UNIVERSITY OF CAPE COAST

A MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR MANAGEMENT OF COASTAL LAGOONS IN GHANA – A CASE STUDY OF THE FOSU LAGOON, CAPE COAST

REBECCA KYEREWA ESSAMUAH

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BY

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Thesis submitted to the Department of Fisheries and Aquatic Sciences of the School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of a Doctor of Philosophy degree in Integrated Coastal Zone Management.

OCTOBER, 2020

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:.. Date:..........................

Name: Rebecca Kyerewa Essamuah

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:................................... Date:........................

Name: Prof. Denis W. Aheto

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Name: Dr. Emmanuel Acheampong

ABSTRACT

A Decision Support System (DSS) tool as an analytical advancement of multiple indicators was adapted to give a synoptic yet holistic view of issues confronting coastal lagoons in Ghana for decision making. This study developed and demonstrated multi-criteria effects of a DSS on a heavily pressured urban coastal lagoon, Fosu lagoon in the Central Region of Ghana, from November 2016 to December 2017. The study involved a review of selected *in situ* records and analysis of water and sediment parameters; spectrophotometric analyses of limiting nutrients, chlorophyll-a, and heavy metals; biotic assessments of the size classes of the dominant *Sarotherodon melanotheron*, avifaunal biodiversity, and bacterial counts; and remote sensing of land-use patterns using unmanned aerial vehicle (UAV) imagery. A review of relevant regulations and an institutional network analysis in support of Integrated Coastal Zone Management (ICZM) in Ghana were done. Up to 19% of migratory birds were encountered. The resident African darter, *Anhinga rufa*, constituted the top piscivorous birds. Digital Elevation Model (DEM) analysis of watershed identified major point sources of pollution and 17% of human encroachment within the regulatory 30m buffer width. Infographic outputs showed ecological health state increased from about 33% to 74% and 78% on addressing priority areas of sustainable resource use and water quality restoration, respectively. It is recommended that a designated policy on Coastal Zone Management should focus on ecological health, with lead organizations such as the Environmental Protection Agency (EPA) and Coastal Development Authority (CODA) tasked to coordinate collaborative and intersectoral management.

KEYWORDS

avifaunal biodiversity

coastal lagoon

decision support system (DSS)

ecological health

Integrated Coastal Zone Management (ICZM)

unmanned aerial vehicle (UAV)

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DEDICATION

To my youngest son – Penkyer, who is as old as this work!

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LIST OF ABBREVIATIONS

AEWA – African-European Waterbird Agreement

AHP – Analytical Hierarchy Process

AIC – Akaike Information Criterion

CCMA – Cape Coast Metropolitan Assembly

CCM – Center for Coastal Management

CICES – Common International Classification of Ecosystem Services

CODA – Coastal Development Authority

COSMO – Coastal Zone Simulation Model

CRC – Coastal Resources Center

CRMP – Coastal Resource Management Program

CS – Conservation Status

CSIR – Council for Scientific and Industrial Research

CWA – Clean Water Act

CWQI – Canadian Water Quality Index

DANIDA – Danish International Development Agency

dB – decibels

DEM – Digital Elevation Model

DESYCO – Decision Support System for Coastal Climate Change

DITTY – Information technology tool for the Management of Southern European Lagoons.

DO – dissolved oxygen

DPSIR – Driver-Pressure-State-Impact-Response

DSS – Decision Support System

EAP – Environmental Action Plan

EBM – Ecosystem-Based Management

EJ – environmental justice

EPA – Environmental Protection Agency

EPC – Environmental Protection Council

EQIs – Environmental Quality Indices

ESRI – Environmental Systems Research Institute

EU WFD – European Union Water Framework Directive

FG – foraging/feeding group

GAEC – Ghana Atomic Energy Commission

GCLME – Guinea Current Large Marine Ecosystem

GEF – Global Environmental Facility

GIS – Geographic Information System

GPRS – Ghana Poverty Reduction Strategy

GSS – Ghana Statistical Service

GVT – Vulnerability Tool

HP – Habitat Preference

ICZM – Integrated Coastal Zone Management

IUCN – International Union of Conservation of Nature

IPCC – Intergovernmental Panel on Climate Change

LC – Least Concern (on IUCN list)

LMC-DSS – Lagoon Multi-Criteria Decision Support System

MA – Millennium Ecosystem Assessment

MCDA – Multi-Criteria Decision Analysis

MDGs – Millennium Development Goals

MESTI – Ministry of Environment, Science, Technology, and Innovation

MMDAs – Metropolitan, Municipal and District Assemblies

MS – Migratory Status

MTDPs – Medium Term Development Plans

MWRWH – Ministry of Water Research, Works, and Housing.

NADMO – National Disaster Management Organization

NEMC – National Environmental Management Council

NEP – National Environment Policy

NEPAD – New Partnership for Africa's Development

NGOs – non-governmental organizations

NOAA – National Oceanic and Atmospheric Administration

NTU – Nephelometric Turbidity Units

OECD – Organization for Economic Co-operations and Development

PAHs – polyaromatic hydrocarbons

PCA – Principal Component Analysis

pH – potential of hydrogen (a measure of acidity or alkalinity)

ppm – parts per million

PSU – practical salinity units

RAMCO – Rapid Assessment Module for Coastal Zone Management

RCS – Ramsar Classification System

RCU – Regional Coordinating Unit

RRA – Regional Risk Assessment

SDI – Sustainable Development Index

SIDA – Swedish International Development Agency

SL – standard length

SNA – Social Network Analysis

SP – Spatial Planning

SS – Spatial Solutions

SSAS – suspended solids and sediment studies

TL – total length

TLI – Trophic Level Index

TRVs – Toxicity Reference Values

TSI – Trophic Status Index

TVA – Tennessee Valley Authority

UAV – unmanned aerial vehicle

UCINET – Comprehensive Social Network Analysis Software Program

UNDP – United Nations Development Program

UNIDO – United Nations Industrial Development Organization

US EPA – United States Environmental Protection Agency

USAID – United States Agency for International Development

WM – watershed management

WQI – Water Quality Index

WQI_{GH} – Adapted Solway Index by Ghana Water Research Institute

WQI_{min} – Water Quality Minimal Index

WQI_{moc} – Water Quality Index Based on Minimum Operator Concept.

WQI_{nsf} – Water Quality Index by National Sanitation Foundation

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Ghana is a West African nation with a coastline stretch of about 550km enriched with several unique coastal ecosystems (Armah & Amlalo, 1998; Nixon et al., 2007). The topography varies distinctly over four coastal regions namely; Volta, Greater Accra, Central and Western Regions, with the Central Region having the longest coastline of 150km. Two major wet and dry seasons occur along the coastal area with combinations of savannah to forested vegetation types. Dense human populations concentrate within the coastal areas of Ghana (Armah, 2005), where there is an increasing reliance on coastal resources and related activities for livelihood (Aheto, Mensah, Okyere, & Aheto, 2011; Baffour-Awuah & Tenkorang, 2014). Through fishing, farming, recreation, tourism, industrial and residential development, the coastal zone ecosystems in Ghana, like many parts of the world, are heavily pressured (Lawson, Schluchter, & Gordon, 2010).

Among many coastal zone ecosystems in Ghana are about 90 coastal lagoons which are characteristically associated with shallow depths of less than $0.5km^2$, and permanently or intermittently opened to the ocean (Armah & Amlalo, 1998). Coastal lagoons are considered as inadequately managed wetlands by virtue of their non-consumptive uses, whereby these coastal lagoons are not relied on for the provision of portable water but as; fisheries sites, means of transportation, tourism sites, floodwater collection areas, and units for ecosystem functions (Yeleliere et al., 2018). Further deepening the threats of unsustainably managed coastal lagoons is the process of urbanization.

Barau and Ludin (2012) have characterized the 21st century as strongly influenced by urbanization and globalization. Urbanization has been identified as a major anthropogenic cause of change in biodiversity and deplorable states of coastal environments (Celliers & Ntombela, 2014). Consequently, increasing urbanization in developing countries like Ghana leads to pollution, eutrophication, and the degradation of natural habitats, compounded by global events such as climate change, which compromise the quality of water and functioning of ecosystems owing largely to a lack of inadequate wastewater treatment (Edokpayi, Odiyo, & Durowoju, 2017). Cape Coast, the capital of the Central Region, which is of interest to this study, falls under the jurisdiction of the Cape Coast Metropolitan Assembly (CCMA). With a regional population of about 2,107,209 within its 9,826km^2 area, low development of social facilities, high rates of unemployment, poverty, and illiteracy are major concerns within the metropolis as identified through the 2010 national census survey (Ghana Statistical Service, 2015, 2019). Reports of weak implementation of environmental regulations are attributed to inadequate community participation in programme planning and management of resources (Armah, 2005). The chieftaincy rule in existence in the region is impeded in its governance roles through heavy urbanization and a mix of ethnic groups.

At the national level, a policy framework termed as the Ghana National Water Policy was designed in 2004 by the Ministry of Water Resources, Works and Housing (MWRWH) in collaboration with interest and stakeholder groups, with the intention to focus on integrated water management, provision of water, and adherence to international treaties and advocacy on trans-boundary aquatic systems (Ministry of Water Resources Works and Housing, 2007). One of such iconic international treaties included Chapter 40 of Agenda 21 which states, ‘‘indicators of sustainable development need to be developed to provide solid bases for decision making at all levels and to contribute to a self-regulatory sustainability of integrated environment and development systems’’ (United Nations Division for Sustainable Development, 1992). The National Water Policy for Ghana, however, appears anecdotal in its focus on non-consumptive sources of water such as coastal lagoons. The bias towards management of freshwater systems’ opens up gaps in achieving sustainability goals that emerge from strategies of the Ghana Poverty Reduction Strategy (GPRS), the Millennium Development Goals (MDGs), and the New Partnership for Africa’s Development’s (NEPAD) Africa Water Vision. Starkly, coastal lagoons which are classified as non-consumptive resources, require an integrated and multidisciplinary approach of management that is couched to their unique attributes to address issues confronting their utilization.

Few success stories of coastal management in developing coastal countries such as Ghana, stress the need for shifts in sectoral address of coastal management issues and re-alignment of governance to coordinate efforts through integration and cost-efficient measures of management (Olsen, Lowry, & Tobey, 1999). Integrated Coastal Zone Management (ICZM) is a concept identified as key in the realization of agencies’ collaboration and stakeholders’ participation to achieve objectives leading to sustainable exploitation and/or conservation of coastal ecosystem resources for posterity (Cicin-Sain, Knecht, Knecht, Jang, & Fisk, 1998). A common framework is, however, required across relevant sectors to address issues for a successful ICZM. Bertule et al. (2018) indicate six widely adopted conceptual frameworks for the purpose of ICZM i.e. Drivers-Pressure-State-Impact-Response (DPSIR); Ecological Health; Institutional Performance; Risk Assessment; System Vulnerability; and the Value and Threat Analysis.

1.2 Statement of the Problem

The multiplicity of interactive factors that lead to poor water quality, threats to fish growth and bird biodiversity, and unsustainable exploitation practices of coastal lagoons impress on the need to develop a more holistic assessment of the issues facing coastal lagoons. An ecological health assessment of coastal lagoons, which is needful to evaluate how capable coastal lagoon ecosystems are to support their functioning while providing sustainable benefits to communities and users, requires comprehensive studies. Several studies that have been undertaken to provide information towards monitoring and restoration of coastal lagoons in Ghana have been issue-based, thus, reflective of aspects of the ecosystem and not adequate to address problems that are multi-faceted.

An inadequate number of comprehensive studies on coastal lagoons have impeded decision-making on sustainable exploitation of coastal lagoon ecosystems as resources for development. There is a need to develop a tool which provides a synoptic view of ecological health for decision-makers by considering the multiple interacting factors of abiotic, biotic, and resource use.

A knowledge gap exists in documented reviews of the mandatory roles and collaborative network of relevant institutions in support of policy implementation and intersectoral management of coastal lagoons in Ghana. This cripples the efforts to realize ecological health improvement after assessments have been undertaken.

1.3 Purpose of the Study

The study attempts to develop a decision support system (DSS) as an ecological health assessment tool in ICZM of coastal lagoons in Ghana. Le Blanc (1991), defines DSS as computer-based information systems developed to tackle problems of varying facets. In the development of a decision support system (DSS), therefore, reliance is made on frameworks, indicators, and indices to reduce the ICZM challenge of a comprehensive information gathering and evaluation process. To be effective, the DSS developed will have the following advantages as identified by Janssen (1991) to:

a) support decision making by several individuals or stakeholder groups
b) aid the decisions taken to be representative of the collective agenda
c) enhance the process by avoiding overlaps in resource assessment.

In the development of a DSS, two main components are needed which are the framework and structure (Torresan et al., 2010). The framework component provides the user, several functions to enable assessment/evaluation of management issues under consideration whilst the structure component describes the available aspects of the ecosystem on basis of its features such as the indices and management policy options (Agostini et al., 2009). Through a display and 'options' set working area, any typical ICZM DSS tool gives a graphical display for issues of pollution, decline in fisheries, loss of aesthetic value, and poor land-use practices among many others, as sought in the present ecological health study. The Fosu lagoon is used as a case study based on the principle of catchments as a management unit of watersheds that drain an area of less than one square mile.

Selection of ecological health criteria for consideration in a DSS requires the identification of issues of concern through a DPSIR framework. The DPSIR framework idealizes real-time assessment using both numeric and narrative forms of issues descriptors to achieve outcomes that aid in the decision-making process. Figure 1.1 is an adapted framework of the heuristic concept of DPSIR as developed by its earlier proponent Canadian statistician Anthony Fried in the 1970s and enhanced by the Organisation for Economic Cooperation and Development (OECD). The DPSIR shown captures major common issues and their connectivity that have been associated with the deterioration of various coastal lagoons in Ghana (Keelson, 2011). The drivers (D) of coastal lagoon degradation are activities of natural/global or anthropogenic sources that generate pressures (P) that are known to change the states (S) of coastal lagoons due to cumulative stress. Wide variations in the impacts (I) that arise from such modifications in the state of the coastal lagoons may elicit responses (R) to reduce or prevent the pressures, restore or influence the state of the coastal lagoons, and to mitigate the impacts.

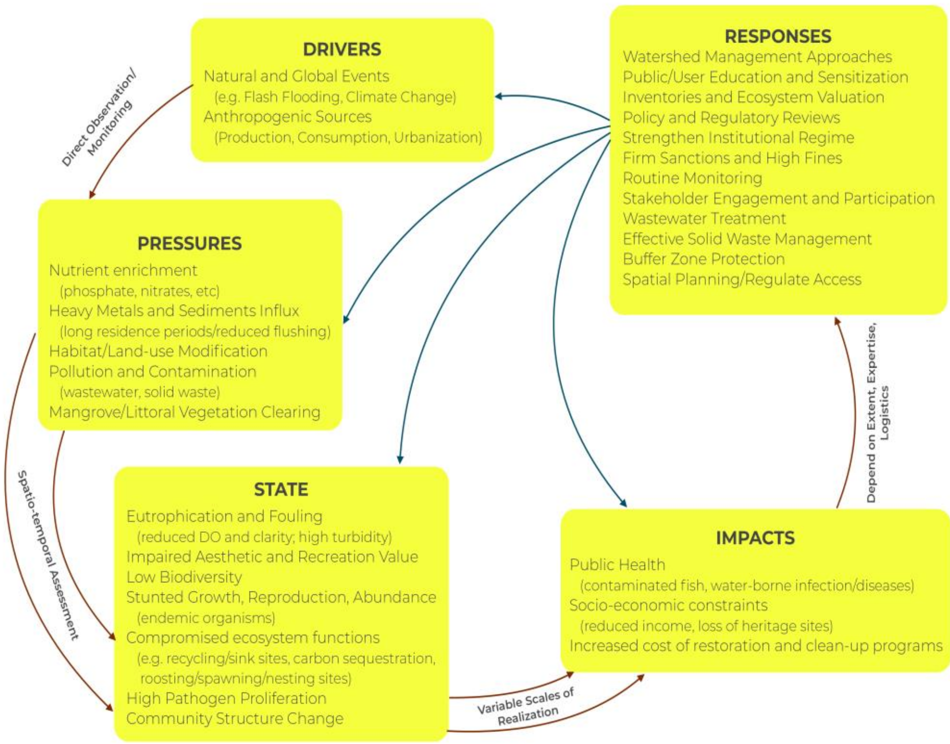


Figure 1.1 A DPSIR framework based on the heuristic concept with a focus on common major issues of coastal lagoons in Ghana (Mattas et al., 2014)

The multiple uses and drivers of coastal resources suggest that a developed DSS will require several inputs to realize objectives of sustainability as depicted in the DPSIR. The DSS is focused on the anthropogenic drivers (D) of coastal lagoons. Criteria of interest, which act as pressures (P), are broadly categorized as ‘Abiotic’, ‘Biotic’ and ‘Resource Use’ Criteria. Indicators, metrics, and indices values of these pressures determine whether they influence the state (S) within acceptable thresholds or otherwise. The status ultimately assigned to

Criteria in the DSS with regards to impacts (I) lead to suggested management options as responses (R) to improve the ecological health of coastal lagoons.

1.3.1 A case study of the Fosu Lagoon

Out of about 90 coastal lagoons found dotting the entire coastline of Ghana, some lagoons such as the Korle and Fosu lagoons are considered polluted because they receive huge volumes of wastewater, industrial contaminants, and municipal stormwater (Armah, Yawson, Pappoe, & Afrifa, 2010; Boadi & Kuitunen, 2002). In Ghana, these coastal lagoons play crucial roles traditionally as heritage sites. The people of Cape Coast (locally named, Oguaa) revere the Fosu Lagoon and celebrate their annual *Fetu Afahye* (festival) undertaking various rites such as breaching the lagoon to allow entry to the sea during every closed season month of August. The lagoon is also relied on as a source of subsistence fishing. The blackchin tilapia (*Sarotherodon melanotheron*) is a favoured delicacy irrespective of its stunted size (Blay & Asabere-Ameyaw, 2007) and studies indicating high levels of heavy metals and polyaromatic hydrocarbons (PAHs) (Akoto, Eshun, Darko & Adei, 2014; Gilbert, Dodoo, Okai-Sam, Essuman, & Quagraine, 2006).

Growing concerns on the ecological health status of the Fosu Lagoon (Armah, Luginaah, Kuitunen, & Mkandawire, 2012) are worth noting because irrespective of the lagoon being categorized as a ‘dead zone’ along with others such as the Korle and Chemu lagoons in the Greater Accra Region, it is still relied on for fishing and recreation among others (Akpabey & Amole, 2015). Characteristics of ‘dead zones’ such as dissolved oxygen deficits, low biodiversity, benthos instability, loss of aesthetic potential, fish mortality, silting, and high concentrations of pollutants negatively affect the functioning of coastal lagoons (Miththapala, 2016). Conflicting and competing uses of the Fosu lagoon have also contributed to the poor state of the lagoon and its benefits to communities and stakeholders (Obiri et al., 2011).

The Fosu lagoon which represents a typical anthropogenic pressured system within the urban settings of Ghana is, thus, selected for the research. It faces several challenges of water quality degradation (B. K. Owusu et al., 2013), littoral vegetation clearing (Armah et al., 2012a), over 90% single species fishery with stunted fish growth (Baffour-Awuah, 2014; Obodai, Okyere, Boamponsem, Mireku, Aheto, & Senu, 2011), runoff of untreated municipal waste (Baffour-Awuah, 2014; Mohammed, 1993) and conflicts in resource use (Essumang et al., 2006). The present research is centered on water quality, biological composition, and diversity, and resource use as drivers of ecological health, and the existing relevant coastal management policies and institutional setup to address issues of the Fosu Lagoon. For a more comprehensive ecological health assessment using a DSS, this present research seeks to add other dimensions to these conventional methods of assessments that were employed in the past.

1. For water quality, an added assessment of sediment quality which improves understanding of the water-sediment exchange phenomenon will be carried out. Jeppesen et al., (2005) have indicated that the primary contribution of nutrients from sediments to the overlying water in relatively shallow systems is key. Therefore, variables of sediment

particle sizes, organic content, and recycled nutrients, within certain physicochemical conditions which have been observed to control water quality and eutrophication events (Avramidis et al., 2013) will be included in a sediment quality assessment.

2. The study is also geared towards the inclusion of avifauna, regarded as major top predators of wetlands (Caro & O'Doherty, 1999), as biological components of the Fosu Lagoon. As highly specialized organisms, their use as biological indicators of ecological health allows levels of stressors to be ascertained, and to understand the suitability of the abiotic environment in the provision of their food and habitat (Ogden et al., 2014).
3. The study also attempts to highlight the need for a watershed delineation for all studies aimed at collecting information to address the complexity of issues on a broad-scale watershed level. A well-defined geographical and physical boundary characterizes the extent of management targets for activities that influence catchments as units of watersheds (Water Resources Management Study, 1998).
4. Finally, the study is intended to include an institutional framework analysis to expose gaps in collaborative roles needful for successful ICZM and to ensure that opportunities not yet realized for coastal lagoon management in Ghana are taken advantage of to achieve the goals of formulated policies and regulations.

1.4 Research Objectives

This research is primarily aimed towards developing a multi-criteria decision support system for ecological health assessment of coastal lagoons in urban areas of Ghana to aid prioritization of management options. The Fosu Lagoon is used as a case study.

The specific objectives are to:

i. determine the present water quality and trophic status of the Fosu Lagoon using selected physicochemical-based indices as a basis for monitoring programs essential in management practices.

ii. provide baseline information on sediment quality considering grain sizes, organic matter content, porosity, and selected heavy metals' concentrations.

iii. compare the growth sizes of blackchin tilapia (*Sarotherodon melanotheron*, Rüppell, 1852) with previous reports on this dominant fish in the Fosu Lagoon and the implications of heavy metals measured in water.

iv. provide an inventory on avifauna encountered, their biodiversity, abundance, functional attributes, and investigate the potential effects of noise and human presence on the abundance of birds.

v. evaluate land-use practices within the catchment that reflect on public and ecological health through bacteria loads, indiscriminate solid waste disposal, and littoral vegetation buffer zone encroachment.

vi. adopt and design a lagoon multi-criteria decision support system (LMC-DSS) for the present and future scenarios of ecological health state of the Fosu Lagoon.

vii. review and examine the institutional framework for relevant policy implementation of coastal lagoon resources management in Ghana.

1.5 Significance of the Study

This study emphasizes the important criteria required during information gathering, monitoring, and assessment for integrated management of coastal lagoons in Ghana. The focus on a proven set of parameters which feed into criteria from different aspects of the ecosystem is needful to reduce unnecessary inclusion of less definitive parameters. (Cicin-Sain et al., 1998) state that, “rarely does a single institution exist, at any level of government, with an overall responsibility” for the purpose of collecting a wide spectrum of necessary parameters for holistic assessment of coastal ecosystems. Existing sectoral efforts could be streamlined and enhanced with a focus on relevant parameters which feed into indicators that are verified to infer on the ecological health status of coastal lagoon ecosystems.

Bower, Ehler, and Basta (1994), reiterate that for consistency, a common adaptable framework with clearly defined focus areas should serve as a blueprint to encourage sustainable ICZM in solving similar multiple issues-based coastal resource use problems such as impaired water quality, low biodiversity, and unsustainable catchment practices as associated with many coastal lagoons. Information gathering to address these issues of concern include elements such as: the determination of the extent and sources of the problem; interactions of both natural and anthropogenic factors; effects of natural events such as climate change (which are more difficult to control); identification of conflicting uses; and the availability of funding, expertise, and commitment of the government. The latter of these elements is considered the most delicate since most developing countries like Ghana are burdened with pressing issues such as meeting basic infrastructural and developmental needs, thus, resulting in limited budgets for ensuring sustainable management of natural ecosystems (White, Awusabo-Asare, Nixon, Buckley, Granger, & Andrzejewski, 2007) particularly coastal lagoons of non-consumptive uses. With the aim of counteracting this challenge of inadequate budgeting, many efficient advances have been made to understand the functions of ecosystems within the coastal zone environment and the application of cost-effective measures necessary to improve coastal environmental quality against increasing complexity (Pina et al., 2008). The establishment of the ecological health status is one of such important factors in a framework for decision-making regarding the exploitation of ecosystem resources (Farley, 2012). This, alongside the suggested use of selected indices and indicators, will be helpful in research and analysis for routine monitoring, assessments, and management by the Ghana Environmental Protection Agency (EPA), the Council for Scientific and Industrial Research (CSIR) Institute, and other relevant research organizations.

Also, this research is significant in a bid to tie scattered efforts geared towards the restoration and improvement of coastal lagoons. The Fosu Lagoon, for instance, has been studied for its water quality, heavy metals and polyaromatic hydrocarbon (PAH) levels, fish assemblages and growth rates, bathymetry, community participation in governance, among many others (Akpabey & Amole, 2015; Armah et al., 2010; Baffour-Awuah, 2014; Darkwa & Smardon, 2010; Okyere et al., 2016; Tamakloe, 2004). Employing both abiotic and biotic components, simultaneously, of ecosystems has proven to equip coastal zone managers with a clearer understanding of which indicators are needed to improve and sustainably manage coastal resources (Regional Environmental Center for Central and Eastern Europe, 2007). It is expected that the disadvantage of rapid changes of abiotic water parameters during monitoring coupled with more stable measures of biotic indicators and baseline information on sediment quality will provide a holistic understanding of the conditions of the coastal lagoon system. The potential and less known importance of the Fosu lagoon will also be highlighted through specific objectives such as the creation of an inventory on avifauna. Thus, progress made through past studies will be enhanced to act as substantive guidelines in proposals of management interventions.

Another key feature of an ICZM framework is to optimize the sustainable use of limited space and resources in coastal zones (Brochier et al., 2001). Thus, the present study of the Fosu lagoon will provide a scientific basis to address the competing, and often conflicting, use of coastal resources such as fishing and speed boating which has been observed in other jurisdictions as a challenge for ICZM adoption from management planning procedures to policy formulation and implementation (Clark, Shroeder, & Baschek, 2014). Through the graphical and visual displays of the developed DSS, decisions can be made on spatial and temporal adaptive strategies that are flexible enough to change yet meet expected goals through government and stakeholder participation.

The developed DSS is also expected to serve as an interactive tool for stakeholders of varying backgrounds through an appropriate framework that is based on the principles of ICZM considering the complexity of growing decline in the quality and natural functioning of aquatic ecosystems from heavy anthropogenic pressures of exploitation (Geist & Hawkins, 2016; Newton et al., 2003). For emphasis, there is the fact that an estimated 60% of the world's population living within the coastal zone (Banica et al., 2017; Martínez et al., 2007) will increase further to an expected coastal population of about 75% by 2025 (European Environment Agency, 1999; United Nations Division for Sustainable Development, 1992), implying heightened deterioration in aquatic environmental quality in the coastal zone. The DSS tool will reduce the extensive time frame of decision making by several stakeholders of varying intellectual backgrounds and disciplines in a management framework. The added advantage of a DSS in making information accessible for decision-makers in a user-friendly computer-based tool cannot be overemphasized. Also, the ability to graphically view changes to several aspects (with variable influences) while reducing the subjectivity involved with human interaction in a DSS through scenario generation during predictive analysis, provides decision-makers clarity in the selection of management priorities.

1.6 Delimitations

The present study attempts to include a reasonable scope of environmental and institutional factors to provide a synoptic view of the present state of the Fosu Lagoon and its catchment. Quantitative assessments of water and sediment quality, and biological health included: selected physicochemical, nutrients, and heavy metals measurement; granulometric, porosity, and organic matter measurements; chlorophyll-a concentration; experimental fish catch abundance and morphometric measurement; avifauna biodiversity and abundance; faecal and coliform bacteria testing; solid waste composition; watershed delineation, streamflow regime, and buffer width assessment; and development of a lagoon multi-criteria decision support system (LMC-DSS), infographic displays of the present ecological health state of the Fosu lagoon, and scenario outcomes. A semi-structured questionnaire was administered to representatives of 33 governmental, educational, and non-governmental institutions/agencies/groups who were regarded as stakeholders of coastal areas.

1.7 Limitations

The results of the study could be affected by considerations made based on documented frames of time that show marked effects in various variables under study. This constituted bimonthly datasets for physicochemical parameters; monthly records of nutrients and chlorophyll-a concentrations and record of biological data; and quarterly records of heavy metal levels from an external study, solid waste composition, and sediment parameters. Comparative and correlation analysis, however, focused on coinciding measurements of respective parameters through multidimensional methods such as the principal component analysis (PCA).

Further, field measurements of several parameters during each visit meant samples were taken at different hours during the day which is likely to affect *in situ* values. Results of the research were envisaged to be affected by the complexities of multi-variate water quality data analysis such as the representation of outliers and sporadic shifts of replicate measurements. Spiked samples were used to reveal the occurrence of any systematic errors from analytical procedures of nutrients' concentrations.

The interpretations of water and sediment variables using criteria from other geographical locations pointed to the need for standards unique to our setting to avoid exaggeration of conditions.

Solid waste sorted was dependent on visibly identifiable and suspended waste. It suggests waste that sunk to the bottom between sampling periods was not accounted for. Counts of sorted waste materials merely provided information on presence but not volume. This was due to the time challenges of waiting to dry out waste before weighing and undertaking volume measurements.

Information gathered on bird assemblages was likely to include double counts for non-solitary birds that moved during counts to other points. Thus, the species encountered was a preferred reference for the analysis conducted.

The absence of hydrodynamic considerations such as circulation patterns, water balance, and movement, serves as a weakness to the key information provided for the coastal lagoon management. The lagoon was generally regarded as shallow and choked.

Possibilities of subjective or opinionated views and reported accounts were anticipated during the administration of the semi-structured questionnaire by organisations' representatives. To reduce the subjectivity, direct and affirmative responses were utilized in the Social Network Analysis (SNA) while open-ended responses served to provide insights on performance and roles undertaken by the relevant groups.

1.8 Definition of Terms

Biodiversity - the measure of the variation of organisms at the genetic, species, and ecosystem levels. Also, termed biological diversity.

Climate change - shifts in climatic patterns on global scales due to modifications induced by geologic, chemical, and mostly anthropogenic influences which result in weather pattern changes, sea-level rise, and other global warming events.

Coastal area – a linkage zone between land and sea where interactions between both result in a unique blend of features.

Coastal governance – a process through which policies, laws, and institutional setups address coastal problems and issues of concern to any group of people.

Coastal lagoon – a shallow body of water-oriented parallel to the sea which it intermittently empties/leaks into through a sand barrier or several inlets.

Decision Support System – a computer program designed to analyse multiple data sets into appreciable visual and graphical outcomes to aid decision-making by stakeholders.

Drivers - global and human factors that tend to affect coastal resources.

Ecological health – assessments that involve the use of hydrological, abiotic, and biotic indicators in the determination of how well the system functions in support of life.

Ecosystem – a biological unit of interacting organisms and their environment.

Framework – the basic structure defining a concept which enables repeatable assessment and evaluation

Impacts – changes in the physical, chemical, and biological state of an ecosystem which ultimately affect the functioning and productivity.

Indicators – communication measures adopted to summarize information about aspects of ecosystems and the effect of anthropogenic activities.

Indices – statistical representations of features of ecosystem concern

Integrated Coastal Zone Management – a multidisciplinary and holistic approach requiring stakeholders' participation to address complex coastal zone issues.

Pollution – contamination of coastal systems with identifiable elements (chemical and biological) at levels that harm organisms or significantly disturb normal functions of the system.

Pressures – first expressed the consequences of human and global factors and activities on coastal resources.

Prioritization – the action taken to rate issues on the basis of most urgent and requiring attention or management.

Responses – feedback and actions taken to restore, remediate, improve, manage, control, or entirely halt effects of harmful activities by humans on coastal systems.

Solid waste – abandoned, discarded, or unwanted materials that are generated from production or consumption processes.

Stakeholders – interested persons, groups, or users of a coastal resource who possess some knowledge and influence required in participatory programs.

State – a condition or phase of an ecosystem due to the effects of changes from pressures.

Subsistence fishing – harvesting of fish on a small scale to feed one's self or to sell in order to meet basic needs, usually undertaken by inhabitants close to a resource.

Sustainability – the ability to utilize resources in quantities and through specified directives in order to maintain levels required for regeneration or renewal for posterity.

Urbanization – population growth in town and city settings, ideally occurring alongside development, infrastructure, and facilities' provision.

Wastewater – contaminated water referred to as a by-product of domestic, municipal, industrial, stormwater runoff, or agricultural activities.

Water quality – the measure of water condition as required for organisms', humans, or other purposes.

Watershed – an area that drains into a common basin or water body.

Watershed delineation – mapping of the drainage boundaries of an area.

1.9 Organisation of the Thesis

The study is organized into six chapters – Introduction, Literature, Materials and Methods, Results, Discussion, and Conclusion.

Chapter One provides background information on the study, the statement of the problem, the significance of the study, the purpose of the study using the Fosu lagoon as a case study area, the research objectives, delimitations and limitations of the research, definitions of terms used, and the organisation of the thesis write-up. Chapter Two gives an account of several reviewed literature of interest to the study with a focus on the unique characteristics of coastal lagoons and threats to their existence and functioning, their ecological assessment on a watershed basis and the role of ICZM in management, and the general advantages of DSS as tools in management practices, policies and legal framework that support coastal management in Ghana.

Chapter Three outlines the methodology of the study by describing the Fosu lagoon study site and its catchment, sampling procedures, and laboratory protocols, samples' quality assurance, and data analyses. Chapter Four is the results section for exploratory and graphical presentations, while information from statistical methods to meet the objectives of the study are outlined.

Chapter Five is a discussion of the results with comparative inferences and implications of the outcomes of the study. Chapter Six gives a summary, conclusions, and recommendations of the study.

1.10 Chapter Summary

Coastal zones have a wealth of resources that provide valuable goods and services in support of life within the coastal zone. The challenges faced by these ecosystems emanate from global natural events such as climate change and anthropogenic impacts. The present study was aimed at developing a decision support system (DSS) to ascertain integrated management options necessary to improve the ecological health of coastal lagoons in Ghana. Coastal lagoons receive inadequate management efforts due to a focus on freshwater systems and general neglect. The major advantage of the DSS, as an analytical tool to synchronously consider the multiple parameters that act as pressures of the observed issues (such as pollution and eutrophication), is in its provision of holistic views of both present and case scenarios required in decision making. The Fosu lagoon which was selected for the study represented a typical coastal lagoon in Ghana which faces many challenges through an increase in urbanization, wastewater discharge, over-exploitation of its fishery, reported high levels of heavy metals and polyaromatic hydrocarbons, leading to subsequent effects of poor water quality and low biodiversity, among others. In addition, the study was carried out to review the policies in support of integrated coastal zone management, and the institutional framework required to achieve an intended set of ICZM objectives was evaluated to inform on mandatory roles and collaboration effort.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter seeks to review relevant literature covering the unique and important roles played by coastal lagoons as integral features along the world's coastline; their degradation through anthropogenic activities; Integrated Coastal Zone Management (ICZM) as an effective process for management; use of decision support systems (DSS) as tools for guiding decision making towards improving and managing coastal lagoons through an ecological health assessment and evaluation of resource use options; coastal governance structure of Ghana considering the coastal environment policies and institutional framework; and comparative analysis (where applicable) with related past studies of the case study site - Fosu Lagoon.

2.1 The Coastal Zone

The coastal zone which encompasses the link area where both inland and marine activities are experienced is very productive and highly vulnerable (U.S. Commission on Marine Science Engineering and Resources, 1969). Depending on several processes primarily including, tectonics, the extent of exposure to waves, levels, and ranges of tides, sediment transport, and deposition, and coastal climate, different types of coastal zones can occur (Inman, 1994), which determine the demarcations of coastal zones specific to the influences experienced. In Ghana, for instance, Ly (1980) describes the zonation along three sections of marine influence on land and vice versa i.e. (a) West of Cape Three Points where the gentle sloping continental shelf which is characterized by low wave heights result in a narrower coastal zone; (b) Between Cape Three Points and the industrial town of Tema where several rocky outcrops are separated by sandy shores bearing a majority of coastal lagoons within its variable coastal zone, and (c) East of Tema extending over the Volta delta.

Krishnan and Soni (2011), state the many benefits of healthy ecosystems including, the provision of many goods (food, shelter, water, fuel, fibre, medicine, raw material for industries, and genetic base for research), coastal tourism, trade, and shipping, oil and gas exploration, and fisheries. Chua and White (1989), indicated the following as among several driving forces for pressure on the natural resources within the coastal environment: fast increasing population growths; poverty in spite of the vast resources through overexploited fisheries and fewer alternative livelihood opportunities; large-scale industrial set-ups which usually side-step environmental impact assessment practices and with inadequate social responsibilities towards local community; lack of proper awareness on sustainable management by local people and policy-makers; inadequate data and information to support the concept of highly-valued ecosystems and resources; and lack of commitment by government and enforcement agencies in monitoring and implementation programs.

2.2 Coastal Lagoons as Productive Ecosystems

Characteristic coastal ecosystem features within coastal zones include mangroves, estuaries, lagoons, wetlands, and salt marshes (Ryan & Ntiamoa-Baidu, 2000). These coastal ecosystems support a wide variety of plant and animal communities that have adapted to a dynamic coastal environment. Natural events such as climate change-induced effects of sea-level rise and temperature hikes, storms, and flooding, compromise the adaptation, survival, and thriving of coastal ecosystem communities (Barbier et al., 2011). Damage by natural events results in habitat loss and displaced communities of unique plants and animals, community structure disturbance, altered food supply, and entire loss of highly vulnerable organisms (Torresan et al., 2007). Perhaps the most disturbing worry by ecologists is the unpredictable long-term effects of such natural phenomena (Pachauri et al., 2007). Hampering, further, the vulnerability of coastal ecosystems are activities by humans, which reach most coastal ecosystems through direct contact activities and runoff from catchment (Ahn, 2006) resulting in pollution, habitat quality decline, and depletion of fish stocks/wildlife (Valiela et al., 2001). The US NOAA has estimated 80% of marine pollution sources from land runoff. Coastal lagoons constitute part of these pollution conduits to the marine environment (de Wit et al., 2020).

Miththapala (2016), also lists, among many other coastal ecosystems, lagoons, estuaries, mangroves, coral reefs, seagrass meadow, sand duress, salt marshes, tidal flats as vulnerable resources providing ecosystem services and products to humans. The author reiterates the immense benefits from observed losses after the collapse and impacts on several other connected ecosystems after the Indian Ocean tsunami of 2004, thus the need to manage coastal zone issues at broad watershed scales.

Management of ecosystems requires a clear understanding of the morphology and processes unique to the ecosystems. Similar characteristics between coastal lagoons and estuaries which are both prominent features along coasts result in unintended interchange in their reference. Despite these similarities in geographical siting and occurrence (formed at connecting land and sea points), geological processes (dependent on water inflow and outflow patterns), and seasonality, Miththapala attempts to define each ecosystem clearly to support adequate management options. From observation, factors such as the extent of depth, rivers flow, flow dynamics, and flushing time differentiate between lagoons and estuaries. Lagoons are generally more vulnerable in their morphology being relatively shallow, receiving water from catchment (not major rivers), flow slowly, and have reduced flushing rates (worst in choked systems). Found lying parallel to most shorelines except in Antarctica, coastal lagoons are a few meters in depth (Kjerfve, 1994). The shallow depth means characteristic experiences of wide ranges in physicochemical conditions specifically due to quick salinity and temperature variation responses to changes in precipitation, evaporation, and wind. These classifications of coastal lagoons dependent on exchange with adjoining oceans are given by Kjerfve – choked, restricted, and leaky lagoons. Constricting inlets that are hardly breached except in severe storms or by physical means result in hypersaline conditions making choked coastal lagoons the least resilient in community structure.

Across the 13% worldwide coverage of coastal lagoons (Diamantopoulou et al., 2008), numerous ecological and socio-economic benefits are derived to support linking ecosystems and humans (Gonenc & Wolflin, 2004). The relatively shallow depth of coastal lagoons (Bird, 1994; Kjerfve, 1994) provides conducive conditions by acting as sinks and recycling sites for nutrients and sediments (Bricker et al., 2003) that are required by mangroves and other such ecosystems, serving as important habitats for many species of fish, birds, and other wildlife. Coastal lagoons, therefore, provide direct products through activities such as fisheries, aquaculture, and tourism which support livelihoods. The benefits of ecological roles such as the provision of habitat sites, hydrological balance, nutrient recycling, storm protection, water recharge, carbon sequestration, water quality enhancement, and others (Barbier et al., 2011; Lopes & Videira, 2013; Solidoro et al., 2010), are not easily quantified to establish a basis to improve management. Thus, coastal lagoons face many challenges of habitat alteration, pollution, unsustainable exploitation of ecosystem goods, eutrophication, and community change (Millennium Ecosystem Assessment, 2005). Valuation of the ecosystem goods and services by coastal lagoons, as practiced in the past twenty years, is a method agreed by many scientists to draw attention by governments and decision-making groups in assessment studies.

Valuation assessments by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005), the Economics of Ecosystems and Biodiversity project (de Groot et al., 2010), and the Common International

Classification of Ecosystem Services (CICES) began with stating the need to clearly define ecosystem services. Valuation of these ecosystem services primarily into monetary figures for appreciation by relevant stakeholders and managers aided in decision making. In the face of the observed low number of coastal lagoon ecosystems that have been studied for valuation purposes (Barbier et al., 2011), a study was conducted on thirty-two selected lagoons found in all five continents to assess, quantify and value ecosystem services to reinforce the importance of coastal lagoons. As indicated in Figure 2.1, the services provided by the selected coastal lagoons were further assessed following questionnaires administered to scientists to ascertain which category was most vulnerable to climate change indicators (freshwater inputs and temperature variations). Results showed that provisioning services such as food provision were expected to be largely affected, whereas cultural services were at lower risk of being affected (less than 30%). The results also emphasized the difficulty in valuing services that leaned toward socio-cultural values based on aesthetics and intrinsic values. The study emphasized the definition variations in ecosystem services, the global differences in valuing these services based on priority placed on the selected study areas by relevant users and stakeholders, and fluctuations in exchange rates.

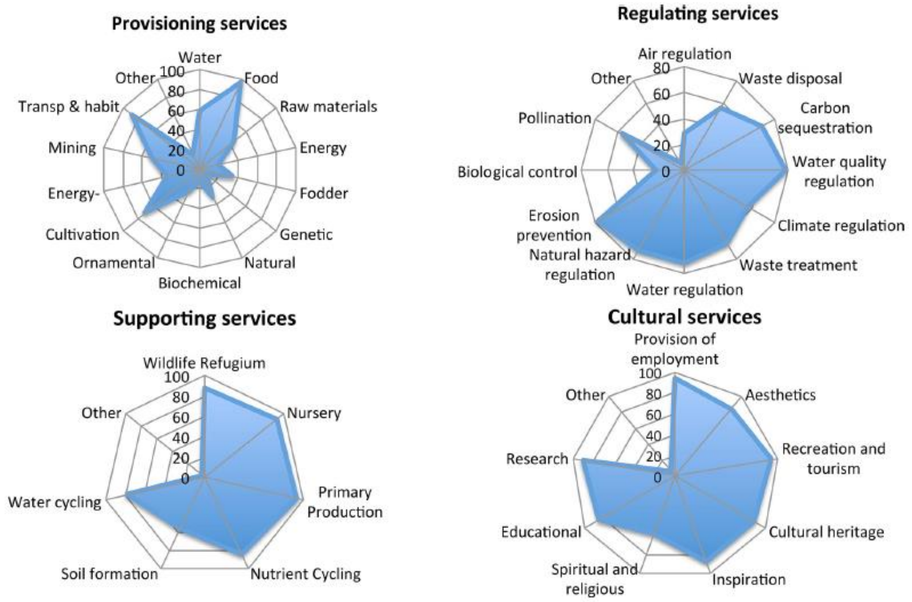


Figure 2.1 Ecosystem services percentage contributions by thirty-two selected coastal lagoons (Newton et al., 2018)

2.3 Assessment of Threatened Coastal Lagoons

Common underlying objectives in the management of coastal resources posit on ecologic health maintenance, improving productivity, sustainability, and ensuring environmental justice (EJ). Sorensen and McCreary (1990), list the top four imperative and convincing reasons to undertake the management of coastal resources including lagoons - improve fisheries productivity, increase revenues from tourism, increase mangrove coverage and health, and provide security from floods related natural hazard events among other activities such as imposed by shipping, recreation, security, sports and mineral/oil exploration.

Based on Kennish and Paerl's assessments and conclusion that coastal lagoons "may now rank among the most heavily impacted aquatic ecosystems on Earth", underlines an imminent need to identify the threats to coastal lagoons for management purposes. Naturally, inputs of nutrients and sediments into lagoon systems are from rivers, other freshwater sources, or runoff within the catchment area. In restricted lagoons where flushing with the open sea is limited, freshwater input and rainfall largely determine the ecological health of the system (Caumette et al., 2012). Pollution, increased sedimentation, aquaculture, drastic changes in water quantity, unsustainable exploitation practices, destruction of unique habitats, and invasive species threaten the functioning and dynamics of coastal lagoons (Bartram & Ballance, 1996). Also, dissolved and suspended materials tend to affect community types of flora and fauna. Seasonal cycles of organisms are observed in such restricted lagoon systems. However, anthropogenic inputs disrupt such cycles owing to the often, unregulated discharge from various sources within the catchment area (Janssen & Taviani, 2015).

Pollution and eutrophication in coastal lagoons result from increased use of fertilizers, pesticides, and other industrialized products that enter flow pathways (Cloern, 2001). Of major concern are the nitrogen and phosphorous compounds from agricultural fields that seep into groundwater and/or runoff leading into lagoons, and heavy metals from industries that enter lagoons via similar media and through atmospheric fallouts (Nixon, 1995). Since highly valued coastal lagoon ecosystems are reflective of the numerous important benefits derived from the studies on the physical, chemical, and biological components of coastal lagoon environments must result in the establishment of the ecological status, documentation of inventories of plant and animal communities, review of potential exploitable resources, and other such aspects which will equip managers and decision-makers (Meybeck & Helmer, 1996).

Management approaches selected by decision-makers differ largely based on expected outcomes for use or restoration of the resource.

There is a paradigm shift to select management approaches that are holistic and sustainable by delineating watersheds of interest, undertaking research, and monitoring considering important parameters and indicators of ecological health and selecting appropriate mitigation or management programs for implementation.

2.3.1 Importance of catchment practices in management approaches

Global events of climate change and its consequential effects of global warming and sea-level rise, droughts, and flooding serve as factors necessary for consideration in global scale management of coastal ecosystem issues. Concepts based on Integrated Coastal Zone Management (ICZM), Ecosystem-Based management (EBM), Spatial Planning (SP), and Watershed Management (WM) typically address management with regards to broad-scale programs. To reduce the difficulty with differences in jurisdiction and legislation across coastal countries, basin-wide management efforts following ICZM and WM have rested on principles of maintenance of the immeasurable benefits from resources in the coastal area; incorporation of water resource management since water serves as an integral element in all coastal zone management programs; consideration of ecosystems interconnectivity; and the need for objective solutions tailored to address issues (Clark, 1992).

Entire watersheds which drain an area, as shown in Figure 2.2, are considered effective units of coastal resources management (U.S. Environmental Protection Agency, 2004). Their ability to regulate water flow, support biodiversity, provide and protect natural resources for local livelihoods, and provide opportunities for recreation, stress the need for holistic management of watersheds. Use of satellite and drone imagery among other aerial maps, aid in watershed delineation. Although best employed as a proactive approach of management for ecosystems that have yet to face decline, watershed management considers all natural and anthropogenic impacts that influence the quality and functioning of ecosystems. The Tennessee Valley Authority (TVA) as part of its issue-based objectives in achieving goals of the US Clean Water Act adopted a watershed approach (OpenEI, 2015). The program included the selection of use for the coastal resource (referred to as designated use for previously assessed systems), the establishment of required water quality standards to sustain the selected use by relevant stakeholders/users, monitoring of conditions on a routine basis following documented protocols, analyses of data to determine issues of priority, and evaluation of solutions to address both point and non-point sources of pollution. A major success of the TVA program was the active involvement and participation of all stakeholders and relevant groups in the planning, monitoring, and implementation to ensure adherence to controls, discharge rates, and regulations. Coastal communities were educated and sensitized to know the immense value of their watershed. For instance, ecosystem inventories that stated the biological components, with emphasis on sensitive and threatened species augmented water quality assessment by defining the acceptable levels of variables for realizing management objectives.

Large-scale watershed management increasingly proves necessary with high urbanisation rates of coastal areas due to economic viability and opportunities encouraging urban migration (Seto, 2011). In Africa, the phenomenon is heightened with climate change variability (Tacoli, 2009) so that waterfronts are congested irrespective of the vulnerability to climate change consequences such as sea-level rise. In spite of the efforts to improve economic relations with the rest of the world through opportunities created in urban coastal settings, Africa still faces “massive urban poverty and other social problems” (UN-Habitat, 2014). Urbanisation complicates a complex coastal management issue considering the milieu of interactions that require holistic approaches. A major concern of urbanisation is the pressure placed on natural resources. Within coastal areas, the effects of growing pressure on estuaries, lagoons, and other unique ecosystems rise from the dependency on fisheries, irrigation, transportation, and waste discharge sites. Developing countries are further challenged with water quality maintenance considering that huge amounts of waste are not properly managed (Celliers & Ntombela, 2014). Conde et al. (2015), through a case study of the Laguna de Rocha (Uruguay), showed the complexity of interaction between coastal lagoon ecosystems and human communities that depend on them. The effects of controlled nutrient concentrations, reduced risks of flooding, improved fisheries, and enhanced oxygen incorporation as a general socio-cultural practice with indigenous fishing communities (Esteves et al., 2008) were enumerated as benefits worth continued in monitoring studies. In support of decision-making concerning optimization of the coastal lagoon's opening timing and duration periods, a multicriteria decision tree was developed based on a selection of natural (with reference to ecological, geomorphological, and hydrogenic parameters) and social indicators.

2.3.2 Research and monitoring regimes necessary for establishing baselines

Attempts to restore, improve, protect and/or sustainably manage coastal resources whether dependent on resolving resource use conflicts or reducing vulnerability to hazards must begin with an assessment of the various components (Figure 2.2) that interact in the coastal environment. As depicted in a conceptualized watershed system in Figure 2.2, these components could comprise failed municipal septic systems which contribute nutrients and pathogens into the watershed; coastal developments and impervious surfaces which increase sedimentation and toxins in water bodies; stormwater runoff which also leads to increased sedimentation, toxins, and pathogen levels; deforestation resulting in sedimentation; oil and chemical spills; and road construction and agriculture which culminate into sedimentation and nutrients release, respectively. These components of a watershed are broadly categorized as the biophysical environment (biotic and abiotic variables), resource use (activities and exploitation), human/social interactions, and the existing coastal governance (Clark, Schroeder, & Baschek, 2014). Clark caveats the need to recognize ICZM programs as important management measures of resources. He regards the various agencies that are mandated to manage coastal resources such as fisheries having a lack of the ICZM Process to help solve conflicts that arise from other uses of the same space within the coastal zone. To buttress this, Henocque and Denis, (2001), probed several failed attempts made to adapt ICZM in some coastal states because various reconciliation strategies expected for integration between environmental, social, and economic issues were not met. For a three-phase ICZM process, tasks set informed participants on tools to be employed for realizing expected products and outcomes (scenarios). The cyclical interconnection depicted the closely interacting parts of each phase of environmental issue identification (feasibility), preparation (evaluation/assessments, outcomes, and management plan options), and implementation. Persistence in separate institutional objectives without integration for common goals resulted in fragmented outcomes and unsustainable management efforts.

