UNIVERSITY OF CAPE COAST

# A STUDY OF THE FOSU LAGOON WATERSHED IN GHANA: A REMOTE SENSING APPROACH

BERNARD YEBOAH ASSIAM

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# A STUDY OF THE FOSU LAGOON WATERSHED IN GHANA: A REMOTE SENSING APPROACH

BY

BERNARD YEBOAH ASSIAM

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 Master of Philosophy Degree in Integrated Coastal Zone Management.

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# 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: Bernard Yeboah Assiam

## 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

Co-Supervisor's Signature: .......................................... Date: .........................

Name: Dr. Isaac Okyere

## ABSTRACT

This work explored a remote sensing research approach for the study of the Fosu lagoon and its watershed. Land-Use/Land-Cover (LU/LC) and estimation of water quality parameters from the watershed and lagoon respectively was undertaken together with confirmatory social data. Landsat satellite data for the years 1991, 2007 and 2018 were used for LU/LC of the Fosu lagoon watershed with net changes for the classes built-up (90.4%), dense vegetation (-32.1%), sparse vegetation (37.7%), bare land (-6.4%) and water (-41%) over the period. Overtime, changes of the LU/LC had effects on the Fosu lagoon and contributed in diverse ways to its degradation. Regression analysis between the water quality parameters and reflectance values of the WorldView-2 satellite at nine sampling points revealed $R^2$ values and corresponding linear equations. The band ratio B2/B4 had the highest $R^2$ (0.512) for DO, B4/B3 for pH ($R^2$ = 0.8209), B2/B5 for Turbidity ($R^2$ = 0.648), single band B6 for TDS ($R^2$ = 0.019), B2 for conductivity ($R^2$ = 0.047) and band ratio B1/B3 for depth ($R^2$ = 0.321) and were selected as such. Results however could not be used for interpolation and possible creation of maps. Social investigation explored existent conditions about the lagoon on the ground. Filth, vegetation and siltation reflected as the highest trend of change with frequency 34.7%. Fishermen also confirmed lagoon depth reduction. Algal blooms had the highest mean statistic of (4.32 ± 0.086) as a single threat. Other significant threats were improper refuse disposal (4.13 ± 0.095), and erosion & siltation (4.29 ± 0.107). The combination, Dredging, Desilting & General Cleaning had the highest frequency (25%) by way of restoration. Fishermen, Policy Makers & Traditional Council (43.7%) were mostly suggested to drive the restoration process.

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I also appreciate the efforts of my siblings especially my brother, Ekow Mensah Bosomtwi Assiam and my sister, Henrietta Assiam for regularly checking up on the progress of my research until completion.

# DEDICATION

To Benjamin Yeboah Assiam & Dina Addae, my lovely parents of blessed memory.

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## ABBREVIATIONS

| | |
|---|---|
| DN | Digital Number |
| DO | Dissolved Oxygen |
| EMR | Electromagnetic Radiation |
| ETM+ | Enhanced Thematic Mapper Plus |
| FAO | Food and Agriculture Organization |
| GSS | Ghana Statistics Service |
| IPCC | Intergovernmental Panel on Climate Change |
| IR | Infrared |
| NIR | Near Infrared |
| OLI | Operational Land Imagery |
| $R^2$ | Coefficient of Determination |
| TDS | Total Dissolved Solids |
| TIFF | Tag Image File Format |
| TM | Thematic Mapper |
| UAV | Unmanned Aerial Vehicle |
| UNEP | United Nations Environment Programme |
| USGS | United States Geological Society |
| UTM | Universal Transverse Mercator |
| WV-2 | WorldView-2 |
| WGS | World Geodetic System |

# CHAPTER ONE

# INTRODUCTION

## Background of the Study

Within the coastal spectrum, many unique habitats with different ecological characteristics with high biodiversity exist (Anthony et al., 2009). These range from coastal lagoons, estuaries, coral reefs, sea grass meadows, among others. Altogether, these natural coastal habitats are termed, coastal ecosystems. Among these, coastal lagoons constitute about 13 percent of coastal regions, globally, ranging in area from less than 0.01 $km^2$ to over 10,000 $km^2$, and typically over 5 m deep with respect to depth (Kjerfve, 1994). This relative shallowness in the depth is highly influenced by the dynamics of rainfall and evaporation that causes fluctuations in the temperature of water, and salinity.

They are usually oriented parallel to the coastline, separated from the ocean by a barrier of sand and possess one or more restricted inlets as connection with the nearby ocean, that intermittently open. Depending on hydrologic balance present, Pérez-Ruzafa et al. (2010) described coastal lagoons as transitional systems that may be found subject to tidal mixing with varying salinities, ranging from that of a coastal fresh-water lake to a hypersaline lagoon. They often present relatively high primary and secondary production rates, with surroundings that represent attractive sites that propels human development and various exploitation for e.g. fisheries, aquaculture, recreation and tourism (Anthony et al., 2009). Ecologically, they are involved in the maintenance of exceptionally high levels of biological productivity, exportation of nutrients and organic materials to connecting waters through tidal circulation and serving the needs of migratory species requiring shallow, protected habitats for breeding and nursing their young.

Dugan (1990) confirmed that coastal lagoons and other vegetation around them function to improve the evaporation and transpiration processes, contributing to the stabilization of climate of surrounding areas. In other cases, vegetation such as mangrove and forested wetlands serve as windbreaks and help dissipate the force and impact of coastal storm surges. However, coastal lagoons are fragile ecosystems and highly susceptible and stressed by anthropogenic inputs and pollution from industrial, municipal and agricultural runoff as well as natural threats of climate change and global warming (Armah et al., 2010). According to Kennish & Paerl, (2010), the ecology of coastal water bodies, especially lagoons and estuaries has been a major topic of discussion, in the context of biodiversity preservation, water management and human dependence.

Generally, coastal ecosystems remain under threat by the activities of man (Showqi et al., 2014). Land usage has changed numerous wetlands in the quest for urban development and other exploits to suit human interest. For example, urban compaction and petrifaction of the grounds surrounding rivers have caused irreversible changes to the hydrology of most rivers with consequent accelerated water discharge to the sea and associated flooding (Showqi et al., 2014).

In coastal ecosystems, especially estuaries and lagoons the world over, land use has caused drastic habitat loss, regarded as the most important threat, strongly connected to increasing population (Mushtaq & Pandey, 2014). Habitat destruction, typically the conversion of natural habitats in commercially exploitable fish and shrimp ponds has negative ecological consequences such as biodiversity losses, malfunctioning of the coastal ecosystems due to excessive discharges of sewage water and accompanied eutrophication and oxygen reduction and depletion in water and sediment. Other documented threats to coastal water resources known are overfishing and chemical pollution of surface water with constant increment in concentrations of heavy metals, organic toxicants and acidifying substances that largely affect biodiversity numbers in their natural ecosystems (Kennish, 2002).

Malmqvist & Rundle (2002) proposed projections of the entire net increase of global population by 2025 to take place in urban areas in developing countries with predictions that almost 60 percent of the population will reside in cities, mostly coastal areas especially to Africa and Asia. Following this, many of these threats to coastal waters are expected in the future in the absence of strong formidable policies (Mushtaq & Pandey, 2014). Remote Sensing (RS) has been suggested as one of the main techniques to combat the degradation of coastal ecosystems in recent years (Duan et al., 2013). Revelations from Yang (1996) and Mass (1999) proved the need for RS to be used to overcome the complications of large spatial water quality monitoring of coastal waters whiles several Land Use and Land Cover studies of coastal water bodies have been done in the past (Coskun et al., 2008).

**Problem Statement**

According to deGraft-Johnson et al. (2010), there are about ninety coastal lagoons documented along the 550km coastline of Ghana. These lagoons range from brackish to freshwater types and are fringed by mostly intertidal mud and mangrove swamps (Yankson & Obodai, 1999). Lagoons in

Ghana are traditionally useful in terms of their cultural and environmental values (Dankwa et al., 2016). In addition, they are local fishing grounds for surrounding communities and support the livelihoods of inhabitants, largely. Most coastal wetlands in Ghana are known centers for economic activities, e.g., salt extraction, fishing, mangrove harvesting, transportation and hub for tourist sites.

Despite the myriad of valuable economic and ecosystem services, coastal lagoons deliver in Ghana, they are threatened anthropogenically and naturally (Klake et al., 2012). In Ghana, large amounts of untreated domestic and industrial waste are emptied into surface drains, which end up in lagoons, disrupting natural ecology (Klake et al., 2012). Some lagoons in Ghana, particularly Korle and Fosu are regarded as polluted (Armah et al., 2010), with some portions described to be 'dead zones' with anoxic bottom water. According to Klake et al. (2012), heavy metal deposits through anthropogenic sources could increase their concentrations in these lagoons and possibly in fish, posing health hazards to consumers due to their non-degradable nature. In addition, many coastal lagoons in Ghana have a high variability of aquatic nutrients linked to the strong influence of terrestrial effluence input, sedimentary releases from sediment resuspension and local biological products.

Existing literature reveals that one major deteriorating factor found within large area coastal watersheds is rapid development from industrialization and urbanization, which have occurred in the past few decades (Huang et al., 2013). For example, high population growth and associated anthropogenic exploitation are threatening most coastal wetland ecosystems along the coast of Ghana (Armah et al., 2012). Some of these sites have been exposed to pressures of excessive human activity, such as estate development and uncontrolled exploitation of ground water in the basins (Ansa-Asare, 2001). In addition, many coastal areas with substantial amounts of vegetation and forests e.g., mangrove swamps have been transformed into bare lands after consistent harvest (Mensah, 2013). This has led to consequences such as natural resource depletion, environmental degradation and loss of habitats and biodiversity.

**Justification**

In the past, widespread evidence of water quality, including physical, chemical and biological characteristics, were traditionally determined by collecting field samples and later analyses in the laboratory. According to Duan et al. (2013), these methods offered relative data accuracy where inferences made were satisfactory. However, the main disadvantage was that it consumed labour and time, therefore not feasible to providing simultaneous water quality database, especially for a regional or global scale (Dewidar & Khedr, 2005). According to Duan et al. (2013), their research demanded more time for data collection from the field, which required several calibration tests at the laboratory. In addition, the authors were not readily able to recognize spatial and temporal water quality fluctuations that were crucial for the comprehensive assessment and management of water bodies. Previously, ecological studies to retrieve water quality parameters of coastal waterbodies within the catchment of large watersheds and associated Land-Use/Land-Cover (LU/LC) were achieved, taking data in areas within or around the study area (Dewidar & Khedr, 2005). This made regular monitoring and management of coastal area watersheds difficult to attain, considering the spatial inaccessibility to certain locations of study areas and the unavailability to make temporal data comparisons (Yang, 1996). Over the years, many researchers e.g., Hadjimitsis & Clayton (2009) and Duan et al. (2013) have acknowledged ecological studies from field estimations as a major drawback in research, especially in the face of ever-increasing anthropogenic pressure on coastal waterbodies and its associated negative ecological consequences.

According to Mróz et al. (2010), remote sensing is an advantageous approach, which operates according to the "three-M" approach, namely Mapping, Monitoring and Modeling under the context of environmental management. Various sensors mounted on different satellites and Unmanned Aerial Vehicles (UAVs) measure radiation at various wavelengths reflected from the surface of the earth (Mass, 1999). For instance, reflectance values of different water quality parameters could be ascertained from coastal water bodies using these sensors. Following this, different parameters e.g., total suspended solids (TSS), chlorophyll-a concentration (Chl-a), turbidity, salinity, temperature and hydrogen ion concentration (pH) can be retrieved (Gholizadeh et al., 2016). A study by Saenz et al. (2015), hinted on a range of studies that proved the potential to find equations for estimating concentrations of pollutants based on reflectance values measured by sensors of various satellite images to detect changes in various time slots and conditions. The author further added that, even though the need for RS data is required to progressively ascertain algorithms and regression relationships for specific water bodies, subsequent studies exclusive to these water bodies may not rely on these algorithms to make certain predictions for the future as such studies are exclusive for a particular time.

In the case of LU/LC change, described as the conversion of different land use types, because of the complex interactions between humans and the physical environment Pielke et al. (2011), RS is useful. Imagery from satellite and UAV have been used to do change detection analysis for various land use types in different jurisdictions of the world, at a relatively fast rate (Mallupattu & Sreenivasula-Reddy, 2013). Their capability for repetitive coverage and mapping of subtle changes of land cover and its associated usage pose a good advantage. Generally, LU/LC change is an ecologically important process for monitoring and managing large coastal watershed because it provides quantitative analysis of the different land covers and their usage in the area of interest with time (Coskun et al., 2008). This also indicates possible source of pollution and their channels into coastal waterbodies e.g., lagoons and estuaries. Additional information on social perspectives may be included to validate RS data and significantly fill in for certain areas where sensors may not relay vivid information (Mensah, 2013). This is also critical as it reveals other information from the perspective of the people. Ecologically, the need for a combination of both approaches facilitates an effective, frequent and a synoptically characterization and monitoring of large coastal watersheds and provide coverage across several spatial resolutions, at regular temporal frequencies, to facilitate monitoring of coastal environments (Mishra & Gould, 2016).

Existing literature proposes that lagoons in Ghana have been studied a lot in the past, with emphasis on the monitoring of pollution and the possible restoration to keep them thriving (Armah et al., 2010). Following immense anthropogenic activities that occur around the Kpeshie lagoon, Apau et al. (2012) assessed its water quality parameters by identifying physical and chemical characteristics of the water. While other works by Mensah (2013) & Yevugah (2017), and Addae & Oppelt (2019) gave insight on the past and current states of coastal watersheds and the relative differences in their trends over the years using satellite data, there still exist gaps to be filled within time. Currently, data gaps regarding the trends of large coastal watersheds have not been filled with only scanty data available for a few areas such as the Amanzule wetland in the Western Region (Mensah, 2013) and the Greater Accra Metropolitan Assembly (Addae & Oppelt, 2019).

To date, assessment of lagoons using geophysical elements such as the use of remote sensors to ascertain physico-chemical parameters of coastal lagoons as well as track the land cover and usage of their watersheds have not been studied in Ghana. The amount of remotely sensed data of coastal waters is still insufficient in the integration of coastal management decisions. This is a disadvantage, comparing to developed countries where the use of remote sensing for research is highly exploited. Tockner & Stanford, (2002), backed this assertion by stating that long-term RS data is lacking largely for underdeveloped countries as compared to developed states. According to the authors, factors ranging from lack of funds, logistics and technical expertise and means to go about gathering remotely sensed data were listed as the lagging differences between developed and undeveloped states.

Hitherto, application of RS technology in assessing coastal ecosystems is still in its nascent stages in Ghana, and therefore requires in-depth research to fully harness its potential to support coastal zone managers and other key stakeholders to combat the myriad of threats that are destroying coastal resources and guide them to make proper management decisions for the future.

The present situation therefore encompasses a strong motivation to perform ecological research in a more relatively faster approach as the basis for the restoration of already degraded lagoons and future biodiversity management.

**Research Objectives**

The aim of this study is to investigate the applicability of remote sensing to study aspects of the ecology of the Fosu Lagoon and its watershed.

The specific objectives of the study are to:

i. map the spatial extents for various Land-Use/Land-Cover of Fosu lagoon watershed for 1991, 2007 and 2018.

ii. estimate the magnitude of spatial changes for the respective Land-Use/Land-Cover classes.

iii. estimate empirical relationships between WV-2 satellite reflectance and in-situ data for several water quality parameters

iv. investigate existent conditions about the lagoon using a social approach.

**Significance of the Study**

The research shall present results to reflect the prevailing conditions as well as identify underlying land cover changes of the Fosu Lagoon watershed from remote sensing and social perspectives. The results may be useful to stakeholders, widely for spatial planning purposes, proper watershed management, potential livelihood support and land use zoning. Data provided from geospatial satellite imagery and data from in-situ physico-chemical parameters shall provide the necessary baseline knowledge for future possible monitoring of the lagoon using GIS. Land-use/land-cover data shall present current spatial knowledge of the lagoon and its watershed, relative to the past. Following the general results of this study, and proper implementations of the recommendations, the lagoon may be given a good outlook in terms of its current ecology, potential restoration and support for livelihood.

**Delimitations**

The scope within which this study was conducted is relatively wide. The area of the Fosu Lagoon and its watershed were covered not excluding surrounding environments of interest. Temporal considerations were not left out. Following this, changes in the spatial coverages of the five land classes, of which the lagoon formed a part, was ascertained, for twenty-seven years period. Landsat satellite data for the years 1991, 2007 and 2018 were used. The study also incorporated the views of respondents whose livelihoods or residential status affects the lagoon one way or another. Other ancillary data used during this work were google earth and WorldView-2 satellite.

**Limitations**

One main limitation to this work as far as data is concerned is the relatively coarse resolution Landsat data presented for area like the watershed of the Fosu lagoon. From literature, free satellite imagery, typically, Landsat is widely known to present appropriate spatial and temporal resolutions for large area watersheds and even Case I and II waters. However, management of data presented satisfactory maps with moderate accuracies that validated them. Secondly, possible projections of LU/LC changes of the watershed for the future (10 or 20 years) time could not be estimated using the several models e.g., Markov Chain Models as used in Addae and Oppelt (2019). Finally, due to the usage of secondary in-situ data, the nine in-situ sampled points from the lagoon could not present a true reflection of the entire lagoon as interpolation to create maps for the water quality parameters were not possible.

**Definition of Terms**

This section provides the operational definition of terms as used in this study.

**Land-Use/Land-Cover Classification**: The categorization of human activities and natural elements on the landscape for a specific period based on accepted scientific and statistical methods of analysis.

**Remote Sensing**: Data collection from an object, event or phenomenon without an intimate contact with the sensor.

**Geographic Information Systems**: A framework for gathering, managing, and analyzing data geospatial.

**Water Quality Parameters**: The chemical, physical, and biological properties of water that may be tested or monitored.

**Region of Interest**: Specific points of emphasis needed for data collection and analysis

**Organization of Study**

The thesis is organized into six different chapters. The first chapter introduces the study, and emphasizes the purpose and objectives. Chapter two provides an in-depth review of relevant researches from books, journals and other online sources that is aligned to the research objectives. Chapter three outlines details of data collection procedure, organization and analysis of data obtained. It covers the various techniques and tools used to collect and analyze data to obtain valid results. Chapter four presents the research findings and analysis obtained through the methodologies already outlined. In chapter five, the results were adequately discussed explicitly in relation to other studies Finally, chapter six outlines a summary of findings, conclusions from the study and recommendations relevant for individuals and stakeholders of the research.

# CHAPTER TWO

# LITERATURE REVIEW

## Introduction

This chapter of the thesis reviews literature of appropriate research obtained through blogs and articles published in journals and books, relevant to the research topic. The subjects covered include the rapid trajectory of remote sensing from its inception to present, the multiple applications globally, as well as the difficulties confronting its usage. Due coverage is given to the concept, data sources, operation as well as data processing. Important water quality parameters e.g., Dissolved Oxygen (DO), salinity, pH and depth are discussed in relation to coastal lagoons. It also describes coastal lagoons and their dynamics, i.e., physical and biological characteristics, threats and restoration strategies.

## Coastal Lagoons

Coastal lagoons as described by Phleger (1969) are shallow bodies of coastal water isolated from the nearby ocean by a sand barrier, connected to it intermittently by one or more restricted inlets, and generally oriented parallel to the shoreline. The most significant feature of a lagoon, according to Kjerfve (1994), is its relation to the open sea, which may be in the form of a direct channel or a stream, under or over a stretch of sand separating it from the ocean. The natural structure, morphological and ecological conditions of the coast is influenced by the nature of the connection existing between the lagoon and nearby sea. In addition, different lagoons, formed in varied ways, interact with their surroundings differently by way of a natural equilibrium and exhibit a range of salinity from fresh water to hypersaline (Kjerfve and Magill, 1989) depending on the local climatic conditions.

**Characteristics of Coastal Lagoons**

Kjervfve (1994) proposed that the formation and maintenance of coastal lagoons is mainly by the processes of sediment transport. The sediment is carried by river waves, currents, winds and tides and accumulates in river and tidal deltas and in marshes and wetlands at which point submerged aquatic vegetation slows down currents. Nichols and Bonn (1994) proposed that this process of sedimentation could eventually fill in lagoons. Lagoon barriers, according to (Bird, 1994) are constantly eroded by wave action and wind on, requiring continuous sediment transport and deposition to maintain. The surface area sizes of coastal lagoons vary greatly from 0.01 to 10,000 $km^2$, with water depth, usually from 1-3 m and less than 5 m, excluding inlet channels and isolated relict holes (Anthony et al., 2009). Kjerfve (1994) noted that coastal lagoons respond differently to different forcing functions they experience such as river input, wind stress, tides, precipitation to evaporation balance and surface heat dynamics. The author added that salinity, water quality and eutrophication in lagoons depend critically on lagoon circulation, dispersal of salt and sediment, movement of water through the ocean canals and flushing times.

**Distribution of Coastal Lagoons**

Lagoons are usually found behind coasts in topographically low regions. Geographically, coastal lagoons exist from the arctic to the tropics, along coastlines with tidal ranges of less than 4 m (Nichols and Bonn, 1994). Covering about 13 percent and 5.5 percent of the earth's surface area and coastlines worldwide respectively, Razinkovas et al. (2008), barrier coasts are usually backed by lagoons and cover a significant portion of the world's combined continental coastline. Globally, they are distributed in continental basis as 17.6% for North America, 12.2% for South America, 5.3% for Europe, 17.9% for Africa, 13.8% for Asia and 11.4% for Australia (Kjervfe, 1994).

**Classification of Coastal Lagoons**

Coastal lagoons may be classified under the geomorphic nature following their water exchange with the nearby ocean (Kjervfe, 1994). Under this consideration, the rate and of the exchange reflects both the dominant forcing function and the time-scale of hydrologic variability. They are therefore chocked, restricted and leaky lagoons respectively.

**Chocked Lagoons**

According to Kjervfe (1994), chocked lagoons are more predominant along coasts with increased wave energy, consisting of a series of connected elliptical cells, connected by a single and long narrow entrance, along coasts with a high wave energy. In chocked lagoons, tidal oscillations are often reduced to about 5 percent or less relative to the nearby ocean tide. Flushing period is long accompanied by occasional stratification caused by extreme solar radiation or events of runoff. Chocked lagoons mostly lie parallel to the shore and occasionally oriented shore-normal.

**Restricted Lagoons**

Kennish and Paerl (2010) described restricted lagoons as large bodies of water, usually parallel to the coast and features dual or multiple inlets. The tidal circulation, wind influence, vertical mixing and wide salinity range from brackish water to oceanic salinities are well defined for restricted lagoons. Unlike chocked lagoons, they have a relatively, shorter flushing time.

**Leaky Lagoons**

Leaky lagoons have several entrance channels to the ocean with sufficiently strong tidal currents to overcome wave action tendencies and littoral drift that may block channel entrances (Kjerfve, 1994). Following the wide tidal passes of leaky lagoons, water exchange with the ocean is significant with strong tidal currents, and salinity close to that of the nearby ocean.

**Closed and Open Lagoons**

As reported by Ansa-Asare and Asante (2005), two types of lagoons are mentioned to fringe the West African Coast. Often referred to as an estuary is the open lagoon, other than which we have the closed lagoon. Due to heavy rainfall, persistent in the western coastline of Ghana, open lagoons are mostly predominant in the area, where it has sufficient volume of water at all seasons to maintain an outflow of water from the mouth of lagoon into the sea (Yankson & Obodai, 1999). Inland rivers and streams, on the contrary, seasonally feed closed lagoons even though the sand barrier that separates them from the sea may be breached, anthropogenically during the rainy season to allow water to exit the lagoon to the nearby ocean to prevent flooding. Closed lagoons are however, more existing along the eastern coastline of Ghana.

**Importance of Lagoons**

Lagoons, being unique with specific ecological conditions, (Nixon, 1982) have been significant to fishing, recreation, transport, and industrial activities (Miththapala, 2013). However, modern industrialization and climate change have subjected them to immense pressure (Anthony et al., 2009). The hydrodynamic nature of coastal lagoons is ideal and highly sensitive. According to Ntiamoa-Badu (1991), their structure embodies all the components of natural life in complete harmony, making it inherent to understand and properly classify the human influences that affect them, without disturbing the ecological balance.

**Ecological Importance**

Lagoons have significant value in terms of the ecological system (Ugurlu et al., 2008). Through the process of photosynthesis, green plants, algae and other phytoplankton, absorb carbon dioxide from air and water to build organic compounds used as energy by other living organisms. This forms the basis of a suitable environment for planktons, the organisms that feed on plankton and the fish that feed on those organisms, depending on the diversity of the organic materials (Ning et al., 2003).

They are also ideal location for birds providing water, reeds, fish and natural sedimentary organic (Ntiamoa-Baidu, 1991). According to Bellio and Kingsford (2013), lagoon systems serve as vital habitats for migratory shorebirds, hosting them during their period of migration. They serve as breeding and nursery grounds for many important fin and shellfishes (Samarakoon & Samarawickrama, 2012). Typically, many finfish and shellfish breed in the constant hypersaline the sea due to lack of adaptability to salinity fluctuation in lagoons. The juveniles later enter nearby coastal lagoons and estuaries with calmer conditions, food and refuge. To complete the life cycles, the adults later exit the lagoon before starting their reproduction.

**Economic Value**

Lagoons provide goods for human use (Samarakoon and Samarawickrama, 2012). They are important in the sustenance of coastal fisheries. Many edible shellfish and finfish exist in lagoons and their associated habitats such as estuaries and mangroves (Apau et al., 2012). The relatively calm habitats of lagoons permit the practice of artisanal fisheries and support the livelihoods of a huge number of people (Bjork et al., 2008). According to Nixon (1982), the yield of lagoon fisheries per unit area may be high or higher relative to the most productive offshore fisheries. Lagoons serve as points for local artisanal fishermen to anchor their boats. Samarakoon and Samarawickrama, (2012) mentioned that several old cities are situated by lagoons and estuaries where they provide safe ports for boats and small ships. Lagoons are critical sites for coastal cage culture practice. Most shallow lagoons support hanged cages at specific points, ensuring survival of variety of fin and shellfishes that are sold either for economic gains or for food.

**Regulatory Services**

Most lagoons and associated coastal habitats absorb the energy from storms and offer flood protection and drainage (Ning et al., 2003). Existing between land and nearby sea, water bodies of lagoons and estuaries function like buffer zones, and protect coastal communities from the full force of weather-related events, e.g. Storm surges, floods and cyclones. This is done through damping wave action, dissipating river discharge and temporal water storage (Kennish and Paerl, 2010). Lagoons and estuaries function like gigantic sponges to absorb excess water during flooding and later drain it to the nearby sea. As regulatory bodies, lagoons in addition trap sediments and filter water

(Ning et al., 2003). The range of habitats, usually found around lagoons e.g., mangroves and salt marshes function as large filters that extract pollutants, excess nutrients and sediments carried from households and industrial wastewater (Samarakoon & Samarawickrama, 2012).

**Socio-Cultural Value**

Coastal water bodies, including lagoons and estuaries are historically significant Ntiamoa-Baidu (1991). Humans have lived along the banks of lagoons and near estuaries due to the presence of nutrient-rich, easily cultivable soils among other substantial contributions. Globally, coastal lagoons present the environment for boating, recreational fishing, swimming and other water sports such as jet skiing and surfing, including bird watching (Anthony et al., 2009).

**Threats**

A number of factors, e.g., tides, morphological changes, sedimentation, wind, waves, water flow and pollution among others affect coastal lagoons (Ozturk & Sesli, 2015). Mostly, morphological changes in lagoons occur because of erosion of the lagoon coasts. Activities, such as excessive construction, dredging for sand, land reclamation and urban, industrial and agricultural waste discharge, cause morphological changes and disturb the balance of the lagoon system (Miththapala, 2013). Kennish & Pearl (2010) hinted the vulnerability of coastal lagoons to anthropogenic activities with rendering them currently as one of the world's most affected aquatic ecosystems on planet, earth. Both human influence and naturally occurring events affect coastal lagoons. Comparing both, anthropogenic stressors have received the greater attention relative to natural influences, mostly linked to increasing population growth and exploitation of the coastal zone (Ozturk & Sesli, 2015). Natural phenomena on the contrary occurs less frequently, with typical examples being effects of global warming and climate change, e.g., El-Niño Southern Oscillation (ENSO) (Paerl et al., 2006).

