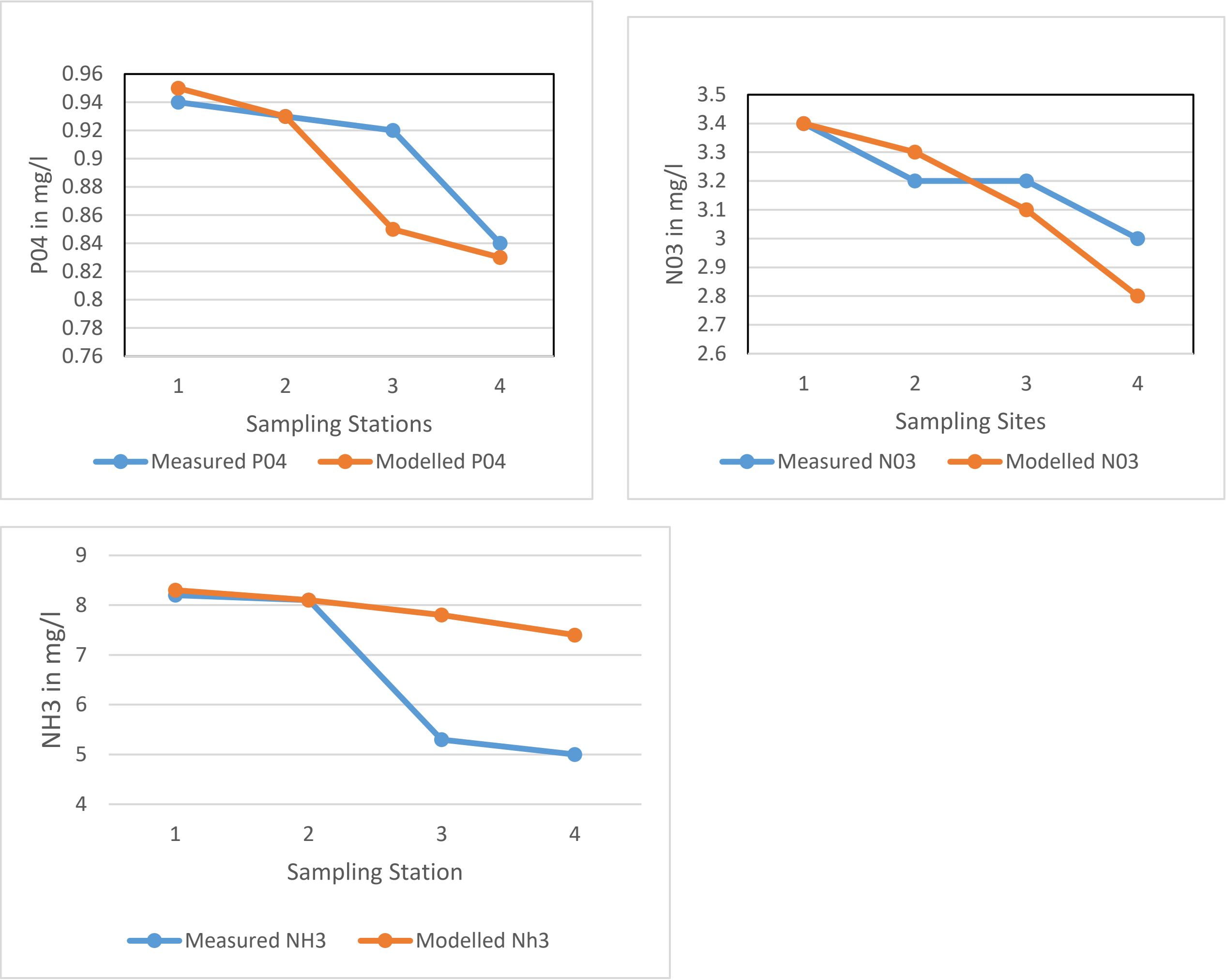


Figure 4.4. 8 Graph of measured nutrient levels against predicted model results in the month of December for the Gao lagoon.

Figure 4.4.9 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of January for the Gao lagoon Plotted values of ammonia, nitrate and phosphate had positive correlations of 0.99, 0.65 and 0.98 respectively

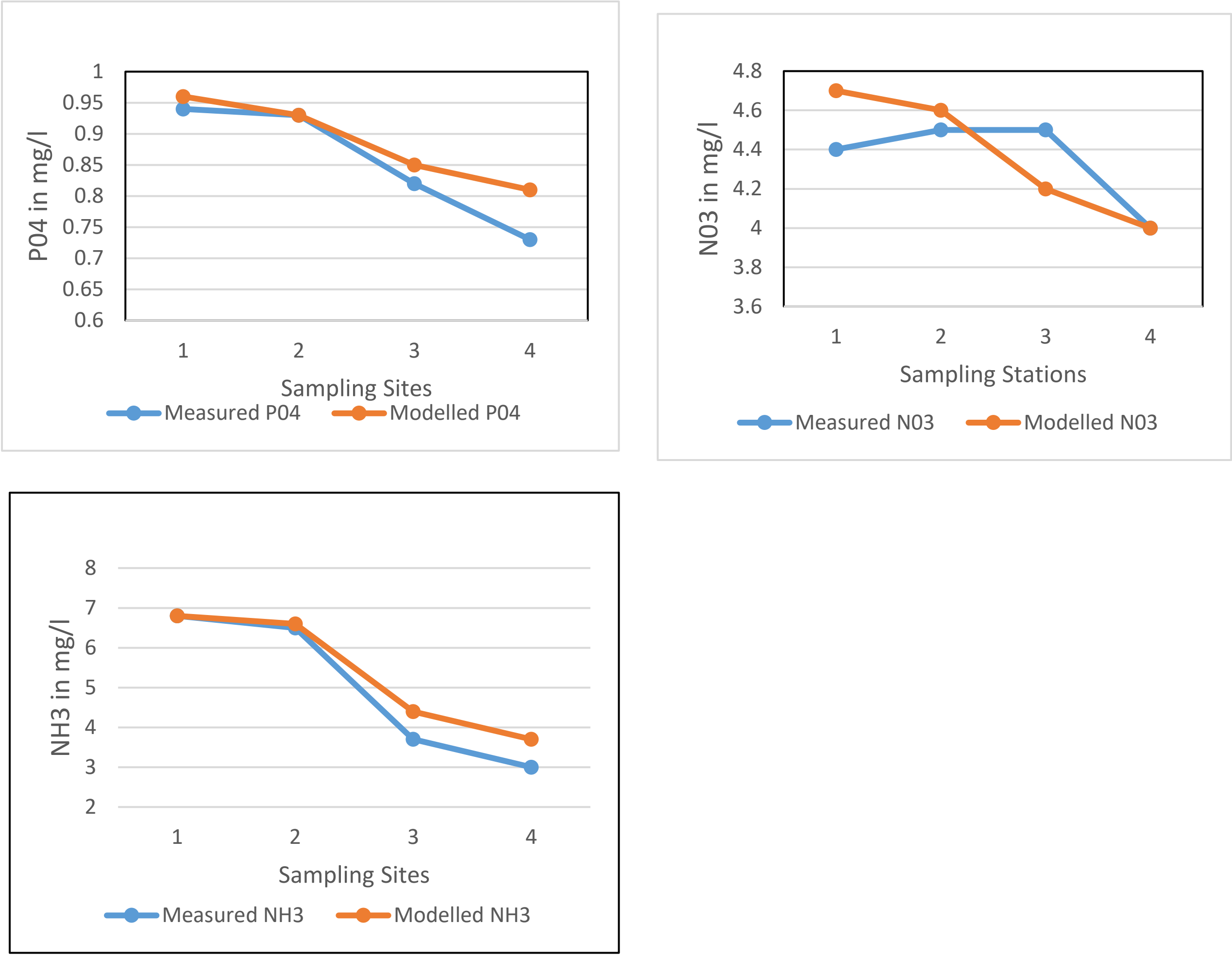


Figure 4.4. 9 Graph of measured nutrient levels against predicted model results in the month of January 2019 for the Gao lagoon.