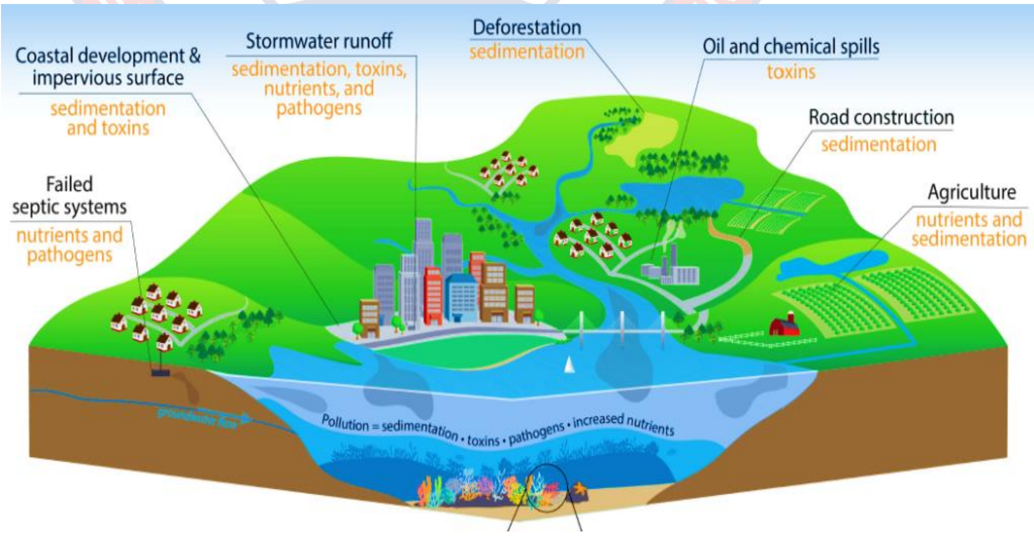


Figure 2.2 Watershed approach to water quality assessment and management (National Oceanic and Atmospheric Administration [NOAA], 2017)

Broad-scale research is important as initiated by the Guinea Current Large Marine Ecosystem (GCLME) project to solve common problems of marine environmental and resource exploitation within the region (Guinea Current Large Marine Ecosystem Project, 2005). With the technical and financial support of groups such as the Global Environment Facility (GEF), the United Nations Industrial Development Organisation (UNIDO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the USA Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), the GCLME project set up their Regional Coordinating Unit (RCU) in Accra. Effective collaboration by participating countries was made to provide an assessment on issues in a holistic manner as sought through integrated approaches. A network of laboratories and trained capacity in all sixteen countries were geared toward providing scientific data, analyses, and information to solve pollution and related issues (Chukwuone et al., 2009). Coastal lagoons were identified as major conduits of waste generated from heavily populated and industrialized urban coastal areas. The effects of nutrient loading and waste discharge due to inadequate treatment plants, which are practically non-existent in some countries, have exacerbated the issues along the West-Central African coast.

Nutrients and other physicochemical studies

Nutrient analyses carried out in preliminary water quality analyses to ascertain levels present in some coastal lagoons, estuaries, and rivers within the GCLME were to serve as baseline information for monitoring. Some baseline information gathered suggested ammonia values of coastal lagoons within a range of 0.14 to 1.4mg/l, where higher values reflected pollution from surrounding catchment. Phosphate values varied from 0.014 to 0.35mg/l. Chlorophyll-a served as a sensitive determinant for phytoplankton biomass estimates through fluorometric and spectrophotometric procedures. Coastal lagoons assessed had surface concentrations of chlorophyll-a ranging between 5 and 75µg/l where higher values were indicative of eutrophication. For assessment purposes, some other parameters that influenced the nutrient distribution and availability/uptake were measured. These physicochemical parameters included concentrations of suspended solids (about 5 to 50mg/l, and >100mg/l during floods); turbidity between 2.0 and 20NTU (>100NTU in very turbid lagoons); salinity and pH which were highly variable dependent on freshwater inflow and intermittent tidal influence.

Other studies in the discipline focused on similar *in situ* procedures, laboratory simulations, and analyses to determine impact levels on coastal lagoons. The GCLME project, however, concentrated largely on the water column as monitoring measures of anthropogenic impacts through the provision of concise protocols for physicochemical measurements and microbiological testing. Sediment-water exchanges in productivity studies and pollution assessments, which were not included in the assessment, are critical in understanding the effects on water quality (Brito et al., 2009). A comprehensive water quality assessment must ideally include sediment analyses for management purposes in shallow coastal lagoons where resuspension occurs over relatively short periods to affect seasonal eutrophication cycles (Avramidis et al., 2013; Bellos & Sawidis, 2005).

Sediment studies complement water quality assessment

The water quality of shallow coastal lagoons has been described as strongly influenced by the underlying sediments (Murray et al., 2006), which either hold on to nutrients and contaminants (as sinks) or release these (as sources) dependent on prevailing dissolved oxygen, salinity and temperature (Gonenc & Wolflin, 2004). Further restrictions on frequent exchanges with adjoining seas imply long residence periods of nutrients and contaminants within coastal lagoons. The Ria Formosa coastal lagoon in Portugal is an example of such a restricted coastal lagoon which was studied to primarily investigate the influence of sediment parameters which encouraged the release of nutrients thus contributing to eutrophication (Brito et al., 2009). The study concluded that sediment-water exchanges provided a supply of phosphate and related nutrients in support of benthic algal growth. Previous studies using quantified interstitial nutrients and diffusion rates across both media indicated the direct influence of nutrients such as nitrate, phosphate, and silicate on photosynthetic activity. The study on the Ria Formosa emphasized the need for long-term monitoring programs involving sediments to establish the uptake rate by benthic microalgal communities.

Sedimentation, or siltation, is listed among other anthropogenic stressors as major causes of alterations in coastal ecosystems (Khan, 2007; National Research Council, 2007). Perez-Ruzafa and Gilabert (2005), describe how sediments enter coastal lagoons through poor practices of mining, agricultural, and land cover striping activities. Sediment studies consisting of grain type and size, composition, and content determination gave a basis for rates of transport and resuspension because of the adsorption potential of sediments to nutrients, organic matter, and heavy metals (Hedges & Keil, 1995; Le Roux et al., 2002).

During a one-year sediment characteristics monitoring of the Myrtari Lagoon in Western Greece, dominant sediment grain size skewed toward finer clay and mud grains with high total organic carbon and total nitrogen concentrations (Avramidis et al., 2013). Though levels of nutrients measured stayed within levels prescribed by authorities for similar brackish systems, the authors advised that results were the baseline for future monitoring with fluctuations in salinity and temperature acting as dissolution agents. The resultant effects of discharged effluents from a wastewater treatment plant of the Vonitsa city along the site were of importance in recommended further studies.

The US EPA includes source identification of contaminated sediments in routine suspended solids and sediments studies (SSAS) to assess watershed management options whether to completely remove or isolate contaminated sediments, reduce exposure to other unaffected parts of the watershed, or a selection of any combinations of the prescribed remediation (Kalin & Hantush, 2003). Lenzi (2010) described an unconventional possible management tool for restricted eutrophic lagoons – resuspension of sediments! Shifts in community structure, starting from benthos and primary producers, during this repeated disturbance, showed potential for replacing nuisance macroalgae with controlled productive species. Studies conducted on the Orbetello lagoon showed effects of resuspended sediments on oxidation and remineralization processes leading to improvement in water quality after settling occurred. Precautionary steps to establish the specific physicochemical and natural buffering potential of sites under consideration were needful in view of variable responses in entire watersheds.

Doamekpor et al. (2018) attributed anthropogenic inputs of heavy metals – copper, lead, iron, nickel, zinc, and manganese estimated in the Sakumo II, Chemu, and Kpeshie lagoons in Ghana to high adsorption by sediments at levels above recommended limits set by the Ghana EPA, World Health Organization (WHO) and the USEPA. The effects of seasonal variations from resulting changes in the volume of water on the concentrations of the investigated heavy metals were however unexplored.

Biological indicators of ecosystem health

Holt and Miller (2010) considered the added advantages of using organisms to measure environmental impacts. They listed these advantages of bioindicators over traditional methods of conducting physicochemical measurements and assays as temporal inclusivity, clear responses of indirect biotic and abiotic effects, and good predictors of stressors. Classically, traditional assessment methods of ecosystems impacted focused unduly on the physical and chemical environment so that the intensive analyses undertaken missed out on the responses by organisms whose survival and thriving depended on the environment. The caution in the choice of bioindicators for anthropogenic impact assessments, however, is to select species that do not oversimplify complex systems that have several influencing factors (i.e. multiple drivers). The study among many things proved the need to select bioindicator species which were neither rare, with very limited tolerance to the identified impacts, nor ubiquitous which were hardy and did not reflect changes in conditions over appreciable time scales. Thus, a biotic index of an area under consideration gives an indication of how suitable the environment supports the community. The study emphasized the need to use biological components in monitoring and valuation assessments.

Biotic components are also studied using biodiversity indices to express species abundance, diversity, and richness (Andersen & Brault, 2010; Hewitt et al., 2010). Trade-offs are made by the decision-makers with regard to resource exploitation when biodiversity indices are provided. In ecosystems where productivity tends to be the focus of interest such as on a fish farm, an ecosystem classified as 'good' using a water quality index (WQI) may not necessarily reflect in 'high' species richness or species diversity. Thus, the need to infer on biotic components of ecosystems in decision making. Biotic indicators are important considerations in long-term monitoring programs especially when they are in quantifiable forms for evaluation of target results (Goudarzian & Erfanifard, 2017). In their study, Goudarzian and Erfanifard, conclude that the selection of biotic indices must be cautionary to reflect dominance, abundance, diversity, or spatial evenness dependent on the objective of the assessment. Their study also gave substantive evidence on the importance of avian diversity inclusion in ecological health research of wetlands because water birds mostly occupy top niches in coastal ecosystems.

2.3.3 Selection of appropriate mitigation and restoration programs for implementation

The Ecological Health of coastal areas is improved through programs designed to achieve outcomes of productivity, improved aesthetics, sustainable exploitation, and ecosystem functioning (Atique et al., 2019). Coastal zone managers and decision-making groups require tools to realize the outcomes objectively. Indices and indicators aid in providing synoptic views of states and vulnerabilities of studied ecosystems (Coulson & Joyce, 2006). Add-on advantages of indices used are employed in decision support systems that consider these indices against a backdrop of other socio-economic and governance interactions.

Use of water quality indices and indicators

Kannel et al. (2007) discuss the advantages of water quality indices to convey the state of aquatic ecosystems through the aggregation of complex and numerous parameters to provide a single value which is easy to understand by decision-makers of varying backgrounds. The index used considers the available standards acting as references for comparison and the duration within which the set objectives are expected to be realized (Abbasi, 2002). Hitherto, large numbers of variables complicated our ability to understand on a synoptic basis, predict and find mitigative effects associated with human use of coastal ecosystems (Babaei et al., 2011). To overcome this problem, environmental quality indices (EQIs) of which water quality indices form an important part, are often derived through the use of computer-based ecosystem models (Gikas & Livingston, 2006). This is helpful because, compared to other investigative tools (e.g., direct observation, experiment, and classification schemes), models have fewer operational limitations, and as a result permit users to realistically describe the combined ecological impact of human actions, including those outside the current range of events in order to help direct reliable management actions (Gikas & Livingston, 2006). Water quality indices (WQIs) are examples of abiotic EQIs, whose proponents developed in the hopes of reducing subjectivity in describing the physicochemical state of an aquatic environment (Carlson, 1977; Taylor et al., 1980; Xu, 1997). A combination of physical, chemical, and proxy biological parameters is used in WQIs to reduce the collection of large amounts of data. Here, the major drivers are targeted in research/monitoring to provide figures on classification scales better understood by non-science decision-makers which also allow comparison with other systems (Lenz et al., 2000). The selection of a WQI is usually dependent on the purpose of information provision i.e. whether to describe the state/conditions of water quality or the ecological functioning of the ecosystem. With this tool in hand, coastal zone managers and/or decision-makers are faced with the task of selecting solutions without losing sight of the socio-economic dimensions unique to the area.

In a study to determine which of three indices, mentioned above, effectively described the effects of aquaculture on holding reservoirs, Simões et al. (2008) based the outcomes as reflections of the respective parameters that were deemed important for the purpose. One of the water quality indices, WQI_{NFS}, proposed by the U.S National Sanitation Foundation comprised nine parameters that were weighted through simulation studies. The other two water quality indices, WQI_{moc}, and WQI_{min}, both relied on the most predictive parameters considered as drivers of poor water quality of the aquatic system. The study concluded by stressing the need to select indices based on the goals of their usage. The WQI_{NFS} emerged as most effective in categorizing the state of the reservoir in which the fish was cultured. The parameters utilized in the WQI_{moc}, however, proved to rank the mentioned index as most reliable in the identification of both point and non-point sources of contamination leading monitoring experts to address issues at specific sites. The opportunity existed to employ both indices in robust management measures. Indeed, a review on the effectiveness of the Canadian Water Quality Index (CWQI) by Painter and Waltho, (2003), in a separate study, emphasized the need for sensitivity analysis to ensure the index covered a good number of parameters, stations (area coverage) and with the sound understanding on site-specific background levels of the selected parameters.

Other indicators and metrics which also summarize large datasets into information, not necessarily statistically generated, support decision-making on coastal ecosystems. Both indicators and metrics are characteristic in the determination of responses expressed due to changes in conditions that deviate from the norm (Costanza & Mageau, 1999). Thus, they are integral tools for the assessment and analysis of ecological health issues (Müller & Burkhard, 2012). In support of this, Zampella, Bunnell, Laidig, and Procopio (2006) showed how a selection of various populations of different endemic organisms (fish, anurans, and vegetation) in conjunction with water quality, acted as indicators for the evaluation of ecological integrity of lotic systems. Results of the study revealed that together with basin hydromorphic features and effects of anthropogenic activities, clearer responses by fish in the more restricted systems was a better indicator of habitat alteration, while selective water quality monitoring of pH and specific conductance, and increases in bull-frog numbers in the heavily disturbed system indicated preference of the anurans to existing conditions. The authors agreed with the ideology adopted by Stevenson and Pan (1999) that a selection of both abiotic and biotic indicators for ecological health assessments produced results that covered the factors that elicited changes in the community structure and functioning, and also those that showed the effects of the changes observed.

Decision Support Systems (DSS) for coastal resource management

The competitive and conflicting uses of the coastal lagoons require management measures that are broad-based, holistic, and well defined. There are several sectors of government, resource users, and major participants expected in management programs to ensure active involvement and sustainability of programs. DSS tools are innovative approaches to addressing multiple uses and related conflicts which are usually associated with the exploitation of coastal zone resources. During the otherwise daunting process of decision making, employing DSS tools provides relevant stakeholders and decision-makers an array of important environmental factors and socio-dynamic elements for considerations. Janssen (1991) described DSS as an aid to effective decision making rather than improving efficiency in decision making. As computer-based information systems, DSS tools are designed to allow assessments, evaluation, and implementation of alternatives for management (Le Blanc, 1991).

Environmental DSS tools are equipped to provide the user with interpretive structures on a graphical interface that relies on geographical information systems (GIS) or spatial mapping techniques. GIS enhances the collection, processing and analysis, and visual display of spatial data that are georeferenced (Environmental Systems Research Institute, 1992; Nobre & Ferreira, 2009). An example of such a GIS-based environmental DSS tool is DESYCO (Decision Support System for Coastal climate change impact assessment) which focuses on climate risks and mitigative measures for adoption in the Mediterranean and Black Sea Basins (Rizzi et al., 2011; Rizzi et al., 2013; Torresan et al., 2016). Two major elements were associated with the DSS DESYCO - a Regional Risk Assessment framework (RRA) and a multi-tier software architecture. The RRA framework, composed of three phases, essentially facilitated the construction of various climate change scenarios at the global scale, assessed the different impact effects from both biophysical and socio-economic and ranked them according to vulnerability extents (shown in visual formats), and finally provided the decision-maker options for adaptation and mitigation (Torresan et al., 2007). The multi-tier software architecture of DESYCO was designed to enable flexibility in access to the tool with added features of different database formats and advanced functions' outputs. The DESYCO DSS tool was successful as it aided the complex dynamics of climate change particularly over sensitive areas such as river deltas, estuaries and lagoons to be assessed. To reduce large uncertainty in predictions from the observed, however, it was recommended that users and decision-makers consider site-specific factors such as weights of driver parameters and scores for vulnerability.

Iyalomhe, Jensen, Critto, and Marcomini (2013) reviewed twenty DSS tools that were developed to assist decision-makers in issues related to climate change and environmental quality in coastal areas. Characteristics of the reviewed DSS including information such as the developer(s) and year of development with references were listed in the review. A general technical assessment of the review provided information such as the specific area or domain where the DSS was employed, the respective supporting legislation and governance regime, and the specific objectives addressed and functions of the DSS (climate change or environmental quality-related). The review also provided information on the specific methodologies, analytical procedures, and applicability levels of the twenty identified DSS (Table 1). As indicated, all the DSS were GIS-based in their output design to allow easy visualization through maps, graphs, tables, and charts by decision-makers and users. The flexibility of usage was dependent on the scope of information so that DSS outcomes at local to regional levels were usually made available to the public.

Table 1: Some DSS tools for coastal resource management (Iyalomhe et al., 2013)

Name	**Objective(s)**	**Methodology**	**Scope, Scale, and Area(s) implemented**
COSMO: Coastal zone Simulation Model (Feenstra, Programme, & Milieuvraagst, 1998)	To evaluate management options from anthropogenic effects and impacts of climate change	Multicriteria decision analysis (MCDA). Ecosystem-based	CZ, National, Local. (Coast of Netherland
DESYCO: Decision Support SYstem for COastal climate change impact assessment Torresan et al., 2010)	Assessment of climate change risks and impacts, and adaptation of mitigative measures	Regional risk assessment (RRA) MCDA Risk analysis	CZ and CL, Regional, Local. (North Adriatic Sea

Table 1: Some DSS tools for coastal resource management (Iyalomhe et al., 2013) continued

Name	Objective(s)	Methodology	Scope, Scale, and Area(s) implemented
DITTY: Information technology tool for the management of Southern European Lagoons (Agnetis et al., 2006)	To realize sustainability goals focusing on major anthropogenic actors	Analysis of uncertainty MCDA Social cost and benefit DPSIR (Driver-Pressure-State-Impact-Response)	CL; Supranational, National, Regional. (Ria Formosa-Portugal; Mar Menor-Spain; Etang de Thau-France; Sacca di Goro-Italy, Gera-Greece).
GVT: Groundwater Vulnerability Tool (Gemitzi et al., 2006)	Assess groundwater vulnerability to pollution	Risk analysis Fuzzy logic MCDA	CZ, Regional, Local. (Eastern Macedonia and Northern Greece).

Table 1: Some DSS tools for coastal resource management (Iyalomhe et al., 2013) continued

Name	**Objective(s)**	**Methodology**	**Scope, Scale, and Area(s) implemented**
RAMCO: Rapid Assessment Module Coastal Zone Management (de Kok, Engelen, White & Wind, 2001; http://www.riks.nl/projects/RAMCO)	To assess effective and sustainable management of coastal resources at regional and local scales	Ecosystem-based	RB and CZ; Regional, Local. (South-West Sulawesi coastal zone).
WADBOS: decision support Systems (Engelen, 2000)	To review and support policy measures designed to achieve integrated and sustainable management	Sensitivity analysis MCDA	RB and CZ; Regional, Local. (Dutch Wadden sea).

Of interest to present research is an adaptable methodology shown through a Multi-Criteria Decision Analysis (MCDA) where management alternatives based on various aspects of an ecosystem can be compared and ranked after a selection process. COSMO, DESYCO, DITTY, GVT, and WADBOS were identified as equipped to evaluate systems through MCDA. RAMCO was better advantaged using an ecosystem approach (supported by policy frameworks) to describe coastal environmental events. MCDA proved a useful methodology in the DSS tools development by anticipating and visualizing coastal problems within a future time frame and to evaluate which options are better suited to solve the problems in the set scenarios.

Other technologies adapted in similar MCDA function mode were the GVT and WADBOS which were developed based on risk analysis evaluation concepts to compare, select, and rank multiple alternatives that involved several attributes. DESYCO estimated indicators in assessing impacts, vulnerability, and risks. It estimated groundwater quality and coastal environmental quality, respectively. Similarly, RAMCO and DITTY employed environmental status evaluation techniques, and spatial analysis for protection measures, identification of resource use, to support the management of coastal ecosystems. Components necessary for the development of a DSS are dependent on the end-users i.e. decision-making groups' requirements and the purpose for which the decision is being made, though the developer's perspectives are obvious in command prompts and functions.

Thus, multi-criteria decision support systems for management decision making may depend on some elements such as adopted from the Analytical

Hierarchy Process (AHP) described by Saaty (1987), where decisions were taken based on concurrent comparisons of influencing parameters and the value placed on output options. Based on a selected and defined set of criteria and indicators (C&I) as employed in a forest restoration exercise (Mansourian, Vallauri, & Dudley, 2005), competing resource use activities of ecological and socio-economic relevance were ranked to guide decisions towards sustainability. Ecological health assessments have typically combined knowledge as gathered from the AHP and multi-criteria decision analysis (MCDA) methods where Convertino, Baker, Vogel, Lu, Suedel, and Linkov (2013) included the prioritization and ranking process levels to reduce the subjectivity based on uncertainty from stakeholders who participate in decision making and provide alternatives to apply weights for less quantifiable parameters,

2.4 Policies and Legal Framework

In the early 1970's conflicts emerging from meeting demands for development in coastal areas while maintaining healthy ecological environments acted as driving factors in the process of identification of environmental issues, undertaking scientific research to assess the environmental variables of concern, and predicting future outcomes from generated scenarios (United Nations, 1987). The gap between relating scientifically experimented environment issues to policymaking through interpretations proved difficult (Morikit et al., 1996).

The gap further delayed quantitative assignments of regulations concerning the use of coastal resources. The shift from reliance on multivariate statistical methods in environmental assessments to multiple criteria methods is stipulated as the way forward to addressing gaps in a large database of physicochemical and biological variables and aspects of human-oriented contributions (Clarke & Green, 1988).

Coastal environment management decisions are best taken within policy and legal frameworks (Godschalk, 2009). An appreciable attempt by the USA to control water pollution and improve water quality was to pass the Clean Water Act (CWA) in 1972 (U.S. Environmental Protection Agency, 2004). Emerging concerns, however, required further address of non-point sources of pollution to buttress efforts made through set limits on the allowable discharge of specified contaminants and pollutants. The process to monitor effluents, stormwater runoff, and sediments received in natural aquatic systems required a first-hand detailed assessment of the status and importance of these systems. Environmental ecologists based on the inventory and functions of aquatic systems classified systems to regularize their uses and management. Thus, the designated uses of such systems as potable water, bathing/recreation, fish/shellfish farming, etc.

Management regulations, following the US CWA, are based on the allowable discharge of nutrients, pathogens, sediments of high priority, and toxic organic chemicals (U.S. Environmental Protection Agency, 2004). The effects of these, respectively, through eutrophication, public health, and ecosystem community health acted as guidelines for monitoring and management. Other constituents considered as of intermediate and low priorities included some selected trace metals such as lead, hazardous materials such as oil and chlorine, plastics, and floatable material. The designated use of the system or its status in terms of water quality was a fundamental basis for setting limits for receiving the mentioned contaminants/pollutants. Thus, a system that was used in shellfish culture had stringent heavy metal loading limits than that which was used as conduits from treated sewage plants.

Similar to findings leading to the enactment of the US CWA and its adherence, the European Union water directive (EU WFD) emphasizes the need for a watershed/river basin approach to addressing management issues of pollution and overexploitation by encouraging stakeholder/ users participation in the planning, management, and policy processes for sustained success, and to improve in evaluation strategies due to the complexity of interlinked urban coastal challenges impacted by global events of climatic change (Voulvoulis et al., 2017). Creary (2003) also identified stakeholder participation among four integral components to achieve coastal zone management - integration (sectoral, disciplinary, and governmental levels), boundary (as associated with watershed issues), governance, and global/regional scale issues. The author described the key role of stakeholders in the entire process to effect transparency needed in reviews and considerations by the local community which shape policy formation.

2.5 General Water Quality Assessments Across Africa

An attempt to undertake a general overview of water quality across Africa shows that many African countries face a plethora of issues due to anthropogenic activities such as urbanization, agriculture, industrial waste dumping, poor sanitation, mining, deforestation, and untreated wastewater runoff (UN Water, 2019). Ecosystem roles and functions which are affected as a result of these activities may include fish catch declines, habitat loss, invasion of non-native species, and weakened support from ecosystems. The effects on public health from increased disease outbreaks, infections, and weak immunity, are usually the riveting reasons to address issues of sanitation and pollution which in turn reflect on improved water quality.

The overarching focus to provide better living conditions for Africans by leaders imply a disjoint in the assessment of natural environments whose resources ensure the realization of the intended goals in preference for infrastructural development. The fact however remains that as regular signatories to environmental conventions and treaties, deliberate and focused efforts must be made to achieve a semblance of sustainability as underpins most environmental agreements. For instance, the Ramsar Classification System (RCS) which forms a part of the Ramsar Convention enjoins all member countries to adopt the Wise Use concept of wetland exploitation (Frazier, 1996). In this regard, the several more wetlands which do not make it on to the List of Wetlands of Importance, are advisedly classified based on their physical and ecological importance and evaluated through the harmonization of policies and jurisdictional legalities to help direct their assessments, use, and protection

(Davis, 1994). When integrated into National Environmental Action Plans and similar programs, the otherwise estranged notion of strictly protecting wetlands can be avoided so that sustainable practices can be employed to support livelihoods (Kabii, 1998) while ensuring maintenance of the functions of wetlands as important interlinking systems for posterity.

Similar issues of coastal environmental degradation affect African countries such as faced by a sub-unit of a Ramsar designated Coastal Lagoon (1017) in Benin where the proliferation of aquatic weeds and decay have led to high organic matter content and eutrophication conditions impairing water quality. Complicating the issues further was observed anthropogenic pressures through salt production, tourism, fishing, oyster farming, untreated wastewater, and solid waste discharge (Adandedjan et al., 2012). Research by the authors showed that macroinvertebrates were good bioindicators for conservation and management programs due to knowledge gathered concerning the relatively long-life cycles of the macroinvertebrates among other taxonomic groups and their sedentary life patterns. Another study on the Ogbe Creek in a heavily-populated city of Lagos, Nigeria, indicated similar negative effects of municipal wastewater and contamination by nutrients on zooplankton and microbenthic communities (Saliu & Ekpo, 2006). The high abundance of pollution-tolerable invertebrates with low species diversity among plankton and microbenthic organisms pointed to the deterioration in the water quality of the urban area.

In South Africa, issues associated with poor water quality included raw and partially treated sewage discharge, unsustainable exploitation through fishing, tourism and recreation, and solid waste disposal (Edokpayi et al., 2017).

The review by the authors ascribed the issues identified to increasing urbanization, industrialization, and the ease of access to natural surface water systems exposing them to runoff from farmlands containing pesticides and nutrients, detergents, and personal care products from households, and pharmaceutical wastewater discharge. The effects of these besides affecting water quality also impacted heavily on the biotic health of fish and other life forms whose habitats were altered, biodiversity, and general use through tourism and aesthetics (Edokpayi et al., 2014). The way forward to improve water quality as suggested by the authors was to strengthen the government's implementation of regulations and application of stiffer sanctions for unlawful usage of surface water bodies.

Gritzner (1986), identified neglect of common property such as coastal lagoons as a major factor in observed unsuccessful development projects. In Africa, the situation persists because while priority is placed on coastal resources based on interest groups and political agenda, ICZM focuses on eliminating the bias which reflects in management by interest groups. As a guiding principle, he advocated that adequate sensitization and education which equipped stakeholders, interest groups, and government institutions in the selection of management options reflective of overall objectives to be set at international/global scales. Thus, regional coordinators could provide long-term objectives and share expertise which leads to local level initiatives and impel adoption strategies tailored to suit unique conditions. Documented efforts by the US and Europe during the early 1970s translated into assistance (funding and training in capacity building towards the 1980s) to African countries by groups such as the United States Agency for International Development [USAID], Swedish International Development Cooperation Agency [SIDA], Danish International Development Agency [DANIDA], etc.

2.6 Is Coastal Management in Ghana a Recently Adopted Strategy?

Environmental issues related to pollution, sustainability, and conservation gained world focus in 1972 at the Stockholm Conference on the Human Environment. Following this, in 1973, Ghana formed the first formal environmental management governing body in Africa called the Environmental Protection Council [EPC] (en.m.wikipedia.org, 30/04/19). Management efforts by the EPC were enhanced further on the international fronts through agreements among states at the World Commission on Environment and Development in 1987. The key focus was to encourage sustainable exploitation through a proposed framework of integrated environment policies and development strategies to ensure poverty alleviation albeit without degradation of the environment. An Environmental Action Plan (EAP) was formulated by the EPC, with help of local participants, to direct development towards more environmentally sustainable programs. Initiatives proposed were to identify land and water environmental issues of concern, evaluate multi-use alternatives necessary to reduce costs of these issues through mitigative measures, and include local community participation in planning and implementation of programs. Separate sector working groups set up in July 1988 prepared, as part of the EAP, marine, and ecosystems' draft strategies for action. The strategies addressed among other objectives were an assessment of existing knowledge, identification of information/data gaps, a review of legislation and recommendation of policies, proposed change monitoring procedures, review of existing projects to ascertain adaptability and suitability and review institutional arrangements required in the entire management process to strengthen appropriate agencies. Thus, Coastal Management is not a recently adopted strategy in Ghana. It succinctly formed a part of EPC's planning, as suggestive of preceeding efforts by several groups' initiatives to safeguard the environment. Some of these initiatives which had restoration and conservation of natural environmental resources as focal areas of address include: the Scientific Committee on Problems of the Environment (SCOPE) of the Ghana Academy of Arts and Science; the Conservation Committee of the Council for Scientific and Industrial Research (CSIR) Institute; the Ghana Working Group on the Environment; and the National Committee on the Human Environment formed by the Ministry of Foreign Affairs

Ghana's Environmental Protection Agency Act of 1994 (*Act 490 - Environmental Protection Agency Act*, 1994) empowers the Environmental Protection Agency (EPA), which metamorphosed from the EPC, as the authority responsible for, among many other functions, the coordination and linkage between mandated organisations and groups on environmental issues. Act 490 also states the monitoring and management opportunities solely by the EPA or in collaboration with other agencies towards the "control and prevention of a discharge of waste into the environment". Pursuant to the protection of environmental quality, Act 490 enjoins the EPA to "prescribe standards and guidelines relating to the pollution of air, water, and land" (Act 490 - Environmental Protection Agency Act, 1994).

The EPA is mandated to address coastal zone issues because, in recent times, growing urbanisation and industrialization have heightened environmental degradation, particularly in natural water bodies and along the coastal zone (I. Boateng, 2006; FIG Commissions 4 & 7 Working Group 4.3, 2006). The coastal zone of Ghana, which is the area below 30m contour, covering about 7% land area supports about 25% of the entire Ghana population and sites 70% of industries and commercial setups (Aryee, 2016; Churcher, 2006). Climate change and its related effects have rendered coastal ecosystems more vulnerable to anthropogenic impacts of urbanisation and industrialization (Pachauri et al., 2007). Besides coastal erosion, flooding, and coastal land loss to development, which put pressure on coastal ecosystems, pollution is a major issue affecting ecosystems' health and provision of ecological goods and services (A. K. Armah & Amlalo, 1998). Coastal ecosystems such as lagoons and estuaries are among the most vulnerable ecosystems in Ghana due to their unique and complex dynamics.

The setting of standards and guidelines by the EPA to provide limits to control the discharge of contaminants and/or pollutants requires water quality assessment to develop numeric/quantifiable criteria or narrative criteria. In this regard, the Ghana National Environment Policy (NEP) and other related policies seek to among others, improve the livelihoods of Ghanaians by ensuring improved water quality, restore and maintain biological diversity in an ecologically healthy environment, support sustainable exploitation for economic growths and conserve highly vulnerable ecosystems. The importance of integration at all levels and covering relevant disciplines is stressed in the policy process.

2.6.1 Sustainable coastal management in Ghana

The 1992 constitution of Ghana states the need to safeguard and protect the environment by all citizens *(The Constitution of the Republic of Ghana: The Directive Principles of State Policy, Chapter 6.*, 1992). Owing to a lack of specific address of policy on the coastal zone, the need for integrated coastal zone management and sustainable development by stakeholders (Amlalo, 2010) have led to plans and projects such as:

a. Coastal Zone Management Indicative Plan, 1990

   The Coastal Management Indicative Plan which was drafted prior to the United Nations Conference on Environment and Development Earth Summit in Rio de Janeiro, Brazil, from 3 – 14 June 1992, later reflected in the National Environmental Action Plan. Under the leadership of Franciska Issaka, who was acting chair of the EPC, the Plan was essentially as its name suggested – indicative, of an agenda to focus on coastal zone issues as unique complexities in environmental issues assessment and address.

b. National Environmental Action Plan, 1994

A group of scientists (environmentalists and academicians) was consulted by the EPC to draft the National Environmental Action Plan in 1991, later adopted in 1994. The Action Plan was as multi-faceted in its outlook considering the government's ratification on international protocols such as the Convention on Biological Diversity and the United Nations Framework on Climate Change. It identified environmental degradation of our coastal areas as a major issue requiring address. The Action Plan was further impressed on through a national environmental policy, which was formulated after the 1992 Constitution was established. The transformation of the EPC to EPA under the Ministry of Environment, Science, and Technology meant a continuum of the Action Plan as a guiding document.

c. Draft Integrated Coastal Zone Plan, 1998

In a collaborative effort with the World Bank, the Draft Integrated Coastal Zone Plan of 1998 which began as an initiative in 1995 focused on the identification of environmental and socio-economic strategies necessary to implement sustainable exploitation of coastal natural resources. A balance between exploitation and protection of coastal ecosystems was a key feature of the Integrated Coastal Zone Plan. It also advocated for a participatory approach involving all relevant sectors, stakeholders, and users of coastal zone resources.

d. Coastal Zone Profile of Ghana, 1998

Documentation of the morphological extent of Ghana's coastal zone is provided in the Coastal Zone Profile of Ghana 1998. The profile showed the various demarcations within which terms of reference can be made for consistency in assessments and exploitation.

e. Environmental sensitivity map of the coastal areas of Ghana, 1999 and 2004

The EPA in collaboration with the United Nations Development Programme (UNDP) produced an Environmental Sensitivity map in support of coastal management as part of a National Oil Spill Contingency Plan. Areas along the coast which were prone to effects of a possible oil spill(s), dependent on ecological and human use exposure, were highlighted. Ecosystems that were focal points included different types of coastal lagoons, mangroves, estuaries, other coastal wetlands especially designated Ramsar sites, rocky and sandy shores.

A coastal and marine habitat management regulations bill has been developed, presently, by the Ghana EPA to protect, enhance, and restore the quality of coastal zones in Ghana (Classfmonline, 2019b). The seeming untouched area, however, has been in existence over several decades in various clearly defined concepts backed by scientific studies. The hope is for an easy passage of the bill into law by Ghana's parliament to reinforce sectoral efforts to curb activities that degrade coastal zone ecosystems. Lagoons are among the six identified sensitive habitats to be regulated. The focus by the bill when it is passed will be to recognize coastal ecosystems as intricately linked ecosystems that require holistic approaches in monitoring, restoration, and management.

DSS tools are a way forward to achieve sustainable management goals through planning within coastal zone environments.

2.7 Chapter Summary

The literature reviewed indicated that the valuation of coastal ecosystems contributes to the monetary appreciation of the many benefits of coastal ecosystems, thus their considerations in environmental conservation and management plans. Coastal lagoons that form integral features in coastal ecosystems have unique characteristics largely influenced by their relatively shallow depths, ephemeral life spans, and hydrological balance. On the basis of environmental justice, the sustainable use and management of coastal lagoons were imperative whether there were present benefits being derived or potential opportunities to exploit. The extent of issues address determined their effectiveness, thus watershed/basin-wide scales are targets for coastal ecosystem assessments. Spatio-temporal assessments essentially included nutrients and physicochemical parameters, and sediment studies. Exchanges between the overlying water and sediments were controlled by factors (referred to as indicators) of importance to note during assessments. Biological indicators were also of importance in the effort to reflect the conditions of the abiotic environment. Biodiversity metrics of abundance, dominance, and distribution indicated the responses of endemic organisms to the environment and subsequently to changes in the coastal ecosystem from stressors. The use of indices and indicators, and a more advantageous DSS aided in the selection of measures for remediation, restoration, and management of coastal lagoons. The policy environment in support of coastal management in Africa was reviewed. With many African countries being regular signatories to agreements and treaties, important requirements of sustainable funding, adequate expertise, and political will to execute plans and programs successfully are necessary. Ghana's formation of an Environmental Protection Council following the 1972 Stockholm Conference on Human Environment, set the pace to enact environmental protection laws in the sub-region. The sustainability of programs by the present Environmental Protection Agency, however, hints at opportunities to improve on sectoral efforts to address coastal ecosystem issues.

CHAPTER THREE

MATERIALS AND METHODS

Introduction

This Chapter describes the Fosu lagoon as the study site, its topographical and climatic characteristics, and socio-cultural dimensions. It also elaborated on the sampling protocol following six selected stations with unique immediate surroundings and activities to fairly reflect on processes while representing the entire watershed. Monthly *in situ* measurements for physicochemical parameters, and collection of water for laboratory analysis for nutrients, chlorophyll-a, and bacterial testing, were carried out over the 14-month study period from November 2016 to December 2017. Three replicate samples, over quarterly intervals, of sediments, were taken to undergo granulometric analyses. Fish catch data and a bird survey was employed to evaluate the quality of the environment on biotic health. Land-use practices were observed and assessed through digital elevation models of drone imagery. Data analyses of the various elements under consideration included a principal component analysis of physicochemical parameters and nutrients for variability information required for water quality and trophic status indices utilization, sediment quality considering the dominant grain sizes, porosity, organic matter content, and ammonia concentrations. Biotic metrics of fish growth and avifauna assemblages/functionality were analyzed. Both abiotic and biotic indicators and metrics were included in a multi-criteria DSS

3.1 The Study Area

The Fosu lagoon (5°6'17.87" N, 1°15' 18.68" W), is a major feature within the Cape Coast Metropolis, the capital of the Central Region of Ghana covering an area of about 122 km^2. The Fosu lagoon, which covers about 61 hectares (Blay & Asabere-Ameyaw, 1993), is a typically restricted lagoon with its longest axis perpendicular to the Atlantic Ocean. It receives runoff from several drainages within its catchment. It is bounded at the northern sections by a mechanical garage, an intercity bus transport terminal, and several municipal infrastructure and developments. Some schools, a hospital, morgue, nursing training centre, and recreation facility are found on the eastern bank of the lagoon. The western side is dominated by communities and local small-scale setups of livestock rearing (piggery), sawdust mill, and molding of building blocks (using sand from sand-winning activities).

Two wet seasons and a dry season which are typical of Ghana's coast influence the lagoon – the major wet season is from April to July and a minor wet season from September to November (Gilbert, Dodoo, Okai-Sam, Essuman, & Quagraine, 2006). Flood events tend to reflect in wider coverage of the lagoon. A small thatch of mangrove is found at the south-western side of the lagoon and lush vegetation is seen on a hilly north-western side.

The National census estimated about 169,894 population within the Cape Coast metropolis in 2010, an increase of about 2.0% of the year 2000 census figure (Ghana Statistical Service, 2015, 2019). The heavily populated area (Figure 3.2) faces two major social issues of concern of perennial portable water shortages and poor sanitation. In communities such as Bakaano where several socioeconomic issues of poverty affect many inhabitants, a scalogram analysis by the GSS points to the following as areas that require address: unemployment, inadequate employable skills, large dependent households, the poor land tenure system, and inadequate involvement by communities in facilities/amenities provision. The latter is reflective of low patronage of government initiatives and low participation in developmental projects. The Fosu lagoon regarded as a goddess by the indigenes plays a significant role during the annual Fetu *Afahye* (festival) of the traditional clans of Cape Coast (see Figure 3.3). The annual festival celebrated in September is preceded by a ban on fishing and access to the lagoon in August, while a ritual is done involving breaching of the sand bar which restricted the lagoon flows into the sea. Fishing activities, primarily subsistence fishing, occur daily except every Tuesday and in August which are regarded as taboo day and month, respectively. The blackchin tilapia (*Sarotherodon melanotheron*) is dominant and caught using traps, cast nets, and drag nets. Fishers wade through the lagoon at shallow ends or use paddled wooden boats.

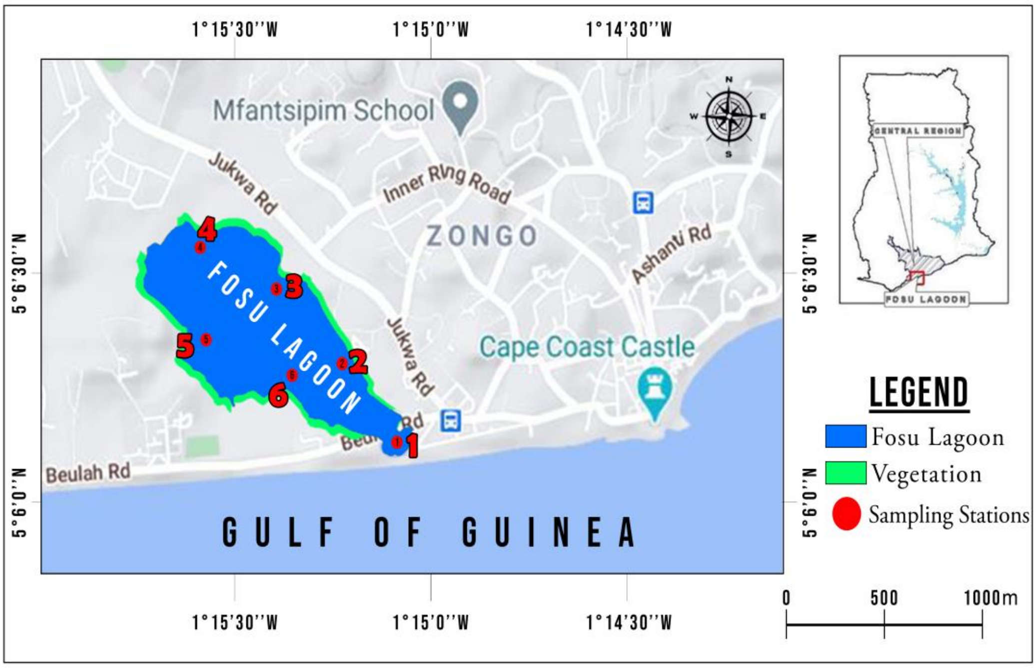


Figure 3.1: Site map of Fosu Lagoon

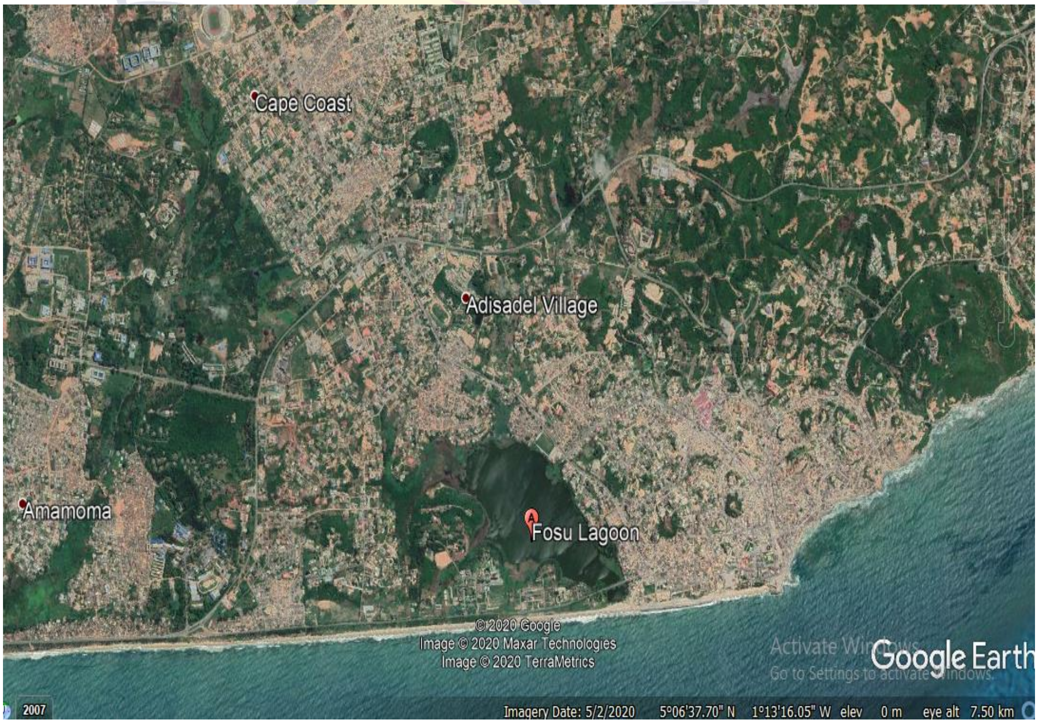


Figure 3.2: A georeferenced image of the Fosu Lagoon showing heavy human settlement (courtesy: Google Earth)

Figure 3.3: Fetish shrine hidden in the mangrove, symbolic of cultural reverence by indigenes

3.2 Sampling Procedures

Six sections of the Fosu lagoon were sampled to represent the upper reaches, middle section, and lower reaches of the lagoon. Stations 1 and 2 represented the lower reaches of the lagoon, however, Station 1 was the mouth of the lagoon connected to the entire lagoon via a concrete constructed culvert. Station 3 was closest to the garage and Siwdu vehicle mechanic working area, whereas Station 4 was the farthest accessible upper reach of the lagoon. Stations 5 and 6 were located behind the St. Augustine's Senior High School field and morgue of the Cape Coast Metropolitan Hospital, respectively. Monthly field visits and sampling were carried during the third week of every month over a 14-months period starting November 2016 and ending in December 2017. During each monthly visit, human activities within the catchment were noted, while sampling and recording were conducted aboard a motorized and paddled dinghy for physicochemical, biological, and related land-use impacts.

3.2.1 Sampling of abiotic parameters

A multi-parametric water quality checker probe (H19829) was used for mid-depth *in situ* measurement of water temperature (°C), dissolved oxygen (mg/L), specific conductance (µS/cm), total dissolved solids TDS (ppm), salinity (PSU), and pH. A turbidimeter (Oakton T-100) was used in measuring turbidity (NTU).

Samples of water were collected in 500ml bottles for nutrient analyses in the laboratory. Bottles containing sampled water for chlorophyll estimates were covered with black plastic bags and taped to avoid light penetration which supports photosynthetic activities by phytoplankton. All samples were stored at 0^{o}C under ice in an ice chest and later transported to the Department of Fisheries and Aquatic Sciences laboratory for analyses.

Inorganic nutrients analyses

Following instructions by the HACH Company, spectrophotometric analyses (Spectrophotometer HACH DR 900) were carried out involving reagent powder pillows which were added to aliquots of previously sieved samples to be assessed for nutrients – nitrates, phosphates, ammonia, and silicates in water.

Nitrate was measured following the Cadmium reduction method (Hach Company, 2014a). Here, the test type was selected (353 N, Nitrate MR PP) and an aliquot of 10ml sample taken. The sample was prepared by the addition of the contents of one NitraVer 5 reagent powder pillow. The instrument timer was set for a one-minute reaction time within which period the prepared sample was shaken vigorously. Then, after the 1min expired, the timer was set for a five-minute reaction time (an amber colour was indicative of nitrate presence). A blank was prepared and used to zero the instrument. Within two minutes of reaction time expiration, the prepared sample was read in mg/L NO_3-N.

For phosphate analyses, guidelines in the USEPA PhosVer 3 (Ascorbic Acid) method (Hach Company, 2017) were followed in the preparation and analyses of samples. After the selection of the test type on the spectrophotometer, a sample cell was filled with 10ml of the sample. The entire contents of one PhosVer 3 phosphate powder pillow were added, the sample was stoppered and shaken vigorously for 30 seconds. The timer was set for a two-minute reaction period. A 10ml blank solution was prepared (without reagent), wiped, and inserted into the spectrophotometer's cell holder after the timer set at 2 mins beeped. The instrument was then zeroed, the blank was taken out and the prepared sample was inserted into the cell holder for reading in mg/L $PO4^{3-}$.

Nitrogen-Ammonia was measured following the Salicylate method (Hach Company, 2018). The test program was selected at 385 N-Ammonia-Salic. Two cell bottles were filled with a sample of 10ml (test sample) and 10ml of deionized water (blank). The contents of one Ammonia Salicylate were added to each cell, stoppered, and shaken to dissolve. The instrument timer was set for a three-minute reaction period. After the period expired, the contents of one ammonia cyanurate reagent powder pillow were added to each cell. They were both stoppered and shaken to allow dissolution. A 15-minutes reaction period was allowed (green colouration indicated the presence of ammonia-nitrogen). After 15 minutes, the instrument was zeroed using the blank. The sample was then read in mg/L NH_3-N.

Following the Silicon molybdate method (Hach Company, 2014b), the spectrophotometer was set at 656 Silica HR program. A sample cell was filled with 10ml of the sample. One molybdate reagent powder pillow was added to the sample and swirled until completely dissolved. Then, one acid reagent powder pillow for high-range silica was added and swirled (a yellow colour indicated the presence of silica or phosphorus). A 10-minute reaction period was set. After that, one citric acid powder pillow was added to the sample cell and swirled to dissolve. The yellow colour due to phosphorous was expected to be removed after that addition. A blank was prepared by filling a cell with 10ml of the original sample, the blank was used to zero the spectrophotometer. The prepared sample was inserted and read in mg/L SiO_2.

Sediment parameters

A surficial grab sample of 2 litres volume was collected at each station in three replicates. The sediment samples were bagged in plastic seal bags, labelled accordingly, and transported to the laboratory for analysis. These sediment samples were characterized based on grain size, porosity, and organic matter content. These parameters were measured as follows:

a) The sediment grain size was estimated by the following steps. Firstly, 300g of the wet sample was measured by a taring technique using a

Ranger 7000 Balance (Model: R71MD15, Max. 15kg Min. 0.04kg, error = 0.002kg, precision) and spread in a polystyrene tray for air drying. Then, about 120g of the dried sample was weighed into a petri dish. A 10% sodium hydroxide solution was prepared to be mixed with the dried sample to aid the separation of sediment particles. The measured sediment sample was poured into a 63µm mesh sieve and washed gently in the prepared sodium hydroxide solution. Fine sediment particles (silt) smaller than 63µm washed through into a holding pan. The remaining sample (i.e. the residue left in the sieve) was gently washed (with the aid of a wash bottle) into a pre-weighed beaker and oven-dried at 60°C for 24hrs. The dried sample was weighed again to determine the actual weight. Then, the sample was shaken for 10 minutes over a set of sieves of different mesh sizes - 1mm, 710µm, 500µm, 355µm, 125µm, and 63µm. A collecting pan at the base of the granulometric device collected the finer particles. Samples retained in each sieve were transferred using a soft brush and weighed separately. The weights of each sample were recorded as percentages of the original sediment sample used. The mean grain size of sediment samples, degree of scatter (sorting), and skewness which suggest the dominant grain sizes were calculated as shown in Equations 1, 2, and 3.

b) The porosity of the sediment samples was recorded as the percentage difference of water required to completely saturate a known volume (100g) of dried sediment samples (Banerjee & Law, 1998). This was done by gently pouring water of known volume into a beaker holding the sediment sample till the sediment sample was covered at the immediate surface with water. The difference in water volume (representing the porosity) was recorded as a percentage of the initial water volume.

c) Organic matter content of sediment was determined using the loss of ignition method (Dean, 1974). The crucible for the sample was dried at 105°C for 1 hour. Then, the dry crucible was then cooled in a desiccator for 30 minutes. The weight of the crucible was recorded as W_C. The crucible was half-filled with the sediment sample and dried at 105°C overnight. This was cooled and reweighed as W_S. It was placed into the furnace tray and it was left for 4 hours at 500°C. Here, the hole of the furnace tray faced the door of the furnace to help in extracting the tray after the allotted period. The extracted tray was placed onto an asbestos sheet for at least 5 minutes to initially cool, before placing crucibles in a desiccator to cool completely. The reweighed crucible with ash was recorded as W_A. Equation 4 shows the calculation for organic matter using the loss on ignition method.

Heavy metals in water column and sediments

Secondary data on selected heavy metals was utilized from a separate study within the same period. The levels of heavy metals - arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg);

nickel (Ni); iron (Fe) and zinc (Zn) were measured in collected samples of water and pore water of sediments through the use of the VARIAN AA 240FS – Atomic Absorption Spectrophotometer (AAS) after samples' preparation at the Chemistry Department of the Ghana Atomic Energy Commission (APPENDIX A1 and A2)

3.2.2 Biotic Factors

Biological communities are considered as dependents of the physicochemical environment thus they serve as good indicators of environmental quality (Holt & Miller, 2010; Zhu & Chang, 2008). This research focused on important biotic components of chlorophyll-a concentration (as a measure of primary producers), fish, and water birds.