**Anthropogenic Threats**

Man, and his activities in various forms subject lagoons to several compromises. The functioning and conservation of the biodiversity of lagoons have been put at risk by environmental stressors such as eutrophication, contamination from chemical and physical pollutants, pesticides, and heavy metals, the intrusion of non-indigenous species, over exploitation, and artificial sandbar breach (Samarakoon & Samarawickrama, 2012). Kennish and Paerl (2010) categorized anthropogenic stressors into three groups, that is, habitat degradation, water quality compromise and alteration of biotic communities. Stressors that degrade habitat are mostly physical e.g., dredging and shoreline modification. Nutrient enrichment, organic carbon loading, pathogens, heavy metals, and other chemical contaminants make up examples for water quality compromise while biotic stressors include overfishing and introduction of invasive species.

Pollution from both point and non-point sources that influence changes in water quality is a major anthropogenic threat to coastal lagoons (Rowe & Barnes, 1994). Whereas point source of pollution emerges at a particular location, non-point sources affect environments in a dispersed way through multiple sources. According to Cowardin et al. (1979), some fin and shell fish farms discharge effluents, rich in both nutrients and sediments, into the environment. Many shrimp farmers add synthetic feeds, including chlorine and organochloride, with chemical additives that remain in the environment. In addition, their effluent treatment and disposal procedures are not effective and end up in surrounding land and upstream rivers. Many non-point sources of pollution add large quantities of nitrogen and phosphorus deposited through agricultural runoff, and contributes to eutrophication Gamito et al. (2005), i.e., the state of over-enrichment of nutrients in water, where the excess result in rapid growth and increase in phytoplankton in water. This rapid growth of nutrients may result in high biomass appearing as a mat on the water surface, preventing sunlight from reaching lower layers of water and inhibiting photosynthesis. Submerged aquatic flora remain in darkness, while the fauna in the body of water tend to use the available oxygen for respiring, leading to reduction and loss of oxygen.

Heavy metals e.g., such as lead and mercury, organochlorides and polycyclic aromatic hydrocarbon (PAH) are industrial contaminants that may reach coastal lagoons (Kennish, 2002). Bioaccumulation and bio magnification becomes the result of such discharge. Bioaccumulation is the process by which an environmental contaminant increases in concentration when it moves from the environment into an organism whereas bio magnification occurs when the concentration of a contaminant steadily increases as it passes along the levels of a food chain Kennish & Paerl (2010). According to Klake et al. (2012), both processes are lethal for human health through poisoning from ingested fish or seafood, contaminated by these chemicals.

Solid waste pollution, another critical threat, is unpleasant to sight and affects the aesthetic value of coastal lagoons. Related to this, Kennish (2002) describes the vulnerability of aquatic organisms in terms of consumption of debris and further entanglement leading to their mortality.

Overexploitation of fisheries resources confronts lagoons critically (Miththapala, 2013). Because of the sheltered nature and open access regime of artisanal fishery of lagoons the world over, it is relatively easier to fish in these waters. Fish is therefore harvested to the extent that the stocks cannot naturally regenerate Beare et al. (2013), i.e., beyond maximum sustainable yield, described as the largest catch that can be harvested from the stock of a species over an indefinite period.

Wetland reclamation for agriculture, aquaculture and infrastructure development results in detrimental changes in water inflows, increased sedimentation and changes in species composition (Kennish & Paerl, 2010). According to Barbier et al. (2011), tourism and recreation is significantly linked to habitat destruction. Propellers and jet skis are emerging as a major threat to benthic organisms in coastal ecosystems e.g., lagoons. Propellers of boats used for either fishing or recreation slash the leaves of seagrasses and other submerged vegetation, destroying them. Establishment of sites and structures for recreational purpose, close to lagoons lead to the encroachment of these areas and cause sedimentation and long-term shrinkage (Barbier et al., 2011).

**Natural Threats**

Coastal lagoons the world over are highly vulnerable to some inevitable natural phenomena such as global warming and climate change. The result of these natural threats are diverse and end up affecting biotic communities and productivity of coastal lagoons (Nicholls et al., 2007).

According to UNEP (2012), climate change is the major, over-riding environmental issue of our time, and the single greatest challenge facing environmental regulators. Global Carbon Dioxide emissions have increased by nearly 80 percent between 1970 and 2004 and by a twelvefold during the last century in the atmosphere. It hinted that, the increase in $CO_2$ and methane ($CO_4$) in the atmosphere together referred to as greenhouse gases cause warming of the earth. During the last century, global temperature increased by about 0.8 Degrees Celsius, measured as the largest increase in a thousand years (Hansen et al., 2006). Following this is associated melting of polar ice, continental glaciers, and sea level rise with increasing temperature (IPCC, 2007). The IPCC predicts a rise in global sea levels between 0.09 to 0.88m, by 2100. The negative consequences of these phenomena in coastal areas are diverse e.g., inundation of low-lying coastal areas, changes in rainfall patterns and extremities in weather events. Changes in temperature increases evaporation, which in turn influence the dynamics of salinity and dissolved oxygen, possibly influencing both flora and fauna in lagoons. Precipitation also alters freshwater inputs and increase sedimentation from upstream (Anthony et al., 2009).

Invasive alien species, described as non-native species that are not confined to the region within which they have been introduced but rather compete with native species, and have the ability to eliminate them are recognized natural threats of coastal waters Miththapala (2008). With the displacement of indigenous species by invasive species and the changes with habitats, ecosystem resources can be disrupted and damaged economically. Aquatic alien plants such as *Eichhorna crassipes, Salvinia molesta* and *Hydrilla verticillato* possess filamentous roots with possibilities of blocking underwater canals (Masifwa et al., 2001). Their leaves form dense mats on the surface, clogging waterways, impeding water traffic and preventing fishing (Lu et al., 2007). The results of this surface covering is the prevention of sunlight from reaching submerged plants, with a subsequent drop in the rate of photosynthesis. Advantageously, invasive species can tolerate salinity dynamics and trap sediments among their roots (Masifwa et al., 2001). Aquatic invasive flora can also cause disruption in food webs. Carnivorous invasive fauna may consume naturally existing fauna in lagoons and compete for resources such as nutrients, when herbivorous (Lui et al., 2008).

**Water Quality**

Ecologically, the quality of water is generally described using the physical, chemical, thermal and biological properties (Ritchie et al., 2003). According to Dekker et al. (1996), defining one standard of water quality that meet all uses is difficult as the physical, chemical and biological parameters of water that are suitable for human consumption may be different from those parameters of water for irrigating a crop.

The quality of water may be deteriorated by polluting substances, which negatively affect freshwater and estuarine ecosystems (Dekker et al., 1996) and estimated to cost billions of dollars annually (Pimentel at al., 1995). This reasoning, together with other considerations make the monitoring and assessment of the quality of surface waters a big deal. Following this, water must be tested for different physico-chemical parameters (Dekker et al., 1996). The selection of physico-chemical parameters for water quality test depends on the purpose and extent for which quality and purity are needed (Patil et al., 2012). For instance, Okyere (2019), in investigating the implications of deteriorating environmental conditions of River Pra for marine fish stocks in Ghana adopted about eight different physico-chemical parameters to make conclusive remarks on the water body.

According to Patil et al. (2012), tests for several components of water quality are performed for testing a water body's physical outlook e.g., temperature, color, odor, pH, turbidity, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) while chemical tests should be performed for parameters like Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), alkalinity and hardness. Heavy metal contents and organic residues are considered for obtaining detailed quality and purity of water. Currently, the popular water quality evaluation is in-situ measurements and collection of water samples for subsequent laboratory analyses.

**Dissolved Oxygen**

Measurement of DO is important in determining whether the water system is either aerobic or anaerobic, predicting the survival of aquatic biodiversity, and proving the possibility of aerobic biological processes utilized to transform biodegradable organic contaminants discharged into water (Kibria, 2004). According to Ibanez et al. (2008), DO decreases sharply caused by the actions of aerobic microorganisms that consume oxygen during metabolic degradation of organic matter in organic discharge situations. This parameter is particularly critical in combination with the presence of $CO_2$, for the determination of the corrosive character of water on metals (Dekker et al., 1996).

A number of factors, including water temperature, dissolved salts, atmospheric pressure, suspended matter and living organism regulates dissolved oxygen content in water (Kibria, 2004). In addition, aquatic flora and fauna, contribute to the consumption or production of oxygen in water. In the case for aquatic flora, the photosynthesis facilitates the generation of oxygen in the presence of light, hence the DO dynamics during the day/night cycles and in the different seasons.

Common processes e.g., organic matter discharge from municipal sewage or industrial wastes and runoff from nearby farms influence DO. In areas where there are industries that require cooling of high-end machinery, the release of warm or hot discharges influence DO (Kibria, 2004). All of these direct discharges (Ibanez et al., 2008) may critically affect DO levels and survival of aerobic organisms. Long-term results of these processes are hypoxia or anoxia.

**Hydrogen-ion Concentration (pH)**

The pH of water is a measure of the hydrogen ion concentration, ranked on a scale of 1.0 to 14.0 (Kelly-Addy et al., 2004). This scale of pH may be interpreted as a low value, representing a high pH and vice versa. In an aquatic system, the different chemical and biological processes in water, including the different organisms have different ranges of pH within which they flourish (Das, 1961). The largest variety of aquatic fauna prefer a pH range of 6.5 - 8.0 to thrive. Outside this pH range may result in consequences such as reduction in the diversity in the waterbody due to the stresses it poses on physiological systems of most organisms, and in some cases, reduced reproduction (Das, 1961). Low pH conditions (acidic) may permit mobility of toxic elements and compounds and make them readily available for uptake by aquatic plants and animals (Kelly-Addy et al., 2004).

Kulthanan et al. (2013) hinted that, technically, the pH scale measures the logarithmic concentration of hydrogen (H+) and hydroxide (OH-) ions, whose combination make up water ($H_2O$). In relatively equal concentration for both ions, the pH is 7.0 (neutral). Alternatively, a pH below 7 is acidic, which means that there are more hydrogen ions than hydroxide ions and vice versa for hydroxide ions and its corresponding increase in concentration, suggesting alkalinity.

**Total Dissolved Salts (TDS)**

According to Sluiter et al. (2008), dissolved solids may be minerals, salts, metals, cations or anions dissolved in water. TDS may comprise inorganic salts e.g. calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates and trace amounts of organic matter, dissolved in water. According to Weber-Scannell & Duffy (2007), the concentration of TDS is the sum of the cations and anions originating from sources, such as sewage, urban run-off and industrial wastewater.

The test for TDS according to Weber-Scannell & Duffy (2007) is known to provide a qualitative measure of the amount of dissolved ions but may not tell the relationship between the ions. In addition, the test does not provide insight into the specific water quality issues, such as increased hardness, salinity or corrosiveness but rather used as an indicator to determine the general quality of the water. Therefore, increased TDS concentration may not mean that the water is a health hazard, but may have aesthetic problems.

**Turbidity**

The measure of the relative clarity of a liquid may be described as turbidity (Huey & Meyer, 2010). It is described as the optical characteristic of water, which measures the amount of light that is scattered by material in the water when light is shone through it. As a result, a water sample with a higher turbidity tend to scatter more light and vice versa. Turbid waters may usually contain materials such as clay, silt, very tiny inorganic and organic matter, algae, dissolved colored organic compound, plankton and other microscopic organisms (Allen et al., 2008). High concentrations of these materials may affect firstly, light penetration and ecological productivity, recreational value, and habitat quality (Gregory, 1985).

**Bathymetry (Depth)**

Lister (2010) described bathymetry as the study of under water depth of lake and ocean floors with a main objective to retrieve an accurate data to produce a nautical chart. Bathymetry data usually produce charts that show seafloor terrain as contour lines of depth, and provide surface navigational information for future studies (Chukwu & Badejo, 2015). According to the authors, bathymetric monitoring and resurvey gives room for reliability of determination of sediment transport pathways, magnitude of sediment transport estimates and validity of sediment budget estimates. Depth estimations for water bodies are important for many purposes e.g., sedimentation to check for accretion or erosion and dynamics of bathymetry before and after dredging to determine the existing status of the water body to ascertain the dredged volume. Prior to pipeline and cable laying, fishing, aquaculture and other geophysical exploration exercise, bathymetry data is critical (Arzu, 2004)

**Remote Sensing**

Remote Sensing is the acquisition of spectral, spatial and temporal information from any place, object or phenomenon without physical contact to it Joseph (2005). The American Society for Photogrammetry and Remote Sensing (ASPRS) as quoted by Colwell et al. (1983), defined it as the measurement or acquisition of information of some property of an object or phenomenon, by a recording sensor that is not in contact with the object or phenomenon under study. These sensors are advanced in information gathering without physical contact and often times positioned at distances, very far from the object of interest on several platforms such as helicopters, airplanes, and satellites (Awange & Kiema, 2013). The basic operating mode of RS is the measurement of the electromagnetic energy transmission from reflecting and radiating surfaces by sensing and recording the data (Colwell et al., 1983).

As a rule, RS studies require ancillary data to allow imagery interpretation (Joseph, 2005). On ground sampling, familiarity with Land-Use/Land-Cover of area under study, and knowledge of species trends and habitat usage, ecological communities and systems may be needed to form a solid basis for interpretation. While RS enable the earth's surface to be observed repeatedly, it has limited thematic, spatial and temporal resolutions (Strand, 2007). Therefore, field sampling fills the gap for the detailed, local biological information for small areas, even though it can be expensive. While field surveys, are said to be hindering in terms of accuracy, RS technique increases the speed and frequency with which one can analyze a landscape (Strand, 2007). Therefore, RS contributes to the development of objective and comprehensive assessments over larger geographic extents than is impossible with fieldwork alone (Moshen et al., 2018). However, Strand (2007) mentioned that combining both strategic ground sampling and knowledge and analysis of RS could provide a credible, repeatable and cost-effective analytical tool for accurate assessment of change in study areas.

**Science of Remote Sensing**

This basis of the science of RS is information transfer without direct contact with the object, site or phenomenon under investigation (Joseph, 2005). However, there is utilization of information transfer via space, allowing it to function. The medium through which remote sensing operates is called Electromagnetic Radiation (EMR), defined by Awange & Kiemah (2013) as a form of energy which reveals its existence by the measurable effects it produces when it hits matter. However, media, such as gravity or magnetic field, can be used in RS. The range of EMR spans across shorter to longer wavelengths, that is, from gamma and x-rays to microwaves and radio waves respectively. However, only a part of this large EMR enables RS to work, mostly the shortest wavelength area and the ultraviolet (UV) array. Other literature, Graham (1999), suggests a three regional system for wavelengths within which RS functions, which include visible and reflective infrared RS, thermal infrared RS and microwave RS. This suggests that the EMR appears as either visible or not, relative to which sensor is, under consideration. The visible portions of EMR is said to be smaller relative to the non-visible portions, in which case the human eye cannot visualize some radiations as there are (Baumann, 2009). Some other remote sensors however, detect the invisible portions, advantageously. The visible wavelengths cover a range from approximately 0.4 to 0.7 µm, with the longest and shortest wavelengths being the red and violet respectively (Graham, 1999).

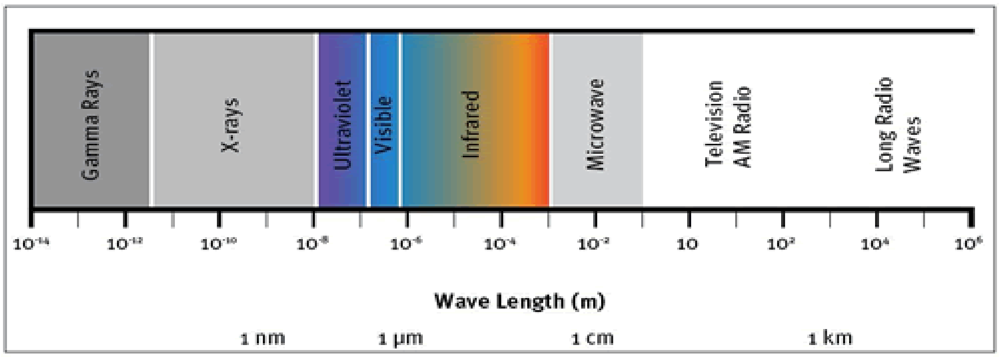


*Figure 1:* Range of Electromagnetic Radiation showing wavelength values (Graham, 1999)

The concept of RS may be split into two broad categories based on the type of energy and the scope of electromagnetic spectrum (Colwell et al., 1983). Under the former, exists passive and active sensors. Whereas passive sensors detect reflected electromagnetic radiation from natural sources e.g., sunlight, active sensors detect reflections from objects that are irradiated from artificially generated energy sources e.g., RADAR and LiDAR. In passive RS, Lugari (2014) hints that the sun's energy is either reflected, as it is for visible wavelength or absorbed and then re-emitted for thermal infrared wavelength. On the contrary, active sensors are capable of data acquisition at any time of the day irrespective of light availability. Under the range of electromagnetic spectrum, there are the optical, thermal and microwave RS. As the name suggests, sensors of optical RS operate in the visible, near infrared, middle infrared and short-wave infrared portion of the electromagnetic spectrum and are sensitive to the wavelength range of 300nm to 3000nm. EMR of most RS are recorded within this range. Thermal RS devices operate within two RS ranges, 3000nm to 5000nm and 8000nm to 14000nm respectively. Whiles both are known to deal with high temperature phenomenon, the former is related to high temperature situations like forest fire whiles the latter deals with general earth features having lower temperatures (Awange & Kiemah, 2013). With microwave RS, Samvedan (2007) interprets, how they record backscattered microwaves in the wavelength range of 1 mm to 1 m of the electromagnetic spectrum. Further, they have a significant advantage over other sensors since they are independent of weather and solar variations and as such are active sensors.

Widely known, RS science involves using sensors, mounted on several platforms, which are fixed at distances away from the earth surface with series of repetitive observations and recordings on a suitable medium (Awange & Kiemah, 2013). As such, EMR travels through a distance in the earth's atmosphere before it hits the surface. Particles and gases in the atmosphere influence this radiation either by scattering or absorption, and the rest of the radiation reflected. Other surfaces, also naturally emit radiation, in the form of heat, which is subsequently recorded on a digital sensor.

The three phases to be considered in this system are the interaction and interdependence between the primary sources of electromagnetic energy, the atmospheric windows through which the energy source can be transmitted to and from the earth's surface features, and the spectral sensitivity of the sensors required to detect and record the energy (Hussein et al., 2018). Therefore, the intensity and wavelength of a radiation are a function of the surface in question where each surface processes its own characteristic spectral signature. This means, the capability of a sensor to identify and distinguish between different spectral signatures gives it the ability to identify and map the objects and surfaces of the earth using RS.

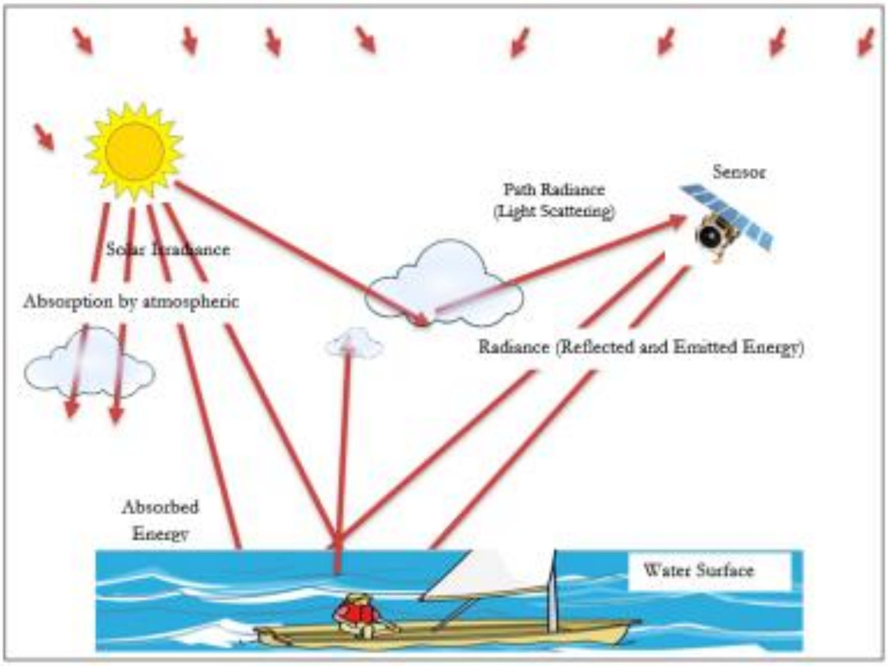


*Figure 2:* A schematic illustration of RS sun-sensor pathway (Graham, 1999)

**Remote Sensing in Coastal Environment**

In recent times, RS application in multiple coastal ecosystems have gained a lot of attention (Strand, 2007). According to Jensen (2007), RS data has been used successfully to forecast weather and monitor hurricanes, observe coastal patterns, detect pollutants, map coastal zones, agricultural and urban areas. The basis for the protection of coastal ecosystems, according to Klemas (2009), is the need to monitor the biophysical features and characteristics and major controlling processes at relatively high resolutions. Either satellite or airborne sensors can potentially achieve this. The sensors minimize the need for extensive field measurements by mapping these features and processes over large spatial scales and resolutions (Ramachandran et al., 2000). Satellite RS is commonly used as a management and protection tool in many parts of the world, safeguarding corals, shorelines, mangroves and nutrient-rich waters connected to major coastal zones (Jensen, 2007).

In addition, Klemas (2009) stated that a good correlation exists between known coastal watershed models and consequent LU/LC models due to their usage as input data. Appropriate predictions can be made about the amount and type of run-off into rivers and estuaries using these models together with a few other inputs like slope and precipitation. However, successful usage of these known models may require some physical data to do some calibrations and validations (Hadjimitsis & Clayton, 2009).

**Change Detection**

The concept of change detection is the identification of differences in the state of an object or phenomenon by observing it at different times (Bruzzone & Prieto, 2002). According to Othman et al. (2014), it involves the ability to quantify temporal effects using multi-temporal datasets. As stated by Lambin & Strahler (1994), the five categories of causes known to influence change on the earth surface are, long-term natural climate changes, geomorphological and ecological processes, human-induced alterations of watersheds and landscapes and the greenhouse effect caused by human activities.

**Land-Use/Land-Cover Change**

According to Alam et al. (2019), land use and land cover are transposable terms that are mostly used with different connotations in land change science. While land use was described by (Lo, 1986) as the human activities that occur on land, land cover was described by Burley (1961) as mainly the vegetation and artificial constructions covering the land surface. Alam et al. (2019) described land use and land cover, together, as an important element of the landscape, with direct and indirect links with varied geophysical and socioeconomic processes. The controlling factor of rapidness and pattern in LU/LC change by humans depend on their social, economic, and political characteristics (Addae & Oppelt, 2019). According to Lesschen et al. (2005), this change is the complete replacement of one cover type by another, mainly, due to anthropogenic factors. During LU/LC change studies, information regarding where change is occurring, what land cover types are changing, the types of transformation occurring, the rates of land change, and the driving forces and proximate causes of change are estimated (Loveland and Acevedo, 2006). In addition, what would be the future change patterns of the LU/LC, derived through simulation modelling can be predicted (Alam et al., 2019).

As stated by Alam et al. (2019), LU/LC change has been one of the most immense and perceptible transformations of the earth's surface being one of primary factors responsible for degradation. According to Ringrose et al. (1997), LU/LC, including surface water change in Africa is currently accelerating and causing widespread environmental problems and thus, needs to be mapped. This is important because the changing pattern of LU/LC reflect changing economic and social conditions. Evaluating LU/LC is imperative to overcoming series of environmental issues at local and regional scales, such as unregulated development, loss of agricultural lands, destruction of wetlands, and wildlife habitat (Alam et al., 2019).

Modern technologies such as RS and Geographic Information System (GIS) provide some of the most accurate means of measuring the extent and pattern of changes of earth surface conditions over a period of time (Miller et al., 1998). With particular reference to change detection, the pattern of change, processes of the change and human response to these changes are mainly sought using RS and GIS (Alam et al., 2019)

**Remote Sensing & Water Quality**

According to Gholizadeh et al. (2016), RS technique ensures the possibility to identify and monitor large areas and water bodies, in an effective and efficient manner. In addition, collection of RS data appears in a digital form that is easily readable in computer processing. According to Hadjimitsis & Clayton (2009), RS techniques have been used over the past five decades and continue to be widely used in water quality assessment in the contemporary space.

In the assessment of water quality, important considerations are the spectral characteristics of water and pollutants, which are the functions of the waters' hydrological, biological and chemical characteristics (Klemas, 2009). These spectral properties of water are easily mapped by multispectral and hyperspectral sensors, once they remain in the visible part of the electromagnetic spectrum (Gholizadeh et al., 2016). This way, the amount of radiation at different wavelengths that is reflected from the surface of water is measured by sensors mounted on satellites and drones (Kutser, 2004). The visible and near infrared bands of the electromagnetic spectrum is frequently used by researchers in their exploit to obtain robust relationships between spectral reflections of water and water quality parameters. These reflections are useful to creating interpolation maps for the parameters prior to biological sampling and other useful exploits. However, other parameters such as acidity and pathogens do not alter the spectral properties of reflected light and as a result, have no direct detectable signals to be measured by sensors.

Khattab and Merkel (2014) confirmed the usage of satellite-based approach of RS as an efficient and effective approach to routine lake-water quality assessment and its provision of appropriate methods as compared to the conventional traditional in situ measurements. Sáenz et al. (2015) developed an empirical relationship of TSS concentrations and reflectance values using a quadcopter drones' aerial photos and processed those using RS tools. In the study, a mathematic algorithm for the local micro-watershed of the Teusacá River was developed based on the computation of four bands from its consumed-grade cameras obtained from each of their corresponding reflectance values.

While using satellites to do these estimations are widely known to work successfully, they are accompanied by a few constraints (Gholizadeh et al., 2016). In the usual case, spatial resolutions of most current multispectral satellite imageries are inadequate for trophic mapping of small waterbodies, which cover several hectares. The other, is the temporal gap between effective satellite imaging and in-situ measurements, which is usually a few days or weeks, which may compromise the establishment of regression models between reflectance values (or their band ratios) and water quality parameters (Su & Chou, 2015). In addition, RS technique alone is not sufficient to make precise inferences and must be used in combination with traditional sampling methods (Strand, 2007). According to Kallio (2000), this integration gives a synoptic view of an entire waterbody for a more effective monitoring of the spatial and temporal variation.

**Regression in Remote Sensing**

Regression is used if the aim of a study is estimation of a response variable based on a set of explanatory input variables (Dekker et al., 1996). The author describes regression model development to be based on a set of input variables for which the response is known. The estimated model can then be used to predict responses for test datasets with input variables but no response variable (Dekker et al., 1996).

The science behind the estimation of the best empirical model between reflectance values of remotely sensed devices and concurrent in-situ data as a way to understand the relationship of the water quality parameters is by correlating the spectral brightness, measured by their sensors with several water quality variables that affect a lagoon's optical properties (Nas et al., 2010). These variables together, affect the quality of water and are unique to different respective water bodies. Strong relationships between reflectance collected by remote sensors and standard water quality variables have been proven by several previous studies (Kloiber et al., 2002; Tyler et al., 2006; Nas et al., 2010). Major remote sensors, such as the Landsat series have been used largely to establish the relationships between water quality parameters of inland water bodies and spectral reflectance (Khattab & Merkel., 2014).

The method most often used to demonstrate these unique relationships is regression analysis. The key in regression analysis is to select an appropriate regression method and independent variables that result in a high coefficient of determination ($R^2$) value. A $R^2$ value approaching 1, indicates good correlation between the predicted and measured data (Wang et al., 2011).

# CHAPTER THREE

# METHODOLOGY

## Introduction

This section describes and reviews the processes, methods and apparatus used for data collection and analysis for the research. It outlines the area of study, research layout, population and sampling processes, sample size, research tools, data collection, data processing and analysis used for the study with justifications.

## Study Area

The study was conducted on the Fosu lagoon, a classically closed lagoon (Yankson & Obodai, 1999), whose sand bar is occasionally breached by heavy rainfall or manually as part of celebrations of the 'Fetu' Festival (Dankwa et al., 2016) and its watershed. The lagoon is located within the Cape Coast metropolis, the capital of the Central Region of Ghana. The 2010 Population and Housing Census describes the city as having a population of about 169,894 made up of 82,810 and 87,084 males and females respectively (GSS, 2010). The Fosu lagoon lies along the Atlantic coast, at latitude 5° 06′ N - 5° 07′ N and longitude 1° 15′ W - 1° 16′ W with a surface area of about 97.3 acres and average depth of 1.6 m (Essel et al., 2019). Blooms of algae with remnant areas of mangrove vegetation dominate the land cover of the lagoon catchment (Essel et al., 2019). Temperatures around the lagoon are high, ranging between 25° and 35°C with little variation throughout the year (Gilbert et al., 2006). Two wet seasons exist during the year, which are, April to July and September to November, constituting respectively, the major and minor periods (Yankson & Obodai, 1999). The dry season occurs between December and March during which dry, dusty winds blow from northeast to southwest, thus lowering the relative humidity.

