UNIVERSITY OF CAPE COAST

ASSESSMENT OF THE ECOLOGICAL HEALTH OF MANGROVE FORESTS ALONG THE KAKUM AND PRA ESTUARIES IN GHANA

GERTRUDE LUCKY AKU DALI

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BY

GERTRUDE LUCKY AKU DALI

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 fulfilment of the requirements for the award of Doctor of Philosophy degree in Integrated Coastal Zone Management

JUNE 2020

DECLARATION

Candidate's Declaration

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

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

Name: ……GERTRUDE LUCKY AKU DALI……………………………..….

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.

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ABSTRACT

Mangrove forests provide a variety of valuable uses and resources for inhabitants of coastal communities. This study was aimed at assessing the health of mangrove forests at the estuaries of Kakum and Pra using multi criteria approach involving social, biological, chemical and physical factors. The study was conducted from March 2017 to August 2018. Socioeconomic data were gathered from 136 respondents through field surveys in ten communities around the two estuaries while remote sensing and Geographic Information System (GIS) were used to characterize mangrove cover change between the period 2005-2017. Species inventory, structural parameters, litter production and soil analyses were estimated in four study plots of sizes 0.25 ha within each mangrove forest whereas physico-chemical parameters of estuarine water were measured *in situ*. It was observed that coastal inhabitants harvested fuel wood, timber (poles), crabs, periwinkles and tilapia from these mangrove forests. Mangrove area at Kakum reduced by 41.58 % while that of Pra increased by 12.54 %, from 2005 to 2017. A total of 23 and 20 plants species, including five and three true mangroves were encountered at the Kakum and Pra mangrove forests, respectively. The mangrove species had low structural developments in terms of size and height. Annual litter production rate was lower at the Kakum mangrove forest (9.60 t ha^{-1} y^{-1}) than at the Pra mangrove forest (10.72 t ha^{-1} y^{-1}). The estuaries and mangrove sediments were of moderate quality. On the basis of computed mangrove health indices (MHI), the overall health of the Kakum mangrove forest was bad, whereas the Pra mangrove forest was moderately healthy. There is the pressing need for stakeholders to institute stringent management measures for sustainable conservation of both forests.

KEY WORDS

Ecological health

Estuaries

Ghana

Litter production

Mangrove forests

Mangrove health index

Mangrove sediment

Socioeconomic characteristics

Structural parameters

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DEDICATION

To my heroes (sons) – Joshua Etornam Dali and Jerome Edudzi Dali.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
CBD	Convention on Biological Diversity
CCMSWA	Convention on the Conservation of Migratory Species of Wild Animals
CO_2	Carbon dioxide
CRC	Coastal Resources Centre (University of Rhode Island)
DFAS	Department of Fisheries and Aquatic Sciences
FoN	Friends of the Nation
IUCN	International Union for Conservation of Nature
MEA	Millennium Ecosystem Assessment
NGOs	Non-Governmental Organisations
SGP	Small Grants Programme
SPSS	Statistical Package for Social Sciences
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
USAID	United States Agency for International Development
WWF	World Wide Fund for Nature

CHAPTER ONE

INTRODUCTION

This chapter gives a brief introduction to the study including a background to the study, statement of the problem, purpose and significance of the study, as well as the set objectives to guide the research. Existing literature are presented and the gaps in them identified. The scope of the study is also stated. The research generally assesses the health of mangroves to help develop comprehensive conservation strategies for mangroves in Ghana.

1.1 Background to the Study

Coastal ecosystems comprise coastal lands, areas where fresh water and salt water mix, and nearshore marine areas, including coral reefs, seagrass meadows, sand dunes, mangroves, salt marshes, tidal flats, lagoons and estuaries (Miththapala, 2013). These ecosystems are highly linked, with water being the facilitator of most of the linkages, hence considering them as different subtypes may obscure the habitants as well as the ecological processes within them (MEA, 2005). These linkages make them highly diverse, productive, ecologically important, and provide highly valuable services (MEA, 2005). Nonetheless, each of these ecosystems serves as habitat for numerous species of plants and animals and provides a wide range of ecosystem services vital to humans and other organisms.

Mangroves are salt-tolerant evergreen coastal ecosystems occurring mainly as forests found mainly growing on soft substrates along shielded coastlines, shallow-water lagoons, estuaries, rivers or deltas in countries and areas of tropical and subtropical regions of the world (FAO, 2007). Mangroves are found in about 123 countries worldwide (Ahmed & Glaser, 2016; Romañach et al., 2018; UNEP, 2014), with majority occurring in Asian countries (MEA, 2005).

The mangrove ecosystems provide several important functions and services such as provision of wood and non-wood forest products, habitats, spawning grounds, nurseries and nutrients for a number of animals including reptiles, amphibians, mammals and birds (FAO, 2007). They are also important in coastal protection, by preventing and reducing coastal hazards and natural disasters such as coastal erosion, cyclones, typhoons, strong wind and salt spray, as well as climate regulation (UNEP, 2014). López-Angarita, Roberts, Tilley, Hawkins and Cooke (2016) emphasized that mangroves have played an important role in providing goods and services to human societies for millennia. For instance, they provide coastal communities with food security, protection and livelihoods (UNEP, 2014).

However, despite the importance of mangroves such as supporting the well-being of several organisms including human populations, mangroves are continually being destroyed and degraded. Valiela, Bowen and York (2001) confirmed that the destruction of mangrove forests is a global issue. Romañach et al. (2018) enumerated worldwide decline in mangrove cover from 18,100,000 ha in 1997 to 8, 349, 500 ha in 2016; accounting for more than 50% loss globally. In Ghana, the loss is estimated at about 50 % (Asante, Jengre, Asare & Mason, 2014), and as high as 50–80% in Asian countries (Wolanski, Spagnol, Thomas, Moore, Alongi, Trott & Davidson, 2000).

Most of the global losses of mangroves are attributable to increase in human population and human activities such as urban development, aquaculture, conversion to agriculture such as rice farming, and overexploitation of timber (Romañach et al., 2018). An earlier study by Spalding, Blasco and Field (1997) confirmed that deforestation accounted for more than 80% of original mangrove cover loss in some countries.

Loss of mangrove ecosystems also means a decline or total loss of goods and services provided by these ecosystems, which in turn threatens the well-being of not only coastal communities, but also coastal nations and the world at large (MEA, 2005). The decline in mangrove forests therefore calls for continuous monitoring through research on spatial–temporal dynamism in the coastal land-use/cover patterns (Chauhan & Dwivedi, 2008), in addition to mangrove ecology. A holistic approach such as assessing ecological health to determine the prevailing physical, chemical and biological conditions, that will indicate the current integrity or quality of these mangrove ecosystem, is worthwhile.

1.2 Statement of the Problem

Mangroves remain one of the most threatened ecosystems worldwide and continue to reduce at an alarming rate (UNEP, 2014). These mangroves are depleting fast not only because of overexploitation, but more so because of indiscriminate conversion of these areas to other land uses (Acharya, 2002). It has also been stressed that mangroves continue to be lost at a rate, 3-5 times faster than global deforestation rates, mainly because they are undervalued and hence receive little attention by decision makers (UNEP, 2014). Considering the rate at which mangrove ecosystems are being depleted, concerted efforts must be made to protect and sustainably manage the remaining mangrove ecosystems, in order to safeguard their long-term future and the well-being of all the organisms that depend on the mangrove ecosystems for survival.

This therefore, necessitates immediate improvement on scientific data on mangrove extent, health and ecosystem service provision in every country to help inform decision on mangrove uses, land uses and management practices (UNEP, 2014). Importantly, Acharya (2002) pointed out clearly that if there is no or little information on what is being lost, there is little motivation to protect the mangroves. Although Valiela et al. (2001) argued that globally, information on mangrove including the extent, changes, function and the effects of human uses is growing and readily available, the same cannot be said for Ghana. Unfortunately, unlike terrestrial forests in Ghana, management of mangrove forest has not been placed under any legislative framework which could ensure that they are utilized sustainably and efforts made for conservation and sustainable use are usually championed by development and civil society organizations (Asante, Acheampong, Boateng & Adda, 2017).

Despite these efforts made towards mangrove conservation and mangrove restoration, degradation of mangrove forests still exists nationwide, probably due to limited available scientific information and assessments needed for regular monitoring to feed into management strategies. There is also the challenge of limited technical and scientific capacity needed for research and management at all levels most especially, institutional and local levels. Therefore, over the past years, decisions on mangrove conservation have not emanated from informed scientific basis.

Undoubtedly, several studies have been done on estuaries and mangroves in Ghana, most especially in recent years. The Kakum Estuary in the Central Region and the Pra Estuary in the Western Region are two such estuaries that have been studied over the years. Previous studies on the Kakum Estuary and mangrove forest mostly sought to characterize and quantify biodiversity (Adotey, 2015; Aheto, Aduomih & Obodai, 2011; Aheto et al., 2014; Okyere, 2010; Sackey, Kpikpi & Imoro, 2011), while some assessed quality of water and sediments (Dzakpasu & Yankson, 2015; Fianko, Osae, Adomako, Adotey & Serfor-Armah, 2007; Koranteng–Addo, Bentum, Awuah & Owusu–Ansah, 2011; Levy, Asare, Yankson & Wubah, 2015; Okyere & Nortey, 2018). Few published literature are available on the ecological parameters of mangroves (see FoN, 2014) and estuarine water quality (Donkor, Bonzongo, Nartey & Adotey, 2006; Okyere, 2015; Okyere & Nortey, 2018) at Pra Estuary, although other works looked at issues concerning conservation of the estuary (FoN, 2015, 2016, 2017; Kankam & Robadue, 2013).

A holistic research which assesses the ecological health of these mangrove forests is non-existent/limited. Moreover, there is discrepancy in the exact number of true mangrove species found in Ghana. Whereas Sackey et al. (2011) identified five true mangrove species comprising red mangroves, *Rhizophora racemosa* G. F. W. Meyer, *Rhizophora mangle* L. and *Rhizophora harrisonii*, Leechm., black mangrove *Avicennia germinans* L. (L.) and white mangrove *Laguncularia racemosa* (L.) C. F. Gaertn. within the Kakum mangrove forest, the FAO (2007), reported there are only four species of true mangroves in Ghana and this excluded *Rhizophora mangle*.

This research therefore, deployed ecological and socio-economic techniques to bridge the knowledge gap between what have been recorded and what is currently present in the mangrove forests at the Kakum and Pra estuaries. Overall, this study contributes to existing scientific information on ecological parameters, litter fall, soil and water quality, ecosystem services and land use types required for the effective and sustainable management of the mangrove ecosystems in Ghana using the study sites as case studies. This work also serves a strong basis for comparison to other West African countries with similar ecological conditions.

1.3 Purpose of the Study

The goal of this study was to assess the health of mangrove forests in the Kakum and Pra estuaries of Ghana with special reference to the socio-ecological and geo-spatial contexts to produce comprehensive data needed for the sustainable management of these important mangrove ecosystems.

1.4 Objectives of the Study

The specific objectives of the study were to:

i. determine socioeconomic characteristics of the mangrove-dependent population in the study areas;

ii. assess land use and land cover changes of the Kakum and Pra estuarine areas in relation to the mangroves;

iii. develop an inventory of plant species of the Kakum and Pra mangrove forests and determine the ecological significance of the mangrove species encountered based on their structural parameters;

iv. measure productivity of the mangrove forests based on litter production; and

v. assess the quality of estuaries and mangrove sediments, using physico-chemical parameters of water and sediment, available nutrients and heavy metal concentrations in the sediments.

1.5 Significance of the Study

Effective conservation and management of mangrove habitats requires primarily, continuous detailed baseline assessment of their biodiversity, functions or services they provide, environment within which they occur, their interactions and prevailing threats there. It was against this backdrop that this holistic approach which considered all the major components of the natural ecosystem including biological, chemical and physical components were determined to monitor the health of these mangrove ecosystems. This study therefore helped to address issues from a capacity development point of view, besides providing comprehensive data source that not only informs policy decision making, but also, helps with the design of effective and lasting management strategies for conservation of mangrove forests in Ghana.

The findings of this study would contribute to the establishment of a national data base on mangrove ecosystems to significantly facilitate data accessibility. Furthermore, the outcome of this study would contribute to these global efforts to eliminate poverty, improve food security and decrease exposure to climate change. It would also contribute immensely to the scientific data base critically needed in Ghana for decision making towards the effective protection and management of existing mangrove forests by the Forestry Commission and other relevant organisations and stakeholders.

1.6 Delimitations of the Study

The research was narrowed to two mangrove forests in estuaries within the Central and Western regions of Ghana. The Kakum mangrove forest is the most diverse mangrove forest in Ghana, however, there is no conservation or restoration efforts put in place. The Pra mangrove forest is the second largest mangrove forest in Ghana and on the contrary, there are some efforts in place towards conservation and restoration of the mangrove forests.

1.7 Limitations of the Study

There were some constraints encountered during the research, however, these did not represent nor constitute errors in the outcome of the research.

The determination of the concentrations of heavy metals in the mangrove soils was done at the Chemistry Laboratory of Ghana Atomic Energy Commission (GAEC), Accra, where the researcher had little control over the analyses.

Environmental factors used in the research were not measured directly but were rather retrieved from Tutiempo Network (2018). These measurements for the Kakum and Pra estuaries were taken at Saltpond and Sekondi – Takoradi weather stations respectively.

Although a minimum of three time periods were needed to clearly delineate a direction of change, it was impossible to have other aerial photos (orthoimages) other than the 2005 and 2017 images used for characterisation of mangrove cover change.

There were a lot of human activities that took place within the demarcated sampling plots, however, precautionary measures were taken that ensured errors were eliminated.

1.8 Definition of Terms

Alluvial soil: A fine-grained fertile soil deposited by water flowing over flood plains or in river banks.

Diameter at Breast Height (DBH): Diameter of the trunk of a standing tree measured at 1.3 m above the ground.

Ecological health: The state of functioning ecosystems, which is determined by a combination of many different factors.

Ecological risk: The risks posed by the presence of heavy metals in mangrove environment.

Estuary water quality: Quality of the estuarine water based on its physico-chemical parameters.

Gley: A sticky waterlogged soil lacking in oxygen, typically grey to blue in colour.

Human pressures: Impact of human activities such as logging on the mangrove ecosystems.

Hydromorphic soil: A soil in which the effects of poor drainage is the main factor in determining its morphology, giving rise to a predominance of gley colours.

Litter production: Shedding of vegetative and reproductive structures of mangroves, as a measure of productivity of the mangrove ecosystem.

Mangrove cover change: Change in mangrove area or extent over time.

Sediment quality: Quality of mangrove sediments based on nutrient contents and physico-chemical parameters of the sediment.

1.9 Organisation of the Study

This work has been structured into six chapters. The first chapter introduces and emphasises the objectives and relevance of the study.

Chapter two gives a comprehensive review of previous works retrieved from several sources such as books, theses and journals that were relevant to this research.

In chapter three, information on the study areas, detailed field and laboratory procedures on data collection and analyses are provided. The various ecological and statistical methods and tools used to analyse data to get accurate and valid results are also presented.

Chapter four presents the major findings from the methodology and analyses outlined in chapter three.

Thorough discussion on the results obtained is provided in chapter five, taking into account relevant literature reviewed earlier.

Lastly, in chapter six, a summary of findings and conclusions from the study, as well as and recommendations to relevant individuals and stakeholders are outlined.

1.10 Chapter Summary

This chapter generally gave a brief overview of the entire research. It identified research gaps in mangrove studies and provided objectives to be achieved to help bridge these gaps. This research promised to produce a comprehensive data that would help in designing effective management strategies for conservation of mangrove forests in Ghana. The chapter ended with the details on the organisation of the study.

CHAPTER TWO

LITERATURE REVIEW

The previous chapter provided a general overview and importance of the study. This chapter presents relevant literature that is reviewed in this study. The literature was revised on the global distribution of mangroves, distribution of mangroves in Africa and Ghana, environmental factors influencing mangrove distribution and mangrove biodiversity. Reviews were also done on the thematic areas of the study which include mangrove forest structure, litter production and mangrove ecosystem services. Deliberations were also made on threats to mangroves ecosystems, mangrove restoration and conservation, and ecosystem health. The chapter concludes with relevant studies on mangroves in Ghana.

2.1 Coastal Ecosystems

Coastal ecosystems may be generally defined as the portion of the sea influenced by land and the portion of the land influenced by the sea (Iglesias-Campos, Meiner, Bowen & Ansong, 2015). That is, they represent the boundary where the land meets the sea, covering shoreline environments and adjacent coastal waters (The World Bank, 1996). Some of the principal habitats include salt marshes, sandy beaches and dunes, tidal areas, sea grass meadows, intertidal flats, rocky shores, coastal plains, reefs, muddy sea beds, coastal lagoons, estuaries, wetlands and mangrove forests. These coastal ecosystems are complex and inter-dependent, and provide a wide range of ecosystem goods and services, used by people for food, fuel, construction, income and other uses, that support human wellbeing (IUCN, 2007).