Determination of Chlorophyll-a concentration

Bottles containing samples were well shaken and filtered using Whatman 210µm ashless paper. The filtrate was placed in Petri dishes and covered. A 10 ml acetone solution was measured and poured into each petri dish, covered to avoid evaporation, and kept in a refrigerator overnight. Acetone solution was used in the extraction of the pigment from the filtrate. The sample was then pipetted into reaction tubes for spectrophotometric tests (using HACH DR 2800) (Hach Company, 2007). The absorbance of each sample was read at wavelengths of 630nm, 647nm, and 664nm, and their Optical Densities (OD) were recorded and used in the calculation of chlorophyll-a as shown in Equation 4.

Fish counts

On each monthly visit (except in August), experimental fishing was carried out for 4 hours from 6.00 – 10.00 GMT, which is a typical fishing period, by three hired local fishermen in the upper, middle, and lower reaches. Cast nets of half-inch mesh size (12.7mm) were used. Fish caught were gathered into floating baskets (Figure 3.4) as fishing continued. Fish was kept on ice and transported to the laboratory of the Department of Fisheries and Aquatic Sciences, University of Cape Coast, for counts and measurement of standard length (SL), total length (TL), and total body weights (W).

Figure 3.4 Floatable baskets for holding caught blackchin tilapia while fishing continues

Avifauna survey

Four points were selected as stations (north, central, south, and mid-south) for bird counts. These points were about 30m - 50m apart to reduce the possibility of double-counting of birds (Hostetler & Main, 2014). Each station's counting point was approached quietly and the birds were allowed to get used to the invasion by waiting a few minutes before counts were taken. The counts were made in the morning at 6.00 – 9.00 GMT and evenings from 15.00 – 18.00 GMT when bird activities were at their peak (Figure 3.5). Identification of birds was done to the species level using the "Helm Field Guides: Birds of Ghana" (Borrow, Demey, Owusu, & Ntiamoah-Baidu, 2010). Birds were counted by the aid of binoculars (at 10x magnification, 50mm diameter objective lens) and distinct calls associated with common birds were included as the presence of birds. Other variables noted during bird counts included noise rate measured in decibels (dB) by an installed sound level meter application, and human presence was done through counts. The selected variables are termed as identifiers of anthropogenic effects on bird assemblages (Posa & Sodhi, 2006).

Figure 3.5 Bird sighting among mangrove plants

3.2.3 Land-use effects

Previous studies by the Centre for Scientific and Innovative Research for the CCMA in 2013 included delineation of the Fosu Lagoon catchment. The shifts in boundaries as revealed by the study were indicative of changes in the hydrography and related factors, and changes in land-use practices from growing urbanisation. In the present study, a bathymetry map accessed from processed digital elevation models (DEM) by the United States Geological Survey was used to determine the extent of flow into the watershed, while land-use changes resulting in point sources of drainage/pollution and vegetation buffer zone extent were studied using an unmanned aerial vehicle (UAV) and through direct observation through frequent field visits. Public health issues resulting from disposed of solid waste and levels of bacteria (coliform and *Escherichia coli*) in the lagoon were also assessed.

Drone/UAV work

Drone flights were undertaken in December 2018 by deploying an Aerospace fixed-wing Bramor. Under the guidance of a trainer, the drone was catapulted to a height of about 40m above the ground reference point while covering a pre-demarcated area (Figure 3.6) to capture imagery at 10cm/pixel resolution within the Fosu Lagoon catchment.

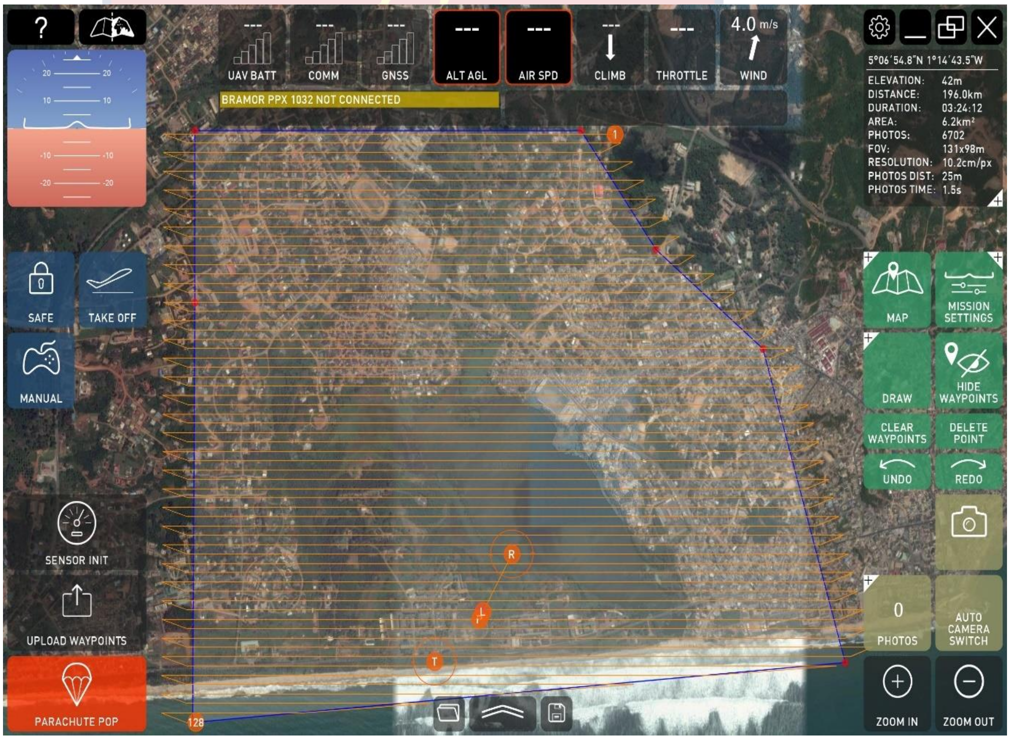


Figure 3.6 Bramor UAV flight plan over the Fosu Lagoon catchment

Littoral vegetation estimates

Vegetation that fringed the lagoon was of importance to the study. Field visits were intended to determine vegetation type along transects of the regulatory buffer width of 30m for wetlands (Ministry of Water Resources Works and Housing, 2011). Littoral vegetation coverage was estimated from drone images to ascertain breached buffer zones through encroachment.

Solid waste collection and sorting

Solid waste found within the lagoon area (flotsam) were sampled over a 35m radius (about the length to the base dimension of a cast net). Waste was spread on a makeshift working area at the bank of the lagoon, allowed to drain, and sorted into groups. Counts were made where possible and weights were estimated for items that were water-resistant.

Bacterial loads

Bacteriological analysis was needed to ascertain loads of coliform bacteria and *Escherichia coli* due to untreated waste discharges from the municipal and surrounding catchment. On each monthly visit, 20ml samples were taken in three replicates at the six stations. Sterile tubes that were used in the collection of samples were stored over ice. Laboratory analysis was done following "Standard Methods for the Examination of Water and Wastewater of the Water Research Institute". A serial dilution of 15ml to 9ml phosphate buffer saline solution was prepared and autoclaved to control the increase or decrease in suspected bacteria loads in samples during the culture period. *E. coli* and coliform brilliance in selective agar (showed as a chromatographic medium) were prepared without autoclaving. The medium was heated to boil so that the agar melted to have uniform suspension in the petri dish, then it was cooled at

50°C to 45°C. Serial dilutions were made from the stock sample i.e. 9ml to 1ml of the sample. The dilutions of the stock were put in corresponding labelled tubes (i.e. from the stock to10^{-1} strength, from 10^{-1} to 10^{-2}, and from 10^{-2} to 10^{-3}). Observations were made for bacteria growth in the dishes. With the aid of a colony counter (Figure 3.7), *E. coli* colonies which were seen as pink circular patterns were counted, and likewise, coliform colonies were indicated by purple coloured colonies.

Figure 3.7 Bacteria colony counts using the GEKAMP Ccdsolony Counter

3.2.4 Questionnaire administration

A semi-structured questionnaire was designed (as shown in APPENDIX B-1) and administered to 33 selected relevant ministries, agencies and groups, via one-on-one interviews and telephone communication. The relevant agencies and groups (APPENDIX B-2) were selected based on their mandatory roles through the 1992 Constitution of Ghana or documented roles played in coastal resources management as lead implementers of environmental regulations (*Act 490 - Environmental Protection Agency Act*, 1994; Sarpong, 1995; Water Resources Management Study, 1998). Criteria for exclusion were dependent on a lack of agencies' direct involvement and responsibility for coastal management in Ghana. The semi-structured questionnaire was composed of a background on the concept of 1CZM and the challenges of its adoption and success regarding disjointed sectoral efforts. Then, information about the respondent/agency was recorded. Representatives of the selected agencies and groups responded to questions intended to: determine the level and scope of their coastal zone management related activities; functions of their groups; collaboration efforts and situations which elicited their responses; specificity of their responses and mandatory roles i.e. in awareness creation or direct field assessment/implementation; sustainability of activities; funding sources; time frames of activities; and level of success associated with their activities. Through a review of literature, a list of selected agencies and groups was made and an enquiry was made on other aspects such as the challenges experienced in mandates/roles and opportunities available to assist in future management projects.

3.3 Quality Assurance

- Measuring instruments and probes were calibrated prior to each field visit and laboratory use.

- Field visits were made as routinely as possible. However, a couple of days was allowed for conditions to return to normal after heavy rains.
- The dinghy's outboard motor was turned off as each station was approached. A few minutes were allowed for settling prior to inserting a water quality probe to read variables and during the collection of samples.
- Samples for chlorophyll-a analysis were kept covered with black plastic to prevent light penetration.
- Sediment samples that contained more than half of debris in the grab were discarded and the closest point sampled. The top 5cm layer, where most active biological activity occurs, was sampled.
- Samples sent for laboratory analysis were kept on ice/refrigerated and worked on as quickly and efficiently as possible.
- Equipment for bacteria testing was autoclaved to prevent compromising results.
- Contents of reagent powder pillows were inspected to be certain they showed characteristic colour before used in the nutrient analysis.
- Raw data were expressed in the exploratory analysis as mean values with stated deviation, while others such as results of bacteria tests were expressed as percentiles.
- Reproducibility studies included utilization of secondary data of heavy metals analyzed in sediments in relation to aspects of other recent studies (Armah et al., 2012b; Eshun, 2011; Owusu et al., 2013). Differences in

sampling periods of the studies and protocols of analyses, however, were noted. Physicochemical parameter measurements in the mentioned studies informed of conditions that existed. Bacteria tests of faecal coliform and *Escherichia coli* tests in the latter were used in comparison of results in this present studies. Experimental fishing using a cast net gear for morphometric analyses of the *Sarotherodon melanotheron* i.e. dominant blackchin tilapia (Dankwa et al., 2016) was carried out in the present studies over a 14-monthly period in comparison to the 5-days sampling period in the earlier work.

3.4 Data Analyses

3.4.1 Water and sediment quality assessment

To ascertain major drivers of eutrophication and pollution in the Fosu lagoon, a principal component analysis (PCA), was used to show the contributions of water quality variables focusing on the strongest patterns within the dataset. Gan et al., (2017) indicate two main methods required in the development of sustainability indicators and indices – Weighting Methods and Aggregation Methods. The water quality indices selected for this research rely on the weighting concept whereby existing conditions of water quality are empirically proven to be dependent on major factors among other interacting abiotic variables. In the review conducted by Gan et al, environmental studies' statistical-based weighting methods adopted included; PCA, Benefit of the Doubt Approach, Regression Analysis, and Unobserved Component Models.

The PCA was selected out of other weighting methods for its major aim, like Factor Analysis, to reduce dimensionality in data with few losses in significant information. Also, the PCA was selected because it considers a large number of variables. In the present study, three replicates of seven physicochemical parameters per sampling session over a 14-months period were analyzed to find which parameters represented the strongest relationships along dimensions produced. Brems (2017), emphasized that the "new" variables (which are transformations from the raw data), referred to as principal components, were independent of each other, to clearly support the assumption of independent variables made in linear models i.e. water quality indices for the present study. To interpret the PCA, the total factor loading of the PCA1 (along the first dimension and the second factor loading of PCA2 (along the second dimension) must provide a good percentage to show reflection of the analysis with the original dataset. Thus, preference is made for the closer summed values of two dimension to 100%. However, in the present study, the first two dimensions are used for comparative purposes. The eigenvalues, which indicated the direction and magnitude of the variables showed the relationship (positive or negative) between variables. Eigenvectors, reflected same i.e. direction of variables in relation to others. Shorter vectors pointed to weak representation to the selected dimensions of analysis, while obtuse angles inferred on the wide relationship between variables, and vice versa for angles less tha 90^{o}. The contributions of all variables to the PCA is, in effect, the 'weights' of the variables to the observed conditions. A disadvantage of the PCA as a weighting method however, is that more pronounced relationships along selected dimensions that were not included may be overlooked.

PCA was done by employing an add-on feature XLSTAT in Microsoft Excel. Physicochemical parameters variations on estimated Chlorophyll-a concentrations, and between nutrients and Chlorophyll-a were analyzed through correlation analysis. The data was normalized prior to this analysis since the dataset did not meet the assumptions of normality and equality of variance (Mascaro et al., 2011). The identified major drivers were weighted and used in a lagoon water quality index (WQI).

Other indices used to describe water quality-focused on selected parameters (from indices' proponents) which are known to indicate water clarity and dissolved oxygen concentration in a Water Quality Minimum (WQI_{min}), and the adapted WQI by Ghana's Water Research Institute referred to as the Solway Index (hereafter, referred to as WQI_{GH}) which focused on dissolved oxygen, ammonia concentrations, faecal coliform, pH, nitrates, phosphates, conductivity, and temperature because these were also considered important for existing water uses of the Fosu Lagoon. The trophic status and trophic level indices (TSI and TLI) were used for the assessment of primary productivity of the system on the assumption that samples collected contained a true representation of phytoplankton biomass of the Fosu Lagoon. Table 2 shows a summary of indices used in the assessment of water quality and trophic state of the Fosu Lagoon. The three water quality indices used were ranked dependent on their summed Akaike Information Criterion (AIC) values to obtain the most appropriate in the evaluation process. The purpose of the selection of one water quality index was important for further relatable studies and comparisons during monitoring programs.

Heavy metals data were utilized in this study from an independent study carried out by a doctorate student, Margaret F. Dzakpasu, at the Chemistry Department of the Ghana Atomic Energy Commission on quarterly sampled water and sediment within the research period. An outline of the laboratory analytical process is provided in APPENDIX A-1 and A-2. Concentrations of heavy metals in both water and sediments are compared to toxicity reference values from the US EPA and other related studies carried out on the Fosu lagoon to ascertain the levels and implications on water quality and use of the resource.

Table 2: Indices used for the characterisation of water and sediment quality

Index	Functions Definition of variables	Interpretation of Results
Water Quality Index (WQI). (Miller, Joung, Mahannah & Garrett, 1986)	$WQI = \frac{\sum_{i-1}^{n} CiPi}{\sum_{i=1}^{n} Pi}$ Ci = normalized value of parameter Pi = relative weight given to parameter	90–100: Excellent quality 70–90: Good quality 50–70: Medium quality 25–50: Bad quality 0–25: Very bad quality.
Minimum Water Quality Index (WQImin). (Pesce and Wunderlin, 2000)	$WQImin = \frac{C_{Do} + C_{Cond} + C_{Turb}}{3}$ WQI_{min} = Water Quality Index Minimum C_{DO} = the value due to DO after normalization C_{cond} = the value due to either conductivity or dissolved solids (TDS) after normalization; C_{turb} = the value due to turbidity after normalization	A quality percentage, 0-100 scale, with 100 representing the highest quality.
Adapted Solway (weighted) Index for Ghanaian surface waters WQI_{GH} (Ghana Raw Water Quality Criteria & Guidelines, 2003)	$WQI\ GH = \frac{1}{100}(\sum_{i=n}^{n} qi\ wi)\ 2$ WQI_{GH} = Water Quality Index for Ghanaian surface water q_i =quality respective to the parameter under consideration w_i = Weight assigned parameter n = number of parameters (refer to APPENDIX C for weights per parameter measurement)	Class I = >80, water quality is good (unpolluted) and/or recovering from pollution Class II = >50 – 80, water quality is fairly good Class III = 25 – 50, water has poor quality Class IV = water is grossly polluted
Trophic State Index (TSI) (Carlson, 1977)	$TSI = 9.81[In\ (*\ Chl\ a\ average)] + 30.6$ TSI = Trophic Status Index Chl a = Chlorophyll–a, measured in mg/L	The TSI scale ranges from 0 (ultraoligotrophic) to 100 hypereutrophic). 40-50 mesotrophic (moderate productivity) >50 eutrophic (high productivity) <40 oligotrophic (low productivity).
Trophic Level Index (Lambou, Taylor, Hern &Williams 1983)	$TLI = 2.22 + 2.54\log(Chl\ a)$ TLI = Trophic Level Index Chl a = Chlorophyll–a, measured in mg/L	The higher the TLI, the lower the water quality.

$$*\ Chlorophyll - a = \frac{\{11.85(OD666) - 1.54(OD647) - 0.08(OD630)\}}{Sample\ volume\ (L)}$$

where OD(x) is the optical density at the specific wavelength(x) at which spectrophotometric readings of the extract were recorded.

3.4.2 Granulometry

A plotted cumulative frequency curve of the fractions of retained sediment weights in respective sieves (APPENDIX G) allowed the following to be derived following sedimentological equations proposed by Pethick (1969):

$$Mean\ grain\ size\ (\mu) = \frac{(\emptyset 16 + \emptyset 50 + \emptyset 84)}{3} \qquad \text{Equation 1}$$

$$Sorting\ (\text{ø}i) = \frac{(\emptyset 84 - \emptyset 16)}{4} + (\text{ø}95 - \text{ø}5)/6.6 \qquad \text{Equation 2}$$

$$Skewness\ (sk) = \frac{\emptyset 16 + \emptyset 84 + 2\emptyset 50}{2(\emptyset 84 - \emptyset 16)} + \frac{\emptyset 5 + \emptyset 95 - 2\emptyset 50}{2(\emptyset 95 - \emptyset 5)} \qquad \text{Equation 3}$$

where (in Equations 1, 2, and 3), the *phi* ø(x) represents the respective value read on the x percentile of a cumulative frequency curve i.e. ø50 is the value read at the 50th percentile on the cumulative frequency curve. Phi refers to the particle size of sediment that was retained in the mesh of a sieve during granulometric analyses.

Also, $\emptyset = -log2(sieve\ mesh\ in\ millimetres)$

$$Organic\ matter = \frac{(Ws)-(WA)}{(Ws)-(Wc)} \times 100 \qquad \text{Equation 4}$$

where Ws is the weight of the crucible and sediment, W_A is the weight of the crucible and ash,

and Wc is the weight of the crucible.

3.4.3 Biotic metrics

Fish counts were recorded as abundance by numbers. Morphometrics data (standard length, L, and weight, W) was used in the calculation of condition factor (K) to determine the physiological well-being of the blackchin tilapia.

$K = W \times 100 \, L^{-3}$ Equation 5

(where W is the weight of fish in grams, g; and L is the standard length of fish measured from snout to base of caudal fin in centimetres)

Bird counts were recorded in a species inventory data format showing abundance and number of encounters. Each species was assigned their respective conservation status, migratory status, functional/foraging preferences, and their habitat preference (Borrow & Demey, 2010). Species abundance of birds encountered was estimated per functional groups (Blair, 1996). Prevailing environmental variables noted within the sampling period included noise levels classified as 'Low noise' $\leq$ 40dB, 'Moderate noise' 41dB – 55dB, and 'High noise' $\geq$56dB; and human presence recorded by counting the number of people and/or fishers within counting stations. The effects of these independent variables on the abundance of birds were ascertained using correlation and regression analyses. Thus, noise and human presence were regarded as direct measures of anthropogenic pressures resulting from activities such as fishing and recreation.

3.4.4 Ortho mapping of drone imagery in ArcGIS

Hundreds of images captured were pieced together in a mosaic pattern through an ArcGIS processing software (ArcGIS by the Environmental Systems Research Institute [ESRI]). Figure 3.8 provides a summary of the major steps taken in the processing of images from multispectral data and the Digital Elevation Model (DEM). Information worth noting from the Bramor UAV such as the geolocation and camera specifics were taken. The geolocation ideally gives points of latitude, longitude, and height above the given ground reference point. While the camera type information allows the program to adjust settings to the make of the camera and its model. After a folder was created in the workplace, the drone imagery was uploaded and available base map options were selected. Against a preferred background of base maps, several visuals could be observed. Streamflow depicting the natural drainage pattern within the watershed was derived by tying points of equal elevations to delineate the watershed. Thus, land-use patterns, the extent of human encroachment, and impacts from major point sources of pollution such as drainage gutters were pictorially displayed and/or estimated from processed imagery.

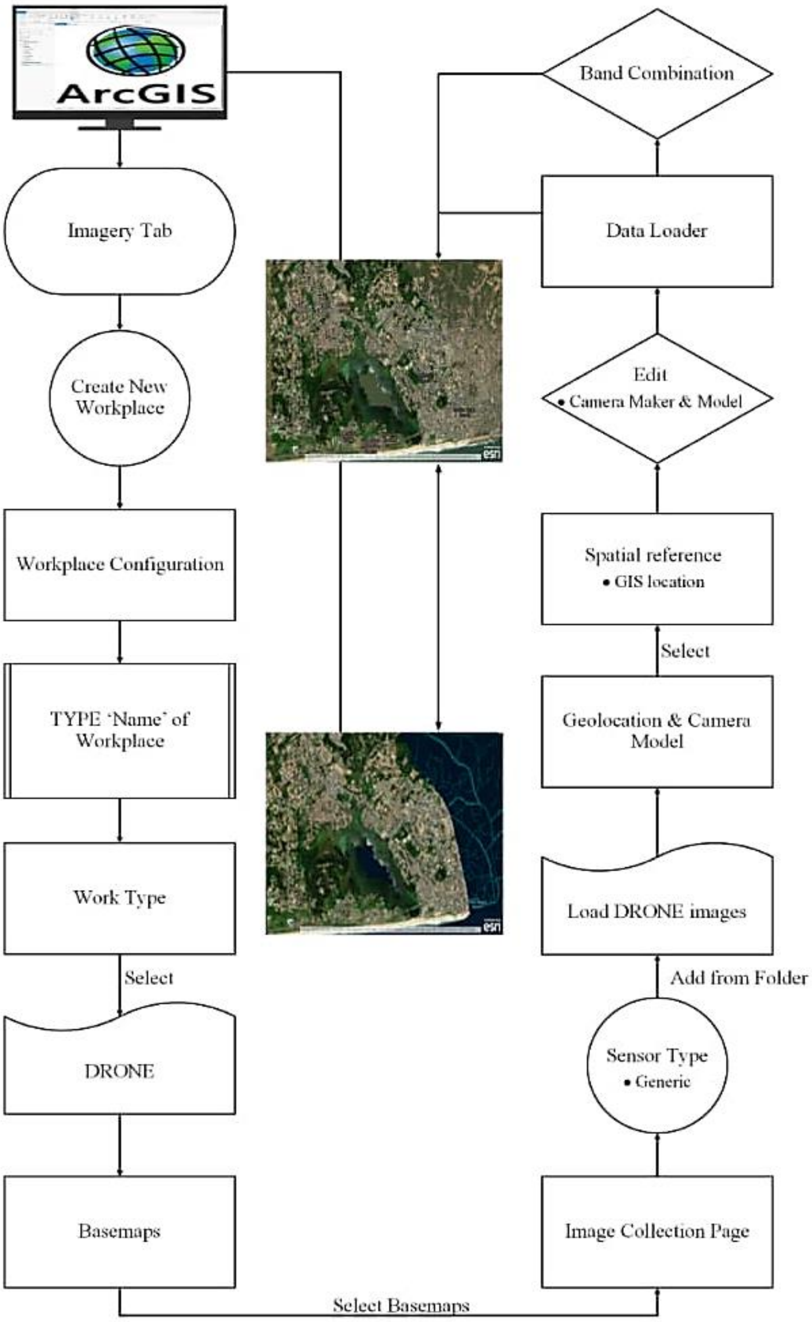


Figure 3.8: Drone imagery processing steps in ArcGIS on Fosu Lagoon

3.4.6 Decision support system development

A lagoon multi-criteria decision support (LMC-DSS) was developed for the management of coastal lagoons in Ghana that are heavily relied on for livelihoods yet facing poor ecological health and pollution resulting from unsustainable exploitation, conflicting uses, and weak governance. Using the Fosu lagoon as a case study, the connectivity of major criteria (Water Quality Restoration, Biotic Health Improvement, and Sustainable Resource Exploitation) with respective indicators and metrics, and further to various measured/analyzed parameters were produced. The pattern, such as displayed in a hypothetical Black River Ecosystem Restoration decision support model by Convertino et al. (2013), emphasized the intricacies of overlaps in a multi-use resource.

The development of LMC-DSS began with the rating of selected Ecological Health criteria from A, B, C as shown in Table 3 with an ideal criterion being rated with an A and subsequent criteria B, C, etc. in order of importance. Here, the bias with rating depended on the general objective of the majority or most opinionated decision-makers (Convertino et al., 2013). In a classical scenario, a conservation expert will give a rate of A to the obvious i.e. ecosystem restoration/conservation, and the lowest rate to a criterion that deals with the exploitation of the natural resource, while an economist decision-maker will select the reverse in attempts to maximize the monetary potential of the resource.

Table 3: Ranking factors for indicators and metrics used in three multi-criteria LMC-DSS tool development

A. Water quality restoration	B. Biotic health improvement	C. Sustainable resource use
1. Prevalence/type of drivers 2. Sensitivity level/range and the response of the environment to changes 3. The magnitude of effect - species-community levels 4. Monitoring and assessment protocols 5. Expertise requirement	1. Vulnerability status (international recognition) 2. Ecological roles (e.g. Food web, the position occupied) 3. The time frame of response to change/impact 4. Expertise requirements in monitoring	1. Value (economic and social) 2. Goods/services longevity 3. Existing policy/regulatory framework 4. Conflicting/competing uses 5. Potential for exploitation (alternatives) 6. Stakeholders/community acceptance of selected use 7. Level of participation in specific 'no-use' programmes

In the assessment of ecological health of the Fosu lagoon considering i.e. water and sediment quality, biodiversity, and land-use practices, the use of related metrics and indicators which reflected on aspects of ecosystem productivity and functioning, as described by Chapman (1992) and Gomez & Defeo (2012), served as important quantifiable scorers. Also, termed as criteria inputs, these selected metrics and indicators characterized the state of a coastal resource (Ehrenfeld, 2000) in need of adoptive mitigative and restorative alternatives in coastal zone resource management. The cumulative performances, expressed as a percentage, of metrics and indicators per criteria which were included in the present study, indicated the ecological health state of the Fosu Lagoon.

The efficiency to rate metrics and indicators, prior to scoring from their respective parameters' performances was dependent on factors such as including the responsive level of the indicator, required indicator monitoring expertise level, and stakeholders'/users' acceptance of the indicator (Table 3). Adopting approaches by Schlacher et al. (2014), the metrics and indicators that reflected ecological health were scored dependent on their ability to indicate 'within expected range/threshold of relevant parameters' per criteria, or otherwise i.e. 'out of range or significant degradation', from selected anthropogenic pressures of fishing, habitat loss (mangrove), eutrophication, pollution (solid waste, untreated liquid waste), recreation (speed boating), and aesthetics. Accumulated scores facilitated ranking of the indicators/metrics, and subsequently, the criteria they fed into so that a rank of 1 (for the lowest accumulated score) indicated the poor performance of the indicator/metric showing deplorable changes in the system from effects of anthropogenic pressures thus requiring immediate management attention. The closer the summed performances of metrics and indicators of all the selected Criteria neared 100%, the better the ecological health state of the Fosu Lagoon.

Metrics of water quality used in the assessment of ecological health constituted identified major physicochemical parameters from PCA on water quality variability; nutrients' concentrations; bacteria loads; sediment quality metrics of dominant grain size, organic matter composition, and porosity; and heavy metal levels which were impacted by selected pressures. For biological indicators, metrics of fish abundance and condition factor; species richness and diversity (encounter rate) of birds; and mangrove/littoral vegetation cover estimates, were used in environmental health assessment. Resource uses considered in the criterion included fishing, recreation, waste discharge sites, which affected the state of the Fosu Lagoon.

As an illustration, after rates were assigned to each criterion, the relevant indicators/metrics were weighed following their importance in relation to their effect on life forms within the lagoon and/or human health, level of expertise required in monitoring/assessment, cost of the assessment, to ascertain the highest (1) to lowest in descending order (2, 3, 4, …). To keep track of each indicator/metric specific to the set criterion, metric weights were labelled with a prefix of the criterion e.g. A.1, A.2, A.3, from highest weighted metrics to the lowest with respect to Criteria A. Then, following the connection links between the indicators/metrics to parameters, every set of parameters was averaged per their assessment within favourable/acceptable levels (value = 1) or unfavourable/unacceptable levels (value = 0). As an example, if recorded parameters such as dissolved oxygen (DO) and temperature which are within acceptable levels are awarded '1' each, whereas pH, nitrates, phosphates, and salinity are awarded zero (0) for falling out of acceptable levels based on studies conducted, then a score of 2/6 (i.e. 33%) is given to the respective indicator/metric of the six (6) parameters. All metrics would have had scores that are normalized because they would range between 0 – 1 which allows easy comparisons and identification of priority areas requiring interventions, improvement, monitoring, or any such appropriate management measures. The process will also encourage an evaluation of a misplaced criteria importance and opportunities to revise regulations on different aspects of the resource use.

3.4.7 Social Network Analysis (SNA)

To review the institutional framework for the enhancement of policy-making and implementation of regulations for coastal management on lagoon resources, a social network analysis (SNA) tool was employed. A simple 'Yes' or 'No' answer to administered questions (APPENDIX B-1) allowed a binary output (APPENDIX B-3 and B-4) in UCINET software (Borgatti, Everett, & Freeman, 1992). Graphical displays showed linkages between institutions/agencies with either mandatory or obligatory roles of coastal zone management. The description of linkages was dependent on the arrangement (grouping), thickness, and closeness of foci points.

Gaps and overlaps in the institutional framework were highlighted. The effect of the gaps or overlaps was ascertained by reviewing existing environmental policies and regulations. Necessary efforts required to strengthen the institutional framework in support of urban coastal zone management were proposed.

3.5 Chapter Summary

The research methods employed followed a mixture of quantitative and qualitative types. In the quantitative methods of research employed: a systematic sampling of six stations to represent the entire lagoon area was considered. Monthly sampling of the water column abiotic parameters aided seasonal influences to be interpreted during analysis. However, quarterly samples of sediments were on the basis of a relatively long span on significant changes to be observed and for expertise levels required in the process. Aspects of biological components selected i.e. fish counts and length, and biodiversity of avifauna also provided quantitative information through exploratory displays and statistical analysis. The qualitative method utilized was the administration of questionnaires to environmental and coastal management groups for an institutional framework analysis.

The impracticality to concurrently take measurements and sampling from the six stations, and undertake laboratory analysis of samples, inferred on the systematic errors that could arise. Close adherence to quality assurance protocols was the basis to consider results as reliable for the purpose.

The non-inclusion of hydrological balance analysis, possibilities of fly-overs within the four accessible avifauna stations during bird counts, and ethical restrictions to determine the intent of responses provided during questionnaire administration rank some of the uncontrolled shortcomings of the data gathered during the study period.

CHAPTER FOUR

RESULTS

Introduction

Results of monthly data collected over the fourteen months period (from November 2016 to December 2017) are displayed in various descriptive and graphical formats. The following are presented, after data analyses, to meet the objectives set, respectively: i) principal component analyses (PCA) depicting spatio-temporal variability of physicochemical parameters and to determine the driving factors of both nutrients' concentrations and chlorophyll-a concentrations for calculations in selected indices of water quality and trophic status/level; ii) estimation of the dominant grain size of sediments, correlation between organic matter content and interstitial ammonia concentration, determination of the porosities of sediments, and comparison of heavy metals' concentrations measured (secondary data source) with US EPA Toxicity Reference Values TRVs; iii) histogram display of size class of the blackchin tilapia, *Sarotherodon melanotheron,* and a display of the heavy metals concentrations measured in water (secondary data source) with US EPA TRVs as an inference on their exposure to the blackchin tilapia; iv) inventory and total encounters of avifauna species during the bird survey along with literature-informed functional and foraging/feeding guilds, and significance between bird encounters and independent variables of noise levels and human presence; v) estimates of coliform bacteria and *Escherichia coli* counts and two-tailed t-test results of their levels' comparisons between combinations of the upper, middle and lower reaches of the lagoon, solid waste composition which inferred on improper solid waste management within the catchment, a watershed delineation through Digital Elevation Model (DEM) of drone imagery which was further analyzed to identify major point sources of runoff and wetland buffer zone encroachment levels using ArcGIS techniques; and vi) ecological health status outcomes from a three-tiered Lagoon Multi-criteria DSS designed in Microsoft Excel software which utilized present conditions of the Fosu lagoon and case scenarios generated on the assumption of improved conditions per criterion of priority. This Chapter also presents a coastal governance review of Ghana's coastal zone focusing on policies and regulations that cover common major issues confronting coastal lagoons in Ghana and the responsible organisations mandated to oversee their implementation/adherence. Also, the results of an institutional framework analysis through outputs in a social network analysis (SNA) of the UCINET program are presented.

4.1 Abiotic Environment of the Fosu Lagoon

The present conditions of the abiotic environment of the Fosu lagoon are depicted through results of analyses conducted on measured *in situ* data – pH, dissolved oxygen [DO], temperature, salinity, conductivity, total dissolved solids [TDS], turbidity, nutrients [nitrates, phosphates, silicates, and ammonia] within the Fosu lagoon of 1.5m average depth (APPENDIX EI – E5), and relevant information on the underlying sediments. Each abiotic parameter had 42 data inputs (comprising three replicates over a 14-months period). Thus, there were: 294 data inputs for seven physicochemical parameters, 168 for the four nutrients analyzed, and 42 inputs for chlorophyll-a measurement.

4.1.1 Principal Component Analysis (PCA) of physicochemical parameters

Factor loadings of the recorded seven physicochemical parameters (pH, DO, temperature, salinity, conductivity, TDS, and turbidity) were considered in the selection of two-dimensional optimal variance planes (F1 and F2). That is, raw data of parameters collected from field measurements that have the strongest correlations were described relative to the calculated variance planes and with respect to other parameters. To reduce errors in variability comparisons, the first two-dimensional planes were maintained for all observation descriptions.

PCA spatio-temporal codes utilized were composed of prefixes (A2-N2) which represented the temporal information about data collected i.e., sampling months, whereas, suffixes a-f represented the specific sampling stations from which replicate samples and measurements were taken (APPENDIX D). So that; a = Station 1 (mouth of the lagoon), b = Station 2 (site close to major community drain), c = Station 3 (site close to garage/mechanic's working area), d = Station 4 (dinghy's most accessible point at head reaches of the lagoon), e = Station 5 (area behind cliff and St. Augustine's College), f = Station 6 (site behind morgue of the hospital). Therefore, for instance, codes A2b would translate as samples/measurements in November 2016 at Station 2. Interrelations of parameters per month (temporal variations) and relative to the sampling stations (spatial variations) are shown in Figure 4.1 – Figure 4.14.

In November 2016, PCA along dimensions F1 and F2 contributed about 66% to the observed variations of parameters (Table 4). The eigenvalue of 3.280 and 1.348 along the first and second factor loadings indicate the scales by which the original data is transformed to provide the observed relationships. Dissolved oxygen showed an inverse response to all variables with the strongest inverse relationship with temperature (Figure 4.1). Classical responses between TDS, salinity, turbidity, and conductivity were displayed. Spatial variations of DO at the upper reaches indicated some incorporation and possible contribution by suspended aquatic vegetation. The mouth section of the lagoon did not show any strong association with parameters' representation on the PCA produced.

Table 4: Eigenvalues and Variability of PCA for November 2016

	F1	F2	F3	F4	F5
Eigenvalue	3.280	1.348	0.942	0.852	0.578
Variability (%)	46.860	19.252	13.457	12.174	8.256
Cumulative %	46.860	66.112	79.569	91.744	100.000

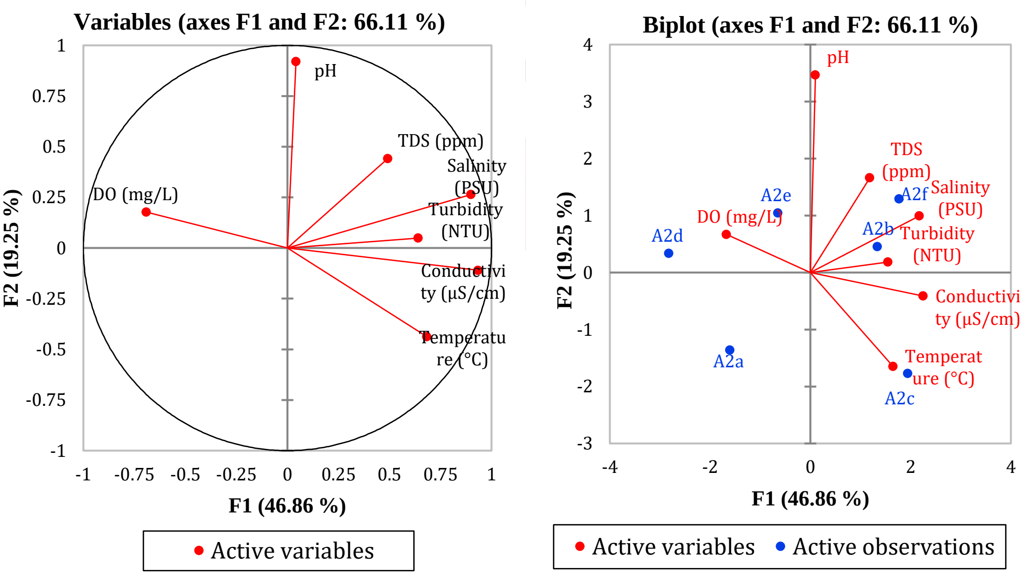


Figure 4.1: PCA of physicochemical variables of Fosu Lagoon in November 2016

In December 2016, where Harmattan dry conditions persisted, turbidity was closely associated with TDS though poorly represented along the PCA F1 axis (Figure 4.2). Dissolved oxygen was inversely related to conductivity as represented in the previous month. Stations in the furthest sections of the lagoon, upper and lower reaches responded in the same quadrat of PCA where salinity and TDS were represented with no significant responses to pH or DO along PCA dimension F2. The cumulative variability by the factor loadings was 67% (Table 5).

Table 5: Eigenvalues and Variability of PCA for December 2016

	F1	F2	F3	F4	F5
Eigenvalue	2.855	1.843	1.524	0.564	0.213
Variability (%)	40.793	26.334	21.765	8.064	3.044
Cumulative %	40.793	67.127	88.892	96.956	100.000

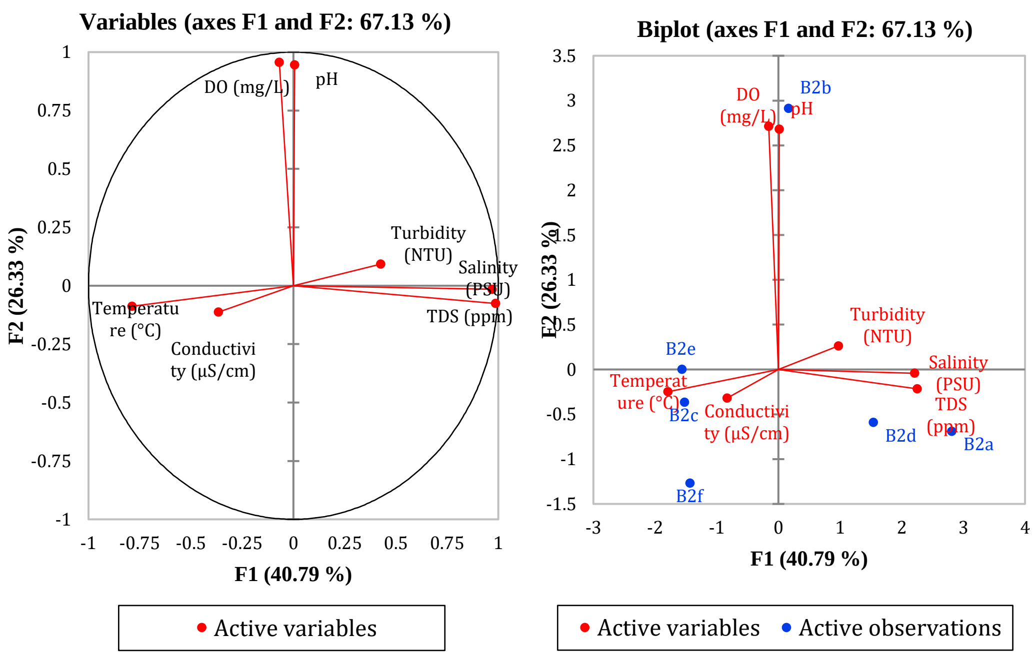


Figure 4.2: PCA of physicochemical variables of Fosu Lagoon in December 2016

In January 2017, the PCA was scaled by 6.440 and 3.383 respectively for the first and second factor loadings (Table 6). The variability was highest among other PCAs of the months i.e., about 82%. Figure 4.3 showed closely associated effects between conductivity, pH, TDS, and salinity of the lagoon. Dissolved oxygen was markedly unaffected by temperature which was represented in the opposite quadrat of the PCA plot. Superimposed nutrients measurements to decipher controlling effect on chlorophyll-a as a pigment of primary producers, indicated inverse effects of phosphate and ammonia which were closely represented at the mouth of the lagoon.

Table 6: Eigenvalues and Variability of PCA for January 2017

	F1	F2	F3	F4	F5
Eigenvalue	6.440	3.383	1.402	0.588	0.186
Variability (%)	53.669	28.195	11.685	4.898	1.553
Cumulative %	53.669	81.864	93.548	98.447	100.000

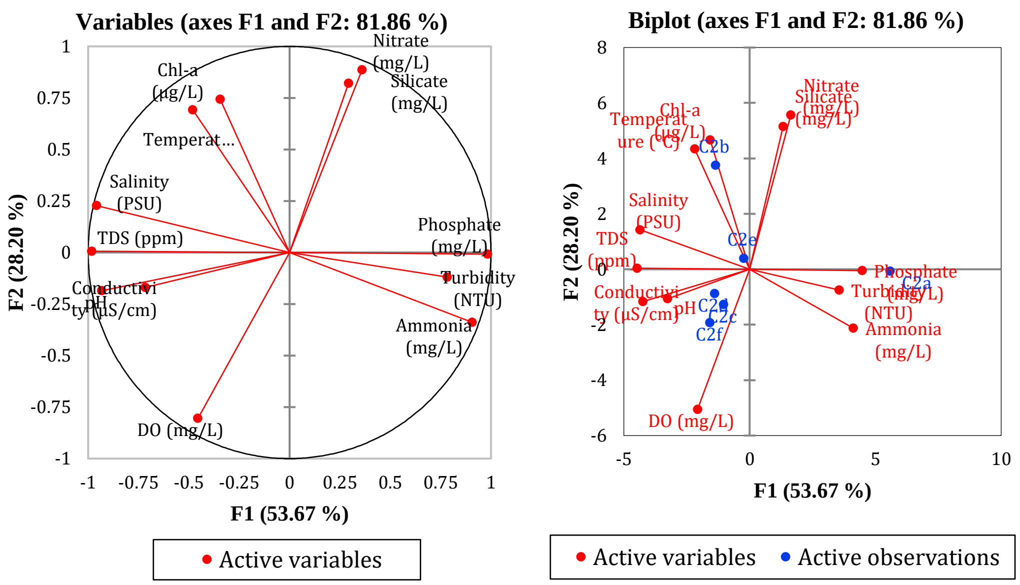


Figure 4.3: PCA of physicochemical variables of Fosu Lagoon in January 2017

In February 2017, about 82% variability response along F1 and F2 showed a strong representation of the interactions among the seven abiotic parameters. The eigenvalues were 4.037 and 1.687 along F1 and F2, respectively (Table 7). In the biplots, turbidity levels were unrelated to any other physicochemical parameter especially in the mouth section of the lagoon (Figure 4.4). Dissolved oxygen was inversely related to other parameters while conductivity, salinity, TDS showed similar interactions in other sections of the lagoon.

Table 7: Eigenvalues and Variability of PCA for February 2017

	F1	F2	F3	F4	F5
Eigenvalue	4.037	1.687	0.958	0.297	0.021
Variability (%)	57.666	24.101	13.690	4.246	0.297
Cumulative %	57.666	81.768	95.457	99.703	100.000

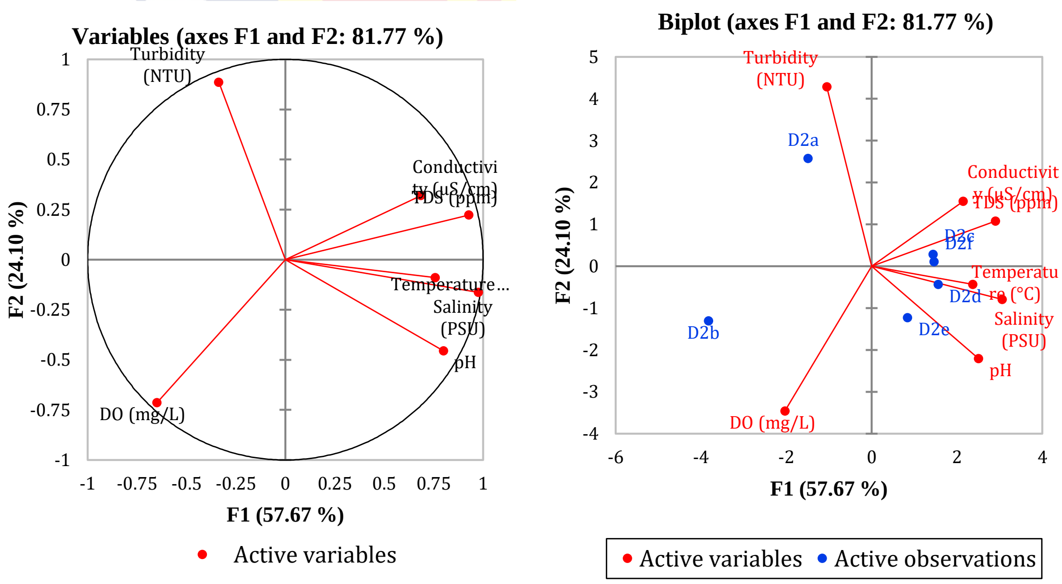


Figure 4.4: PCA of physicochemical variables of Fosu Lagoon in February 2017

In March 2017, the data was transformed by 3.075 and 2.122 along F1 and F2, with a cumulative variability of 74.245 % (Table 8). Close variation responses between DO and turbidity which were inversely related to other parameters may signal pulse events at the mouth and upper sections of the lagoon (Figure 4.5). Salinity and pH were most closely represented along the PCA axis F2.

Table 8: Eigenvalues and Variability of PCA for March 2017

	F1	F2	F3	F4	F5
Eigenvalue	3.075	2.122	1.258	0.412	0.132
Variability (%)	43.933	30.313	17.976	5.890	1.889
Cumulative %	43.933	74.245	92.221	98.111	100.000

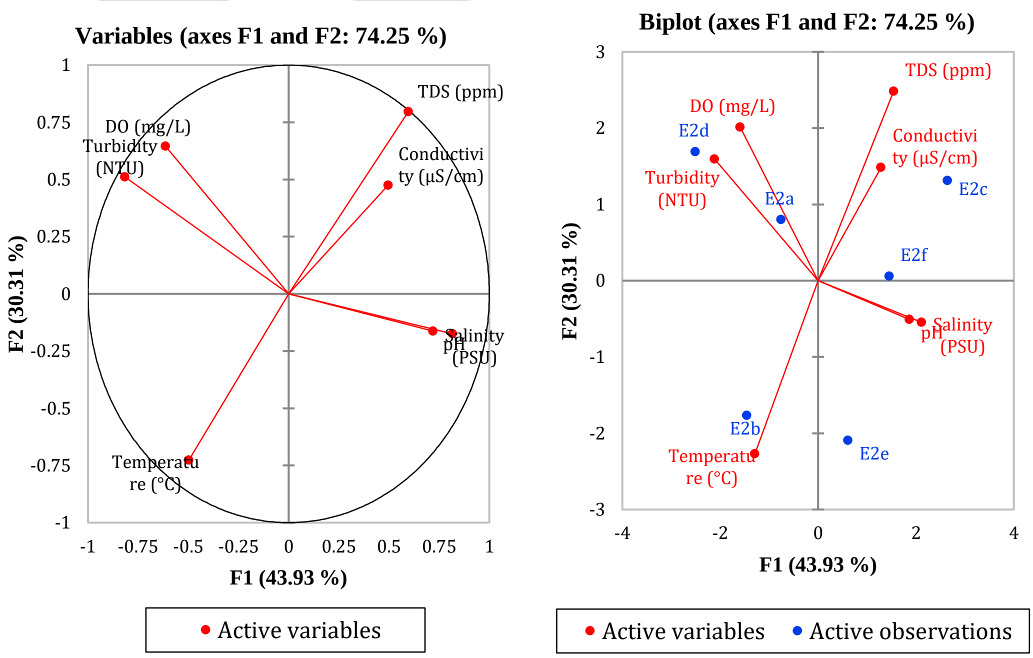


Figure 4.5: PCA of physicochemical variables of Fosu Lagoon in March 2017

For April, temperature responded positively as the major wet season progressed in comparison to previous sampling months from the biplots of PCA shown (Figure 4.6). The PCA at about 76% variability of initial information interpretation (Table 9), indicated a direct inverse relationship between measurements of TDS and conductivity, and seemingly no relatedness between turbidity and salinity. Wide spatial variation between the extreme reaches F2a and F2d were expected for the season. Consequently, stations F2b and F2c, then F2e and F2f that constituted the larger middle zone produced similar PCA parameter variations.

Table 9: Eigenvalues and Variability of PCA for April 2017

	F1	F2	F3	F4	F5
Eigenvalue	3.257	2.031	1.311	0.328	0.074
Variability (%)	46.531	29.014	18.722	4.679	1.054
Cumulative %	46.531	75.545	94.267	98.946	100.000

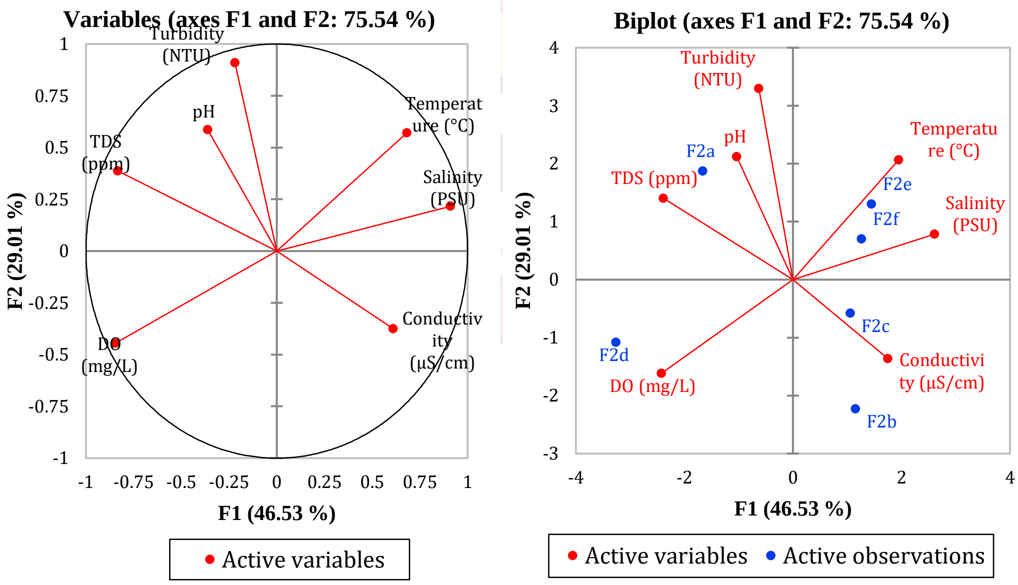


Figure 4.6: PCA of physicochemical variables of Fosu Lagoon in April 2017

In May, a similar representative interpretation of parameters at about 74% variability (Table 10) was shown along PCA dimensions F1 and F2 (Figure 4.7). Short vector lengths pointed to likely suppressed effects of interacting conditions even at that significant representation of PCA. Stations closeness to axes F1 and F2, except for the upper reaches (G2d) indicated a direct contribution to the observed variations.