According to Armah et al. (2012), the lagoon is surrounded by many sites that act as point sources for discharge of pollutants i.e., domestic waste discharges, metropolis transport garage and waste discharge from a mechanical workshop as well as drains from a school and a nearby hospital. According to Baffour-Awuah (2014), residential, industrial and commercial structures are still being developed close to the lagoon. Dankwa et al. (2016) hinted that the human activities in the study area is immense and the waste generated from these settlements, industries or institutions are disposed haphazardly, which eventually end up in the lagoon. This has led to massive sedimentation especially in the more populated northern sector with several settlements and an expanded fitting shop. In addition, Gilbert et al. (2006) reported significant concentrations of copper and zinc in the lagoon, especially in areas close to the fitting shop and settlements.

The Fosu lagoon presents an ideal site to carry out this study considering all the anthropogenic pressure, under which it is subjected and the urgent need to drive its restoration. It is a major source of livelihood e.g., fishing and tourism for inhabitants of the Cape Coast town (Dankwa et al., 2016). It plays an important role traditionally, in terms of annual festivities and the religious life of the people. Ecologically, the lagoon provides a habitat for fisheries, feeding and roosting areas for water birds (Essel et al., 2019). Other than anthropogenic influences, the lagoon is naturally threatened by changes in climate resulting in wide fluctuations in water (Armah et al., 2010).

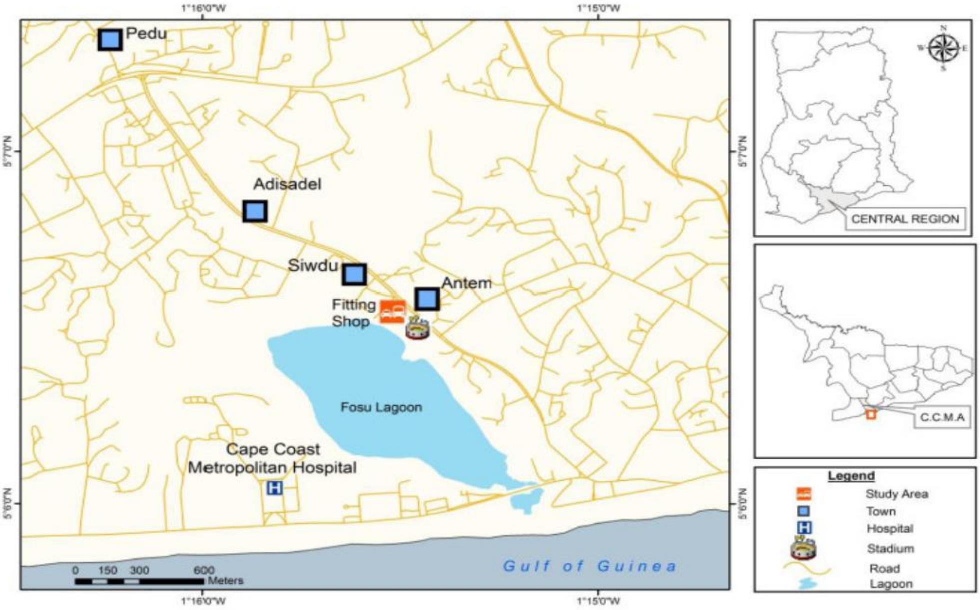


*Figure 3:* Map of Ghana showing Fosu Lagoon and its environs (Arthur & Eshun, 2012).

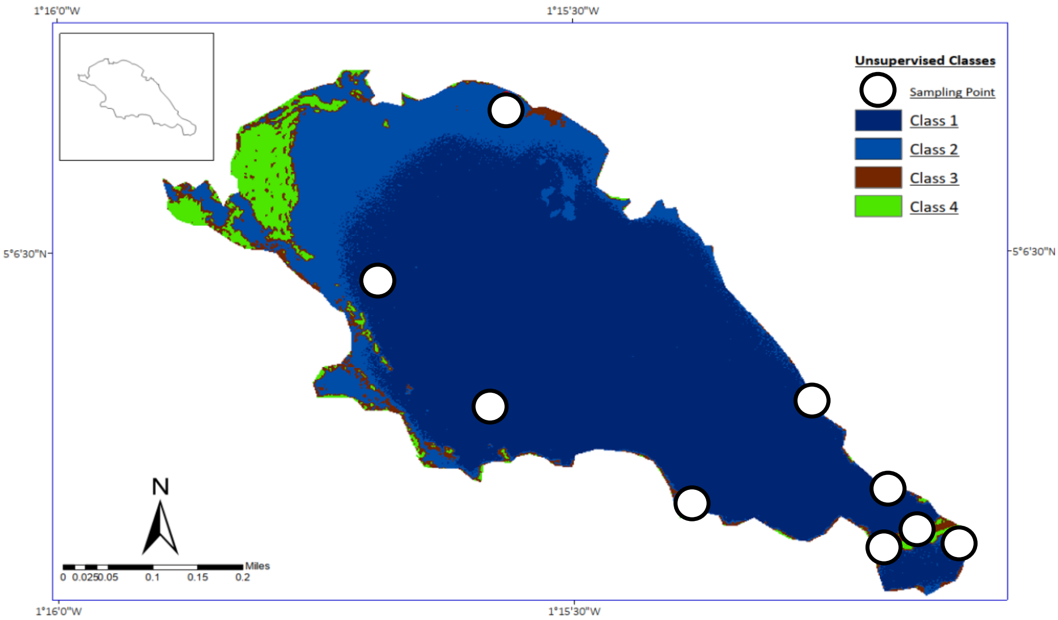


*Figure 4:* Unsupervised classification map showing different spectral water classes of Fosu lagoon and the selected sites for water sampling.

These factors have led to morphological and physiological changes, decreased species diversity and alteration in the fish community structure and composition, which influences negatively on the fisheries of the lagoon (Dankwa et al., 2016).

**Landsat Dataset, Processing and Analysis**

In monitoring LU/LC change for any area, it is imperative to present, at least data of two periods for comparison (Alam et al., 2019). In quantifying the LU/LC changes in any area, RS employs usage of satellite images for two or multiple dates. In this study, the selection of a satellite imagery for LU/LC was made in the light of its compatible spatial resolution (30 m) and past LU/LC analysis compatibility for different areas. Landsat data archive presents ready images consistent with data from the earlier missions that allows assessment of long-term regional and global LU/LC change (Alam, et al., 2019). Three main Landsat datasets were used as primary data for LU/LC mapping of the Fosu Lagoon watershed because of availability of images for an extensive period. These were Landsat 4 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 Operational Land Imagery (OLI). The Landsat 4 was captured on 1 January 1991 and has a spatial resolution of 30 m. The Landsat 7 data was captured on 13 January 2007 and has a spatial resolution of 30 m. Finally, the Landsat 8 OLI data was captured on 3 January 2018 and has a spatial resolution of 30 m with 11 spectral bands. This data was obtained from the United States Geological Survey (USGS) online data portal with further details in Table 1. Other ancillary GIS data such as shape files of the study area and reference data from google earth were used to support the Landsat data used in mapping the LU/LC of the study area. Because of priority placed on obtaining images with less clouds and avoid difference in land cover reflectance due to weather changes, the images were acquired for January, corresponding to the dry season in Ghana (Addae & Oppelt, 2019). The impossibility with maintaining regular year difference between the three Landsat satellite images used in the study was because of the presence of clouds and scan lines on some of the images. All three images were atmospherically corrected using the Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH) tool in the software package ENVI version 5.1. In addition, they were projected into the Universal Traversal Mercator (UTM) Zone 30 North projection.

**Table 1: Characteristics of Landsat data used in the study**

| Landsat | Sensor | Number of Bands | Resolution (m) | Path/Row | Acquisition Date |
|---|---|---|---|---|---|
| 4 | TM | 7 | 30 | 194/056 | 1/1/1991 |
| 7 | ETM+ | 9 | 30 | 194/056 | 13/01/2007 |
| 8 | OLI | 11 | 30 | 194/056 | 03/01/2018 |

**Classification for Land use and land cover**

The LU/LC information is usually obtained from the multiband raster imageries through image interpretation and classification (Li et al., 2014). The authors described image classification, whether supervised or unsupervised, to be intended for an automatic categorization of pixels with a common reflectance range into specific LU/LC class. Supervised classification is a user-guided approach that involves selection of training sites as reference for the categorization (Jensen, 2007). It classifies by grouping pixels into classes by comparing the spectral properties of each pixel to a set of representative pixels, which are known as training data or sample specified by the user. In this study, the supervised classification was adopted. Several methods e.g., parallelepiped classification, K-nearest neighbor, minimum distance classification are available to be used in implementing supervised classification (Li et al., 2014). Out of these methods, maximum likelihood classifier algorithm, which is the most widely, used classification technique Alam et al. (2019), was used in this case for the classification. According to Bolstad & Lillesand (1991), the maximum likelihood algorithm is popular among RS researchers because of its strong theoretical foundation and the ability to accommodate varying data, LU/LC types and satellite system.

In the Arc GIS software, training samples for each land cover type were collected by creating polygons on the features that are representative of each LU/LC type. These random polygons across the image were created in order to capture the spectral variability within each land cover type. Using the researcher's personal knowledge and experience of the study area, as well as Google Earth and topographic maps the training samples were successfully collected. After training samples collection, polygons for each LULC type were converted into Region of Interests (ROI) for classification using the Maximum Likelihood algorithm.

The USGS LU/LC classification system developed by Anderson et al. (1976) was adopted to identify and group the LU/LC feature in this research. However, the system was slightly modified to suit the study area. Following this, five LU/LC classes (Table 2) were identified and classified as such. These classes were used for the respective satellite imagery of different dates for the Fosu lagoon watershed after which accuracy assessment was done.

**Table 2: Description of Land-Use/Land-Cover types**

| LU/LC Type | Description |
|---|---|
| **Water** | Lagoons, Estuaries, Wetlands, Streams, Ponds & Reservoirs, Swamps |
| **Built-up** | Residential Areas, Mixed Urban Areas, Industrial and Commercial Units, Transportation Facilities |
| **Sparse Vegetation** | Herbaceous Vegetation, Shrub and Bush Areas, Mixed Grassland with Few Scattered Trees |
| **Dense Vegetation** | Evergreen Forest Land, Mixed Forest Land, Deciduous Forest Land, Forest Reserves |
| **Bare-land** | Sandy Areas, Exposed Soils, Sand Fill, Land Fill Sites, Quarries and Gravel Pits, Transitional Areas, |

(Anderson et al., 1976)

The multitemporal (1991, 2007 and 2018) raster images were then generated and their corresponding statistics was compared for estimation of the LU/LC change. Finally, the area of coverage of visually interpreted LU/LC classes was computed using Arc GIS. The percentage of LU/LC change statistics of the respective years was calculated by the following formula:

$$K = \frac{Ub - Ua}{Ua} \times 100 \qquad \text{(Eq. 1)}$$

Where K is the percentage of land cover change

Ua - LU/LC at the beginning of a period

Ub - LU/LC at the end of a period

**Accuracy assessment**

In doing LU/LC classification, unavoidable errors may be incurred, demanding assessment of output maps for accuracy using reliable statistical techniques. Following this, LU/LC maps are usually accompanied by an accuracy assessment index (Olofsson et al., 2013). A confusion matrix, i.e., the proportion of area of each category according to the map, and descriptive accuracy measures such as user's, producer's and overall accuracy may therefore be adopted. Important accuracy assessment elements, such as Overall Accuracy, Omission Error, Commission Error and Kappa Coefficient, can be obtained (Lu and Weng, 2007). In the present study, accuracy of all the raster layers (1991, 2007, and 2018) was assessed through the development of Kappa Coefficient.

The accuracy is calculated by comparing the corresponding Region of Interest (ROI) that is generated from a reference data (google earth) with the classified land use maps. Google earth data for the years, 1991, 2007 and 2018 corresponded with the years for which the classification was done for Landsat data. Ten ROIs were collected for each LU/LC class and used for the accuracy assessment. The classified image was used in preparing an error matrix to get Producer's Accuracy, User's Accuracy, Overall Accuracy and Kappa Coefficient. The rationale behind comparing the two data is to determine how much the reference data is represented in the classified image for all the respective years.

Producer's Accuracy =

$$\frac{\text{Total number of correct pixels in a category}}{\text{total number of pixels of that category derived from reference data (i.e.column total)}}$$

(Eq. 2)

User's Accuracy =

$$\frac{\text{Total number of correct pixels in a category}}{\text{otal number of pixels of that category derived from reference data (i.e.row total)}}$$

(Eq. 3)

Overall accuracy =

$$\frac{\text{Sum of the diagonal elements in matrix table}}{\text{Total number of accuracy sites (pixels)}}$$

(Eq. 4)

$K_{hat}$= (Obs – Exp) / (1 – Exp) (Eq. 5)

Where,

$K_{hat}$ - Kappa Coefficient

Obs - Observed correct, it represents accuracy reported in error matrix (overall accuracy)

Exp - Expected correct, it represents correct classification (Anand, 2017).

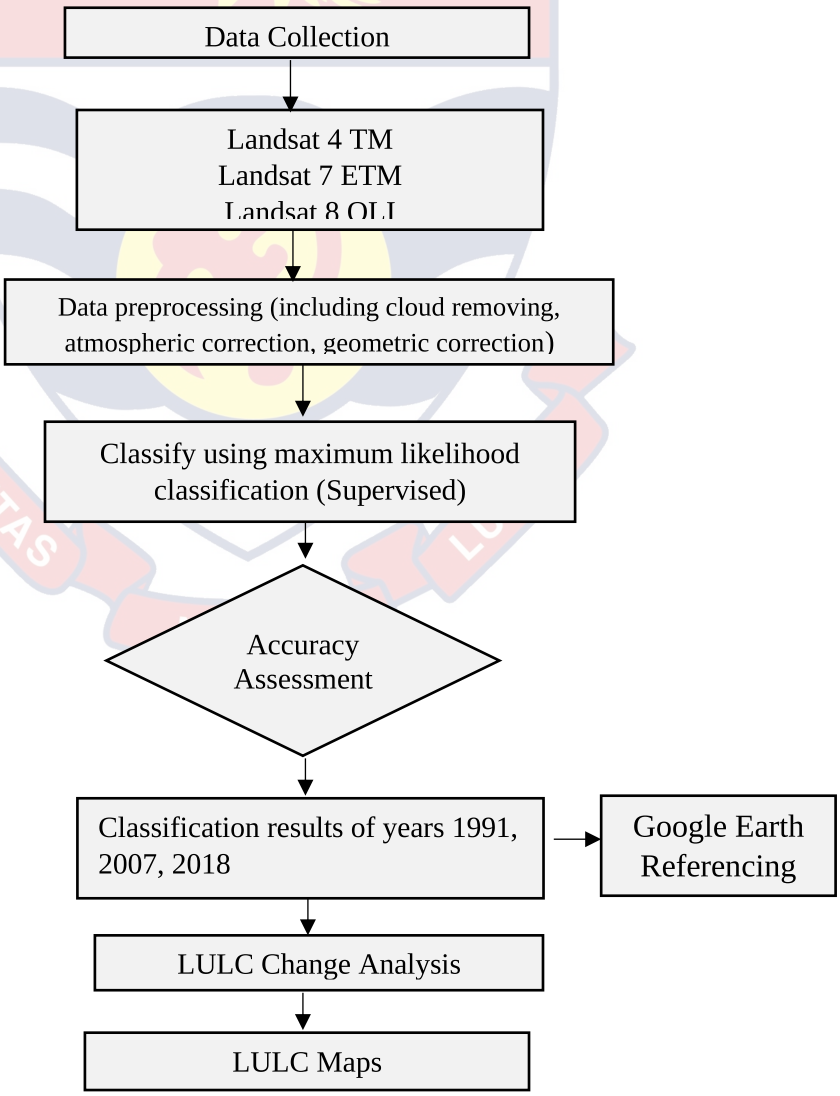


*Figure 5:* Flowchart of methodology of LU/LC classification

**WorldView-2 Dataset, Preparation and Processing**

**WorldView-2 Dataset**

The WorldView-2 (WV-2) satellite image used as part of the primary data in this study is a commercially high spatial resolution imaging satellite, launched on October 8, 2009 (Martin et al., 2012). It offers a panchromatic band with high resolution and eight multispectral bands; (red, green, blue, and near-infrared 1) and additional bands (coastal-blue, yellow, red bottom, and near-infrared 2) (Maglione et al., 2013). A combination of these bands represents full-color images for enhanced spectral analysis, mapping and monitoring applications, land-use planning, disaster relief and exploration, among other uses. With its improved agility, the WV-2 is able to take multispectral imagery of very large areas in a single pass (El-Din et al., 2013). WV-2 images provides a good clarity and geospatial accuracy, increasing their use in both commercial and government markets.

The imagery for the study area was acquired on December 8, 2018 through a customer order from LAND INFO Worldwide Mapping LLC (LAND INFO). LAND INFO was founded in 1993 and is a leading global provider of digital topographic map and nautical chart data, high resolution aerial and satellite imagery and medium-resolution satellite imagery. In addition, they improve imagery via a range of processing services such as ortho rectification, pan sharpening, tonal balancing, and mosaic output and wavelet compression.

This WV-2 data was received in the TIFF file format with about 32.9% cloud cover. The image came as a View-Ready (standard) product, in a 16-bit depth, a map projection in the WGS_1984_UTM_Zone_30N. Its eight spectral bands are found in the visible to near infrared (NIR) region with 50 cm spatial resolution. The wavelengths of the multispectral 8-bands of the WV-2 image are shown in Table 3 below. The additional spectral bands (coastal-blue and yellow) of WV-2 images permit increased accurate retrievals of water quality parameters from observed reflectance values as compared to other high resolution sensors, e.g. QuickBird (El-Din et al., 2013).

**Table 3: Effective wavelength of the WV-2 spectral bands**

| Bands of WorldView-2 Image | Wavelength Centre (nm) |
|---|---|
| Band 1 (Coastal blue) | 427.3 |
| Band 2 (Blue) | 477.9 |
| Band 3 (Green) | 546.2 |
| Band 4 (Yellow) | 607.8 |
| Band 5 (Red) | 658.8 |
| Band 6 (Red-edge) | 723.7 |
| Band 7 (Near Infrared 1) | 832.5 |
| Band 8 (Near Infrared 2) | 908.0 |

**WV-2 Data Preparation**

**Data Calibration**

WV-2 raw image products are distributed in units of relative radiance, recorded as digital numbers (DN) by the sensor. LAND INFO provides calibration information in a metadata file that is used to convert the pixels in the imagery from DN to absolute radiance. The calibration routine is expressed mathematically, as:

$$L_{Pixel,Band} = AbsCalFact_{Band} * q_{Pixel,Band} \quad \text{(Eq. 6)}$$

Where:

$L_{Pixel,Band}$ is the absolute radiance of each pixel in each band

$AbsCalFact_{Band}$ is provided by LAND INFO in the metadata file, &

$q_{pixel,Band}$ is the original DN value of the pixel per band (El-Din et al., 2013)

ENVI software provides a pre-processing utility that calculates this calibration automatically. Thus, the ENVI utility was used to calibrate the WV-2 image used for this research. The resultant image is in units of $(\mu W)/(cm^2 * nm * sr)$

**Spatial Subsetting and Masking**

The second pre-processing step was to remove land areas, vegetation cover and other undesired areas e.g. bridges and boats not required for the water quality assessment. A region of interest (ROI) was created which became the water surface area, where water quality parameters were picked. This suggested that the reflectance value of each pixel of the WV-2 image came only from the water surface of Fosu Lagoon.

**Conversion to Top-of-Atmosphere Reflectance**

In order to generate spectral profiles, it is necessary to convert the images to reflectance. The radiance of an image depends on how the image is illuminated, which is a factor dependent on the time of day, season, and latitude at which the region lies (El-Din et al., 2013). Reflectance is the ratio of radiance to irradiance; therefore, it creates a standard by which images acquired at different times by different sensors can be compared. The ENVI band-math function was used to convert the WV-2 image to reflectance. The WV-2 image metadata file contains the required information such as average sun elevation angle (57.4°) and image acquisition date (December 8, 2018) to calculate the

Earth-sun distance (0.998703 AU) and solar zenith angle (54.7°). This information was needed in equation 7 below, to derive reflectance value:

$$\rho_{Pixel,Band} = \frac{L_{Pixel,Band} * d_{ES}^2 * \pi}{Esun_{\lambda band} * \cos(\theta_s)} \quad \text{(Eq. 7)}$$

Where:

$\rho_{Pixel,band}$ is top-of-atmosphere band-averaged spectral radiance

$L_{Pixel,Band}$ is the absolute radiance of each pixel in each band

$d_{ES}$ is the Earth-Sun distance during the image acquisition

$Esun_{\lambda Band}$ is the band-averaged solar spectral irradiance (Wm- µm-1) normal to the surface being illuminated, and

θs is the solar zenith angle (degrees) during the image acquisition (El-Din et al., 2013)

The band-math expression is calculated for each band individually. Afterwards, all bands are stacked into a single image file with pixel values converted into reflectance.

**Estimation of Water Quality Parameters (WQPs)**

The parameters DO, turbidity, salinity and pH, temperature, TDS and depth were particularly considered, due to their significant contribution to the biophysical nature of coastal waters (Mushtaq & Nee Lala, 2017). The readings of WQPs used in this study were retrieved from Duker (2020). The author sampled from nine points on the lagoon. Sampling points were identified from the clear water area, excluding portions covered by aquatic vegetation, due to their interference with the true reflectance of the water. In addition, the author considered certain factors such as accessibility and nearness to human activity, which were critical to this study. Lastly, the author considered the relatively small sized nature of the lagoon. According to Duker (2020), all nine points were accessible through navigation by boat where a hand-held Trimble GPS receiver picked their respective GPS points. The author used water quality checker to pick the various water quality parameters, listed and the depth, by sonar gun on 12 December 2018. The averages of three replicate readings were calculated and recorded.

**Estimating Regression Models using WQPs & WV-2 data**

After preprocessing, the next step was to determine the relationships between WV-2 spectral bands and various water parameters, at the nine selected sampling sites. Regression models and correlation matrices were used to investigate the relationship between the WQPs and WV-2 radiance data. Selected band ratios used, were adopted from (El-Din et al., 2013). These were (B3/B2, B3/B4, B1/B5, B2/B5, B4/B3, B4/B2, B2/B4, B1/B3 and B2/B3), generated from the visible bands only, since RS for water quality assessment is usually investigated using optical bands in the visible part of the electromagnetic spectrum (Gholizadeh et al., 2016). By using these generated band ratios from the visible bands only, the insignificant band ratios were eliminated and only those that had higher probability of significant correlations with WQP were kept. Following this, only reflectance values of WV-2 visible bands corresponding to the nine surveyed sites were used to calculate eight raw bands and a set of nine band ratios that were subsequently regressed against the WQPs. This was done by using the linear regression to quantify the relationships between the various WQPs and the reflectance values of the selected WV-2 bands.

Abdelmalik (2018) stated that correlation and regression analysis techniques are used for studying and investigating the strength of the relationship between two quantitative variables. While the correlation analysis quantifies the relation's strength, regression analysis develops the mathematical equation between the two variables. This way, the determination coefficients ($R^2$) of the WV-2 variables (independent bands and band ratios) and WQPs (dependent variable) adopted from El-Din et al. (2013) and Mustaq & Nee Lala (2017) could be calculated.

The multiple coefficients of determination ($R^2$), and probability (P) at 95 % confidence level were used to establish the statistical significance of these regression models (El-Din et al., 2013). Following this, the band that yielded the highest $R^2$ was selected. The study used the Excel software package of Microsoft Office version 20 to estimate both correlation and regression analyses in order to investigate and study the relationship between WQPs and RS data. Unlike other studies (Mushtaq & Nee Lala, (2017) and El-Din et al. (2013), the empirical relationships obtained could not be fully interpolated to the entire lagoon thereby not permitting the production of series of maps for WQPs.

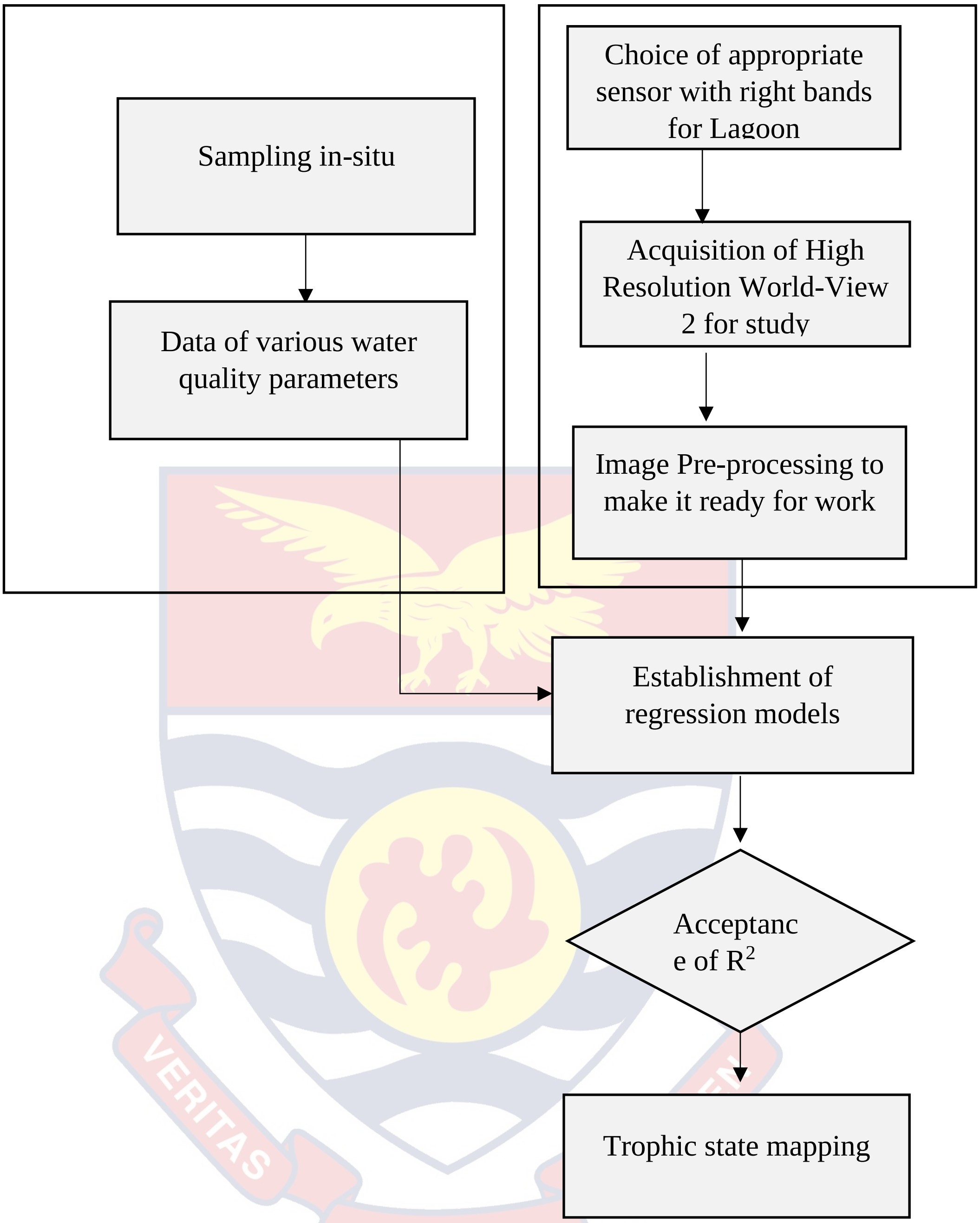


*Figure 6:* Flowchart showing estimation of regression relationships between World-View 2 data and Water Quality Parameters

**Survey Data**

In an effort to make solid conclusions to validate data from RS about the Fosu lagoon, complementary social interaction with respondents were done. The target population, consisting individuals whose livelihoods and housing were in proximity to lagoon surrounding were interviewed to get ground information to enrich the research. This was done through a series of field visits.