Figure 4.4.10 shows a plotted graph of measured nutrient in the laboratory and predicted model result in the month of February 2019 for the Gao lagoon plotted values of ammonia, nitrate and phosphate had positive correlations of 0.99, 0.96 and 0.84 respectively

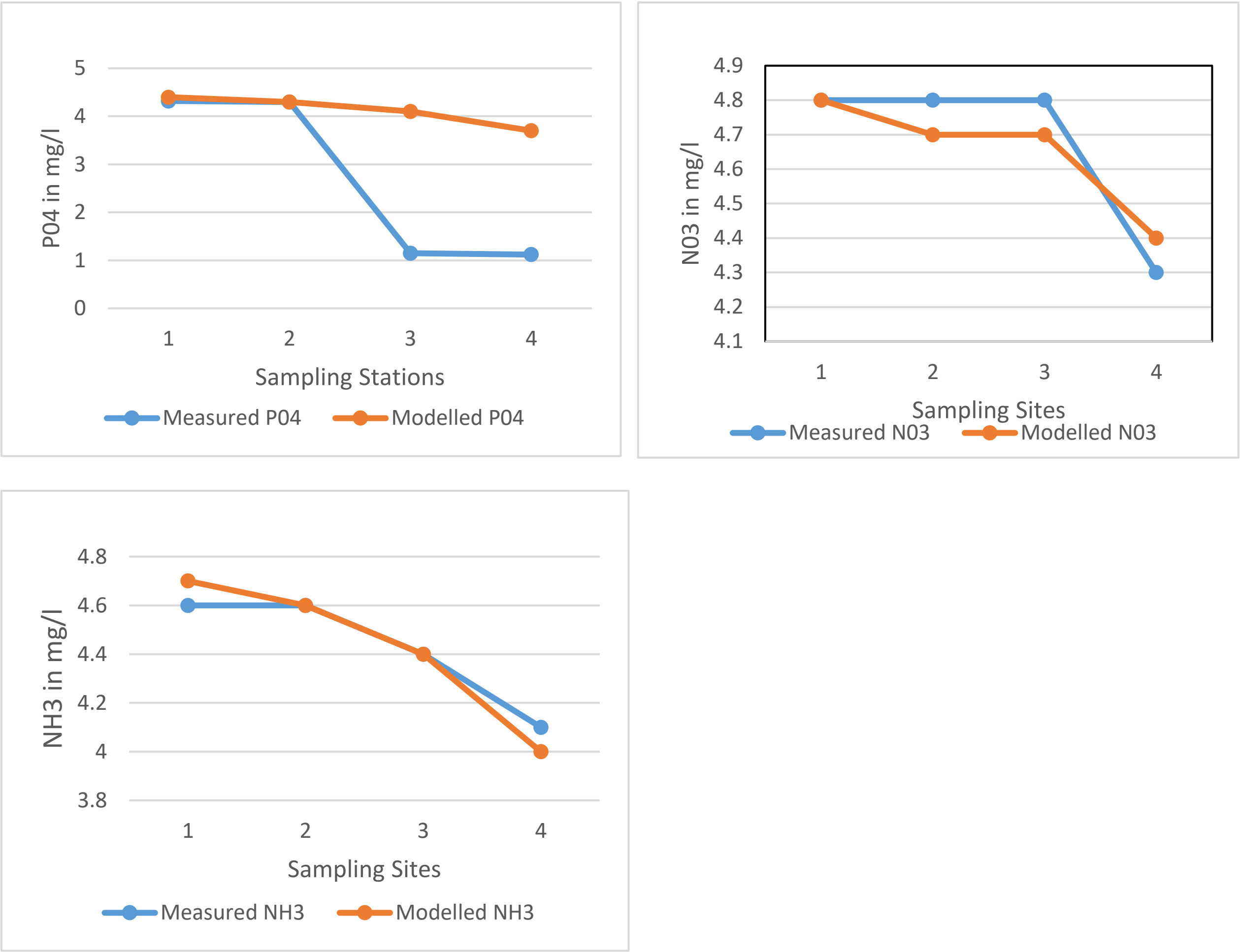


Figure 4.4. 10 Graph of measured nutrient levels against predicted model results in the month of February 2019 for the Gao lagoon.

4.5 Laloi Lagoon

Spatial maps were developed for the Laloi lagoon based on the metadata on nutrients collected from the period of August 2018 to February 2019. Sediment discharge rates and water discharge rates were also calculated.

Figure 4.5.1 shows phosphorus levels in the Laloi lagoon for six months of research. The highest phosphorus level measured during the period of study was in January 2019 at concentration of 7.5 mg/l. The lowest phosphorus level recorded was in August 2018 at a concentration of 0.02 mg/l

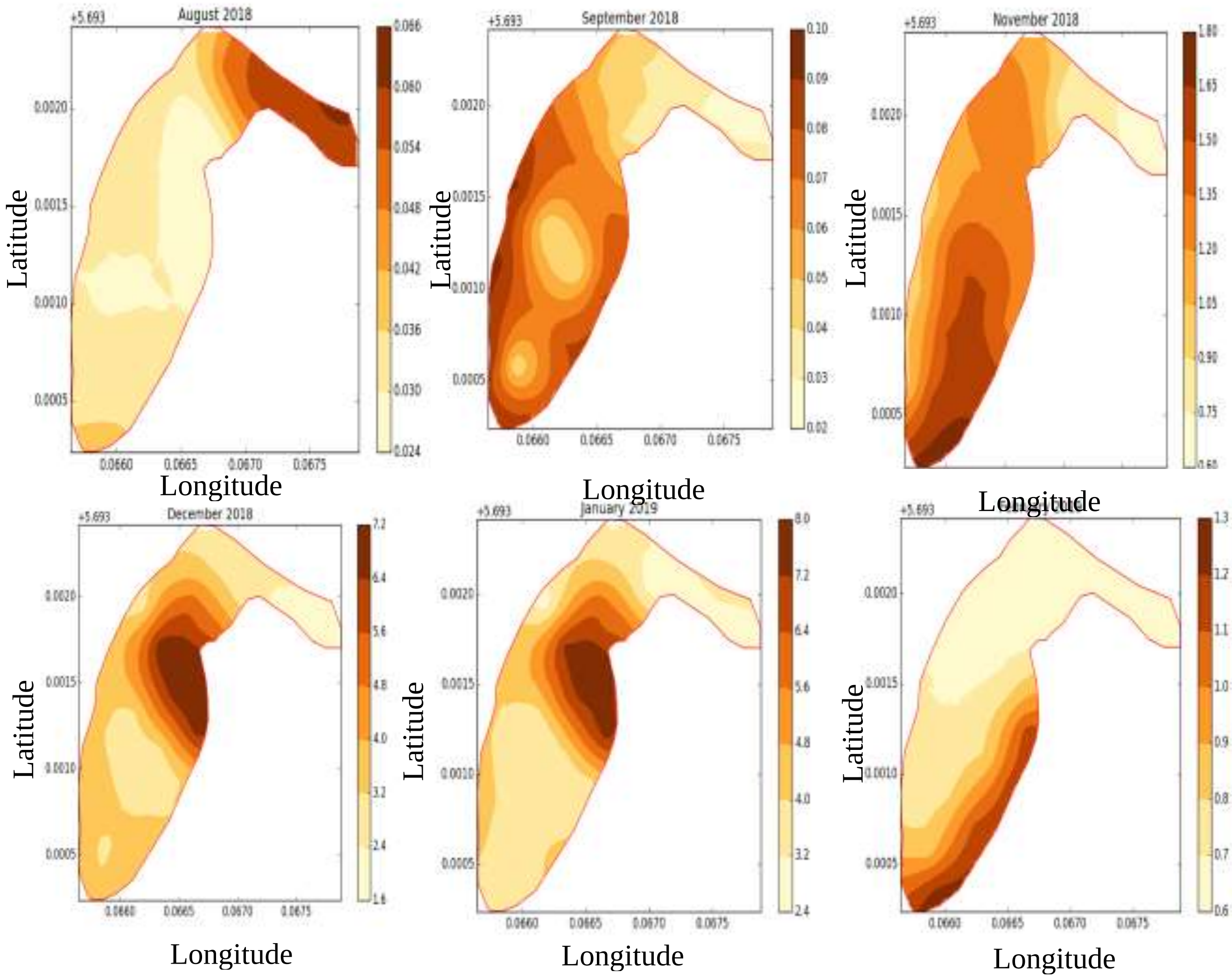


Figure 4.5. 1 – Phosphate levels in the Laloi lagoon.