Table 10: Eigenvalues and Variability of PCA for May 2017

	F1	F2	F3	F4	F5
Eigenvalue	3.056	2.158	1.146	0.532	0.109
Variability (%)	43.651	30.832	16.366	7.600	1.551
Cumulative %	43.651	74.483	90.849	98.449	100.000

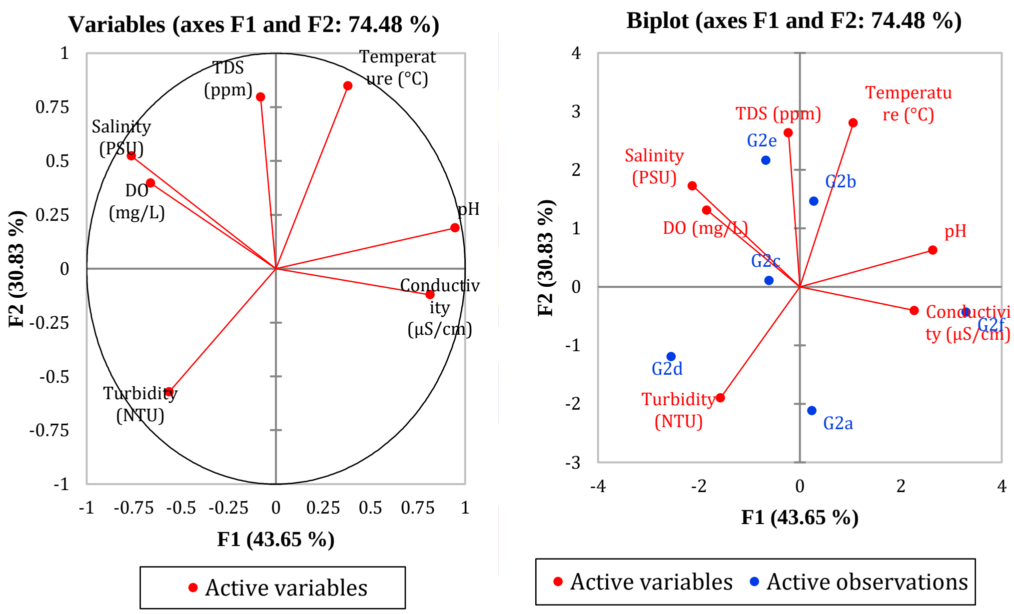


Figure 4.7: PCA of physicochemical variables of Fosu Lagoon in May 2017

In June, the temperature measured was consistent (insignificant variation) indicated by lying along the first PCA dimension in the positive direction (Figure 4.8). Dissolved oxygen's inverse relationship with temperature is a classical response, likewise the close positive relationship of conductivity, turbidity, and TDS. Station H2e however, showed no direct contribution to variations observed. The eigenvalues of the factor loadings F1 and F2 were 3.572 and 1.746, respectively. While the cumulative variability at F2 was about 80%.

Table 11: Eigenvalues and Variability of PCA for June 2017

	F1	F2	F3	F4	F5
Eigenvalue	3.572	1.746	1.061	0.384	0.238
Variability (%)	51.027	24.942	15.151	5.484	3.396
Cumulative %	51.027	75.970	91.121	96.604	100.000

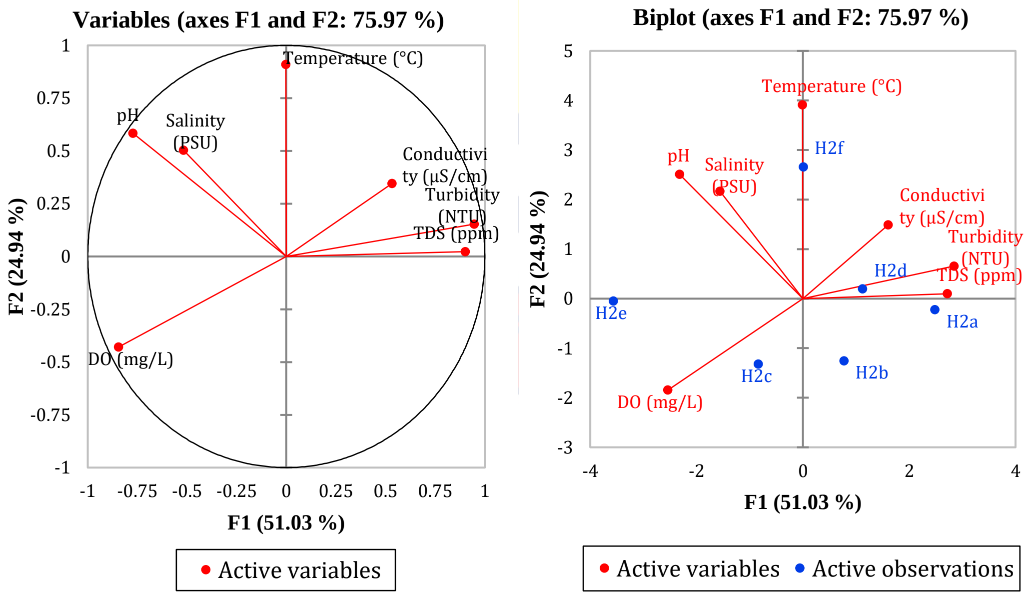


Figure 4.8: PCA of physicochemical variables of Fosu Lagoon in June 2017

PCA of July 2017 showed dissolved oxygen and conductivity of unusual close association. This required further investigation, considering inflow from catchment due to a storm earlier. TDS and turbidity were, typically, closely related to the strongest spatial representation at the mouth of the lagoon (Figure 4.9). Salinity, temperature, and pH, understandably, were relatively stable in clustered stations of the middle section of the lagoon. The head section of the lagoon did not show a strong association with the variability of all measured parameters. Variability measured was about 65% at F1 and F2 (Table 12).

Table 12: Eigenvalues and Variability of PCA for July 2017

	F1	F2	F3	F4	F5
Eigenvalue	2.538	2.031	1.194	0.789	0.449
Variability (%)	36.254	29.016	17.056	11.266	6.408
Cumulative %	36.254	65.270	82.326	93.592	100.000

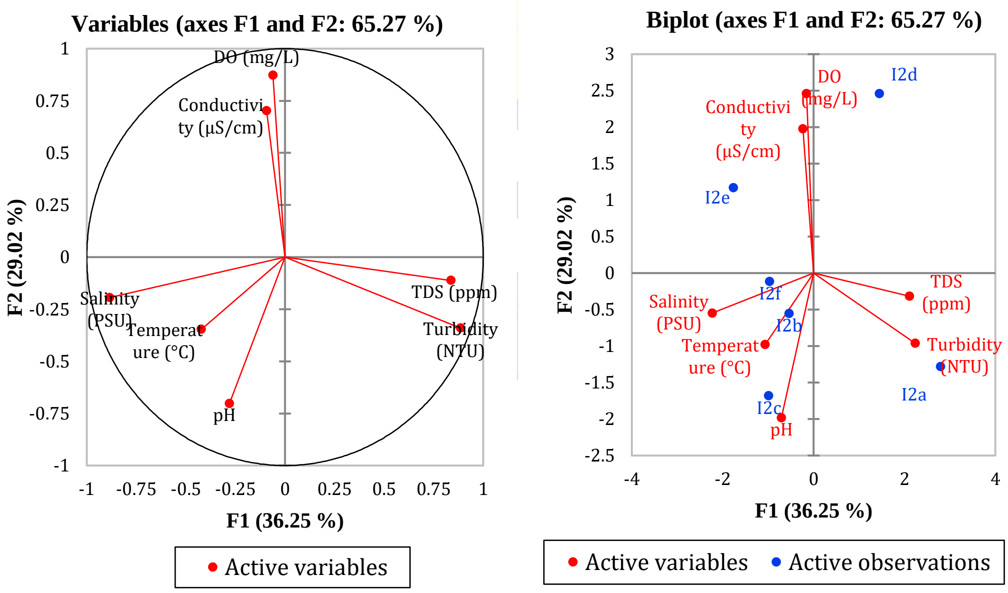


Figure 4.9: PCA of physicochemical variables of Fosu Lagoon in July 2017

PCA for data taken in August 2017, showed short vector lengths thus a poor representation of the parameters (Figure 4.10), although about 69% variability of initial information was produced (Table 13). Devising measures to parameters owing to the traditional ban placed on lagoon entry may have compromised data. Four out of six stations were completely separated from the contributing variables.

Table 13: Eigenvalues and Variability of PCA for August 2017

	F1	F2	F3	F4	F5
Eigenvalue	2.991	1.859	1.054	0.676	0.421
Variability (%)	42.730	26.552	15.053	9.650	6.015
Cumulative %	42.730	69.282	84.334	93.985	100.000

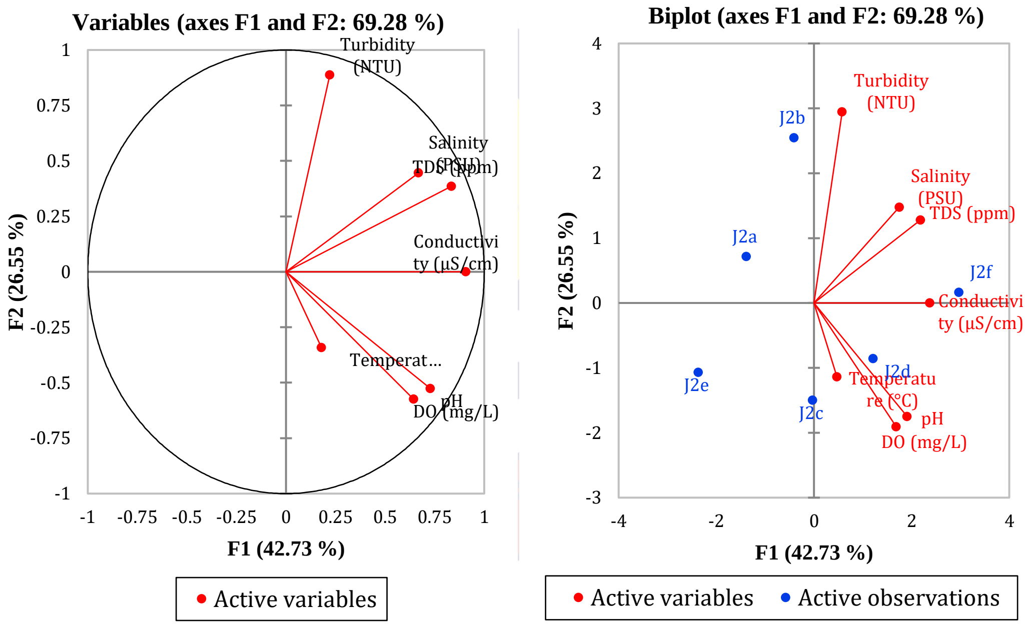


Figure 4.10: PCA of physicochemical variables of Fosu Lagoon in August 2017

In September 2017, PCA dimensions F1 and F2 contributed to about 72% of the information (Table 14). The eigenvalues were 2.827 and 2.225 in the transformation of original data along the factor loadings. The strongest representation by turbidity, temperature, pH, and DO were shown (Figure 4.11). when spatial variability was superimposed, however, it reduced the representativity of the mentioned parameters. Classical relationships between TDS, conductivity, and salinity occurred whereby the parameters were closely related. The temperature data showed no seeming influence on DO measured.

Table 14: Eigenvalues and Variability of PCA for September 2017

	F1	F2	F3	F4	F5
Eigenvalue	2.827	2.225	1.361	0.560	0.026
Variability (%)	40.391	31.789	19.449	8.005	0.366
Cumulative %	40.391	72.180	91.629	99.634	100.000

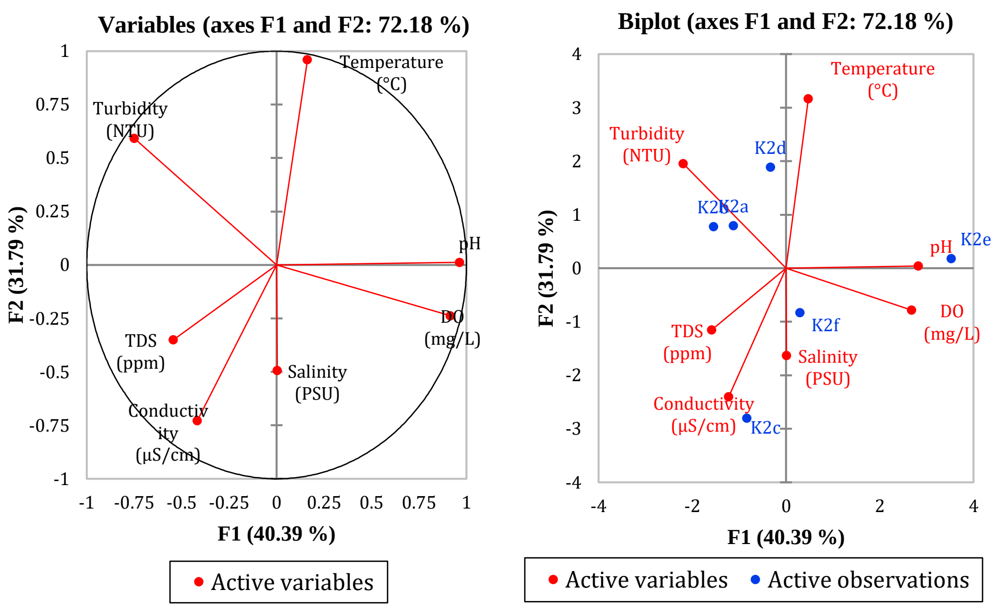


Figure 4.11: PCA of physicochemical variables of Fosu Lagoon in September 2017

In October 2017, from PCA produced, close relatedness was observed between TDS and turbidity, conductivity and DO, and salinity and temperature. Cumulative variability of the representation was about 69% of the factor loadings F1 and F2 (Table 15). The pH was directly represented along the negative direction of PCA dimension F1 (Figure 4.12). The mouth and head of the lagoon were separated from other stations indicating no strong contribution to observed variations.

Table 15: Eigenvalues and Variability of PCA for October 2017

	F1	F2	F3	F4	F5
Eigenvalue	2.560	2.253	1.354	0.507	0.326
Variability (%)	36.572	32.180	19.342	7.244	4.662
Cumulative %	36.572	68.752	88.094	95.338	100.000

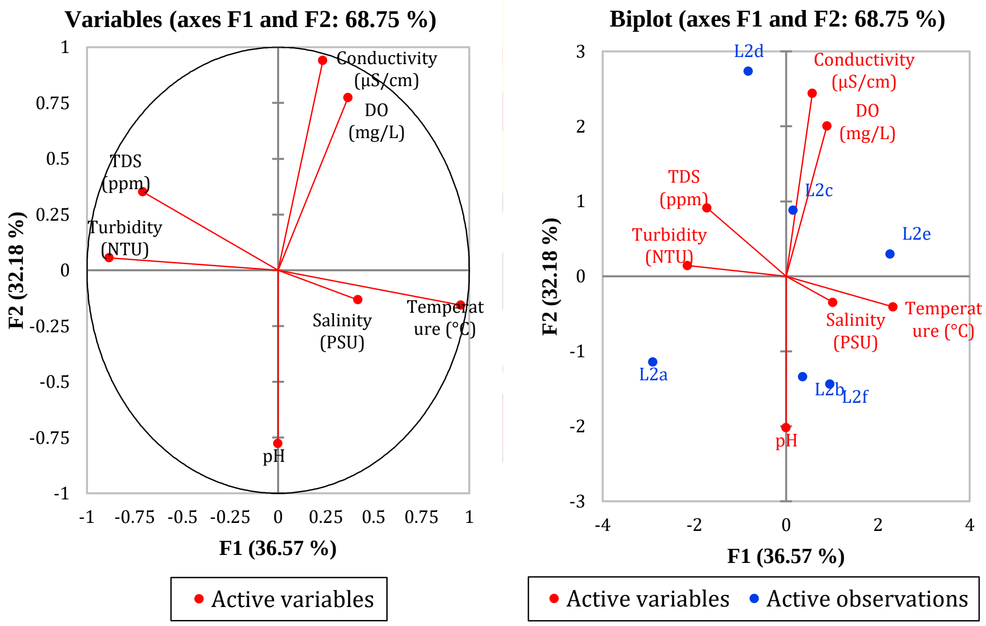


Figure 4.12 PCA of physicochemical variables of Fosu Lagoon in October 2017

A similar vector spiral was repeated in November 2017 from the previous year when sampling began. However, PCA dimensions F1 and F2 provided a greater percentage of initial information i.e., 70.36% (Table 16). Also, turbidity was inversely related to DO, while, pH and conductivity occurred along the same vector indicative of some interfering factors (Figure 4.13). Spatial dissociation of the mouth section and Station 5 required further investigations due to the clustering effects of other stations in relation to measured parameters.

Table 16: Eigenvalues and Variability of PCA for November 2017

	F1	F2	F3	F4	F5
Eigenvalue	2.618	2.307	1.312	0.628	0.135
Variability (%)	37.400	32.959	18.748	8.964	1.929
Cumulative %	37.400	70.359	89.107	98.071	100.000

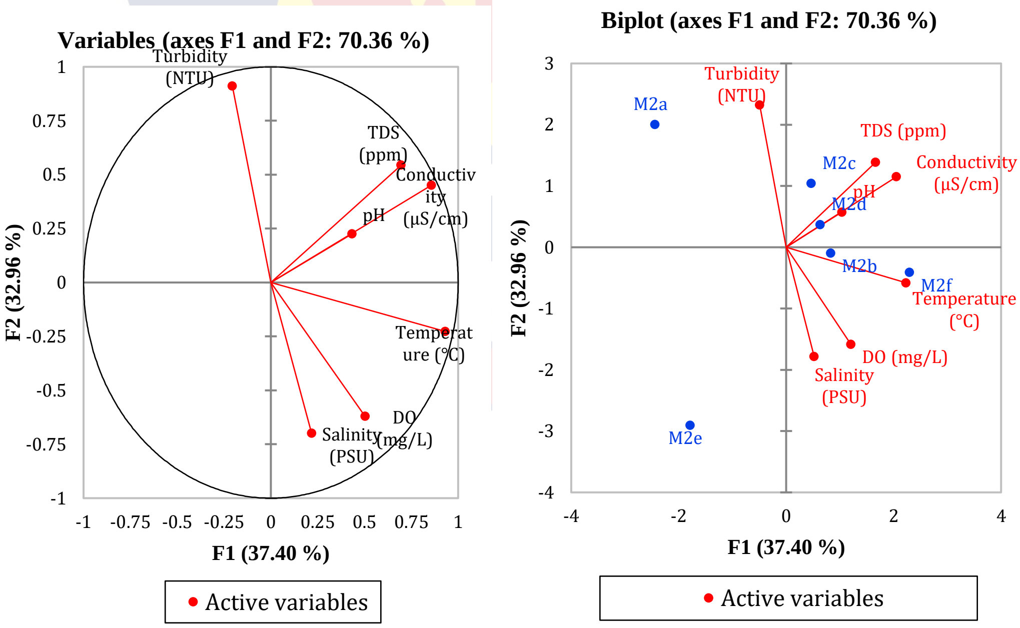


Figure 4.13 PCA of physicochemical variables of Fosu Lagoon in November 2017

By December 2017, dry conditions generally observed by reduced water volume, resulted in the PCA shown in Figure 4.14. TDS and conductivity were closely related (Figure 4.14). Their seeming unrelatedness to salinity, however, required further assessment. The cumulative variability was about 69%, while eigenvalues were 2.678 and 2.179, respectively, along the F1 and F2 dimensions. Turbidity was spatially represented at the mouth and Station 5. Temperature was moderately represented, with its closest spatial variability at the head reaches of the lagoon.

Table 17: Eigenvalues and Variability of PCA for December 2017

	F1	F2	F3	F4	F5
Eigenvalue	2.678	2.179	1.234	0.860	0.048
Variability (%)	38.264	31.129	17.633	12.285	0.689
Cumulative %	38.264	69.393	87.026	99.311	100.000

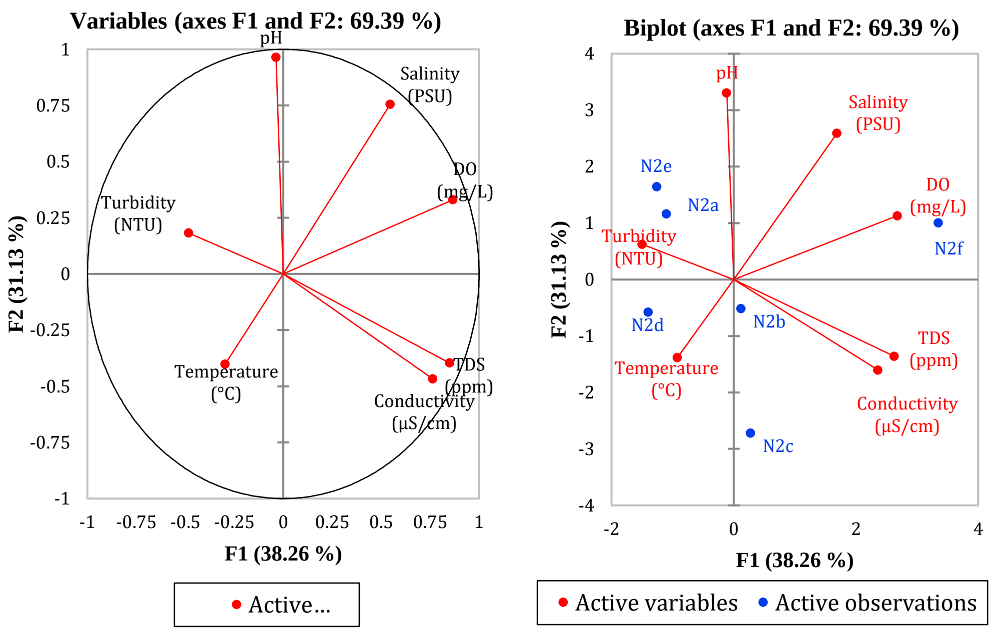


Figure 4.14 PCA of physicochemical variables of Fosu Lagoon in December 2017

4.1.2 Nutrient - chlorophyll-a relationship within water column

Data on limiting nutrients of primary productivity i.e. nitrates and phosphates were analysed to ascertain correlations with chlorophyll-a through plotted scatter diagrams (Figure 4.15 and Figure 4.16). The coefficient of determination (R^2) was used to explain how the difference in the photosynthetic pigment can be explained by the difference in the nutrient's concentrations. The R-squared, (R^2) falls within a range of 0 to 1, whereby the closer the value is to 1, the stronger the explained variation.

Scatter plots of nutrients – nitrates, phosphates, and silicates against corresponding chlorophyll-a concentrations produced positive inclined correlation lines indicating positive effects of nutrients on the chlorophyll-a concentration of phytoplankton (Figure 4.15, Figure 4.16, Figure 4.17). The weak R^2 values produced from scatter plots, however, presupposes other underlining factors that contributed to phytoplankton biomass evident in chlorophyll-a concentration. Scatter plots showed points that appeared as outliers but which were considered in the analyses since they were not errors of laboratory procedures. Spiked samples were used in laboratory procedures to ascertain measurements recorded.

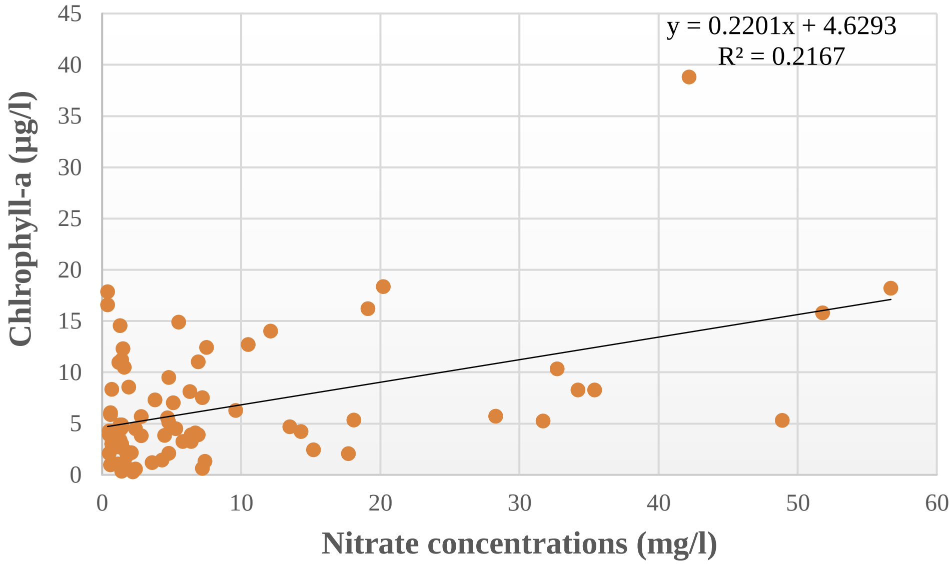


Figure 4.15: A scatter plot showing correlation between chlorophyll-a and nitrate concentrations of Fosu Lagoon

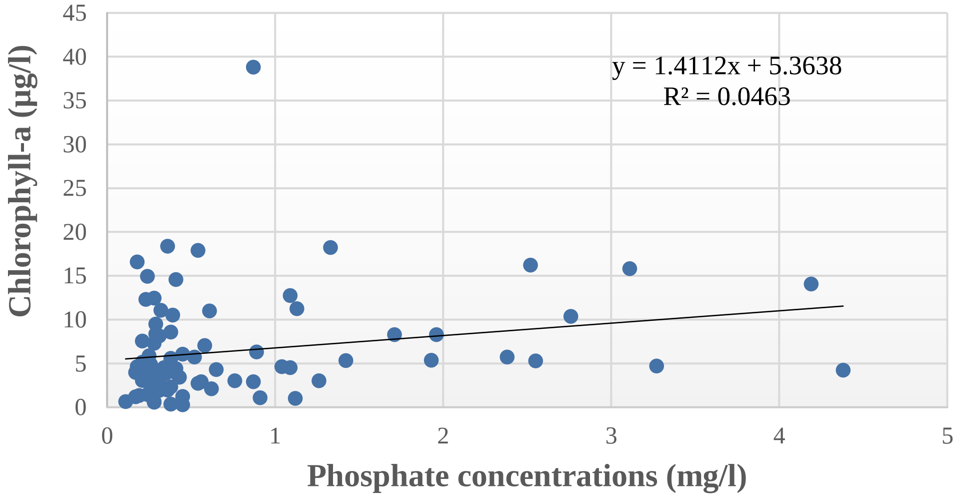


Figure 4.16: A scatter plot showing correlation between chlorophyll-a and phosphate concentrations of Fosu Lagoon

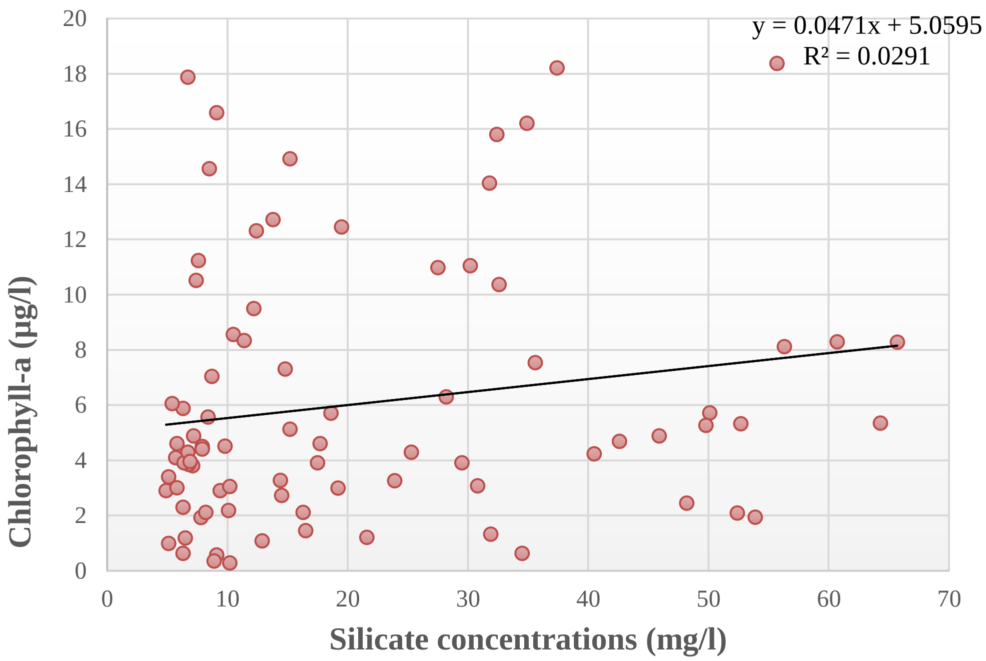


Figure 4.17: A scatter plot showing correlation between chlorophyll-a and silicate concentrations of Fosu Lagoon

4.1.3 PCA of physicochemical parameters' effects on Chlorophyll-a concentrations

Spatio-temporal influence of the physicochemical parameters on chlorophyll-a concentrations were displayed on a biplot of PCA (Figure 4.18, Figure 4.19, and Figure 4.20). Codes (see APPENDIX D) indicate the month and corresponding sampling location points at which chlorophyll-a observations were considered.

Weights of each parameter considering their relations to other parameters were provided based on the factor loadings as contributions (APPENDIX F) to the observations of Chlorophyll-a concentrations in a PCA ran for the different sections of the lagoon (termed; lower, middle, and upper reaches). Thus, the major drivers of the collective parameters along the selected dimensions of analysis (that is, FI and F2) were noted for possible implications on chlorophyll-a concentrations analysed from samples within the study area.

The PCA of parameters in relation to chlorophyll-a at the lower reaches during the 14-months study period showed a close association between the photosynthetic pigment measured and turbidity levels (Figure 4.18). Station 2 which was closest to the constructed culvert (suffix 'b') showed this association in August and September 2017. High chlorophyll-a occurrence in December 2017 at the mouth of the lagoon also resulted from the same association shown in the second PCA quadrat. Extreme inverse relationships were observed between the pH and Chlorophyll-a and between DO and chlorophyll-a. These observations in May, July, September, and October 2017 at Station 2 hinted at a trend during bloom events. Also, some positive influences between salinity, conductivity, and temperature on chlorophyll-a were indicated in the first PCA quadrat. TDS which was represented by a short vector length and at a right angle to chlorophyll-a pointed to an unclear association between the two parameters in comparison to the others.

Clustered points representing periods particularly of station 1 (mouth of lagoon) in the 3rd PCA quadrat showed inconclusive dependency of the parameters on chlorophyll-a concentration of phytoplankton in the lower reaches.

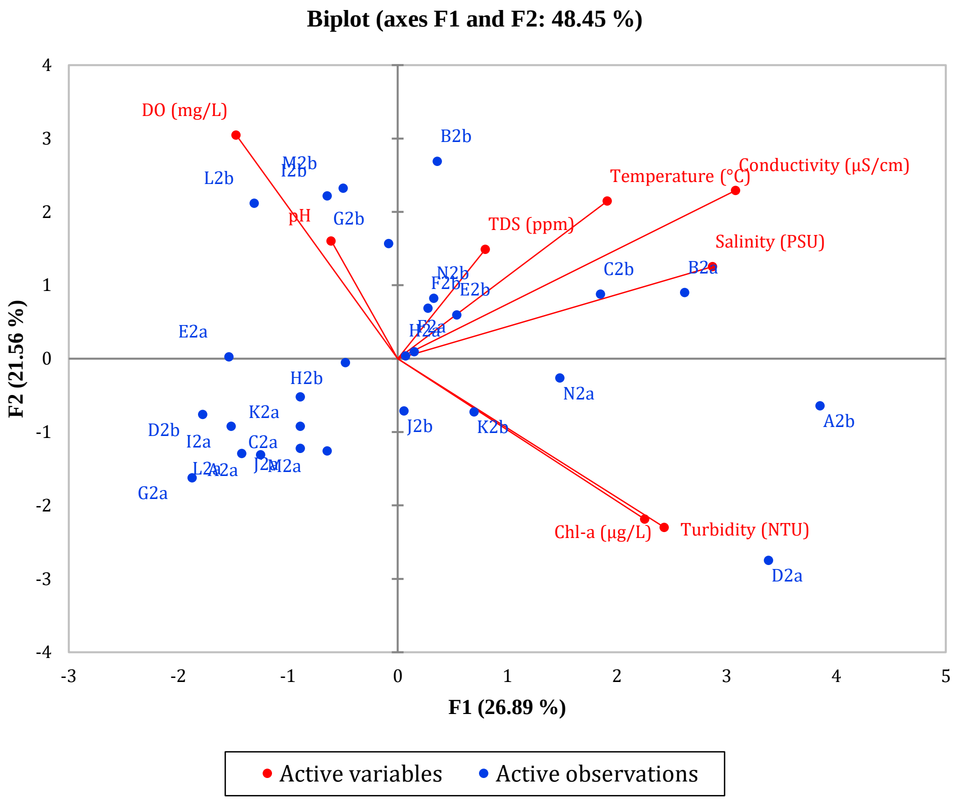


Figure 4.18: A two-dimensional PCA plot of spatiotemporal interrelations between physicochemical parameters and chlorophyll-a at the lower reaches

For the middle reaches of the Fosu lagoon, at a relatively low PCA original data interpretation level of about 44%, chlorophyll-a was represented by a short vector length. Its strongest positive response with temperature in November and December 2016, continued in January 2017, and in March and June 2017 (Figure 4.19).

In the second and fourth PCA quadrat (Figure 4.19), some influences between chlorophyll-a and the parameters of turbidity, TDS, and conductivity (latter represented in 4th quadrat). Salinity and pH, however, appeared not to contribute to concentrations of chlorophyll-a. Tight clusters of monthly occurrence and influence indicated fair uniformity of trends in the middle reaches. Possible vertical mixing processes could account for observations. A strong inverse relationship was shown between the pigment and DO at similar clustered stations.

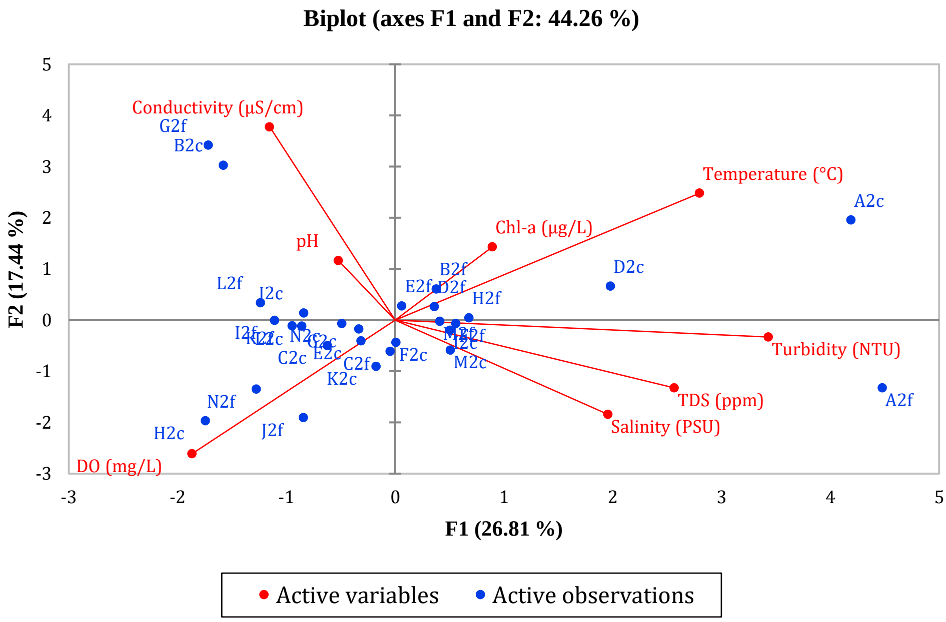


Figure 4.19: A two-dimensional PCA plot of spatiotemporal interrelations between physicochemical parameters and chlorophyll-a at the middle reaches

Chlorophyll-a was poorly represented along the two-dimensional planes of the PCA produced for the upper reaches of the Fosu lagoon (Figure 4.20), although about 52% of the initial information from data collected in comparison to the lower and middle reaches was retained. DO had the closest parameter association with chlorophyll-a. Also, the observations were primarily concentrated in April to October 2017 except in September. The uppermost accessible section of the lagoon (suffix ‘d’) was represented in the same PCA quadrat of chlorophyll-a vector.

A direct inverse relationship was shown between chlorophyll-a and pH and salinity at the upper reaches. In the fourth PCA quadrat, there were no vectors represented. Consequently, observations of station 5 (prefix ‘e’) were largely spread in the same quadrat.

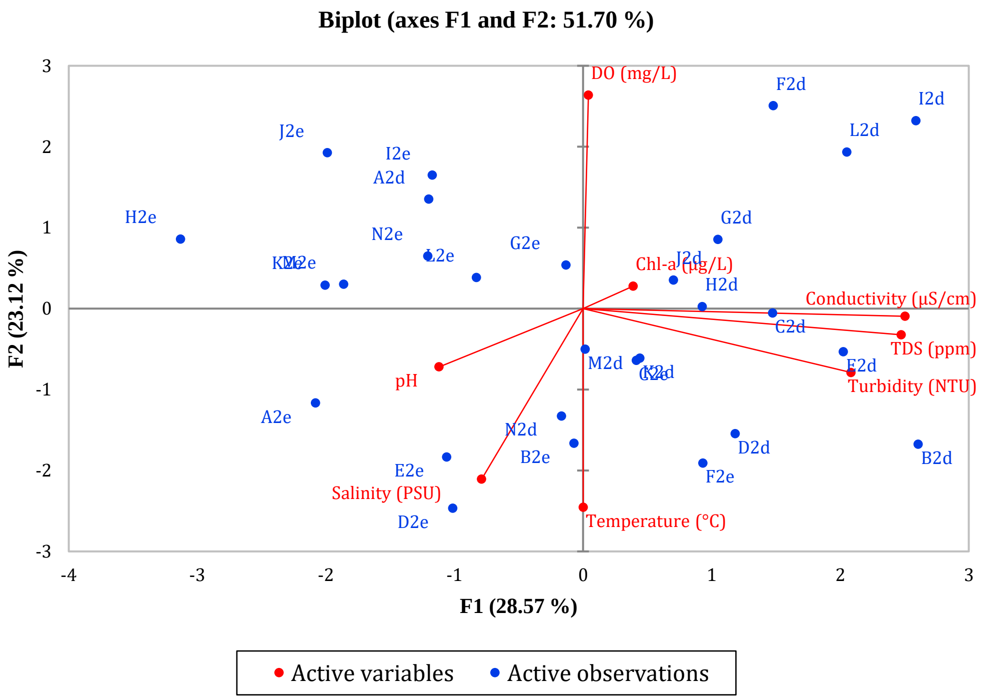


Figure 4.20: A two-dimensional PCA plot of spatiotemporal interrelations between physicochemical parameters and chlorophyll-a at the upper reaches

4.1.4 Water quality of the Fosu Lagoon using selected indices

Three water quality indices were employed to provide water quality classifications of the Fosu lagoon during the period of study.

Water quality index (WQI)

Based on the analyses done to ascertain the major drivers of the physicochemical environment of Fosu lagoon, weights were assigned for water quality assessment from PCA variable contribution tables (APPENDIX F). After calculations using the WQI mathematical equation (Table 2), the various water quality index values are shown in Figure 4.21.

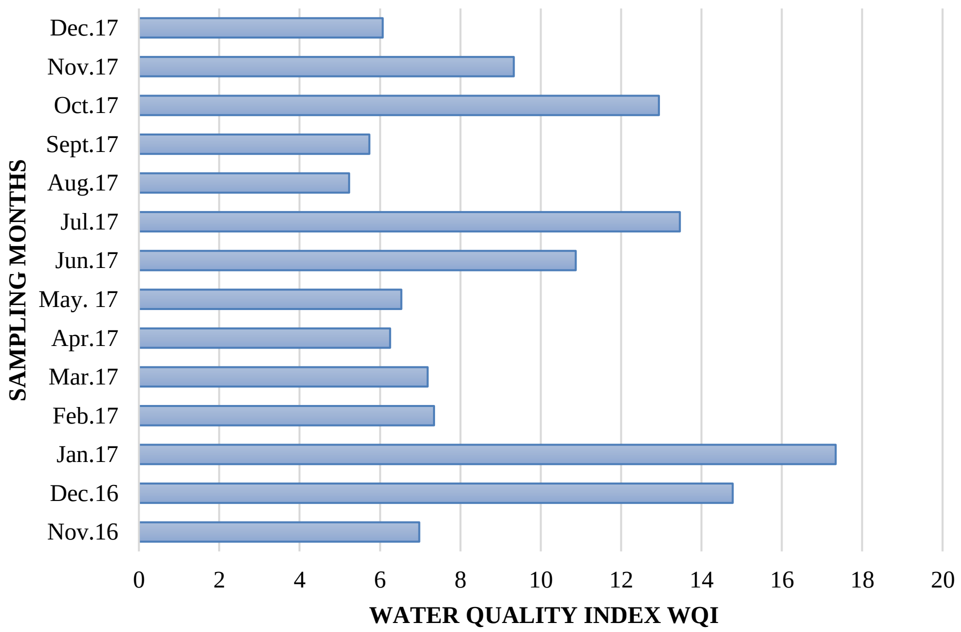


Figure 4.21: Monthly WQI of Fosu Lagoon using seven weighted physicochemical parameters

The classification scheme for WQI by Pesce and Wunderlin (2002) states ‘very bad water quality’ for WQI values between 0 and 25. From Figure 4.21, WQI calculated from *in situ* measurements for all months fell within this range. However, some months were worse than others in this category. A seeming cyclical trend was noted for worst water quality conditions during the months leading to the peak of major rainy and minor rainy seasons. It was not clear, however, of the response pattern to restore water quality after these events since different WQI was recorded during the repeated months of November and December.

Water quality minimum index (WQImin)

Another Water quality index (WQI_{min}) by Pesce and Wunderlin which concentrates on three factors (DO, conductivity, and turbidity) developed to provide an assessment on surface waters was used after normalization of the data. Figure 4.22 shows water quality using WQI_{min} over the study period.

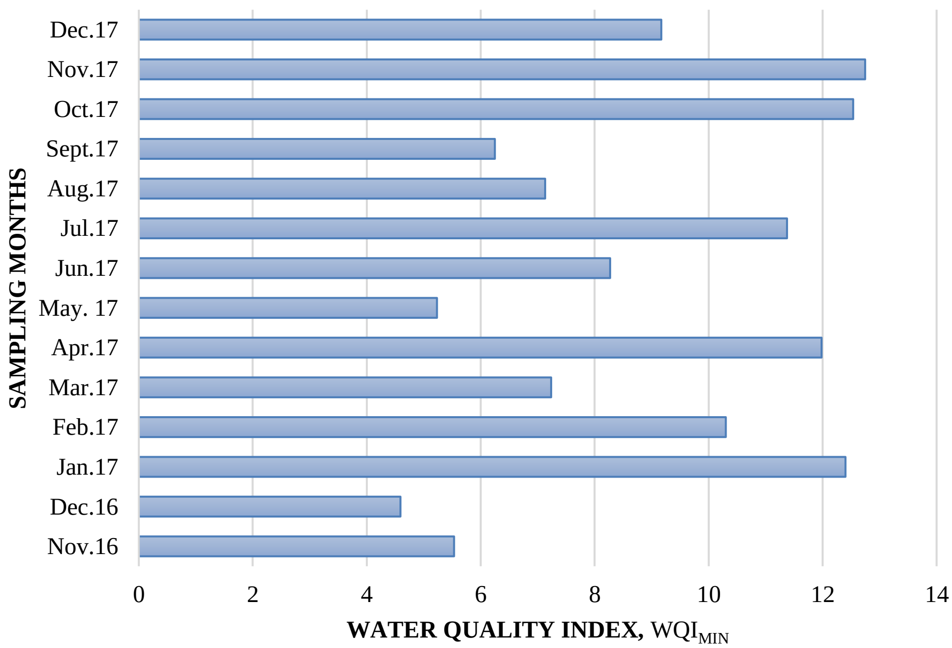


Figure 4.22: Monthly Water quality of the Fosu Lagoon using WQI_{min}

The classification scheme for WQI_{min} is not as fine-tuned as that stated for WQI. That is, it classifies water quality between 0 (worst water quality) to 100 (best water quality). By this classification, the water quality of Fosu lagoon within the period of study fell below 14% as shown in Figure 4.22. A reduction in water quality after each seeming improvement throughout the study period was an indication that the system attempted to restore itself which is hampered by pressure from the catchment area. The dips in the suggested trend were in December 2016, March, May, August to September, and December 2017.

Water quality index for Ghana (WQI_{GH})

Following a water quality index for the Solway River Purification Board by Bolton et al. (1978), and adapted and modified water quality index by the Ghana Water Research Commission (Owusu et al., 2013) was used to calculate the water quality of Fosu lagoon using stated weights (APPENDIX C) for six parameters: DO, ammonia, faecal coliform, pH, nitrates, phosphates, conductivity, and temperature. Below is a bar graph (Figure 4.23, Figure 4.24, Figure 4.25 showing the monthly water quality at the main reaches of the Fosu Lagoon. Values obtained were compared with the Classes of Water Quality.

At the lower reaches of the Fosu lagoon, water quality using WQI_{GH} fell within the Class IV of calculated values of 'less than 25'. The Class IV water is described as 'grossly polluted' where most of the expected uses are impaired, while some interrupted uses could occur since the water quality has fallen below the natural or desired levels. Within this category, worst still conditions were shown in two prolonged batches of months as shown in Figure 4.23 – from November 2016 to February 2017, and May to October 2017.

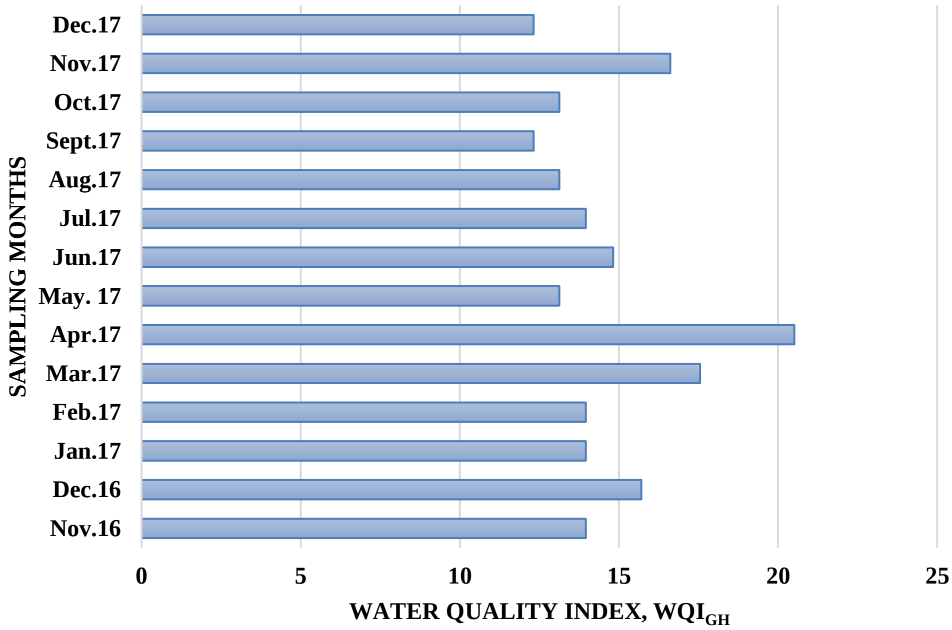


Figure 4.23: Monthly water quality of the lower reaches of the Fosu Lagoon using WQI_{GH}

From Figure 4.24, water quality within the middle reaches using the WQI_{GH} seems improved over the lower reaches, falling within Class III water category of 'poor quality'. These occurred in January, June, August, and December 2017 where the calculated values fell within the Class III range of 25–50. There was a pattern of improvement and dips in water quality through the entire study period over shorter monthly periods unlike observed at the lower reaches.

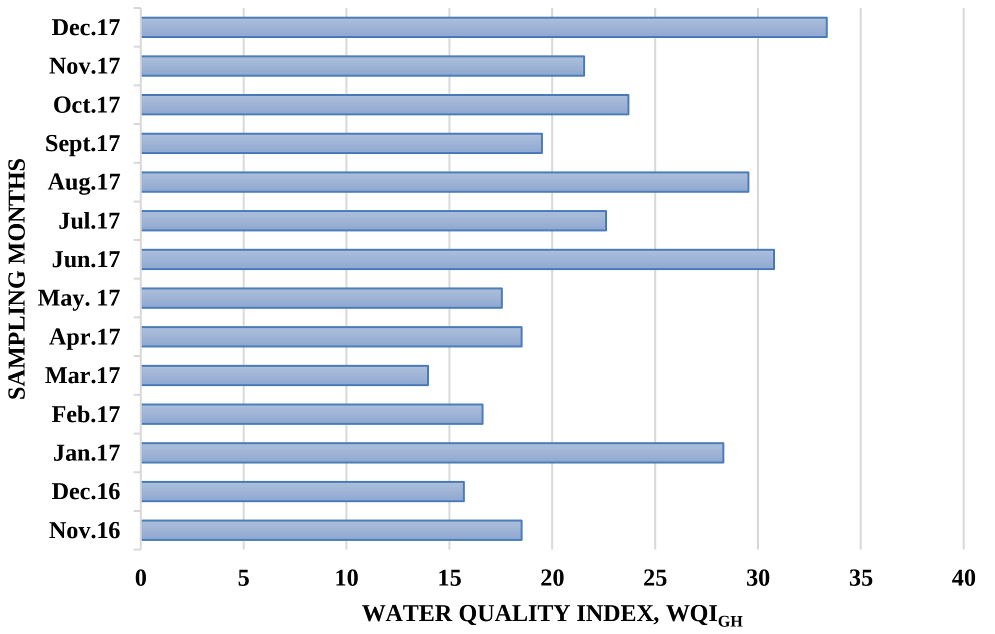


Figure 4.24: Monthly water quality of the middle reaches of the Fosu Lagoon using WQI_{GH}

In the upper reaches of the Fosu lagoon, water quality based on the WQI_{GH} generally placed that section in Class III, ‘poor quality’, state. Water quality within that class was, comparatively, maintained through the major and minor rainy seasons except in September that dipped sporadically. The Class III water is described as having several uses threatened or impaired with standards below natural or desirable levels.

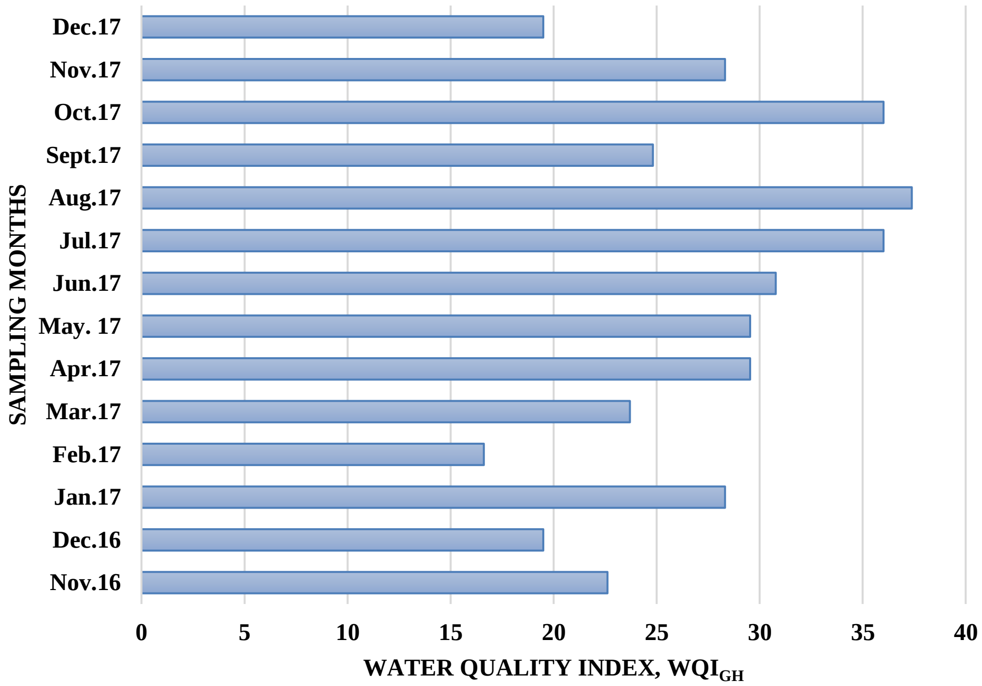


Figure 4.25: Monthly water quality of the upper reaches of the Fosu Lagoon using WQI_{GH}

Akaike Information Criterion (AIC) for three water quality indices

An AIC was employed to find the most appropriate index among the three indices to define lagoon water quality along Ghana's coast. Table 18 shows AIC values and suggests the best fit to observed quality from the lowest AIC value.