**Target Population**

The target population consisted, fishermen, who either regularly or seldom fish from the lagoon, women who stay around to buy fish from fishermen, owners and operators of various facilities around the lagoon, e.g., bars, restaurants and metal scraps, mechanics and generally, people who reside close to the lagoon. Fishermen from the lagoon knew the ecological and social dynamics of the lagoon year after year, the fish traders also had on ground information, which was critical to the study. Operators of various facilities around the lagoon had rich information, which was critical to the lagoon. Finally, residents who had stayed in close proximity to the lagoon over long periods had in-depth information critical to the study and as a result, were engaged. All of these people were targeted due to their exposure to the lagoon over a long period and the diverse opinions each group had that was critical to the research.

**Sampling Technique**

Considering the different groups of people and localities, convenient technique for sampling had to be used. Other than the different groups of people listed, respondents beyond a particular age were needed to be interviewed because of their long-term exposure to the lagoon. In total, 72 respondents were interviewed. During the interviews, the snowball sampling technique was used, where most of the respondents knew themselves, and directed the researcher to other people who fell within the purpose of the research.

**Data Collection Instrument**

During the data collection stage, a structured interview schedule was used as the main data collection instrument, which involved asking respondents questions in Fante and noting down their responses, together with observation guide. The main rationale for using the interview schedule was because of the fact that most people in the target group did not have formal education, which could not allow them to answer interview questions on their own. Thorough interpretations had to be made concerning interview guide to get the right responses, relevant to the research. The instrument presented both open and close-ended questions, with the former, dominating. These questions were based on the specific objectives of the study that contained relevant variables. The structured interview-schedule used here, remained the same but for particular portions, exclusive to fishermen by virtue of their direct involvement with the lagoon.

Like most questionnaire structure, it had four different sections, which carried different motives. The first section was demographics of respondents, the second, general lagoon perceptions, third, myriad of threats to the lagoon, and fourth, restoration and livelihood support systems for the lagoon. Under perceptions of lagoon by respondents, the questions exclusive to only fishermen regarding lagoon bathymetry and its dynamics, were indicated. Unlike other social research, pilot test was not conducted on the structured interview. This was because they were presented in clear, concise and interpretable way, which was easy to answer by respondents.

**Interview**

Face-to-face interviews, using the questionnaire structure were conducted after the researcher had met the respondents to explain the purpose of the study. Individual respondents from the different groups and locations were interviewed using the structured questionnaire. The interview was conducted by literal translation of the questions to the local dialect (Fante) common to the respondents. This was done to ensure better communication and retrieval of reliable and accurate responses. The student researcher throughout the period of data collection did the interview sessions. This was done to ensure that the researcher through dialogue and observation of the situation gathered enough on-ground information. Even though there were identifiable, informal groups through which interviews were conducted, respondents were interviewed as individuals, applying the snowball technique. A little skepticism was observed among respondents to participate, raising concerns of past interviews that had been conducted without proactive implementation of suggestions raised about the lagoon. Fishermen respondents who agreed to be part of the study were interviewed upon agreeing to respond to questions the researcher asked. The interview period coincided with the period of ban on fishing on the lagoon, as part of preparations towards the annual Festival, making it easy to reach the fishermen since most were either involved in artisanal fishing from the sea or idle. Others, such as mechanics and household individuals were easily involved in the interview since they were relaxed at their work places and homes and were ready to share information about the lagoon.

Overall, about seventy-two respondents were involved in the face-to-face interviews. The average duration for an interview was approximately twenty minutes, conducted during the period from July to September 2019.

**Data Processing and Analysis**

The data collected form the survey were thoroughly edited to ensure that it was simple for subsequent entry, coding and analysis. The edited data was critically organized and coded for statistical analysis. Using SPSS computer software version 25, the data were then analyzed. The demographic information of the respondents were analyzed using descriptive statistics such as central tendencies, frequencies and percentages, presented in tables and figures. The qualitative data was transcribed and those that needed to be coded were done. Following these steps, logical and comprehensive outcomes were obtained which helped explain the quantitative data.

# CHAPTER FOUR

# RESULTS

## Introduction

The findings of the study, expressed as results in statistical figures are presented in this chapter. Results of regression analysis of WQPs and depth estimated from the bands of WV-2 sensor and in-situ estimations are shown in tabular forms and expressed in models. Information regarding the social and economic exploits, and perceptions gathered from the respondents living and working around the Fosu Lagoon is found in this chapter. In addition, LU/LC of the watershed of the lagoon, typically showing the entirety of the Cape Coast metropolis, have their results expressed in maps, tables and graphs, showing trends of changes, over the years.

## Land-Use/Land-Cover of Fosu Lagoon Watershed

The cover and usage of lands may appear in various forms depending on spatial and spectral properties of available data and in some cases, the extent of area under consideration (Alam, et al., 2019). In this study, five land classes, water body, built up, sparse vegetation, dense vegetation and bare land were identified and used. The water body consisted lagoons, of which Fosu lagoon was part, Kakum River, wetlands, streams, ponds, reservoirs and swamps within the metropolis. Built-up comprises human related exploits developed for non-agricultural uses e.g. residential and industrial units established in between time because of rapid population growth and associated urbanization. Both sparse and dense vegetation together, constituted, vegetation with the former being herbaceous, shrubs, mixed grassland, plantation and scrubland areas with few scattered trees and latter, being forest. Forests were mainly evergreen, mixed forestland, deciduous forest and other forest reserves. Bare-lands were sandy areas, exposed rocks, quarries, gravel pits, and uncultivated lands for various activities. The entire study area covered 100.7 $km^2$ from which all five different land covers and associated changes represented in respective years were represented.

**Table 4: Percentage constitution of LU/LC classes for respective years**

| LULC Classes | 1991 | | 2007 | | 2018 | |
|---|---|---|---|---|---|---|
| | Area (km²) | Area (%) | Area (km²) | Area (%) | Area (km²) | Area (%) |
| **Water Body** | 3.05 | 3.0 | 1.93 | 1.9 | 1.8 | 1.8 |
| **Urban (Built Up)** | 11.60 | 11.5 | 17.41 | 17.3 | 22.09 | 21.9 |
| **Sparse Vegetation** | 21.14 | 21.0 | 24.81 | 24.6 | 29.10 | 28.9 |
| **Dense Vegetation** | 50.91 | 50.6 | 39.12 | 38.9 | 34.59 | 34.4 |
| **Bare land (Soil)** | 14.01 | 13.9 | 17.43 | 17.3 | 13.12 | 13.0 |

**Land-Use/Land-Cover in 1991**

In the year 1991, the area of water, mapped from Landsat 4 TM satellite image, of which the Fosu lagoon formed a part, was 3.05 $km^2$, comprising 3.0 percent of the entire area. Bare land areas some of which surrounded the water body and spread in central and northern parts of the map covered 14.01 $km^2$ (13.9 %). Vegetation covered majority of the area. Dense vegetation, mostly forested areas were observed from central to upper portions of the map with few scanty covers at the south. It was the largest land cover of 50.91 $km^2$ and constituted 50.6 percent of the area. Sparse vegetation, on the other hand covered 21.14 $km^2$, constituting 21 per cent of the area and mostly centralized on the map with extensions to different directions towards the south and a few clusters at the northern end. Finally, built-up and mixed urban areas covered an area of 11.6 $km^2$ (11.5 %), being the second least among the land covers of the year, 1991. Most built-up seen in the map for the particular year were found mostly at the southern end close to the water bodies and the sea with a few clusters from the middle belt all the way up north.

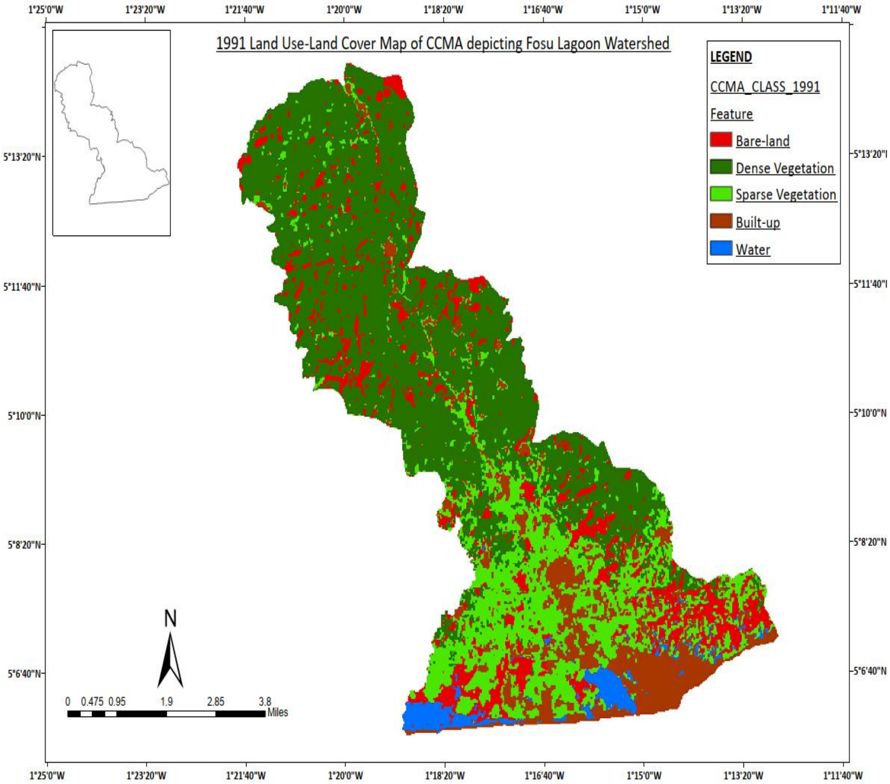


*Figure 7*: 1991 LU/LC map of the study area

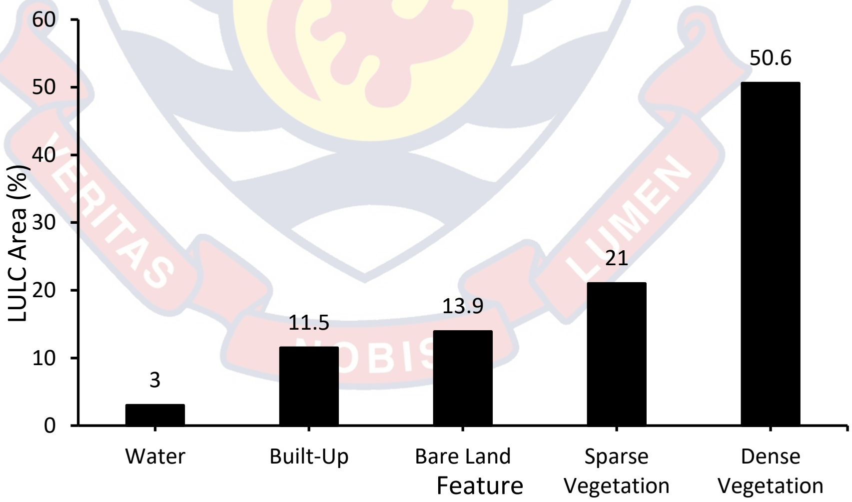


*Figure* 8: Percentage coverage of LU/LC for 1991

## Land-Use/Land-Cover in 2007

Landsat 7 ETM image acquired in 2007 displayed classification map of the Fosu lagoon watershed, with total water cover of 1.93 km$^2$ comprising 1.9

percent of the study area, a reduction relative to water cover in 1991. Bare land expanded and went beyond previous points where they were located in 1991, increasing to 17.43 km$^2$ (17.3 %) of the total area. Relative to 1991, dense and sparse vegetation respectively reduced and slightly increased in spatial extents to 39.12 km$^2$ (38.9 %) and 24.81 km$^2$ (24.6 %). Built-up was 17.41 km$^2$ in aerial extent and constituted 17.3 per cent of the total area. Similar to previous year, 1991, dense vegetation, remained the highest cover of land whiles water body on the other hand, was the least. References from the 2007 LU/LC map indicate changes relative to the previous year where respective land covers either increased or decreased for expansion and reduction in space respectively, mostly related to anthropogenic reasons.

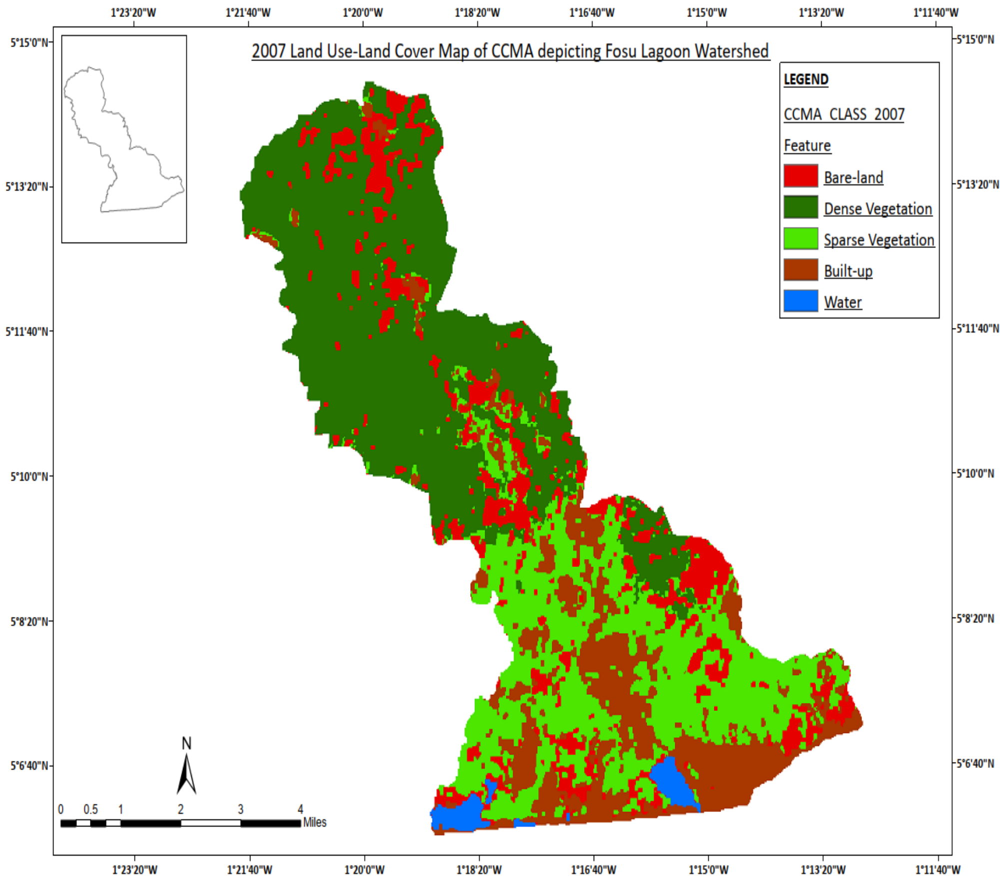


*Figure 9:* 2007 LU/LC map of the study area

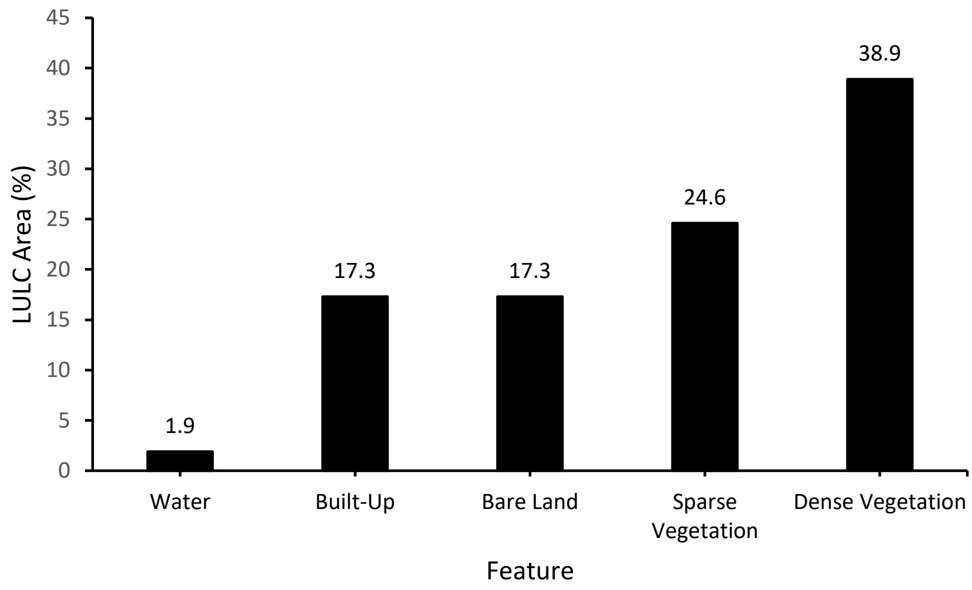


*Figure 10:* Percentage coverage of LU/LC for 2007

**Land-Use/Land-Cover in 2018**

Operational Land Imagery (OLI) version of Landsat (Landsat 8) was used for the LULC classification map of the year 2018. The map revealed that water body within the space was 1.8 $km^2$, constituting 1.8 per cent of the watershed area. Observing from the map, changes in extent of water body relative to previous years, reduced in area, slightly as compared to other land covers in the catchment, even though they did not appear much evident. Bare-land interestingly reduced in area after initially rising from 1991 to 2007. In 2018, it covered 13.12 $km^2$ (13 %). Initial patches of bare-land initially observed from mid to upper portions of the map were replaced with other land covers. Down south, it dynamically evolved in other built-up and sparsely vegetated areas, and seen more aggregated. Sparsely vegetated areas of land cover and usage continuously increased in area to 29.10 $km^2$ (28.9 %). Unlike sparse vegetation, densely vegetated areas continuously reduced in spatial extent from

2007 to 2018, recording 34.59 km$^2$ (34.4 %). Sparsely vegetated areas expanded to portions of previously dense vegetated areas around the middle belt, towards the eastern and western ends while dense vegetation presented aggregations at the upper part of the map, but rather reduced in size in 2018. Lastly, built-up and urban catchments followed continuous trend of increasing spatial area, recording 22.09 km$^2$ constituting 21.9 percent of the area. Built-up in 2018 was observed to have risen through the mid through to the upper belt, expanding in size accordingly. Initial patches are seen to have increased in size with new patches around places previously, bare.

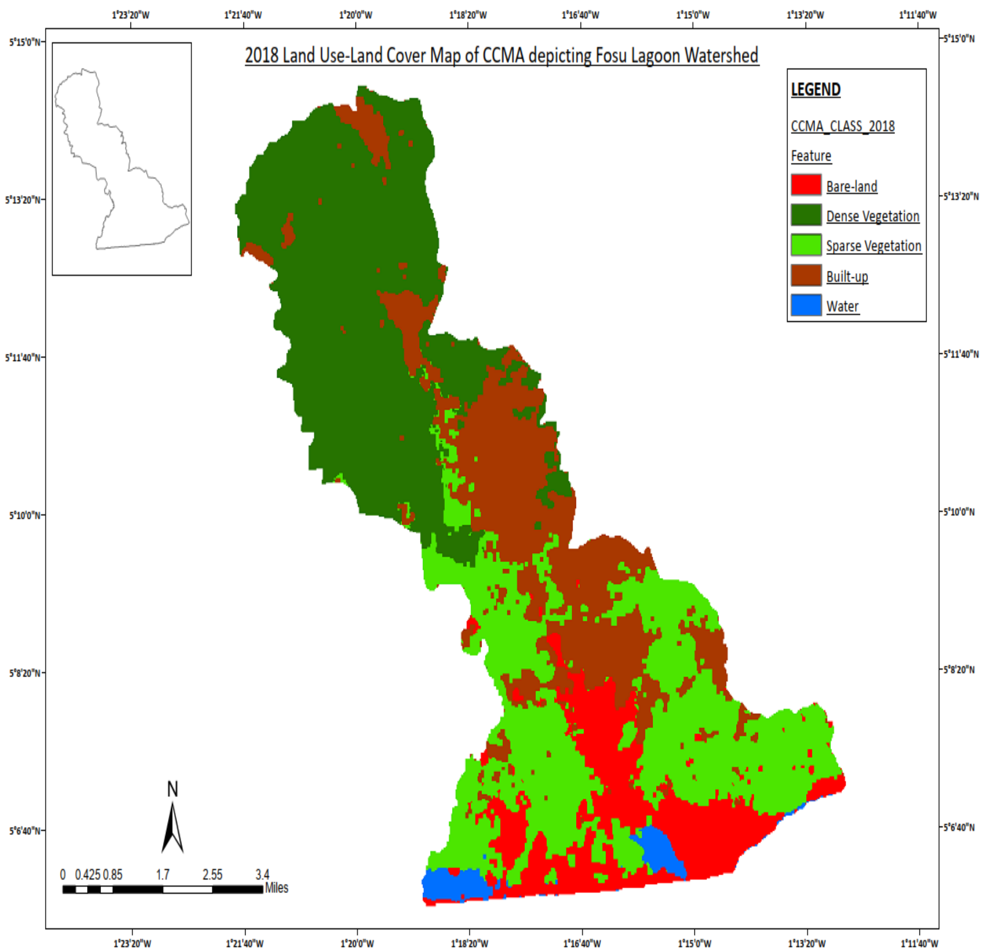


*Figure 11:* 2018 LU/LC map of the study area.

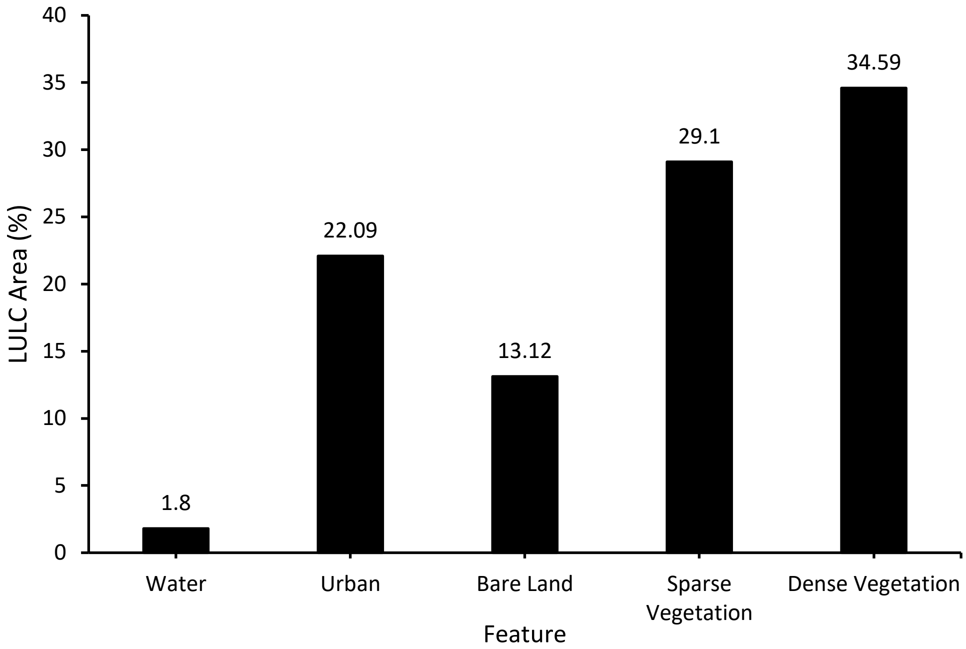


*Figure 12:* Percentage coverage of LU/LC for 2018

**Land use changes (1991 – 2007)**

During 1991 to 2007, major changes were observed incrementally in built up, bare land and subtly, in sparse vegetated whereas dense vegetation and water body, respectively decreased significantly and slightly as seen in Table 5 below. For the sixteen years, water body reduced by - 36.7 % comparably, more in magnitude than dense vegetation which reduced by - 23.2 %. Built-up increased in percentage by 50.1, followed by bare-land 24.4 percent and finally, sparse vegetation, 17.4 percent.

**Land use changes (2007 – 2018)**

The 11 years period from 2007 to 2018 presented significant changes in built-up and bare-land, in terms of increment 26.9 % and reduction - 24.7 %, respectively. Dense and sparsely vegetated areas as well as water body had relatively slight changes in land usage and cover. As stated already, dense vegetated areas reduced - 11.6 % in catchment for this period, similar to water body - 6.37 %. Sparse vegetation continuously increased in area by 17.3 percent for the period.

**Land use changes (1991 – 2018) Changes**

The total duration of time under which the area was studied is 27 years (1991 to 2018), whose total percentage change in land cover and usage is presented in Table 5. During this period, a lot of the bare land areas were converted into built ups, with the other land classes observing respective changes. A possible linkage of this change is the increment and decrement in sparse vegetation & dense vegetation respectively because of human exploitation within the region for the period. In addition, increments in sparsely vegetated areas may have been due to expansions in agricultural activities and plantations across the region. Further, it could be linked to the reduction in dense vegetated areas, showing decreasing forested catchments within the region in addition to water body, which exhibited gradual shrinkage, resulting in decrease of water catchment.

**Table 5: LU/LC changes between respective years for study area**

| LU/LC Classes | 1991 - 2007 | | 2007 - 2018 | | 1991 - 2018 | |
|---|---|---|---|---|---|---|
| | Area (km²) | Area (%) | Area (km²) | Area (%) | Area (km²) | Area (%) |
| **Water Body** | - 1.12 | - 36.7 | - 0.13 | - 6.7 | - 1.25 | - 41.0 |
| **Urban (Built Up)** | 5.81 | 50.1 | 4.68 | 26.9 | 10.49 | 90.4 |
| **Sparse Vegetation** | 3.67 | 17.4 | 4.29 | 17.3 | 7.96 | 37.7 |
| **Dense Vegetation** | - 11.79 | - 23.2 | - 4.53 | - 11.6 | - 16.32 | - 32.1 |
| **Bare land (Soil)** | 3.42 | 24.4 | - 4.31 | - 24.7 | - 0.89 | - 6.4 |

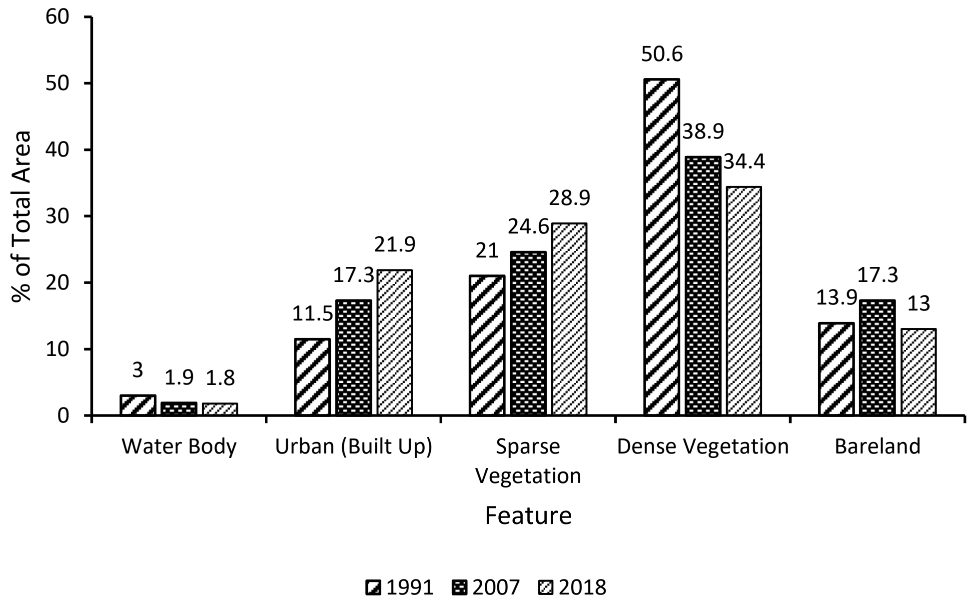


*Figure 13*: Percentage distribution of LU/LC classes for respective years

**Accuracy Assessment**

Accuracy assessment calculated for the three classified maps with reference google earth data presented a Producer's and User's accuracy as well as their Kappa Coefficients. Commonly, Kappa Coefficient ($K_{hat}$) value ranges from 0 - 1. Kappa index less than or equal to 0.4, suggested poor consistency between the classified and referenced points. Kappa between 0.4 - 0.75, indicate general consistencies. Kappa values of 0.81 – 1.0 means an almost perfect classification with accurate consistencies (Liping et al., 2018).

The Kappa Coefficient of the 1991 map was 0.675 (67.5%), beyond the average 0.4 mark hinting a moderately accurate map with land classes at their right distributions.

Accuracy assessment for the map for 2007 presented a Kappa coefficient value of 0.725 (72.5%), slightly higher than that for 1991, indicating a rather nearer accurate map relative to it even though it also fell in the category of moderate. In 2018, accuracy assessment calculated also presented a moderately accepted Kappa coefficient of 0.649 (64.9%) being the lowest relative to the two previous maps.