Figure 4.5.2 shows Nitrate levels in the Laloi lagoon for six months of research. The highest nitrate level measured during the period of study was in February 2019 at a concentration of 6.2 mg/l. The lowest nitrate level recorded was in September at a concentration of 0.3 mg/l.

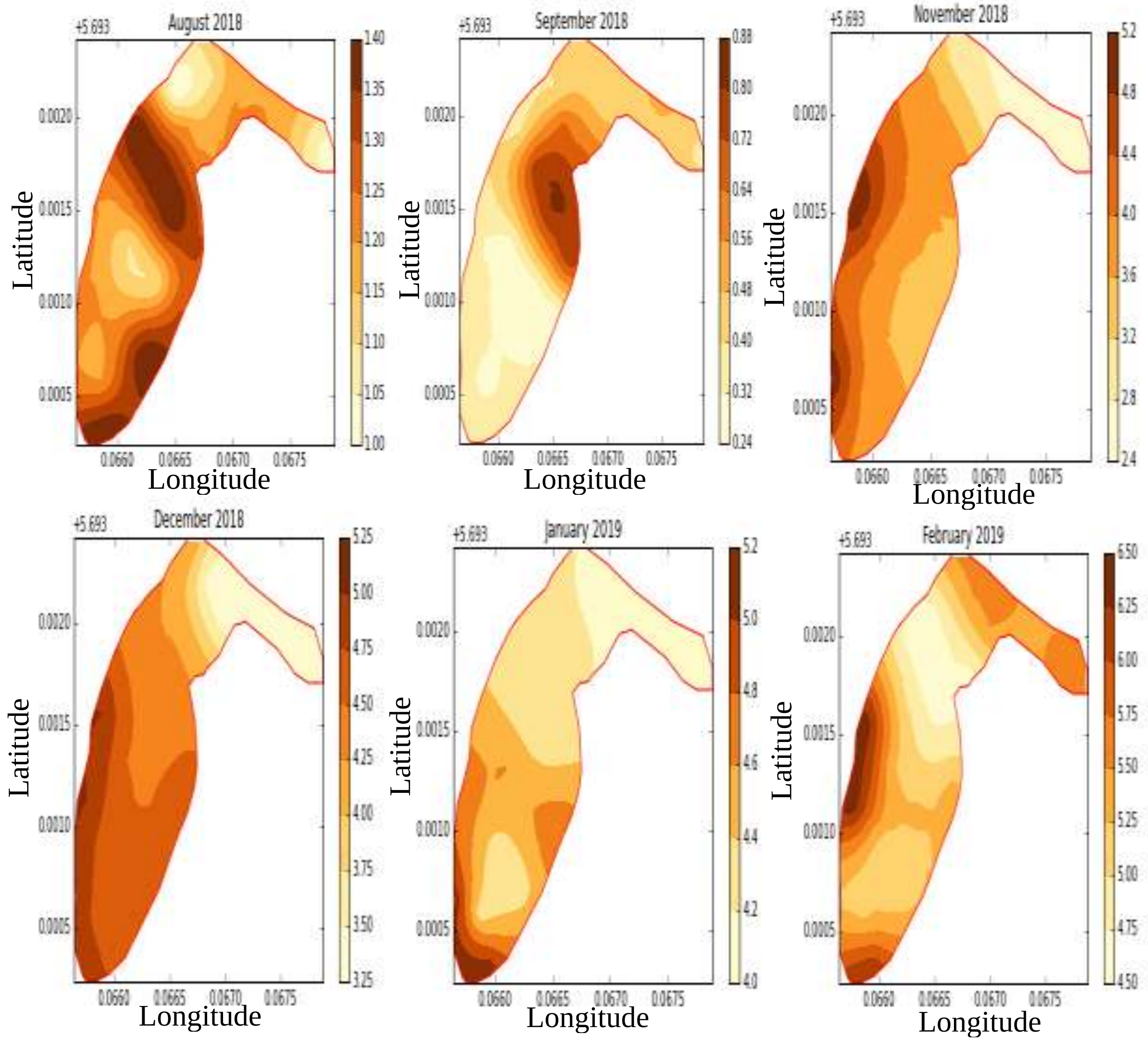


Figure 4.5. 2 – Nitrate levels in the Laloi lagoon.

Figure 4.5.3 shows ammonia levels in the Laloi lagoon for six months of research. The highest ammonia level measured during the period of study was in November 2018 at a concentration of 7.5 mg/l. The lowest ammonia level recorded was in August 2018 at a concentration of 0.03 mg/l.