Worldwide, coastal ecosystems occur in 123 countries and within coastlines exceeding 1.6 million kilometres (Burke et al., 2001), including Ghana with a 550 km coastline (DeGraft-Johnson, Blay, Nunoo & Amankwah, 2010). Over 50 percent of the world's population live within 60 km of the coast, whereas there is considerable increased migration of people from inland areas (The World Bank, 1996), increased fecundity, and tourist visitation to the coast (MEA, 2005). The coastal zone of Ghana for instance, covers only 6.5% of land area but is populated by a quarter of Ghana's population (DeGraft-Johnson et al., 2010)

The population densities of coastal inhabitants are said to be increasing exponentially, making the coastal population densities almost three times that of inland regions (Barbier et al., 2008; MEA, 2005). Earlier, it has been projected that two-thirds of the population (3.7 billion) in developing countries, will live in coastal areas by the turn of this century (The World Bank, 1996). Increasing population is of a major concern worldwide. These coastal inhabitants are dependent on coastal ecosystems and their services such as fisheries, storm buffering, and enhanced water quality for their sustainability (Barbier et al., 2008).

In spite of the importance of the valuable goods and services, coastal ecosystems are being degraded and lost at an alarming rate within the past two to three decades. The global annual loss is estimated at 4–9 % for corals (Bellwood, Hughes, Folke & Nyström, 2004; Gardner, Côté, Gill, Grant & Watkinson, 2003), 2–5 % for seagrass meadows (Duarte, 2002; Orth et al.,

2006) and 1–3 % for mangroves (Valiela et al., 2001). Duarte, Dennison, Orth & Carruthers (2008) reiterated these losses will not only erode biodiversity, but also result in reduction in the provision of valuable ecosystem functions provided by these coastal ecosystems.

The sustained global loss of coastal ecosystems is attributed to ever-increasing population growth along the coast which comes with increasing anthropogenic pressures on these ecosystems. These losses are caused by multiple mechanisms such as land reclamation, coastal development, nutrient and organic inputs, overfishing, intensive aquaculture, mechanical damage by fishing boats and gears, logging and vulnerability to climate change (Bellwood et al., 2004; Duarte, 2002; Orth et al., 2006). These development-related loss of coastal habitats and ecosystem services remain the greatest cause of change to the coastal zone (Iglesias-Campos et al., 2015).

Duarte et al. (2008) proposed that understanding of the causes of these losses as well as public education on these losses, is necessary for effective management and protection or restoration of these ecosystems. As a result, scientific research has improved in response to these ecological challenges, with the annual rate of publication on some coastal habitats increasing by about twofold over the past 10 years (Orth et al., 2006). However, there is contrasting research effort on these coastal habitats with coral reefs receiving 60 %, while salt marshes, seagrass meadows and mangrove forests received 11–14 % each of all of the published research (Duarte et al., 2008). They also pointed out that these ecosystems are highly connected, therefore, their conservation must be done holistically, involving all ecosystems in the coastal zone.

2.1.1 Estuaries

Estuaries are places where the fresh water from rivers meets the saline water from oceans. About 1,200 major estuaries have been identified, mapped and digitized within an approximate area of 500,000 square kilometres (MEA, 2005). The coastline of Ghana is lined with about ten estuaries including the Kakum and Pra River estuaries. Mangroves are often found in estuaries. In Ghana for instance, they are found in estuaries of major rivers and lagoons (Agyeman, Akpalu & Kyereh, 2007).

2.2 Description of Mangroves and Mangrove Ecosystems

"The word 'mangrove' is usually considered a compound of the Portuguese word "mangue" and the English word 'grove' (Kathiresan & Bingham, 2001). The FAO (2007) defines mangroves as "salt-tolerant evergreen forests, found mainly growing on soft substrates along sheltered estuaries, shallow-water lagoons, deltas or rivers in tropical and subtropical areas and countries". Mangroves are generally, woody plants that grow at the interface between land and sea in tropical and sub-tropical latitudes (Kathiresan & Bingham, 2001). According to them, the mangroves, together with the related plants, microbes, fungi, and animals, form the mangrove forest community or mangal, while the mangal and its associated abiotic factors or components constitute the mangrove ecosystem.

The term "mangrove" is commonly used to refer to both the plant species and the ecosystem or forest community (Tomlinson, 1986; Kathiresan & Bingham, 2001; UNEP, 2014). Consequently, with the intention of avoiding confusion, it was proposed by Macnae (1968) that, the word "mangal" should be specifically used to refer to the mangrove community whereas "mangroves" should refer to only the plant species.

Another definition of mangrove given by Duke (1992), is a "tree, shrub, palm or ground fern, generally exceeding more than half a meter in height, and which normally grows above mean sea level in the inter tidal zones of marine coastal environments, or estuarine margins". This definition is however, not fully acceptable because of the inclusion of ground ferns which may be regarded as 'mangrove associates' instead of 'true mangroves'. 'True or exclusive mangroves' are species which occur only in intertidal habitats or only rarely elsewhere while 'mangrove associates' or 'non-exclusive mangrove species' include a large number of species which occur typically on the landward border of the mangal and mostly in non-mangal habitats such as salt marsh, lowland freshwater swamps or rainforest (Hogarth, 2007).

The mangrove associates include climbers such as the vines *Caesalpinia* and *Derris* (Leguminosae), lianes, the orchid Vanda, the mangrove rattan palm (*Calamus erinaceus*) of Malaysia, and climbing ferns which depend on mangrove trees as a firm substrate, as well as parasitic mistletoes (Loranthaceae) found in many parts of the world (Hogarth, 2007). In Ghana, mangrove associates such as *Paspalum vaginatum* (Poaceae), *Tapinanthus bangwensis* - parasitic mistletoe (Loranthaceae), *Thevetia peruviana* (Apocynaceae) and *Thespesia populnea* (Malvaceae) have been reported (Sackey et al., 2011).

Mangrove ecosystems are described variously as "mangrove forests", "tidal forests", "coastal woodlands", or "oceanic rain forests." (Aksornkoae, 1993; FAO, 1994; Kathiresan & Bingham, 2001; UNEP, 2007). In the context of this study, mangroves and mangrove forests refer to the plant species and the mangrove ecosystem respectively.

2.2.1 Mangroves and their adaptations

The mangrove ecosystem which embodies an interphase between terrestrial and marine communities, receives daily inputs of freshwater, sediments, nutrients and silt deposits from upland river water and water from the ocean (FAO, 2007). Mangroves thus, tolerate wide range of salinities- from freshwater through to hypersaline conditions exceeding 100 parts per thousand (Romañach et al., 2018). The inhabitants of the mangrove ecosystem including the mangrove trees are adapted to their harsh environment, and are able to cope with fluctuating tides and salinity, low oxygen concentrations and frequently high temperatures (Hogarth, 2007).

The most striking adaptations developed by mangrove trees are various forms of aerial root systems (FAO, 2007; Hogarth, 2007). They are mainly used for the exchange of gases and absorption of nutrients, as well as providing anchorage to the tree in the muddy soil (FAO, 2007). The aerial roots are developed only in the 'strict or true mangroves' (Tomlinson, 1986) and there are different structures of aerial roots in each species (FAO, 2007). For example, still roots grow from the trunk and lower branches of the genus *Rhizophora*; to a limited extent, in the sapling stage of the genera *Bruguiera* and *Ceriops*; and occasionally in other mangroves such as *Avicennia alba* and *A. officinalis* (Tomlinson, 1986).

Another aerial root in mangroves is 'pneumatophores' which are pencil-like extensions or appendages of the subterranean rooting system (FAO, 2007;

Tomlinson, 1986), that rise from the ground and extend a long distance from the parental tree (FAO, 2007). These pneumatophores are erect and found in the genera *Avicennia*, *Sonneratia* and *Laguncularia* (FAO, 2007; Tomlinson, 1986). In the genera *Ceriops*, *Bruguiera*, and *Xylocarpus*, the pneumatophores may form a series of arched or knee shapes, so-called 'knee roots' (FAO, 2007; Tomlinson, 1986).

The aerial roots have numerous tiny pores, or lenticels, which air passes through while the roots in the soil are principally made up of aerenchyma tissue with air spaces which run longitudinally down the root axis, to ensure adequate gas exchange in hypoxic, or even anoxic environment (Hogarth, 2007).

The roots of mangrove tend to remain close to the surface, due to the nature of mangrove soil, hence, they lack deep taproots for anchorage. To augment this, the aerial roots of *Rhizophora* produce both flying buttresses and guy-ropes while the horizontally spreading system of *Avicennia* are effective in providing anchorage in the often fluid and unstable soil (Hogarth, 2007). The roots of mangroves therefore, cover a relatively high proportion of the tree.

Another adaptation to cope with the unstable environment is the development of several methods to remove excessive salt in the water they absorb. For instance, in *Avicennia* spp, salt excretion glands are used to remove excess salt - the leaves accumulate the salt in the tissues after which the leaves are shed, or reject the uptake of salt at the root level (FAO, 2007; Kathiresan & Bingham, 2001).

Mangroves have different reproductive strategies and a majority of them produce unusually large propagules (propagating structures) that leave the parent tree as a seedling (Hogarth, 2007). The Rhizophoraceae family shows viviparity, whereby, the seed, is not released but germinates on the parental tree, while the seedling is used as the propagule and is only detached when mature and ready to be established (FAO, 2007). Viviparous reproduction allows seedlings to develop some salinity tolerance before being released from the parent tree (Aluri, 2013). The genus *Avicennia* and other genera exhibit crypto-vivipary, where the offspring are attached to the parents only for a short period, while the embryo emerges not from the fruit, but from the seed coat, before it abscises (FAO, 2007; Tomlinson, 1986). Aluri (2013) specified that the true mangroves are viviparous and crypto-viviparous plants whereas mangrove associates are non-viviparous ones. All these adaptations enable mangroves to survive extreme and ever-changing environments.

2.3 Distribution of Mangroves in the World

Globally, mangroves are generally found within tropical and subtropical coastlines in 112-124 countries (Ahmed & Glaser, 2016; FAO, 2007; Massó et al., 2010; Romañach et al., 2018; UNEP, 2014), between latitudes 30° N and 30°S (Giri et al., 2011; Kathiresan & Bingham, 2001). However, a recent report indicates that mangroves occur in only 105 countries (Hamilton & Casey, 2016). Mangroves cover an area of 152,000 -156,000 km^2 (15.2 – 15.6 million ha) worldwide (Ahmed & Glaser, 2016; Barbier, 2016; FAO, 2007, 2010; Winders, 2012) and this forms only about 0.39% of the world's forest area (Ahmed & Glaser, 2016).

However, there have been several reviews on the total mangrove area in the world due to disparities in these estimates. For instance, Hamilton and Casey (2016) pointed out that there have been vast variations in the yearly estimates of worldwide mangrove cover by authors within each decade. Available data indicate downward estimates of global mangrove coverage from 18.8 million ha in 1980 to 18.1 million ha in 1997 (Spalding, Blasco & Field, 1997), 15.2 million ha in 2005 (FAO, 2007), and 13.8 million ha in 2011 (Giri et al., 2011), and further reduced to13.2 million ha in 2014 Hamilton & Casey, 2016).

Most of the world's mangroves are found in Asia, making it the continent with the most extensive mangrove area in the world (Ahmed & Glaser, 2016; FAO, 2007), followed by Africa and North and Central America (FAO, 2007). Giri et al. (2011) also confirmed that Asia had the largest extent of global mangroves and coined the global distribution of mangrove in this order: Asia (42%), Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). Remarkably, 47- 48% of the total global area occurs in five countries including Indonesia, Australia, Brazil, Nigeria and Mexico (Ahmed & Glaser, 2016; FAO, 2010). Friess (2016) pointed out that in 2001, over one fifth of the world's mangrove was found in Indonesia alone. Consequently, 65 % of the total global mangrove area occurs in just ten countries, while the remaining 35 % is distributed in 114 countries and areas (FAO, 2007). Notably, the world's largest single patch of mangrove forest is Sundarbans Reserve Forest, which covers 6000 km^2 in Bangladesh and 4000 km^2 in India (Uddin, Steveninck, Stuip & Shah, 2013).

The precise number of mangrove species in the world is still unknown but ranges from 50 to 73 based on different classifications (e.g. Tomlinson, 1986), with Asia having the highest species diversity, followed by eastern Africa (FAO, 2007). Based on variations in the definition of mangrove, there are on-going discussion on the exact number of mangrove species that exist in the world (FAO, 2007). There are also inconsistent estimates of mangrove extent across space and time, mainly due to different data sources, and classification approaches and systems (Giri et al., 2011). The inconsistency may also be attributed to the inaccurate estimates in published literature (Alongi, 2002), as well as a change in assessment methodologies from different countries that are incompatible (FAO, 2010).

2.3.1 Mangrove ecotypes

Mangroves have been classified into different mangrove community types or ecotypes according to topography, geology, hydrology and forest appearance of the areas colonized by mangroves (FAO, 1994; Hoff & Michel, 2014). Each of these types has unique community components, environmental factors such as soil salinity range, soil type and depth, and flushing rates, as well as ranges of primary production, litter decomposition and carbon content in addition to different nutrient recycling rates. Five or six of mangrove ecotypes have been described, based on the location of the mangrove forests (FAO, 1994; Hoff & Michel, 2014).

Six common ecotypes including overwash, fringe, riverine, basin, hammock and scrub or dwarf forests are described by the FAO (1994). *Overwash mangrove forests* are islands frequently inundated or washed over by tides; and generally dominated by red mangrove with tree maximum height of about 7 m. *Fringe mangrove forests* are found along waterways and shorelines at higher elevations than mean high tide levels, and maximum height of mangroves is about 10 m. According to Hoff & Michel (2014), fringe forests are found on edges of protected shorelines, lagoons, and canals, and are flooded by daily tides. *Riverine mangrove forests* are tall forests of maximum stand height of 18 - 20 m and found along tidal rivers and creeks, and subject to consistent flushing. *Basin mangrove forests* are mangroves of a height of 15 m, located in drainage depression in the interior of swamps, with red mangroves present at areas with tidal flushing while white and black mangroves predominate the inland portion. *Hammock mangrove forests* are generally similar to the basin forests but are found on slightly elevated sites compared to adjoining areas while the height is rarely more than 5 m. *Scrub or dwarf mangrove forests* are characteristically found in the flat coastal fringe, rarely exceed 1. 5 m, with nutrient being limiting factor. Scrub forests grow in areas with stressful environmental conditions such as high salinity, high evaporation, or low nutrient status which lead to stunt mangrove growth (Hoff & Michel, 2014).

2.3.2 Mangrove zonation and prevailing environmental factors

Mangrove zonation

Mangrove vegetation shows unique zonation, where species dominate specific zones from the edge of the estuary to inland parts (Tomlinson, 1986). FAO (2007) reported that mangrove forests may either show zonation parallel to the shore that is, frequently occurring in visible monospecific bands or occur as dwarf stunted trees in isolated patches.

Hogarth (2007) outlined four potential causes of zonation of species which are 1) physical sorting of floating propagules by water movement to the point where a propagule gets stranded; 2) selection might take place after settlement, for example by different species thriving at different positions along some physical gradient; 3) a consequence of gradients created by major geomorphological changes, and 4) the product of ecological interactions between species in the community. Kathiresan and Bingham (2001) emphasised the need for further studies to help understand zonation in mangrove ecosystems, since debatable causes of zonation including geomorphology, physiological adaptation, plant succession, seed predation, propagule size, inundation and depth of water, wave action, drainage and interspecific interactions among others have been identified by other workers. For example, small propagules have the ability drift further inland and establish better in shallow water than do large propagules, as clearly shown in *Avicennia* and *Rhizophora*, where the former grows inland and the later grows seaward (Kathiresan & Bingham, 2001). Hogarth (2007), however, argued that the reality is not often that simple - as for example, bimodal distribution is often exhibited by *Avicennia*, which can be abundant near the seaward side as well as some way up shore. It has also been emphasised by Hogarth (2007) that patterns of zonation are not clear in all mangrove zones, as demonstrated by mangroves in Tanzania, which may either be zoned or un-zoned, whereas those in adjoining Mozambique are seemingly un-zoned. Subsequently, it was concluded that the phenomenon of zonation is complex while the underlying causes do not seem to apply universally.