The lowest AIC value was approximately 607.2 by the WQI_{min}. Fewer parameters employed in that index, as expected, resulted in the low value calculated. However, the approximate AIC values for WQI and WQI_{GH} were 1470.0 and 1022.1, respectively. Both indices which used about the same number of parameters resulted in significantly different AIC values. This suggested the use of the WQI_{GH} as an appropriate index for the measurement of water quality for the Fosu lagoon.

Table 18: AIC values of three water quality indices (WQI, WQI_{min}, and WQI_{GH})

	Number of Observations (N)	$\sum SS_{errors}$	ln ($\sum SS_{errors}$/N)	K	2K	AIC
WQI	84	2749491103	17.30386488	8	16	1469.52465
WQI_{min}	84	105231.2798	7.133099073	4	8	607.1803221
WQI_{GH}	84	13054767.29	11.95384714	9	18	1022.123159

Where, $\sum SS_{errors}$ = Sums of errors

K = number of parameters fit + 1

$AIC = N \ln (\sum SS_{errors}/N) + 2K$

4.1.5 Chlorophyll-a as a proxy estimate of primary production by phytoplankton

The trophic status and trophic level indices were calculated from chlorophyll-a concentrations at the various reaches following equations detailed in Table 2.

Trophic status of Fosu Lagoon using the Trophic Status Index (TSI)

The trophic status index (calculated using the formula as shown in Table 2) with a classification scheme ranging between 0 to 100, was used to ascertain the primary productivity of the lagoon. The upper and middle reaches fell between the range 40 to 50, termed mesotrophic (moderate productivity) as displayed in Figure 4.26. While the TSI of the lower reaches of the lagoon was 52, which fell within the eutrophic (high productivity) class.

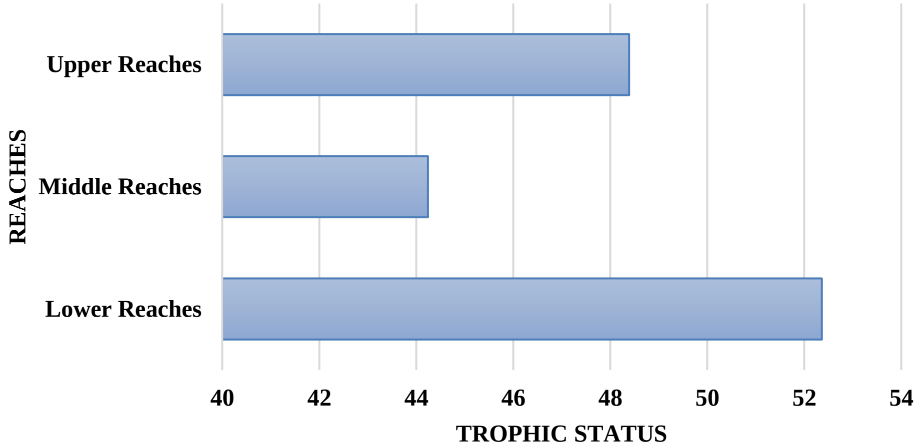


Figure 4.26: Estimated trophic status index of the Fosu Lagoon at various reaches

Trophic level of the Fosu Lagoon

The trophic level index (TLI), calculated using the formula as shown in Table 2, was used as a measure of the nutrient status of lentic systems considering that nutrients affect the growth of phytoplankton. The TLI at the lower, middle, and upper reaches of the Fosu lagoon is shown in Figure 4.27. Similar to the descriptions using the TSI, the TLI also classified the upper and middle reaches of the lagoon in the mesotrophic class i.e. between 3 and 4, while the lower reaches were classified as eutrophic between 4 and 5.

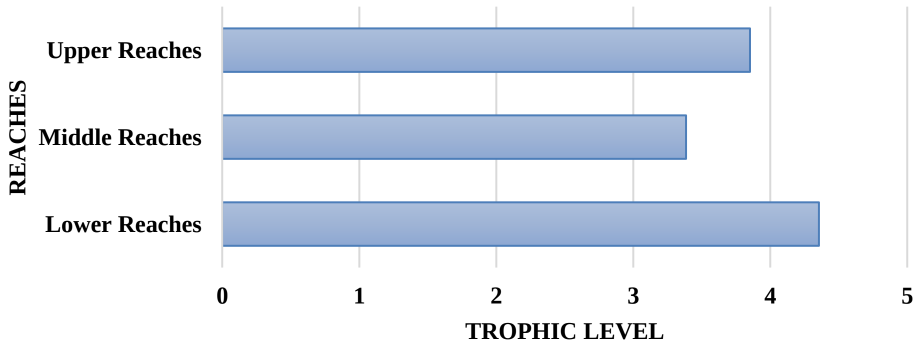


Figure 4.27: Estimated trophic level index of the Fosu Lagoon at various reaches

Figure 4.28: Algal scums clog nets of a fisherman in Fosu Lagoon

4.1.6 Heavy metals in water samples

The range of heavy metals measured on a quarterly basis was compared to surface water toxicity reference values (TRVs) by the US EPA (U.S. EPA Environmental Restoration Division, 1999) as shown in Table 19. All measurements fell above the toxicity levels considering warmer temperate regions coupled with certain site-specific characteristics result in elevated effects on organisms.

Table 19: Range of heavy metal concentrations in comparison with US TRVs

Element (mg/l)	US water TRVs	2016/2017 Research
Arsenic (As)	0.190000	0.1000 - 0.9450 (↑)
Cadmium (Cd)	0.000660	0.2500 - 0.3500 (↑)
Chromium (Cr)	0.117320	0.1125 - 0.8850 (↑)
Copper (Cu)	0.006540	0.1000 - 0.5500 (↑)
Iron (Fe)	1.000000	0.1000 - 1.5820 (↑)
Lead (Pb)	0.001320	0.2000 - 0.8500 (↑)
Manganese (Mn)	0.120000	0.1000 - 0.9500 (↑)
Mercury (Hg)	0.000012	0.1000 - 0.5000 (↑)
Nickel (Ni)	0.087710	0.1000 - 0.9000 (↑)
Zinc (Zn)	0.120000	0.1000 - 0.9500 (↑)

(↑) Values above recommended TRVs

4.1.7 Sediment parameters analyses

Quarterly measurement of aspects of sediments provided data (APPENDIX G) to aid understanding of the underlying sediments and dynamics influencing nutrients release and pollution.

Dominant sediment grain sizes of the Fosu Lagoon

In the first and fourth quarters of the sampling period, i.e. January to March 2017 and October to December 2017, similar patterns were observed in the grain sizes retained after granulometric procedures as shown in Figure 4.29. Grains larger than 63µm were dominant, followed by fine sediments and silt in the end pan, then sediments larger than the 125µm sieve. Fewer sediments were retained in the larger mesh sieves.

Similar patterns were also observed for both second and third quarters i.e. from April to June 2017, and July to September 2017. Here, larger particles dominated found retained in the 1000µm sieve. Fewer finer sediments and silt occurred, though some grains were retained in a similar fashion in the 63µm and 125µm mesh sieves.

Based on formulae by Pethick for grain size analyses, a summary of the sediment description is provided in Table 20. The sediments sample picked in October to December 2017 were well sorted in comparison to other periods, whereas the sediments in the first quarter, was largely skewed towards finer sediments.

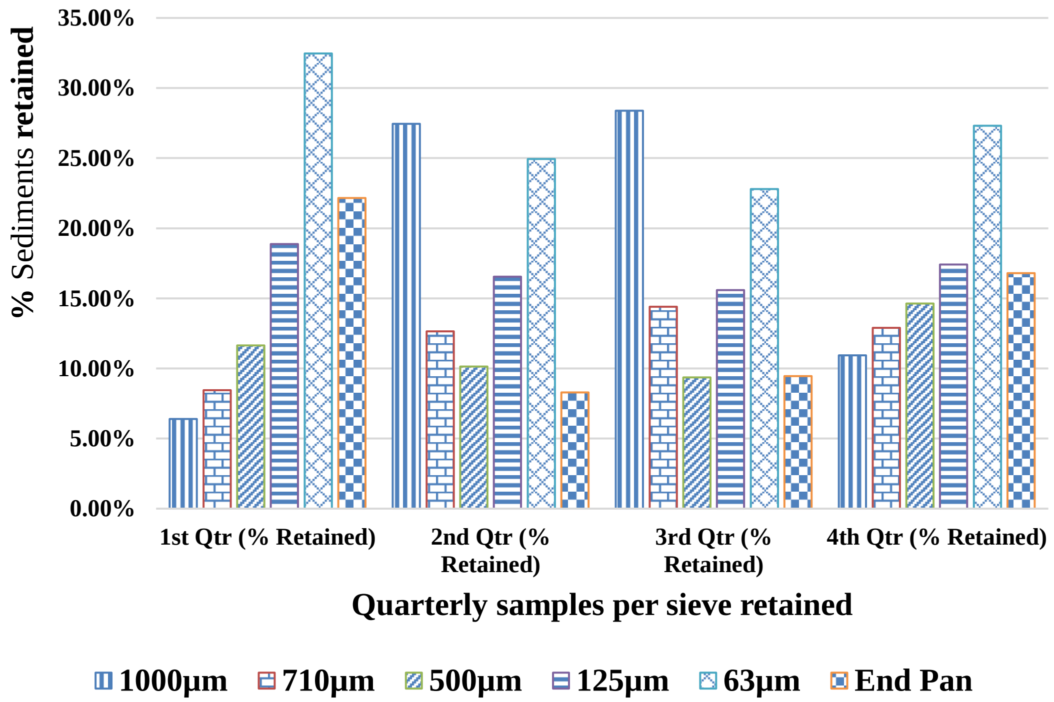


Figure 4.29: Sediments retained after quarterly granulometric analyses

Table 20: Sorting and skewness coefficients of sediments from Fosu Lagoon

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Sorting	29.83	30.00	30.12	30.71
Skewness	0.82	0.58	0.55	0.72

Average porosity of Fosu Lagoon sediments

Figure 4.30 shows the percentage porosity of sediments that were analyzed for grain size distribution. A clearer perspective was provided by grouping the six collections into two sections, i.e. the first three sieves as larger grain sizes and the last two, together with the end pan, as the smaller grain sizes. The porosities did not widely vary as shown in Figure 4.30. However, in the second and third quarters where grain sizes were generally larger, the porosities were higher than in the other two quarters where grain sizes skewed towards smaller and finer particles.

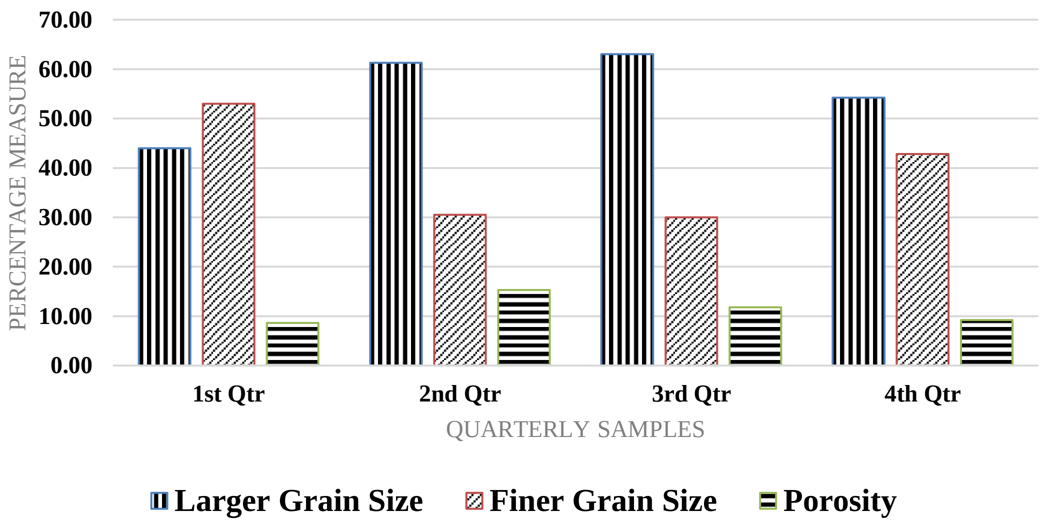


Figure 4.30: Grain size distribution and porosity of sediments in Fosu Lagoon

Sediment ammonia and organic matter content

A scatter plot (Figure 4.31) was done to find the correlation between measured interstitial ammonia concentration and organic matter content. The coefficient of determination, R^2 value was about 0.71 which showed a strong explanation of variation between the two variables. That is, organic matter in the sediments sampled, accounted for about 71% of the concentration of ammonia measured in the interstitial water of sediments sampled.

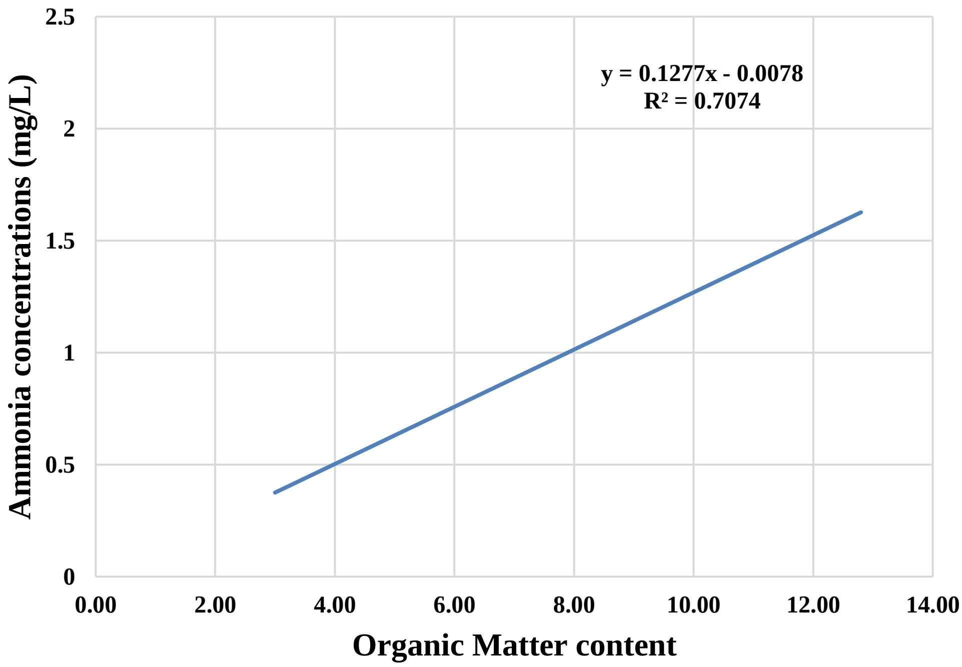


Figure 4.31: Correlation between interstitial ammonia concentration and organic matter content

Heavy metals in sediments

All heavy metals assessed, except for mercury (and Fe & Mn whose TRVs were not provided), fell below the sediment toxicity reference values (Table 21).

Table 21: Range of heavy metal concentrations in comparison with US TRVs

Element (mg/kg)	US sediments TRVs	2016/2017 Research
Arsenic (As)	8.2	4.4400 – 5.7600
Cadmium (Cd)	1.2	**
Chromium (Cr)	8.1	0.6200 – 2.6600
Copper (Cu)	34	0.3200 – 8.3200
Iron (Fe)	*	17.5140 – 219.2400
Lead (Pb)	46.7	0.8000 – 26.2000
Manganese (Mn)	*	2.7980 – 99.8000
Mercury (Hg)	0.15	1.7600 – 4.4000 (+)
Nickel (Ni)	20.9	0.8600 – 4.6000
Zinc (Zn)	150	1,4000 – 12.8600

*Not provided, highly variable

**Not assessed

(+) value significantly above-set standard

4.2 Biological Components of the Fosu Lagoon

Data collected to provide ecological information on the Fosu lagoon concentrated on top food web components i.e. fish and waterbirds of the lagoon, and vegetation cover.

4.2.1 Fish growth in Fosu Lagoon

As reported in earlier studies (Blay, 2009; Dankwa et al., 2016), the dominant fish species encountered was the blackchin tilapia, *Sarotherodon melanotheron*. The standard length of fish collected from experimental sampling was recorded to find the size classes of fish.

Size classes of fish

A fair representation of blackchin tilapia was utilized in the assessment through experimental fishing at the various sections of the lagoon. Wooden dug-out boats were used at the deeper sections of the middle and upper reaches while at shallower depths, fish were caught by the same gear but by wading through the water.

Over the study period, a total of 4,135 individuals of *S. melanotheron* were obtained at the three reaches of the lagoon monthly over a 4-hours fishing period using a 6.5m-wide cast net of mesh size 12.7mm (1/2 in.). Figure 4.32 displays the 1cm spaced class size distribution of fish measured. The modal class was at total length of 8.0-8.9cm, followed closely by individuals measuring between 7.0-7.9cm. Both class sizes contributed about 43% of the total catch.

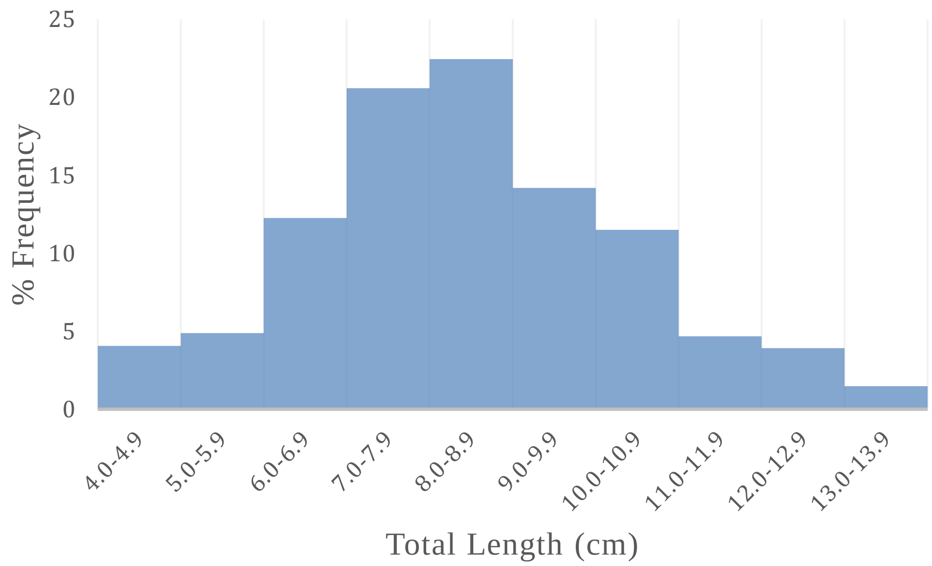


Figure 4.32: Composite %frequency distribution of *S. melanotheron* (all individuals) from the Fosu lagoon from November 2016 to December 2017

4.2.2 Waterbirds of the Fosu Lagoon

Table 22 provides data on species of birds encountered during the study period.

Table 22: Inventory of birds encountered at Fosu Lagoon

Common name	Species	CS	MS	FG	HP	Encounters
African darter	*Anhinga rufa* (Daudin. 1802)	LC	R	P	A	182
Great egret	*Egretta alba* (Linnaeus, 1758)	LC	R	P	A	141
Squacco heron	*Ardeola ralloides* (Scopoli, 1769)	LC	M	P	A	134
Cattle egret	*Bubulcus ibis* (Linnaeus, 1758)	LC	R	O	T	130
African pied wagtail	*Motacilla aguimp* (Temminck, 1820)	LC	R	I	A	120
Yellow-billed kite	*Milvus migrans parasitus* (Gmelin, 1788)	NT	M	O	T	119
African jacana	*Actophilornis africanus* (Gmelin. 1789)	LC	R	I	A	113
Common sandpipers	*Actitis hypoleucos* (Linnaeus, 1758)	LC	M	I	A	109
Black-winged stilt	*Himantopus himantopus* (Linnaeus. 1758)	LC	R	I	A	94
Subtotal A						**1142**

CS–Conservation Status; MS-Migratory Status; FG–Foraging Group; HP–Habitat Preference

Table 22: Inventory of birds encountered at Fosu Lagoon (continued)

Common name	Species	CS	MS	FG	HP	Encounters
Western reef egret	*Egretta gularis* (Bosc, 1792)	LC	M	P	A	88
Woodland Kingfisher	*Halcyon senegalensis* (Linnaeus, 1766)	LC	R	P	T	87
Spur-winged lapwing	*Vanellus spinosus* (Linnaeus, 1758)	LC	R	I	A	85
Laughing dove	*Spilopelia senegalensis* (Linnaeus, 1766)	LC	R	G	T	79
Grey headed sparrow	*Passer griseus* (Vieillot, 1817)	LC	R	G	T	48
Village weaver	*Ploceus cucullatus* (Muller, 1766)	LC	R	G	T	44
Senegal coucal	*Centropus senegalensis* (Linnaeus, 1766)	LC	R	C	T	42
Common swift	*Apus apus* (Linnaeus, 1758)	LC	R	I	T	34
African pygmy kingfisher	*Ispidina picta* (Boddaert, 1783)	LC	R	I	T	21
Subtotal B						**528**

CS–Conservation Status; MS-Migratory Status; FG–Foraging Group; HP–Habitat Preference

Table 22: Inventory of birds encountered at Fosu Lagoon (continued)

Common name	**Species**	**CS**	**MS**	**FG**	**HP**	**Encounters**
Black crake	*Amaurornis flavirosta* Swainson, 1837)	LC	R	O	A	17
White faced whistling duck	*Dendrocygna viduata* (Linnaeus, 1766	LC	R	O	A	21
White-tailed tropicbird	*Phaethon lepturus* (Daudin, 1802)	LC	R	P	A	18
Western grey plantain-eater	*Crinifer piscator* (Boddaert, 1783)	LC	R	G	T	13
Common bulbul	*Pycnonotus barbatus* (Desfontaines, 1789)	LC	R	G	T	12
Little ringed plover	*Charadrius dubius* (Scopoli, 1786)	LC	M	I	A	8
Pied crow	*Corvus albus* (Statius Muller, 1776)	LC	R	O	T	8
Pacific golden plover	*Pluvialis dominica* (Gmelin, 1789)	LC	M	I	A	7
Subtotal C						**104**

CS–Conservation Status; MS-Migratory Status; FG–Foraging Group; HP–Habitat Preference

Table 22: Inventory of birds encountered at Fosu Lagoon (continued)

Common name	Species	CS	MS	FG	HP	Encounters
Green- backed heron	*Butorides striata*	LC	R	P	A	6
Grey heron	*Ardea cinerea* (Linnaues, 1758)	LC	R	P	A	3
Sunbird		LC	R	G	T	2
Little green woodpecker	*Campethera maculosa* (Valenciennes, 1826)	LC	R	I	T	1
Purple Swamphen	Porphyrio madagascariensis	LC	R	O	A	1
Subtotal D						**13**
Subtotal A + Subtotal B + Subtotal C + Subtotal D						**1787**

CS–Conservation Status; MS-Migratory Status; FG–Foraging Group; HP–Habitat Preference

In Table 22, a total of 1,787 encounters of thirty-three bird species were made (Appendices E-1, E-2, and E-3). . The conservation status of birds (CS) was mostly in the 'Least Concern' (LC) category except for the Yellow-billed kite which was categorized as 'Not Threatened' on the International Union on Conservation of Nature (IUCN) List. Also, twenty-five species of birds were identified as resident (R) species while six birds were migratory (M), spending a part of their wintering periods, or using the site as a stopover destination (Figure 4.33). The foraging groups (FG) encountered included ten insectivorous (I), eight piscivorous (P), six granivorous (G), six omnivorous (6), and one carnivorous (C) bird species. For habitat preferences (HP), seventeen of the species encountered were largely aquatic (A) preferring the lagoon water for most of their activities, and fourteen were terrestrial (T) living a greater part of their lives away from the lagoon waterbody (Figure 4.34). The top five encountered bird species were the African darter, Great egret, Squacco heron, Cattle egret, and African pied wagtail. The Little green woodpecker and Purple swamphen were the least encountered during the study period. Some pictures of birds encountered are shown in APPENDIX H1 – H4.

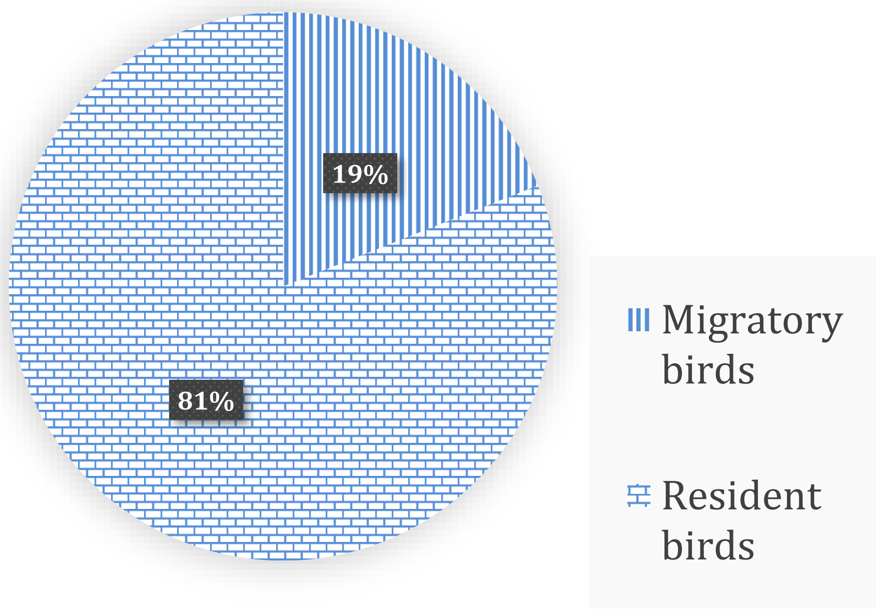


Figure 4.33: Migratory status of birds encountered at the Fosu Lagoon from November 2016 to December 2017

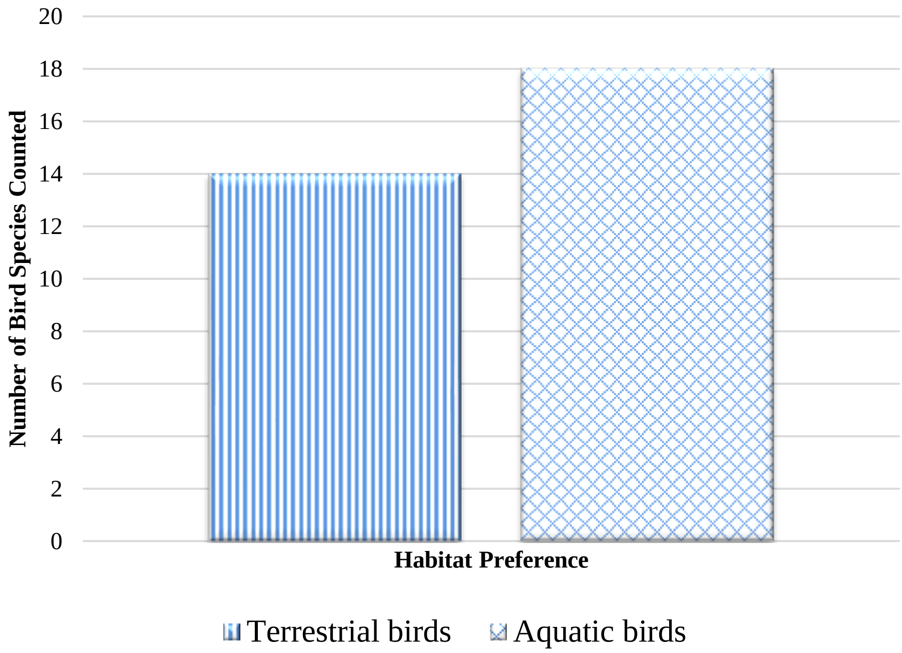


Figure 4.34: Habitat preference of birds encountered at the Fosu Lagoon from November 2016 to December 2017

Trophic structure of birds

Of importance to the study were the beneficial uses of the lagoon as a suitable habitat regarding the categories of habitat preference and the support for feeding/foraging activities. The total number of birds in each identified foraging guild was represented in a pie chart (Figure 4.35). Piscivorous birds accounted for 37% of the total number of birds counted, while 33% of birds were insectivorous. However, eight piscivorous species accounted for the composition found, while ten species accounted for the insectivorous birds encountered. Omnivorous and granivorous birds followed with 17% and 11%, respectively. Carnivorous birds formed 2% of the total number of birds.

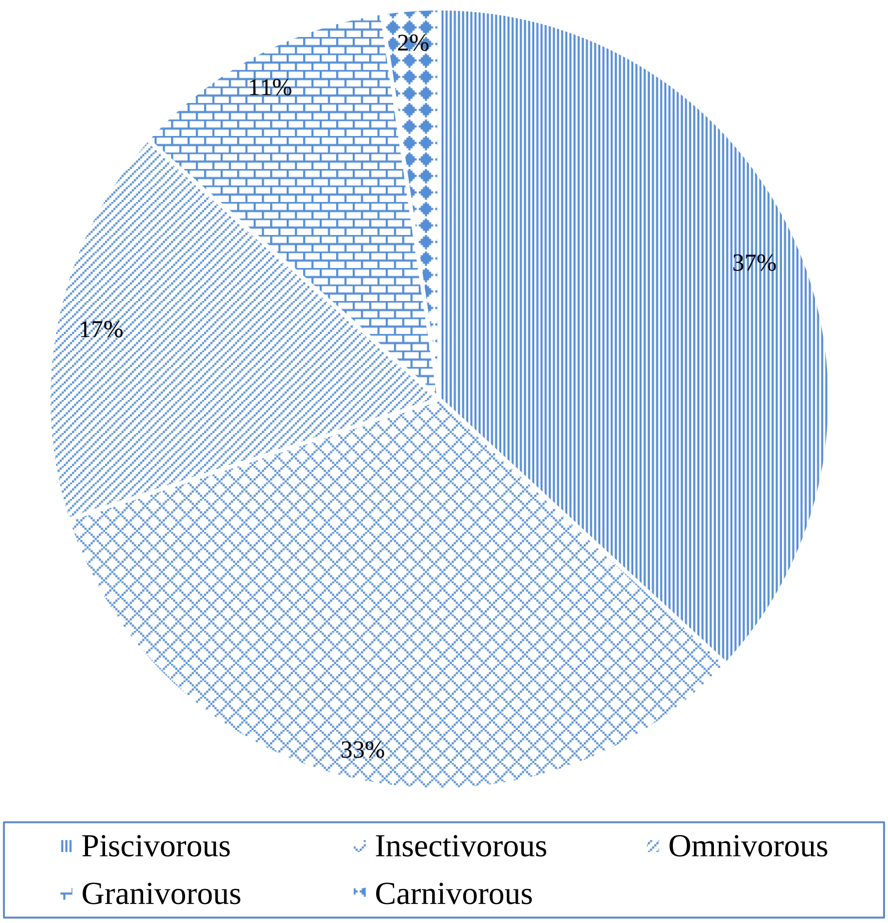


Figure 4.35: Foraging habits of birds encountered at Fosu Lagoon

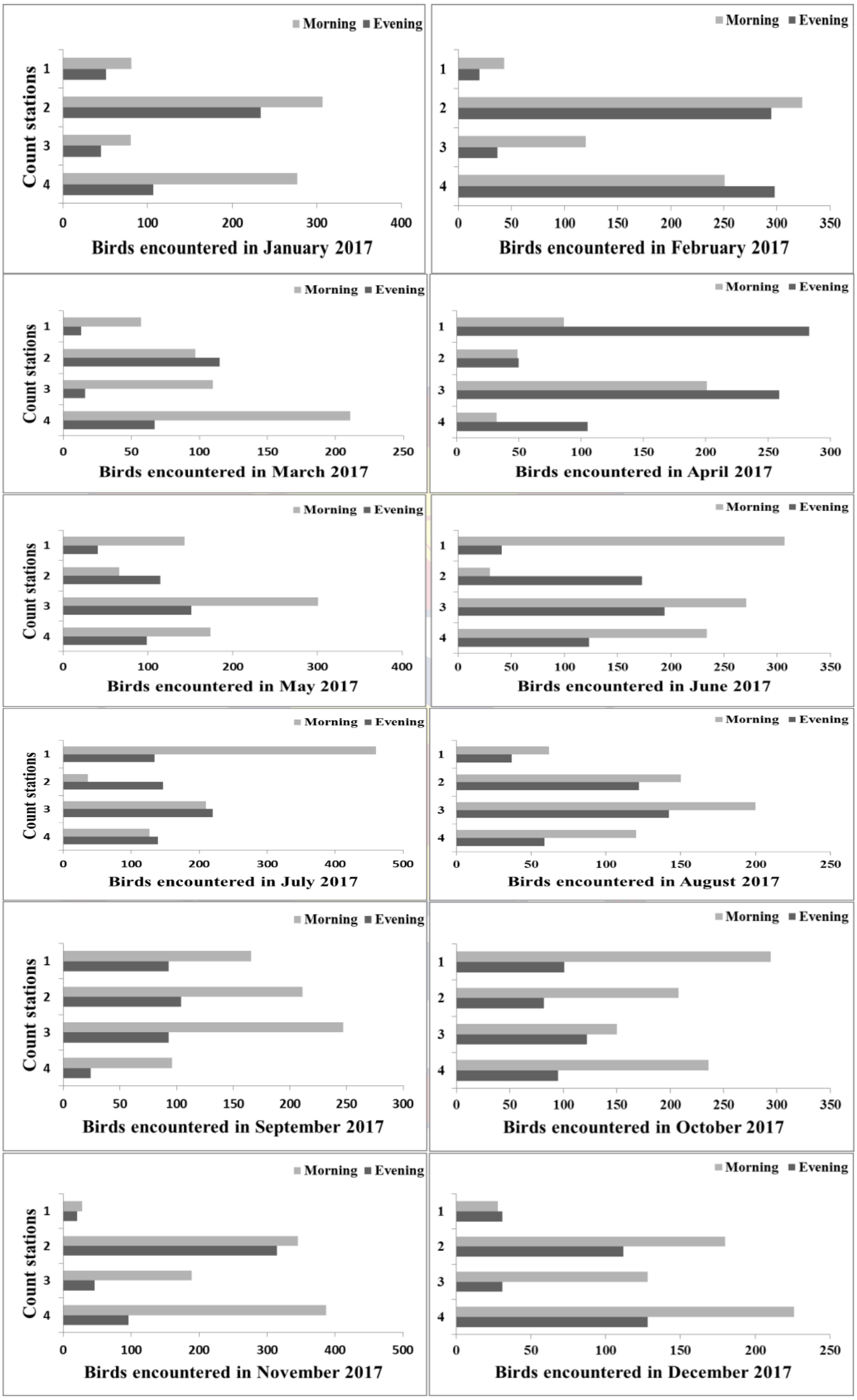


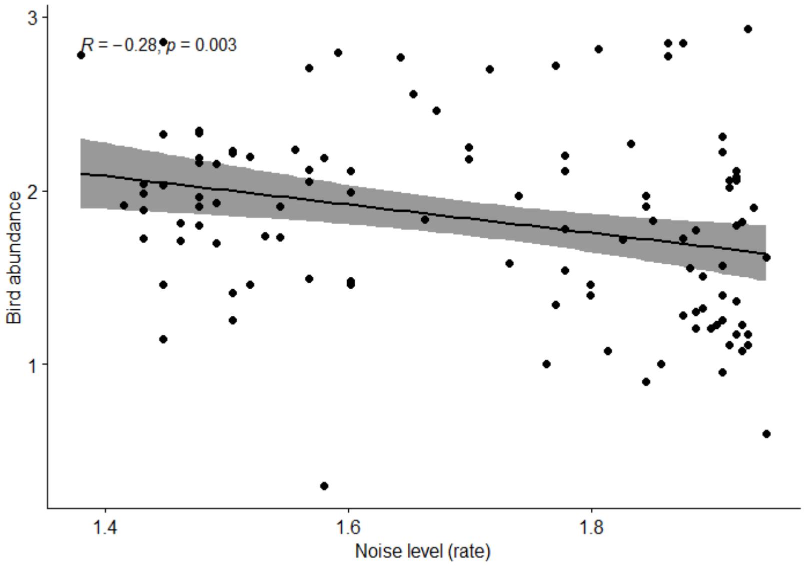
Figure 4.36 Monthly bird counts recorded at four stations (1, 2, 3, and 4) during foraging periods (morning = 6am – 9am; evening = 3pm – 6pm)

Generally, the most active periods of bird activity were in the mornings from 6am – 9am, as shown in Figure 4.36, where the number of birds for all functional groups ranked highest in all the months except in April where activity was highest in the evenings from 3pm – 6pm. Also, higher numbers of birds were recorded in the northern section of the lagoon (Station 4).

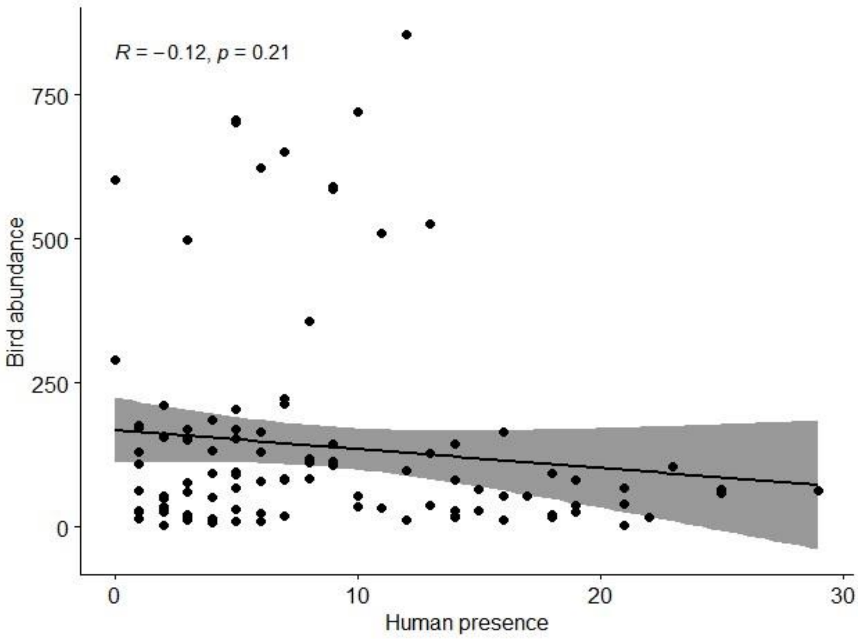
Effects of noise and human presence on the abundance of birds

On the basis of parametric assumption, the data required for correlation analysis on birds' abundance per influence by noise rate (dB) (APPENDIX I) had to be log-transformed since the distribution was not normal i.e the data was skewed when plotted. This improved the dataset before the correlation (Figure 4.37) analysis.

A scatter diagram in Figure 4.37, showing the correlation line, confidence interval, correlation coefficient, and p-value aided in correlation analyses between noise rate and abundance of birds, and also between human presence and birds' abundance. A gentle slope between both sets of variables depicted the type of relationships. A negative relationship (correlation coefficient, $r = -0.28$) between bird abundance and noise points to a decrease in the number of birds while noise increased. A p-value of 0.003 showed a statistically significant relationship (APPENDIX I). Also, a negative relationship (correlation coefficient, $r = -0.12$) existed between human presence and the abundance of birds. However, its p-value of $0.21 > 0.05$, indicated a statistically insignificant relationship (APPENDIX I).



(a)



(b)

Figure 4.37: (a) Correlation between Log transformed data of noise rate and birds' abundance and (b) between human presence and bird abundance

4.3 Resource Use and Human Impacts

Anthropogenic impacts resulting in bacterial loads, solid waste pollution, water drainage, and runoff into the Fosu lagoon through point sources of pollution, and littoral vegetation buffer width, were assessed.

4.3.1 Bacteria loads

Tables 23 and 24 provide information on faecal coliform and *Escherichia coli* counts, respectively, as inference on public health through handling and consumption of fish, and exposure through recreation contact and fishing by wading.

Of the fourteen monthly samples, the highest total coliform count of 7514cfu/100ml was at the lower reaches of the lagoon while the lowest of 2751cfu/100ml was recorded at the upper reaches (Table 23). A two-sample t-test on the assumption of unequal variances produced and a p-value of 0.00009 which was lower than 0.05 reflected a significant difference in the means of 536.71cfu/100ml and 196.5cfu/100ml at the lower and upper reaches, respectively.

The middle reaches of the lagoon recorded 4212cfu/100ml total coliform counts with a mean of 300.86cfu/100ml. A significant difference between the means of the recordings at the middle and lower reaches was noted from the t-test with a p-value of 0.01212 (<0.05). However, no significant difference was noted between the mean values of faecal coliform counts at the middle and upper reaches (p = 0.13360; > 0.05).

Table 23: Faecal coliform counts of 14 monthly water samples from Fosu Lagoon during sampling from November 2016 to December 2017

	Faecal Coliform (Counts/100ml)		
	Lower Reaches	**Middle reaches**	**Upper reaches**
Mean	536.71	300.86	196.50
Standard Deviation	232.99	229.76	92.97
Minimum	250.00	108.00	103.00
Maximum	900.00	740.00	350.00
Sum	7514.00	4212.00	2751.00

Similar results were produced for *E. coli* counts at the three sections (lower, middle, and higher reaches) in sampled water from the top 0.5m depth of the lagoon. The highest total *E. coli* count of 6188cfu/100ml was at the lower reaches, followed by 3551cfu/100ml and 2236cfu/100ml at the middle and upper reaches, respectively (Table 24). A two-tailed t-test on the assumption of unequal variances showed significant differences in the mean counts of the lower and middle reaches ($p = 0.02505; <0.05$) and between the mean values of *E. coli* counts at the lower and upper reaches ($p = 0.00037; <0.05$). However, no significant difference was noted between the mean values of the middle and upper reaches of the Fosu lagoon ($p = 0.099; >0.05$).

Table 24: ***Escherichia coli*** **counts of 14 monthly water samples from Fosu Lagoon during sampling from November 2016 to December 2017**

	E. coli (Counts/100ml)		
	Lower Reaches	**Middle reaches**	**Upper reaches**
Mean	442.00	253.64	159.71
Standard Deviation	224.65	192.24	54.62
Minimum	192.00	102.00	100.00
Maximum	835.00	605.00	250.00
Sum	6188.00	3551.00	2236.00

4.3.2 Solid waste assessment

Solid waste sampled constituted about 54.60% plastics and plastic products (Figure 4.38 and 4.39). This was followed by organics (17.69%), fabrics and clothing (11.98%), metallic items (11.90); and charcoal/unidentifiable items (3.83%). The festive periods contributed to higher waste disposal indicated in higher wastes of the December 2016 and April 2017 sampling (APPENDIX J).

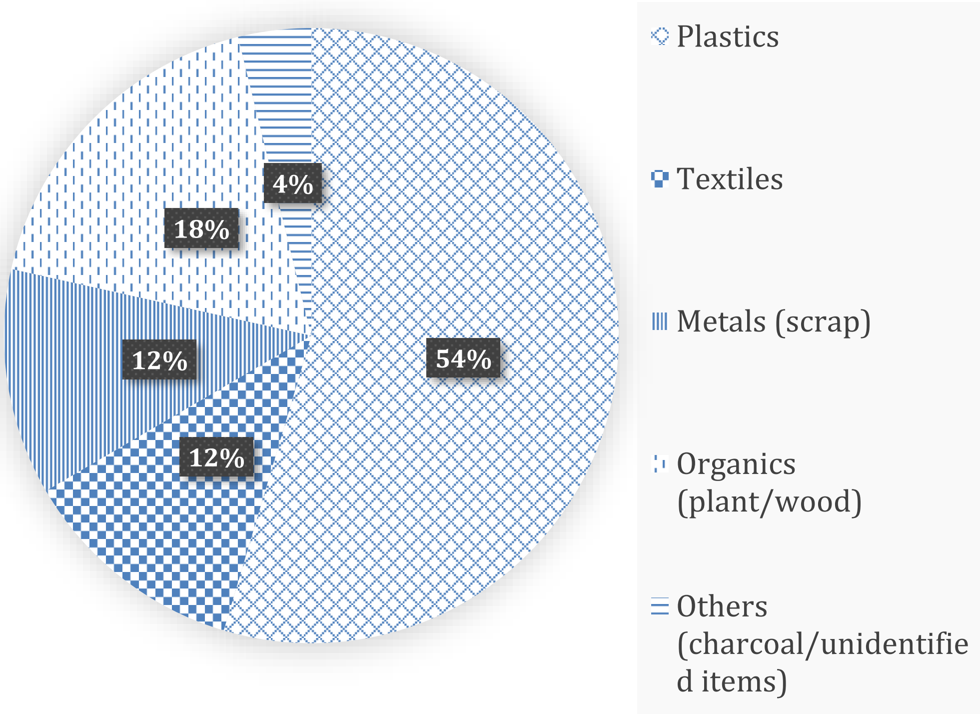


Figure 4.38 Total solid waste composition from the Fosu Lagoon

Figure 4.39 Flotsam largely composed of plastic solid waste in the Fosu Lagoon

4.3.3 Watershed delineation of the Fosu lagoon catchment

Prior to UAV flights and acquisition of drone data, available geo-spatial data of August 2018 on the United States Geological Survey (USGS) Earth Explorer was utilized to view the extent of the basin of the Fosu Lagoon and its catchment (Figure 4.40). It had a total perimeter of approximately 16,886 m and an area of 15,297,541 m^2. A digital elevation model (DEM) of the selected area allowed the delineation of a watershed (shown in Figure 4.41).

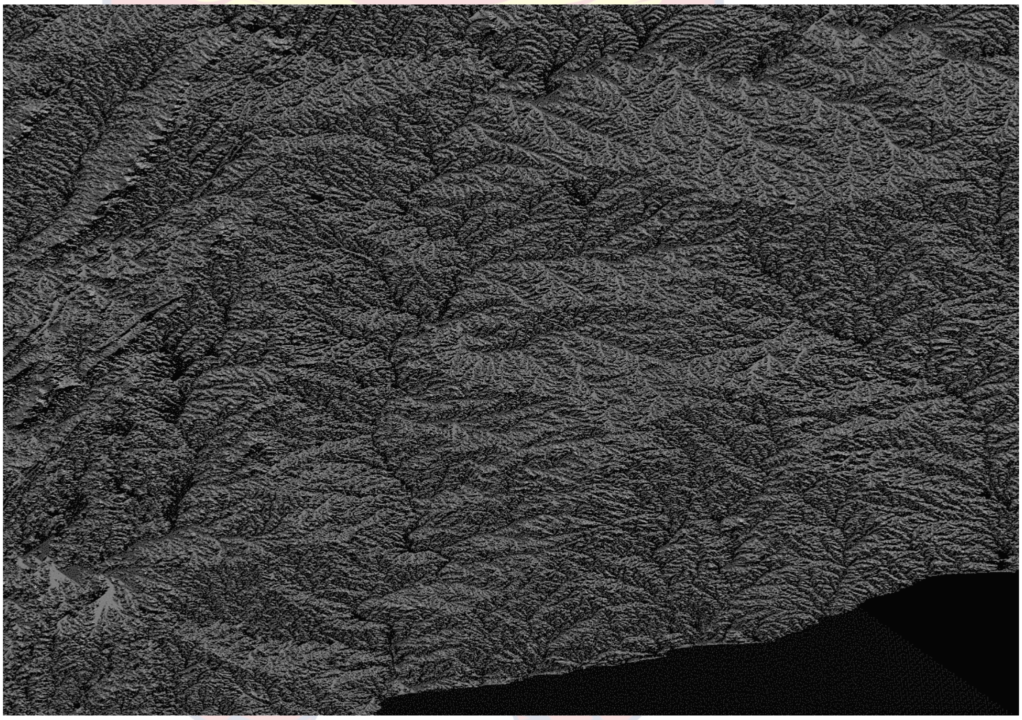


Figure 4.40: Basin feature of the Fosu lagoon catchment using USGS Earth Explorer (geo-dataset April 2018)

Figure 4.41: Watershed delineation using USGS Earth Explorer (geo-dataset April 2018)

4.3.4 Drainage regime and major runoff point sources

Resolution of the USGS DEM dataset (at 30m horizontal, 10m vertical) however emphasized the need to undertake UAV flights to ascertain immediate point sources of pollution into the Fosu lagoon. Drone DEM data analyzed in ArcMap version 10.3 produced the runoff points due to natural flow and artificially constructed drain gutters (Figure. 4.42)

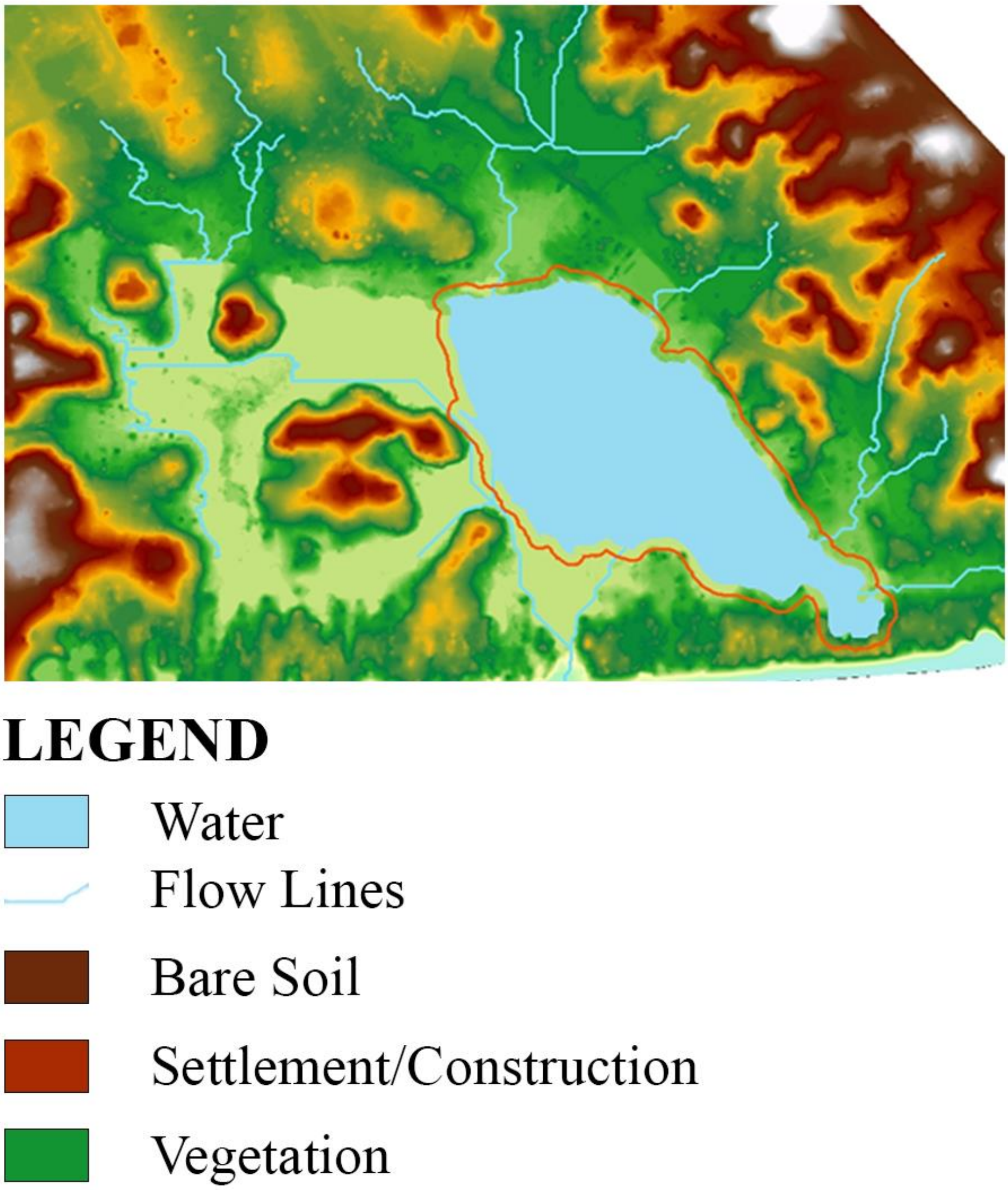


Figure 4.42 Flow lines showing major point sources of runoff and pollution of the Fosu Lagoon

4.3.4 Land-use within buffer perimeter

Buffer zones were marked at 30m, 50m, and 80m contour, from UAV multispectral band imagery of the Fosu lagoon catchment area (Figure 4.43). Land use within these buffers was estimated according to three classes – littoral vegetation, settlement, and bare soil/ground (Table 25). Littoral vegetation constituted 10.13ha, 15.61ha, and 22.67ha as one moved from the lagoon within the 30m, 50m, and 80m buffer perimeters. Buildings and other construction setups constituted 2.17ha, 4.80ha, and 9.86ha, respectively. While, bare soil/ground constituted 0.37ha, 0.82ha, and 1.68ha within the marked buffer perimeters.