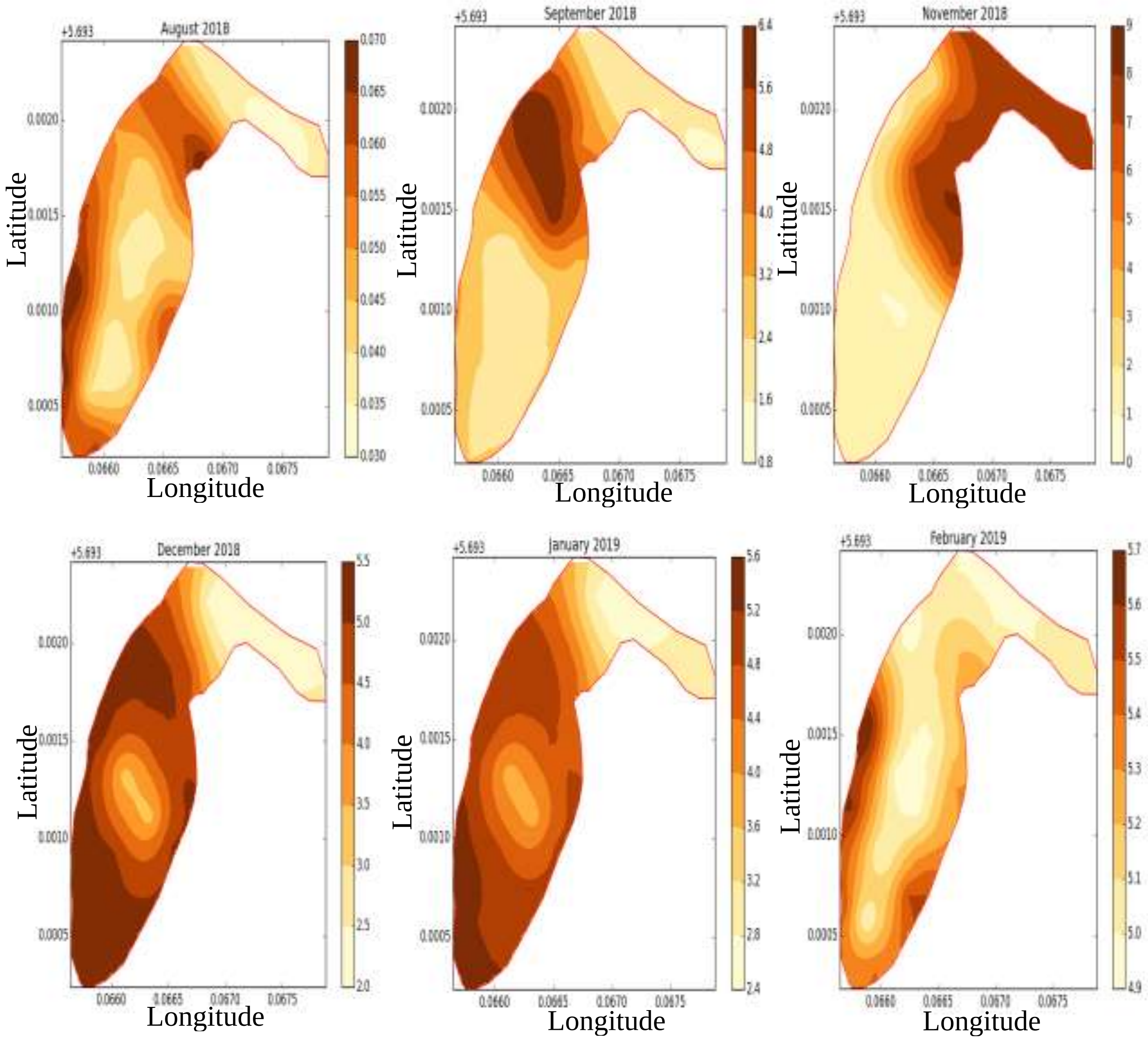


Figure 4.5. 3 – Ammonia levels in the Laloi lagoon.

Table 4.5.1 shows the means of sediment nutrient levels for ammonia, nitrate and phosphorus in mg/kg in the Laloi lagoon in both dry and rainy seasons during the study period.

Table 4.5. 1 – Mean sediment nutrient levels in the Laloi lagoon during period of study.

			NUTRIENT (DRY SEASON)			NUTRIENT (WET SEASON)		
SITE	LAT	LONG	NH3	N03	%TP	NH3	N03	%TP
L1	5.693243	0.065737	46.8	15.48	0.134	45.3	14.3	0.124
L2	5.693701	0.066236	45.2	15.33	0.124	43.7	14.01	0.114
L3	5.694463	0.066459	41.4	12.14	0.117	40.41	10.41	0.111
L4	5.694827	0.066683	37.8	12.03	0.113	40.2	10.12	0.104
L5	5.694803	0.06761	37.5	11.13	0.071	35.04	10.02	0.06

Table 4.5.2 shows the average of various discharge rates of sediments per day in the Laloi lagoon for the study period.

Table 4.5. 2 – Sediment discharge rate in the Laloi lagoon

NUTRIENT	SEDIMENT DISCHARGE RATE
NH3	0.00001624 m^3/s
N03	0.0000537 m^3/s
P04	0.0000000465 m^3/s

Table 4.5.3 shows the mean water discharge rate in the Laloi lagoon during the dry season and the rainy season.

Table 4.5. 3 – Mean discharge rate of Laloi lagoon during study period.

Dry Season	Rainy Season
0.02m3/s	0.09m3/s

4.6 The Bias Model Measure

Modelling and measure data can be compared using bias measure (Lemke *et al.*, 2017). The bias (v) calculates the derivation between modelled data (m^1) and observed data (o^1). V is being calculated from values in Appendix B.

$V = m^1 - o^1$ ……………………………….Equation 4.6.1

Nutrient	Bias value (v)	Percentage bias (%v)
Ammonia	-0.008	-0.05%
Nitrate	0.098	2.65%
Phosphate	0.08	1.71%

CHAPTER FIVE

DISCUSSION

5.1. Trends of Physico-Chemical Parameters Measured

5.1.1 pH

The measure of the acidity or alkalinity in an aquatic system is the pH. The pH indicates the hydrogen ion activity in the aquatic system. In America, lagoons that have pH in the range of about 6.5 to 8.5 are graded as healthy lagoons (USEPA, 2006). The value of pH in lagoon systems is important for the normal biological function of the system (World Health Organization, 2007). The value of pH is expressed as logarithm, which means a change in pH by a value of 1.0 is ten times that value (USEPA, 2006). pH measurements from the Sakumono II lagoon ranged from 7.83 to 9.82, Mukwe pH measurements ranged from 8.66 to 9.41, Gao pH measurement ranged from 6.64 to 7.23 and the pH in Laloi lagoon ranged from 7.8 to 8.6.

pH values recorded from past studies in the Sakumono II lagoon are in line with values from this study. Agbemehia (2014), Tay *et al* (2010) and Kwesi (2017) recorded pH values of 8.8, 9.5 and 8.83, respectively in the Sakumono II lagoon. In the Mukwe lagoon, a study by Addo *et al*. (2012) recorded slightly lower pH values of 7.84 which suggests that over time the lagoon is becoming more basic (alkaline). In the Gao lagoon, previous studies and reviews by Biney (1982) and :Gordon (1987) showed the pH of the lagoon to be around the range of 6.6 to 7.5. This shows that the lagoon is slightly acidic in nature and this agrees with the measurement from this study. Relatively, the Gao lagoon has little literature compared to the other lagoons.

The Laloi lagoon is known to be alkaline in nature Armah (2001). Past studies by Biney (1982),and Badu Bortely (2012) reported pH of 7.9, 8.6 and 8.1 respectively in the Laloi lagoon.

Higher pH values in these lagoons is as a result of anthropogenic activities (use of pesticides and farming) around the catchment area of the lagoons. Chemicals in pesticides and fertilizers in the surrounding farms end up in the lagoon when there is surface runoff (Laar *et al*., 2011; Kwesi, 2017).

Ghana's EPA acceptable value of pH is within the range of 6.0 to 9.0 (Taylor, 1999). This means areas of the Sakumono and Mukwe lagoons, which have pH of 9.82 and 9.41 are above Ghana's EPA permissible levels. This affects the normal biological function of these lagoons (USEPA 2006). pH measurements of the Gao and Laloi lagoons are all within the EPA permissible ratings. The pH range of all the lagoons suggest that they are mostly alkaline in nature. This can be as of result of the lagoons being open lagoons (Karikari *et al*., 2009). Open lagoons have a considerable amount of fresh/seawater exchange. Hence the alkalinity of the sea affects the pH of the lagoon.

5.1.2 Dissolved Oxygen (DO)

The term "dissolved oxygen" refers to oxygen molecules disintegrated in water. Dissolved oxygen is an indicator of water quality in a lagoonal system (Minnesota Pollution Control Agency, 2009). Aquatic organisms in lagoons depend on oxygen for survival and therefore, lower oxygen levels pose as a threat to these organisms (Conley *et al*., 2009). Dissolved oxygen levels measured in the Sakumono, Mukwe, Gao and Laloi lagoons were averagely around 2.64 mg/l, 3.14 mg/l, 4.34 mg/l and 5.17 mg/l respectively.

In the United States of America, studies relating to water quality classify the minimum required concentrations for dissolved oxygen in lagonal water to be in the range of 5 mg/l to 6mg/l (EPA-Washington, 2009). This is also in line with dissolved oxygen standard provided by the World Health Organization (Enderlein & Peter, 1996). Studies by Tay *et al* (2010) and Agbemehia (2014) in the Sakumono II lagoon reported DO values of around 6.1 mg/l and 4.36 mg/l respectively.