Environmental factors

According to Aksornkoae (1993), the composition, distribution and growth patterns of mangrove organisms, depend greatly on eight environmental factors which are coastal physiography, climate, tides, waves and currents, salinity, dissolved oxygen, soil, and nutrients. For example, salinity of the water, the climate, edaphic features and topography of the area may determine the habit of the mangroves - as shrubs or trees, while the canopy can reach a height of 30–40 metres under suitable environmental conditions (FAO, 2007).

Topography affects the characteristics of mangrove structure, especially species composition, species distribution and size as well as the extent of mangrove forest (Aksornkoae, 1993).

Climatic factors such as temperature, light, wind and rainfall influence the mangrove ecosystem strongly, contributing significantly to the growth of plants and animals as well as, affecting other factors such as water and soil (Aksornkoae, 1993). Temperature is of importance to physiological processes such as photosynthesis and respiration. Although there is not much evidence of the connection between temperature variation and the growth of mangroves, high temperature combined with prevailing winds and full sunlight may cause intense physiological stress to the plant FAO (1994).

Light is essential for photosynthesis and growth processes of mangroves; influences the transpiration, respiration, germination, flowering, physiology and morphology of the mangrove plants (Aksornkoae, 1993). According to Macnae (1968), mangrove plants generally, need high intensity of full sunlight, since they are long-day plants. There is however, evidence that intense light is harmful to the mangroves (Kathiresan & Bingham, 2001).

Wind may affect the mangrove ecosystem in many ways, such as influencing waves and currents, increasing evapotranspiration, hampering plant growth and causing abnormalities in physiology of plants. FAO (1994) indicated that severe storms have intense impact on the forest resulting in not only breaking of canopy of the forests along the coasts, but also making the trees structurally shorter. This partially explains why tall mangroves are usually found in more sheltered locations (FAO, 1994). Aksornkoae (1993) nonetheless, stressed that the winds serve as agents of seed dissemination and pollination for mangrove plants.

Since mangroves can extract fresh water from the sea through salt excreting glands, they do not rely totally on rainfall for survival. Yet, the amount of rainfall controls the rate of weathering which accounts for the quantity of silt transported to the mangrove forest, and also decreases the incidence of hyper-salinity (FAO, 1994). Consequently, FAO (1994) reported that the length of the wet season as well as the number, duration and intensity of dry seasons directly affect the distribution of salinity, hence the distribution of mangroves.

Tides as opined by Aksornkoae (1993) have great influence on horizontal distribution (zonation) and vertical distribution of plant and animal communities found within the mangroves. Tides also eliminate organic debris, sulphurous toxic wastes, accumulated carbon dioxide, maintains salinity levels of soil and regulates benthonic activity (FAO, 1994). According to Mckee (1993), tides may also cause seedlings of mangroves to be prone to oxygen deficiencies.

Waves and currents influence the distribution and development of mangrove species, for example, waves and currents carry the seedling of plants in the family Rhizophoraceae to distant areas along the coast (Aksornkoae, 1993). They also influence the survival of aquatic organisms, transporting nutrients from mangrove regions to the open sea.

Salinity is very important for growth, survival and zonation of mangrove species (Macnae, 1968). Aksornkoae (1993) reported that although mangroves are normally found in estuaries with a salinity between 10-30 ppt, several species of mangroves such as some species of *Avicennia*, *Ceriops* spp., *Sonneratia* spp. and *Rhizophora* spp. tolerate very high salinities between 44 ppt and 85 ppt. However, hypersalinity, a situation whereby the salinity of interstitial or surface soil levels exceeds that prevailing in the sea, can have adverse effects on the mangroves (FAO, 1994).

Dissolved oxygen is one of the vital factors controlling species composition, distribution and growth by helping, especially, in the photosynthetic and respiratory processes (Aksornkoae, 1993). Concentration of dissolved oxygen varies according to time, season, and species richness of plants and aquatic organisms present in mangroves, with highest occurring during the day and lowest at night.

Mangrove soils are alluvial, featureless and hydromorphic with the subsoil horizons showing different degree of gleying (FAO, 1994). They are formed by the accumulation of sediment derived from river bank or coastal erosion, or eroded soils from elevated areas transported down along rivers and channels, in addition to degradation of organic matter deposited through time (Aksornkoae, 1993). Mangrove sediments have different characteristics, depending on their origin. Mckee (1993) also explained that there are spatial variations in vegetation and soil chemistry, mostly caused by changes in complex interactions between biotic and abiotic factors over time, along environmental gradients within the mangrove ecosystem. As a result, species composition, richness, growth, and distribution of plants and other mangrove organisms are dependent on soil characteristics with soil pH being an important factor (Aksornkoae, 1993).

Mangrove soils are particularly susceptible to acid sulphation or 'the acid sulphate problem' due to oxidization, which occurs from combination of the high organic and iron content in mangrove soils, and the constantly present sulphate from tidal seawater (FAO, 1994). It was noted that the sulphates from the sea are reduced to iron sulphide or pyrite (FeS and FeS_2) by sulphate-reducing bacteria under anaerobic conditions, which results in 'the acid sulphate problem' and black colour of many mangrove muds.

Maintenance of the stability of the mangrove ecosystem depends largely on sufficient supply of nutrients, which can be grouped as 1) inorganic nutrients and 2) organic detritus (Aksornkoae, 1993). With the exception of nitrogen and phosphorus, all the inorganic nutrients including, potassium, magnesium, calcium and sodium are available in adequate quantities. The survival of mangrove organisms is essentially dependent on these inorganic nutrients that are mainly sourced from sea water, sediment, rain, river runoff and degraded organic matter.

2.3.3 Mangrove biodiversity

Mangroves support biological diversity by providing spawning grounds, nutrients, nurseries and habitats for several animals (FAO, 2007). Mangrove-associated flora include bacteria, fungi and fungus-like protists, microalgae (phytoplankton and benthic microalgal communities), macroalgae (Red algae, especially *Bostrychia* and *Caloglossa*) and seagrasses. The mangrove-associated fauna include zooplankton, epifauna (e.g. sponges, anemones, polychaetes, bivalves, barnacles and ascidians), epibenthos, infauna, meiofauna, crustaceans (e.g. shrimps, barnacles, lobsters and crabs insects and molluscs (Kathiresan & Bingham, 2001) According to Ntyam (2014), the crabs form the most abundant and important crustaceans and consequently, play significant roles in mangrove ecosystems. The most prominent are indisputably the fiddler crabs *(Uca* spp.), which create burrows at all levels of the shore (Hogarth, 2007).

Other fauna include reptiles such as crocodiles, alligators, lizards, snakes and turtles, as well as amphibians including ground frog, tree frogs and toads. Sunderbans of Bangladesh for instance, habours about 35 reptile species such as saltwater crocodiles (*Crocodylus porosus*), rock pythons (*Python molorus*) and monitor lizards (*Varanus* spp) (Kathiresan & Bingham, 2001). Hogarth (2007) also indicated that the Nile crocodile (*Crocodylus niloticus*) is found in West Africa. Many of the snake species however, are not mangrove specialists and enter mangrove ecosystems intermittently from adjacent terrestrial habitats just to forage, whereas some use the mangroves as their primary habitat (Hogarth, 2007).

Mangroves also provide important habitat for several birds such as shorebirds, land birds, and waterfowl, some of which are resident birds, while others are migratory bird species (Kathiresan & Bingham, 2001). Hogarth (2007) emphasised that “many species spend only part of their time in mangroves, either migrating seasonally, commuting daily, or at different tides, using the mangroves as a feeding area, a nesting area, a refuge from the rising tide, or some combination of these".

A variety of mammals also make their homes in the mangal, notably among them are dolphins (*Platenista gangetica*), mangrove monkeys (*Macaca mulatta*), otters (*Lutra perspicillata*) and flying fox (*Pteropus* spp.) (Kathiresan & Bingham, 2001).

Furthermore, mangrove ecosystems have rich fish biodiversity of importance which comprise fish with commercial value which serve as important links in food web, while others live there temporarily and spend greater part of their life stages elsewhere (Kathiresan & Bingham, 2001). Thus, a vast number of commercial and non-commercial fish, including shellfish depends largely on mangrove forests (FAO, 2007).

2.3.4 Mangroves of Africa

According to the FAO (2007), mangroves are found in almost all African countries, except Namibia, perhaps, due to climate. These mangroves occur in about 19 countries with varying habitat types along the coastline, extending from sandy desert shores (in Mauritania), to deep and depressed estuarine and island coasts (in Guinea Bissau), through countries in the Gulf of Guinea and to the occasionally large mudflats and deltas in the Gambia and the Niger Delta (Feka & Ajonina, 2011). African mangrove forests cover over 3.2 million ha and grouped into three major coastal segments namely, western Atlantic, central Atlantic and eastern Indian Ocean, representing 49 %, 37 % and 14 % of mangroves found along the coasts of Africa (Ajonina, Diame & Kairo, 2008). According to them, the mangroves in the western Atlantic coastal section of Africa stretch from Mauritania through Guinea Bissau to Senegal; those in the central Atlantic stretch from Liberia to Angola; while the mangrove covered countries in the eastern Indian Ocean include Somalia, Madagascar and South Africa among others.

Within the various regions in Africa, mangroves are very diverse (Ajonina et al., 2008), with significantly different species structure and composition (FAO, 2007). In total, Africa hosts 17 mangrove species, with nine and eight species uniquely found in eastern African and west and central Africa coasts respectively (Ajonina et al., 2008). They specified that mangrove species in eastern Africa include *Avicennia marina*, *A. officinalis*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum*. While species such as *R. mucronata* and *A. marina* are widely distributed along and occur in almost all countries, other species such as *Bruguiera cylindrica* and *Ceriops somalensis* are found only in Mozambique and Somalia respectively (FAO, 2007). According to the FAO report, countries with highest diversity include Mozambique, Kenya and Seychelles.

Out of the eight species found in West Africa and Central Africa, five are true mangrove species while the remaining three are mangrove associates. The five true mangrove species include three red mangroves (family, Rhizophoraceae) namely *Rhizophora racemosa*, *R. mangle* and *R. harrisonii*, the white mangrove--*Laguncularia racemosa* and the black mangrove--*Avicennia germinans* (Feka & Ajonina, 2011). The mangrove associates include *Cornocarpus erectus*, *Acrostichum aureum*, and *Nypa fruticans* - an exotic species from Asia hosted in Nigeria (Feka & Ajonina, 2011). FAO (2007) reported that the most dominant mangrove species in the region is *R. racemosa*.

FAO (2007) reported that as of 2005, about 70 % of all African mangroves were found in just five countries, including Nigeria (32 %), Mozambique (12 %), Madagascar (9 %), Guinea (9 %) and Cameroon (8 %), while the remaining 30 % are found in other countries such as Gambia, Guinea-Bissau, Kenya, Senegal and Ghana.

Mangroves of Ghana

Mangroves in Ghana are very limited in distribution and area, occurring in estuaries and lagoons (Agyeman, Akpalu & Kyereh, 2007). According to Ajonina (2011) and Gordon, Tweneboah, Mensah and Ayivor (2009), the mangroves are most extensively found to the western part of the country; in areas around Half Assini, Amanzure lagoon, Axim, Princes Town and Shama. Patches are found at Apam, Muni lagoon, Winneba, Sakumo-1 lagoon, Bortiano, Korle lagoon, Teshie, Sakumo-2 lagoon, Ada, Sroegbe and Keta lagoon, to the east of the country. The best developed mangrove stands are found in the Western Region precisely between Cape Three Points and Cote d'lvoire (DeGraft-Johnson et al., 2010; Spalding et al., 1997; UNEP, 2007).

The five true mangroves of West-Central Africa, *Rhizophora racemosa*, *R. mangle*, *R. harrisonii*, *Laguncularia racemosa* and *Avicennia germinans* are found in Ghana (DeGraft-Johnson et al., 2010; Sackey et al., 2011). They stated that all these five species of mangroves occur in the Kakum River estuary making it the estuary with the richest diversity of mangroves in the country.

Mangrove associates such as *Cornocarpus erectus* and *Acrostichum aureum* are also found in Ghana (Ajonina, 2011; Armah et al., 2009; DeGraft-Johnson et al., 2010; UNEP, 2007). Other species for examples, *Paspalum vaginatum*, *Sesuvium portulacastrum*, *Tapinanthus bangwensis* and *Thespesia populnea*, also occur in Ghana (Sackey et al., 2011).

The mangrove cover of Ghana was estimated to have reduced from 181 km^2 in 1980 to 137 km^2 in 2006 (UNEP, 2007). The mangrove ecosystems are endowed with resources which are exploited by coastal communities for different purposes (Agyeman, Akpalu & Kyereh, 2007), thus providing tremendously valuable ecosystem services (Ajonina, 2011).

2.4 Ecological Characteristics of Mangroves

Ecological characteristics of mangroves is an important prerequisite for understanding and the development of improved management systems for sustainable mangrove ecosystems. They help to acquire knowledge on their structure and dynamics, as well to ecosystem functions (Nebel, Dragsted & Vega, 2001).

2.4.1 Mangrove forest structure

Mangrove structure generally refers to the composition of a mangrove community in relation to attributes such as tree diameter and height, stem density, age, and species present (Queensland Government, 2018). Other standard attributes that are usually measured include tree height, density of the trees that is, number of individuals of species per unit area of land sampled and basal area (the cross-sectional area of the tree trunks per unit area of land sampled) (Aheto et al., 2011). The mangrove structure differs greatly between different or same forest types, and are also influenced by various factors comprising climate, soil pH and salinity and amount of freshwater the community is exposed to, among others (Queensland Government, 2018). The structure is related to the productivity of the mangrove forest and the assessment of these valuable attributes of mangrove forests are crucial in understanding mangrove ecosystem dynamics and health.

2.4.2 Mangrove litter production

Mangrove litter production is the shedding of vegetative and reproductive structures (e.g. leaves and seeds respectively) of mangroves. These may be caused by factors such as natural growth cycles, age, death, withering, stress and environmental factors, such as wind (Queensland Government, 2018; Siddiqui & Qasim, 1990). Litter production is an important component of mangrove primary productivity and has been widely used as a measure of productivity since technically, there is difficulty in measuring primary productivity in mangrove forests directly with other methods (Liu et al., 2014). Thus, litter fall, that is, production and standing crop is essential for ecosystem process because of its importance in organic matter production and the decomposition cycle (Hemati, Hossain & Rozainah, 2017), as well serving as the basis of detritus food chains (Queensland Government, 2018). Litter produced by mangrove forests also is a principal source of organic matter serving as food for a wide variety of marine invertebrate and detritus feeding organisms, that occur in the mangrove forests, the intertidal mudflats and near shore waters (Bouillon et al., 2008; Mulya & Arlen, 2018). Rani, Sreelekshmi, Preethy and BijoyNandan (2016) added that litter also plays a critical role in both carbon storage and carbon exchange to other nearby coastal ecosystems. For instance, Mohit and Appadoo (2009) indicated that organic carbon enter estuaries in the form of fallen vegetative and reproductive structures, making mangrove forest an important source of carbon in estuaries.

Globally, seasonal and spatial variations occur in the quantity and composition of mangrove litter (Cunha, Tognella-de-Rosa & Costa, 2006; Rajkaran, Anusha & Adams, 2007; Rani et al., 2016; Sharma, Analuddin & Hagihara, 2010), with the highest peak occurring during summer and the lowest during winter (Cunha et al., 2006; Sharma et al., 2010). Varied estimates of litter production have been reported for several mangrove forests worldwide (Hemati et al., 2017), ranging from 0.8 to 28.1 t ha^{-1} $year^{-1}$ (800 to 20300 kg ha^{-1} $year^{-1}$) (Rafael & Calumpong, 2018; Siddiqui & Qasim, 1990). These variations are influenced by several factors including type of species (Rafael & Calumpong, 2018), geographical location (Liu et al., 2014), tree height and human activities (Shunula & Whittick, 1999) and other factors such as, type of forest, available nutrients and fresh water drainage sediments (Siddiqui & Qasim, 1990).

Zhang, Yuan, Dong and Liu (2014) pointed out that seasonal litterfall patterns exhibit varied forms among the various forest types. For a sub-tropical mangrove forest, distinct seasonal (unimodal) pattern with maximum litter fall occurred during the autumn season while minimum during winter (Mfilinge, Meziane, Bachok & Tsuchiya, 2005). Wang'ondu et al. (2014) reported that for a tropical mangrove forest, litter production was continuous throughout the year and showed peaks (bimodal pattern) influenced by both the wet and dry seasons.

For example, Ntyam (2014) reported that litterfall was observed throughout the year in Cameroon and Ghana, with the highest litterfall occurring in the dry season while the lowest occurred in the wet season.