**Estimation of $R^2$ between WQP and WV-2**

The results of the WQPs, together with the GPS for the nine points on the lagoon is displayed in Table 6 below. From the table, it can be observed that depth of lagoon, measured in meters is generally low with the highest being 2.41 m and lowest, 0.67 m. Readings for DO were found within 1.08 mg/l and 2.01 mg/l. pH values were observed to be beyond 7, showing alkalinity of lagoon at the time sampling. Salinity values for all nine points were 4.1 ppt respectively.

Turbidity values, measured in NTU ranged from 25.4 NTU to 36.1 NTU. Total Dissolved Solids measured in the lagoon had values relating to 4 mg/l. Values ranged from 4.70 mg/l to 4.73 mg/l. Temperature readings from the lagoon ranged between 30.20 °C and 31.05 °C, depicting usual temperatures (25°C to 35°C) of the lagoon (Armah et al., 2012).

Table 7, shows reflectance values of the bands and band ratios of WV-2 extracted from the ENVI software for the nine points on the lagoon. From the table, each of the nine sites had respective band reflectance values, from B1 to B8. In addition, reflectance values of the band ratios, B3/B2, B3/B4, B1/B5, B2/B5, B4/B3, B4/B2, B2/B4, B1/B3 and B2/B3 are seen. Together, these reflectance values were used as independent (X) variables for regressions against the WQPs (Y variables) and the resultant coefficients of determination ($R^2$) are reported in a correlation matrix in Table 8. From the results, it can be seen that some of the $R^2$ values selected were as low as 0.019, which according to El-Din et al. (2013) could reduce the accuracy of distribution maps, usually generated from interpolation using the linear equation model for the different

WQPs. However, these lower $R^2$ values could still be valid since the maps made out of their equations are mostly used temporarily to do biological monitoring on a water body.

**Table 6: Water quality parameters and GPS points of nine sample sites on the Fosu Lagoon, Cape Coast (Dec, 2018)**

| Sample Stn. | Longitude | Latitude | Depth (m) | DO (mg/l) | pH | Turbidity (NTU) | TDS (mg/l) | Cond. mS/cm |
|---|---|---|---|---|---|---|---|---|
| 1 | -1.252319 | 5.103113 | 1.01 | 1.38 | 8.99 | 33.3 | 4.73 | 7.52 |
| 2 | -1.252730 | 5.103163 | 2.41 | 1.08 | 8.95 | 28.6 | 4.70 | 7.46 |
| 3 | -1.253294 | 5.102975 | 0.73 | 1.58 | 9.01 | 31.5 | 4.75 | 7.55 |
| 4 | -1.253278 | 5.103954 | 0.67 | 1.98 | 8.93 | 28.7 | 4.70 | 7.48 |
| 5 | -1.256457 | 5.103857 | 0.82 | 1.75 | 8.88 | 26.3 | 4.71 | 7.48 |
| 6 | -1.254618 | 5.105700 | 1.34 | 2.01 | 8.85 | 27.8 | 4.73 | 7.51 |
| 7 | -1.259477 | 5.111141 | 0.98 | 1.56 | 8.78 | 25.4 | 4.72 | 7.49 |
| 8 | -1.261483 | 5.107822 | 1.07 | 1.68 | 8.84 | 36.1 | 4.72 | 7.49 |
| 9 | -1.259779 | 5.105647 | 0.82 | 1.68 | 8.80 | 33.0 | 4.71 | 7.49 |

On the other hand, $R^2$ for some parameters were as high as 0.8209 and 0.648, 0.6063 and 0.512 for pH, turbidity, temperature and DO respectively. The total of the single band and band ratios were seventeen, statistically regressed against seven WQPs in this study.

The highest coefficient of determination ($R^2$) for depth was 0.321, which was the result of regression from the band ratio, B1/B3 (Coastal Blue/ Green). Other than B1/B3, the ratios B2/B3, B3/B2, B2/B4 and B4/B2 all recorded relatively high ($R^2$). From the list of $R^2$, the highest $R^2$ was chosen whose linear model equation and graph can be seen in Figure 14. The $R^2$ shows a weak positive correlation between the WV-2 radiance and depth, which even though low, can be used to estimate a bathymetry map to be used for further ecological research for the Fosu lagoon. The correlation is regarded as a weak one relative to ($R^2 = 1$), which represents a perfect score correlation and ($R^2 = 0$), indicating a null correlation.

The highest $R^2$ for DO after regressions was 0.512, produced by the band ratio, B2/B4 (Blue / Yellow). Band ratios B4/B2 and B2/B3 produced $R^2$ values of 0.506 and 0.501 respectively. $R^2$ value of B3/B2 was 0.499. The highest $R^2$ for a singular band was 0.118 for B4 (Yellow), which is relatively not significant comparing to other band ratios of DO. The highest $R^2$ value 0.512, produced by the band ratio B2/B4 produced a rather negative correlation, though strong. Significant F and P-value were 0.030 and 0.022 respectively emphasizing the significance of the relationship between the band ratio B2/B4 and DO. The linear model equation for DO in Fosu lagoon is found together with the relational plot graph in Figure 15 below.

**Table 7: WV-2 Radiance values calculated at nine surveyed sites**

| Site No. | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B3/ B2 | B3/ B4 | B1/ B5 | B2/ B5 | B4/ B3 | B4/ B2 | B2/ B4 | B1/ B3 | B2/ B3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.10 | 10.22 | 8.16 | 6.52 | 5.58 | 4.61 | 4.01 | 2.32 | 0.80 | 1.25 | 1.63 | 1.83 | 0.80 | 0.64 | 1.57 | 1.11 | 1.25 |
| 2 | 9.14 | 10.18 | 8.10 | 6.48 | 5.54 | 4.59 | 4.05 | 2.33 | 0.80 | 1.25 | 1.65 | 1.84 | 0.80 | 0.64 | 1.57 | 1.13 | 1.26 |
| 3 | 9.10 | 10.14 | 8.10 | 6.48 | 5.48 | 4.55 | 4.01 | 2.33 | 0.81 | 1.25 | 1.66 | 1.83 | 0.80 | 0.65 | 1.55 | 1.12 | 1.24 |
| 4 | 9.14 | 10.12 | 8.23 | 6.58 | 5.56 | 4.54 | 4.06 | 2.39 | 0.81 | 1.25 | 1.64 | 1.82 | 0.80 | 0.65 | 1.54 | 1.11 | 1.23 |
| 5 | 9.12 | 10.12 | 8.23 | 6.59 | 5.63 | 4.58 | 4.10 | 2.41 | 0.81 | 1.25 | 1.62 | 1.80 | 0.80 | 0.65 | 1.53 | 1.11 | 1.23 |
| 6 | 9.24 | 10.22 | 8.27 | 6.66 | 5.65 | 4.65 | 4.10 | 2.45 | 0.81 | 1.24 | 1.63 | 1.81 | 0.80 | 0.65 | 1.53 | 1.12 | 1.23 |
| 7 | 9.35 | 10.41 | 8.55 | 6.83 | 5.86 | 4.88 | 4.43 | 2.62 | 0.81 | 1.24 | 1.60 | 1.78 | 0.81 | 0.66 | 1.53 | 1.10 | 1.23 |
| 8 | 9.16 | 10.12 | 8.27 | 6.58 | 5.50 | 4.61 | 4.16 | 2.43 | 0.81 | 1.24 | 1.67 | 1.84 | 0.80 | 0.65 | 1.54 | 1.12 | 1.24 |
| 9 | 9.10 | 10.18 | 8.12 | 6.55 | 5.48 | 4.48 | 3.96 | 2.32 | 0.80 | 1.24 | 1.66 | 1.86 | 0.81 | 0.64 | 1.56 | 1.12 | 1.25 |

**Table 8: Results of regression ($R^2$ values) between the WQP and WV-2 data of Fosu Lagoon**

| WV-2 Data | Depth (m) | DO (mg/l) | pH | Turbidity (NTU) | TDS (mg/l) | Cond. (ms/cm) |
|---|---|---|---|---|---|---|
| B1 | 0.008 | 0.024 | 0.373 | 0.304 | 0.000 | 0.022 |
| B2 | 0.029 | 0.028 | 0.310 | 0.190 | 0.010 | 0.047* |
| B3 | 0.045 | 0.109 | 0.362 | 0.365 | 0.002 | 0.023 |
| B4 | 0.038 | 0.118 | 0.535 | 0.308 | 0.002 | 0.027 |
| B5 | 0.000 | 0.009 | 0.224 | 0.534 | 0.001 | 0.026 |
| B6 | 0.011 | 0.011 | 0.158 | 0.252 | 0.019* | 0.003 |
| B7 | 0.000 | 0.002 | 0.317 | 0.222 | 0.000 | 0.041 |
| B8 | 0.014 | 0.069 | 0.434 | 0.281 | 0.000 | 0.029 |
| B3/B2 | 0.275 | 0.499 | 0.095 | 0.203 | 0.002 | 0.000 |
| B3/B4 | 0.003 | 0.065 | 0.8207 | 0.015 | 0.000 | 0.021 |
| B1/B5 | 0.007 | 0.002 | 0.099 | 0.579 | 0.004 | 0.022 |
| B2/B5 | 0.021 | 0.072 | 0.097 | 0.648* | 0.001 | 0.008 |
| B4/B3 | 0.003 | 0.065 | 0.8209* | 0.015 | 0.000 | 0.020 |
| B4/B2 | 0.229 | 0.506 | 0.362 | 0.194 | 0.001 | 0.002 |
| B2/B4 | 0.233 | 0.512* | 0.360 | 0.190 | 0.001 | 0.002 |
| B1/B3 | 0.321* | 0.229 | 0.165 | 0.240 | 0.014 | 0.011 |
| B2/B3 | 0.277 | 0.501 | 0.095 | 0.200 | 0.002 | 0.000 |

‘*’ Selectable Coefficients of determination ($R^2$) for regression models.

In the case of pH, regressions run produced a highest $R^2$ of 0.8209 with B4/B3 (Yellow / Green) ratio, the highest $R^2$ among all other parameters. pH produced strong $R^2$ with other band ratios, B3/B4 (0.807), slightly lower than the highest $R^2$ value. Remaining single bands such as B3, B7, B2 and band ratios B2/B4 and B4/B2 all had relatively low $R^2$ values, comparing to B4/B3. The highest $R^2$ value for pH can be described as a significant one even though negatively correlated, following significant F and P-value of 0.0008 for each. The linear model equation for pH as a parameter in this study is found with Figure 16.

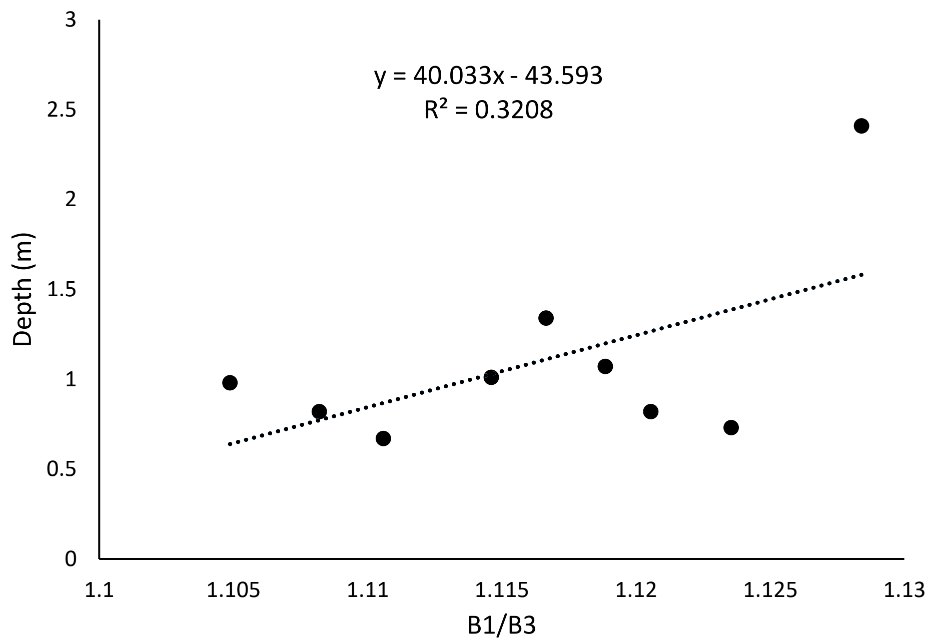


*Figure 14:* Relational plot of band ratio B1/B3 and Depth (m) of Fosu Lagoon. Depth Model: Y = 40.03X - 43.59 (X = B1/B3)

Salinity values recorded from the Fosu lagoon on sampling day were 4.1 ppt for all nine points. This contributed to producing a null correlation relationship with all the single eight bands and nine band ratios. Following this, salinity as a WQP was eliminated from further analysis in the study.

Turbidity as a WQP recorded a strong, significant positive correlation, represented by an $R^2$ of 0.648 for the band ratio, B2/B5 (Blue / Red). Significant F and P-value were 0.008 each hinting a significant correlation. While that was the highest $R^2$ for turbidity, it can be observed that all the other single bands and band ratio values were fairly recorded but relatively low. Band 5 produced a striking $R^2$ of 0.534, which could have been valid to be accepted in this study. The linear model equation for turbidity is shown with Figure 17.

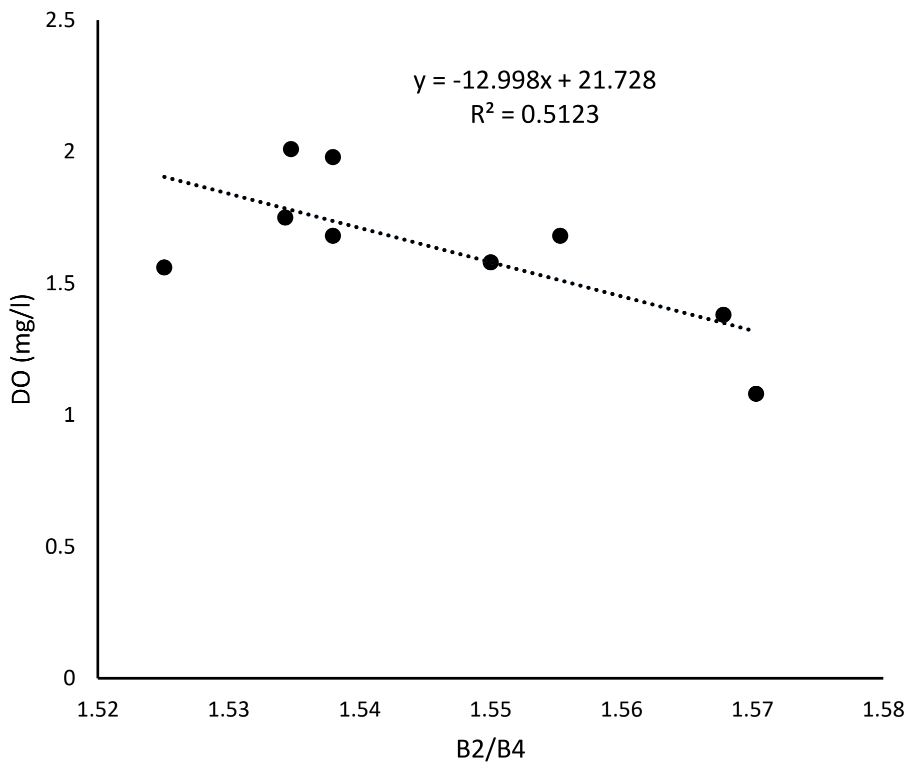




*Figure 15:* Relational plot of band ratio B2/B4 and DO (mg/l) Fosu lagoon. DO Model: Y = - 12.99X + 21.73 (X = B2/B4)

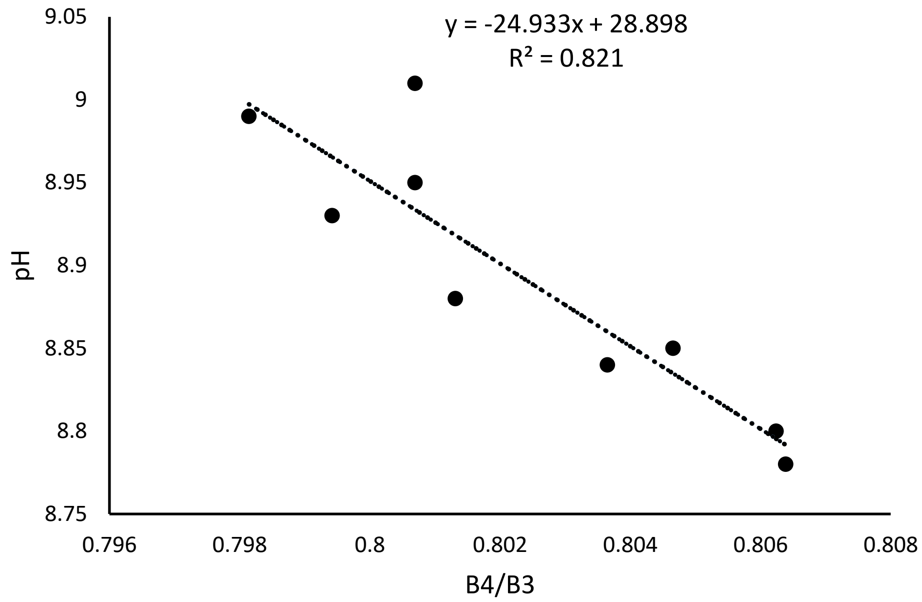


*Figure 16:* Relational plot of band ratio B4/B3 and pH of Fosu lagoon.

pH Model: Y = - 24.93X + 28.89 (X = B4/B3)

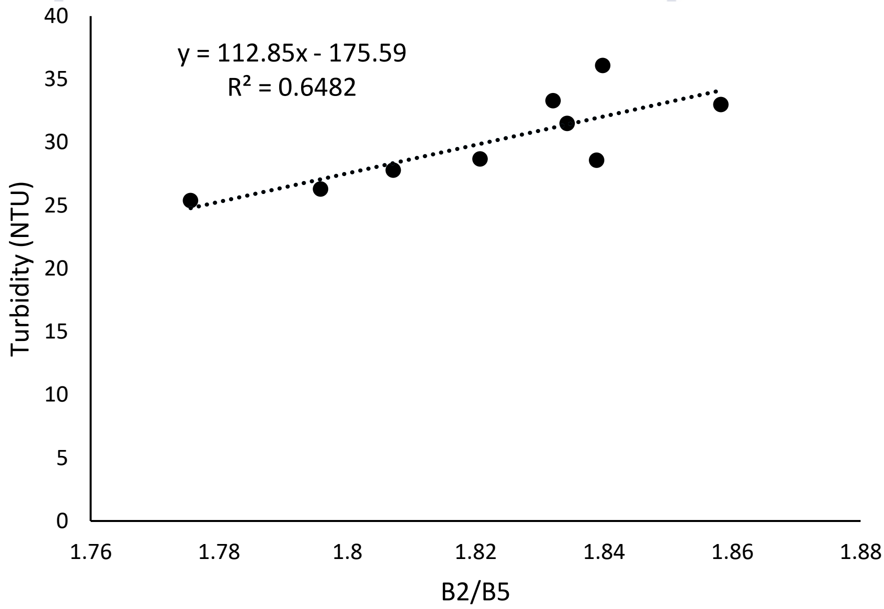


Figure 17: Relational plot of band ratio B2/B5 and turbidity (NTU) of Fosu lagoon.

Turbidity Model: Y = 112.85X – 175.59 (X = B2/B5)

The $R^2$ values for TDS in this study were the lowest recorded among all the WQPs. Values ranged from 0.001 to 0.019, with 0.019 as the highest. To its extremity, some bands and band ratios produced an $R^2$ of 0.000, indicating null correlations and relationships between turbidity and bands and band ratios. The highest 0.019 was recorded for the single band 6 (Red Edge). It was then followed by 0.014 and 0.010 for the ratio, B1/B3 (Coastal Blue / Green) and the single band 2 (Blue) respectively. The highest $R^2$ value 0.019 from the band 6 hinted an insignificant positive correlation, confirmed by significant F and P-value of 0.726. Model linear equation of the TDS for the Fosu lagoon is indicated with Figure 18 below.

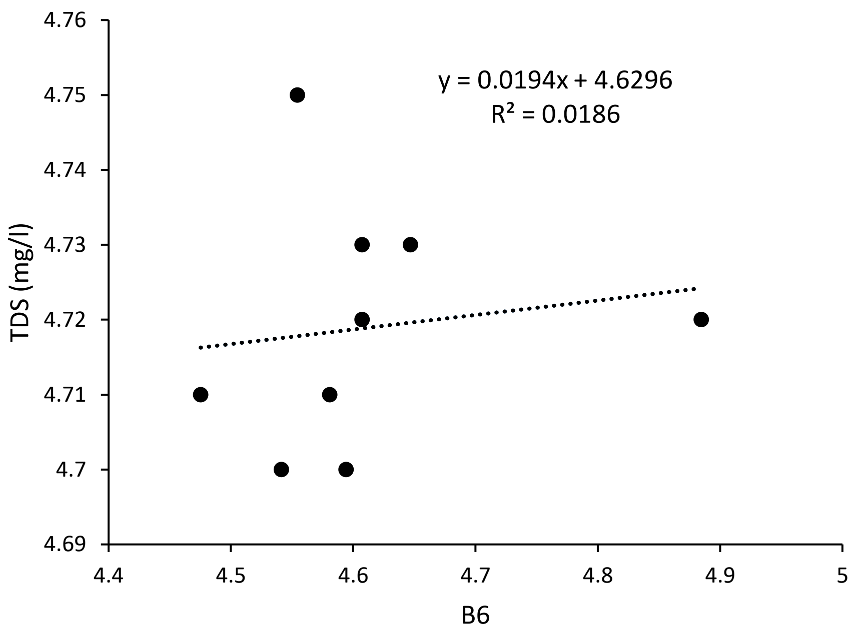


Figure 18: Relational plot of band B6 and TDS (mg/l) of Fosu lagoon
TDS Model: Y = 0.019X + 4.630 (X = B6)

The highest $R^2$ value calculated for conductivity is 0.047, produced from the regression with the single Band 2 (Blue). This value was slightly (0.006) higher than the $R^2$ of B7 (NIR-1) which was 0.041. While the highest $R^2$ value for this parameter was B2, the correlation relationship was barely strong, and negative as shown in Figure 19. P-value from the regressions were 0.577, emphasizing the relatively weak relationship between B2 and conductivity. $R^2$ values of other band ratios, as seen from Table 8 were also low like the other single bands. Some of the low values were extreme to the point where they recorded 0.000 as their $R^2$ value (B2/B3 and B3/B2).

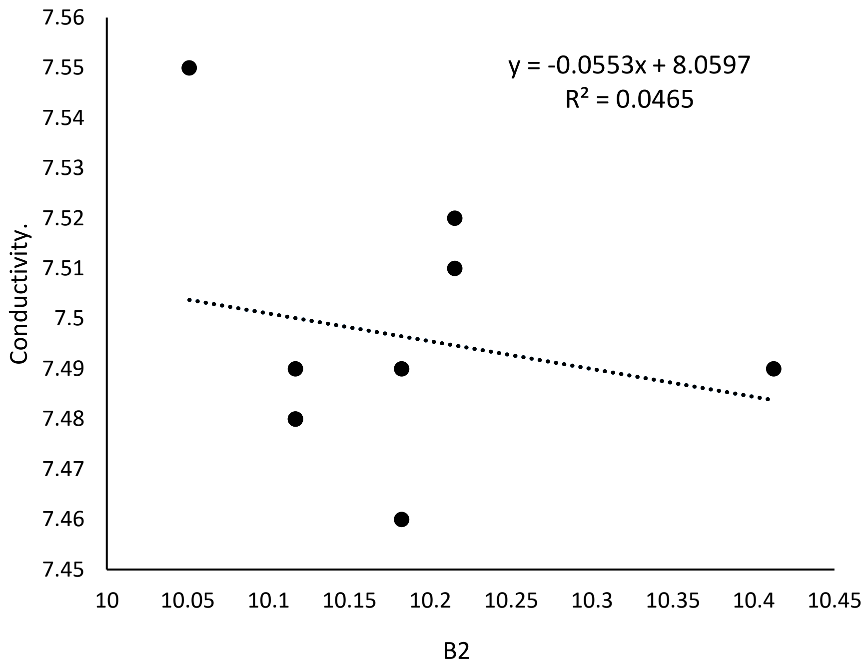


*Figure 19:* Relational plot of Band 2 and Conductivity (ms/cm) Fosu Lagoon Conductivity Model: Y = -0.0553X + 8.0597 (X = B2

**Demographics of Respondents**

The total number of respondents were 72, made up of individuals with different livelihoods, some of which were directly involved with the lagoon or reside close to it. Out of the total number of respondents interviewed, 47 individuals, representing 65.3 percent and 25 individuals representing 34.7 percent were males and females respectively.

The age group (31 – 40) years had the highest percentage frequency of 37.5, followed by 23.6 percent for (41 – 50) years. The age group (51 - 60) years, represented with 18.1 percent, 11.1 percent for those aged, (61 and above), 6.3 percent for the youthful (21 – 30) years, with the lowest, 2.8 percent being those aged below 20. In addition, the male population of respondents for all age categories were relatively more than the female, except for the age group

(> 60 years) where there was a tie. This information depicts a predominantly mid-youth respondent group, followed by an aged and younger population (Figure 20).

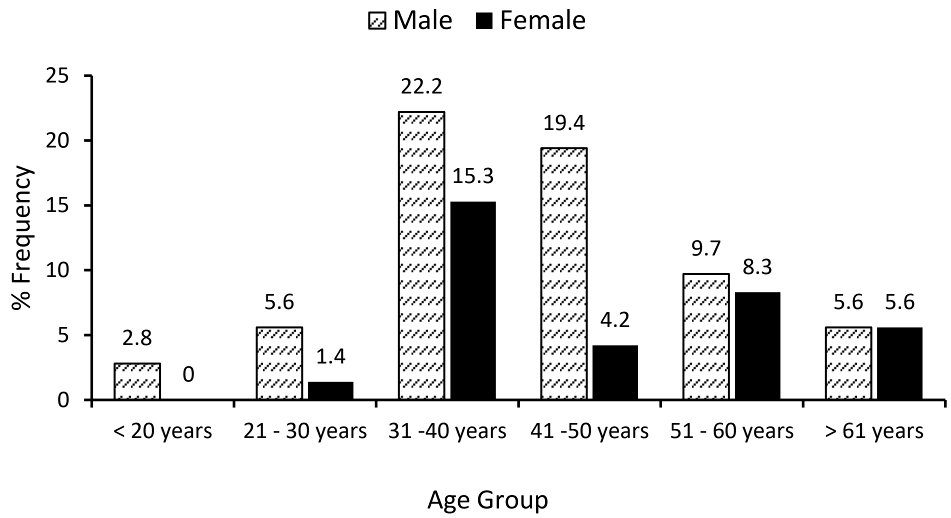


*Figure 20:* Age classes of respondents around the Fosu Lagoon

The literacy rate is generally low for the respondents. 21 individuals (29.2 %) and 29 individuals (40.3 %) respectively, had up to only basic education. On the other hand, education up to the secondary and tertiary levels, representing higher-level learning were 6.9 percent (5 individuals) and 9.7 percent (7 individuals) respectively. 13.9 percent of the respondents had no formal education.

Among the respondents were 20 fishermen, representing 27.8 percent as the highest among all occupations. Traders, predominantly women, were 14 in number, representing 19.4 percent. Mechanics and construction workers, mostly, masons had 15.3 percent and 11.1 percent respectively. Some of the residents being teachers, constituted 8.3 percent, followed by fish processors, 6.9 percent. Livelihoods relating to tourism and health, constituted a relatively small percentage 5.6 and 4.2. Finally, one farmer reported the lowest percentage, 1.4. A mean of 23.93 representing average 24 years of respective occupations can be observed from the Table 9 Maximum and minimum years of occupation engagement were 50 and 2 years, respectively out of which the most frequent occurring years in occupation was 30 (Figure 21).