Comparing these two past studies to this current study, it depicts that the lagoon is becoming anoxic with time. Addo *et al* (2012) reported dissolved oxygen between 2.08mg/l and 3.65mg/l in the Mukwe lagoon. This is in line with the dissolved oxygen measurements gathered from this study. Low dissolved oxygen concentrations cause aquatic organisms to perish in lagoons (Kamer *et al*., 2004; Minnesota Pollution Control Agency, 2009). However, in the Sakumono II and Mukwe lagoons since few fishes were being harvested from the lagoon during the period of this study. This therefore suggests that some fish species can survive the harsh conditions in these lagoons. Past studies in the Laloi lagoon reported DO values of 4.7 mg/l and 5.2 mg/l (Badu Borteley, 2012). These values are close to the current values which is around 5.17 mg/l. This therefore suggests that the dissolved oxygen concentration in some parts of the Laloi lagoon is within the WHO permissible range. The Laloi lagoon has been classified as one of the less polluted lagoons in Ghana with high biodiversity (Armah 2001).

Low dissolved oxygen concentration recorded from the Sakumono II, Mukwe and the Gao lagoons can be as a result of algal growth caused by phosphorus and nitrogen in the water column. It can also be as a result of the level of biological respiration or pollutants from land based runoff (Addo et al., 2012).

5.1.3 Temperature

Mean temperature values recorded in the Sakumono II, Mukwe, Gao and Laloi lagoons were 29.7°C, 29.9°C, 29.6°C and 27.9°C respectively. Disparities in temperature values can be as a result of 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). This shows the mean temperature recorded in the Sakumono II, Mukwe and Gao lagoon was above the EPA permissible range except for Laloi lagoon. In the Sakumono II lagoon, past studies by Leeuwen *et al.* (2018), Tay *et al.* (2010) and Beatrice (2013) recorded mean temperatures of 29.6°C, 29.8°C and 30.4°C. Temperature in an aquatic system is necessary for oxygen solubility, therefore high temperature will lead to low oxygen concentrations in these lagoons. Past studies conducted by Badu Borteley (2012) in the Laloi lagoon reported a temperature of 27.1°C. Addo *et al.* (2012), reported temperatures in the range of 29.5°C to 32.3°C in the Mukwe lagoon and concluded that these high temperatures could be part of the reason why fish stock was low.

5.1.4 Total Dissolved Solids (TDS)

The Total Dissolved solids in an aquatic system is summation of all the inorganic and organic composite of the system or it can also be described as the addition of all the cations and anions in an aquatic system (Daniel, 1988). Miraj *et al.* (2017) suggested that high TDS levels in aquatic systems could result from high levels potassium, chlorides and sodium all of which are caused by anthropogenic activities. Measured values of TDS in Sakumono, Mukwe, Gao and Laloi lagoons were in the ranges of 1270 to 1460 mg/l, 2690 to 17500 mg/l, 17200 to 23600 mg/l and 1650 to 2640 mg/l respectively. Ghana's EPA acceptable rating for TDS in an aquatic system is 500mg/l. Comparing EPA to the USEPA standards, there is a great difference. USEPA permissible limit for TDS in estuarine or open lagoon systems is 2000 mg/l (Onojake *et al*., 2017). This therefore suggests that all the lagoons have values above Ghana's EPA acceptable limit but Sakumono and Laloi lagoons are within the USEPA permissible limit.

Past studies in the Sakumono lagoon by Agbemehia (2014) reported higher TDS values of around 3601.42 mg/l. This can be as a result the difference in the calibration of the Probe used for that study and this present study or it can also be as a result of increased anthropogenic activities around the lagoons.

In Sri Lanka, studies done in the Thamirabarani Estuary revealed that TDS measurements were in the ranges of 144 to 64600 mg/l. The study further went ahead to show that there is a positive correlation between Total Dissolved Solids and pH values. High TDS indicates high alkalinity content in a waterbody (Arockia & Devaraj, 2014). High TDS values may also result from heavy rainfall since there is a lot of water inflow from farmlands (Arockia & Devaraj, 2014). TDS in aquatic systems come from natural sources, runoffs from land as well as sewage and other effluents from industries (World Health Organization (WHO), 1996).

5.2 Nutrient Load

Phosphorus, nitrate and ammonia were the nutrients measured in the water samples. These nutrients were chosen because they give an indication of considerable human activity that impacts the lagoons (Mensah & Biney, 2008).

5.2.1 Phosphate (PO_4^{3-}).

Phosphate is known to control primary productivity in a lagoonal system because it is a limiting factor in the growth of algae (Goucher & Maas, 2014). High presence of phosphorus in a lagoon shows considerable anthropogenic intervention (Addo *et al*., 2011). Phosphate measurements for Sakumono lagoon during the dry season and rainy season were the ranges of 0.8 to 9.6 mg/l and 0.1 and 1.7 mg/l respectively. PO_4^{3-} measurements for Mukwe lagoon during the dry season and rainy season were in the ranges of 1.2 to 14.8 mg/l and 0.4 to 16.9 mg/l respectively. PO_4^{3-} measurements for Gao lagoon during the dry season and rainy season was between the ranges of 0.73 to 5.79 mg/l and 0.1 to 4.7 mg/l respectively. PO_4^{3-} measurements for Laloi lagoon during the dry season and rainy season was between the ranges of 0.6 to 7.5 mg/l and 0.02 to 1.7 mg/l respectively. Ghana's EPA maximum permissible value for phosphate in aquatic system is 2.0 mg/l (Nartey *et al*., 2012). This suggests that phosphate levels in all the lagoons during the dry season and rainy seasons are above the EPA permissible limit except for Laloi, which has values within the acceptable EPA range during the rainy season.

Previous studies in the Sakumono lagoon by Tay *et al* (2010), Nartey *et al* (2012) and Agbemehia (2014) recorded phosphorus values of 0.585 to 2.924 mg/l, 0.805 to 5.125 mg/l and 0.32 to 4.1 mg/l respectively. Also, studies by Kwesi (2017) and Leeuwen *et al* (2018) in the Sakumono recorded phosphate values of 2.68 to 5.02 mg/l and 7.43mg/l respectively. Comparing phosphate level from this study to the levels from past studies shows an increasing trend of phosphate pollution in the Sakumono lagoon. In the Laloi lagoon past studies by Badu Borteley (2012), recorded phosphate values in the range of 0.07 to 1.98 mg/l. Comparing the (Badu Borteley, 2012) study to this current study, it shows the level of phosphate in the lagoon has increased. In the Mukwe lagoon, studies by Addo *et al* (2012) recorded phosphorus values within Ghana's EPA permissible range of 0.212 to 0.371mg/l. Comparing the results of Addo *et al*. (2012) to this study, there is evidence that phosphate values have increased over the years. High Phosphorus levels in Sakumono, Mukwe, Gao and Laloi lagoons indicate the presence of organic pollutants (fertilizers and faeces) in the lagoons.

5.2.2 Nitrate (NO_3^-)

Nitrate inputs in lagoons occurs through runoff of fertilizers from farmlands, septic tanks and city drains (MPCA, 2008). Nitrate is transported in the water column when it bonds with suspended sediments (Tang & Maggi, 2018). Nitrate measurements for Sakumono lagoon during the dry season and rainy season were in the ranges of 4 to 7.96 mg/l and 3.1 to 9.7 mg/l respectively. In addition, NO_3^- measurements for Mukwe lagoon during the dry season and rainy season was between the ranges of 2 to 15.9 mg/l and 3 to 19 mg/l respectively. Again, NO_3^- measurements for Gao lagoon during the dry season and rainy season were in the ranges of 3 to 8.2 mg/l and 0.2 to 12 mg/l, while those for Laloi lagoon were in the ranges of 3.3 to 6.4 mg/l and 0.3 and 7 mg/l. Ghana's EPA permissible limit for nitrate in an estuarine system or open lagoons is 0.1mg/l (Nartey *et al*., 2012). Thus, this suggests that all the lagoons are above the permissible limits. Previous studies in the Sakumono lagoon by Tay *et al.,* (2010), Nartey *et al.*, (2012) and Agbemehia (2014) recorded nitrate levels in the ranges of 0.334 to 0.851mg/l, 0.025 to 0.047 mg/l and 2.53 to 8.5 mg/l, respectively. More recent studies by Kwesi (2017) and Leeuwen *et al* (2018) in the Sakumono lagoon recorded nitrate levels of 21.60 to 34.79 mg/l and 3 mg/l, respectively. In the Laloi lagoon past studies by Badu Borteley (2012) recorded nitrate values in the ranges of 0.30 to 5.2 mg/l. In the Mukwe lagoon, studies by Addo *et al.*, (2012) recorded nitrate values of 0.35 to 1.25 mg/l. Comparing the results of Addo *et al*., (2012) to the current study shows considerable increase in nitrate levels over the years.