2.5 Importance of Mangroves

Mangroves ecosystems form integral part of highly productive and biologically complex ecosystems (UNEP, 2014) on earth. Mangrove ecosystems provide a wide range of ecosystem goods and services that millions of people heavily depend on to support their livelihoods (USAID, 2014). These valuable ecosystems contribute significantly not only to livelihoods, but also to the overall security of coastal communities (FAO, 2007; UNEP, 2014). Generally, mangrove ecosystems play pivotal roles in coastal economies (Ahmed & Glaser, 2016), contributing to an annual estimate of US$ 2000-9000 per ha (Alongi, 2014). Mangrove forests thus, influence both local and national economy, in addition to livelihoods (Uddin et al., 2013).

Some valuable ecosystem services provided by mangrove forests include provision of fuel wood, charcoal and timber; flood control, erosion control, breeding and spawning grounds for fish species, recreation and other aesthetic values (FAO, 2007). Mangrove forests have been recognised as economic and ecological ecosystems on earth (Ahmed & Glaser, 2016; Alongi, 2014), because they provide ecosystem services. MEA (2005) defines ecosystem services as the benefits humans obtain from nature and categorised them into four ways including provisioning services, regulating services, supporting services and cultural services.

Provisioning services

Mangrove ecosystems are sources of biodiversity because they serve as habitats as well as breeding, nursery and feeding grounds for a variety of organisms (FAO, 2007). They provide distinctive fisheries and forest products (Uddin et al., 2013). The fisheries comprising fishes, crustaceans (crabs, shrimps), molluscs and oysters which provide income for coastal communities. Timber, fuel wood, charcoal, fibre, fodder, tannins, dyes and medicines (Brander et al., 2012; UNEP, 2014), are examples of forest products provided by mangrove ecosystems.

Additionally, mangrove ecosystems provide honey and other raw materials (Barbier et al., 2011) that human beings rely on for their sustenance. Moreover, the wood from mangrove ecosystems that are used for construction, smoking fish, fuel wood, charcoal production, dyes and preservatives for fishermen's nets are believed traditionally to be superior in quality (USAID, 2014). In Ghana for instance, the total estimated value for mangrove forestry and fishery resources for the lower Volta was over US $ 500 per hectare, while the country estimates are well over US $ 6,000,000 per year (Ajonina, 2011).

Regulatory ecosystem services

Regulating services can be considered as benefits obtained from ecosystems through the maintenance of favourable environmental conditions by ecosystem processes and functions. Mangroves provide these crucial and numerous regulating services by the regulation of ecosystem processes. There are numerous studies that confirm regulatory and protective roles of mangrove ecosystems, including coastal protection, erosion control, climate regulation as well as maintenance of water quality (Brander et al., 2012; UNEP, 2014).

Coastal protection

Mangrove ecosystems play a critical role in protection of shoreline by serving as natural barriers against strong waves and negative impact of cyclones, storm surges and tsunamis (Salem & Mercer, 2012; UNEP, 2014). Indeed, many studies have shown the crucial roles played by mangroves in buffering coastlines against storm surges and tsunamis through wave attenuation (Badola & Hussain, 2005; Barbier et al., 2011; Horstman et al., 2012; Kathiresan & Rajendran, 2005; Sandilyan & Kathiresan, 2015; Spalding et al., 2014; Teh, Koh, Liu, Ismail & Lee, 2009). For instance, studies have proven that mangroves prevented about 70 % of the flooding into inland when Hurricane Wilma occurred in south-western Florida in 2005 (Liu, Zhang, Li & Xie, 2013). Badola & Hussain (2005) and Das & Vincent (2009) also reported that there were significant reduction in damage and deaths caused by the 1999 cyclone that hit Orissa in India because of the presence of mangrove ecosystems.

Erosion control and shoreline stabilization

Mangrove ecosystems provide a wide range of hydrological services, including reducing sediments and erosion (Wattage, 2011). Mangrove forests significantly protect the coast against flooding and erosion, by absorbing and scattering energy of wave (Duarte, Losada, Hendriks, Mazarrasa & Marbà, 2013; Pramova, Locatelli, Djoudi & Somorin, 2012), and reducing erosive forces acting on the sediment thereby, stopping it from being carried away from the shore (Di Nitto et al., 2014). Mangroves also stabilise shorelines by decreasing the height and energy of waves (Mazda, Magi, Ikeda, Kurokawa & Asano, 2006; McIvor, Möller & Spencer, 2012).

Climate regulation

The role of mangroves in global climate regulation is perhaps the least investigated ecosystem service of mangroves (UNEP, 2014). Mangroves play a crucial role in carbon sequestration. They have the capacity to sequester more carbon (UNEP, 2014), 3-4 times (Donato et al., 2011), or even almost five times, (USAID, 2014) more than any other forest type within a given unit area. According to Donato et al. (2011), sediments of mangrove forests are organic-rich and this accounts for about 49-98% of carbon storage in the costal environment, which plays a crucial role in carbon sequestration. Additionally, mangrove forests are able to store large quantity of carbon in their root systems and reduce the effect of harsh environmental conditions, which in turn help in fighting against sea level rise and salinity (Abdullah-Al-Mamun, Masum, Sarker & Mansor, 2017). Mangroves have therefore been labelled "blue carbon" sinks since they are in the coastal environment (Winders, 2012). However, their contribution to Reducing Emission from Deforestation and Degradation of Forests (REDD+) has either been underestimated or not estimated at all in most national REDD+ strategies, particularly in Africa (USAID, 2014).

Huxham et al. (2010) pointed out that high mangrove biodiversity and productivity brings about protection from increased water salinity, temperature,

CO_2 and variations in rainfall patterns. Donato et al. (2011) noted that although mangroves account for only 0.7% of the extent of tropical forest, deforestation of mangroves contributes to 10% of CO_2 emissions.

Furthermore, mangroves provide resilience to effects of droughts (Ahmed & Glaser, 2016) and aid in coastal adaptation to sea-level rise (Alongi, 2008; Duarte et al., 2013; Pramova et al., 2012). It has been noted that, healthy mangrove ecosystems are very important for climate change adaptation strategies for coastal habitants (USAID, 2014). Consequently, restoration, protection or rehabilitation of mangroves form integral part of adaptation strategies to sea-level rise in coastal zone of Martinique in the West Indies (Schleupner, 2007) and the Pacific Islands region (Huxham et al., 2010).

Maintenance of water quality

Mangroves also filter minerals, pollutants, sediments and nutrients from river and tidal waters thereby maintaining quality of surrounding water (Ahmed & Glaser, 2016; UNEP, 2014). Gillis et al. (2014), Satheeshkumar and Khan (2012) and UNEP (2014) opined that the physical structure of mangroves slows down flow of water, enabling sand, clay and heavy metals to drop out of suspension in the water column. They further noted that mangroves also alter the turbidity of ambient waters through sediment trapping.

In addition, mangroves protect groundwater salinity by preventing the entry of saltwater to inland areas (Kathiresan & Rajendran, 2005). Furthermore, Gillis et al. (2014) and Pramova et al (2012) stated that mangroves also play a crucial role in maintaining water temperature through sediment trapping, bio-filtration and salt absorption. Nevertheless, UNEP (2014) cautioned that even though mangrove and associated plants are effective in bio-filtration and waste processing, beyond certain critical thresholds of salinity, sediments, heavy metals and other organic contaminants, mangrove die-back will result.

Supporting services

Supporting services are those ecosystem services such as photosynthesis, soil formation, primary production, water cycling and nutrient cycling, that are essential for all other ecosystem services (Walters et al., 2008). Mangrove ecosystems provide supporting services such as habitat of biodiversity, nursery ground of fish and nutrient cycling (Kathiresan & Rajendran, 2005; Walters et al., 2008). Thus, mangroves contribute to maintenance of fisheries by providing suitable reproductive habitat and nursery grounds, as well as sheltered living space (Barbier et al., 2011).

For the habitat function of mangroves, the aerial roots of mangroves provide a substratum on which many species of plants and animals live, the trees and canopy serve as important habitat for different kinds of species, including mammals, birds, reptiles and insects; epibionts such as bivalves, tunicates, algae, while sponges overgrow on the roots below the water; and the space between roots offers shelter for motile fauna such as crabs, prawns, and fishes (Nagelkerken et al., 2008).

Mangroves provide nursery habitats for commercially important species such as fish, prawn and crab, which in turn, support offshore fish populations and fisheries (Nagelkerken et al., 2008). Kauffman and Donato (2012) indicated that as much as 75% of all tropical commercial fish species spend part of their lifecycle in mangrove ecosystems. Food chain in marine environments also begins in the mangrove ecosystems since they serve as the source of detritus that are carried by tidal currents into the coastal waters (Wattage, 2011).

Cultural services

Cultural services stem from dynamic and complex social attributes. Mangrove ecosystems provide cultural services such as tourism, heritage, worship, educational research (Brander et al., 2012; Kathiresan & Rajendran, 2005; UNEP, 2014; Walters et al., 2008), recreational, spiritual and other non-material benefits (Wattage, 2011). Sundarbans Reserve Forest is a World Heritage site in Bangladesh which provides education and research, and tradition of livelihoods, while its scenic beauty, fishing, river cruising, jungle trails, bird watching and wildlife watching attract a large number of national and international tourists every year (Uddin et al., 2013).

All these important ecosystem services are heavily dependent on healthy mangrove ecosystems (Hoppe-Speer, Adams & Bailey, 2015). However, mangrove ecosystems are threatened worldwide (Salem & Mercer, 2012), with an alarming increase in the rate of global mangrove degradation (Valiela, Bowen & York, 2001).

2.6 Threats to Mangrove Ecosystems

Mangroves of the world face a number threats from both natural and anthropogenic causes (Giri et al., 2011), leading to mangrove forests being considered as one of the most threatened tropical ecosystems in the world (Valiela et al., 2001). Estimates on extent of mangrove loss around the globe have been very alarming. For instance, the decline in mangrove in the past half century is estimated to be 30–50% (Alongi, 2002; Donato et al., 2011; Duke et al., 2007; FAO, 2007; Valiela et al., 2001), with disturbing destruction of 50-80% in Asian countries in regions such as Java and the Philippines (Wolanski et al., 2000). In Ghana, 50 % mangrove loss occurred in some communities over the past two decades (Asante, Jengre, Asare & Mason, 2014).

Thus globally, more than 3.6 million ha of mangrove forests were lost from around 1980 through to 2010 (Ahmed & Glaser, 2016; Uddin et al., 2013). Estimated rates of annual loss of mangroves ranged between 1-3 %, which is above rates of loss for other forests (Valiela et al., 2001), making it three to five times greater than that of other forests on a global scale (UNEP, 2014; Valiela et al., 2001). Duke et al. (2007) lamented about the worrying trend of mangrove decline in almost every country that has mangroves, with the developing countries, where more than 90% of the world's mangroves are found, experiencing highest and rapid rate of mangrove loss. Indonesia for example, is reported to experience the greatest rate of annual mangrove loss in the world (Feller, Friess, Krauss & Lewis, 2017).

A recent review of the state of the world's mangroves by Friess et al. (2019) confirmed that mangrove use during pre-industrial period did not have any significant impact on the extent and quality of mangrove forests, rather, impact of humans on mangrove resources increased during the past few centuries, then peaked in the twentieth century. Romañach et al. (2018) stated that human population growth with its associated development in the coastal zone is the primary cause of global losses of mangroves. By and large, 39 - 40 % of the world's population live within 100 km of the coast (MEA, 2005; Romañach et al., 2018). It has been reported that from 1990 to 1995 alone, the population of people living within 100 km of the coast worldwide rose by 20% from about 2 - 2.2 billion (MEA, 2005).

Valiela et al. (2001) attributed the increasing rate of worldwide mangrove degradation to increase in human activities. Earlier, Alongi (2002) reported that human population density is generally positively related with destruction of mangroves. Giri et al. (2011) recounted that in the last three decades, mangrove forests were lost significantly because of anthropogenic factors. A recent review of the global status of mangrove forests by Romañach et al. (2018) revealed that the global loss of mangroves are primarily caused by human population growth and development in the coastal zone specifically, urban development, aquaculture, conversion to agriculture and overexploitation of timber.

Several studies (Alongi, 2002; Barbier et al., 2011; Brander et al., 2012; Primavera, 2000; UNEP, 2014; Valiela et al., 2001; Winders, 2012; Wolanski et al., 2000) have proven that pond aquaculture is presently the leading threat to mangrove forests worldwide, causing a lot of direct and indirect problems such as immediate loss of mangroves, alteration of natural tidal flows and reduced water quality (Alongi, 2002). The discharges including nutrients, chemicals and pollutants from coastal aquaculture also have continuous harmful impacts on neighbouring mangroves (UNEP, 2014). Barbier et al. (2011) reported that shrimp farming alone contributes to 38% to mangrove loss in Asia.

Other major causes of mangrove loss are urban development such as roads, hotels, ports and golf courses; agriculture, mining, salt evaporation ponds, and overexploitation for timber, fish, crustaceans and shellfish (Alongi, 2014; Brander et al., 2012; Salem & Mercer, 2012; UNEP, 2014). These anthropogenic threats to mangrove loss vary slightly across regions and countries. In Ghana, for example, urbanization, salt and sand mining, exploitation of fisheries and forest resources, and illegal gold mining are among the key factors causing mangrove loss along the coast (Armah et al., 2009; Asante et al., 2014; Coleman et al., 2004). Aheto et al. (2016) suggested that these human factors that threaten mangrove ecosystems may either be location-specific or originate from sources that are outside the communities surrounding mangrove forests.

Mangroves are also threatened by climate change (Brander et al., 2012; UNEP, 2014; Winders, 2012), and this could lead to a further loss of 10-15% by 2100 (UNEP, 2014). Giri et al. (2011) projected that sea-level rise could possibly be the major threat to mangrove ecosystems in the future. Alongi (2002) however, predicted that human activities are the greatest threats to the continued existence of mangroves in future, indicating that global warming may pose less threat.

Deforestation of mangroves has had considerable negative effects on mangrove biodiversity (Richards & Friess, 2015). According to Polidoro et al. (2010), 16% of the world's mangrove species are at an elevated threat of extinction, while as high as 40% of mangroves of Central America are threatened with extinction.

Mangrove ecosystem loss does not only result in biodiversity loss, but also implies loss of ecosystem services provided by these mangroves as well. Hence, concerted efforts are necessary towards the preservation and conservation of these mangrove ecosystems.

2.7 Mangrove Conservation and Restoration

According to Romañach et al. (2018), several international actions have been taken towards the conservation and sustainability of mangroves and wetlands as a whole, resulting in protection of large areas of mangrove forests around the globe. Some of these protective authorities include the UNFF, CBD, UNFCCC, Ramsar Convention and CCMSWA.

Besides these international agreements, various NGOs, governments to locally-initiated efforts have been made by individual countries to protect or restore these forests. For example, many governments in Africa have also developed various National Action Plans towards effective implementation of these international conventions comprising inclusion of mangroves in protected areas, resulting in protection of some 18 – 22 % mangroves in Central and West Africa (Ajonina et al., 2008). African Mangrove Network (AMN) which comprised 22 countries including Ghana, was also established in Cameroon in May 2003 with the aim of fostering regional collaboration to save African mangroves from further destruction (Armah, Diame, Ajonina & Kairo, 2009). Through this, mangrove reforestation and evaluation are supported in Benin, Congo, Guinea, Nigeria, Senegal and Ghana, among other accomplishment.

Specifically, in Ghana, quite a number of strategies including National Wetlands Conservation Strategy and Action Plan (2007-2016), the National Environmental Policy, Coastal Zone Management Indicative Plan, 1990, Draft Integrated Coastal Zone Plan, 1998, National Environmental Action Plan, 1994, Biodiversity Strategy and Action Plan and Fisheries Policy were put in place, targeted at sustainable use of resources and managing the environment (DeGraft-Johnson et al., 2010). However, DeGraft-Johnson et al. (2010)

lamented that there is no precise policy on the coastal zone and this supports the assertion by Ajonina et al. (2008) that there is inadequate law, policy and institutional provision for mangrove forests in Africa, despite all the international efforts.

Restoration of mangrove forests through planting has been the most dominant strategy adopted by many NGOs for mangrove conservation in the past two decades, with a coalition of all major global conservation organizations, the new Global Mangrove Alliance (GMA; https://mangrovealliance. org/), setting major goal of increasing mangrove area by 20 % by 2030 (Lee, Hamilton, Barbier, Primavera & Lewis, 2019). This target was supported by three international partners - the German Federal Ministry for Economic Cooperation and Development (BMZ), WWF and IUCN, which joined forces in the international mangrove initiative "Save Our Mangroves Now!" to halt the worldwide loss of mangroves (Slobodian, Chaves, Nguyen & Rakotoson, 2018).