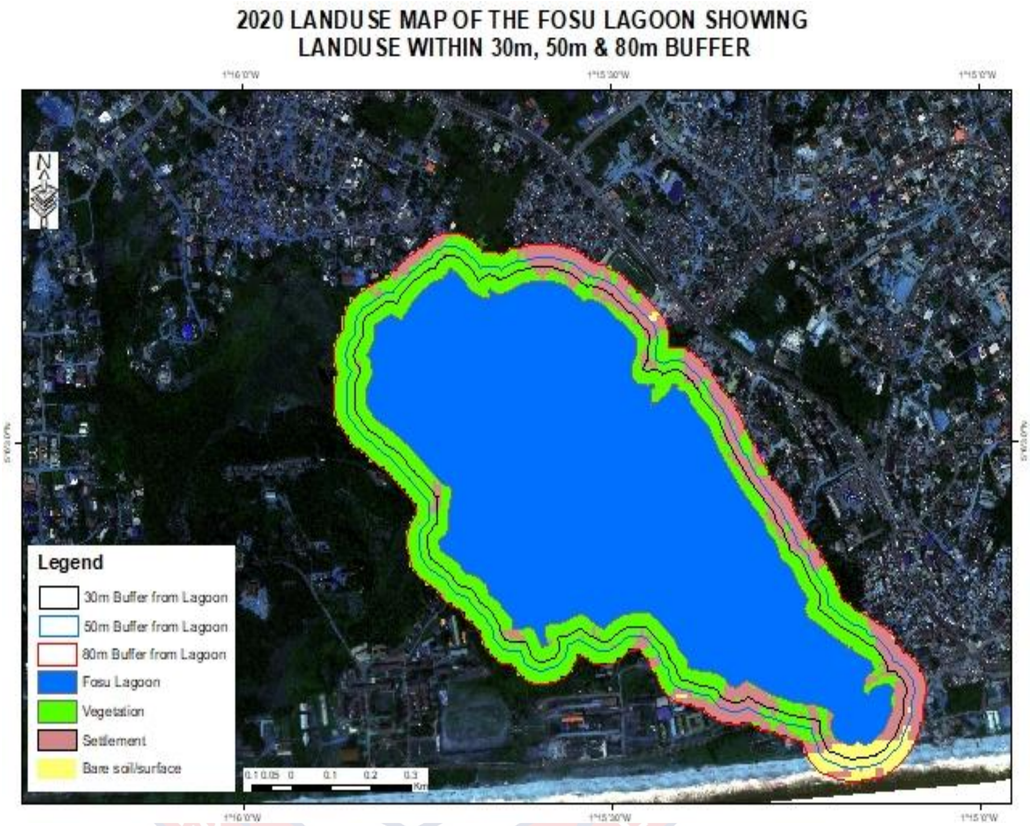


Figure 4.43: Estimated land use based on classification within 30m, 50m, and 80m contour buffer zones

Figure 4.44: Mixed littoral vegetation along banks of the Fosu Lagoon

Table 25: Area covered by various land use categories with reference from the Fosu Lagoon within buffer zones

Land use Class (ha)	**30m Buffer**	**50m Buffer**	**80m Buffer**
Vegetation	10.13	15.61	22.67
Settlement	2.17	4.8	9.86
Bare soil/Surface	0.37	0.82	1.68
Total	12.67	21.23	34.21

4.4 Developing a Decision Support System for the Fosu Lagoon

Three criteria were selected for consideration in the management of the Fosu lagoon towards optimum ecological health attainment – water quality restoration, biotic health improvement, and sustainable resource exploitation. Figure 4.45 shows the complex interconnectivity of the developed LMC-DSS as adapted from principles of a multi-criteria DSS by Convertino et al. (2013). The connectivity began from the objective of management of the Fosu lagoon in respect of its ecological health. It radiated into the three criteria under consideration. Each criterion then emanated into selected indicators and metrics which reflected the criterion's performance. Then, the indicators/metrics linked to the observation and quantifiable parameters which fed into the indicators/metrics derivation. The parameters could affect and feed into more than one indicator or metric thus the complexity represented in Figure 4.45.

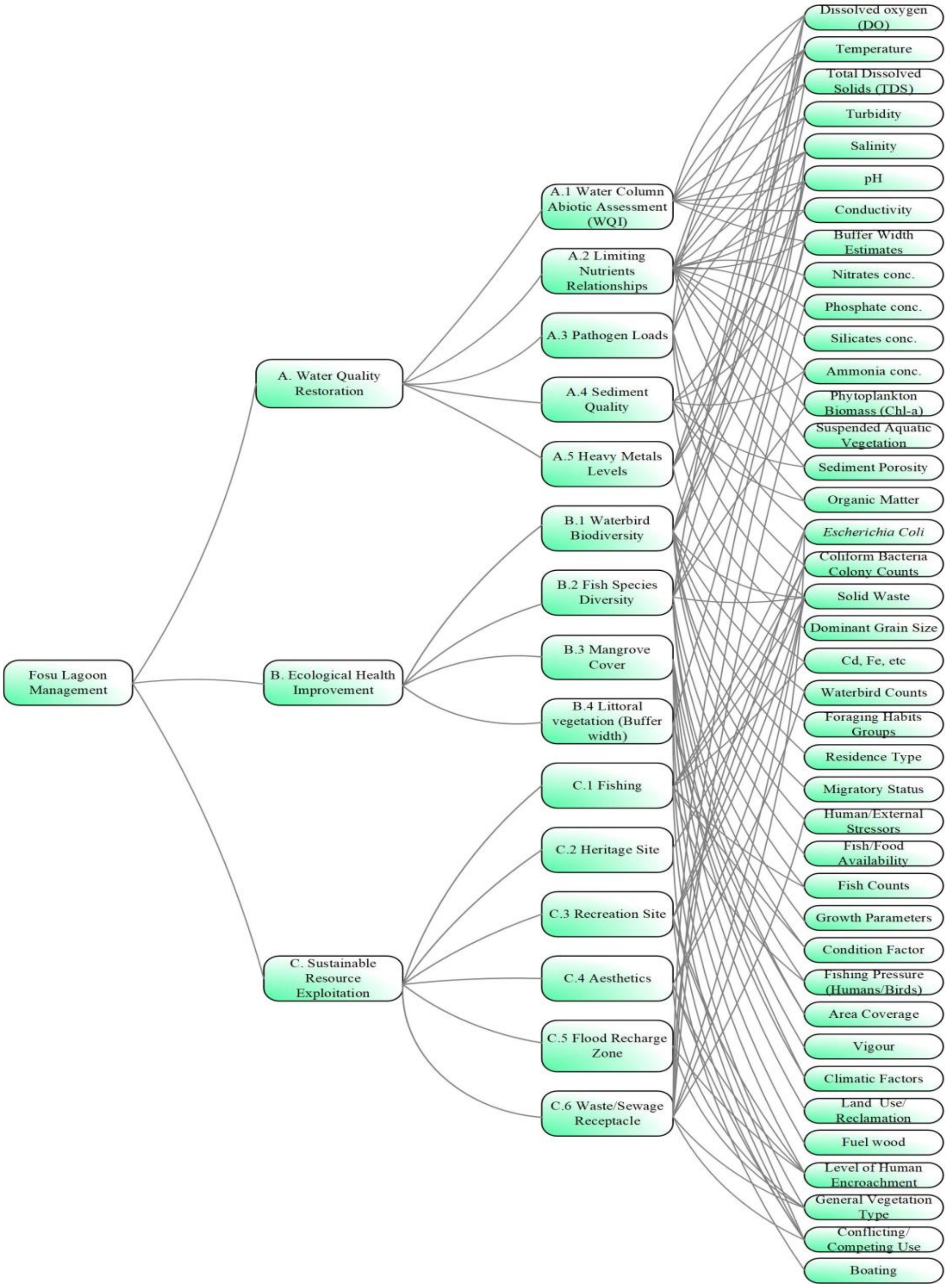


Figure 4.45: A 3-tiered Multi-criteria decision support for management of Fosu Lagoon

4.4.1 Present state of the Fosu Lagoon using the LMC-DSS

The criteria utilized were ranked based on the objectives of the research. Thus, water quality restoration was rated ‘A’ because the physicochemical conditions defined and supported life within that habitat. Rate ‘B’ was given to biotic health since the natural biological components’ well-being relied on the abiotic environment. Rate ‘C’ was assigned to exploitation in view of the community and stakeholders’ reliance on the system for certain ecosystem products and services.

Selected indicators and metrics for water quality restoration followed the order: water column abiotic assessment (A1); limiting nutrients (A2); pathogen loads (A3), sediment quality (A4), and heavy metals (A5). Dependent on the performance of each measureable parameter in relation to the relevant indicator (APPENDIX K-1), a grading (expressed as percentages of an ideal 100%) provided information on the indicators’ status so that the lowest percentage values signified a need to address related issues. In Figure 4.46, the indicators’ stata performances for the Criterion A (water quality restoration) showed 25% score for the indicator A1, while A2, A3, A4, and A5 scored 37.50%, 33.33%, 66.67%, and 20.00%, respectively.

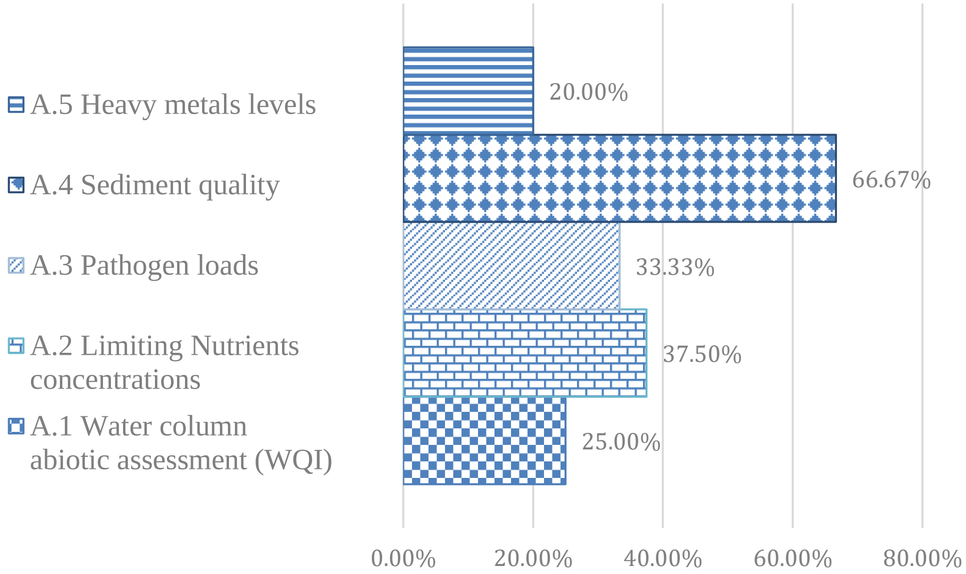


Figure 4.46: LMC-DSS output for relative percentage performance of Water quality restoration

Biotic health improvement was assigned four scored indicators/metrics (APPENDIX K-2) – Waterbird biodiversity (B1); fish species diversity and growth (B2); mangrove cover (B3), other littoral vegetation buffer width (B4). Fish species diversity and growth had the lowest performance of 22.22%, while bird biodiversity was highest at 54.55%, and both mangrove cover and littoral vegetation scored 40% each (Figure 4.47).

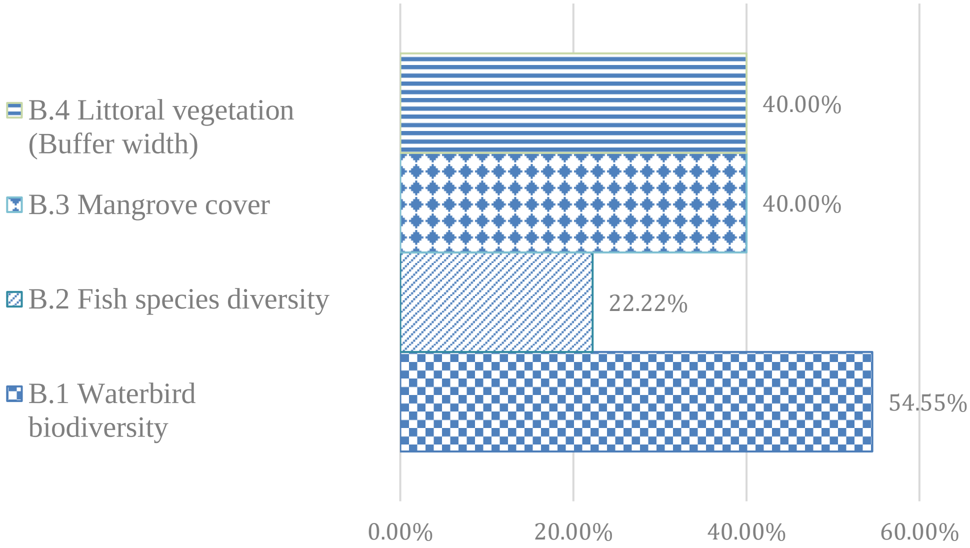


Figure 4.47: LMC-DSS output for relative percentage performance of biotic health

Rated C, Sustainable resource exploitation as a criterion was assigned six (6) indicators. These were fishing (C1); heritage site (C2); recreation site (C3); aesthetics (C4); flood control zone (C5); and waste disposal site (C6) [APPENDIX K-3]. The lowest scoring resource use indicators were in the order – heritage site, fishing, recreation site, and waste/sewage receptacle (0%, 12.50%, 16.67%, and 22. 22% respectively) as shown in Figure 4.48. The results also indicated that 'flood control' and 'aesthetics' performed at 33.33% and 40%.

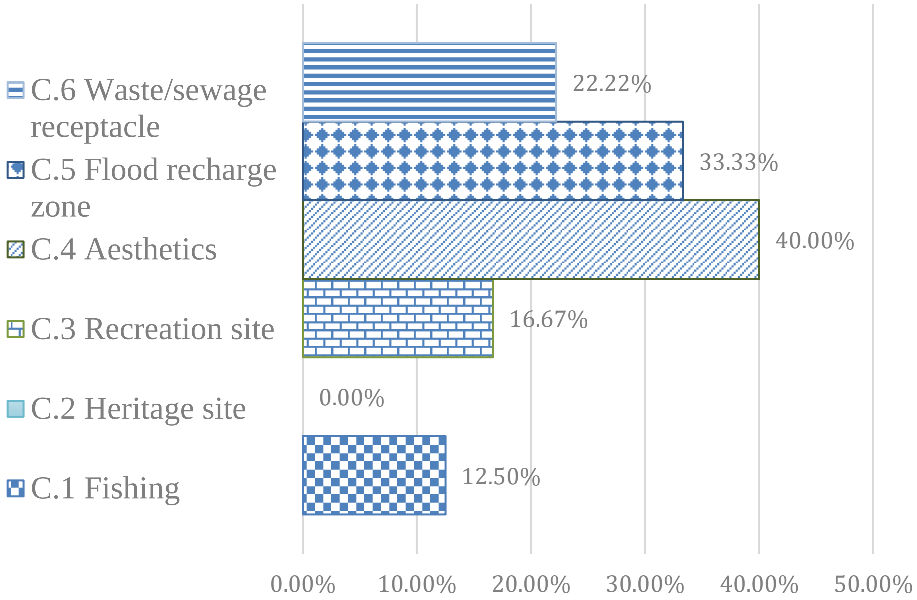


Figure 4.48: LMC-DSS output for relative percentage performance of sustainable resource exploitation

The final grading of the three selected criteria focused on the collective performance of the related indicators' variables. The percentage of total 'pass' per total number of variables produced a priority status expected to guide a decision-maker on each criterion's requirements for immediate address (Figure 4.49). Criterion C (Sustainable resource use) had the lowest total performance of 21.21% prioritizing it for management over water quality restoration (36.59%) and biotic health improvement (40.00%).

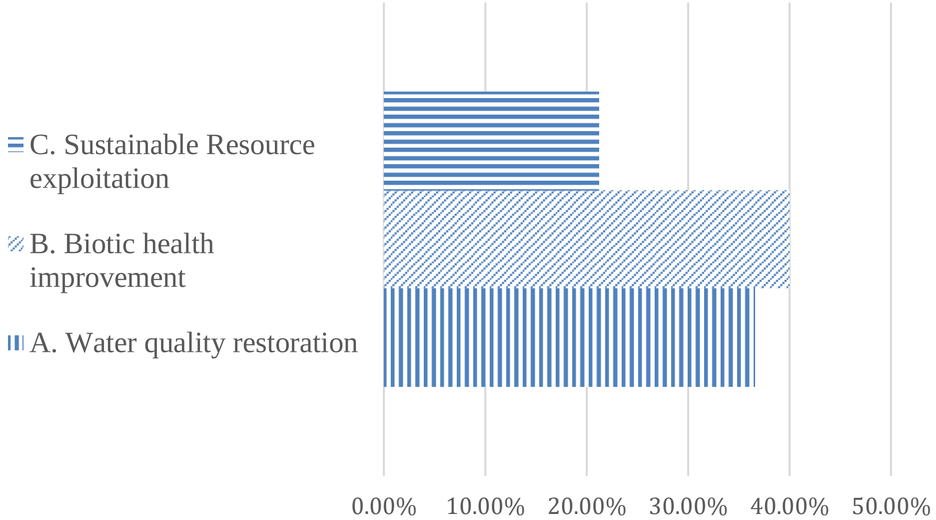


Figure 4.49: LMC-DSS output for criteria prioritization in Fosu Lagoon management

An infographic display option of the developed LMC-DSS provided a decision-maker with a visual display of the ecological health state, at about 33%, of the Fosu lagoon in response to data provided on the various parameters utilized in the process (Figure 4.50). Here, predictions could be made possible as a decision-maker could envisage different scenarios in relation to changes made to improve and manage the Fosu Lagoon. As one neared ideal restoration objectives, the visual displayed favourable, natural, or desired outcomes.

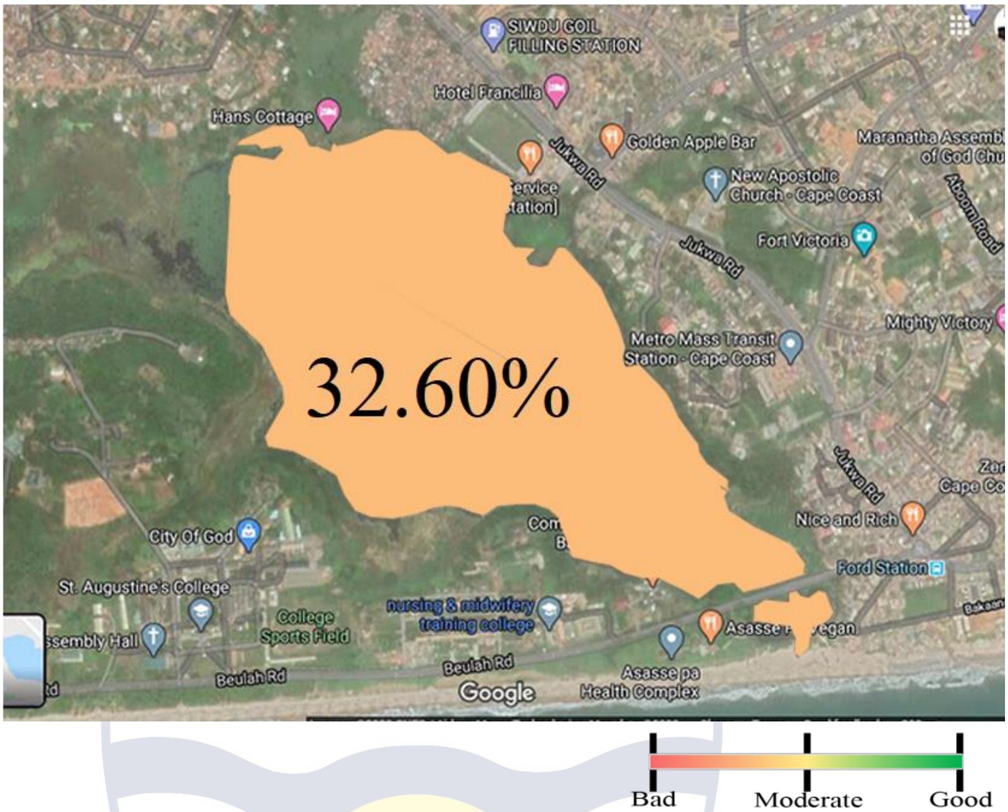


Figure 4.50: The ecological health state of the Fosu Lagoon in view of management requirement

4.4.2 Scenario creation on the state of Fosu Lagoon using the LMC-DSS

Two scenarios were created to provide options for decision-making on the instance of addressing the priority areas identified with each criterion.

The ecological health of the Fosu lagoon improved vastly to nearly 74% on changes made to deplorable and unsustainable use of the resource (Figure 4.51). The priority focus shifts to addressing water restoration issues. Whereas, when the second scenario creation fully addresses water quality issues of concern i.e. Criterion A, the ecological state of the Fosu lagoon is appreciably improved to about 78% (Figure 4.52). Policies and interventions through regulations can be adopted over short- to long-term goals using similar scenarios generated.

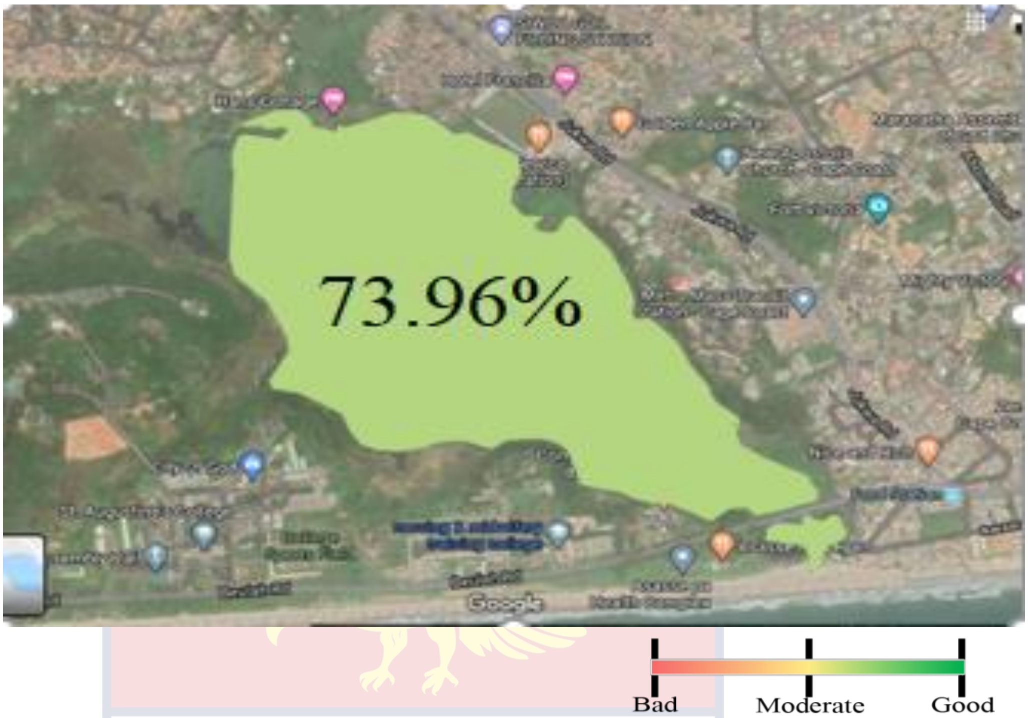


Figure 4.51: State of the Fosu Lagoon after improving Criterion C (Sustainable Resource use) using the LMC-DSS

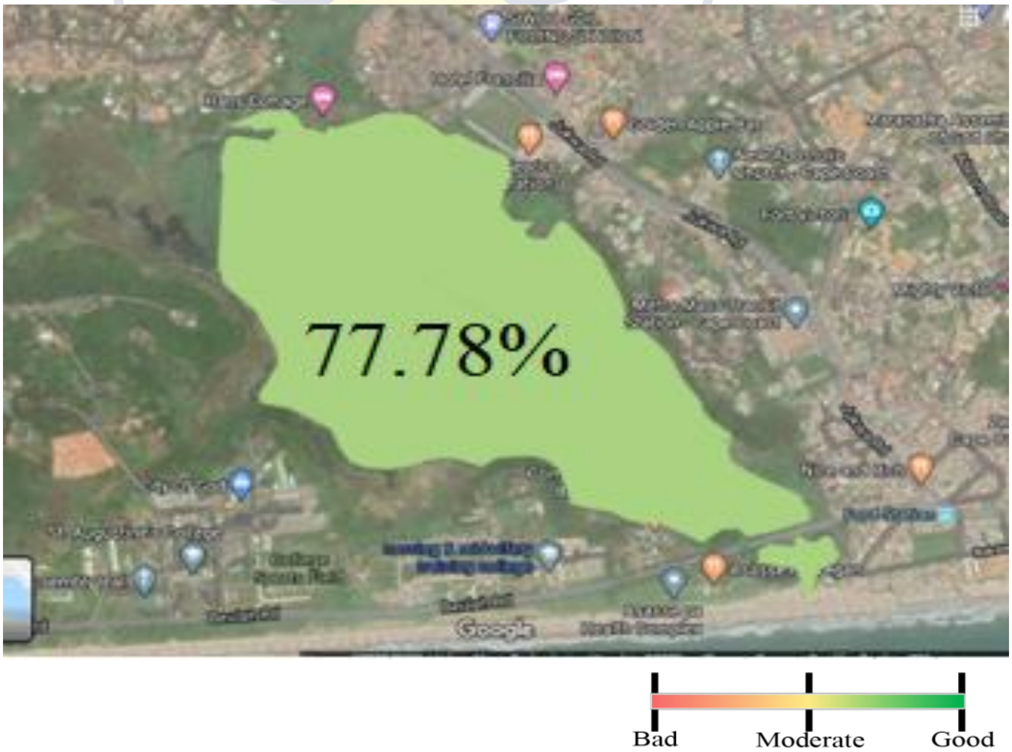


Figure 4.52: State of the Fosu Lagoon after improving Criterion A (Water quality restoration) using the LMC-DSS

4.5 Coastal Governance in Ghana

Aspects of coastal governance in Ghana were reviewed to ascertain the existing structure and institutional framework considering the ministries, agencies, and/or stakeholder groups that support it.

4.5.1 Evaluation of Institutional framework for Coastal management

Common major coastal issues along the coast of Ghana, in relation to resource use and exploitation, were identified and relevant administrative groups responsible for undertaking management were indicated (Table 26). Also, related to these identified coastal issues are the: legal bases through which awareness is created; educational programmes are undertaken; enforcement of regulations occurs, and policies reviewed are captured in constitutional acts and bye-laws (Table 26).

Table 26: Major coastal issues in Ghana

Issue	**Act(s) /Regulation(s)**	**Objective(s)**	**Lead Agency/ Group**
Biodiversity	Wild Animals Preservation Act, Act 235 1964 Wildlife Conservation Regulations 1971 (LI685)	Promote adherence to all laws on the protection of wild animals, birds, and fish. Observe regulations as stated in the London Convention.	Forestry Commission Fisheries Commission
Eutrophication	EPA Act, 1994 (Act 490)	Control and prevent discharge of waste detrimental to environmental health	Environmental Protection Agency (EPA)
Water quality	Water Resources Commission Act, 1996 (Act 522) EPA Act, 1994 (Act 490)	Set standards, prescribe guidelines on sustainable water use	Water Resources Commission (WRC) EPA
Solid waste	Environmental Assessment Regulations 1999, (LI 1652) Beaches Obstruction Ordinance, 1897 (Cap 240)	Control, manage and ensure safety in the disposal of waste by municipalities and industry to protect the integrity of the environment	EPA Ministry of Local Government and Rural Development DAs

Table 26: Major coastal issues in Ghana (continued)

Issue	**Act(s) /Regulation(s)**	**Objective(s)**	**Lead Agency/ Group**
Sewage	Town and Country Planning Ordinance (Cap 84)	Spatial planning, consolidate land use laws, promote health and safety in living spaces	Land Use and Spatial Planning Authority (LUSPA) Ministry of Sanitation and Water Resources EPA District Assemblies (DAs)
Heavy metals	The Mineral and Mining Law, 1986 (PNDC 153)	Promote BMPs, regulate activities of mining and related services, provide standards for wastewater release into the environment	Ministry of Lands, Forestry, and Mines Ministry of Environment, Science, Technology, and Innovation (MESTI) WRC
Flooding, Erosion, Siltation	National Building Regulations 1996 (LI 1630)	Regulate and supervise planning and construction	LUSPA Hydrological Services Department

Table 26: Major coastal issues in Ghana (continued)

Issue	Act(s) /Regulation(s)	Objective(s)	Lead Agency/ Group
Fisheries overexploitation	Fisheries Act 2002, Act 625	Ensure sustainable exploitation, regulate fishing and related activities	Ministry of Fisheries Ministry of Food and Agriculture (MoFA)
Habitat destruction	Land Planning and Soil Conservation (Amendment) Act, 1957 (No. 35 of 1957) The Wetland Management (Ramsar sites) Regulation, 1999	Implement policies on municipal and industry siting	LUSPA Ministry of Works and Housing National Development Planning Commission DAs
Industry and municipal setups	Environmental Assessment Regulations, 1999 (LI 1652) Town and Country Planning Ordinance (Cap 84)	Undertake environmental impact assessment (EIAs), issue permits on treated waste discharge, ensure continuous adherence to stated regulations	EPA LUSPA Ministry of Local Government and Rural Development DAs

4.5.2 Social Network Analysis (SNA) of relevant agencies in coastal management

The first visual generated from the NetDraw option of the UCINET provided information on three main aspects of agencies/groups' interaction towards coastal management. Red dots in the visual (Figure 4.53) represented specific questions affirmed during interviews and research, while blue squares represented codes of agencies and groups involved in the analysis process. Figure 4.53 shows the interactions dependent on the type of services provided by the agencies, the duration of their projects/programmes, and the funding options available to support their activities.

The bottom outliners in Figure 4.53 showed that the bottom-to-right clustered agencies were mostly on the field (FW) and primarily generated funding (FP) to support their activities without over-reliance on the central government. Some groups within this cluster included the Universities (UNI), Center for African Wetlands (CAW), Fisheries Commission (FiC), Water Research Commission (WRC), and other non-governmental agencies such as the Hen Mpoano and Sustainable Fisheries Management Project (SFMP). The top right cluster was strongest in responding to coastal issues based on sporadic events i.e. they were more reactive than proactive in their roles. They included the National Disaster Management Organisation (NADMO), Friends of the Nation (FN), Spatial Solutions (SS), and other foreign groups.

The middle cluster had affirmative responses (Figure 4.53) regarding the level of success (SU) for both short- and long-term projects (ST and LT) which aimed at both sustainable management of coastal resources (SM) and restoration of coastal systems (RS) yet primarily focused on awareness (AW) creation. Awareness creation however appeared closely tied to projects that were funded through foreign donors (FF). Also, the clustered top groups engaged in a regional and/or national level (RN). This group included the Ministry of Communication (MC), Ministry of Water Resources, Works and Housing (MWRWH), National Development Planning Commission (NDPC), and the Ministry of Health.

In the left cluster of responses (Figure 4.53), linkages to that group worked at the local/district level (LD) relying on government and NGO funding (GF and NF), engaged in relative routine monitoring (MR), and faced many constraints in coastal management (CM). Closest to this cluster of responses is the Land Use and Spatial Planning Authority (LUSPA).

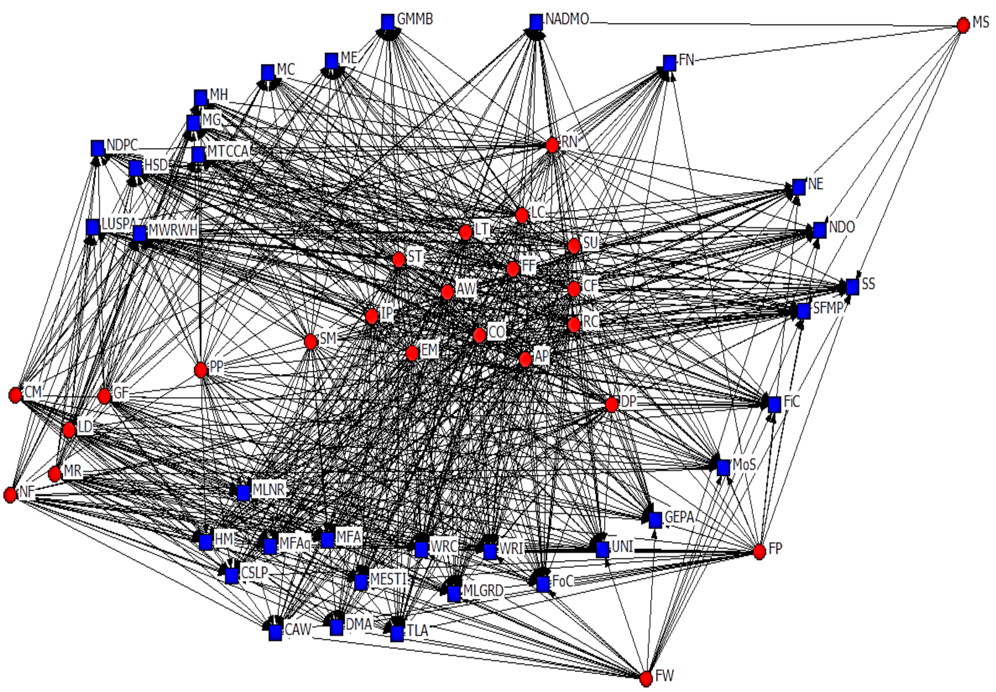


Figure 4.53: UCINET SNA Visual 1 of relevant agencies focusing on the type of services provided, duration of projects undertaken, and funding options available

In another visual (Figure 4.54), the connectivity of roles played by relevant agencies and stakeholders was assessed. The clear disjoint among actors in the provision of coastal environmental data (DP), analysis on data (AP), policy/regulatory setup (AP), and implementers (IP) was noted.

The close association of universities and other research groups (UNI) with traditional and local authority (TLA) on gathering information during projects was of interest to note. Also, short-term projects (ST) were the most successful (SU) from respondents' views.

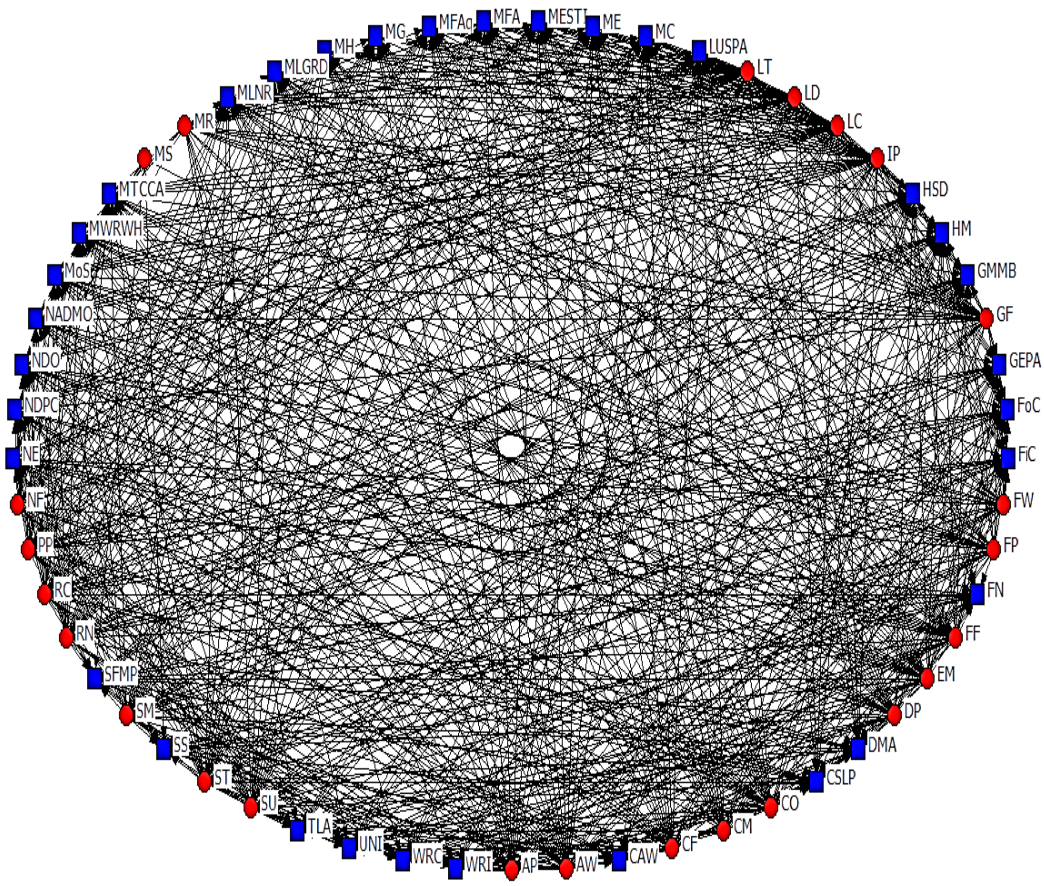


Figure 4.54: UCINET SNA Visual 2 of relevant agencies focusing associations by relevant agencies and stakeholders

Agencies and stakeholders' roles towards coastal management were more clearly displayed in Figure 4.55, to inform on collaborative strategy options. Here, groups at the lower bottom cluster who are funded through other means besides government funding such as foreign donors/grants could collaborate on projects with the top clustered groups for expertise share.

Also, the policy providers (PP) did not appear to occupy a central position in the analysis (Figure 4.55). Their closest counterparts were implementers (Figure 4.56) such as the Ministry of Environment Science, Technology and Innovation (MESTI), while the groups furthest from the coastal management policy and implementing process were those such as the traditional and local authority (TLA) and Ministry of Gender (MG).

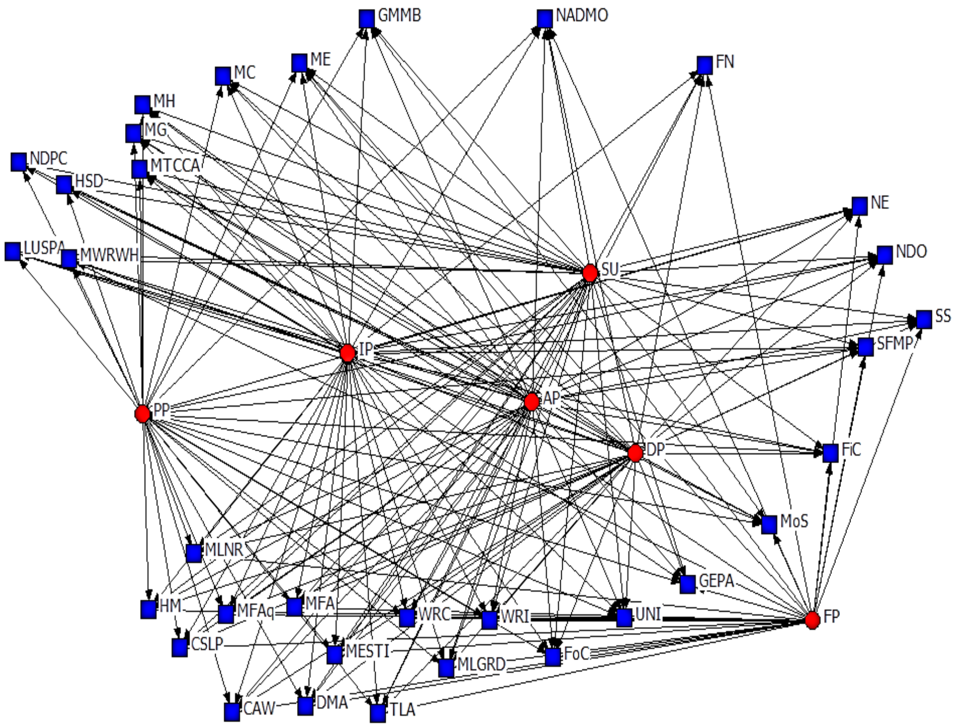


Figure 4.55: UCINET SNA Visual 3 of relevant agencies focusing on roles played by relevant agencies and stakeholders

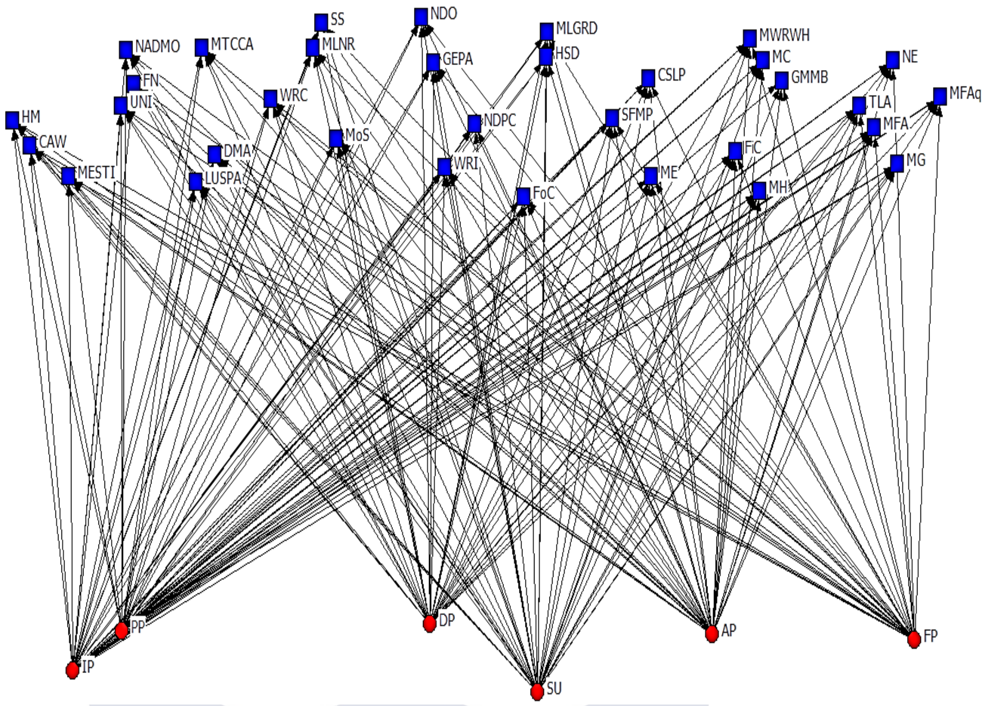


Figure 4.56: UCINET SNA Visual 4 of relevant agencies focusing on roles played by relevant agencies and stakeholders

CHAPTER FIVE

DISCUSSION

This chapter is oriented toward discussing the findings of this research. Comparisons are made, where possible, with other findings per related issues to analyze the possible trends or unique outcomes. The Fosu lagoon ecosystem is discussed based on the present abiotic and biotic environment indicative of its ecological health; selected land-use practices of concern to integrated management; present case scenario description of its ecological state based on a developed decision support system juxtaposed with scenario creations of improved management; and Ghana's coastal governance structure in support of its management.

5.1 The Abiotic Environment of the Fosu Lagoon

The abiotic environment comprises the physical and chemical elements of the environment that infer on the ability of the environment to support life, processes, and provide ecological services (Fondriest Environmental Inc, 2014). The physicochemical parameters selected in monitoring programs are suitable as they show immediate responses to climate patterns, geological influences, and catchment activities. Physicochemical parameters selected to assess the water column for the present study included temperature, dissolved oxygen (DO), conductivity, total dissolved solids (TDS), salinity, pH, turbidity, and nutrients (nitrates, phosphates, ammonia, and silicates).

5.1.1 Physicochemical driving factors

The major physicochemical drivers of the Fosu Lagoon which were determined using principal component analysis (PCA) enabled large dataset interpretation while reducing the loss of original information (Gan et al., 2017) which made it suitable for the study over the 14-months period. Interpretation of the dataset focused on the first two-dimensional view to allow comparison among monthly measurements.

In the context of major driving factors of lagoon processes and ecological functioning as stated by Kjerfve (1994) for restricted lagoons, the hydrological balance of the Fosu Lagoon was considered a priority in assessing the physicochemical environment. Thus, factors such as rainfall and runoff which are as a result of climatic seasons and catchment activities, respectively, served as a basis for describing the interrelations of physicochemical measurements. In this regard, the Fosu lagoon's physicochemical environment was described based on the local climatic seasons where there are two main seasons, the wet and dry seasons. In the past 30 years, patterns of these seasons are observed in four periods (Ministry of Foreign Affairs of the Netherlands, 2018). The months of November to March are considered as a long dry season, followed by a long wet season from April to July, then, a month of the short dry season (August), and a short, wet season from September to October. Average rainfall for the period of study ranged between 25mm and 229mm (Weather – atlas.com/en/Ghana/cape-coast-climate), inferring on the shifts in hydrological balance for the Fosu Lagoon which is a major receiving basin within the metropolis.

Temperature's effect on many water quality parameters such as dissolved oxygen (DO), salinity, conductivity, pH, TDS, and nutrient availability makes it an important parameter to monitor even in tropical shallow systems where a slight variation results in profound effects (Fondriest Environmental Inc, 2013; Isla, 1995). A bathymetric survey of the Fosu Lagoon indicated a range of profile depths from 1.1(±0.62)m to 1.5(±0.76)m (Restoration and Renaturation of the Fosu Lagoon, 2013) which allows its classification as a shallow system. Classical responses expected between the parameters on assumption that other interacting parameter influences are insignificant include a decrease in DO, on increasing temperature within the water column. However, classical direct positive relationships are usually expected and observed between temperature and salinity, conductivity, TDS, or nutrients availability. pH which is the measure of hydrogen ions in a solution is not necessarily affected although temperature influences the rate of shift of ions in a balance. Turbidity ideally informs on the heat-holding capacity of the water column thus, increasing the temperature in highly turbid waters (Avramidis et al., 2013).

At the beginning of the sampling period in November 2016, variations in temperature were inversely related to DO as shown by obtuse vector planes in the PCA. Close relationships between salinity and conductivity substantiated known observations. The strongest representation of these in the upper reaches suggested influences from the head section of the lagoon catchment. The mouth of the lagoon, as was observed in subsequent months, seemed to experience less regular influx by runoff. Temperature variations in December 2016 were closely related to conductivity although the representations of these along PCA vectors suggested underlying interactions. The increase in data representations in the following three months of January to March provided a basis to classify the Fosu lagoon as a typical tropical coastal lagoon where warm temperatures resulted in variations with less DO concentrations. Turbidity was generally highest (182.5 NTU, APPENDIX E-2) at the mouth section of the lagoon. In March, however, high turbidity variations with close relationships with DO confirmed the first heavy rainfall after many weeks of slow runoff entries coupled with the incorporation of oxygen at confluence points and also aided by wind action at the surface

The frequent rainfall and consequential runoff in the months of April to July 2017 indicated closer relationships between cooler temperature variations and higher DO. Turbidity variations in upper sections of the lagoon were expected, although similar occurrences at the mouth of the lagoon were closely associated with total dissolved solids. The distinction in possible causes of turbid occurrences in the separate sections was noted to inform on the management measure required for the purpose. A seeming spatial detachment of the upper reaches to all recorded variables in July suggested other significant processes not considered in the water quality assessment study. As mentioned earlier, bathymetric maps by CSIR in a study indicated depths of about 1.5m which could account for stratification whose effects are mostly observed in ambient colder periods.

The month of August 2017 was observed as a closed season for the start of the annual *Fetu Afahye* (festival) by the people of Cape Coast. The PCA plots produced showed a spatial unrelatedness of observed variations in two-thirds of the sampled areas. Temperature, DO and pH variations were poorly represented although closely related while turbidity, salinity, TDS, and conductivity also remained closely related. The upper reaches of the Fosu lagoon, from PCA produced, contributed insignificantly to the observed variations in parameters recorded in the months of September and October. The apparent swap in representations quadrats by temperature and DO stressed the transition from colder temperatures to warmer periods in the ensuing months.

The physicochemical environment was also assessed in the months of November and December 2017, to provide an overlap to ascertain possible trends. However, uniquely different responses were shown in these repeated months for the Fosu lagoon. A close association between warming temperature variations and DO for these two months, as observed from PCA for August also, hints of blooms that have yet to deplete the system of DO.

5.1.2 Nutrients' role in chlorophyll-a concentrations and eutrophication

Eutrophication episodes were physically evident as patches of algal mats/scums were observed during the study period. Recognition of nutrients' effects on boosting primary production in lentic systems, then later when unchecked into burgeoning issues of eutrophication dates back to the 18th Century (Nixon & Pilson, 1983; Vollenweider, 1976). In this research, however, poor positive correlations between estimated chlorophyll-a concentrations and documented limiting nutrients of nitrates and phosphate suggested additive effects by other parameters and conditions in the phenomena of blooms. Silicate concentration which was postulated to be a vital "building block" of diatoms, thus reflecting on the primary productivity also correlated weakly with estimated chlorophyll-a concentrations.

5.1.3 Spatial assessment of physicochemical parameters on chlorophyll-a

Low PCA representation percentages for all three sections of the Fosu lagoon (48.45%, 44.26%, and 51.70%) during the sampling period underpinned the complexity of coastal lagoon processes to understand which physicochemical driving factors mostly affected chlorophyll-a estimates.

At the lower reaches of the lagoon, the pigment variations were closely related to turbidity and inversely related to DO and pH. High turbidity has been noted to increase surface area for attachment in the case of total suspended solids (Serajuddin et al., 2019). However, the reduction in clarity/transparency also suggested poor penetration of needed sunlight for primary production by phytoplankton and other suspended aquatic plants. Inverse relationships between Chlorophyll-a and DO was a classical response for fast uptake of DO through respiration processes by primary producers. These observations made primarily in the months of August and September reflected earlier indicated physicochemical environmental conditions of the mouth sections.

At the middle reaches. chlorophyll-a estimates were closely related to temperature. As expected, more stable temperatures associated with the middle sections of the system substantiated the fact that a significant change in temperature was required to shift primary production. Also, DO remained inversely related to chlorophyll-a concentration estimates. Tightly clustered monthly observations at the middle reaches were evident of the relative stability of parameters within the middle sections of the lagoon.

At the upper reaches of the Fosu lagoon, however, chlorophyll-a was closely related to DO which did not appear to alter much in variability. The presence of suspended vegetation in this section coupled with relatively high oxygen incorporation by wind action could account for the observed relationship in the wet months of April to October.

5.1.4 Water Quality of the Fosu Lagoon

Water quality indices, which primarily serve the purpose of bridging the gap between water quality scientists and users/stakeholders/decision-makers towards coastal management (Sanchez Hernandez et al., 2007), were adopted in the present study. Water quality indices utilized were interpreted based on their respective scales in order to enhance the understating of the state of water and to provide a basis for comparison (Pesce & Wunderlin, 2002), and improve on existing conditions through management. Weighting factors included in the water quality indices formulation stressed the importance of some parameters in defining the quality of water based on the objective of assessment (Juwana et al., 2012; Munda & Nardo, 2005).

Assessment of the Fosu lagoon using three water quality indices

Three water quality indices were used in the assessment of the Fosu lagoon: WQI, WQI_{min}, and WQI_{GH}. These indices were used with various weighting factors and against their respective classification schemes to determine the water quality of the Fosu Lagoon.

The WQI developed by Pesce and Wunderlin (2002) which is aimed at including all relevant water quality parameters were weighted dependent on the relative contributions of parameters towards observed conditions. In the present study, WQI was calculated based on the overall contribution of the physicochemical parameters measured through PCA. All the monthly water quality values which fell within a range of 5 – 17, were described as ‘very bad water quality’ class (i.e. below 25), with water quality in certain months being worse still, particularly in peak rainy periods. Contrary to the status quo that dilution reduces pollution, the worst water quality at rainy periods suggests increased runoff containing contaminants from the Fosu lagoon watershed.

Interestingly, the WQI_{min} which focused on averaged normalized values of three parameters considered as most important for defining the water quality of surface water by its proponents also put the water quality of the Fosu lagoon below the 15th percentile (i.e. 5 – 13) on a scale ranging 1 – 100.