Oxygen is needed to convert excess ammonia into nitrate (Tay et al., 2010; Leeuwen *et al*., 2018). Therefore, nitrate levels are expected to increase when there is enough oxygen in the lagoon. As observed by Nartey *et al.*, (2012), this study also showed that nitrate levels are relatively higher in the rainy season than in the dry season, suggesting that rapid mixture of sub-surface and surface water occur during the rainy seasons (Kwesi, 2017).

5.2.2 Ammonia (NH_3)

Anthropogenic activities result in the input of ammonia into waterbodies. Ammonia is toxic. Nitrate in an estuarine systems is always changed into ammonia and then assimilated into amino acids in organisms (Ozcoasr, 2019).

Ammonia measurements for Sakumono lagoon during the dry season and rainy season were in the ranges of 1.5 to 33 mg/l and 0.3 to 8.56 mg/l respectively. NH_3 measurements for Mukwe lagoon during the dry season and rainy season were in the ranges of 16 mg/l to 80.2 mg/l and 0.5 to 60.4 mg/l, respectively. In the Gao lagoon, NH_3 measurements during the dry season and the rainy season were in the ranges of 3 to 11.5 mg/l and 0.5 to 14.5 mg/l, respectively. NH_3 measurements for Laloi lagoon during the dry season and rainy season were the ranges of 2.2 to 5.7 mg/l and 0.03 to 7.3 mg/l, respectively.

Ghana's EPA and USEPA acceptable limit for ammonia in an estuarine system is 1.5 mg/l and 0.02 respectively (Nartey *et al*., 2012;USEPA, 2014). This therefore suggests that the Sakumono, Mukwe, Gao and Laloi lagoons are above Ghana's EPA and USEPA permissible limits.

Previous studies in the Sakumono lagoon by Nartey *et al*., (2012), Agbemehia (2014) and Leeuwen *et al* (2018) recorded nitrate levels between the ranges of 0.992 to 5.653, 0.53 to 7.85 mg/l and 26.8 and 32.8 mg/l respectively.. High levels of ammonia in the lagoons and relatively low nitrate values indicate that dissolved oxygen levels available are not enough to convert ammonia into nitrate (Leeuwen *et al*., 2018).

5.3 Discharge rates

Water and sediment discharge are important features in the normal functioning of every aquatic system. It helps in the rejuvenation of the aquatic system by helping to expel waste from the water column, thereby improving the water quality of the system (Rantz, 1982; Stewart, 2015). Calculating the discharge rates of a lagoonal or an estuarine system helps coastal managers to proper manage these waterbodies (Stewart, 2015).

5.3.1 Water Discharge Rate

Water discharge rates measured in the Sakumono lagoon during the dry and the rainy season were 0.002 m^3/s and 0.04 m^3/s, respectively. Measured water discharge rates for the Mukwe lagoon during the dry and rainy season were 0.01 m^3/s and 0.08 m^3/s, respectively. Again, measured water discharge rates for the Gao lagoon during the dry and rainy season were 0.007 m^3/s and 0.05 m^3/s, respectively. In the Laloi lagoon, water discharge rates measured during the dry and rainy season were 0.02 m^3/s and 0.09 m^3/s, respectively. Discharge rate calculations suggest that the Laloi lagoon discharges faster, followed by the Mukwe lagoon and then the Sakumono lagoon and lastly the Gao lagoon. That is (Laloi > Mukwe > Sakumono > Gao). The reason for this order could be as a result of the width of the lagoons as well as the shape of the basin. The wider the lagoon the faster the rate of discharge and the deeper it is (Meals & Dressing, 2008). Also lagoons with wider mouth have faster discharge rates (Miththapala, 2013).

In Sri Lanka, a ten year study by Gunaratne *et al.*, (2010) in the Rekawa lagoon measured water discharge rates to be in the range of 0.003 m^3/s to 0.139 m^3/s with a negative tidal net discharge (total outflow runs towards the sea). The study further suggested that the discharge rate was slower and therefore caused more sedimentation. The discharge rates of the Rekawa lagoon and that of the lagoons under this study have similar discharge rates. Sorensen *et al.*, (2003) and Agbemehia (2014) reported that most lagoon in Ghana have high sediment deposition rate.

5.3.2 Sediment Discharge

Mean sediment discharge was calculated using the instantaneous suspended sediment discharge formula (Boateng *et al.*, 2012). In the Sakumono lagoon average sediment discharge rate for the study period for ammonia, nitrate and phosphate was 0.00000399 m^3/s, 0.00000133 m^3/s and 0.0000000143 m^3/s respectively. Sediment discharge rates in the Mukwe lagoon for ammonia, nitrate and phosphate was 0.0000377 m^3/s, 0.0000126 m^3/s and 0.00000131 m^3/s respectively. In the Gao lagoon, sediment discharge rate for ammonia, nitrate and phosphate was 0.000021 m^3/s, 0.0000073 m^3/s and 0.0000000746 m^3/s respectively. Sediment discharge rates measured in the Laloi lagoon for ammonia, nitrate and phosphate was 0.00001624 m^3/s, 0.0000537 m^3/s and 0.0000000465 m^3/s respectively. From the instantaneous sediment discharge calculation, it is evident that sediment nutrient concentration has an effect on sediment discharge rate.

5.4 Model description

The Ecolab module in the MIKE 3 model was used to predict the nutrient concentration (phosphorus, ammonia and nitrate) in the water column for Sakumono and the Gao lagoon. In general the model gave good predictions though there were few over predictions from the model compared to the concentration from the spectrophotometer and this could be as a result of the calibration of the spectrophotometer (Reule, 2012) or the calibration of the model using fairly accurate rainfall and depth parameters.

Correlation analysis was strictly used to determine whether or not the modelled values were in line or direction with the measured values and not to measure the performance of the model. To access the performance of the model, the bias model measure was used.

5.4.1 Sakumono Lagoon

Analysis for the month of August and November showed a strong positive correlation between predicted and measured concentrations of ammonia and nitrate. Negative correlations of -0.92 and -0.91 were calculated in predicted and measured concentrations of phosphorus for the month of August and November 2019 respectively. This suggests that organic pollutants rich in phosphorus were introduced into the estuarine part of the lagoon thereby causing fluctuations in concentration of phosphorus. Analysis for the months of September 2018 and February 2019 showed strong positive correlation between predicted and measured concentration of ammonia, nitrate and phosphate. Analysis for December showed a strong positive correlation between predicted and measured concentration of ammonia and phosphorus but a negative correlation for nitrate concentration.

In setting up boundary conditions of the model, rainfall and bathymetric data are need for more accurate results. Using less accurate rainfall values and bathymetry measurement can cause over prediction or under prediction of nutrient concentration (DHI, 2019). This could result in negative correlation values of phosphorus calculated for the month of August and November.

A study by Borah *et al* (2004) which involved the use of the DWSM for sediment simulations in some Agricultural Watersheds in Illinois USA, recorded some discrepancies in prediction from the model. The study suggested that differences in model results was caused by model limitations and boundary condition values.