There are however, some great challenges in replanting mangroves including low survival rates in mangrove afforestation and reduction in biodiversity of replanted forests (Chen, Wang, Zhang & Lin, 2009). This is due to mono-species or mono-generic planting of mainly *Rhizophora* and *Sonneratia* species in most of the reforestation projects (Chen et al., 2009; Lee et al., 2019). Lee et al. (2019) elucidated that *Rhizophora* species are the preferred choice because of convenience, since their propagules are large and elongated, easy to collect and planted by simple insertion into the substrate, as well as their fast growth. Chen et al. (2009) alluded to the fact that most of the reforestation projects are mainly concerned about the appearance of the vegetation and their high survival rates. A study by Aheto et al. (2016) in the Anyanui area in the Volta Region of Ghana also suggested that the mangrove planters are involved in the management of the mangroves principally for the monetary benefits that they obtain through the harvesting and sale of mangrove wood, but less concerned about the protective and ecological functions of the mangroves. Lee et al. (2019) pointed out that these planting schemes boost mangrove area for only short-term increases but lack the long-term usefulness.

Besides reforestation, protected areas (PAs) appear as an essential mangrove conservation strategy specific locations (López-Angarita et al., 2016). For example, between 2000 and 2010, PAs aided in conserving mangroves by preventing approximately 14,100 ha loss of mangrove in Indonesia (Miteva, Murray & Pattanayak, 2015). A recent study conducted to assess the influences of PAs on mangroves of the eastern tropical Pacific revealed that out of a total of 564 ha loss, only 25 % of mangroves were cleared from inside PAs while most of the loss occurred in locations outside PAs (López-Angarita, Tilley, Hawkins, Pedraza & Roberts, 2018).

Although the target agreed under the CBD is 10% by 2010, currently 7.7% the total mangrove area is being protected, whereas only around 6.9% is protected under IUCN protected areas categories I-VI (Giri et al., 2011). In West Africa, it is claimed that 14 % of mangrove areas are located within internationally and nationally designated protected areas, while that of Ghana is only 1.5 % (UNEP, 2007). Conversely, Fan (2002) pointed out that the designing of PAs is just the starting point for mangrove conservation and that tangible management strategies, with improvements of practices are required.

Overall, the future for mangroves worldwide is not completely bleak, because rehabilitation and restoration projects are increasing, with rises in mangrove area in some countries; however, extra efforts need to be taken to safeguard their lasting survival (Alongi, 2002). Again, Slobodian et al. (2018) pointed out that although there is no comprehensive global mandatory framework targeted at mangrove conservation, the various international legal provisions if appropriately implemented in national law, can be used for effective mangrove conservation.

2.8 The Concept of Ecosystem Health

The first principle of the ecosystem health concept was developed by James Hutton, a Scottish geologist who started to describe the Earth as an integrated system in the eighteenth century, and later the first origins of the eco-system health concept was created by a pioneering ecologist Aldo Leopold through his works on land sickness in 1941 (Burkhard, Mὒller & Lill, 2008). Also, ecologists started to study the response of natural ecosystems to variety of stresses from human activities since the Stockholm Conference on Human Environment in 1972 (Lu et al., 2015). However, the concept of ecosystem health has received tremendous recognition as a result of initiatives that arose from the Rio Declaration of the United Nations Conference on Environment and Development in 1992 and the 1992 CBD, with both highly connected with sustainable development (Hopkins, 2005).

Rapport (1989) pointed out that the integrity of the ecosystem is determined by a few critical structures and functions such as maintenance of efficiency in nutrient cycling and energy transfer, and maintenance of high species diversity such that the larger life-forms and longer-lived are dominantly present in the mature stage. He also listed some symptoms of ecosystem breakdown including 'reduced primary productivity, loss of nutrients, loss of sensitive species, increased instability in component populations, increased disease prevalence, changes in the biotic size spectrum to favour smaller life-forms, and increased circulation of contaminants'.

A variety of definitions of ecosystem health appears in literature, expressing different opinions ranging from combination of biophysical, human, and socio- economic components to a single component, on the general goal of ecosystem management and conservation (Mark, Provencher & Munro, 2003). However, most of these definitions share common elements (Rapport, Cairns, Costanza & Karr, 2001).

Generally, a healthy ecosystem is an ecosystem that is sustainable – meaning it is capable of maintaining its structure (organization) and vigour (function) over time in the presence of external stress (resilience) (Burkhard et al., 2008; Costanza & Mageau, 1999). Costanza and Mageau (1999) defined ecosystem health as "a comprehensive, multi-scale, dynamic, hierarchical measure of system resilience, organization, and vigour". They accordingly, identified three specific components of ecosystem health, namely structure, vigour and resilience and integrated them into quantitative assessment of ecosystem health.

2.8.1 Three components of ecosystem health

The structure or *organization* of a system refers to the quantity and variety of interactions among the various components of the system; example, diversity index. Thus, a measure of organization depends both on the diversity of species and the number of pathways through which materials are exchanged among each of the components

The *vigour* (or function) 'of a system is simply a measure of its activity, metabolism or primary productivity; examples are gross primary productivity in ecological systems, and gross national product in economic systems' (Costanza & Mageau, 1999). It shows the ability of the system to respond to stress of species. It is thus, the overall activities of that particular ecosystem, while its measure will give an indication of the quantity of energy the ecosystem captures (Jørgensen et al., 2010).

The *resilience* of a system refers to the capacity of a system to resist a change from a disturbance or recover from disturbance (Unnasch, Braun, Comer & Eckert, 2008). That is, the system's ability to maintain its organization and vigour in the presence of stress – examples include scope for growth, population recovery time and disturbance absorption capacity (Costanza & Mageau, 1999). There are two components of resilience, namely, resistance and recovery (Lu et al., 2015). According to Unnasch et al. (2008), 'resistance refers to the capacity of ecosystems to tolerate disturbances without exhibiting significant change in structure and composition'. Lu et al. (2015) identified three methods for recovery of ecosystem health: restoration, rehabilitation, and remediation.

2.8.2 Ecosystem health assessment and indicators

The concept of ecosystem health assessment (EHA) began in the late 1980s and this subsequently led to extensive discussions about suitable concepts and methodologies (Burkhard et al., 2008). Since then, a variety of metrics and approaches which focus on different components of the ecosystem have been used in assessing ecosystem health (Roley et al., 2014). Despite the fact that several metrics have been developed, a comprehensive, all-encompassing framework for their application is still lacking (Roley et al., 2014). This is because every ecosystem has its own unique basic features, which make it difficult to use a common framework, hence, case-specific methods are used in the assessment (Burkhard et al., 2008; Jørgensen, 2010; Roley et al., 2014). Accordingly, choosing the most appropriate metric comes with uncertainty and in some circumstances, an appropriate metric may be unavailable, so, characterisation of ecosystem integrity, its relation to the stressors involved, and its appropriateness for the intended usage must be importantly considered (Roley et al., 2014).

Ecosystem health cannot be directly measured or detected, so, alternate measures are used to assess it (Burkhard et al., 2008). Again, even though several indictors have been used in assessing ecosystem health, Jørgensen (2010) pointed out that no general ecological indicators do exist and it is impossible to specify a set of indicators for specific ecosystems or specific problems. Indicators chosen must however, be applicable on varying spatial and temporal scales, and be supported by ecological principles and systems theory (Burkhard et al., 2008). According Lu et al. (2015), the variety of indicators chosen must represent significant information on the structure and function of the ecosystem, as well as the specific goal of the assessment.

In addition, the health of the ecosystem is measured against several reference levels or points, so that degree in which it is in good condition or otherwise will be determined (Hopkins, 2005). The reference points or standards indicate the quality status in an ecological system or under natural conditions where the ecosystem is undisturbed or anthropogenic influence is minimal (Hopkins, 2005; Mark et al., 2003). Practically, this standard can be very difficult or even impossible to be determined since it is only found in an ideal situation, where there is minimal anthropogenic impact on the ecosystem (Mark et al., 2003). Rice (2003) stated that estimating reference points or standards is practical, so far as there are available informative historic data on the ecosystem.

It can be comprehended that different variety of indicators do exist for ecosystem health assessment and choosing from these can be challenging. Also, there are general criticisms that are associated with the use of ecological indicators (Marques et al., 2010). The first has to do with oversimplification of the ecosystem under study due to aggregation. Furthermore, the use of indicators to explain numerous characteristics of a specific system, as well as different kinds of factors brings about problems. So, in order to avoid confusing interpretations of data, indicators must be chosen using the right criteria and used consistently in line with their intended use and scope (Marques et al., 2010).

2.8.3 Mangrove health assessment

Assessment of mangrove health is an important way of monitoring the condition of the mangrove ecosystems periodically and varied variables or parameters are considered in these assessments. Some of the commonly used parameters for mangrove health assessment include mangrove litter production, seedling regeneration, canopy cover and leaf area index, mangrove forest structure and crab burrow counts (Queensland Government, 2018).

These parameters are used in developing indices such as Sediment Quality Index (SQI) and Normalized Difference Vegetation Index (NDVI) which constitute aspects of mangrove health assessment. For example, Prasetya, Ambariyanto, Supriharyono and Purwanti (2017) employed single value index based on ecological data including mangrove density, diversity, similarity index and the number of species, to develop Mangrove Health Index (MHI) for the mangrove ecosystem at Karimunjawa National Park in Indonesia. Vaghela et al. (2018) however, pointed out that these approaches are based on a single parameter such as the vegetation vigour or canopy density, as represented by NDVI and are not robust for all mangroves with varying conditions. They added that multi-parametric health approaches which take into consideration various factors like mangrove vigour, the weather, hydrology and stress, among others may be more robust.

Multi Criteria Decision Making (MCDM) approach involves the use of various parameters and input data, the decision maker's preferences and manipulation of both information using specified decision rules (Vaghela et al., 2018). They detailed that in MCDM approach, parameters are ranked based on the importance of their impact on the health, but the choice of these indicators as well as the weighting factors assigned to each indicator, differ from one mangrove zone to the other.

Recently, Ibrahim et al. (2019) developed a comprehensive MHI by using integrated variables comprising biological variables (e.g. tree height, basal area and crab abundance), soil variables (e.g. nitrogen, carbon, phosphorus and pH), hydrological variables (e.g. dissolved oxygen, pH and temperature), marine-mangrove health biological variables (e.g. number of species and abundance of total phytoplankton, diatoms and jellyfish) and socio-economic variables (e.g. fish landing, income, age and education). They concluded that despite the fact that a comprehensive assessment that integrates factors is needed, not all factors can be incorporated in establishing mangrove quality index, and hence, suitable strategies should be used in selecting effective indicator for the mangrove ecosystem health status to select appropriate indicators that could adequately reflect its real-time health status.

2.10 Chapter Summary

In this chapter, an in-depth existing literature on mangrove ecosystems was presented. It covered relevant literature on the distribution of mangrove species around the globe, mangrove ecology, importance of mangroves, threats to mangroves, as well as conservation efforts towards mangrove restoration. Also, the concept of ecosystem health was well elaborated, with the varying indicators and various methods of assessment explained. It was established that numerous works had been done on mangroves, both in and outside Ghana, however, the health of mangrove ecosystems has not been extensively assessed. Thus, the assessment of the health of mangrove ecosystems is worthwhile.

CHAPTER THREE

MATERIALS AND METHODS

The previous chapter reviewed relevant literature related to the study. This chapter describes the study areas and sites where the research was undertaken, as well as the materials and methods employed in the data collection and analyses. As part of the description of the study area, the locations and sampling sites are detailed. This section emphasises the sampling design and methods used for socioeconomic conditions assessment, mangrove cover change characterisation, vegetative assessment, litter production, sediment analyses, assessment of physico-chemical parameters, mangrove health assessment, and data analyses employed.

3.1 Study Area

The study was conducted in the mangrove forests associated with the Kakum and Pra estuaries, between March 2017 and August 2018. The two ecosystems are located in a semi-deciduous ecological zone of Ghana. The Kakum mangrove forest is situated along the Cape Coast-Takoradi trunk road, between Cape Coast and Elmina in the Central Region of Ghana (5° 05′ 01.4″ N and 5° 03′ 56.3″ N and longitudes 1° 18′ 48.3″ W and 1° 19′ 19.9″ W), and the Pra mangrove forest (5° 01' 06" N, 5° 02' 14" N and 1° 35' 56"W, 1° 39' 33"W), in the Western Region of Ghana (Figure 3.1).

The Kakum catchment experiences two peaks of wet season; the major peak occurs between May and July, while the minor occurs between September and December, with a mean annual rainfall between 1,500 mm and 1,750 mm

(Adombire, Adjewodah & Abrahams, 2013). There is a short dry period in August and a long dry season from January to April.

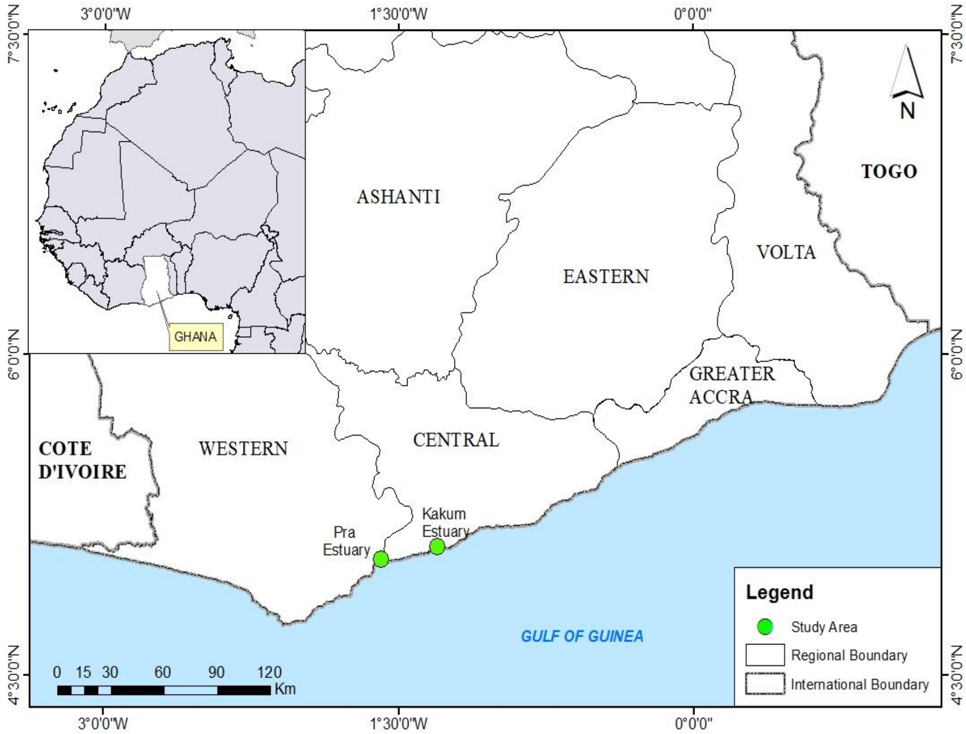

Figure.3.1: Map of southern Ghana showing locations of the Kakum and Pra estuaries

3.1.1 Kakum mangrove forest

The Kakum Estuary is formed by the Sorowie (Sweet) River and the Kakum River and discharges into the Atlantic Ocean at Iture. Mangroves fringe the banks of the estuary which was estimated to cover an area of 2 km^2 (SGP, 2012).

The Kakum mangrove forest is reported (DeGraft-Johnson et al., 2010; Sackey et al., 2011) to have the highest diversity of mangroves in Ghana, and contains all five known species of mangroves in Ghana, i.e. *Rhizophora mangle*, *R. harrisonii*, *R. racemosa*, *Avicennia germinans* and *Laguncularia racemosa*.

The mangrove forest is surrounded by two communities, Abakam and Iture. Some of the inhabitants of these two communities depend on the estuary as a source of fish and water for domestic activities, whereas the mangrove trees are harvested for fuel wood. Inhabitants from other nearby communities including Abina, Atonkwa, Ntranoa and Amamoma also collect shell fish (crabs and periwinkles) from the mangrove forest. Furthermore, inhabitants engage in sand winning along the banks of the estuary, and dispose of solid and liquid waste into the estuary (SGP, 2012). No regulation exists on the use of the mangrove ecosystem apart from the traditional norm against harvesting of mangrove trees on Tuesdays (Adotey, 2015). There are no replanting efforts or programmes aimed at sustainable use of the resources in the forest, in spite of evidence of its massive degradation.

Figure 3.2: Kakum Estuary—(a) Portion of Kakum Estuary mangrove forest; (b) Dumping site at mangrove forest; (c) Plastic waste within the mangrove forest; (d) Wood collection within study plot; (e) Sand winning in estuary; (f) Harvested mangrove saplings

3.1.2 Pra mangrove forest

The Pra Estuary is the second largest estuary in Ghana and has approximately 1,000 ha of adjoining marshlands and floodplains which serve as important fishery resources for the people of Anlo Beach, Shama Apo, Bosomdo and Krobo (Okyere, 2015). The estuary and its associated wetland has rich biodiversity and diverse ecosystems consisting of mangrove forests, swamps and salt marshes (Kankam & Robadue, 2013).