**Table 9: Demographics of respondents**

| **Variable** | | **Respondents** | | |
|---|---|---|---|---|
| | | **Male** | **Female** | **Total** |
| **Gender** | | 47 (65.3%) | 25 (34.7 %) | 72 (100 %) |
| **Age** | (up to 20 years) | 2 (2.8%) | - | 2 (2.8%) |
| | (21 – 30 years) | 4 (5.6%) | 1 (1.4%) | 5 (6.3%) |
| | (31 – 40 years) | 16 (22.2%) | 11 (15.3%) | 27 (37.5%) |
| | (41 – 50 years) | 14 (19.4%) | 3 (4.2%) | 17 (23.6%) |
| | (51 – 60 years) | 7 (9.7%) | 6 (8.3%) | 13 (18.1%) |
| | (> 61 years) | 4 (5.6%) | 4 (5.6%) | 8 (11.1%) |
| **Educational Level** | Primary | 17 (23.6 %) | 4 (5.6 %) | 21 (29.2%) |
| | JHS | 18 (25 %) | 11 (15.3 %) | 29 (40.3%) |
| | Secondary | 2 (2.8 %) | 3 (4.2 %) | 5 (6.9%) |
| | Tertiary | 4 (5.6 %) | 3 (4.2 %) | 7 (9.7%) |
| | None | 6 (8.3 %) | 4 (5.6 %) | 10 (13.9%) |
| **Marital Status** | Married | 32 (44.4 %) | 13 (18.1 %) | 45 (62.5 %) |
| | Single | 4 (5.6 %) | 3 (4.2 %) | 7 (9.7 %) |
| | Divorced | - | 1 (1.4 %) | 1 (1.4 %) |
| | Separated | 11 (15.3 %) | 8 (11.1 %) | 19 (26.4 %) |
| **Occupation** | Fishing | 20 (27.8 %) | - | 20 (27.8 %) |
| | Construction | 8 (11.1 %) | - | 8 (11.1 %) |
| | Mechanic | 11 (15.3%) | - | 11 (15.3 %) |
| | Farming | 1 (1.4 %) | - | 1 (1.4 %) |
| | Trading | 1 (1.4 %) | 13 (18.1 %) | 14 (19.4 %) |
| | Fish Processing | - | 5 (6.9 %) | 5 (6.9 %) |
| | Health | 3 (4.2%) | - | 3 (4.2%) |
| | Education | 2 (2.8 %) | 4 (4.2 %) | 6 (8.3 %) |
| | Tourism | 1 (1.4%) | 3 (4.2 %) | 4 (5.6 %) |

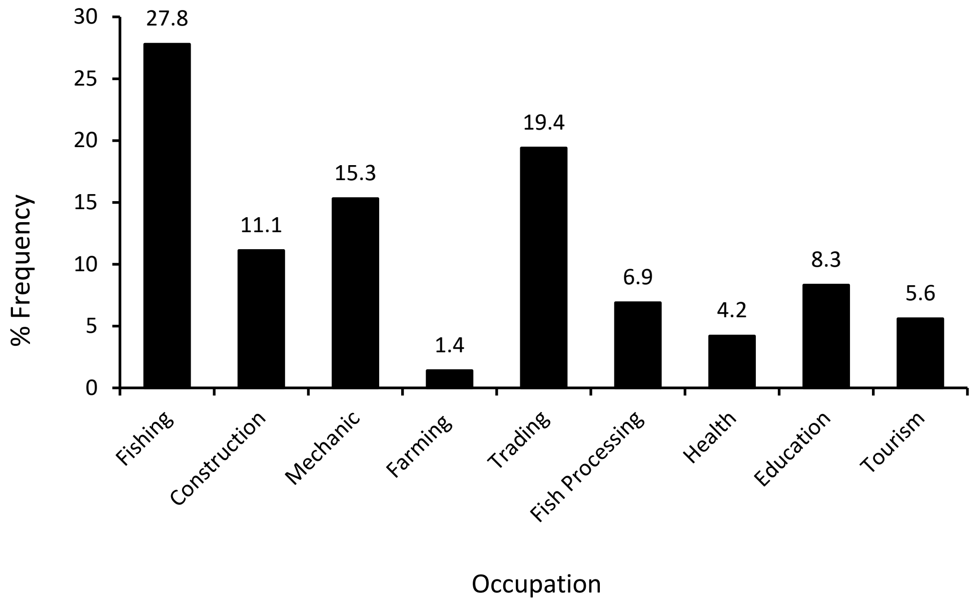


*Figure 21:* Occupation of respondents around the Fosu Lagoon

A majority 61 individuals representing 84.7 percent proved to have been staying near the lagoon for the range of distance (10 - 500m). On the other hand, 11 individuals, representing 15.3 percent indicated, staying (> 500m) away from the lagoon. Out of the majority 84.7 percent, 44 individuals (61.1 %) of the respondents resided in very close proximity (10 – 100m) to the lagoon. 17 individuals (23.6 %) of the respondents residing (101 – 500 m), followed. An average of 26 years was recorded for the duration of stay of the respondents at their respective abode. The least and highest duration of years spent at their various homes were 4 and 50 years respectively. This depicted a relatively long-term stay of respondents around the lagoon, indicating readily available of information, critical to the work.

Majority percentage, 83.3 of the population generally indicated to be working close to the lagoon. About 65.3 percent were working either in or in very close range to the lagoon (10 - 100m). The (101 – 500m) and (> 500m) range of distance from the lagoon in relation to livelihoods, were 18.1 percent and 16.7 percent respectively. Analysis indicated minimum and maximum years of work to be 2 and 50 years respectively. The average number of years of work at various distances was 21 indicating a relatively longer time spent in work as far as the lagoon is concerned as indicated in table 5.

**Respondent Perception of Lagoon**

98.6 percent of the total 72 individuals, indicated "Yes" to interest in existence of lagoon. However, one individual opposed. Reasons ranged from food, livelihood, tourism, cultural heritage, biodiversity support and their respective combinations. Livelihood & food as one combination, food and livelihood (as singles) constituted the highest percentages, respectively 23.6, 22.2 and 15.3 (Figure 22). The least occurring reasons (1.4 % each) were respectively for biodiversity support, and the one person expressing disinterest in the lagoon. All remaining reasons had fair representations.

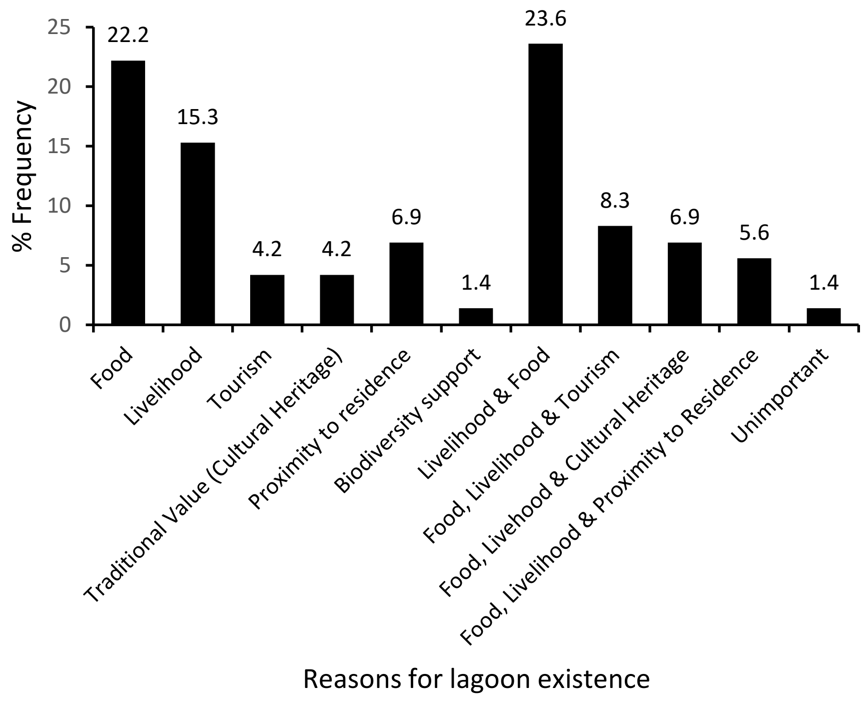


*Figure 22:* Perception about lagoon existence

The perception of changes on the lagoon, according to the respondents was, 100 percent. General trend of changes of lagoon ranged from filth, unwanted vegetation, flooding, siltation and their combinations. The combination (filth, vegetation & siltation) was 29.2 percent, being the highest. On the other hand, disregard for traditional laws, recorded the lowest percentage of 1.4. Other combined reasons had fair representations among the respondents as seen in Figure 23.

Respondents, hinted that these changes were observed about (11 – 20 years) ago, constituting 73.6 percent, followed by 6 – 10 years (19.4 percent). 4 individuals (5.6 percent) indicated that these changes started over 21 years ago. General results proved that observed changes had been occurring for a relatively long time.

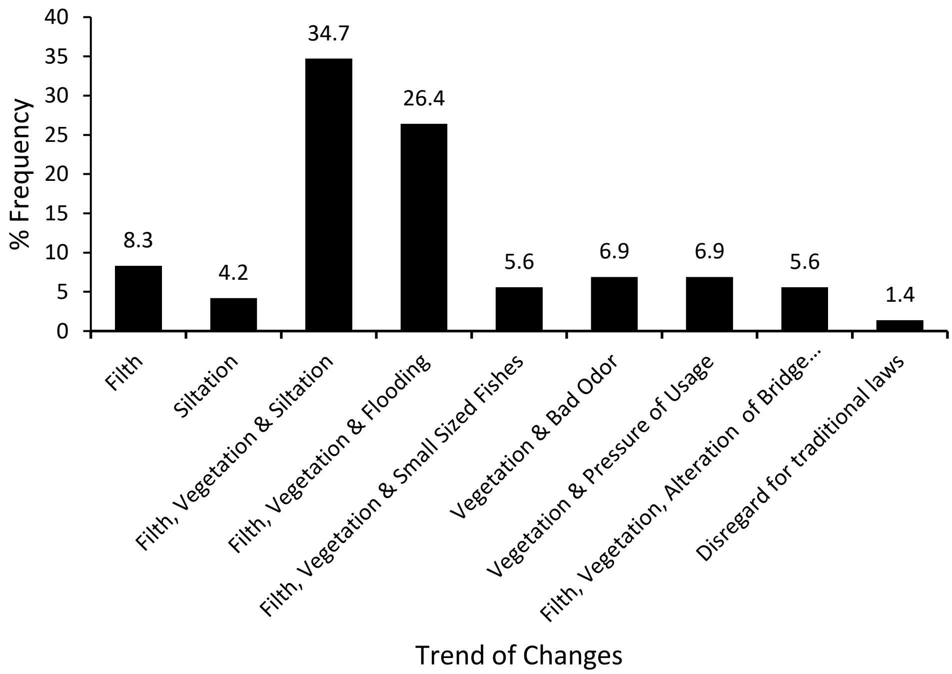


*Figure 23:* Trend of changes occurring within & around lagoon

Questions posed strictly to Fishermen, concerning lagoon depth, by virtue of their work and livelihood revealed that all the twenty fishermen knew about lagoon depth. 95 percent of them agreed that the lagoon depth had changed with time, with one opposing. Out of the 20 fishermen, 55 percent agreed that the depth of the lagoon had normally reduced. 25 percent indicated that lagoon depth has reduced drastically. 15 percent agreed that depth reduction occurred in specific areas with remaining 5 percent suggesting no difference in depth of the lagoon.

Various threats identified about the lagoon were defined and presented to respondents in a five Likert Scale format, that is, (Strongly Agree, Agree, Uncertain, Disagree & Strongly Disagree). In that order, Strongly Agree, was the highest, with the figure (5), decreasing to Strongly Disagree (1). The calculated true mean of the threats was then calculated to be (3.0), the reference figure about which the mean of the various threats were compared as shown in Table 10. The highest mean for a threat was 4.3194, representing blooms that are fast spreading across all portions of the lagoon and causing shrinkage of the lagoon. Following this was the means for 4.2917 and 4.1250 found for the threats, siltation and improper refuse disposal respectively. The least mean was 2.4722 for deforestation practices around the lagoon. Other threats e.g. mechanical waste and encroachment were slightly higher that the true mean with means 3.6389 and 3.3056 respectively.

**Table 10: General threats to lagoon**

| Threats | N Stat. | Mean Stat. | Mean Std.Error |
|---|---|---|---|
| Mechanical waste affect health of biodiversity in/around the lagoon | 72 | 3.639 | 0.112 |
| Leachates & effluents influence nutrients & cause algal blooms | 72 | 3.917 | 0.098 |
| Algal blooms are gradually spreading & contributing to lagoon shrinkage | 72 | 4.319 | 0.086 |
| Improper refuse disposal is consuming portions of the lagoon | 72 | 4.125 | 0.095 |
| Erosion and Siltation have been major causes for depth reduction | 72 | 4.292 | 0.107 |
| Agricultural activities influence the chemistry of the water | 72 | 2.681 | 0.086 |
| Overfishing is causing depletion of fish species in the lagoon | 72 | 3.694 | 0.139 |
| Deforestation is destroying the habitats of some biodiversity | 72 | 2.472 | 0.093 |
| Encroachment and recreational activities have effects on the lagoon | 72 | 3.306 | 0.134 |
| Open defecation is rampant around the lagoon surrounding | 72 | 2.569 | 0.161 |

**Scale: 1.00-1.49 (SD); 1.50-2.49 (D); 2.50-3.49 (U); 3.50-4.49 (A); 4.50-5.00 (SA)**

**Restoration & Support System for Lagoon**

Questions regarding restoration, posed to respondents revealed that 71 individuals (98.6 %) out of 72 believe that the Fosu Lagoon can be restored. Respondents suggested a number of measures ranging from dredging, desilting and clearance of weeds & unwanted vegetation. The combinations, (Dredging, Desilting & General Cleaning), (Dredging & Clearance of Weeds) and (Dredging & Desilting) significantly had the highest percentages, 25, 19.4 and 19.4 respectively. Deep Water Dredging followed with 13.9 percent, with the rest having fair representations of the total percentage as indicated in Figure 24 below.

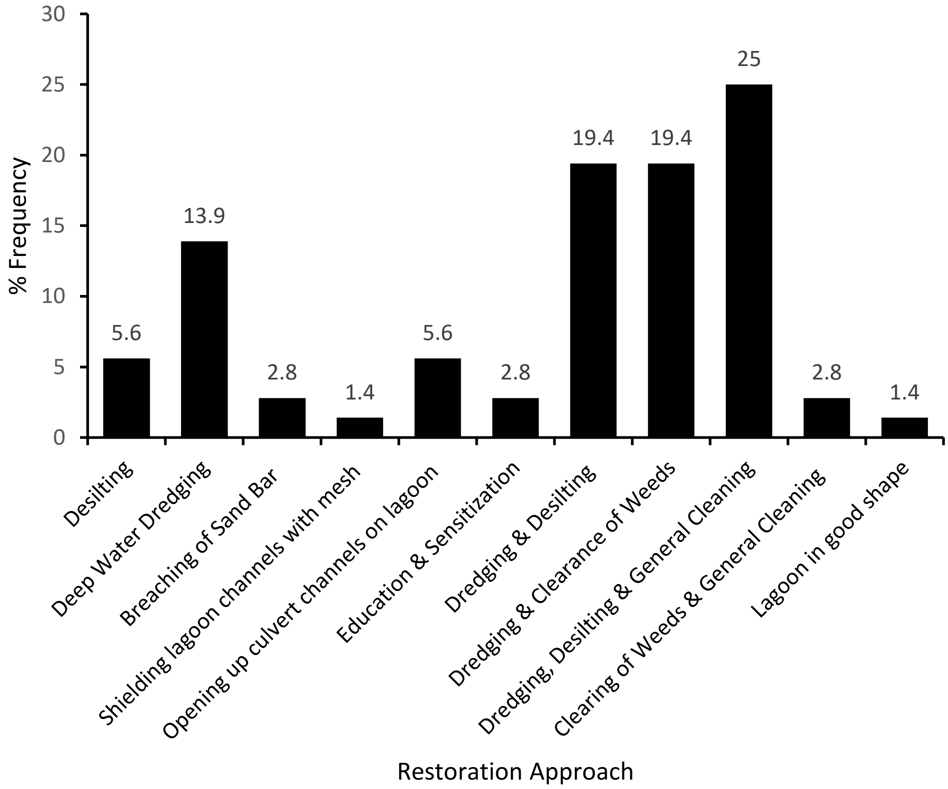


*Figure 24:* Restoration Approaches for Fosu Lagoon

Further, respondents gave insights into the groups of stakeholders who should play major roles in making the restoration a reality. The combination of (Fishermen, Policy Makers (PM) and Traditional Authority (TA)) had the highest percentage of 43.7. The second combination had same stakeholders as the first in addition to academia, constituting 16.9 percent. The combinations, (Fishermen, Traditional Authority & General Population (GP)) and (Fishermen & Policy Makers reported the lowest percentage, 8.5 each. Remaining combinations had fair representations each as seen in Figure 25. Respondents generally indicated that they were ready to support the lagoon restoration process and play their roles alike. Whiles 58 individuals (80.6%) out of the total were ready to support the process irrespective of their jobs, 14 (19.4) were not.

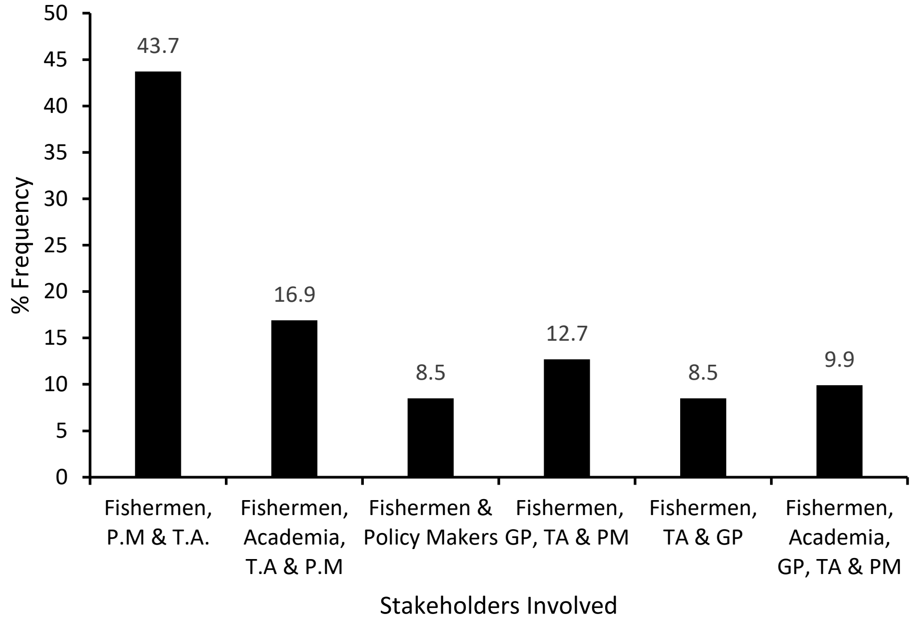


*Figure 25:* Stakeholders involved in restoration

About 45 individuals (62.5%) agreed to the fact that restoration efforts have been channeled to the lagoon in the past, even though, 27 individuals (37.5%) did not. Out of the 62.5 percent, several reasons could be connected to the current lagoon situation. These were lack of commitment, inconsistencies/irregularities in effort, lack of collaboration between stakeholders and unavailability & embezzlement of funds constituting respectively in percentages, 23.6, 27.8, 4.2 and 8.3. On the other hand, remaining 37.5 percent of individuals who did not agree to efforts of restoration in the past, suggested investment & commitment of funds, proper collaboration organization, commitment to efforts, and education & sensitization as ways to help facilitate the restoration process. Respectively, they constituted 11.1, 9.7, 9.7 and 5.6 in percentages of the total.

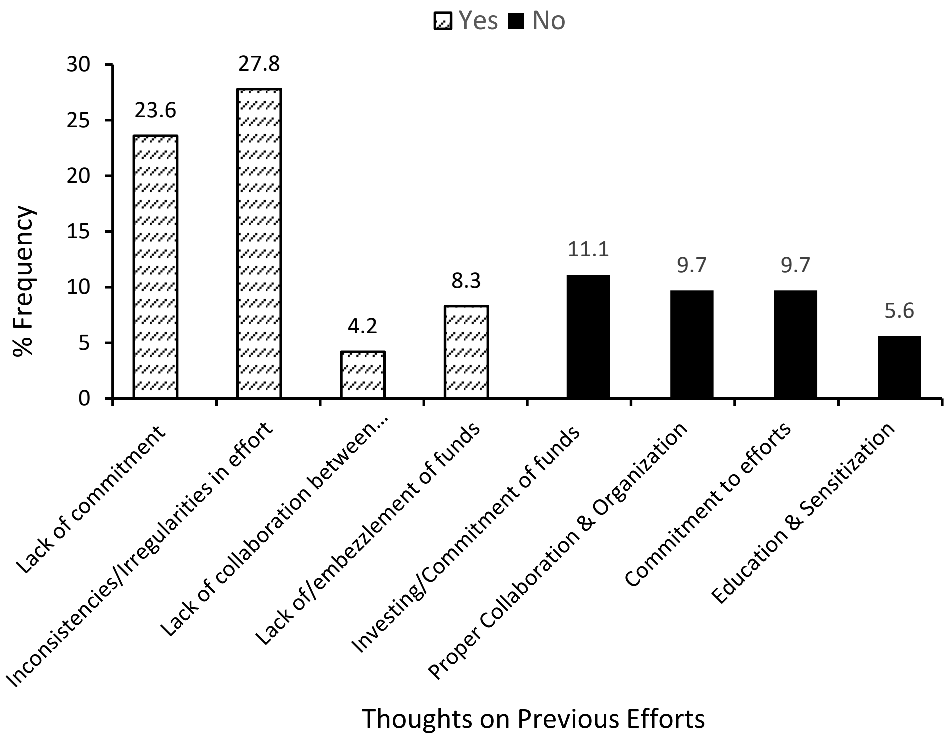


*Figure 26:* Thoughts on restoration efforts towards the lagoon

# CHAPTER FIVE

# DISCUSSION

## Introduction

This chapter discusses the findings of this study. The chapter is organized into three sections. First, the LULC of the Fosu lagoon's watershed, detailing the five main land classes and their characteristic change over close to three decades and their effect on the lagoon is interpreted. Secondly, estimations of regression models establishing the relationship between water quality parameters and World-View 2 imagery is discussed. Finally, social perceptions about the Fosu lagoon is also discussed.

## Dense Vegetation

In this study, the dynamism of changes in the LU/LC of dense vegetation, inherently made up of forests could be linked to mainly, anthropogenic activities due to which its space decreased from 50.91 $km^2$ (50.6 %) to 34.59 $km^2$ (34.4 %) over the period, studied. Amisah et al. (2009) indicated that, in Ghana, forests provide goods e.g. timber and other non-timber products, such as bamboo & game, helping most communities to meet requirements for rural economy. Possible reasons for reduction in areas of forests in Ghana could be due to aggravated human exploitation for some of these goods and services within the area over the time. The demand for various products from timber such as furniture, fuelwood, paper, etc. is high and therefore require their incessant harvesting. Amisah et al. (2009) further indicated that the livelihoods of about 20 million inhabitants, mostly in rural areas are said to be highly dependent on forests confirming this reduction. Further reports of forest reduction, especially from the 2010 Forests Resources

Assessment indicated that in Ghana, an annual 2% loss representing (135,000 ha) of forest from 1990 – 2000 was recorded (FAO, 2010).

Anthropogenic activities ranging from unsustainable agricultural practices, excessive logging, bush fires, firewood collection, and charcoal production, population pressure and poorly defined land and resource could be some of the reasons for the reduction in the forest space over the period. Appiah et al. (2009) hinted on other possible external factors, which could contribute to the reduction of forest space in Ghana, such as market failure, international trade, and the imposition of certain economic schemes, typically the Structural Adjustment Program (SAP). Both internal and external factors that cause reduction in forest areas, inherently converts these spaces to mainly, areas of sparse vegetation and bare lands overtime. The continuous exploitation with little or no efforts to replace cut down trees lead to long-term deforestation that presents its own consequences within an area, as seen in this study.

Observing the maps Figures (7, 9 & 11) of the respective years, areas that were previously covered with dense vegetation began by being converted to sparse vegetation, and then to bare lands and finally to built-up. A similar case was presented in Mushtaq & Pandey (2013) with a relatively wider scope of area, 425 $km^2$, more than times four, the area considered in this study. In their study, forest decreased in an area from 93 $km^2$ (21.88 %) to 32 $km^2$ (7.52 %) from 1992 to 2008, respectively representing a duration of 16 years. The authors reported a 61 $km^2$ reduction in forest space, converted to scrublands and agricultural space, which was later, converted to built-up comparing to previous years. Similar to this work, the authors described the changes in LU/LC as primarily the consequence of human activities. According to the work, the rapid degradation of forest indicated their exploitation for fuel wood and overgrazing of pastures within the area, which consequently lead to soil erosion and sedimentation. Observation of the map of 1991 showed that Forests were mostly thick at upland areas whiles the water body, inclusive the Fosu lagoon is located, lowland, close to the nearby ocean. Like Mushtaq & Pandey (2013), increased levels of exploitation of forested areas could affect the lagoon, lowland through regular soil erosion and associated sedimentation load of the lagoon leading to its loss of water-holding capacity. This situation was confirmed by the fishermen during the interview session in this study, that the lagoon depth has either mildly reduced or drastically reduced and in some cases with depth reduction in specific areas of the lagoon. They emphasized how much the Fosu lagoon readily floods to nearby areas during downpours, proving that the lagoon is shallow in terms of depth.

**Sparse Vegetation**

Areas of sparse vegetation increased moderately over the 27 years period from 21.14 $km^2$ (21 %) to 29.10 $km^2$ (28.9 %) mainly following the decline in the forest cover. As hinted already, the elements of sparse vegetation in this study were herbaceous vegetation, shrub and bush areas, and mixed grassland with few scattered trees. Different literature, Addae & Oppelt (2019) and Mushtaq & Pandey (2013) defined sparse vegetation and its elements respectively as grassland and scrubland even though the constituents are the same.

According to Liping et al. (2018), sparse vegetation may either follow natural events to develop or in most cases become the resultant effect of previously exploited forested areas following the events of previous anthropogenic activity. Following this, the slight increment in the area of sparse vegetation, in this study was due to loss of dense vegetation, representing a total percentage change of about 37.7 percent. However, this value was low relative to the increment of built-up. A number of reasons could be linked to this slight change in area of sparse vegetation, inherently made up of farmlands and plantations of scrub nature. Referring from GSS (2010), the Cape Coast metropolis has been considered to be undergoing urbanization at a relatively fast rate as compared to neighboring districts hinting a possible reduction in the rate of general farming and agricultural activities. Connected to this, it reported that individuals involved in agriculture and fishing were 7.4 percent, relatively lower as compared to other areas of occupation such as construction, transport and manufacturing. Whiles this could be given as the possible reason for the slight change in the sparse vegetation land class, low to moderate scale agricultural activities to feed family and for personal economic gains could be the justification for the change. In addition, the activities of charcoal production that is existent in smaller villages within the township could be considered a typical case of forest reduction that consequently transforms to sparsely vegetated areas and increase their space.

A similar moderate increment in the LULC of plantations and farmlands within the region of Wular Lake and its environs in India was reported (Mushtaq & Pandey, 2013). The authors highlighted a similarly slight increment in area from 75 $km^2$ to 87 $km^2$ representing a total increment change of 12 and 16 in square kilometers and percentage respectively, from 1992 to 2008. The main reason for increase in plantation for Wular lake environs was mainly economic, which caused the usage of certain agro chemicals to boost the growth of crops.

Consequently, these chemicals leached into the nearby lakes causing the deterioration of the quality of water for biodiversity. Similar possible reasons could be attributed to the Cape Coast township considering the fact that most plantations and agricultural activities were located upland and midland with a few within the catchment of the lagoon even though respondents from the interview conducted in this work responded negatively towards the influence of chemical fertilizers to the chemistry of the lagoon. In this regard, about 50 percent hinted on their uncertainties about it whiles about 41 percent hugely disagreed. While it remains uncertain from respondents that farming activities are reliably dependent on pesticides and other agrochemicals, other elements e.g., nutrients load, sediments and refuse were mentioned to directly end up in the lagoon considering its positioning, lowland.

**Built-Up**

The built-up change of the area yielded the highest total percentage change (90.4 %) increasing to about times two the size of the beginning year. In 1991, the built-up comprising residential areas, industrial and commercial units and other infrastructure were relatively few, covering an area of 11.60 $km^2$ increasing moderately to 17.41 $km^2$ (17.3 %) in 2007 and the leaping to 22.09 $km^2$ (21.9 %) in 2018 as shown in Figure 11. The trend of change observed for this LU/LC for the first phase suggest that the rate of urbanization was at a higher scale as compared to the second suggesting a massive drive for change from 1991 to 2007 in the metropolis. This trend of change could be justified by the ever-increasing rise in population within the study area. Series of anthropogenic activities, relating to urbanization and industrialization due to population growth accelerated the establishment of new residential and commercial structures. The many infrastructural & residential built-up were the result of conversion from other LU/LC such as forests, sparsely vegetated plantations and other bare lands. Observing the maps, most of the settlements and infrastructure were converted from areas of sparse vegetation and bare lands with minor to no farming activities, rendering their ease of conversions for developmental purposes. However, a few areas representing urban interests were found within the dense vegetation, located uplands indicating gradual invasions of such areas as well, due to anthropogenic exploitations.