5.4.2 Gao Lagoon

Point sources were identified in the Gao lagoon so the model was calibrated to include those areas of the lagoon. Correlation analysis showed strong positive correlations between predicted and measured nutrients (ammonia, nitrate and phosphorus) for the month of February 2019, January 2019, December 2018, November and September 2018. Likewise, in August 2018, there was a strong positive correlation between predicted and measured concentration of phosphorus and ammonia but it could be observed that, there was high nitrate fluctuation midstream of the Gao lagoon. This therefore caused nitrate measurement to have a negative correlation. This fluctuation could be as a result of the introduction of a nitrate rich substance into the lagoon which could be as a result of a runoff from a farm or domestic waste (MPCA, 2008).

5.5 Model Performance

The model performance shows functioning of a particular model (Willmott et al., 1982). How well a model performs can be determined with the use of statistical tools to investigate if there is significant difference between predicted model values and the actual value. In this study the Bias model measure approach was used to check the performance of MIKE Zero model. A study by Lemke *et al.*, (2017) stipulated that when the percentage bias of a model is less that 20%, the model is considered to have performed well. Percentage bias for ammonia, phosphate and nitrate were -0.05%, 1.71% and 2.65% respectively. Though there were some few overpredictions which resulted from calibration, all of the percentage bias values are less than 20% and hence the model performed well in predicting nutrient quality.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

From this study, physicochemical parameters (Temperature, pH, dissolved oxygen), discharge rates for water and sediment and nutrients (nitrate, phosphate, and ammonia) concentrations were analyzed in water and sediment samples from the Mukwe, Sakumono, Gao and Laloi Lagoons. Sampling was done over a period six months, from August 2018 to February 2019 to cover both the dry and rainy seasons. Measurements obtained from this study was compared to Ghana's EPA, USEPA and WHO permissible limits. Most of the measured results from this study (example phosphate concentration in the Sakumono II, Mukwe, Gao and Laloi lagoons) were higher (during the dry and rainy seasons) than the permissible limits of the aforementioned institutions which suggests that these lagoons are all polluted. Results from this study were also compared to accessible literature from previous studies. There was evidence that the water quality was poor and a trend showing increasing poor water quality as the years go by. This will affect the normal biological functioning of the lagoon system as well as the biodiversity. Measured pH values in the Gao and Laloi lagoon were within the EPA permissible limits whilst pH of the Sakumono and Mukwe lagoon were above Ghana's EPA permissible limit. This suggests that there is relatively high anthropogenic influence (farming) around the Sakumono and Mukwe lagoon. Total Dissolve Solid measurement measured showed that Total Dissolved Solid levels for all the lagoons were above the EPA permissible limits. Ammonia measurements for Mukwe, Sakumono and Gao lagoon were high with relatively lower nitrate concentrations which suggested that oxygen level needed to convert ammonia to nitrate was slow and therefore when oxygen concentration increases nitrate concentrations are expected to go up. This further suggests that objectives 1 and 2 have been achieved.

Objective 3 was successfully achieved by calculating sediment discharge rates as well as water discharge rates using the instantaneous sediment discharge formula and water discharge formula. It was observed that sediment nutrient concentration had an effect on the rate of sediment. Water discharge rates measured indicated that lagoon discharge rates were little during the dry season and relatively high during the rainy season. Also, there was evidence that sedimentation in Ghana lagoons which could be linked to the relatively low water and sediment discharge rates.

The Mike 3 model used to predict nutrient concentrations for the Sakumono and Gao lagoon showed strong positive correlation between predicted modelled results and results from the spectrophotometer with few negative correlations for phosphorus prediction in the Sakumono lagoon for August 2018 and November 2018. Likewise, in the Gao lagoon there was a negative correlation of nitrate in the month of August 2018 which suggest that pollutants were released specific parts of the lagoons thereby causing discrepancies in model prediction.

Correlation analysis was just used to determine whether predicted values were in line with measured values but not used to determine the performance of model. The bias model measure was however used to determine if the model performed or not. The percentage of bias value was less than 20% which suggested that the model performed well generally even though there were some few discrepancies. Indicating that objective 4 of the study has been achieved.

6.2 RECOMMENDATION

Based on the conclusion of the study, it is recommended that farming activities around the catchment areas of these lagoons should be discouraged inorder to prevent nutrient loading. Also, industries which are close to the lagoons or within the catchment should be advised to treat waste waters before discharging it into rivers or streams which end up in the lagoons. Municipal assemblies should find better ways of treating and discharging domestic waste so that it does not end up in lagoon waters. Again, mangrove harvesting in the lagoons should be discouraged because mangroves helps to hold the soil together thereby preventing siltation. Re-channelling of freshwater feeding the lagoons should be discouraged because freshwater input into lagoon waters helps in increasing oxygen levels.

Rainfall and bathymetry data used for calibrating the boundary conditions should have less errors to help make better predictions. It is also recommended that subsequent studies should be done over a longer period to understand the dynamics that exist in these lagoons systems better. Lastly, different flow models should be used to assess water quality inorder to make good comparisons of the lagoons.

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APPENDICES

APPENDIX A: Mean physico-chemical parameters measured in Sakumo II, Mukwe, Gao and Laloi lagoon during the study period.

SITE CODE	LAT	LONG	TDS mg/l	PH	SAL (ppt)	TEMP (°)	NTU	DO mg/l	ms/cm
S1	5.614446°N	0.031466°W	1270±78.02	7.83±0.17	0.5±2.07	29.7±1.19	59±9.02	2.34±0.27	1.78±0.23
S2	5.614361°N	0.031492°W	1370±74.21	8.14±0.19	1±1.17	28.4±1.18	49.6±7.21	2.57±0.25	1.99±0.21
S3	5.614106°N	0.031550°W	1330±79.24	8.45±0.14	1.3±1.14	30.2±1.25	83±9.07	2.64±0.31	2.28±0.17
S4	5.614013°N	0.031553°W	1445±78.14	9.42±0.21	5±2.11	27.9±1.23	38±9.24	2.77±0.33	1.94±0.24
S5	5.613969°N	0.031524°W	1460±77.2	9.82±0.15	34±1.09	27.4±1.20	13.3±8.62	3.12±0.25	2.3±0.27
M1	5.609392°N	0.05612°W	2690±78.5	8.66±0.19	1.6±2.18	29.9±0.91	139±9.78	3.76±0.31	3.04±1.21
M2	5.609164°N	0.05598°W	5870±79.4	8.45±0.24	2.2±1.20	28.7±0.97	93.8±9.89	3.14±0.21	4.2±1.25
M3	5.609054°N	0.05571°W	10340±4124	9.28±0.12	17.4±2.14	28.8±1.12	78.6±9.77	3.24±0.27	28.2±1.08
M4	5.608424°N	0.05554°W	17500±4001.12	9.38±0.15	15.9±2.16	30.7±1.08	89.4±9.87	3.34±0.23	26.1±1.24
M5	5.608244°N	0.05514°W	17470±425.14	9.41±0.18	35.3±1.11	28.7±1.04	22.9±9.45	3.87±0.34	26.7±1.28
L1	5.696178°N	0.067156°E	1650±347.214	7.8±0.16	2.5±2.12	27.9±0.61	20.5±9.04	5.870.64	4.76±0.7
L2	5.696825°N	0.069921°E	1950±337.23	6.84±0.14	1.6±2.15	27.6±0.53	36.9±9.23	6.75±0.61	3.02±0.74
L3	5.695529°N	0.070610°E	2340±388.15	6.77±0.14	1.6±2.17	26.4±0.47	35.2±8.5	6.16±0.35	3±0.64
L4	5.694425°N	0.070218°E	2341±382.21	6.74±0.18	1.7±2.12	26.8±0.51	28.2±9.21	6.43±0.62	3.24±0.66
L5	5.673425°N	0.070018°E	2640±376.54	8.6±0.23	1.3±2.08	27.1±0.42	39.5±7.23	8.21±0.57	2.58±0.7