Ascertaining the water quality through the use of a National Adopted Scheme by the Water Resources Commission (WRC), Ghana, required added parameters that were not considered in the WQI and WQI_{min} i.e. faecal coliform, ammonia, and nitrates/phosphates (Ghana Raw Water Quality Criteria and Guidelines, 2003). Pre-assigned weights were dependent on several studies conducted on selected Ghanaian waters of varying characteristics and use by the WRC. Generally, water quality WQI_{GH} at the three sections of the Fosu lagoon fell within two main classes, Class III and Class IV, described as ‘poor quality’ and 'grossly polluted'. During most months, the water quality was typically grossly polluted at the mouth of the lagoon in comparison to the middle and upper reaches. The continuous months of observed WQI_{GH} states pointed to persistent impacts from the catchment.

Selection of an appropriate water quality index

An Akaike Information Criterion (AIC) measure (Glen, 2015), was adopted and used to quell uncertainty on which of the applied indices appropriately defined the conditions of the Fosu Lagoon. The purpose of the AIC which focused on errors in measurements of relevant parameters provides information to guide water quality monitoring programs. The WQI_{min}, as expected, had the lowest AIC value of 607.18 (approx.). The significantly low number of parameters considered in its calculation made it an unsuitable selection for detailed monitoring purposes. The risk assessment measures provided a basis for employing such indices as the WQI_{min} for rapid first-hand assessments or in situations of scanty data and logistics. Also, WQI_{min}'s inadequately classified scheme of index interpretation from 1 to 100 emphasized the need to select an appropriate water quality index with fine-tuned classes. Therefore, the WQI_{GH} which had a lower AIC value of 1022.12 than the WQI value of 1469.52, would be a more appropriate index to be used in the calculation of the water quality of the Fosu Lagoon. Considering that the water quality definitions for both indices' classification schemes fitted the present conditions of the lagoon, WQI_{GH} is suggested as a more appropriate index for water quality assessment on coastal lagoons in Ghana.

5.1.5 Trophic status of the Fosu Lagoon

To enhance knowledge for sustainable management and decision-making concerning conservation, assessment of the primary production of coastal lagoons is vital. Primary production serves as the foundation of food chains and energy transfer from sunlight and nutrients within the lagoon ecosystem (Botello et al., 2019). The present study focused on Chlorophyll-a as a proxy for phytoplankton biomass among other forms of primary producers such as benthic micro- and macro-algae, and macrophytes. The use of chlorophyll-a as a proxy for primary production was based on the assumption that the pigment fully represented other pigments found in phytoplankton and the efficiency of the pigment did not vary with species and age of phytoplanktonic organisms (Hall & Moll, 1975).

The trophic state index (TSI) and trophic level index (TLI) each provided insight into the potential primary production capacity of the lagoon in support of energy transfer. Whereas the TSI focused on an algorithm based on transparency, chlorophyll-a, and phosphate (Carlson, 1977), the TLI included nitrates in its trophic characterization of lentic systems (Burns et al., 2009). Similar information produced from both TSI and TLI at the various reaches of the Fosu lagoon suggested that nitrates did not strongly act as a limiting nutrient compared to phosphates in the Fosu lagoon. The TSI (Upper Reaches = 48.5, Middle Reaches = 44.5) and TLI (Upper Reaches = 3.8, Middle Reaches = 3.4) characterized the upper and middle reaches of the lagoon as mesotrophic (moderately productive), while the lower section (TSI = 52.4; TLI = 4.4) was eutrophic (highly productive). In the calculation of the TSI, although nitrate concentrations were not involved, the characterization remained as found in the TLI. Knoppers (1994) provided several other short-term processes that are likely to affect the characterization of the trophic state of coastal lagoons such as geomorphological features, hydrodynamics, and interactions between other nutrients and existing autotrophic communities. The author further described mesotrophic and eutrophic states in restricted coastal lagoons with deeper depths (>2m) as owing to reduced sunlight penetration thus enhancing phytoplankton communities to dominate. In shallower sections (<2m) of the lagoons studied by the author, perennial macroalgae were noted to proliferate in succession with microalgae. These observations were also made at the mouth section of the Fosu lagoon, forming nuisance algal scums that disrupted fishing activities, clogging nets of fishers.

5.1.6 Implication of heavy metals in the water on aquatic life

All of the ten metals (Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, and Zinc) measured in water samples of the Fosu lagoon showed upper limits (Table 5) above the U.S EPA Toxicity Reference Values (US EPA, 1994, 2007). The assessment was conducted to relate the possibility of these heavy metals to bioaccumulate in fish caught. Public health concerns for heavy metals in consumed black chin tilapia have been raised (Baffour-Awuah, 2014; Blay, 2009). High concentrations of essential metals i.e. Fe, Mn, Zn, Cu, Cr, Co, and Ni, and the presence of non–essential metals such as Pb, Cd, and Hg served as the focus in heavy metal measurements in fish sampled during studies conducted by the Council for Scientific and Industrial Research (CSIR) Institutes in January 2013, and in a separate study by Akoto, Eshun, Darko and Adei (2014). The CSIR recorded lower concentration values of Pb and Fe in muscles of sampled tilapia in comparison to an earlier study in 2011. However, an improvement in the study (as recommended by the earlier study) focused on heavy metals bioaccumulated in the gills of fish. Allen-Gil and Martynov (1995) and Terra et al. (2008) had stressed the need for other organs such as gonads, gills, liver, and kidneys for heavy metals assessment due to low binding proteins in muscles of fish. Thus, for small fish such as the blackchin tilapia which were eaten whole after food preparation without gills being removed after degutting, public health concerns were salient. Indeed, the study by CSIR recorded higher concentrations of heavy metals in gills than muscles to support the conclusions by other studies in different locations.

In the present study, the high concentrations of heavy metals in water sampled when taking into account prevailing physicochemical conditions, age and condition factor of fish, and bioaccumulation rate, suggest valuable information to coastal managers on public health and safety in fish consumption from the Fosu lagoon.

5.1.7 Sediments of the Fosu Lagoon

Sediment analyses focused on the grain sizes to infer on resuspension, transport, and adsorption by contaminants such as heavy metals and nutrients. In an evaluation conducted by Kalin and Hantush (2003) on models suitable for sediment analyses, a sedimentological characterization using the grain sizes showed larger grain particles (>l mm) dominated the site during the rainy periods reflecting sediment-laden runoff from the catchment. Also, the authors concluded that a non–cohesive sediment transport module out of five other modules emerged as the most user-friendly since it relied on average particle size and grain size distribution to find the relationship between the transport and adsorption potential of sediments. The generalized outcomes related finer grain-sized sediments to longer resuspension rates, and higher adsorption potential to contaminants serving as a concern for watersheds that received runoff on stormwater with high loads of finer sediments.

In the Fosu lagoon, finer sediments (grain sizes less than 125µm but greater than 63µm) dominated during the dry seasons. Sorting and skewness coefficients calculated from the sediment distribution grain curve put the sediments from the Fosu lagoon in the 'poorly sorted' and 'strongly skewed towards fine particles' descriptions, respectively. These descriptions are characteristic of terrigenous sources of sediments that reach the lagoon through several points and nonpoint sources within the catchment (Luyendyk, 2016). Bormann et al. (1998) and Saintilan and Williams (1999) emphasized the retaining effects of littoral vegetation in trapping larger sediments from runoff, which is important in management measures.

Sediment-water fluxes are an important consideration in ecological studies of coastal systems (Boynton et al., 2017). The nutrient supply effect in shallow systems (<10m) from the sediment-water interface is as a result of more efficient demineralization and aerobic activities by benthos (Bricker et al., 2008). Litchman et al. (2006) also noted the release of limiting nutrients (nitrogen- and phosphorus-based, and dissolved silica) necessary to enhance primary production in relatively shallow systems. Also, the organic matter load in sediments is significantly related to the release of nutrients particularly ammonia at the sediment-water interface dependent on porosity and oxygen availability (Denis & Grenz, 2003). To ascertain these findings, the present study showed a strong positive relationship between interstitial ammonia in the upper sediment layer and the organic matter content estimated. Coupled with the prior assessment of porosity, where relatively higher porosities occurred with larger grain particles in the system, the potential of additional nutrient release in support of primary production and eutrophication from the sediment-water interface is of knowledge value to management decisions.

In an assessment of heavy metals in sediment, results showed high levels of mercury (range of 1.7600 – 4.4000 mg/kg) as compared to other heavy metals which were within permissible levels by the US EPA (US EPA, 2007). This study did not, however, investigate whether the mercury was in a methyl state which is the process by which mercury is made biologically available to life forms (Frohne et al., 2012). The possible occurrence of dissolved organic matter (DOM) from dead organisms which aids the process of methylation serves as an opportunity for investigation. Of pollution concern and influences on benthos, are the assertions by Adomako et al. (2008) on the long-term effects of the aggregation of metals in sediments forming denser particles and their release at certain favourable conditions to the water column. This is because heavy metals measured in the Fosu lagoon sediments generally fell below the US TRVs (Table 7). However, concerns of additive effects at certain conditions require further investigations. Li et al. (2013) explained heavy metal release rates at critical pH, temperature, DO, and flow rates. Evidence of increased heavy metal release at a low pH range of 4-7, temperature of 30^oC, and high DO is shown for Zn, Cu, Cr, and Pb, while increased flow rates affected Zn, Pb, and Cr. The authors further explained the absorption of heavy metals studied at high pH ranges of 8-12 and in colder temperatures and the release of Cd in anaerobic conditions.

In his masters' dissertation on the Fosu lagoon, Eshun (2011) through the use of geo-accumulation index classifications, indicated "extremely contaminated sediments" concerning iron (Fe) and manganese (Mn) and "strongly contaminated sediments" with zinc (Zn) and lead (Pb). The author also attributed these to point sources of pollution such as the automobile garages at the northern section of the Fosu Lagoon. The present study measured Fe ranges between 17.5140 - 219.2400 mg/kg, whereas Eshun measured Fe values between 114.80 – 1341.50 mg/kg. The present reduced concentrations are suggestive of changes in catchment activities over the five-year period. The reduced upper limits of concentrations for Zn i.e. 1.4000 - 12.8600 mg/kg (present study) and 11.95 – 124.35 mg/kg were noted. Bentum et al. (2011) in a study conducted in 2009, two years prior to Eshun's study, had however concluded based on averaged geo-accumulation values and pollution index that the Fosu lagoon sediments sampled were practically unpolluted with Fe, Cu, and Zn, but moderately polluted with Pb.

5.2 The Biotic Environment of Fosu Lagoon

The use of biological indicators of the Fosu lagoon was deemed useful based on assertions made by Holt and Miller (2010) that biological components reflected the impacts of anthropogenic activities. Responses through species biodiversity, abundance/presence, and effect on natural functioning were important measures in this regard. Implications for selecting organisms as bioindicators of anthropogenic stress were explored.

5.2.1 Dominant single cichlid species - blackchin tilapia, *S. melanotheron*

In an inaugural lecture delivered at the University of Cape Coast on May 14, 2009, speaker John Blay (Ph.D.) provided a bio-profile of lagoon tilapia species in coastal waters of Ghana and the prospects of its fisheries development (Blay, 2009). The lecture brought to bear the dominance of the blackchin tilapia (*Sarotherodon melanotheron*), its stunted growths, and the support the fishery provided to coastal inhabitants. Of essence, the maximum theoretical lengths (L_∞) were explored to postulate the maximum length possible for the blackchin tilapia to attain in the absence of fishing pressure, disease, or any other restrictive growth determinants. Blay and Asabere-Ameyaw (2007) and Koranteng and Patrick (2018) concluded from studies that maximum observed total lengths (TL) of the blackchin tilapia were 15.9 cm, 18.5 cm, 11.3 cm, and 11.0 cm in the Fosu lagoon, Benya lagoon, Kakum estuary, and Muni lagoon, respectively. These, as reasonably expected, fell short of the L_∞ calculated i.e. 16.1cm, 19.0cm, 12.1cm, and 16.3cm, respectively. Reaching maturity sizes at 5.7 cm to 7.2 cm by ages 4 – 6 months, the speaker stressed the assertions made by Panfili et al. (2004) on stunting and early maturity by teleost as strategies to overcome unfavourable conditions in brackish systems. Unfavourable conditions spanned from the ephemeral nature of coastal systems (Noakes & Balon, 1982) and wide variations in temperature, dissolved oxygen, and polluted conditions (Blay & Dongdem, 1996). The lecture further impressed on the opportunity to improve the blackchin tilapia fishery as the Brimsu Reservoir had supported species that could grow up to about 36 cm at 1 kg. In more recent studies, however, Mireku et al. (2016) and Tibu et al. (2019) showed maximum standard lengths (SL) of 7.5 – 17.6 cm in the same reservoir for 457 individuals caught by gillnet and from 3.9 -13.8 cm SL for sampled fish in the Etsir lagoon.

The size distribution analysis of the same dominant fish species, *Sarotherodon melanotheron*, in this present study was to serve as a comparison to similar studies conducted in 2013 on the Fosu lagoon by Dankwa, Quarcoopome, Owiredu, and Amerdome, (2016). In that study, the cast net was recommended for fishing as the two other gears - gill and drag nets, selected smaller individuals of the population. Their experimental fishing study recorded 2,049 individuals, and total length measurements from 5.0 – 14.0 cm, with a modal class size of 7.0 – 7.9 cm TL. Compared to the present study, which recorded a length range of 4.0 cm to 14.0 cm and a modal length of 8.0 - 8.9 cm for 4,135 individuals, the shift in modal length could be attributed to a larger sample size, longer sampling period, and possible changes in environmental conditions over the 14-months study period. Although the condition factor, K, calculated was 3.9 SL, which was typical for cichlids, hinted on fairly sustainable environmental conditions, the occurrence of small sizes suggested fishing pressure as a deterrent to prolonged life spans (Dankwa et al., 2016). The study by Tibu et al. (2019) on the blackchin tilapia in the Etsir lagoon stated a modal class size of 7.0 – 7.9 cm SL. The authors also contributed the stunted growths by the cichlids to high exploitation rates irrespective of the regular recruitment of the cichlids throughout the year.

5.2.2 Avifaunal composition and human impacts

Caro and O'Doherty (1999) impressed on the choice of avifauna as important bioindicators of aquatic systems health as they usually occupied top positions in food webs, possessed outstanding abilities to adapt or move due to changes from environmental and anthropogenic pressures, and were easier to observe and quantify in monitoring studies. Along Ghana's coastal zone, several studies have been conducted to observe activities of waterbirds because West Africa serves as important wintering habitat and stopover for Palearctic migrant waterbirds (Gbogbo et al., 2014; Lamptey et al., 2015; Ntiamoa-baidu et al., 2001). Some relationships have been made between the species abundance of water birds and seasonality such as through studies conducted by Mundava et al. (2012) who associated high species abundance during dry seasons to the congregation of waterbirds at available water holes and systems that support bird ecology, while dispersal of birds to several other systems occurred during the wet seasons accounting for low numbers observed during the study period. In this present study, the close representation of aquatic birds' species group with terrestrial birds' species group points to the importance of the lagoon catchment for bird populations. Both groups relied on the lagoon for several ecological functions. A high percentage of resident birds compared to 19% of migratory birds encountered may suggest the catchment as unsuitable for wintering birds. Birds such as the Spur-winged lapwing (*Vanellus spinosus*, Linnaeus 1758), White-faced whistling duck (*Dendrocygna viduata*, Linnaeus 1766), and Little winged plover *Charadrius dubius*, Scopoli 1786) were important on the African-European Waterbird Agreement (AEWA) list as part of the 254 species of birds of which the Agreement on the Conservation of African-Eurasian Migratory Waterbirds apply. These species whose dependency on identified wetlands for parts of their life cycles or across international boundaries posit as indicators to protect wetlands.

With the complexity of additions of a few wintering birds and associated environmental factors that limit strong links between water birds and abundance (Stolen et al., 2004), caution is taken in descriptions of species abundance with any one factor. Ramli and Norazlimi (2016) however, indicated a strong relationship between the availability of food and bird counts. Piscivorous birds such as the darters, *Anhinga rufa* (Daudin. 1802) were recorded in high numbers. This is expected for a catchment that supports a fishery with fish sizes that can be eaten whole (McParland & Paszkowski, 2006). The presence of omnivorous birds suggests adaptations to feed on any available food for survival which is a foraging tactic usually associated with resident bird species that are restricted to a particular wetland (Mayntz, 2019). Other representations by groups of insectivorous, granivorous, and carnivorous birds provide implications for management and conservation.

Also, the time of day was suggested from studies as an important factor affecting the abundance of birds (Lehmicke et al., 2013), because morning survey counts showed high activity thus abundance due to cooler temperatures and less human activity. The results of this present study showed similar patterns of bird abundance in relation to the time of the bird survey. Generally, the number of water birds encountered in the mornings exceeded the counts made in the evenings.

The effects of human activities within wetlands have been observed to affect the diversity, abundance, and functions of water birds (Chawaka et al., 2017; Golzara et al., 2019). In a study of the Keta and Muni Pomadze Ramsar sites of Ghana, conservation strategies that were recommended to improve bird diversity and abundance included discouraging human activities such as refuse dumping, open defecation, and untreated wastewater discharge which affected waterbird assemblages (Lamptey, 2014). The present study of the Fosu lagoon showed significant negative effects of noise on bird abundance, while human presence though negatively affected the abundance of birds did not suggest a statistically significant effect. Many birds encountered during the surveys such as the Great egret, Cattle egret, and African pied wagtail (which all constitute part of the top five species encountered) are described as ‘cosmopolitan’ with the ability to be widespread around the world and adapt to urbanization and human presence. Other species of birds encountered, such as the Black crake and Little greenwood pecker which are known to be associated with open spaces caused by deforestation and vegetation clearing, serve as indicators to be monitored for the mentioned impact in management efforts.

5.3 Effect of Anthropogenic Activities on the Fosu Lagoon

5.3.1 Bacterial loads and public health implications

The Fosu lagoon recorded a monthly faecal coliform range of 103-900cfu/100ml. The highest total count of 7514cfu/100ml was recorded in water samples from the upper reaches of the lagoon over the 14-months sampling period. Comparatively, the studies by CSIR in 2013 recorded a range of 40-93cfu/100ml with the highest counts recorded at the mouth of the lagoon closest to a constructed drain from the community and a piggery (Owusu et al., 2013). The findings in the present research give concern for direct waste inflows in the lagoon from households upstream. Also, *Escherichia coli* which belongs to the faecal coliform group ranged between 100-835cfu/100ml while bacterial testing by CSIR measured up to 315cfu/100ml. The differences in sampling points and frequency of sampling are considered as the most probable reasons for the wide variations in the recorded values. Both studies, however, recorded values of faecal coliform and *E. coli* above our EPA limit of 10cfu/100ml for wastewater discharge and 130cfu/100ml for recreational water use. The values also exceeded the 10cfu/100ml limit prescribed for aquaculture by the Ghana Raw Water Criteria and Guidelines (Water Resources Commission, 2003).

Mean-variance testing was done to inform on the significant differences between the bacterial loads at the upper and lower reaches, and also between bacterial loads at the middle and lower reaches, whereas no significant difference showed between bacterial counts in the upper and middle reaches. The trend suggested a significant influx of contaminated runoffs at the upper and lower reaches of the lagoon.

5.3.2 Pollution by solid waste

Increasing coastal populations and high consumption of products (Achankeng, 2003) which are complicated further by inadequate provision of solid waste management measures have resulted in indiscriminate solid waste disposal into waterways and aquatic systems (Shin et al., 2014). Lack of proper solid waste disposal measures results in filling up of natural depressions and along banks of wetlands with municipal and industrial solid waste, by both urban and rural communities (Babanawo, 2007). Studies of the Korle, Chemu, and Kpeshie lagoons of major coastal urban settings in Ghana show worsening cases of poor water quality, silted and shallowing wetlands, and poor sanitation from huge accumulated loads of solid waste (Aglanu & Appiah, 2014; Apau et al., 2012; S. S. Koranteng & Darko, 2011).

Several studies have indicated a large composition of organic-based waste in waterways from solid waste generated in urban settings (Boateng et al., 2016; Couth & Trois, 2011; Government of Ghana, 2018; Sinthumule & Mkumbuzi, 2019). A study across three income groups within the Cape Coast metropolis indicated a cumulative percentage of 31.1%, 27.6%, 12.7%, 6.0%, and 5.6% of organics, plastics, papers, metals, and glass, respectively, among household waste generated (Akuoko, 2018). I. S. G. Akuoko (2018) also indicated, approximately, 48.1%, 14.9%, 3.2%, 0.5%, and 22.3% inert (ash, dust, sand) for similar classes of solid waste sorted from households in Tertrem, a suburb in Elmina, Central Region.

Perhaps, of the 44% of solid waste collected from the six major metropolises in Ghana which largely ends up in landfill sites (Addaney &

Oppong, 2015), the composition of organic-based waste found in solid waste may result in decomposition if properly buried. However, solid waste from land-based sources found in wetlands and aquatic systems has shown high percentages of plastics and long-term biodegradable materials (Barnes et al., 2009; Rech et al., 2014; UNEP, 2010). The present study showed the highest composition of solid waste belonged to plastic and rubber products (54.6%), followed by groups of organic-based waste, fabrics, and clothing, metallic items, charcoal/unidentifiable items. The observed swap in flotsam groups in the present study with solid waste collected from household and municipal solid waste quantification and assessment (Akuoko, 2018; Gyimah, 2018) was attributed to the easing of debris flow from sources of waste accumulation and inadequate collection measures from recreation facilities surrounding the Fosu lagoon. The latter was evident in higher figures of plastics recorded during the festive periods of the study. There are documented effects of plastics and other suspended solid waste acting as substrate and breeding grounds for disease-causing pathogens, bioaccumulation, and biomagnification of carcinogenic constituents such as bisphenol A and phthalates, and the foul stench with poor aesthetics rendering polluted systems undesirable for intended uses (Adu-boahen et al., 2014; Ivar do Sul & Costa, 2014; Karak et al., 2013).

5.3.3 The Fosu lagoon watershed extent

Basin-wide assessments have been sought to address environmental issues that encompass complex interactions between physical and biological components (Tiner, 2004). The advantage of hydrogeomorphic assessments in addition to well-known water quality methods over large watersheds provides monitoring towards effective management strategies (Stevenson & Hauer, 2002). In this regard, the determination of the watershed extent was necessary to complement information collected on the physicochemical and biological environment of the Fosu Lagoon.

Communities within the watershed

At resolutions of up to 1000 meters, digital terrain metadata provided by the USGS Earth Explorer allowed preliminary examination of the extent of the Fosu Lagoon catchment. Natural flow lines allowed the connection of elevations at common contour points to be linked indicating influence from adjoining wetlands. A polygon is drawn in an attempt to show communities and areas that fell within the Fosu lagoon watershed covered a total perimeter of approximately 16,886 m and an area of 15,297,541 m^2. Communities within this delineated watershed include; Antem, Amosima, Adisadel Village, Kotokuraba Market, areas close to Prospect Hill, Zongo, Ola, Amosima, sections of Abura and Pedu, and Nkanfoa. The latter, Nkanfoa Community, was put on the radar in 2014 for public outcry concerning uncontrolled dumping of collected solid waste from other communities since the CCMA designated the area many years ago as a landfill site (Ghana Television, 2014).

Major pollution point sources and vegetated buffers for non-point sources

Drone imagery was necessary to provide information on immediately achievable monitoring assessments of direct point sources of pollution. Seven major point sources were identified from processed orthophotos, leading to the lagoon. Of these point sources, two concrete drainage gutters carried wastewater and stormwater runoff from communities, schools, and the hospital. The study by CSIR indicated shallowing of the lagoon with a depth profile of 1.2m-1.5m from bathymetric map assessment. Sediment and solid waste entry into water systems are of major concern affecting the quality of water and ecological functions (U.S. Environmental Protection Agency - Office of Research and Development, 2011), thus the point sources identified for the Fosu lagoon provide the opportunity to target contamination by a large extent through these conduits. False-colour utilized gave other implications of settlements/ physical structures and vegetation within the catchment. Bourgeois-Calvin (2008) explained that the below-average success derived from the US EPA targets industries, wastewater treatment plants, and other such point source contributors required a tightening of regulations and enforcement and the improvement in addressing the more worrying diffused sources of pollution into water bodies.

Numerous diffuse sources of pollution termed 'non-point contribute to difficulties in resource management and ecosystem restoration, thus, the advice to maintain vegetated buffers along wetlands to protect water quality for fish and other life forms (Hay, 1996; Kilgo et al., 1998; Osborne & Kovacic, 1993; Smith et al., 2006). There are studies supporting certain types of vegetation i.e. grass, forested vegetation (Hefting & de Klein, 1998) as more efficient in buffer zones in comparison to others. Other authors also argued that no significance was found in the selection of buffer vegetation type for efficient pollutants and sediment retention from catchment runoff. A mixed vegetation type made of remaining strands of mangroves (*Avicennia germinans*); dominant species of grass such as *Paspalum vaginatum* and *Typha domingensis*, and other macrophytes including *Pistia stratiotes*, *Eleocharis sp.*, *Ipomea aquactica*, and *Nymphaea sp*. were identified and recorded during the CSIR research for the CCMA on the Fosu lagoon (Owusu et al., 2013). Concerns were raised about such vegetation serving as breeding sites for vectors of water-borne diseases. The importance of vegetated buffers, however, implies a need for alternative control of these disease vectors without clearing vegetation. Also, the width of vegetated buffers has been studied to impress the need for their use in controlling non-point sources of pollution. Messer et al. (2012) and Smith et al. (2006) concluded that wider buffer zones efficiently absorbed pollutants and sediments, resulting in better water quality of aquatic systems. In Ghana, a buffer width of 30m is expected in wetlands (Ministry of Water Resources Works and Housing, 2011), although this was found to be breached at some sections of the lagoon. In the present study, 50m and 80m buffer widths were demarcated on drone images, in addition to the required 30m buffer width, to provide options for the management of land uses within the Fosu Lagoon catchment. As expected, settlement and infrastructure setups increased as the buffer width increased whereas vegetation cover reduced from the estimated 80% within 30m buffer width to 73.5% (50m buffer width) and 66.3% (80m buffer width). About 17% of human encroachment within the 30m buffer width and 3% (approx.) bare soil/surface suggested weak wetland use regulatory enforcement.

5.4 The LMC-DSS for Fosu Lagoon Resource Management

A computerised DSS was developed with the intention to reduce the time-consuming task of complex analyses characteristic of the multi-use lagoon system towards improving decision-making by stakeholders and resource managers from various disciplinary backgrounds. As a guiding principle, the DSS developed allowed an input structure and a description assignment output necessary to inform on decision options. Similar to design considerations for the MULINO-DSS by MULINO Consortium for European Water Resource Management where the Driver-Pressure-State-Impact-Response (DPSIR) framework was used to build a multi-criteria analysis tool (Mysiak et al., 2002), a lagoon multicriteria decision support system (LMC-DSS) was developed for the Fosu lagoon, however, without the constraints of high uncertainties as a result of routinely modeled scenarios. To overcome the subjectivity of two separate actors needed in the input and analysis stages leading to decisions, the present study used a popular Microsoft Office suite program, Microsoft Excel, employing 'command inputs' designed to grade/rank/weigh conditions and scenarios on the basis of expected ideal resource use and ecological states.

The hierarchical organization of the multicriteria decision support system for Fosu lagoon management provided a visual display of all the interwoven linkages between the metrics/indicators of desired criteria outcomes and the quantifiable parameters/variables that affected them. The connections emphasized the complexity of interactions among the physicochemical, biotic, and socio-economic variables of the coastal lagoon. The predictive ability of the developed LMC-DSS relied on the assumption that defined thresholds remained valid for the description of the states of variables.

The LMC-DSS was tested with the present scenario of the Fosu Lagoon. Three criteria measures of consideration in the management of the lagoon - water quality restoration, biotic health improvement, and sustainable resource management, were rated accordingly based on the dependency of each on the other. Thus, water quality restoration which was deemed fundamental in all ecosystem support was rated A. Brenner (2019) describes the physicochemical role of water as “the lifeblood of an ecosystem” linking the various components of an ecosystem. Poor water quality, therefore, affected the potential of ecosystems to support life and functions. Also, in spite of many scattered efforts to address water quality issues, the real issues of improving water quality in many places appear to have been neglected, requiring the local input of communities and stakeholders as observed by UN Water (2019). The second rate ‘B’ was assigned to biotic health improvement with a focus on the biological components whose reliance and functions complemented the physicochemical environment. The criterion was necessary as a general reflection of the quality of the environment, coupled with the environment’s diversity and suitability to support indigenous species of animals and plants. Holt and Miller (2010) stress the need to use biological components of ecosystems in the determination of the extent of ecosystem change emerging from anthropogenic influence. The third rate ‘C’ was assigned to resource utilization comprising all the identifiable socio-economic uses of the Fosu Lagoon. The consideration for resource utilization was backed by the ICZM principle of striking a balance between the protection of valuable ecosystems and their exploitation by humans as defined by Post and Lundin (1996).

Standardized evaluation techniques are vital in the design of DSS tools (Matthies et al., 2007; Mysiak et al., 2002; Primicerio et al., 2012). A simple additive operation after weighting was utilized after scoring the respective indicators and metrics of a selected criterion in the LMC-DSS. This technique, according to Mocenni et al. (2009), defined the relative values of the indicators in achieving desired criteria outcomes. Also, thresholds were defined for a given variable that contributed to an indicator. For qualitative variables, two extremes were awarded, a good standing warranted a '1', and the reverse was assigned a '0'. Data on variables collected over the period of study were graded in this manner per their performance seen as a 'pass' when the measured parameter fell within the upper and lower limits of the threshold range. A 'fail' (0) was assigned for parameters that fell out of the threshold range.

Therefore, for Criterion A (water quality restoration), even though scored indicators and metrics used followed the order: A.1 water column abiotic assessment; A.2 limiting nutrients; A.3 pathogen loads; A.4 sediment quality; and A.5 heavy metals concentration/toxicity, the infographic showed the relative performances in the order A.5, A.1, A.3, A.2, and A.4. This stressed the need to shift focus from addressing issues to meet the Criterion requirements. That is, in planning water restoration plans for the Fosu lagoon under the defining circumstances, a coastal zone manager needs to consider strategies to control heavy metals concentrations and toxicity, followed by monitoring the physicochemical environment and the underlying factors that result in the observed conditions. Pathogen loads, nutrients' concentrations, and sediment quality would be the next to be considered in a restoration program, respectively. The outcome was unexpected, although plausible, as it reflected the otherwise long-term effects of heavy metals which have made them a seemingly neglected aspect in environmental studies. The physicochemical environment of the Fosu lagoon, ranking second, remained an important aspect for consideration in the achievement of the criteria. Pathogen loads, irrespective of being affected by fewer parameters, ranked below metrics of limiting nutrients showing the need to address both on the basis that these indicators are largely influenced by physicochemical parameters. Sediment quality ranked 5th, reiterating the silent role played by sediments as nutrients sources and sinks dependent on conditions of salinity, temperature, and dissolved oxygen (Falcão, 1996; Gonenc & Wolflin, 2004). Brito et al. (2009) stress the important role played by sediments in shallow systems in the adsorption and release of nutrients, contributing inadvertently to the water quality of lagoons through eutrophication events.

For Criterion B, i.e. biotic health improvement, indicators of waterbird diversity (scored B.1), fish diversity and growth (scored B.2), mangrove cover (scored B.3), and littoral vegetation (scored B.4), ranked B.2, B.4, B.3, and B.1. The ranking was expected for a consistently observed single-species-dominated fishery which primarily suffers stunted growth as a result of polluted conditions coupled with intense fishing pressure (Blay & Asabere-Ameyaw, 1993; Dankwa et al., 2016). Littoral vegetation and mangrove cover ranked next in view of encroachment and use within the catchment. The diversity of bird species ranked 4th, the major threats were linked to human influence, food availability, and habitat loss. Efforts to mitigate the effects of these impacts on bird assemblages are worthwhile because the indicator status was slightly above average. Although resilience and adaptability of birds within a stressed environment are common features (Neagle, 2008; Noske, 1995; O'Leary et al., 2017), the indicator score was a good basis to involve waterbirds in the ecological health improvement of the Fosu Lagoon.

Resource exploitation in conjunction with minimized environmental impacts is one of the strategies for integrated coastal management (Chua & Scura, 1992). The ranking of uses of the Fosu Lagoon was C.2 Heritage sites, C.1 Fishing, C.3 Recreation site, C.6 Wastewater receptacle, C.5 Flood recharge zone, C.4 Aesthetics. The metric percentage scores were generally low for all the uses exposing the unsustainable exploitation practices that existed. Of immediate importance to achieving Criterion 'C' was the need to redefine the use of the site as heritage, fishing, recreation, and waste receptacle sites. These conflicting uses of the Fosu lagoon resulted in constraints on the functioning of the system due to the complexities of the ecological roles played.

The LMC-DSS was developed to assist decision-making by pointing out priority areas for the management of the Fosu Lagoon. The status of the three criteria showed 'Resource Exploitation' required immediate address in intended management plans. Of second and third priorities to management, efforts are the' Restoration of Water Quality' and 'Improvement in Biotic Health', respectively. Both second and third criteria management priorities are closely related because of established connections between abiotic and biotic components of the ecosystem. Present inadequate management measures put the ecological health state of the Fosu lagoon at 32.6%, which calls for a review of policies leading to regulations on use, and institutional strengthening. This was highlighted in the ideal case scenarios created to change resource trends to sustainable forms (Criterion C) and also completely restore water quality (i.e. Criteria A). The sharp response in ecological health to about 74% and 78%, respectively, was glaring off the need to prioritize management of the Fosu lagoon to enhance the resource's benefits to stakeholders, users, and as an integral component within the coastal zone of Cape Coast.

5.5 Ghana's Coastal Ecosystem Governance – A Review.

Burroughs (2011) defined coastal ecosystem governance as "sustainable social and natural systems through diverse management techniques that shape human activity in concert with limits of natural systems". The author delved into common environmental issues and their impacts that confront resource users and inhabitants within the coastal zone, constraints of solving issues owing to competing/conflicting exploitation and expectations per coastal resource, processes of addressing issues, and the various actors/agencies involved at each phase. The issues identified were most prevalent in urban areas where sprawling developments, increase in impervious surfaces, and increases in pollution from waste and stormwater runoff affected the quality of water and other connected ecosystems (Goonetilleke & Thomas, 2003). These are also common to Ghana's urban coastal areas. Urban poverty and other socio-cultural problems are associated with urbanization in many African countries (UN-Habitat, 2014) restricting the use of public funds on environmental quality issues. To combat this situation, effective coastal governance is required to maximize available funding and expertise.

Olsen (2003) categorized coastal governance into four orders along three scales - enabling conditions, changes in behaviour, the harvest, and sustainable coastal development. They attributed the complexities of arriving at these outcomes along with the local, regional, and national scales of governance. As a prototype to the Coastal Resource Management Program (CRMP) initiated by the Coastal Resources Center (CRC) of the University of Rhode Island, a coastal governance review of Tanzania in 1997 revealed the need to set up a National Environmental Management Council (NEMC) to achieve holistic coastal management goals. Reverting to the aforementioned orders outlined by Olsen, Tanzania had successful local coastal programs such as mariculture and tourism which were however impeded by regional and national authority due to inadequate understanding and expertise assistance curtailing potential growth. Thus, the required ‘enabling conditions’ of relevant established policies and mandated agencies’ efficiency, available funding, and stakeholder participation were lacking along the national level to support the identified coastal issues. Unparalleled to this setting, coastal governance in Ghana tends to have a semblance of a top-down approach albeit with sectoral efforts that trickle into disjointed outcomes difficult to sustain. This primarily arises from a decentralized system which, although, was intended from its onset in the late 1980s to strengthen local involvement at Metropolitan, Municipal and District Assemblies (MMDAs), are met with challenges to undertake and sustain successful development plans at local levels (Coastal Resources Centre, 2012). Similar to Tanzania's CRMP, however, capacity building efforts by government and institutions such as the Center for Coastal Management (CCM) of the University of Cape Coast, seek to closely involve relevant stakeholders at all phases of coastal management planning to realize 2nd, 3rd, and 4th order outcomes as described by Olsen.

5.5.1 A review of coastal management policies in Ghana

Amlalo (2010) lists plans such as the Coastal Zone Management Indicative Plan of 1990, National Environmental Action Plan of 1994, Draft Integrated Coastal Zone Plan of 1998, Coastal Zone Profile of Ghana 1998, and the Environmental Sensitivity map of the coastal areas of Ghana 1999 and 2004, geared towards raising awareness and changing the status quo to elicit 'changes in behaviour' by both users and agencies concerning coastal management. The hopes of such changes in behaviour are hinted at through intersectoral efforts in the 4-year Medium Term Development Plans (MTDPs) by Metropolitan, Municipal, and District Assemblies (MMDAs). Two major issues i.e. coastal erosion and conservation of marine areas, alongside prevailing pollution and sanitation, are identified in the MTDPs (*Medium-Term National Development Policy Frame Work: Ghana Shared Growth and Development Agenda (GSGDA) II, 2014-2017*, 2014). As part of the MTDPs sustainable management measures include the preparation and implementation of an Integrated Coastal Zone Management (ICZM) Plan and the establishment of a Coastal Zone Commission.

In the present study, a review of policies that synchronize with coastal management which cover issues of biodiversity, eutrophication, water quality, sewage, solid waste, heavy metals, flooding and erosion events, fisheries exploitation, habitat destruction, and industrial/municipal development particularly in coastal urban communities, show a lag in realizing the third order of governance outcomes - the harvest (Olsen, 2003). Loss of biodiversity, poor environmental quality and sanitation, compromised public health/safety, and poor land-use practices, are just but a few conditions that indicate that 'the harvest' is yet to be realized. The present study, in agreement with other assessments by others such as Boateng (2006), shows the minefield of gaps in institutional structures, agencies mandates, and stakeholder/community participation which hamper the objectives of the 4th coastal governance order of sustainable coastal management. There are several windows of opportunity that could push effective coastal management on the public agenda. For instance, since the most vigorous attempt was made by a World Bank-Ghana EPA assisted project in 1996 where sensitivity maps were produced to draw attention to the coastal zone (Environmental Protection Agency of Ghana, 2004), a Coastal and Marine Habitat Management Regulations Bill is expected to be passed into law by an Act of Parliament (Classfmonline, 2019a). The move, despite 25 years of inadequate coordination of programs, serves as a basis for inclusive budgetary allocation for programs and projects directly related to coastal management. Also, capacity-building efforts have increased expertise, whereas an increase in public awareness resulting from disasters and environmental degradation (*Ghana National Climate Change Policy*, 2013;

Srivastava & Pawlowska, 2020) has magnified the need to put coastal environmental issues on the public agenda. In an assessment of the challenges of urbanization on environmental quality in coastal areas of Ghana, White et al. (2007) concluded from a study that the tentative embrace of the phenomenon based on the accompanying economic development and reduction in population growth could be beneficial. They raise concerns, however, about the needed infrastructure and institutional coordination which is necessary to address the challenge of unpredictable rural-urban migration patterns and changes in cultural diversion on environmental quality improvement in coastal areas.

5.5.2 SNA of mandated agencies' collaboration and efficiency

Our institutional framework contributes to the weak enforcement of environmental regulations and bye-laws. As surreptitiously and repeatedly indicated through responses given during the semi-structured questionnaire survey by respondents, funding and expertise collaboration were inadequate for Ghana's coastal management. Creary (2003) stated resistance to collaborative work across horizontal integration by agencies due to constraints in budgeting and share of logistics. A Social network analysis (SNA) of mandatory roles and collaborations among governmental agencies and related corroborators indicated that groups that engaged in direct field monitoring assessments relied on other sources of funding with little reliance on the government as shown in Figure 4.51. This raises a flag on how efficiently scientific knowledge informed policy since respondents indicated their agencies' experiences of long bureaucratic processes of including other actors in government proceedings.

Universities established research centres, foreign-donor support teams such as Hen Mpoano (HM) and Sustainable Fisheries Management Project [SFMP] are examples of organisations that constitute this monitoring and analyst group.

On the issue of determinant occurrences that called for environmental issues to be addressed, sporadic events that emerged as narratives drew attention for short-term relief attempts. For instance, a window of opportunity is mostly presented whenever flooding events occur claiming lives and damaging public property, during heavy rains. The medium to long-term damage to natural systems such as coastal lagoons and wetlands through changes in flora and fauna communities, habitat loss, and contamination by nutrients and sediments, are inevitable yet they are rendered silent in relief efforts. The National Disaster Management Organisation (NADMO) and Spatial Solutions (SS) form part of this group that responds to relief or planning in a bid to avoid similar eventful occurrences.

Foreign donor groups mostly undertook an aspect of societal awareness and sensitization to coastal issues as part of projects undertaken towards coastal management. This, according to Olsen (2003), is characteristic of well-planned environmental programs with secured financial allocations. Stewardship and stakeholder participation are considered as major sustainability drivers in projects. However, constraints to successful implementation were tied to local/district levels of operation indicating that more efforts were needed to run projects. The disconnect at the national levels where many conventions and treaties informed policies' design without site-specific infusions meant innovative measures were needed to realize goals anticipated. Tighter links among providers of scientific/evidence-based data, expert analysts, policy and regulatory bodies, and implementers are useful for efficient transition in project phases. In respondents' view of local collaboration over the past thirty years, the more successful collaborations occurred between groups and communities that were directly involved in monitoring projects. Successful projects received assistance and participation from traditional authorities to improve coastal environmental conditions of interest. This finding shed light on keeping representatives of these groups such as chiefs/sub-chiefs/opinion leaders during interactive project planning sessions since they dealt directly with coastal communities. The political will to, however, sustain long-term projects was an issue raised from the survey. This perhaps, as indicated by Creary (2003), is the toughest challenge in the ICZM process requiring strategic coordination mechanism as outlined in Agenda 21. Approaches to consider include: (a) formation of an inter-ministerial coordination agency, (b) addition of policy-planning and budgeting roles to an existing coordination agency, and (c) creation of an entirely new agency with mandatory levels at both national and local levels. The Coastal Development Authority (CODA) created in 2017 by an Act of Parliament (Act 963), is a more recent attempt to achieve the latter approach (Ministry of Special Development Initiatives - Ghana, 2017). The vision of the CODA to work together with coastal communities to alleviate poverty however creates a lacuna in the objectives of ecosystem restoration and improvements. Such a gap is obvious in CODA's project to import machinery from Hong Kong to develop the coastal areas of Cape Coast (Coastal Development Authority, 2020). There is an unclear understanding of how the deteriorated and polluted states of the natural ecosystems will be addressed in such an endeavoured by CODA for the people of Cape Coast. Therefore, the continued efforts by MESTI, EPA, NPA, LUSPA, MMDAs, traditional authority, and other stakeholders must be supported and collaborations fostered to realize coastal management goals.

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

The present study was conducted based on the philosophy that multiple coastal resource uses such as fishing, tourism, industrial and municipal setups result in competition for space and conflict among interest groups resulting in pollution and disease outbreaks, fisheries decline, erosion, loss of wetlands and mangroves in the absence of sustainable management. The situation in coastal areas is further complicated through inadequate comprehensive approaches to assessment to support decision-making for management. Thus, a decision support system to undertake holistic ecological health state assessment to guide management options was needful.

In developing countries, high population growth within coastal areas adds to these issues arising from weak implementation of land-use and development planning, inadequate provision of social amenities and infrastructure, and high poverty and its associated dependency through unsustainable exploitation of resources. Integrated Coastal Zone Management (ICZM) has been emphasized as a solution to resolving the myriad of problems faced by coastal areas. Innovative approaches of ICZM focus on inter-disciplinary measures of managing the diverse ecosystems and the functions they play for life support while promoting sustainable exploitation to improve livelihoods and investment without degradation of coastal resources. An effective ICZM process earns the trust of inhabitants and resource users through participatory engagement, and fostered political commitment indicative through policy-making.

Finding an appropriate approach to ICZM in urban settings such as the Fosu Lagoon catchment, thus, required an assessment of the coastal zone to identify, evaluate and establish; (a) the importance of the ecosystem and the resources/services it provides; (b) geographical boundaries and extent of identified issues; (c) problems due to anthropogenic impacts (and natural events); (d) existing approaches with a focus on ecological health to prioritize management and encourage stakeholders involvement; and (e) gaps in policies for sustainable management, and the institutional framework required to undertake management strategies. The coastal lagoon, located in the Cape Coast metropolis was rated by the Ghana EPA as the third most polluted lagoon in Ghana. Besides pollution which arises from anthropogenic activities that affect the lagoon, other studies have indicated fishery decline resultant of poor water quality and fishing pressure; eutrophication and macrophyte proliferation as a result of nutrient enrichment, the former contributing to anoxia while the latter being a source of a public health concern due to siltation and a conducive environment created for vectors of diseases and other water-borne diseases; heavy metals bioaccumulative potential in fish and implications on public health, indiscriminate disposal of solid waste by inhabitants and related environmental issues; hydrological issues reflective of water balance and bathymetry; and loss of mangrove.

6.2 Conclusions

The present research was geared toward developing a decision support system (DSS) for the assessment of the ecological health state of the Fosu Lagoon to enhance decision-making for sustainable management. The research acknowledged the multi-disciplinary efforts made by several researchers and stakeholders through studies of various aspects of the lagoon to understand the issues and quantify (at best) the implications of coastal resources' issues. These studies collectively indicated a gradually deteriorating system threatened by a near-collapse in its ecological functions and socio-economic importance. The present research brought to bear the need for a computerized user-friendly interface that relies on empirical data of several selected indicators required in an effort to integrate ecological health parameters, establish the ecological health state of the lagoon, and underline opportunities to evaluate different scenarios of impacts. The intended role of the developed DSS was to, essentially, realize the major principle of ICZM where a clearly outlined framework is required with a focus on improving the states of coastal zone resources that support livelihoods irrespective of the complexity associated with these fragile ecosystems and their utilization. The research also provided a review of the institutional framework and existing policies that were aimed at addressing identified coastal zone problems. This review was done with the aim of validating the difficulty, perhaps, most mentioned by experts as a major challenge to ICZM – weak coastal governance.

Based on a review of literature, three main tangents were followed to develop a Lagoon Multi-Criteria Decision Support System (LMC-DSS) to assess the ecological health state of the Fosu lagoon for management – the abiotic environment that supported organisms, biotic health from selected observed biological components, and various resource uses and activities that affected the coastal lagoon. In view of the criteria needed to meet the set goals of integrated management of the Fosu lagoon, several indicators and metrics per criterion were assessed.

Indicators that were scored to ascertain the first rated Criteria (A) of 'restoration of water quality' indicated that heavy metals concentrations and toxicity were the first important considerations for management. Granted that the toxicity reference values used for all assessed heavy metals i.e. Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, and Zinc were based on the U.S. EPA standards, the slow build-up of heavy metals were hinted at in the site-specific studies conducted. The next consideration for management was in line with the expected because abiotic variables of the water column indicated a need for immediate interventions. Principal Components Analysis (PCA) of the observed parameters had indicated wide variations on a spatio-temporal scale for drivers of the water column. Seasonal and anthropogenic influences were posited to cause several responses in dissolved oxygen, conductivity, salinity, turbidity, and pH leading to their effects on other factors such as nutrient availability. The different outcomes in the PCA on the monthly data gathered, emphasized the complexity of the situation should coastal managers follow the status quo of monitoring and planning projects entirely based on selected physicochemical parameters. Water quality indices employed to concentrate the effects of these parameters while providing information on the general state of the Fosu lagoon aligned towards a heavily deteriorated state. As encouraged by proponents, the more specific the water index was couched to suit the prevailing conditions, the more reliable the outcomes that were derived. Thus, the use of the water quality index by the Ghana Water Research Institute for surface waters emerged as most appropriate to ascertain the water quality of the Fosu Lagoon. It characterized the Fosu Lagoon as having 'poor quality' and 'grossly polluted' i.e., Class III and IV. Other indicators that needed considerations to meet the set Criterion A were pathogen loads, limiting nutrients, and sediment quality. Field measurements of respective parameters reflected anthropogenic impacts in all three indicators. Faecal and coliform counts exceeded standards set by the Ghana EPA for water used for fishing and recreation; eutrophication episodes were evident irrespective of weak correlations with nutrient concentrations subtly enforcing the interactive effects of other physicochemical factors, and sediment granulometric analyses alongside measured organic matter and porosity pointed to the contaminants' holding capacity of the lagoon. The implications of restricted flushing of the Fosu lagoon, except in August when the sand bar is breached, coupled with the uncontrolled entry of untreated wastewater, stormwater runoff, and leachates presented a challenge for address in the realization of Criterion A. The LMC-DSS (K-1) provided suggestions of strategies to achieve water quality restoration including:

(a) setting water quality standards purposefully for wetlands and brackish systems as the purpose of all water quality restoration does not imply crystal clear lagoon systems lacking life forms.

(b) controlling contaminants, nutrients, and heavy metals inputs by adopting measures such as Total Maximum Daily Loads (TMDLs) as practiced by the US EPA

(c) adopting a more robust and well-managed database from routine monitoring to assist assessment and planning

(d) enforce best management practices (BMPs) for livestock rearing, agriculture, and other similar land use activities within the watershed

(e) building a sewage treatment plant as part of municipal development plans.

Based on the expression of the physicochemical environment quality through biological communities' abundance, species diversity, functional roles, and resilience/vulnerability, the 'biotic health improvement' criterion was rated B with indicators such as waterbirds' diversity, abundance, and functionality; fish diversity and abundance; mangrove and other littoral vegetation coverage. Although the indicators were initially rated dependent on known vulnerability status, ecological roles, the time frame of response to changes/impacts, and level of expertise required in assessments, the present scenario ranking directed a decision-maker to address issues in the order of fish abundance and growth, littoral vegetation and mangrove loss, and parameters of the birds' survey due to scores gathered by respective parameters. Stunted growths of a highly dominated single fish species fishery where there was a modal class length of 8cm for blackchin tilapia known to grow to bigger sizes in other systems stressed the urgent need for management to improve the fishery. Strategies suggested included improving water quality, reducing fishing pressure, and more frequent breaching of the sand bar to allow entry of juvenile marine species. Interventions recommended for reducing the loss of mangrove and littoral vegetation included reiterating the important roles played by such flora through public awareness creation, enforcement of measures to discourage encroachers, and replanting of native vegetation species such as the *Avicennia germinans* which is estimated to be reduced by 81% over the past forty years. Waterbirds showed better adaptability to the Fosu lagoon environment in spite of the established negative influence of fishing pressure and human presence, and noise (which, however, was determined as statistically insignificant). The former has consequential effects on the most abundant groups of piscivorous birds such as the *Anhinga rufa* (darters). Low numbers of migratory bird species that largely fitted IUCN's list of 'least concern' suggested a low possibility of advocacy for the area to be considered as a Ramsar site under the stipulated conventions. However, opportunities to conserve the resource leaned on traditional and local consensus generation as hinted through the preserved thatch of mangroves where the Bakaano fetish shrine is situated, the strictly observed non-fishing day (Tuesday), and the closed access month of August which were adhered to.

The sprawling urban growth within the Fosu lagoon catchment exposes the system to heavy anthropogenic impacts. A watershed delineation that was done, in this present study was based on drone imagery. This added to the knowledge-base on considerations for effective spatial scale management. Identified major point sources of pollution will serve as target locations for proposed wastewater treatment plants and solid waste collection points. Efforts to retrieve collected and trapped debris at point sources are important considerations for remediation programs. In addition to valuable information from drone work, the LMC-DSS relied on observable and documented information to score the level of importance for identified resource uses. Management priorities followed the order: heritage site, fishing, recreation site, wastewater outlet, and aesthetics value. As indicated, the Fosu lagoon represents a traditional symbol for indigenes because it is regarded as a goddess playing an important role during the annual *Fetu Afahye*. Its reverence, though muffled by non-indigenes' settlement and integration in the metropolis, may serve as an avenue to establish the importance of the resource as a heritage site. Also, efforts to reduce fishing pressure while improving the fishery are of importance as is reportedly seen in the high taste acquired by patrons of the blackchin tilapia who defy awareness created about potential traces of bioaccumulated heavy metals and PAHs in the delicacy. Conflicting uses of the resource as a recreation and wastewater holding site draws attention to the need to treat wastewater to permissible levels at which selected recreation activities could be allowed Aesthetic values of the Fosu lagoon did not appear to be affected considering that the lagoon generally had collection points where currents naturally gathered solid waste and algal mats that formed during eutrophication episodes. Thus, the lagoon still remained a welcoming natural spectacle set among the communities that bordered it. The use of suspended platforms/booms at collection zones as employed by the Ocean Cleanup in relying on nature's sweep of debris towards points through currents and wind action could be explored as short-term restoration attempts. Also, improving littoral vegetation growth, further increasing expected wetland buffer width from 30m to 50m or 80m in heavily populated areas, will slow sediments entry which silt the lagoon. Longer-term strategies may require addressing land use such as enforcement of regulations regarding setting up buildings outside the suggested buffer perimeter. The implications of mangrove and littoral vegetation clearing as a result of lessons learned from other studies could serve as narratives in public awareness programs.