Mangrove trees of the genera *Rhizophora*, *Avicennia* and *Laguncularia* which extend several kilometres, are found along the banks of the estuary (Okyere, 2015). These trees are harvested mainly by inhabitants of Anlo Beach and Shama Apo, as the main source of firewood for cooking and smoking fish, while Bosomdo and Krobo communities also depend heavily on the shell fishes from the mangrove swamp. Buttonwood, *Conocarpus erectus* (Combretaceae), a mangrove associate and the saltwater grass *Paspalum vaginatum* (Poaceae) are also found in the adjoining marshland. The stretch of sandy beach, bordering the settlements had a lot of coconut trees, however, the trees have reduced drastically in number due to flooding and sea erosion in 2017. Exploitation of the mangrove species for fuel wood has led to degradation of the mangrove forest.

Through an Integrated Coastal and Fisheries Governance (ICFG) Initiative in the Western Region of the country, several activities such as land use mapping, mangrove and coastal zone use designation, as well as livelihood activities at Anlo Beach have been undertaken (FoN, 2015). Subsequently, over 14,000 mangrove tree seedlings were planted to contribute to recovering more than 76 hectares of lost mangrove cover.

Figure 3.3: Pra Estuary—(a) Portion of Pra mangrove forest, (b) Unidentified vegetation in the forest, (c) Stem of *Avicennia* showing regrowth, (d) A local collecting periwinkles, (e) Harvesting of mangrove within study plot, (f) Heaps of mangrove fuel wood

3.2 Assessment of Socioeconomic Characteristics

Field surveys were undertaken from May to August 2018, to gather information on the economic importance of mangrove forest and fish resources used by the inhabitants associated with the Kakum and Pra mangrove ecosystems. Perceptions on the spatial and temporal changes in mangrove cover, ecosystem services, replanting efforts and alternative uses, among others were also ascertained.

A census was conducted in ten communities, five from each mangrove forest area, which had their inhabitants engaged in mangrove resource harvesting. The communities surrounding the Kakum mangrove forest that were studied were Abakam, Abbina, Atonkwa, Koful and Ntranoa; and at the Pra mangrove area, the communities investigated were Anlo Beach (Shama-Kedzi), Shama-Apo, Bosomdo, Krobo and Fawomanye. Respondents were selected using purposive and snowball sampling techniques (Abdullah, Said & Omar, 2014). Purposive sampling was employed since the study was aimed at only people who exploited mangrove resources for their livelihood, and snowball sampling was used in situations where it was required to access other users of mangrove resources.

Data was gathered using an interview guide (Appendix A) with four sections. In the first section, detailed information on the socioeconomic and demographic characteristics of the survey respondents such as: sex, age, education, occupation (both main and part-time), residential status (native or migrant) and period of mangrove use were obtained. The second section aimed at ecosystem services the respondents obtain from the mangrove forests. These direct services included both forest (fuel wood and poles/timber) and fishery (periwinkles, crabs and tilapia) products. Frequency of harvesting, quantities of product collected, as well as prices at which the products were sold, among other information were obtained. The third section involved eliciting the level of benefits (or knowledge) derived from indirect use values or ecosystem services such as provisioning, regulating and cultural services. In the fourth section, respondents were asked several questions concerning changes in mangrove cover and how long it took such changes to occur, mangrove-related health and conflict issues, restoration efforts and possible alternative uses of the mangrove forests.

Figure 3.4: Photographs of interview sessions with respondents at (a) Fawomanye (July 2018), (b) Shamo-Apo (August 2018)

3.3 Characterisation of Mangrove Cover Change

3.3.1 Data type and sources

Two aerial photos were used in this study. These comprised an orthoimage with a spatial resolution of 0.05 m, taken in May 2005 and an aerial photograph with a resolution of 0.01 m, taken with an unmanned aerial vehicle (UAV) in January 2017. The 2005 orthoimage was obtained from the Department of Geography and Regional Planning of the University of Cape Coast, while the 2017 aerial photograph was obtained from the Centre for Coastal Management, University of Cape Coast.

3.3.2 Aerial image data processing

The remotely sensed aerial images were subjected to the following pre-processing procedures; geometric correction, resampling and sub-setting, using the Envi 5.0 software. The geometric correction involved two processes: 1) coordinate transformation, where the 2017 images of the study areas were transformed from global coordinate system (UTM zone 30N) to a local projected coordinate system (Ghana Metre Grid) and 2) geo-referencing, where image registration workflow was used to geometrically align the two images (2005 and 2017) which ensured the corresponding pixel represented the same object. The geo-referencing process involved locating and matching a number of feature points (called tie points) in two images (a warp image and a base image) selected for registration, while the corresponding tie points were used to compute the parameters of a geometric transformation between the two images. Resampling was also done by multiplying the pixel size by a scale factor to change the resolution of the 2017 aerial images from 0.01 m by 0.01 m to 0.05

m by 0.05 m. Sub-setting was undertaken using bounding polygon to subgroup of the two study areas.

3.3.3 Image classification

The overall objective of image classification procedure was to categorize all pixels in an image into land cover classes or themes (Lillesand, Kiefer & Dupman, 2004). Bands 1, 2 and 3 of the 2005 and 2017 images were classified into four land cover classes using K-Means unsupervised classification algorithms. This method utilized the spectral information (image pixels across different bands) and calculated initial class means evenly distributed in the data space, then iteratively clustered the pixels into the nearest class using a minimum distance technique.

3.3.4 Detection of land cover change

Changes in land cover classes in terms of aerial extent, spots of change, and the path of change were tracked with the post-classification change detection technique which involved an overlay of independently classified images. Land use/cover change maps were derived for the years 2005 and 2017 for Kakum and Pra estuaries using the respective maps.

The land use and land cover change (LULC) was calculated using the formula:

$$\text{Percentage LULC} = \frac{Area\ final\ year - Area\ initial\ year}{Area\ initial\ year} \times 100\%$$

3.4 Demarcation of Study Plots

Four 50 m x 50 m (0.25 ha) study plots were demarcated within each of the two mangrove forests, making a total sampling area of 10,000 m² (1 ha), within each mangrove. At Kakum mangrove forest, the four study plots were demarcated as follows: Plot I—about 13 m from the mouth of the estuary; Plot II—at the confluence of Kakum and River Sorowie, about 22 m from the mouth of the estuary; Plot III—along the arm of the Sorowie River, about 33 m from the mouth of the estuary; and Plot IV--along the arm of Kakum, about 140 m from the mouth of the estuary (Figure 3.5).

The study plots at the Pra mangrove forest included: Plot I—about 0.3 km close to the mouth of the estuary (referred to as 'old mouth' in this study) and 0.4 km from Shama-Apo community; Plot II-- along the arm of the Pra River about 1.7 km from the mouth of the estuary and 0.9 km away from Anlo Beach community (referred to as 'new mouth' in this study); Plot III— along the arm of a tributary about 2.7 km from the mouth of the estuary and 0.6 km from Anlo Beach community; and Plot IV-- along the arm of a small tributary, about 4.1 km from the mouth of the estuary and about 1.8 km away from Anlo Beach community.

Accessibility, ecological sensitivity and most importantly, avoidance of obviously disturbed areas were some of the factors taken into consideration when selecting the study plot. Additionally, attributes such as the presence of pneumatophores, mud, deep channels, standing water and extremely dense thickets composed of stilt roots and main stems were considered, since movement is very difficult in the mangrove forests (Kauffman & Donato, 2012).

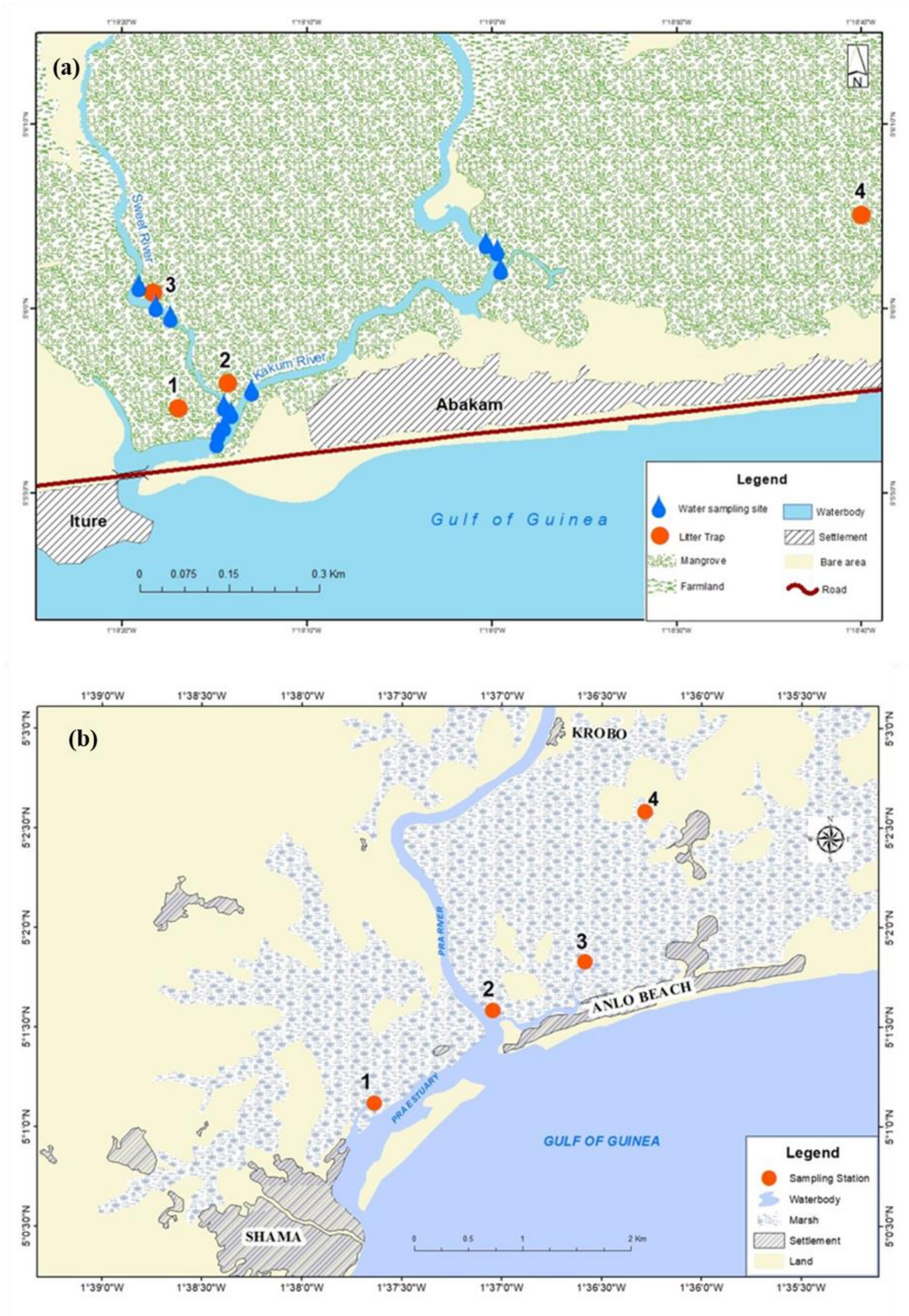

Figure 3.5: Maps showing locations of study plots in the mangrove forests at (a) Kakum Estuary, (b) Pra Estuary

3.5 Measurement of Structural Parameters of Mangrove Trees

Mangrove trees with diameter ≥ 2cm were measured at breast height, that is, 1.3 m above ground level. A vernier caliper was used to measure the diameter of smaller trees and in cases where the trunks of the mangroves were large, a tape measure was used to determine their girths at breast height (Figure 3.6) from which diameter (D) was calculated as D = girth/ π. Measurements of diameter at breast height (DBH) of mangrove trees with irregularities were done following guidelines provided by Kauffman et al. (2016). Trees having forked stems or with the stem branching below 1.3 m were considered as separate individuals, while the diameter of trees with buttress or prop root height greater than 1.3 m was taken 20 cm above the topmost root.

Figure 3.6: Data collection—(a) Measurement of tree girth, (b) Data recording

The height of each mangrove tree was measured using a graduated pole or a clinometer (Model; Suunto) where necessary. Trees with recorded diameter and height were marked to avoid repeating their measurements.

The density of each mangrove species was calculated as follows:

$$\textbf{Density}\ (\textbf{ha}^{-1}) = \frac{\text{Number of individuals of a species}}{\text{Area Sampled}}$$

3.6 Measurement of Litter Production

Litter traps were constructed using nylon fabric of mesh size of 1 mm × 1 mm. Each trap had the form of a basket 75 cm deep, with a 0.25 m^2 quadrat at the opening. In each of the study plots, seven traps were randomly suspended on tree branches of mixed stands, about 1 m from the ground to prevent flooding by tidal water. The traps were emptied every month and the litter was stored in labelled polythene bags for analyses in the laboratory. In the laboratory, litter from each trap was wrapped in aluminium foil and oven dried at a temperature of 105°C to constant weight. The dried litter was sorted into leaves, flowers (and other reproductive parts), fruits (and propagules) and twigs, and the weight of each component was recorded.

Rate of monthly litter fall was calculated for each mangrove forest (surface area of 0.25 m^{-2}) per litter trap as:

$$\text{Monthly Litter fall}\ (g\ m^{-2} month^{-1}) = \frac{Dry\ Weight\ of\ monthly\ litter\ (g)}{0.25\ m^2}$$

Data on temperature, relative humidity, rainfall and wind speed in the vicinity of the study areas from May 2017 to July 2018 were retrieved online (Tutiempo Network, 2018) and used to assess the relationship between these factors and litter production.

(a) (b)

Figure 3.7: Litter Measurement — (a) Placing of litter traps in the mangrove forest, (b) Drying of litter in oven

3.7 Measurement of Physico-chemical Parameters of Estuaries

Four sampling stations in both estuaries were established close to the four sampling plots in both mangrove forests. Triplicate measurements of temperature, salinity level, conductivity, dissolved oxygen (DO) concentration, pH and total dissolved solutes (TDS) concentration were taken by using HANNA HI 9829 multi-parametric water quality checker. Turbidity was also measured using Oakton T-100 turbidimeter. The measurements were made monthly from May 2017 to August 2018 during low tides between 07:00 and 10:00 GMT.

Figure 3.8: Measurement of physico-chemical parameters of estuary water

3.8 Analyses of Mangrove Sediments

3.8.1 Collection of soil samples

Triplicate mangrove sediment samples were collected quarterly for nutrient and heavy metal, and monthly for physico-chemical analyses at the two sites with a 15cm x 15cm Ekman grab from each study plot at low tide. That is, twelve sediment samples were collected from each mangrove forest for six quarters of the year and 15 months, making a total number of 72 and 180 sediment samples for the nutrient and heavy metal, and physico-chemical analyses respectively. The samples were air-dried, ground in a mortar and sieved through a 1 mm mesh screen to obtain a homogeneous mixture for the analyses.

3.8.2 Measurement of soil physico-chemical parameters

Twenty grams of the prepared soil was weighed into a beaker and 50 ml of distilled water was added, thoroughly stirred with a glass rod for 5 minutes and allowed to settle for 30 minutes, following the protocols developed by Pawar et al. (2009). After settlement of the sediment without further agitation, pH measurements were taken, using Oakton pH 700 meter. Salinity and conductivity were also measured using HANNA HI 9829 multi-parametric water quality checker.

3.8.3 Measurement of concentrations of soil nutrients

Percentage organic carbon

The modified UV spectrophotometer method (Pawar et al., 2009) was followed to determine percentage organic carbon in the soil samples. The procedure was started by dissolving 12.26g of 1N potassium dichromate ($K_2Cr_2O_7$) in 250 ml of distilled water.

Two hundred and fifty millilitres (250 ml) of distilled water was added to 0.25 g of sucrose. Ten different volumes of this solution were poured in ten different 25 ml flasks and 2.5 ml potassium dichromate and 5 ml sulphuric acid were added to the solution in each flask. Each mixture was shaken well and allowed to cool, after which the volume of each solution was made up to 25 ml with distilled water. The optical densities of the resultant solutions were measured at 660 nm wavelength with a Jenway 7315 UV Visible Spectrophotometer. The results were used to plot a standard curve for estimation of percentage carbon.