G1	05.682559°N	0.041809°E	17200±227.21	6.64±0.17	24.5±2.17	29.4±0.49	49.1±3.08	4.34±0.52	38.1±2.3
G2	05.672605°N	0.042377°E	19300±214.5	6.88±0.21	19.2±2.17	29.6±0.47	49±3.12	3.21±0.51	30.9±2.75
G3	05.672176°N	0.043043°E	21340±237.9	6.95±0.11	26±2.21	28.4±0.51	47±3.23	3.45±0.47	40.7±2.54
G4	5.671131°N	0.042881°E	23540±204.51	7.02±0.13	17±2.14	29.1±0.47	44.1±3.08	3.78±0.52	27.7±2.51
G5	05.67134°N	0.04378°E	23600±214.20	7.23±0.15	24.2±2.15	28.7±0.44	42.1±3.23	4.34±0.5	38.2±2.21

APPENDIX B: Measured Spectroscopy Data and Predicted Values from MIKE 3 For Sakumono and Gao lagoon

Sample Area	NH3 (measured)	NH3 (modelled)	PO4 (measured)	PO4 (modelled)	NO3 (measured)	NO3 (modelled)
AUGUST						
S1	4.47	4.94	1.7	1.687	9.5	9.306
S2	4.44	4.91	1.7	1.677	9	9.268
S3	3.46	4.7	1.9	1.607	8.5	8.95
S4	3.4	3.17	2.1	1.081	8.5	6.077
SEPTEMBER						
S1	12.6	12.86	0.8	0.88	3.3	3.3
S2	12.4	12.8	0.88	0.88	3.22	3.29
S3	12.1	12.77	0.93	0.9	3.21	3.26
S4	11.65	12.7	0.98	0.9	3.18	2.26
NOVEMBER						
S1	5.6	5.64	0.6	0.8	2.9	2.8

S2	5.6	5.64	0.66	0.77	2.9	2.8
S3	4.3	5.63	0.7	0.7	2.84	2.75
S4	3.2	5.62	0.7	0.7	2.78	2.74
DECEMBER						
S1	27.5	27.59	6.9	7.16	3.07	3.17
S2	27.3	27.57	6.9	7.18	2.13	3.21
S3	27	27.53	7.8	7.18	2.47	3.23
S4	24	27.52	7.8	7.21	2.3	3.24
JANUARY						
S1	23.4	23.58	7.9	8.25	3.07	3.14
S2	24.1	23.59	7.9	8.3	2.13	3.16
S3	22.56	23.56	8.8	8.4	3.10	3.17
S4	22.2	23.54	8.8	8.24	3.16	3.19

FEBRUARY						
S1	26.7	23.098	9.66	9.539	2	2.19
S2	33.02	23.099	9.66	9.535	2.03	2.20
S3	24.1	22.097	9.4	9.534	2.14	2.24
S4	21.3	22.095	9.3	9.5	2.17	2.26

Sample Area	NH3 (measured)	NH3 (modelled)	PO4 (measured)	PO4 (modelled)	NO3 (measured)	NO3 (modelled)
AUGUST						
G1	0.54	0.57	0.95	0.95	8.1	8.5
G2	0.53	0.55	0.95	0.83	12	8.5
G3	0.52	0.51	0.58	0.74	12	7.6
G4	0.5	0.47	0.5	1	8.5	6.077
SEPTEMBER						
G1	5.5	5.5	0.09	0.09	0.33	0.35
G2	5.4	5.3	0.09	0.07	0.32	0.33
G3	4.3	4.5	0.1	0.06	0.2	0.3
G4	4	4.1	0.07	0.04	0.2	0.28
NOVEMBER						
G1	5.3	5.3	1.66	1.68	4.2	4.4
G2	5	5.1	4.7	4.83	4.2	4.2
G3	4.1	4.7	4.65	4.75	3.1	3.8
G4	3	4.4	4.44	4.73	2.8	3.4

DECEMBER						
G1	8.2	8.3	0.94	0.95	3.4	3.4
G2	8.1	8.1	0.93	0.93	3.2	3.3
G3	5.3	7.8	0.92	0.85	3.2	3.1
G4	5	7.4	0.84	0.83	2	2.8
JANUARY						
G1	6.8	6.8	0.94	0.96	4.4	4.7
G2	6.5	6.6	0.93	0.93	4.5	4.6
G3	3.7	4.4	0.82	0.85	4.5	4.2
G4	3	3.7	0.73	0.81	4	4
FEBRUARY						
G1	4.6	4.7	4.32	4.4	4.8	4.8
G2	4.6	4.6	4.3	4.3	4.8	4.7
G3	4.4	4.4	1.15	4.1	4.8	4.7
G4	4.1	4	1.12	3.7	4.8	4.4

APPENDIX C: Mean sediment nutrient levels in the Gao lagoon during period of study.

			NUTRIENT (DRY SEASON)				NUTRIENT (WET SEASON)		
SITE	LAT	LONG	NH3	N03	%TP		NH3	N03	%TP
G1	5.672026	0.042366	4.97	4.19	1.8		4.57	3.76	1.5
G2	5.672326	0.04293	4.83	4.01	1.6		4.48	3.55	1.47
G3	5.671574	0.042742	4.75	3.98	1.3		4.34	3.45	1.3
G4	5.671053	0.04278	4.24	3.74	1.3		4.31	3.45	1.04
G5	5.67114	0.042832	4.13	3.21	1.1		3.87	3.07	0.8

APPENDIX D: Python Script for showing distribution pattern in lagoons

```
# -*- coding: utf-8 -*-
"""
Created on Fri Apr 19 14:24:53 2019

@author: Mykel.
"""

import netCDF4 as nc
import os
import numpy as np
```

```
import matplotlib.pyplot as plt
from matplotlib import cm
import shapefile
import imageio


files = os.listdir(r"C:\Users\Nana K\Desktop\phosp\raw")

water_boundary = shapefile.Reader(r"C:\Users\Nana K\Desktop\phosp\shapefile\Export_Output")
feature = water_boundary.shapeRecords()[0]
first = feature.shape.__geo_interface__
t_shape = first['coordinates']
Lons = []
Lats = []
months = {'Aug':'1', 'Sep':'2', 'Nov':'3', 'Dec':'4', 'Jan':'5','Feb':'6'}

#plt.figure()

for i in t_shape[0]:
    Lat = i[1]
    Lon = i[0]
    #print ('the coord for {} is - {}, {}'.format(x, Lat, Lon))
    Lons.append(Lon)
    Lats.append(Lat)

for filename in files:
    plt.figure()
    print (filename)
    content = nc.Dataset(r"C:\Users\Nana K\Desktop\phosp\raw\\" + filename)
    data = content.variables['data']
    x = content.variables['longitude']
    y = content.variables['latitude']
    plt.contourf(x[:330], y[:281], data[:281,:330], cmap = cm.YlOrBr) # :269,:371
```

```
    titles = ['August 2018', 'September 2018','November 2018', 'December 2018', 'January 2019', 'February 2019']
    title = str(filename[:3])
    for gt in titles:
        if gt.startswith(title):
            title = gt
    plt.title(title)
    plt.colorbar()
    plt.plot(Lons, Lats, 'r-')
    save_name = months[filename[:3]]
    plt.savefig((r"C:\Users\Nana K\Desktop\phosp\results\\"+save_name))

print ("making gifs . . .")
images = os.listdir(r'C:\Users\Nana K\Desktop\phosp\results')
gif_files = []
for image_filename in images:
    if image_filename != 'Thumbs.db':
        print (image_filename)
        gif_files.append(imageio.imread(r'C:\Users\Nana K\Desktop\phosp\results\\'+image_filename))
kargs = {'duration':3}
imageio.mimsave(r'C:\Users\Nana K\Desktop\phosp\mykil.gif', gif_files , **kargs)
```