It was emphasized from the present scenario analysis using the LMC-DSS, that the Fosu lagoon is indeed requiring immediate interventions to restore and sustainably manage the resource. The study provided the most recent, holistic, and quantifiable terms of indicators and metrics to focus on in any management exercise. Important abiotic factors, biological indicators, and resource use options were considered to assist decision-making on the priority areas to address in a sequence to improve the present state of the lagoon which scored a paltry 32.6% of ecological health performance. Decision-making was directed at tackling issues on resource use, which follows a logical path of lifting the pressures within the catchment area that negatively affect the ecosystem's functioning. Water quality improvement, based on the physicochemical environment of both water and sediment, was the next priority for management considerations which imply its reflected responses by the biological components such as fish and birds that relied on the resource. Thus, goods and services of an ecologically balanced and healthy ecosystem were assured to support livelihoods in a sustainable manner from case scenarios generated based on priority areas. On the explorative basis of scenarios created, sustainable resource use (Criterion C) interventions raised the ecological health state of the Fosu lagoon to about 74%. While, effective measures to restore the water quality, as expressed for Criterion A, improved the ecological health of the Fosu lagoon to 78%.

Environmental justice (EJ) may seem like a buzzword in coastal management practices around the world, however, its emphasis on bringing all stakeholders irrespective of knowledge background or level of power to a consensus in planning, implementation, and evaluation of outcomes in view of set regulations and policies towards healthy environments, cannot be ignored. Of major importance to achieving this consensus was to analyze the framework that goes through the various phases from problem identification; solution options (as proposed through the use of the LMC-DSS for management); selection of appropriate solution based on available logistics, technical know-how/expertise, and political will; implementation utilizing existing traditional and governmental structures; and evaluation of goals. The review of the institutional framework and existing policies stressed the need for overcoming the disjointed attempts by sectors (in some cases, repeated efforts over short time scales) and the gaps in legislative, regulatory, and policy frameworks towards precise coastal management goals. Perhaps, a decentralized system that does not fully equip MMDAs and relevant stakeholders to plan coastal management projects requires a neutral entity with representation from all sectors to coordinate between the central government which welds the political will and influence, and NGO’s/donor groups/research groups that address issues holistically but lack the power of influence through legislative means. A Social Network Analysis (SNA) pointed out the gaps in the role of scientific studies informing policy, thus, the reduced efficiency of regulations and projects. It also highlighted the responses that were generated due to sporadic events such as flooding that received immediate support to avert consequences of politically aligned narratives, in comparison to the long-term effect of the ecosystem collapse from neglect. The linkages in the SNA also revealed how the ephemeral nature of programmes due to reliance on donor groups, inadequate collaboration with traditional authority, and infrastructure provision bias in coastal development projects (against increasing need for attitudinal change towards pollution, sanitation issues, fisheries overexploitation, mangrove cutting, etc.) crippled well-intended management efforts.

The Fosu Lagoon is an ideal example of a pressured wetland type within a coastal urban settlement in Ghana. A decisive approach through ICZM processes to manage and utilize the resource depended on expected goals whose selections can be aided with the LMC-DSS. In between the two extreme scenarios of sustainably managing anthropogenic activities of the Fosu lagoon and neglecting it as a sink for all contaminants are several scenarios that could be visualized to enhance trade-offs between stakeholders and competing users while informing decision-making of costs per objectives.

As a contribution to knowledge, this research has demonstrated that a well patronized Microsoft Office application software – Microsoft Excel can be utilized as a decision support system tool for ecological health assessment and management of coastal lagoons. The multi-criteria dimensions of the tool reduce the time frame for complex analytical studies while providing information that is holistic in its outlook. The predictive advantage of the LMC-DSS also equips stakeholders and policy formulators with a wide variety of options to consider during resource use trade-offs based on agreed objectives. Also, of essence to this study was the opportunities presented through the institutional network analysis for several collaborative efforts to fill in gaps of mandates/roles of relevant coastal management groups. The central role played by the Ghana EPA is overwhelming and in need of inputs by other groups such as the universities and NGOs that directly engage with stakeholders. The recently formed Coastal Development Authority (CoDA) could support other projects that directly involved sustainable exploitation of coastal resources in addition to the developmental infrastructures provided.

6.3 Recommendations

The following are recommended in relation to the research undertaken for considerations:

- The Ghana Environmental Protection Agency (EPA) and Water Research Institute of the CSIR must set water quality sampling protocols and criteria purposefully for coastal lagoons used for fishing, recreation, etc. to allow comparisons with set criteria.
- Voluntary water quality monitoring programmes must involve communities and relevant stakeholders to harness stewardship of a

common public resource while providing reliable and consistent data needed for water quality assessment.

- Educational and research institutions must be encouraged to create a database on water and sediment variables, similar to the publications hub by FishCoMGhana of Centre for Coastal Management (CCM), which makes related publications accessible for academics, public information, and policy-making purposes. Long-term trend analysis that fine-tunes models and tools such as the LMC-DSS require such a database.
- The CCMA, together with relevant agencies such as the Land Use and Spatial Planning Authority (LUSPA), must implement decisions taken to relocate garages at Siwdu and discourage other set-ups whose activities affect the lagoon. This would reduce pollution and heavy metals' effects on fish growth.
- Government through the Ministry of Water Resources and Sanitation and other related agencies must include wastewater treatment plants at the major point entries of effluents.
- Proper solid waste disposal, retrieval, segregation, and recycling, must be improved by the CCMA to reduce debris that reaches the coastal lagoon through waterways.
- Regular community clean-up exercises must be encouraged following recently past national initiatives of monthly communal clean-ups.
- The Environmental Protection Agency (EPA) and Coastal Development Authority (CODA) must act as lead organisations to coordinate and foster collaborative efforts in the coastal management of Ghana.

The following are recommended for further studies:

- Research efforts must include other driving factors of sediment quality such as the bioturbation effect by benthos, oxidation-reduction potential, and flux rates as part of water quality assessments.
- Undertake experimental simulations using cichlid species from the Fosu Lagoon to prove to fishermen and other relevant stakeholders that improved water quality conditions and reduced fishing pressure positively improves the growth sizes of the blackchin tilapia.
- A more detailed and extended duration of bird survey should be conducted to add further insights on the trophic and other ecological roles played by avifauna species of the Fosu Lagoon.
- Zooplankton studies will complement ecological studies of the lagoon as hinted through the preliminary study (APPENDIX L).
- Research organisations must extend the concept of building site-specific DSS by including other watersheds.

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APPENDIX A-1

LABORATORY ANALYSIS FOR HEAVY METALS

(Conducted at the Chemistry Laboratory, Ghana Atomic Energy Commission by PhD. Student Margaret F. Dzakpasu, USAID-UCC FCMCBSP on Quarterly Samples of Water from the Fosu Lagoon – June 2016; September 2016; December 2016; March 2017; June 2017 and August 2017)

Heavy Metals in Water Samples

Pre-acidified 500ml samples of water, collected over four quarters during the study period, were analysed to ascertain concentrations of heavy metals under considerations. In a fume chamber, an aqueous regia was prepared from 4.5 ml concentrated HCl and 0.5 ml concentrated HNO_3 and added to 100 ml of pre-measured water sample poured into a 100 ml borosilicate beaker. The solution was digested on a hot plate at 45 ^{o}C for a period of 3 hours after covering the beaker with a cling film. The entire content which was transferred into a 100 ml beaker, with distilled water topping it to 30 ml, was then assayed to determine levels of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg); nickel (Ni); iron (Fe) and zinc (Zn) through the use of the VARIAN AA 240FS – Atomic Absorption Spectrophotometer (AAS) in an acetylene-air flame. For three replicates assayed, the final concentration of each detected heavy metal was:

$$Final\ concentration\ (mg/l) = \frac{Concentration\ (df) \times Nominal\ volume}{Sample\ volume}$$

where, the nominal volume represented the volume after digestion (i.e., final volume).

APPENDIX A-2
LABORATORY ANALYSIS FOR HEAVY METALS

(Conducted at the Chemistry Laboratory, Ghana Atomic Energy Commission by Ph.D. Student Margaret F. Dzakpasu, USAID-UCC FCMCBSP on Quarterly Samples of Sediments from the Fosu Lagoon – June 2016; Sept. 2016; December 2016; March 2017; June 2017 and August 2017)

Heavy Metals in Sediment Samples

To ascertain the concentrations of heavy metals in sediment samples, dried sediments were sieved to eliminate organic matter and debris. A 25 ml aqua regia prepared from 3 ml concentrated HCl and 1 ml concentrated HNO_3 was added to 1 g sediment sample in a 100 ml borosilicate beaker which was digested at 45 ^{o}C for a period of 3 hours on a hot plate. A similar protocol was followed where the digested sample was poured into a 100 ml beaker, topping to 30 ml and the clear filtrate in test tubes were assayed for As, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Fe and Zn using the VARIAN AA 240FS – Atomic Absorption Spectrophotometer (AAS) in an acetylene-air flame.

The concentration of detected heavy metals in sediment samples was determined by:

$$Final\ concentration\ (mg/kg) = \frac{Concentration\ (df) \times Nominal\ volume}{Sample\ weight}$$

where the nominal volume represents the volume after digestion (i.e., final volume).

APPENDIX B-1

SEMI-STRUCTURED QUESTIONNAIRE ADMINISTERED TO SELECTED AGENCIES AND GROUPS

Responses: YES or NO to questions (Yes = 1, No = 0)

1. Are your operations at a local/district level? LD
   Are your operations on a regional/national level? RN

2. Are your operations related to coastal zone management as a result of established mandates? EM
   Are there constraints (as a result of overlaps in other agency's mandates) in implementing mandates? CM

3. [Are you data providers (research oriented)? DP] [Are you analysts? AP] [Are you policy advisors? PP] [Are you implementers? IP] [Are you financiers? FP]

4. Do you often collaborate with other agencies for Coastal zone management? CO
5. Does your management role follow routine/monitoring patterns? MR
   Are your roles 'sparked' by events (needs basis)? MS

6. [Are your CZ projects/programs awareness/sensitization related? AW] [Are the CZ projects/programs on site (fieldwork)? FW]

7. Are your objectives/goals largely to sustainably manage ecosystems? SM
   Are your objectives/goals to restore and/or conserve ecosystems? RC

8. Is your source of funding from the government? GF
   Do you rely on corporate organisations for funding? CF
   Do you rely on community-generated funds, philanthropists, NGO? NF
   Do you get foreign donors to sponsor projects? FF

9. Can time frames of projects be described as short-term (less than 5years)? ST
   Are projects geared towards long term (up to about 10years and more)? LT

10. [Are there any evident success of projects? SU] [Did local communities participate willingly in projects? LC]

APPENDIX B-2

CODES FOR AGENCIES, MINISTRIES, INSTITUTIONS ETC

List of Institutions/organisations involved in CZM	**CODE**	**List of Institutions/organisations involved in CZM**	**CODE**
Centre for African Wetlands, UG	CAW	Ministry of Gender	MG
Coastal Sustainable Landscapes Project	CSLP	Ministry of Health	MH
District/ Metropolitan Assemblies e.g., CCMA	DMA	Ministry of Lands and Natural Resources	MLNR
Fisheries Commission	FiC	Ministry of Local Government and Rural Development	MLGRD
Forestry Commission	FoC	Ministry of Sanitation and Water Resources	MoS
Friends of the Nation, FoN	FN	Ministry of Tourism, Culture and Creative Arts	MTCCA
Ghana Environmental Protection Agency	GEPA	Ministry of Works and Housing	MWRWH
Ghana Museums and Monuments Board	GMMB	National Disaster Management Organisation	NADMO
Hen Mpoano	HM	National Development Planning Commission	NDPC
Hydrological Services Department	HSD	Netherlands Development Organisation	NDO

APPENDIX B-3

CODES FOR AGENCIES, MINISTRIES, INSTITUTIONS ETC

List of Institutions/organisations involved in CZM	**CODE**	**List of Institutions/organisations involved in CZM**	**CODE**
Land Use and Spatial Planning Authority	LUSPA	Norwegian Embassy (Oil for Development program)	NE
Min. of Environment, Science, Technology & Innovation	MESTI	Spatial Solutions	SS
Ministry of Communications	MC	Sustainable Fisheries Management Project,	SFMP

APPENDIX B-4

BINARY CODE FORMAT FOR RESPONSES FROM QUESTIONNAIRE ADMINISTRATION (YES – 1; NO – 0)

LIST OF INSTITUITIONS

			Centre for African Wetlands, UG	Coastal Sustainable Landscapes Project	District / Metropolitan Assemblies e.g. CCMA	Fisheries Commission	Forestry Commission	Friends of the Nation, FoN	Ghana Environmental Protection Agency	Ghana Musuems and Monuments Board	Hen Mpoano	Hydrological Services Department	Land Use and Spatial Planning Authority	Min. of Environment, Science, Technology &Innov	Ministry of Communications	Ministry of Education	Ministry of Fisheries and Aquaculture
QUESTION		CODE	CAW	CSLP	DMA	FiC	FoC	FN	GEPA	GMMB	HM	HSD	LUSPA	MESTI	MC	ME	MFAq
1	Are your operations at a local/district level	LD	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1
	Are your operations on a regional/national	RN	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
2	Are your operations related to coastal zone management as	EM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are there constraints (as a result of overlaps in other agency's mandates) in	CM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	Are you data providers (research	DP	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
	Are you analysts	AP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are you policy advisors	PP	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
	Are you implementers	IP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are you	FP	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1
4	Do you often collaborate with other agencies for Coastal zone management	CO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Does your management role follow routine/monitoring patterns	MR	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
	Are your roles 'sparked' by events (needs	MS	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6	Are your CZ projects/programs awareness/sensi	AW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are the CZ projects/programs on site	FW	1	1	1	1	1	0	1	0	1	0	1	1	0	0	1

			Ministry of Food and Agriculture	Ministry of Gender	Ministry of Health	Ministry of Lands and Natural Resources	Ministry of Local Government and Rural Develo	Ministry of Sanitation????	Ministry of Tourism, Culture and Creative Arts	Ministry of Water. Resources. Works and Housin	NADMO	National Development Planning Commission	Netherlands Development Organisation	Norwegian Embassy (Oil for Development progra	Spatial Solutions	Sustainable Fisheries Management Project, SFMP	Traditional Local Authority – Chiefs, Opinion	Universities – UCC, UG, UDS, KNUST	Water Research Commission	Water Research Institute
QUESTION		CODE	MFA	MG	MH	MLNR	MLGRD	MoS	MTCCA	MWRWH	NADMO	NDPC	NDO	NE	SS	SFMP	TLA	UNI	WRC	WRI
1	Are your operations at a local/district level	LD	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1
	Are your operations on a regional/national	RN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
2	Are your operations related to coastal zone management as	EM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are there constraints (as a result of overlaps in other agency's mandates) in	CM	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	0	1	1
3	Are you data providers (research	DP	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
	Are you analysts	AP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are you policy advisors	PP	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
	Are you implementers	IP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are you	FP	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
4	Do you often collaborate with other agencies for Coastal zone management	CO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Does your management role follow routine/monitoring patterns	MR	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1	1	1	1
	Are your roles 'sparked' by events (needs	MS	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0
6	Are your CZ projects/programs awareness/sensi	AW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are the CZ projects/programs on site	FW	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1

APPENDIX B-5

BINARY CODE FORMAT FOR RESPONSES FROM QUESTIONNAIRE ADMINISTRATION (YES – 1; NO – 0)

			LIST OF INSTITUITIONS																																
			Centre for African Wetlands, UG	Coastal Sustainable Landscapes Project	District / Metropolitan Assemblies e.g. CCMA	Fisheries Commission	Forestry Commission	Friends of the Nation, FoN	Ghana Environmental Protection Agency	Ghana Museums and Monuments Board	Hen Mpoano	Hydrological Services Department	Land Use and Spatial Planning Authority	Min. of Environment, Science, Technology &Innov	Ministry of Communications	Ministry of Education	Ministry of Fisheries and Aquaculture	Ministry of Food and Agriculture	Ministry of Gender	Ministry of Health	Ministry of Lands and Natural Resources	Ministry of Local Government and Rural Develo	Ministry of Sanitation????	Ministry of Tourism, Culture and Creative Arts	Ministry of Water. Resources. Works and Housin	NADMO	National Development Planning Commission	Netherlands Development Organisation	Norwegian Embassy (Oil for Development progra	Spatial Solutions	Sustainable Fisheries Management Project, SFMP	Traditional Local Authority - Chiefs, Opinion	Universities - UCC, UG, UDS, KNUST	Water Research Commission	Water Research Institute
	QUESTION	CODE	CAW	CSLP	DMA	FiC	FoC	FN	GEPA	GMMB	HM	HSD	LUSPA	MESTI	MC	ME	MFAq	MFA	MG	MH	MLNR	MLGRD	MoS	MTCCA	MWRWH	NADMO	NDPC	NDO	NE	SS	SFMP	TLA	UNI	WRC	WRI
7	Are your objectives/goals largely to sustainably	SM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
	Are your objectives/goals to restore and/or conserve	RC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	Is your source of funding from the government	GF	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1
	Do you rely on corporate organisations for funding	CF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Do you rely on community-generated funds,	NF	1	1	1	0	0	1	0	0	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
	Do you get foreign donors to sponsor projects	FF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	Can time frames of projects be described as short-term (less than 5years)	ST	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Are projects geared towards long term (up to about 10years	LT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	Are there evident success of	SU	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Did local communities participate willingly in	LC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

APPENDIX C-1

WATER QUALITY BY SOLWAY

Table 1-1 Rating Table for Weighted Arithmetic and Weighted Solway WQIs (referred to as WQI_{GH} in this research)

Weighted Water Quality Rating (q_i x w_i)	DO (per cent saturation)	BOD (mg/l)	Amm-N (mg/l as N)	Faecal Coliform (Counts/100ml)	pH	NO_3-N (mg/l as N)	PO_4-P (mg/l as P)	SS (mg/l)	Conductivity (µS/cm)	T (°C)
18	93-109									
17	88-92 110-119									
16	85-87 120-129									
15	81-84 130-134	0-0.9								
14	78-80 135-139	1.0-1.9								
13	75-77 140-144	2.0-2.4								
12	72-74 145-154	2.5-2.9	0-0.09	0-249						
11	69-71 155-164	3.0-3.4	0.10-0.14	250-999						
10	66-68 165-179	3.5-3.9	0.15-0.19	1 000-3 999						
9	63-65 180^+	4.0-4.4	0.20-0.24	4 000-7 999	6.5-7.9					
8	59-62	4.5-4.9	0.25-0.29	8 000-14 999	6.0-6.4 8.0-8.4	0-0.49	0-0.029			
7	55-58	5.0-5.4	0.30-0.39	15 000-24 999	5.8-5.9 8.5-8.7	0.50-1.49	0.030-0.059	0-9		
6	50-54	5.5-6.1	0.40-0.49	25 000-44999	5.6-5.7 8.8-8.9	1.50-2.49	0.060-0.099	10-14	50-180	
5	45-49	6.2-6.9	0.50-0.59	45 000-79 999	5.4-5.5 9.0-9.1	2.50-3.49	0.100-0.129	15-19	0-49 190-239	25^+
4	40-44	7.0-7.9	0.60-0.99	80 000-139 999	5.2-5.3 9.2-9.4	3.50-4.49	0.130-0.179	20-29	240-289	23.0-24.9
3	35-39	8.0-8.9	1.00-1.99	140 000-249 999	5.0-5.1 9.5-9.9	4.50-5.49	0.180-0.219	30-44	190-379	21.5-22.9
2	25-34	9.0-9.9	2.00-3.99	250 000-429 999	4.5-4.9 10.0-10.4	5.50-6.99	0.220-0.279	45-64	380-539	19.5-21.4
1	10-24	10.0-14.9	4.00-9.99	430 000-749 999	3.5-4.4 10.5-11.4	7.00-9.99	0.280-0.369	65-119	540-839	17.5-19.4
0	0-9	15.0^+	10.00^+	$750\,000^+$	0-.3.4 11.5-14	10.00^+	0.370^+	120^+	840^+	0-17.4

Note: If some parameters are missing, the arithmetic weighted WQI as calculated from Table 1-1 has to be corrected by multiplying the Index by 1/x, where x is the sum of the weightings of the parameters being considered. The adjusted arithmetic weighted index should be used, where appropriate, in the calculation of Solway weighted index.

APPENDIX C-2

WATER QUALITY BY SOLWAY

Class	Range	Description
I	> 80	Good -Unpolluted and/or recovering from pollution
II	> 50 – 80	Fairly good,
III	25 – 50	Poor quality,
IV	< 25	Grossly polluted,

APPENDIX D

SPATIAL AND TEMPORAL CODES FOR PCA PLOTS

Temporal codes	Months
A2	Nov. 2016
B2	Dec. 2016
C2	Jan. 2017
D2	Feb.2017
E2	Mar. 2017
F2	Apr. 2017
G2	May. 2017
H2	Jun. 2017
I2	Jul. 2017
J2	Aug. 2017
K2	Sept. 2017
L2	Oct. 2017
M2	Nov. 2017
N2	Dec. 2017

Spatial Codes	Stations
a	1
b	2
c	3
d	4
e	5
f	6

APPENDIX E-1

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (µg/L)
Month	Code	pH	DO (mg/L)	Cond. (µS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
Nov.16	A2a	8.01	2.02	6320	4985	2.98	28.26	62.7	2.38	28.3	0.43	50.1	5.723
	A2b	8.36	2.15	9820	5880	6.71	31.02	234.1	0.28	7.5	0.21	19.5	12.452
	A2c	8.09	2.14	12110	6491	6.88	38.42	94.1	0.39	1.6	0.75	7.4	10.523
	A2d	8.31	5.47	5773	2725	3.11	29.02	26.1	0.26	1.4	0.98	7.2	4.895
	A2e	8.51	2.35	6009	1630	6.31	31.01	25.1	0.34	2.4	0.67	7.9	4.508
	A2f	8.36	2.15	11820	55880	6.71	31.02	104.1	0.27	2.1	0.54	10.1	2.189
Dec.16	B2a	8.31	2.12	9950	8580	9.31	28.55	47.1	2.52	19.1	1.05	34.9	16.213
	B2b	9.15	7.21	9890	5145	5.76	30.32	65.1	0.21	6.4	0.79	14.4	3.284
	B2c	8.42	2.83	92170	3904	4.28	30.08	28.3	0.58	5.1	1.31	8.7	7.045
	B2d	8.26	2.09	11520	6570	6.52	29.82	106.1	0.34	2.8	0.75	7.1	3.816
	B2e	8.62	2.41	6782	3954	4.32	33.64	54.9	0.23	1.5	0.34	12.4	12.319
	B2f	7.88	2.48	7740	3828	4.08	32.56	52.2	0.31	1.8	1.41	7.8	1.932

APPENDIX E-2

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (μg/L)
Month	Code	pH	DO (mg/L)	Cond. (μS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
Jan.17	C2a	7.85	4.11	6220	3112	3.37	29.56	107.1	4.38	14.3	1.66	40.5	4.239
	C2b	8.74	3.19	9360	5120	6.25	31.07	53.4	0.36	20.2	0.16	55.7	18.379
	C2c	8.82	6.48	9603	5125	5.47	29.76	46.7	0.27	6.4	0.65	17.5	3.917
	C2d	8.91	7.12	10380	5194	5.82	29.78	78.9	0.24	5.5	0.53	15.2	14.928
	C2e	9.02	6.82	6017	5189	5.91	30.72	87.2	0.31	6.3	0.95	56.3	8.124
	C2f	9.15	7.21	9890	5145	5.76	30.32	65.1	0.38	1.7	0.67	6.3	2.309
Feb.17	D2a	8.02	1.78	8502	4250	4.68	30.41	182.5	0.87	42.2	1.51	98.6	38.817
	D2b	8.04	6.16	5101	2152	3.56	29.11	49.6	0.41	1.3	0.86	8.5	14.569
	D2c	8.59	2.57	10080	6201	7.08	32.23	73.4	0.32	6.9	0.16	30.2	11.051
	D2d	8.81	3.32	12570	6284	7.24	30.44	36.7	0.36	1.8	0.15	53.9	1.949
	D2e	8.84	3.12	5408	4260	7.18	33.23	46.5	0.52	2.8	1.27	18.6	5.717
	D2f	8.38	2.62	11960	6000	6.74	32.67	33.5	1.12	0.6	0.92	5.1	1.001

APPENDIX E-3

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (µg/L)
Month	Code	pH	DO (mg/L)	Cond. (µS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
Mar.17	E2a	8.71	4.82	5372	5002	3.01	29.81	54.7	1.71	35.4	0.26	65.7	8.286
	E2b	7.88	2.48	7740	3828	4.08	32.56	52.2	0.38	4.7	0.27	8.4	5.568
	E2c	8.53	2.81	12480	6201	7.12	29.45	34.1	0.26	15.2	0.18	48.2	2.451
	E2d	7.76	5.66	9902	4926	4.21	31.55	102.7	0.23	1.3	0.67	45.9	4.891
	E2e	8.82	3.05	6119	4178	6.88	32.19	30.9	0.38	1.9	0.61	10.5	8.561
	E2f	8.74	3.19	12360	5120	6.25	31.07	40.2	1.04	1.4	1.01	17.7	4.613
Apr.17	F2a	8.92	4.97	7023	5781	4.06	29.91	84.3	1.33	56.7	0.18	37.4	18.215
	F2b	6.23	4.97	9402	4789	4.85	29.76	45.9	0.24	6.7	0.83	5.7	4.107
	F2c	9.02	5.17	10690	5345	7.09	30.09	48.1	1.09	5.3	0.14	9.8	4.518
	F2d	8.91	11.2	8934	6143	1.98	29.17	52.1	1.09	10.5	0.15	13.8	12.729
	F2e	8.17	3.04	9201	5458	6.32	32.12	65.7	0.56	0.9	1.48	9.4	2.903
	F2f	9.01	4.12	10760	5389	6.15	31.34	63.2	0.45	3.6	1.04	21.6	1.218

APPENDIX E-4

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (µg/L)
Month	Code	pH	DO (mg/L)	Cond. (µS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
May.17	G2a	8.74	3.32	5021	3076	2.96	28.17	49.2	4.19	12.1	0.53	31.8	14.045
	G2b	9.32	3.82	8004	6523	4.56	30.58	45.9	0.31	4.5	0.65	6.8	3.854
	G2c	8.45	5.61	7203	4782	4.02	30.33	57.9	0.31	5.8	0.71	23.9	3.268
	G2d	8.12	8.73	11236	3047	5.25	29.03	82.3	0.89	9.6	0.19	28.2	6.309
	G2e	8.92	10.2	8146	4802	4.99	31.25	33.4	0.18	1.3	0.76	5.8	4.614
	G2f	10.41	3.65	91930	3091	3.04	30.98	46.3	0.28	2.4	0.94	9.1	0.58
Jun.17	H2a	7.31	3.08	6732	8206	3.98	30.02	78.2	1.93	18.1	1.99	64.3	5.357
	H2b	6.77	3.98	7038	5018	5.58	28.92	52.4	0.17	1.6	0.98	6.5	1.191
	H2c	7.97	10.5	8604	5193	6.23	28.76	28.9	0.45	2.2	1.15	10.2	0.292
	H2d	8.27	4.51	9245	4912	3.92	30.04	62.8	0.38	1.4	0.73	8.9	0.363
	H2e	10.56	12.1	3881	1975	6.12	30.09	20.6	0.28	1.5	0.55	6.3	0.641
	H2f	9.65	2.48	9563	5447	8.02	30.81	50.4	0.41	0.5	0.65	6.4	3.921

APPENDIX E-5

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (µg/L)
Month	Code	pH	DO (mg/L)	Cond. (µS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
Jul.17	I2a	8.77	3.82	5412	7129	2.01	28.29	98.6	1.96	34.2	1.22	60.7	8.293
	I2b	9.22	5.91	7981	5892	3.56	31.24	34.7	0.41	1.3	0.93	7.9	4.413
	I2c	8.09	3.87	4034	4984	5.87	31.24	54.1	0.23	0.7	0.65	6.7	4.297
	I2d	6.17	10.3	9824	7028	2.88	29.16	55.3	0.25	0.6	0.55	6.3	5.881
	I2e	8.24	9.88	7428	2064	4.85	29.07	29.5	0.45	0.6	0.59	5.4	6.064
	I2f	9.11	3.03	10420	4998	5.19	28.55	31.5	0.17	0.7	0.61	6.9	3.958
Aug.17	J2a	8.45	1.15	6541	4503	3.18	28.92	65.7	2.55	31.7	0.41	49.8	5.271
	J2b	8.07	4.08	5782	5129	6.04	28.95	98.8	1.13	1.4	0.68	7.6	11.237
	J2c	8.76	10.7	5193	4657	3.45	30.47	45.4	0.18	0.4	0.61	9.1	16.59
	J2d	8.59	8.03	10913	5001	5.64	30.66	24.6	0.54	0.4	0.78	6.7	17.883
	J2e	8.35	7.24	4019	2125	3.94	28.01	20.6	0.29	0.7	1.04	11.4	8.347
	J2f	9.06	12	12400	5927	6.01	28.15	72.1	0.28	0.5	1.93	16.3	2.118

APPENDIX E-6

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (µg/L)
Month	Code	pH	DO (mg/L)	Cond. (µS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
Sept.17	K2a	8.09	1.95	6017	7119	2.04	30.12	68.5	3.27	13.5	1.48	42.6	4.694
	K2b	7.86	2.18	6542	4306	6.14	30.12	97.3	0.28	3.8	0.29	14.8	7.314
	K2c	7.98	3.56	12046	5389	7.22	28.72	45.9	0.32	17.7	0.14	52.4	2.094
	K2d	8.01	3.45	7609	2886	3.99	31.06	92.9	0.87	0.9	0.34	4.9	2.907
	K2e	8.59	6.44	4192	2843	5.18	30.22	23.1	0.24	4.3	0.81	16.5	1.458
	K2f	8.14	5.13	10640	5571	2.99	29.86	48.9	0.91	1.1	0.81	12.9	1.087
Oct.17	L2a	8.85	2.82	4218	6145	4.19	28.02	70.3	2.76	32.7	1.03	32.6	10.368
	L2b	10.56	6.59	6140	5072	5.52	29.98	53.4	0.19	7.4	0.12	31.9	1.337
	L2c	8.16	5.37	9902	6298	4.56	29.44	34.8	0.21	7.2	0.13	35.6	7.549
	L2d	7.27	10.1	11083	5614	3.48	28.95	62.1	0.65	0.5	0.76	25.3	4.295
	L2e	8.16	8.17	8101	3016	6.01	30.14	30.8	0.21	0.7	0.73	10.2	3.056
	L2f	8.57	3.72	5174	2018	3.07	30.01	35.2	1.26	1.4	0.56	5.8	3.014

APPENDIX E-7

MONTHLY PHYSICOCHEMICAL, NUTRIENTS AND CHLOROPHYLL-A MEASUREMENTS FROM FOSU LAGOON

Month		Physicochemical parameters							Nutrients				Chl-a (µg/L)
Month	Code	pH	DO (mg/L)	Cond. (µS/cm)	TDS (ppm)	Sal. (PSU)	Temp. (°C)	Turb. (NTU)	PO_4^{3-} (mg/L)	NO^3 (mg/L)	NH_3 (mg/L)	$Si_2O_3^{2-}$ (mg/L)	
Nov.17	M2a	8.76	2.08	6837	4567	3.95	28.05	100.2	1.42	48.9	0.16	52.7	5.326
	M2b	9.02	6.65	8925	6525	3.92	30.14	45.8	0.35	6.9	0.44	29.5	3.912
	M2c	7.99	3.85	10854	7718	5.65	29.34	70.3	0.25	1.3	0.82	30.8	3.086
	M2d	11.56	6.57	9076	4556	5.05	29.66	80.4	0.11	7.2	0.09	34.5	0.638
	M2e	7.83	5.85	4821	2168	6.93	28.93	27.4	0.61	1.2	0.65	27.5	10.982
	M2f	9.61	5.22	10983	6783	6.73	31.65	54.1	0.54	1.2	0.69	14.5	2.739
Dec.17	N2a	8.95	1.89	8209	4271	5.69	30.67	87.3	3.11	51.8	0.77	32.4	15.812
	N2b	8.12	3.58	9016	5449	4.23	30.28	59.4	0.21	4.8	0.36	15.2	5.138
	N2c	6.37	3.06	9805	5587	3.08	30.54	41.3	0.62	4.8	1.08	8.2	2.115
	N2d	8.11	3.33	7338	3714	4.06	33.91	40.9	0.29	4.8	1.08	12.2	9.502
	N2e	8.78	4.56	5393	3156	4.52	28.44	40.9	0.43	1.3	1.87	5.1	3.405
	N2f	8.69	9.94	10298	6160	6.74	29.77	28.4	0.76	0.7	0.45	19.2	3.005

APPENDIX F-1

PRINCIPAL COMPONENET ANALYSIS CORRELATION TABLES (USING XLSTAT)

XLSTAT 2018.1.49310 - Principal Component Analysis (PCA) - Start time: 12/8/2019 at 3:43:37 PM / End time: 12/8/2019 at 3:43:43 PM
Observations/variables table: Workbook = Physicochemical and Nutrients Raw.xlsx / Sheet
Observation labels: Workbook = Physicochemical and Nutrients Raw.xlsx / Sheet = Dec.17 - Physico /
PCA type: Correlation
Standardisation: (n)
Type of biplot: Distance biplot / Coefficient = Automatic

Contributions by variables along two dimensions F1 and F2

	Nov. 16		Dec. 16		Jan. 17		Feb.17		Mar.17		Apr.17		May.17	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
pH	0.054	62.775	0.001	48.492	13.510	1.019	15.876	12.314	16.857	1.253	4.023	16.907	29.420	1.658
DO (mg/L)	14.609	2.338	0.166	49.607	3.212	19.152	10.459	30.245	12.236	19.583	21.975	9.766	14.347	7.300
Conductiv	26.563	0.890	4.672	0.690	7.971	0.850	11.636	6.058	8.000	10.629	11.444	6.926	21.786	0.687
TDS (ppm)	7.379	14.468	34.170	0.316	14.970	0.001	21.333	2.939	11.556	29.862	21.331	7.381	0.214	29.303
Salinity (P	24.661	5.154	32.956	0.012	14.238	1.527	23.665	1.586	21.649	1.439	25.480	2.303	19.063	12.638
Temperat	14.232	14.199	21.655	0.417	3.582	14.132	14.234	0.475	8.057	24.936	14.272	16.045	4.761	33.251
Turbidity (	12.502	0.176	6.380	0.466	9.534	0.421	2.797	46.383	21.645	12.300	1.475	40.672	10.409	15.161

APPENDIX F-2

PRINCIPAL COMPONENET ANALYSIS CORRELATION TABLES (USING XLSTAT)

XLSTAT 2018.1.49310 - Principal Component Analysis (PCA) - Start time: 12/8/2019 at 3:43:37 PM / End time: 12/8/2019 at 3:43:43 PM
Observations/variables table: Workbook = Physicochemical and Nutrients Raw.xlsx / Sheet
Observation labels: Workbook = Physicochemical and Nutrients Raw.xlsx / Sheet = Dec.17 - Physico /
PCA type: Correlation
Standardisation: (n)
Type of biplot: Distance biplot / Coefficient = Automatic

Contributions by variables along two dimensions F1 and F2

	Jun.17		Jul.17		Aug.17		Sep.17		Oct.17		Nov.17		Dec.17	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
pH	16.645	19.452	3.095	24.287	17.728	14.892	32.907	0.007	0.000	26.768	7.197	2.210	0.050	42.645
DO (mg/L)	19.954	10.538	0.146	37.389	13.883	17.783	29.680	2.534	5.217	26.529	9.682	16.718	28.039	4.992
Conductiv	7.952	6.848	0.339	24.196	27.499	0.000	6.181	23.861	2.143	39.204	28.090	8.826	21.795	10.032
TDS (ppm)	22.837	0.030	27.663	0.624	23.258	7.994	10.438	5.507	19.575	5.486	18.491	12.834	26.975	7.233
Salinity (P	7.508	14.505	30.774	1.856	14.922	10.668	0.000	10.972	6.839	0.787	1.808	21.167	11.134	26.150
Temperat	0.000	47.284	7.012	5.922	1.079	6.306	0.936	41.376	35.653	1.088	33.114	2.233	3.298	7.432
Turbidity (	25.104	1.344	30.970	5.727	1.632	42.358	19.856	15.743	30.572	0.138	1.617	36.011	8.709	1.516

APPENDIX G-1

GRANULOMETRY OF SEDIMENTS FOR GRAIN SIZES ACROSS SIX SAMPLED STATIONS

Sieve Size	Station 1			Station 2			Station 3			Station 4			Station 5			Station 6		
	Amount Retained	Station 1 (% Retained)	Cumm.	Amount Retained	Station 2 (% Retained)	Cumm.	Amount Retained	Station 3 (% Retained)	Cumm.	Amount Retained	Station 4 (% Retained)	Cumm.	Amount Retained	Station 5 (% Retained)	Cumm.	Amount Retained	Station 6 (% Retained)	Cumm.
1000µm	25.5	41.87%	41.87%	24.5	26.75%	26.75%	30.1	34.44%	34.44%	57.1	49.52%	49.52%	37.6	47.24%	47.24%	0.3	5.88%	5.88%
710µm	4.4	7.22%	49.10%	6.8	7.42%	34.17%	8.2	9.38%	43.82%	13.8	11.97%	61.49%	6.9	8.67%	55.90%	0.1	1.96%	7.84%
500µm	3.8	6.24%	55.34%	6.4	6.99%	41.16%	16.7	19.11%	62.93%	11.3	9.80%	71.29%	6.4	8.04%	63.94%	0.3	5.88%	13.73%
125µm	14.3	23.48%	78.82%	37.7	41.16%	82.31%	21.9	25.06%	87.99%	26.3	22.81%	94.10%	20.4	25.63%	89.57%	1.3	25.49%	39.22%
63µm	8.4	13.79%	92.61%	11.4	12.45%	94.76%	5.8	6.64%	94.62%	3.8	3.30%	97.40%	5.4	6.78%	96.36%	0.1	1.96%	41.18%
End Pan	4.50	7.39%	100.00%	4.80	5.24%	100.00%	4.70	5.38%	100.00%	3.00	2.60%	100.00%	2.90	3.64%	100.00%	3.00	58.82%	100.00%
Total	**60.9**	**100.00%**		**91.6**	**100.00%**		**87.4**	**100.00%**		**115.3**	**100.00%**		**79.6**	**100.00%**		**5.1**	**100.00%**	

APPENDIX G-2

PERCENTILE RANKING OF SEDIMENTS FOR GRAIN SIZES ACROSS SIX SAMPLED STATIONS

PERCENTILE RANKING						
Percentiles	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
5th	1.33	1.28	1.56	2.91	1.93	0.07
16th	4.24	4.08	4.98	9.30	6.18	0.48
25th	6.63	6.38	7.78	14.53	9.65	0.75
50th	15.45	19.35	28.00	35.95	22.75	3.05
75th	36.75	57.30	58.43	82.13	54.23	4.58
84th	48.22	73.75	70.31	95.17	65.27	5.12
95th	58.81	87.97	83.98	110.49	76.57	5.80

APENDIX H-1

AVIFAUNA ENCOUNTERED DURING RESEARCH ON THE FOSU LAGOON

	
Grey heron (black arrow) and a Great egret (red arrow)	Two African jacana
	
African pied wagtail (red arrow) and a Black crake	Woodland kingfisher

APPENDIX H-2

AVIFAUNA ENCOUNTERED DURING RESEARCH ON THE FOSU LAGOON

	
African jacana in flight	Great egret
	
Black winged stilt	African darters (pale brown females/juveniles and dark plumage males)

APPENDIX H-3

AVIFAUNA ENCOUNTERED DURING RESEARCH ON THE FOSU LAGOON

	
Yellow billed kite in flight	Cattle egret
	
Common sandpiper	Black-winged stilt

APPENDIX H-4

AVIFAUNA ENCOUNTERED DURING RESEARCH ON THE FOSU LAGOON

	
Great egret	Squacco heron (red arrow)
	
Woodland kingfisher	Yellow billed kite in flight

APPENDIX I

CORRELATION OF NOISE LEVELS AND HUMAN PRESENCE ON THE ABUNDANCE OF BIRDS AT THE FOSU LAGOON

Relationship between Noise rate, human presence, and birds

		Noise Rate	**Human Presence**	**Birds**
Noise Rate	Corr.	1	0.417**	-0.281**
	p-value		0.000	0.003
Human Presence	Corr.	0.417**	1	-0.058
	p-value	0.000		0.544
Birds	Corr.	-0.281**	-0.058	1
	p-value	0.003	0.544	
	N	110	110	110

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

APPENDIX J

COMPOSITION OF SOLID WASTE COLLECTED AT THE FOSU LAGOON

Solid Waste	Period									
	December 16		April 17		July 17		November 17		OVERALL	
	Qty	%tage	Qty	%tage	Qty	%tage	Qty	%tage	Qty	%tage
Plastics	1296	58.38	1122	55.00	876	50.00	726	53.78	4020	54.60
Textiles	270	12.16	240	11.76	192	10.96	180	13.33	882	11.98
Metals (scrap)	252	11.35	240	11.76	216	12.33	168	12.44	876	11.90
Organics (plant/wood)	312	14.05	366	17.94	408	23.29	216	16.00	1302	17.69
Others (charcoal/unidentifiable items)	90	4.05	72	3.53	60	3.42	60	4.44	282	3.83
TOTAL	**2220**	**100.00**	**2040**	**100.00**	**1752**	**100.00**	**1350**	**100.00**	**7362**	**100.00**

APPENDIX K-1

LAGOON MULTI-CRITERIA DECISION SUPPORT SYSTEM (LMC-DSS) PERFORMANCE OUTPUT FOR PRESENT CONDITIONS AT THE FOSU LAGOON

Criteria	Indicator	Parameter	Parameter Weighted Status	Indicator Status	Indicator Priority Ranking	Criteria Status	Criteria Priority Ranking	Management actions/strategies
A. Water quality restoration	**A.1** Water column abiotic assessment (WQI)	Dissolved oxygen (DO) (mg/l)	Fail	**25.00%**	**2nd**	36.59%	2nd	Set water quality standards purposefully for wetland/ brackish system, TMDL, routine monitoring, farming BMP, public sensitization on watershed activity implications.
		Temperature (°C)	Fail					
		Total dissolved solids (TDS) (ppm)	Fail					
		Turbidity (NTU)	Fail					
		Salinity (PSU)	Pass					
		pH	Pass					
		Conductivity (µS/cm)	Fail					
		Buffer Width estimates (m)	Fail					
	A.2 Limiting Nutrients	Nitrates conc. (mg/l)	Fail	**37.50%**	**4th**			Establish nutrient budgets per catchment area, strengthen regulations through TMDL, reduce fertilizer use, improve buffer width
		Phosphate conc. (mg/l)	Fail					
		Silicates conc. (mg/l)	Pass					
		Ammonia conc. (mg/l)	Pass					
		Dissolved oxygen (DO) (mg/l)	Fail					
		Temperature (°C)	Fail					
		Total dissolved solids (TDS) (ppm)	Fail					
		Turbidity (NTU)	Fail					

		Salinity (PSU)	Pass					
		pH	Pass					
		Conductivity (µS/cm)	Fail					
		Phytoplankton biomass (Chl-a) (µg/l	Fail					
		Suspended Aquatic vegetation	Pass					
		Sediment Porosity (%)	Fail					
		Organic matter (mg/l)	Pass					
		Buffer Width estimates (m)	Fail					
	A.3 Pathogen loads	*Escherichia coli*	Fail	**33.33%**	**3rd**			Build sewage treatment plants, provide toilet facilities in communities, consistent public education, routine monitoring, safe fish handling and processing
		coliform bacteria colony counts (cfu/ml)	Fail					
		solid waste	Fail					
		Temperature (°C)	Fail					
		pH	Pass					
		Salinity (PSU)	Pass					
	A.4 Sediment quality	Dominant grain size (µm)	Pass	**66.67%**	**5th**			Improve littoral buffer width, monitoring programmes must involve sediment quality analyses, increase flushing frequency in restricted systems
		Sediment Porosity (%)	Fail					
		Ammonia conc. (mg/l)	Pass					
		Organic matter (mg/l)	Pass					
		pH	Pass					
		Buffer Width estimates (m)	Fail					
	A.5 Heavy metals levels	Cd, Fe, etc	Fail	**20.00%**	**1st**			Establish background levels, regulations for discharge from major sources such as garages
		pH	Pass					
		Dissolved oxygen (DO) (mg/l)	Fail					

		Temperature (°C)	Fail					and industries, re-site direct inlet sources
		Total dissolved solids (TDS) (ppm)	Fail					

(LMC-DSS Table continued from Appendix H-1)

APPENDIX K-2

LAGOON MULTI-CRITERIA DECISION SUPPORT SYSTEM (LMC-DSS) PERFORMANCE OUTPUT FOR PRESENT CONDITIONS AT THE FOSU LAGOON

Criteria	Indicator	Parameter	Parameter Weighted Status	Indicator Status	Indicator Priority Ranking	Criteria Status	Criteria Priority Ranking	Management actions/strategies
B. Ecological health improvement	**B.1** Waterbird biodiversity	Waterbird counts	Pass	54.55%	4th	40.00%	3rd	Adopt conservation measures for waterbirds, reduce fishing pressure, encourage frequent clean-up for solid waste
		Foraging habits groups	Pass					
		Residence type	Pass					
		Migratory status	Pass					
		Human/external stressors	Fail					
		Fish/food availability	Fail					
		solid waste	Fail					
		Temperature (°C)	Fail					
		Turbidity (NTU)	Fail					
		pH	Pass					
		Salinity (PSU)	Pass					
	B.2 Fish species diversity	Fish counts	Pass	22.22 %	1st			
		Growth parameters	Fail					

		Condition factor	Fail					Improve water quality, reduce fishing pressure, frequent breaching of sand bars to encourage the entry of juvenile marine species
		Temperature (°C)	Fail					
		Phytoplankton biomass (Chl-a) (µg/l	Fail					
		Fishing pressure (humans/birds)	Fail					
		Salinity (PSU)	Pass					
		Dissolved oxygen (DO) (mg/l)	Fail					
		solid waste	Fail					
	B.3 Mangrove cover	Area coverage	Fail	**40.00%**	**3rd**			Discourage mangrove cutting for fuelwood, reiterate the importance of mangrove through public education, research on climate change and disease in mangroves
		Vigour	Pass					
		Climatic factors	Pass					
		Land use/reclamation	Fail					
		Fuelwood	Fail					
	B.4 Littoral vegetation (Buffer width)	Area coverage	Fail	**40.00%**	**2nd**			Relocate encroachers, public education on importance of buffer zone maintenance, replant native species in strongly cleared patches
		Buffer Width estimates (m)	Fail					
		Level of human encroachment	Fail					
		General Vegetation type	Pass					
		Climatic factors	Pass					

(LMC-DSS Table continued from Appendix H-2)

APPENDIX K-3

LAGOON MULTI-CRITERIA DECISION SUPPORT SYSTEM (LMC-DSS) PERFORMANCE OUTPUT FOR PRESENT CONDITIONS AT THE FOSU LAGOON

Criteria	Indicator	Parameter	Parameter Weighted Status	Indicator Status	Indicator Priority Ranking	Criteria Status	Criteria Priority Ranking	Management actions/strategies
C. Sustainable Resource exploitation	**C.1** Fishing	Fish counts	Pass	**12.50%**	**2nd**	21.21%	1st	Increase non-fishing days, increase mesh size of gears, improve water quality
		Fishing pressure (humans/birds)	Fail					
		Conflicting/Competing use	Fail					
		Condition factor	Fail					
		solid waste	Fail					
		Cd, Fe, etc	Fail					
		Escherichia coli	Fail					
		coliform bacteria colony counts (cfu/ml)	Fail					
	C.2 Heritage site	Conflicting/Competing use	Fail	**0.00%**	**1st**			Initiate public education during festive activities, encourage clean-up by providing waste
		solid waste	Fail					

								receptacles at vantage points, explore cultural tourism opportunities on the lagoon
	C.3 Recreation site	boating	Pass	16.67%	3rd			Implement regulations on the use of resource during recreational activities, maintain a clean environment, proper waste disposal, public education on resource use
		Level of human encroachment	Fail					
		Conflicting/Competing use	Fail					
		solid waste	Fail					
		Escherichia coli	Fail					
		coliform bacteria colony counts (cfu/ml)	Fail					
	C.4 Aesthetics	solid waste	Fail	40.00%	6th			Station sanitary workers, apprehend and charge guilty litters, provide waste bins for regular proper disposal, provide toilet facilities within the catchment
		Level of human encroachment	Fail					
		Conflicting/Competing use	Fail					
		General Vegetation type	Pass					
		Waterbird counts	Pass					
	C.5 Flood recharge zone	General Vegetation type	Pass	33.33 %	5th			
		Level of human encroachment	Fail					

		Buffer Width estimates (m)	Fail					Maintain a buffer zone, relocate encroachers and structures
	C.6 Waste/sewage receptacle	solid waste	Fail	22.22%	4th			Reduce non-point sources of pollution, frequent cleaning of lagoon bank area, 'sieve-out' waste from major drains from communities, build sewage treatment plants, provide toilet facilities in communities, consistent public education, routine monitoring
		General Vegetation type	Pass					
		Conflicting/Competing use	Fail					
		Escherichia coli	Fail					
		coliform bacteria colony counts (cfu/ml)	Fail					
		Nitrates conc. (mg/l)	Fail					
		Phosphate conc. (mg/l)	Fail					
		Ammonia conc. (mg/l)	Pass					
		Human/external stressors	Fail					

(LMC-DSS Table continued from Appendix H-3)

APPENDIX L

ZOOPLANKTON

Zooplankton identification from a one-off study

Preliminary field visits in October 2016 indicated high dominance of the rotifer *Brachionus calyciflorus* and copepod *Acartia sp.* among zooplankton organisms in an estimated 75% and 25%, respectively, of the filtrate after decantation.

Ecotoxicological opportunities using zooplankton

Pivotal ecological roles are played by zooplankton as linking organisms between primary producers and other consumers in aquatic environments, and as important groups to indicate changes in natural conditions (Keister et al., 2012). The high abundance, short life spans, and varying sensitivities to physical and chemical changes make the zooplankton important considerations in ecotoxicological studies reflecting real-time results as opposed to analytical equipment tests (Shane, 1994).

Two zooplankton groups were identified from a preliminary sampling of the Fosu lagoon in October 2016. The *Brachionus calyciflorus* of the Phylum Rotifera, Class Monogononta, Order Ploima, and Family Brachionidae, are primarily freshwater species and morphologically characterized by a cylindrical body with a distinct corona, trunk, and foot (Rico-Martínez et al., 2016). Rotifers serve as sentinel organisms among other invertebrates in ecotoxicological studies owing to their wide distribution, importance in energy transfer along with the food web, fast ingestion rate, and laboratory handling/cloning ease (Dahms et al., 2010; Janssen, 1991). Several species of the rotifer *Brachionus* have been utilized effectively in responses to the use of dispersants in petroleum and oil spills (Rico-Martínez et al., 2016; U.S.

Environmental Protection Agency - Office of Research and Development, 2010). General observations of the Fosu lagoon show contamination by oils evident from the slick in calmer sections along the banks. Clean up efforts must take into consideration laboratory use of the endemic rotifers to ascertain ecological effects against options such as the use of dispersants.

The copepod *Acartia sp* was also found among zooplankton. The species belonging to the Class Maxillopoda, Order Calanoida, and Family Acartiidae is generally epipelagic and may be found in marine or estuarine systems. Two distinctive antennae radiate from the head region of the copepod. Camatti et al., (2019), have indicated the significant effects of temperature variations, phytoplankton abundance, particulate organic carbon (POC), chlorophyll-a concentrations, and salinity regimes on abundance and distribution of *Acartia* in lagoon environments. Consequential effects of water quality by such parameters suggest biological indicator prospects for the *Acartia sp*. in pollution monitoring studies of the Fosu Lagoon.