A 0.25 g sample of soil was put in a 100 ml flask and 2.5 ml potassium dichromate and 5 ml of conc. sulphuric acid were added. This was thoroughly mixed and allowed to cool, after which 25 ml of distilled water was added and kept overnight. The mixture was analysed for the percentage organic carbon content the following day, with a Jenway 7315 UV Visible Spectrophotometer at 660 nm wavelength. Triplicates of each measurement were taken and their means were recorded.

Determination of concentration of nitrogen

Fifteen grams of the prepared soil was placed in a round-bottom flask and 0.15 g of calcium sulphate was added. Twenty millilitres of distilled water was added to the mixture in the round-bottom flask, capped and shaken vigorously for one minute. The content of the bottle was filtered into another round-bottom flask.

A cuvette was filled with 10 ml of the calcium sulphate extract and the contents of one NitraVer 5 Nitrate reagent powder pillow was added to the sample cell, after which it was capped and vigorously agitated for one minute. The solution was allowed to stand for five minutes. A second cuvette was filled with 10 mL of the extract to serve as the blank. The nitrogen concentration of soil in the solution was measured using a HACH spectrophotometer (DR 900).

Determination of concentrations of phosphorus and potassium

To determine concentrations of phosphorus and potassium in the soil, a concentrate of Mehlich 2 soil extractant was poured into a graduated cylinder up to the 20 ml mark and 180 ml of distilled water was added and mixed thoroughly. Two grams of the prepared soil sample was measured into a round-bottom flask and 20 ml of the diluted extractant was added. The mixture was agitated for five minutes and filtered into another round-bottom flask. The filtered extract was used for the determination of phosphorus and potassium contents.

Measurement of concentration of phosphorus

The Ascorbic acid method was employed in measuring the phosphorus contents in the soil samples. Using a pipette, 2.5 mL of the extract was measured into a round-bottom flask and 22.5 mL of distilled water was added. A cuvette was filled with 10 mL of the solution and the contents of one PhosVer 3 Powder Pillow was added, the cuvette was capped and vigorously agitated for 30 seconds. The solution was allowed to stand for five minutes. A second cuvette was filled with 10 mL of the extract which served as the blank. The concentration of phosphorus in the solution was measured using a HACH spectrophotometer (DR 900).

(a) (b)

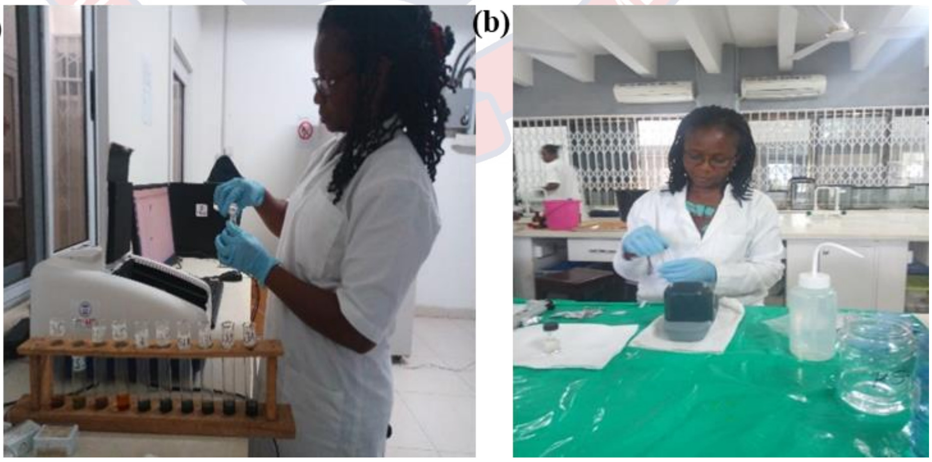

Figure 3.9: Laboratory analyses—(a) Measurement of carbon using UV Spectrophotometer, (b) Measurement of N, P and K using HACH spectrophotometer

Measurement of concentration of potassium

The concentration of potassium was measured using the turbidimetric tetraphenylborate method. With the help of a pipette, 2.5 mL of the extract was transferred into a mixing cylinder and 22.5 mL of distilled water was added. The contents of Potassium 1 Reagent Pillow and Potassium 2 Reagent Pillow were each added. The mixing cylinder was stoppered and inverted several times until the solution became clear. The contents of Potassium 3 Reagent Pillow was then added, the mixing cylinder stoppered and shaken for 30 seconds. A white turbidity which indicated presence of potassium in the extract was formed and was allowed to stand for three minutes.

A cuvette was filled with 10 ml of the solution for the analysis, while a second cuvette was filled with 10 ml of the extract to serve as the blank. The measurement of concentration of the potassium in the solution was done using a HACH spectrophotometer (DR 900).

3.8.4 Determination of concentrations of heavy metals in soils

Dried and sieved soil samples were taken to the Chemistry Laboratory of the Ghana Atomic Energy Commission (GAEC), Accra, for analysis of heavy metals present in the sediments. One gram of the soil sample was put into a 100 ml borosilicate beaker in a fume chamber and 25 ml aqua regia was added in the ratio of 3 ml conc. HCl to 1 ml conc. HNO_3. The sample was digested for 3 hours on a hot plate at 45 °C. The digested sample was transferred into a 100 ml measuring cylinder and filled with distilled water to the 30 ml mark and the mixture transferred into a test tube for analysis.

The concentrations of arsenic, cadmium and zinc were analysed using VARIAN AA 240FS – AAS in an acetylene-air flame. The concentration of mercury was determined using cold vapour atomic absorption technique. The final concentration of each heavy metal was determined as:

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

where final volume refers to volume after digestion.

Table 3.1 - *Quality control/assurance for elemental concentrations*

Element	Wavelength (nm)	Lamb current (mA)	Silt width (nm)	Recovery (%)	Detection Limit (mg/kg)
As	193.7	10	0.5	104	>0.001
Hg	253.7	3	0.5	102	>0.002
Zn	213.9	5	1	101	>0.001

Ecological risk of heavy metal concentration of sediments of Kakum and Pra mangrove forests

The ecological risk index (ERI) was introduced to measure the degree of heavy metal pollution in sediments, based on the toxicity of heavy metals and biological sensitivity to metals (Yi, Yang & Zhang, 2011). The ERI Hakanson (1980) was used to assess the overall ecological risk associated with the heavy metals at each mangrove forest as follows:

$$\text{ERI} = \sum_{i=1}^{n} E_r^i$$

where E_r^i = ecological risk potential of a heavy metal, calculated as:

$$E_r^i = T_f^i \times C_f^i$$

where T_f^i = toxicity response factor of heavy metal;

C_f^i = Contamination level of heavy metal, which is calculated as

$$C_f^i = \frac{C_n^i}{C_r^i}$$

C_n^i= concentration of heavy metal in sediment;

C_r^i = reference value for metal.

The toxicity response factor of heavy metals were: 10 for As, 40 for Hg and 1 for Zn, and their respective reference values (C_r^i) were 15 mg/kg, 0.2 mg/kg and 80 mg/kg (Hakanson, 1980).

Table 3.2 - *Criteria for Determination of Ecological Risk*

Ecological risk potential (E_r^i)	**Ecological risk criteria for heavy metal**	**ERI**	**Ecological risk criteria of environment**
$E_r^i < 40$	Low	ERI < 150	Low
$40 \leq E_r^i < 80$	Moderate	$150 \leq$ ERI <300	Moderate
$80 \leq E_r^i < 160$	Considerable	$300 \leq$ ERI < 600	Considerable
$160 \leq E_r^i < 320$	High	ERI $\geq$ 600	Very high
$E_r^i \geq 320$	Very high		

Source: Hakanson (1980)

3.9 Mangrove Health Assessment

Ecological health of the two mangrove systems was assessed using the Multi Criteria Decision Making (MCDM) approach (Vaghela et al., 2018) based on the following parameters: mangrove tree density, DBH, height, number, litter production, sediment quality (based on nutrient and physico-chemical parameters), ecological risk (based on heavy metal contamination), water (estuary) quality, mangrove cover change and human pressures.

To estimate Mangrove Health Index (MHI), weight or percentage points were assigned to each parameter (by experts), based on its importance to the health of the mangrove ecosystem (Prasetya et al., 2017) (Table 3.2). These parameters were sub-divided into different categories and scored as shown in Table 3.2. The weight and score were multiplied, while the summation of the product of multiplication gave the MHI (Appendix B).

Table 3.3 - *Assessment of Mangrove Health Index*

Indicators	Category	Weight (%)
Diameter at Breast Height (cm)	3) High = > 15.6 2) Intermediate = 4.5 - 14.8 1) Low = > 4.5 (Pellegrini, Soares, Chaves, Estrada & Cavalcanti, 2009)	15
Ecological risk	3) Low risk = ERI < 150 2) Moderate risk = 150 ≤ ERI <300 1) High/Very high risk=300≤ ERI ≥ 600 (Hakanson, 1980)	5
Water (estuary) quality	5) Excellent = WQI > 1.5 4) Good = 0.5 ≤ WQI≤1.5 3) Moderate = - 0.5 WQI ≤ 0.5 2) Bad = - 1.5 QQI ≤ - 0.5 1) Worst = WQI < 1.5 (Ibrahim et al., 2019)	5
Human Pressures	3) Low human activities 2) Moderate human activities 1) High human activities	5
Litter production (t ha-1y-1)	3) High litterfall= ≥ 13.10; 2) Moderate litterfall = 9.35 - 13.09 1) Low litterfall = < 9.35	15
Mangrove cover change	3) Increase; 2) Same; 1) Decrease	15
Sediment quality	5) Excellent = SQI > 1.5 4) Good = 0.5 ≤ SQI ≤ 1.5 3) Moderate = -0.5 SQI ≤ 0.5 2) Bad = - 1.5 SQI ≤ - 0.5 1) Worst = SQI < 1.5 (Ibrahim et al., 2019)	5
Species richness	3) High = 5 species 2) Moderate = 3 species 1) Low = less than 3 species	5
Tree density (inds/ha)	3) Dense or High = >10,000 2) Moderate = 1,000 - 10,000 1) Low/sparse = < 1000 (Hoppe-Speer et al., 2015)	15
Tree height (m)	3) High = >11.8 2) Intermediate = 5.7 - 11.7 1) Low = < 5.7 (Pellegrini et al., 2009)	15

Mangrove health index criteria that were developed following the concepts from Ibrahim et al. (2019) and Prasetya et al. (2017) were used for the determination of the various categories of MHI as follows:

1) Excellent (85-100%) = 272 ≤ MHI ≤ 320

2) Good (70-84.7%) = 224 ≤ MHI ≤ 271

3) Moderate (55-69.7%) =176 ≤ MHI ≤ 223

4) Bad (40-54.7 %) = 128 ≤ MHI ≤175

5) Worst (<40%) = MHI < 128

3.10 Data Analyses

Descriptive statistics involving frequencies and cross tabulations as well as charts were used to express the socioeconomic results using SPSS (Version 17). Microsoft Excel (vs 2013) was also used for graphical representation of information.

ANOVA was done to assess the spatial and temporal distribution of litter. The relationship between climatic factors, nutrients and litter production was ascertained using correlation and a logistic regression in the SPSS, Excel and Minitab 17 Statistical Software. Statistically, the differences between the ecological parameters from the two sites were tested with student t-test, whereas differences among the months and study plots were tested with ANOVA in the SPSS and Minitab software.

Descriptive statistics involving means and standard error, as well as graphs and charts were used to present the observations on water and sediment. Statistically significant differences of the parameters among the different months were tested with ANOVA, while t-test was used to test differences between the areas. Principal component analysis (PCA) was conducted on all water and sediment variables to identify the three most important variables, which were used to determine sediment and water quality indices (Ibrahim et al., 2019). Pearson correlation was run between the soil parameters and water physico-chemical parameters. All the significant differences were tested at 95 % confidence interval.

3.11 Chapter Summary

This chapter provided a detailed description of the study sites, materials and methods used in gathering the data, as well as the different statistical packages and tools used for data analyses. Furthermore, a multi criteria approach involving ten different indicators covering social, biological, chemical and physical factors were employed to assess the health of the Kakum and Pra mangrove ecosystems.

CHAPTER FOUR

RESULTS

The previous chapter provided information on the study sites as well as methods used for data collection and analyses. This chapter presents the essential findings of the study. The findings are grouped into the following categories: mangrove resource use; land use/cover change; inventory of plant species; structural parameters of mangrove species; litter production; concentrations of nutrients and trace elements in mangrove sediments; and physico-chemical parameters (of water and mangrove sediments), soil nutrients, heavy metals and mangrove indices. The chapter concludes with indices evaluating the health of the Kakum and Pra mangrove forests.

4.1 Mangrove Resource Use

4.1.1 Demography

The demographic characteristics of the mangrove resource users are shown in Table 4.1. Females and males constituted 61 % and 39 % respectively of the respondents from communities around the Kakum River mangrove forest. Respondents from communities surrounding the Pra River comprised 49 % females and 51 % males. Majority of the respondents from the Kakum area representing 33.3%, belonged to the 36-55 year category. This was followed by 18-35 year category, whilst the 56-90 year group was the least. Just like the Kakum area, most of the respondents at the Pra area, that is, 41.2 % fell within the 18-35 year category. The next age group with high number of respondents was the 18-35 group (31.8 %) whilst the 14-17 year group had the least representation (5.9 %).

In terms of education, most of the respondents from the surrounding communities of the Kakum and Pra mangrove forests, that is, 52.9 % and 42.4 % respectively, had Junior High School/Middle School education. While none of the respondents from neighbouring communities of Kakum mangrove had secondary and post-secondary/tertiary education, few from the Pra area had secondary (7.1 %) and post-secondary/tertiary (3.1 %) education. A substantial number of respondents forming 29.4 % and 30.6 % respectively from the Kakum and Pra however, had no formal education.

Principally, the mangrove users from the communities fringing the Kakum and Pra mangrove forests were migrants, forming 62.7 % and 76.5 % respectively. Most respondents, accounting for 82 % of mangrove users from communities around Kakum Estuary engaged in other occupations (such as schooling, farming, trading, etc.) but only 17.6% depended solely on mangrove occupation as their main occupation. More respondents (56.5 %) from the Pra area were involved in mangrove resource exploitation as a part-time job while the rest (43.5 %) exploited mangrove resources as their main occupation.

Table 4.1 - *Demographic Characteristics of Mangrove Resource Users around the Kakum and Pra Estuaries (N =136)*

Variable	**Description**	**Percentage of respondents (%)**	
		Kakum (n=41)	**Pra (n=95)**
Gender	Male	39.0	51.0
	Female	61.0	49.0
Age (years)	14-17 (children)	25.5	5.9
	18-35 (young adults)	29.4	31.8
	36-55 (mid adults)	33.3	41.2
	56-90 (old adults)	11.8	21.2
Education level	No School	29.4	30.6
	Primary	17.6	16.5
	JHS/MDLS	52.9	42.4
	Secondary	0.0	7.1
	Post-sec/Tertiary	0.0	3.5
Residential status	Native	37.3	23.5
	Migrant	62.7	76.5
Mangrove occupation type	Main	17.6	43.5
	Part-time	82.4	56.5

4.1.2 Resources exploited

Table 4.2 presents the type and period of mangrove resource use. Most respondents from the Kakum mangrove forest (82.4 %) were involved in fishery than tree harvesting (17.6 %). However, at the Pra mangrove forest more respondents (61.2 %) exploited forest products than fish products (30.6 %), while 8.2 % exploited both products.

These respondents had engaged in mangrove resource harvesting for about one year to more than 30 years, with majority (33.3 %) from communities around the Kakum harvesting within 20-30 year range, while 31.8 % of respondents along the Pra estuary had harvested mangrove resources for 1-10 years.

Table 4.2 -*Type of Mangrove Resource and Period of Use from the Kakum and Pra Estuaries*

Variable	**Description**	**Percentage of respondents**	
		Kakum	**Pra**
Type of mangrove resource	Forest	17.6	61.2
	Fish	82.4	30.6
	Forest & Fish	0.0	8.2
Period of mangrove use (years)	1-10	25.5	31.8
	11-20	29.4	28.2
	20-30	33.3	22.4
	>30	11.8	17.6

Mangrove resource use by gender and among age groups

Types of mangrove resource use by gender from the two mangrove forests are shown in Figure 4.1. Out of the 41 respondents interviewed around the Kakum mangrove forest area, a greater number of men harvested fish resources than women, while more women harvested forest resources and only one man harvested forest resources, thus, forest resources were predominantly exploited by women. Additionally, no particular gender exploited both resources.