The results of both Mallupattu & Sreenivasula-Reddy (2013) and Mushtaq & Pandey (2014) were similar to the results of this study as far as built-up is concerned. A dramatic increment from 7 $km^2$ to 52 $km^2$ representing 642.85 % was observed for built-up in the former whiles an increment from 5.91 $km^2$ to 18.34 $km^2$ representing 210.32 % was recorded for the latter. Considering the span of area across which both studies, in addition to this study were conducted, it can be said that all three total change in percentages were significant, indicating that increasing population is propelling the exploitation of resources and consequent urbanization and industrialization in most developing areas. According to Mushtaq & Pandey (2013), most of the built-up increment were because of invasion into areas of scrublands and little portions of agricultural plantations, which corresponds directly to the results of this study. In the case of Mallupattu & Sreenivasula-Reddy (2013), areas of agriculture land and water spread were focal points of conversion to settlements and urban related activities, including portions of lagoon and estuarine water that has reduced over the time, because of human encroachment.

Among the numerous consequences of the regular expansion of structures within the area of Fosu lagoon is flooding (Essel et al., 2019). Wrongful siting of some structures at certain points block waterways and drainage patterns that are created exclusively into the ocean from upland areas, causes floods, during heavy downpours. In addition, increased settlements, and encroachments very close to the Fosu lagoon were described to release effluents directly into it, which leads to long-term eutrophication, causing blooms in and around the lagoon environment. From Table 10, respondents confirmed to the practice of direct discharge of domestic effluents and the influence on lagoon nutrients and encroachment respectively. In addition, respondents agreed with the effects of irresponsible mechanical waste discharge on the health of lagoon and associated biodiversity and the effects of improper refuse disposal around lagoon surrounding. Essel et al. (2019) confirmed plastic waste and metal pollution as major threats to the lagoon. The author described the discharge of plastic waste into the lagoon as a major threat, hinting on the four major drains that carry huge amounts of plastic waste, some of which end up floating on the lagoon. The overarching cause of the menace of improper plastic disposal was described to be from improper management of waste due to improper household waste disposal through indiscriminate dumping of waste in drains. The existence of this situation could be easily connected to the regular increase of population, and associated urbanization and encroachment to suit human interest within the town.

**Bare land**

The term 'bare land' is described in other literature, Mallupattu & Sreenivasula-Reddy (2013) as 'other land'. In this study, bare land constituted areas of barren land, bare soil and sandy areas, exposed rocks, quarries and gravel pits and other transitional areas. Bare land exhibited unique dynamism in terms of its changes, over the period. Firstly, the area slightly increased from 14.01 km$^2$ to 17.43 km$^2$ (24.4 %) from 1991 to 2007 and rather reduced in size from 17.43 km$^2$ in 2007 to 13.12 km$^2$ in 2018 (- 24.7 %).

As hinted earlier, the relatively low population and associated slow urbanization status of the Cape Coast metropolis by 1991, gives the right indication of bare land representing 13.9 % of the total area. The rise from 14.01 km$^2$ to 17.3 km$^2$ for the first phase could have been the result of gradual expansion and creation of road networks linking localities, increase in bare lands, quarry activities and associated exploitation of some portions of forests whose long-term effects of deforestation could have led to the increasing transitional areas and barren lands. Mallupatu & Sreenivasula-Reddy (2013) reported significant increment in area of bare land from 15.64 km$^2$ to 38.22 km$^2$, expressing a net change of 22.57 km$^2$ (144.30 %) depicting increased urbanization and human exploitation through activities such as mining, and forest exploitation within the area.

Following the first phase of change in increased bare land, subsequent net reduction of (- 4.31 km$^2$) in area from 2007 to 2018 indicated a rather utilization of these bare lands, being converted to other establishments and settlements due to population increase and urbanization. This reduction can be confirmed with Mallupatu & Sreenivasula-Reddy (2013), confirming expectancy in reduction in the area of bare lands if they extended years of study into the future. The study hinted on some possible reasons of exploitation within the catchment connected to expected population increase. In a similar sense, Liping et al. (2018) presented a similar case where authors reported an initial net increase of 19.33 $km^2$ for its first phase of change and a second phase of net change of (- 8.86 $km^2$) in reduction. The authors traced the results of their changes to increased economic development and forest cutting within the city of Jiangle, in China.

Consequences of the dynamism of bare land on the Fosu lagoon watershed and catchment may be connected to sedimentation of the Fosu lagoon. Sedimentation within water bodies is known to cause them to reduce in depth, promote the growth of vegetation and even choke smaller water bodies El-Din et al. (2013) such as the Fosu lagoon. A statistically significant mean of 4.2917 proved that respondents agreed to this assertion that erosion and siltation has been a major cause of depth reduction of the lagoon in the past. On the maps, bare lands were mostly found upland with some scattered at lower parts of the watershed, close to the lagoon. Barren lands of soil and sandy nature are likely to be washed down during heavy downpours, into waterbodies, increasing their sediment load with time. Nineteen out of the twenty fishermen interviewed, representing 95 percent agreed to lagoon depth changing with time with, commenting on a possibly choked lagoon.

**Water body**

Two main water bodies existed within the catchment, namely, the Fosu lagoon and portions of the Kakum River, together with minor streams and other wetlands within the catchment. Together, they all constituted the waterbody class of the LU/LC. However, the vulnerability of the Fosu lagoon was under emphasis even though the consequences of anthropogenic activities on the lagoon could possibly be mentioned for the other water bodies. The lagoon is divided into two, by a bridge with the smaller one very close to the ocean at the southern end and the larger, north. Currently, the land cover of the lagoon catchment is dominated by unwanted vegetation with remnant areas of mangrove vegetation and the remaining, being water (Essel et al., 2019).

Water body in the Cape Coast metropolis for the period studied reduced from 3.05 km$^2$ to 1.93 km$^2$ and finally to 1.8 km for 1991 to 2007 and 2007 to 2018 respectively. Comparing the two phases of change, water body in the catchment reduced by (- 1.12 km$^2$), which was relatively more than the reduction of the second phase, (- 0.13 km$^2$). Overall total change in area of water body was - 1.25 km$^2$ (- 41.0 %) showing a clear decrease in area of water body. However, the relative high reduction from 1991 to 2007 could have been due to the gradual increase in population during the period and the pressure it posed on resources. Considering this water body reduction in the catchment, the Fosu lagoon within the area possibly reduced in size, with consequent reduction in depth. According to Essel et al. (2019), a decline in the standing water of the Fosu lagoon from about 1970 to present, is said to have occurred. Respective areas of 0.60 km$^2$, 0.45 km$^2$ and 0.39 km$^2$ was recorded as the extent of standing water of the lagoon for the years 1970, 2009 and 2017 using used a high-resolution aerial photo in a harmonized manner with object-based classification technique to map the lagoon and its associated vegetation. In addition, a commentary of the lagoon's depth over the period of 40 years, indicated a reduction as confirmed by fishermen whose feeding and livelihoods are primarily dependent on the lagoon. Similarly, Mallupattu & Sreenivasula-Reddy (2013) recorded reduction in water spread from 12.09 km$^2$ to 9.91 km$^2$ from 1976 to 2003 (27 years), same number of years as that used in this study.

The striking difference however was between the overall spatial extents of study areas, which in this study was lesser (100.7 $km^2$) than that of the former (125.00 $km^2$) conducted within the catchments of the urban area of Tirupati in India. Other studies, Mushtaq & Pandey (2013) and Liping et al. (2018), conducted in parts of India and China respectively, proved reductions in the spread of water bodies comparing with previous years.

Over the years, various reasons could be linked to the Fosu lagoon's standing water and depth reduction, under the scope of LU/LC, most of which are anthropogenic as well as other natural causes, such as climate change (Essel et al., 2019). Observation and field interviews indicated that the reduction in the lagoon's standing water and depth was due to the presence of unwanted vegetation and blooms, erosion and siltation, human encroachment that has resulted in refuse and filth, and degradation of the lagoon in general. Largely, the LU/LC in the watershed of the Fosu lagoon, over the past few decades has contributed to its current degraded state. Rapid urbanization within the Cape Coast metropolis because of weak regulations regarding land use has contributed to the degradation of the lagoon's habitat (Essel et al., 2019). In this regard, high demand for land coupled with improvement in standard of living in the city has triggered urban dwellers to acquire environmental sensitive areas.

According to Essel et al. (2019), the mechanical workshop, sited at the northern end of the lagoon, covers an area of 7.10 acres (0.03 $km^2$), being the biggest in the metropolis, thereby accommodating huge numbers of vehicles for servicing. Respondents described the mechanic shop to have been farther inland in the past, which with time has encroached close to areas of the lagoon water. In addition, they indicated a significant mean of 3.6389 for reasons for mechanical wastes having effects on the health of biodiversity in and around the lagoon because of improper treatment and discharge before discarded into the lagoon. Eshun (2011), revealed high levels of metals (iron, lead, zinc, and manganese) in the lagoon sediment and fish samples, as confirmatory basis of the mechanic effects of the lagoon. Other establishments within the lagoon's catchment regularly release effluents into the lagoon directly. Essel et al. (2019) hinted on four main drains from the inner city of Cape Coast connecting to the lagoon. Released effluents inherently increases the nutrient load of the lagoon leading to increment in unwanted vegetation and associated weeds some of which form dense mats, disrupting the aquatic environment by impeding the penetration of light and gaseous exchange, as well as promoting sedimentation as in the case of Mushtaq and Pandey (2013). This unwanted vegetation were mostly observed around the banks of the lagoon, aggregated more at points of regular effluents passage and entry into the Fosu lagoon. In addition, the biochemistry of the lagoon is affected in myriad ways, some of which alter the hydrogen ion concentration (pH), reduces the dissolved oxygen (DO) content, and salinity of the water, which affects biodiversity, especially fauna.

**Accuracy Assessment**

For classification data to be accepted in the event of change detection, it is essential to perform accuracy assessment for the respective classification maps (Cheruto et al., 2016). Accuracy assessment is a crucial part of studying image classification and LU/LC in order to prepare near accurate maps. It reveals the extent of correspondence between what is on the ground and the classified maps.

In this study, google earth images for 1991, 2007 and 2018 were used for the accuracy assessment, where 50 random GPS points with 10 points in each class were generated for verification between classified maps (data) and google earth (reference data). Accuracy assessment performed for the three classified maps (1991, 2007 and 2018) to produce the Kappa values as done in (Cheruto et al., 2016). Kappa statistics obtained for 1991, 2007 and 2018 were 0.675, 0.725 and 0.649. The range within which Kappa values for the study fell (0.4 – 0.75) proved moderate consistencies between the generated maps and what is on the ground, suggesting that maps were fit to be accepted.

While the Kappa coefficients in this research were generally moderate, comparison with Essel et al. (2019) and Mohajane et al. (2018) showed that Kappa coefficients were relatively low in this study. While the former had Kappa values of 0.8599 and 0.8251 for 2009 and 2017 respectively, the latter presented 0.413, 0.974, 0.995, 0.998 and 0.999 for 1987, 1995, 2000, 2011 and 2017 respectively. Both studies had very strong Kappa values for most of the years, studied. The difference in Kappa value for this study, relative to the two other studies could be the fact that accuracy assessments were performed by going to the field to pick random GPS points (ground trothing) instead of using google earth to generate due to the relatively smaller area, especially for Essel et al. (2019). Secondly, the relatively few LU/LC classes (3) used in Mohajane et al. (2018) could have contributed to attaining such high coefficients of Kappa, due to possible minimized errors.

**Regression Analysis between WQPs and WV-2**

This research sought to deduce a possible relationship between some of the WQPs of Fosu lagoon and reflectance values of the WV-2 band for the same lagoon by performing regression analysis. The results of this study indicated that it was essential to select feasible combinations of bands of WV-2 in multiple linear regression analysis although models were quite different in the selected bands of other studies (Yang et al., 2016; Wang et al., 2006; El-Din et al., 2013). Following this, reflectance values of the WV-2 satellite to recognizable water quality variables was estimated using developed regression models for a possible water quality monitoring system of the Fosu lagoon.

Out of six WQPs, three, (DO, pH & turbidity) were highly correlated while the remaining two (Conductivity & TDS) in addition to depth had relatively weak correlations even though some level of biasness could occur due to the small sample size for the points of data collection as compared to other studies. From the regressions estimated and the $R^2$ values observed (Table 8), the band ratios B1/B3, B2/B4, B4/B3, B2/B5, B3/B4 and Band (B6) from WV-2 satellite were adopted for Depth, DO, pH, turbidity, and conductivity and TDS respectively. While the time discrepancy between acquisition date of satellite imagery and data collection of WQPs could cause errors, the stagnant nature of a classical closed Fosu lagoon and the stable weather condition between both events, minimized it. In reality, the issue cannot be completely avoided (Yang et al., 1996) because of the time consumption nature of in-situ data collection and lags in between satellite data acquisition. Unlike other studies Yang et al. (1996) and El-Din et al. (2013) where other GIS operations, such as feature extraction, interpolation and image creation were developed into an automatic water quality monitoring system in different software, this study focused on a novel development of regression models for the Fosu lagoon that could have been used for further biological data monitoring.

**$R^2$ for Depth**

Depth was included in the parameters to be able to develop a possible linear equation model for bathymetry for the Fosu lagoon, similar to (El-Din et al., 2013). Among all seventeen bands and band ratios used for regression against depth, the band ratio B1/B3 (Coastal Blue / Green) produced the highest $R^2$ value of 0.321. This value, though highest among the other $R^2$, presented a weak correlation between B1/B3 and depth since it presented barely 32.1 percent correlation between the variables. Though El-Din et al. (2013) used WV-2 satellite for water quality assessment in Lake Timsah of Suez Canal in Egypt, the three shortlisted band ratios among which the highest was used, were different which were 2/3, 4/2 and 3/4. These band ratios presented $R^2$ values of 0.368, 0.522 and 0.445 respectively. The same band ratios used in El-Din et al. (2013) presented $R^2$ values of 0.277, 0.229 and 0.003 respectively in this study. Even though comparison proves $R^2$ values from this study to be relatively low, the band ratio 4/2 is observed among the band ratios with high $R^2$ suggesting a general support for this band ratio and water depth as far as the usage of WV-2 satellite is concerned. However, while the highest $R^2$ value for the band ratio 4/2 for El-Din et al. (2013) was 0.5226, indicating 52.26 percent correlation between the band ratio (4/2) and depth, it was 0.229 in this study. The possible differences in final band selection for the different waters for depth could have been due to the sixteen sites used in the Lake Timsah as compared to the nine sites from the Fosu lagoon. In addition, the morphology (near oval and triangular) and nature of the two different water bodies (lagoon & lake) differ. Whiles the Fosu lagoon is a classical closed water body with minimal movement of water, a regular flowing lake Timsah could influence its depth, which could possibly influence the selection of bands or band ratios. Finally, weather conditions of the different sites could also have influenced band selection for depth in a way.

The model linear equation for depth (Y = 40.03X - 43.59 (X = B1/B3)) in this study could have been used to develop a temporal bathymetry map for the Fosu lagoon where the dynamism of depth of the lagoon across its spatial dimensions could have been estimated. However, due to the relatively few sites for WQPs extraction on the Fosu lagoon, interpolation for the creation of maps for depth could not be attained. On the contrary, the mapping of depth for the Lake Timsah formed a part in a subsequent sediment investigation for bio monitoring.

**$R^2$ for DO**

The $R^2$ values produced by DO, generally presented significant correlation between the parameter and the WV-2 reflectance data. The first three highest $R^2$ values were 0.512, 0.506 and 0.501 produced from regressions with band ratios B2/B4, B4/B2 and B2/B3. Out of these values, B2/B4 (Blue / Yellow) produced the highest $R^2$. This value hinted a strong, significant correlation between B2/B4 and DO. However, from Figure 15, the direction of slope was downward, indicating a possible decreasing DO with a corresponding increase in reflectance band ratio, B2/B4. The linear equation produced from this relationship was (Y = - 12.99X + 21.73 (X = B2/B4)). This equation presented proved the possibility monitoring of DO in the Fosu lagoon basing on the possibility of making a map that can be used to study the dynamics, similar to the case of (El-Din et al., 2013).

In other literature, Somvanshi et al. (2012), where investigations into a possible model estimation of DO on Gomti River was done for pre-monsoon and post-monsoon seasons, the $R^2$ values were 0.7601 and 0.563, produced by regressions with B3/B1 and B4/B1 respectively. The changes for both values indicated the seasonal differences for which the data were collected. The differences in band ratio compatibility for DO between Somvanshi et al. (2012) and this study could be linked to the usage of different satellites for band extraction and regression analysis. The former used the Indian Remote Sensing Satellite (IRS) P6 LISS III (Path - 100, Row - 52, 53) with four bands including near infrared (NIR) and middle infrared (MIR) while the WV-2 used in this study had eight bands. Secondly, the periods of pre-monsoon (10th May 2006) and post-monsoon (6th October 2006) for which the IRS satellite data were acquired, were different from WV-2 satellite data capture date (8th December 2018) in this study. Possible differences between band ratios selection for DO could exist due to the unique nature of weather at the different times even though the pre-monsoon period is synonymous to dry season, similar to December. Another reason for the differences could be due to the nature of ever flowing Gomti river, and the total number of sites for data collection as compared to a relatively few points for DO data collection from the Fosu lagoon.

Similar to this study, Dewidar & Kedr (2005) who conducted their water quality studies on Burullus Lake in Egypt, at twenty-one sampling points using Landsat Thematic Mapper produced low $R^2$ values that did not merit the production of a possible DO map. In this case, author could not really ascertain a reason to the extremely low $R^2$ values of DO, but hinted on a possible incompatibility of the Landsat data used or selection of bands and band ratio.

**$R^2$ for pH**

The concentrations of hydrogen ions (pH) of Fosu lagoon for the period collected can be interpreted as alkaline. $R^2$ values obtained from regression analysis with band and band ratios were clearly the highest among all the parameters used in the study. The top three $R^2$ values were 0.8209, 0.8207 and 0.534, produced from regressions with band ratios, B4/B3 and B3/B4 and single band, B4. Aside the fact that the highest $R^2$ was produced from regressions with B4/B3, B4/B3 produced the $R^2$ that is only slightly lower (0.0002) than the former. Interestingly, the single band that also produced the third higher $R^2$ value was Band 4. Derivations from this observation is that, Band 4 (Yellow) and Band 3 (Green) are inherently involved in regressions of pH that produced the top three $R^2$ values as far as the usage of WV-2 is concerned.

The linear model equation brought out of this regression was Y = -24.93X + 28.89 (X = B4/B3). Even though the correlation between pH and WV-2 reflectance value was the strongest, (0.8209), the nature of the relationship was a somewhat negative one, since for every increase in value of B4/B3, there is a corresponding decrease in pH values of the lagoon.

The $R^2$ value of this study for pH was similar to that of El-Din et al. (2013) which also had a significant $R^2$ value (0.546) from B3/B4. In addition, B4/B3 produced the second highest $R^2$ value of 0.526 in El-Din et al. (2013), expressing similarity to this study in terms of the slight difference between the values. From observation of both studies, it can be proposed that for pH studies on different water bodies with WV-2 satellite, the bands B3 and B4 can be used to retrieve high $R^2$ values and possible linear model equations to be used to create maps for it, for subsequent bio-monitoring.

Somvanshi et al. (2012) presented pH values that depicted alkalinity for both pre-monsoon and post-monsoon seasons. The study presented high $R^2$ values of 0.739 and 0.7082 from band ratios B3/B1 and B4/B1, proving the inherent presence of the bands 3 and 4 in the extraction of a model for pH, regardless of the difference in satellite used in the different studies.

**$R^2$ for Turbidity**

Out of the single bands and band ratios, B2/B5 produced the highest $R^2$ value, 0.648 from regression with turbidity. The two other higher producing $R^2$ values were 0.579 and 0.534 for B1/B5 and B5 respectively. $R^2$ values for turbidity, relative to the other parameters were high and significant. From these three shortlisted band ratios and single band, it could possibly be deduced that the Band B5 (Red), is a critical band for the estimation of turbidity for any water body in an event that WV-2 is used. Considering the relationship between the band ratio B2/B5 and turbidity, the correlation co-efficient (r) value indicated a high positive correlation (0.805). Interpretation made from the strength of this correlation is that while the band ratio B2/B5 rose, the turbidity of Fosu lagoon rose too. Similar interpretation could be given to the band ratio and single band (B1/B5 and B5). The linear equation deduced from this relationship is $Y = 112.85X - 175.59$ ($X = B2/B5$).

Wang et al. (2006) proved the possibility of using Landsat-5 imagery to extract $R^2$ values of turbidity for the Reelfoot Lake in Tennessee adopting the bivariate and multivariate regression. From their study, the band ratio of bivariate regression that produced the highest $R^2$ was B3/B2. The second best and third best predictors were B2 and band ratio B4/B3. Respectively, they presented 0.367, 0.266 and 0.242 $R^2$ values.

The differences in $R^2$ values between Wang et al. (2006) and this study could be the difference in satellite imageries used, especially considering their spatial resolutions (moderate and high). Following this, band arrangement and orientations for both satellites also differ which may influence the result. Considering the difference in approach of regressions, that is linear for this study, bivariate, and multivariate for Wang et al. (2006), differences in $R^2$ values for the latter is purported to be finessed in a way to get them to near accurate predictions. The same approach was adopted in Mushtaq & Nee Lala (2017) where they used several enhancements such as Normalized Difference Vegetation Index (NDVI) as part of regression analysis against turbidity to attain a high $R^2$ value. In this instance, the regression equation was rather exponential.

**$R^2$ for TDS**

Regression analysis conducted between TDS and reflectance values of WV-2 presented the lowest values among all the parameters, where 0.000 were recorded. The highest $R^2$ value was 0.019, deduced from the regression between B6 (Coastal Red) and TDS. Following this was the $R^2$ values for B1/B3 and the single band B2 with respective values 0.014 and 0.010 respectively. Even though the existent relationship between WV-2 reflectance value and turbidity presented a relatively low correlation, it was positive hinting that while B6 increased, the turbidity increased as well.

In Mushtaq & Nee Lala (2017), the likely predicted model of TDS was by Landsat 8 OLI Band 4 (Red) with $R^2$ value of 0.61, a strong positive correlation. However, this correlation was rather exponential instead of linear as used in this study. In Somvanshi et al. (2012), TDS predictions were made with B3/B1 (NIR / Green) and B4/B1 (MIR / Green), producing the highest $R^2$ values for pre-monsoon and post-monsoon seasons respectively. The differences for $R^2$ between these studies and this one could be the variations in satellite and band orientations, not excluding differences in the number of points for data collection of WQPs from the respective water bodies.

Results obtained in this study for TDS could hint the possibility for using the single B6 for the monitoring of TDS of the Fosu Lagoon as far as the usage of WV-2 satellite data is employed following that the study produced the model equation Y = 0.019X + 4.630 (X = B6).

**$R^2$ for Conductivity**

Concerning conductivity, the top three best predictors for linear model equation were 0.047, 0.041 and 0.029 for single bands B2, B7 and B8 respectively. Considering that $R^2$ values for Band 2 and Band 7 were close, Yang et al. (2016), mentioned that closely related $R^2$ values of different band ratios and single bands can both be adopted as the best predictor for a particular water quality parameter. According to the regression, the best predictor of the parameter, conductivity was B2 (Blue) and was adopted. From Figure 19, the model equation for the parameter conductivity, was Y = -0.0553X + 8.0597 (X = B2) with correlation coefficient value (r) of -0.216. It also shows a relatively weak and inverse relationship between B6 and conductivity, hinting that for every increment in B6, a consequent reduction in conductivity of the Fosu lagoon occurs.

From literature, only few studies had been done on the possible estimation of $R^2$ between conductivity and satellite data to for a water body. Wang et al. (2006) proposed that the reason for the none inclusion of conductivity is as a result of the inclusion of TDS or better still not regarded as a good measure of the quality of water. The relationship between TDS and conductivity is a somewhat direct one where increase in the ions in water (TDS) leads to increase in the conductivity within the water body. Following this, Mushtaq & Nee Lala (2017) presented a TDS and conductivity that proved a significant correlation with band 4 (Red), $R^2$ = 0.61 though exponential. The clear differences from study and that of Mushtaq & Nee Lala (2017) could be firstly, the satellite differences with different orientation of bands. The nature of model equations for both studies could have influenced the band selection used in both works.

It is worthy to note that in the estimation of model equations between WQPs and satellites, for different studies, it may depend on the differences in times of data collection, as coefficients in the different equations could vary with different weather and illumination conditions. In addition, the regression models could have a bias because of the few points for which in-situ data collection for the WQPs are done. As hinted already, the equations for the various parameters are all valid to have been used for making maps for the various water quality parameters as done in most studies. In this case, however, it was not done due to the few points for data collection on the Fosu lagoon. The inclusion of depth in this study, unlike most studies was done based on the relative shallowness of the lagoon, the identified potential of the band 1 (coastal blue) and band 6 (red edge) exclusive to WV-2 satellite series (El-Din et al., 2013). On the contrary, Yang et al. (2016) ignored the reflectance from the bottom sediment of Te-Chi reservoir in Taiwan based on the depth that is, more than 40 m and associated high turbidity.

**Socio Demographics of Respondents**

Seventy-two respondents made up of individuals connected to the lagoon one-way or another by residence and livelihood, were interviewed. The findings indicated that majority of the respondents being males, justifying the nature of work in and around the lagoon and residence at large. Most of the occupations reflected in the interview were mostly male dominated with a few skewed towards the female gender. Other occupations e.g., teaching and tourism were for both genders alike. From Table 9, about 70 (97%) respondents fell beyond age 20, which indicated that information they gave concerning the lagoon was critical. In addition, the average duration for the years engaged in their respective occupations at was 21 years and the average duration of stay at their various residences was 27.

The results obtained concerning respondents' level of education give a somewhat positive reflection and widely proved that the respondents knew and gave very vital information about the lagoon from various angles, especially considering that majority of them have had up to basic education. Baffour-Awuah, (2014a) reported a similar case for fishermen around the Fosu lagoon, indicating that about 70 percent had education up to the basic level with remaining 30 percent being illiterates. According to Nsiah (2012), fisher folks and other people living at coastlines in the Central and Western Regions have some form of education but rather low since majority had basic education. Some reasons linked to this were teenage pregnancy, child labor and dropping out of school.

In terms of occupation, total of 20 fishermen representing 27.8 percent formed the majority followed by traders, 19.4 percent. The influence of fishermen as far as the lagoon is concerned was highlighted by (Baffour-Awuah, 2014a) where the author interviewed about sixty fishermen in an exploit for fishermen perception on heavy metal pollution of the Fosu lagoon. Other occupations, masons, mechanics, farmers and fish processors formed the arguably informal occupations and together constituted a relatively higher percentage, justifying majority of the respondents having low level of education. Remaining sectors of work made up of health workers, teachers and tourism & recreation constituted represented small percentage. It can be deduced therefore, that different individuals gave critical information from different occupational perspectives, regarding the lagoon.

**Perception about lagoon**

Respondents clearly indicated how much the lagoon meant to them in diverse ways some of which were because of food, livelihood support, and tourism, among others as these were confirmed by (Baffour-Awuah, 2014c). Out of these, the combination, livelihood & food appeared to be the most important to many of the individuals, followed by food and livelihood as single reason. From Figure 22, food and livelihood as reasons for which respondents preferred the lagoon to exist appeared in about five different combinations suggesting how intense people depend on the lagoon for their daily survival. Other important reasons for lagoon existence to individuals such as cultural heritage and tradition, tourism, proximity to residence and biodiversity support were well represented as confirmed by (Baffour-Awuah, 2014c). However, only one individual selected 'biodiversity support' indicating low levels of environmental resource sustainability towards the lagoon and its resources by users. This reason of user disregard for resource sustainability, among others could have contributed to popular perception that the Fosu lagoon is one of the polluted lagoons in Ghana indicated by Armah et al. (2010) and (Mohammed, 1993).

All the respondents agreed that the lagoon had undergone changes overtime, majority indicating from about (11 – 20) years ago with occurrence at all directions of the lagoon. From Figure 23, it can be observed that filth as an element of change on the Fosu lagoon run through many of the combinations presented by respondents, hinting a major canker as far as the lagoon is concerned. Filth, unwanted vegetation & siltation were represented as major issues affecting the Fosu lagoon. This inherently proves that respondents and users of the lagoon for various reasons litter and release effluents from their homes directly into the lagoon together with leachates from the metropolis, leading to increasing levels of eutrophication and algal blooms. Baffour-Awuah, (2014a) mentioned that Cape Coast as a metropolis in Ghana has continued to have a fair share of waste generation, disposal management problems for which reason the Fosu lagoon, one of the major water bodies in the metropolis has continued to suffer from waste disposal attitude of inhabitants and institutions. According to the author, various solid wastes find their way into the lagoon through drains and run-off from some parts of the metropolis. Other reasons, disregard for traditional laws, bad odor, alteration of bridge and pressure of lagoon usage were all captured.

The twenty fishermen who were involved directly with the lagoon proved good knowledge about the depth by virtue of regular fishing from it. Following this, about 95 percent of them agreed to depth changes of the lagoon overtime confirming results from Mohammed (1993) and Baffour-Awuah, (2014c), who hinted that the depth and surface area of the lagoon had reduced at an alarming rate from the last twenty to thirty years. The authors mainly connected depth reduction of the lagoon to siltation. For this study, 55 percent of them agreed that lagoon depth had normally reduced, 25 percent agreed to drastic depth reduction and 15 percent indicated depth reduction at certain points of the lagoon. One of the fishermen however noted, no difference in lagoon depth. All the fishermen agreed that the lagoon depth was important as it affects their navigation & movement in lagoon during fishing activities.

**General Threats to Lagoon**

The effects of mechanical waste on the health of the lagoon and its biodiversity was found to be 3.6, proving that respondents agreed to it as a major threat to the lagoon. About 61 percent of respondents generally accepted the notion that mechanical wastes that end up in the lagoon from the nearby fitting shop may be a compromise on biodiversity in the lagoon in several ways. The study by Akwansah-Gilbert (2007) on the distribution of polycyclic aromatic hydrocarbons and heavy metals in the Fosu lagoon studied the concentrations of iron (Fe), manganese (Mn), Cadmium (Cd), Zinc (Zn) and nickel (Ni) confirmed that the lagoon was highly contaminated with cadmium and nickel. The author confirmed that about 50% of the samples collected from sediments were higher than accepted standards of cadmium for the protection of aquatic lives. According to the study, the mechanical workshops and garages in the northeastern sector of the lagoon were the main sources of cadmium and its associated heavy metals. The presence of other Polycyclic Aromatic Compounds (PAHs) observed by the study was blamed on the combustion of vehicle scrap-tire to extract steel wires around and near the automobile workshops and garages. In addition, Akwansah-Gilbert (2007) observed an interrelationship between the mechanical workshop activities at Siwdo and the southern sectors of the lagoon where the former could be a contributing factor to pollution in the southern portions of the lagoon. The author stated that, though it could be easier for waste from the automobile workshops and garages to get into the southern part of the lagoon, the few fitting shops in the southern portion could also partially contribute.

A mean statistic value of 3.9 was recorded for the threat of influence of effluents and leachates to nutrients and consequent blooms of algae and other unwanted vegetation. The majority percentage of respondents who generally agreed to this threat were 81 percent showing general agreement and hinting how problematic it is. Essumang (2000) studied the effect of leachate from solid waste disposal sites in Cape Coast metropolis and concluded that apart from chloride concentration levels, all other nutrients studied had higher levels compared with waste characteristics and leachate limits for various types of landfills. Following this, the author hinted that these wastes from landfills carried effluents in the form of leachates with high concentrations of nutrients and toxic substances most of which end up eventually into the Fosu lagoon and cause vegetation to bloom.

Respondents hinted that these blooms are causing shrinkage of the lagoon water due to the rate of spread. About 93% of respondents widely accepted that spatial coverage of water of lagoon has significantly been covered by vegetation making it appear smaller than it actually is. From Table 10, it can be observed that a very significant mean statistic value for this threat of vegetation causing lagoon shrinkage is 4.3 depicting a strong agreement to this threat. Similarly, Avi (1998) confirmed the formation of green scum made up of algal decomposition on the surface of water and how much it had caused the lagoon to shrink in size. Baffour-Awuah (2014c) mentioned that several miniature islands of weeds were being formed in the lagoon indicating surface area reduction and endangering aquatic life. Respondents were of the view that this condition started in a small way, increasing as the years went by. Currently, these blooms appear to have greatly increased in size at different directions of the phone.

The problem of improper refuse disposal and its consumption at portions of lagoon was described as an obvious one, as observed around the lagoon. Mean statistic, 4.1 proved that respondents strongly agreed that this issue was existent. Various wastes such as plastic, metal, rubber, wood, fabric, etc. were found, especially at the banks of the lagoon connected to major channels that enter into it. Most of these wastes are improperly released directly into either the lagoon or the channels whose water run into the water body. For instance, very near to the lagoon were residents with piggeries whose wastes are released directly into the lagoon.

In addition, some human fecal matter were found within the bushes surrounding the lagoon. Respondents however uncertain about this threat. According to them, only a few persons openly defecate around which was not regular as compared to that of the beach. According to Baffour-Awuah, (2014a), Fosu lagoon continually undergoes pollution due to garbage and refuse from the Bakaano Township, St. Augustine's College, Adisadel Estate residential area and the Ola Hospital, together reducing aesthetics of the area

Erosion and siltation, combined, as a threat to the lagoon was one that was widely agreed to, by the respondents. A mean statistic of 4.3 proved that this threat was significant. Widely known, the Fosu lagoon is found lowland with various channels of running water from the Cape Coast metropolis. The channels are made wide enough to be able to convey running water directly into the lagoon to prevent flooding within the city. On many occasions, running water carries with it several waste materials from inland directly into the lagoon, some of which may include eroded sand and silt. Regular carriage of silt into the lagoon has been a major contributory factor to the reduction of depth within the lagoon, preventing it to hold water and causing floods around the surroundings of the lagoon during heavy downpours. Referring from Figure 6, the combined filth, vegetation & flooding recorded about 26.9 percent indicating that flooding is existent around the lagoon, especially during the wet seasons. Mohammed (1993) hinted that siltation has been a major cause of depth reduction as far as the Fosu lagoon is concerned. In addition, comments from Baffour-Awuah (2014c) and Armah et al. (2010) describe the Fosu lagoon as choked, because of silt intrusion, reducing the depth and not making it able to hold enough water.

In this study, a relatively low 2.7 mean statistic gave an impression of uncertainty for the threat concerning the influence of agriculture and its consequence on lagoon water. From observation, there were few small-scale farms, within the catchment of lagoon. Respondents indicated that these farms do not use fertilizers and other chemicals for farming activities. Following this, they generally agreed that chemical run-offs coming into the Fosu lagoon might be part of the leachates from upland farms and not the ones in close proximity with it. Like this study, Mohammed (1993) hinted that residents who lived in suburbs near the lagoon i.e. Adisadel estate and village, Siwdo, Antem, Ola and Bakaano used lagoon water for livestock farming and vegetable cultivation. According to the author, residents made their farm beds where they cultivated their vegetables using the lagoon water for irrigation. In addition, cattle, sheep and goat rearers would also send their livestock to the lagoon for drinking purposes.

Majority of the respondents (53%) proved their disagreement about tree cutting without replacement, around the lagoon. From observation, there were not many canopy trees around the lagoon for people to cut, even though there were smaller forest patches with a few mangroves at particular directions of the lagoon. Information from literature barely talked about deforestation as far as the Fosu lagoon is concerned, possibly endorsing the fact that it has not been a major issue from the past to present days.

In recent times, overcapacity of fishing has been labelled one of major issues of fishing in Ghana (Okyere and Chuku, 2020). The fisheries resource is known to be dwindling at a fast rate with many interventions such as fisheries closed season to limit fishing efforts have been implemented especially in the artisanal marine sector. However, little attention by stakeholders has been put on overfishing of stocks for inland water bodies relative to the marine space. Overfishing was identified as a threat about the Fosu lagoon, observing how local fishermen were found fishing almost every time of every day, with the exception of Tuesdays, declared a traditionally sacred holiday for fishing. To an aggravated end, some of the respondents indicated that fishermen run shifts with most fishing during the day and others, at night. The mean statistic of this threat according to the respondents was 3.7, confirming that this particular issue is existent as far as the Fosu lagoon is concerned. Mohammed (1993) reported that fishing activities were already going down by the beginning of 1993. According to the author, few fishermen and fishmongers could be seen involved in their various economic engagements. The reduction in catch for the lagoon was also reported by Baffour-Awuah (2014a) hinting that it had a direct correlation with the reduced size of the lagoon. According to the author, catch per fisherman had reduced from about 21.6kg to 16.4kg per week, a decrease of 24.1 percent for about a period of ten years to fifty with an annual reduction rate of 2.4 percent per annum. Like this study, Baffour-Awuah (2014a) also reported that the reduction in catch could be because of increase in the number of fishermen and the unregulated open access regime of fishery in the lagoon.

Found in close proximity to the Fosu lagoon was a restaurant and a beach resort. Some other drinking spots and wooden establishments as well as resting spots by fishermen were seen. Encroachment around the lagoon were observed in different forms with recreation being, major. Respondents were uncertain about encroachment and recreation as a threat on the lagoon, depicted by a mean statistic value of 3.3. According to some of the respondents, they believed that the setting up of recreation centers close to any water body could have effects on it since they release their solid and liquid wastes directly into it. They added that these establishments were wrongly cited as they are too close to the water body. Encroachment in other forms observed were the many buildings that respondents hinted to have sprung up around the catchment area where previously was not. According to respondents, a large portion of the lagoon dries up during the dry season to the point that they are used as football pitch, particularly among children. To this end, unsustainable settlement planning was a major contributory factor to the pollution of the Fosu lagoon (Baffour-Awuah, 2014c). According to Mohammed (1993) settlement sites consisting of St. Augustine's College, Metropolitan District Hospital, the Metro Mass transport workshop and terminal, Siwdo automobile garages and workshops and largely, the Bakaano township, were identified as the major sources of pollution of the lagoon.

**Restoration & Support System**

All respondents but one, agreed to a possible restoration of the Fosu lagoon, suggesting various measures and expressing individual possibilities of involvement. Suggestive measures such as desilting, dredging and general cleaning appeared mostly in several combinations. Respondents elicited about 10 suggestive combinations. Majority of respondents, 18 individuals (25%), chose the combination, (Dredging, Desilting & General Cleaning) whereas the least suggested was shielding lagoon channels with mesh (Figure 23).

From the results, it could be said that whiles the different respondents had different ideas about lagoon restoration, some specific approaches run through the several combinations i.e., dredging, desilting and general cleaning. Following this, special emphasis must be placed on the implementation of these measures in the case of restoration intervention. Other measures, education and sensitization, though with a low percentage was raised by respondents to properly educate the people on usage of lagoon after it is put in a good state, similar to the case of Baffour-Awuah (2014a) who prompted stakeholders to conduct regular awareness creation in vernacular as far as usage of the lagoon is concerned.

Relating to which stakeholders should play major roles in the restoration process, the combination of (Fishermen, Policy Makers (PM) & Traditional Authority (TA)) had the highest percentage. 31 individuals (43.7 percent) believed that a collaboration between the above named stakeholders would drive the restoration of the lagoon to a very significant end. Policy makers are the arguably stakeholders with the most influence to make laws regarding the sustainable use of natural resources, traditional authority at the local setting can help with proper implementation of such laws, because of their power and influence and fishermen, users of the lagoon on a daily basis. According to respondents, fishermen ought to be involved in any form of decision-making process to appropriately understand, as far as the lagoon is concerned. This, they described will make implementation easy and facilitate the restoration process.

The next stakeholder front involved the above-mentioned three, in addition to academia. Twelve individuals (16.9 percent) chose this, emphasizing on already stated reasons in addition to the fact that the collaboration should also involve academia since their efforts to the lagoon in terms of research has been laudable. With ample amount of data and scientific evidence that the lagoon is polluted, their involvement in decision making process of restoration was indicated to be important. The next stakeholder group was a combination of fishermen, policy makers, traditional authority & general populace (12.7%). In addition to already mentioned stakeholders, the collaboration with general populace was explained as a useful one. They described a collaboration with the general populace towards sustainable use of the resources about the lagoon because of uses such as recreation, tourism and cultural heritage. They added the need for such collaboration that allows everyone to come on board as far as usage of the lagoon is concerned. Following this, the next group of stakeholders involved all five mentioned already constituting 9.9 percent. Fishermen, Traditional Authority and Policy Makers appeared in at least five out of the six total stakeholder combinations, proving how important they were among the others.

Connected to the restoration process was the need for respondents to express their readiness to support the process even if it was going to affect their occupations. Majority 80.6 percent proved the readiness of respondents to help support the restoration of the lagoon. Individually, they expressed in different forms how the degradation of the lagoon has affected different aspects of their lives and the need for a possible restoration within the shortest possible time. The remaining 19.4 percent however did not agree, placing their livelihoods first.

Even though majority representation agreed that restoration efforts had been channeled towards the lagoon in the past, about 38 percent disagreed. Conclusions made from this was that authorities had tried diversely in the past to begin a restoration program about the lagoon, sponsored by the authorities of the city of Bonn in Germany, in close collaboration with Cape Coast Metropolitan Assembly. This collaboration, according to the people drove the beginning of a dredging process, which came to a halt eventually. In addition, annual general cleaning of the lagoon during the month of August as part of preparations towards the Fetu festival was highlighted.

Out of about 63 percent of respondents who agreed that some restoration efforts had been put in place, a majority 27.8 percent attributed the issue to inconsistencies and irregularities in efforts. They accused mostly the metropolitan assembly for not being committed enough to the course of sustainable use the lagoon. In addition, they expressed negligence on the part of traditional authorities who only have the interest of the Fosu lagoon during the annual Fetu festival. 23.6 percent of respondents proposed lack of commitment towards the lagoon by stakeholders. Like the previous group, they also expressed negligence on part of authorities, especially the metropolitan assembly and traditional rulers. To them, the lagoon had been left to its unpredictable fate since commitment to restore it was low. Blaming academia, they said that not only have students and researchers come to collect series of data about the lagoon from time to time, they do not see positive effects of such data collection and research. Another group, 8.3 percent blamed the issue on unavailability & embezzlement of funds. In connection with lack of commitment, they mentioned that funds to help with the restoration of the Fosu lagoon are not readily available in addition to situations where money available for it has been embezzled. The last group (4.2 %) proposed lack of collaboration between all stakeholders to have been the issue that is compromising lagoon restoration. According to them, they thought that different stakeholders handle efforts of lagoon restoration their own way and barely involve other groups. Typically, they said academia, traditional authority and the metropolitan assembly mostly operate alone in their quest to help in lagoon restoration, which has not helped in the past.

The minority group who disagreed on the fact that efforts had been directed to the lagoon in the past also gave four different reasons in different representative groups. About eleven percent suggested that stakeholders should commit more funds to the course of restoration. According to them, the issue involves money to push the course for change. Next two groups (9.7 percent) each suggested proper collaboration between stakeholders and commitment to the efforts for restoration. Lastly, 5.6 percent proposed education and sensitization for the general populace to create the needed awareness for sustainable use and exploitation of the lagoon, the wide array of value on the lagoon and possible losses following lagoon degradation. They added the need for this to create awareness on involvement by the general public in lagoon restoration by way of physically taking part or helping in broadcasting the message to other people.

# CHAPTER SIX

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## Introduction

In this chapter, the summary, conclusions and recommendations of the study are presented. Summary of the results and conclusions have been organized based on the specific objectives. From the Conclusions drawn, a number of recommendations have been suggested to enrich future research that may be aligned to this study.

## Summary

Out of the many existent coastal ecosystems the world over, lagoons present themselves as unique habitats and support a myriad biodiversity and survival of man in various ways. However, the existence of uncontrollable anthropogenic activities pose a threat to lagoons, of which those in Ghana are inclusive. The Fosu lagoon in Cape Coast is an important water body to the people who depend on it for various reasons including the role it plays during the annual Fetu Festival. It is however surrounded by various human settlements that contributes to its pollution and degradation.

Following that, the lagoon was considered one of the most polluted in Ghana by the year 1992; series of studies have been conducted over the years but with no proper restoration and change in situation. In addition, the use of Remote Sensing as an approach to study coastal environment is in its nascent stages where its applicability to solve problems confronting the coastal environment is not enough. With special reference to the Fosu Lagoon, Remote Sensing application data are scanty.

Therefore, a study to ascertain the current issues confronting the lagoon, from a remote sensing perspective was needed. It is considered one of the most rapid and effective approach to study the environment and even more effective when used in collaboration with social methods. Specifically, the study sought to (i) map the Land-Use/Land-Cover change of Fosu Lagoon watershed (ii) estimate the empirical relationships between WorldView-2 satellite reflectance and concurrent in-situ data for several water quality parameters and (iii) assess from social perspectives, existent conditions of the lagoon.

The study was conducted on the Fosu lagoon, and its watershed. The lagoon is located within the Cape Coast metropolis, the capital of the Central Region of Ghana. Remote sensing was the basis for data collection in this study to investigate the LU/LC changes of the watershed and the possibility of using the methodology to study water quality parameters on the Fosu lagoon. Landsat satellite data for 1991, 2007 and 2018 and WordView-2 for December 2018 were used respectively in this regard. In addition, a confirmatory social study of the lagoon to ascertain issues confronting the lagoon from the perspective of the people was done. Face-to-face interviews, in-depth interview and observation were the methods used to collect the social data from July to September 2019.

Using processing software i.e., ENVI, Arc GIS and Excel, preprocessing and analysis of satellite data was done to extract the LU/LC of Fosu Lagoon watershed into the five classes, Built-up, Water, Dense Vegetation, Sparse Vegetation and Bare-land and their spatial coverages for the three respective years and their influence on the Lagoon. Using the same software, linear equations for the parameters DO, turbidity, TDS, Conductivity, pH and Depth was extrapolated towards understanding the possibility of using Remote

Sensing to extract water quality parameters from a water body. A confirmatory study allowed the use of SPSS computer software to study the demographics, perception, threats and possible restoration interventions for the Fosu lagoon.

**Conclusions**

Based on the objectives of the study, the following conclusions are drawn.

The study concludes that the usage of modern methods i.e., GIS and RS in the determination of the uses and changes of watershed overtime as well as the potential of using it to estimate water quality parameters of a water body at a faster rate is possible.

It can be concluded that the respective changes of LU/LC classes identified within the watershed pose different threats on the Fosu lagoon and it is connected to pollution of the lagoon directly and indirectly.

It is also concluded that possible estimation of water quality parameters using satellite data is certain and permits large bodies of water to be studied. Regression between water quality parameters and reflectance from satellite data to establish linear model equations make this possible. However, every water body is unique and qualifies for its own study at any point in time.

It can be concluded that, there has been existent changes around the Fosu lagoon and has caused pollution to it in various forms, dominated by filth, siltation and blooms. Most of these changes are existent at all directions of the lagoon. Conclusions on the depth of lagoon were confirmed by fishermen to have reduced.

Algal blooms and their spread is the predominant threat of the Fosu lagoon. Following this, it was concluded that the lagoon could be restored with dredging, desilting and general cleaning involving stakeholders i.e., academia, chiefs, government, fishermen and general populace.

It is also concluded that restoration efforts have been channeled towards the lagoon in the past but affected by either less resources or inconsistencies. Therefore, proper commitment of resources, collaboration between stakeholders as well as education for users and general populace is the way forward.

**Recommendations for Policy**

The local government particularly the Cape Coast Metropolitan Assembly, Traditional Council and Fisheries Commission of Cape Coast should collaboratively adopt the strategies of deep-water dredging, desilting, regular cleaning and local education to drive restoration and sustainable use changes for the lagoon. Considering the existent critical condition within which the lagoon exists, it is imperatively recommended that stakeholders confront the challenges affecting the lagoon with immediate attention.

**Recommendations for Further Study**

The use of Remote Sensing and Geographic Information Systems to study coastal environments in future studies is encouraged to speed up research and implementation process.

It is also recommended that future research on water quality parameters using satellite data increase the points for data collection. It is recommended that more datasets be gathered to provide additional reflection on the state of the entire lagoon in terms of its water quality.

Validations of social data in addition to using remote sensing data is encouraged in future research as a combination of both give a holistic picture of the issue on ground.

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# APPENDICES

## Appendix 1: A STUDY OF THE FOSU LAGOON WATERSHED IN GHANA: A REMOTE SENSING APPROACH

**Dear Respondent,**

You have been contacted to participate in this research survey because you may have vital information to share in connection to the Fosu Lagoon. Please understand that your participation is voluntary and responses will be used for academic research purposes only while ensuring that you are kept anonymous.

***Please take out time to answer the questions as appropriate as possible.***

***Thank you for your time.***

Date: ……………………….. Time: ……………………

### A. DERMOGRAPHIC INFORMATION

Please provide this information. Tick or write where appropriate.

1. Age: up to 20yrs [ ] 21-30yrs [ ] 31-40yrs [ ] 41-50yrs [ ] 51-60yrs [ ] >61[]

2. Gender: Male [ ] Female [ ]

3. Educational level: Primary [ ] JHS [ ] Secondary [ ] Tertiary [ ] none []

4. What is your primary occupation? .....................................................

5. How long have you been in this occupation? .......................................

6. Do you stay near the lagoon? Yes [ ] No [ ]

If Yes,

a) How long have you resided at this place? .......................................

7. Do you work near the lagoon? Yes [ ] No [ ]

If Yes,

a) How long have you worked at this place? .......................................

**B. GENERAL PERCEPTION ON LAGOON**

8. Do you care about the existence of the lagoon? Yes [ ] No [ ]

Reason……………………………………………………………………

9. In your opinion, has the lagoon changed in any way? Yes [ ] No [ ]

If Yes? What are the general trend of these changes?

……………………………………………………………………………………………

10. How long have you noticed these changes?

1-5 years [ ] 5-10 years [ ] 10-20 years [ ] >20 years [ ]

11. Have these changes affected you or your line of work? Yes [ ] No [ ]

If yes, How?

……………………………………………………………………………………………

12. Which directions/portions of the lagoon are these changes evident?

Northern [ ] Middle [ ] Southern [ ] Entire Lagoon [ ]

**Fishermen Specific:**

13. Do you know about lagoon depth? Yes [ ] No [ ]

14. Has the lagoon depth changed relative to time? Yes [ ] No [ ]

Please State……………………………………………………………………

15. Do you think the change in bathymetry is a critical thing to consider about this lagoon? Yes [ ] No [ ]

State Reason……………………………………………………………………

C. THREATS TO THE LAGOON

***Indicate to what extent do you agree with the following statements on the different threats to the lagoon (S/A (Strongly Agree) - 1, A (Agree) - 2, U (Uncertain) - 3, D (Disagree) - 4, SD (Strongly Disagree) – 5)***

16.

| **Statement** | **SA** | **A** | **U** | **D** | **SD** |
|---|---|---|---|---|---|
| Mechanical wastes affect the health of biodiversity in/around the lagoon | | | | | |
| Domestic effluents have direct influence on water nutrients and causes subsequent algal blooms | | | | | |
| Algal blooms are gradually spreading and contributing to shrinkage of the Lagoon | | | | | |
| Improper refuse disposal is consuming portions of the lagoon | | | | | |
| Erosion and Siltation has been a major cause for depth reduction | | | | | |
| Agricultural runoffs influence the chemistry of the water | | | | | |
| Overfishing is causing depletion of fish species in the lagoon | | | | | |
| Deforestation is destroying the habitats of some biodiversity | | | | | |
| Encroachment and recreational activities have effects on the lagoon | | | | | |
| Open defecation is rampant around the lagoon surrounding | | | | | |

**D. RESTORATION AND LIVELIHOOD SUPPORT SYSTEM**

17. Do you think the Fosu Lagoon can be restored? [Yes] [No]

18. What can be done to restore the lagoon in your own opinion?

.......................................................................................................................

19. Which group of people should play a part in the restoration?

Academia [ ] Fishermen [ ] Policy Makers [ ] Traditional Authority [ ]

General Populace [ ]

20. Are you ready to support this cause even if it affects your occupation?

Yes [ ] No [ ]

21. Do you think enough efforts have been channeled to the lagoon restoration in the past? [Yes] [No]

State Reason……………………………………………………………………

**Appendix 2: Percentage Frequency of Various Threats by Respondents**

| Questions | Total | Strongly Agree (%) | Agree (%) | Uncertain (%) | Disagree (%) | Strongly Disagree (%) | Total (%) |
|---|---|---|---|---|---|---|---|
| Mechanical waste affect health of biodiversity in/around the lagoon | 72 | 18% | 43% | 24% | 15% | 0% | 100% |
| Effluents & leachates influence nutrients & cause algal blooms | 72 | 21% | 60% | 10% | 10% | 0% | 100% |
| Algal blooms are gradually spreading & contributing to lagoon shrinkage | 72 | 43% | 50% | 3% | 4% | 0% | 100% |
| Improper refuse disposal is consuming portions of the lagoon | 72 | 32% | 56% | 6% | 7% | 0% | 100% |
| Erosion and Siltation have been major causes for depth reduction | 72 | 50% | 38% | 6% | 6% | 1% | 100% |
| Agricultural runoffs influence the chemistry of the water | 72 | 1% | 8% | 50% | 38% | 3% | 100% |
| Overfishing is causing depletion of fish species in the lagoon | 72 | 28% | 40% | 10% | 18% | 4% | 100% |
| Deforestation is destroying the habitats of some biodiversity | 72 | 0% | 4% | 53% | 29% | 14% | 100% |
| Encroachment and recreational activities have effects on the lagoon | 72 | 6% | 56% | 14% | 14% | 11% | 100% |
| Open defecation is rampant around the lagoon surrounding | 72 | 10% | 21% | 15% | 25% | 29% | 100% |

**Appendix 3: Accuracy assessment (confusion matrix) for classified map of 1991**

| CLASSIFIED DATA | REFERENCE DATA | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Built-Up | Bare-land | Sparse Vege. | Dense Vege. | Row Total | User's Accuracy (%) |
| **Water** | 6 | 1 | | 3 | | 10 | 60 |
| **Built-Up** | | 6 | | 4 | | 10 | 60 |
| **Bare-land** | | | 5 | 3 | 2 | 10 | 50 |
| **Sparse Vegetation** | | | | 10 | | 10 | 100 |
| **Dense Vegetation** | | | | | 10 | 10 | 100 |
| **Column Total** | 6 | 7 | 5 | 20 | 12 | 50 | |
| **Producer's Accuracy (%)** | 100 | 85.7 | 100 | 50 | 83.3 | | |

Overall Accuracy (Obs) = 0.74 Exp = 0.2 K = 0.675

**Appendix 4: Accuracy assessment (confusion matrix) for classified map of 2007**

| CLASSIFIED DATA | REFERENCE DATA | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Built-Up | Bare-land | Sparse Vege. | Dense Vege. | Row Total | User's Accuracy (%) |
| **Water** | 9 | | 1 | | | 10 | 90 |
| **Built-Up** | | 6 | 2 | 2 | | 10 | 60 |
| **Bare-land** | | | 5 | 3 | 2 | 10 | 50 |
| **Sparse Vegetation** | | 1 | | 9 | | 10 | 90 |
| **Dense Vegetation** | | | | | 10 | 10 | 10 |
| **Column Total** | 9 | 7 | 8 | 14 | 12 | 50 | |
| **Producer's Accuracy (%)** | 100 | 85.71 | 62.5 | 64.2 | 83.3 | | |

Overall Accuracy (Obs) = 0.748 Exp = 0.2 K = 0.725

## Appendix 5: Accuracy assessment (confusion matrix) for classified map of 2018

| CLASSIFIED DATA | REFERENCE DATA | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Built-Up | Bare-land | Sparse Vege. | Dense Vege. | Row Total | User's Accuracy (%) |
| **Water** | 7 | | | 2 | | 9 | 77.77 |
| **Built-Up** | | 4 | 1 | 3 | 2 | 10 | 40 |
| **Bare-land** | | 3 | 7 | | | 10 | 70 |
| **Sparse Vegetation** | | 1 | | 8 | 1 | 10 | 80 |
| **Dense Vegetation** | | | | 1 | 10 | 11 | 90.90 |
| **Column Total** | 7 | 8 | 8 | 14 | 13 | 50 | |
| **Producer's Accuracy (%)** | 100 | 50 | 87.5 | 57.14 | 76.92 | | |

Overall Accuracy (Obs) = 0.72 Exp = 0.2 K = 0.649