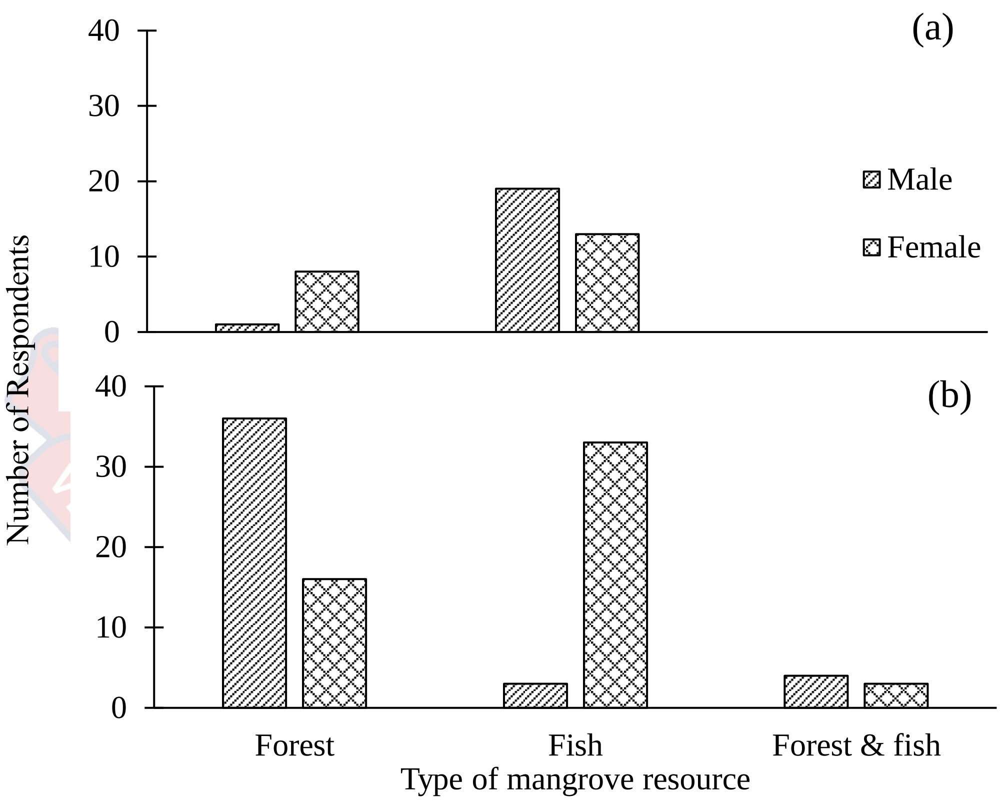

Figure 4.1: Type of mangrove resource use by gender in the (a) Kakum and (b) Pra estuaries

At the Pra mangrove area, the forest resources were exploited by more males than females, whereas the fish resources were harvested mostly by females than males. That is, the forest and fish resources were predominantly exploited by males and females respectively. However, few males and females exploited both resources.

The type of mangrove resource use among age groups of respondents from the two mangrove areas is presented in Figure 4.2. It was found that at Kakum mangrove forest area, all the respondents within the 14-17 age and 56-90 age groups exclusively exploited fish and forest resources respectively. The 18-35 and 36-55 age groups exploited more fish resources than forest resources.

There were varying types of mangrove resource use among the different age groups of respondents around the Pra mangrove area. Both the forest and the fish resources were used by all age groups. However, the forest resources were highly exploited by the18-35 age group while the fish resources were highly harvested by the 36-55 age group. With the exception of the 14-17 year age group, respondents from all the other age groups exploited both resources.

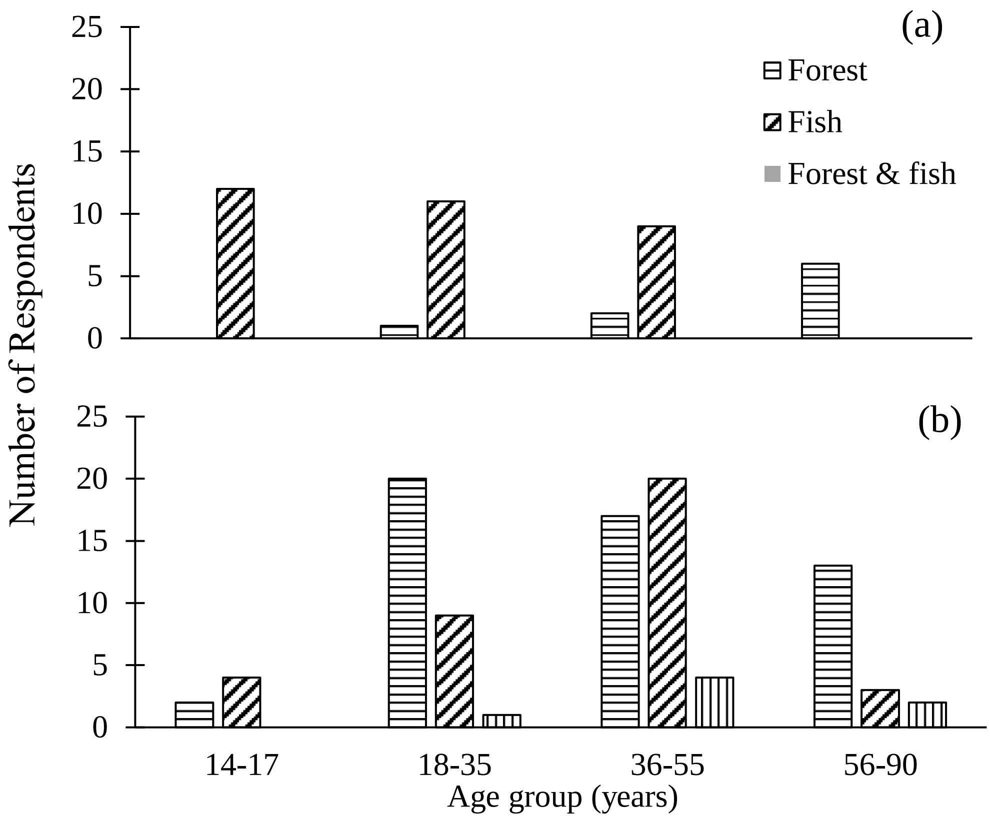

Figure 4.2: Mangrove resource use by age groups in the (a) Kakum and (b) Pra estuaries

Residential status and mangrove resource uses within communities

Table 4.3 provides the residential status of respondents and type of mangrove resource uses within the communities. Out of the 22 migrants from the Kakum mangrove area, nine were from Abakam. All the respondents from Abakam were migrants but the other four communities were made of both migrants and natives. At the Pra mangrove area, apart from Shama-Apo which had almost all its respondents (20 out of 21) being natives, all the respondents from the remaining four communities including Bosomdo, Anlo Beach, Krobo and Fawomanye were migrants. Majority of the migrants were at Anlo Beach.

Table 4.3 - *Residential Status of Respondents and Mangrove Resource Use within Communities*

Mangrove area	**Community**	**Residential status**		**Mangrove resource use**		
		Native	**Migrant**	**Forest**	**Fish**	**Forest & Fish**
Kakum	Abakam	0	9	9	0	0
	Atonkwa	2	3	0	5	0
	Abbina	3	3	0	6	0
	Koful	11	5	0	16	0
	Ntranoa	3	2	0	5	0
	Total	**19**	**22**	**9**	**32**	**0**
Pra	Bosomdo	0	6	1	5	0
	Anlo Beach	0	45	36	4	5
	Krobo	0	9	0	9	0
	Shama-Apo	20	1	15	4	2
	Fawomanye	0	14	0	14	0
	Total	**20**	**75**	**52**	**36**	**7**

In terms of mangrove resource uses, respondents from communities around the Kakum mangrove forests use solely one type of resource each. Whereas the respondents from Abakam exploited exclusively forest resources, those from the other four communities -- Atonkwa, Abbina, Koful and Ntranoa, harvested only fish resources. It was found that inhabitants of Iture no longer harvested mangrove resources. Respondents from two communities adjoining the Pra mangrove forest, Krobo and Fawomanye also harvested solely fish products whereas those from Anlo Beach, Shama-Apo and Bosomdo harvested both forest and fish resources.

Gender preference for harvesting of mangrove species for fuel wood

Table 4.4 indicates gender preference for harvesting mangrove species from the two mangrove forests for fuel wood. It has been shown that *Avicennia* was the most exploited mangrove species for fuel wood, followed by *Rhizophora*, whilst *Laguncularia* was the least exploited species. More females (19) harvested *Avicennia* than males (14), however, males dominated (20) harvesting of *Rhizophora*.

Table 4.4 - *Mangrove Species Harvested by Gender*

Gender	**Mangrove forest**	**Mangrove species**		
		Avicennia	***Rhizophora***	***Laguncularia***
Male	Kakum	0	0	1
	Pra	14	20	0
Female	Kakum	7	0	1
	Pra	12	1	1
Total		**33**	**21**	**3**

4.1.3 Ecosystem services provided by the mangrove forests

Table 4.5 presents information on direct and indirect ecosystem services provided by the Kakum and Pra mangrove forests. Of the 136 respondents, 34.7 %, 33.2 % and 22.6 % reported harvests of fuel wood, periwinkles and crabs respectively, as the direct benefits they obtained from the forests.

With regard to indirect ecosystem services, 23.8 % of respondents cited climate regulation as one of the regulating services provided by mangrove forests, and 6.5 % mentioned disease control. For supporting services, provision of nursery grounds was the most cited (46.6 %), followed by nesting grounds (45.6 %), whereas nutrient cycling was the least (7.8 %). Aesthetic benefits were the most important among cultural services (49.2 %) while education was of least significance (14.3 %).

Table 4.5 - *Ecosystem Services Obtained from the Kakum and Pra Mangrove Forests*

Type of uses	**Categories of Ecosystem services**	**Ecosystem services**	**Percentage use (%)**
Direct uses	Provisioning services	Fuel wood	34.7
		Periwinkles	33.2
		Crabs	22.6
		Tilapia	5.8
		Timber (poles)	3.7
Indirect uses	Regulating services	Climate regulation	25.9
		Flood & storm protection	24.6
		Pollution control	23.6
		Erosion control	18.9
		Diseases control	7.1
	Supporting services	Nursery ground	46.6
		Nesting ground	45.6
		Nutrient cycling	7.8
	Cultural services	Aesthetic	49.2
		Recreation	21.4
		Spiritual	15.1
		Education	14.3

Figure 4.3: Examples of direct ecosystem services derived from the Kakum and Pra mangrove forests: (a) Periwinkles, (b) Crabs, (c) Tilapia, (d) Fuel wood

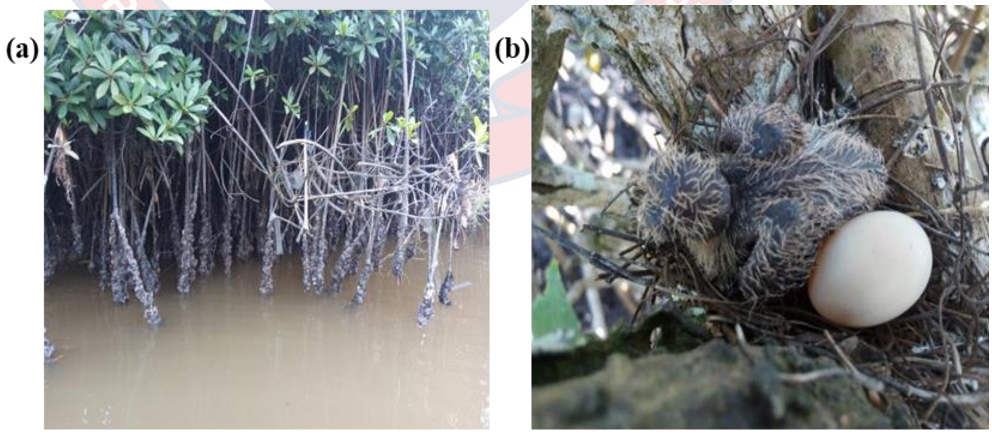

Figure 4.4: Examples of indirect ecosystem services derived from the Kakum and Pra mangrove forests: (a) Roots of *Rhizophora* as habitats for oysters; (b) Stem of *Avicennia* as a nesting place for birds showing an egg and a hatchling

4.1.4 Health, conflict and other issues related to mangrove uses

Responses of the mangrove users on health, conflicts and other issues associated with mangrove use are presented in Table 4.6. Although majority of respondents stated that they experienced no health problems associated with mangrove use, few of them indicated associated problems. Malaria was cited as the commonest health problem related to mangrove use.

With regards to conflicts, 48 respondents, 11 from Kakum mangrove area and 37 from Pra mangrove area indicated occurrence of intra and intercommunity conflicts predominantly over claims of ownership, and trivial issues such as suspected pilfering of mangrove products among users.

Virtually, all the respondents, comprising 40 and 88 from the Kakum and Pra mangrove areas respectively opposed alternative use/s of the entire mangrove forest. That is, they disagreed with the use of the mangrove forest areas for developmental projects. They emphasised alternative use/s would result in loss of their livelihoods.

Table 4.6 - *Issues Related to Mangrove Resource Uses in the Kakum and Pra Estuaries*

Variable	Description	Number of respondents	
		Kakum	Pra
Health problem related to mangrove uses	No	31	76
	Yes	10	19
Health problems	Malaria	10	16
	Skin rashes	0	2
	Worm infestation	0	1
Occurrence of conflicts	No	30	58
	Yes	11	37
Causes of conflicts	Ownership	3	37
	Others	8	0
Alternative use to entire mangrove forest	No	40	88
	Yes	1	7
Reason for opposing alternative use/s	Loss of livelihood	39	87

4.1.4 Respondents' perception on mangrove cover change and reforestation

Table 4.7 presents the perception of respondents on issues pertaining to changes in mangrove cover and replanting efforts. Essentially, all the respondents indicated that there were changes in mangrove cover and established reductions in the mangrove cover as well. Majority believed that these reductions were more pronounced about 1-10 years ago. Most of them affirmed deforestation as the major cause of decline whereas minor causes comprised flooding, invasive plants, illegal mining, sand winning and natural factors.

Regarding reforestation or replanting efforts, all the 41 respondents from Kakum mangrove area confirmed that no replanting efforts had taken place at the mangrove area. Of the 41 respondents, 27 specified the need for replanting to help increase both the mangrove cover and the resources. Twelve of the respondents who disagreed with replanting explained that the mangrove forest would regrow naturally. Unlike the Kakum mangrove area, 71 out of the 95 respondents from Pra mangrove area acknowledged that the mangrove area had been replanted. Of the 71 respondents, 44 admitted that the replanting had helped to improve the mangrove cover, however, 27 disagreed. Of the 24 who stated that there was no replanting in their areas, 18 confirmed the need for replanting, indicating the importance of replanting towards improving mangrove cover as well as mangrove resources. All the six respondents who saw no need for replanting emphasised that there would be natural regrowth of the mangrove forest.

Table 4.7 - *Perceptions of Respondents on Mangrove Cover Change and Replanting Efforts in the Kakum and Pra Estuaries*

Variable	Description	Number of respondents	
		Kakum	Pra
Change in mangrove cover	Yes	41	92
	No	0	3
Nature of change	Reduced	40	92
	Increased	1	0
Period of reduction (years)	< 1	3	4
	1-10	36	74
	11-20	1	11
	21-30	0	3
Causes of reduction	Deforestation	39	83
	Others	2	12
Replanting effort	Yes	0	71
	No	41	24
Improvement in cover after replanting	Yes	-	44
	No	-	27
Need for replanting	Yes	27	18
	No	13	6
Reasons for replanting	To improve cover	18	12
	To improve resources	9	6
Reasons for no replanting	Natural regrowth will occur	12	6
	Access to resources will be restricted	1	0

4.2 Land Cover Change at Kakum and Pra Estuaries

4.2.1 Land use type and cover at the Kakum Estuary

The various land use types, cover and changes in cover at the Kakum estuary are provided in Table 4.8. In 2005, the mangrove forest covered an area of 68.83 ha, water 35.40 ha and other vegetation 7.42 ha, representing 54.72 %, 28.14 % and 5.90 % respectively of the estuary. However, in 2017 the mangrove area reduced to 40.21 ha, other vegetation area increased to 50.30 ha, while the area covered by water reduced to 23.24 ha. Consequently, with the exception of other vegetation type which gained as much as 577.99 % (42.88 ha) cover, all the land use types lost cover areas. The change in mangrove area was -28.62 ha, representing 41.58 % loss, whereas the water also had shrunk by -12.15 ha or 34.34 %.

Table 4.8 - *Land Use/cover in Kakum Estuary Between 2005 and 2017*

Land use/cover	**2005**		**2017**		**Change in Area**	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**
Mangrove	68.83	54.71	40.21	31.97	-28.62	-41.58
Other Vegetation	7.42	5.90	50.30	39.99	42.88	577.99
Water	35.40	28.14	23.24	18.47	-12.15	-34.34
Built/bare-land areas	14.15	11.25	12.04	9.57	-2.11	-14.91
Total	**125.8**	**100**	**125.8**	**100**	-	-

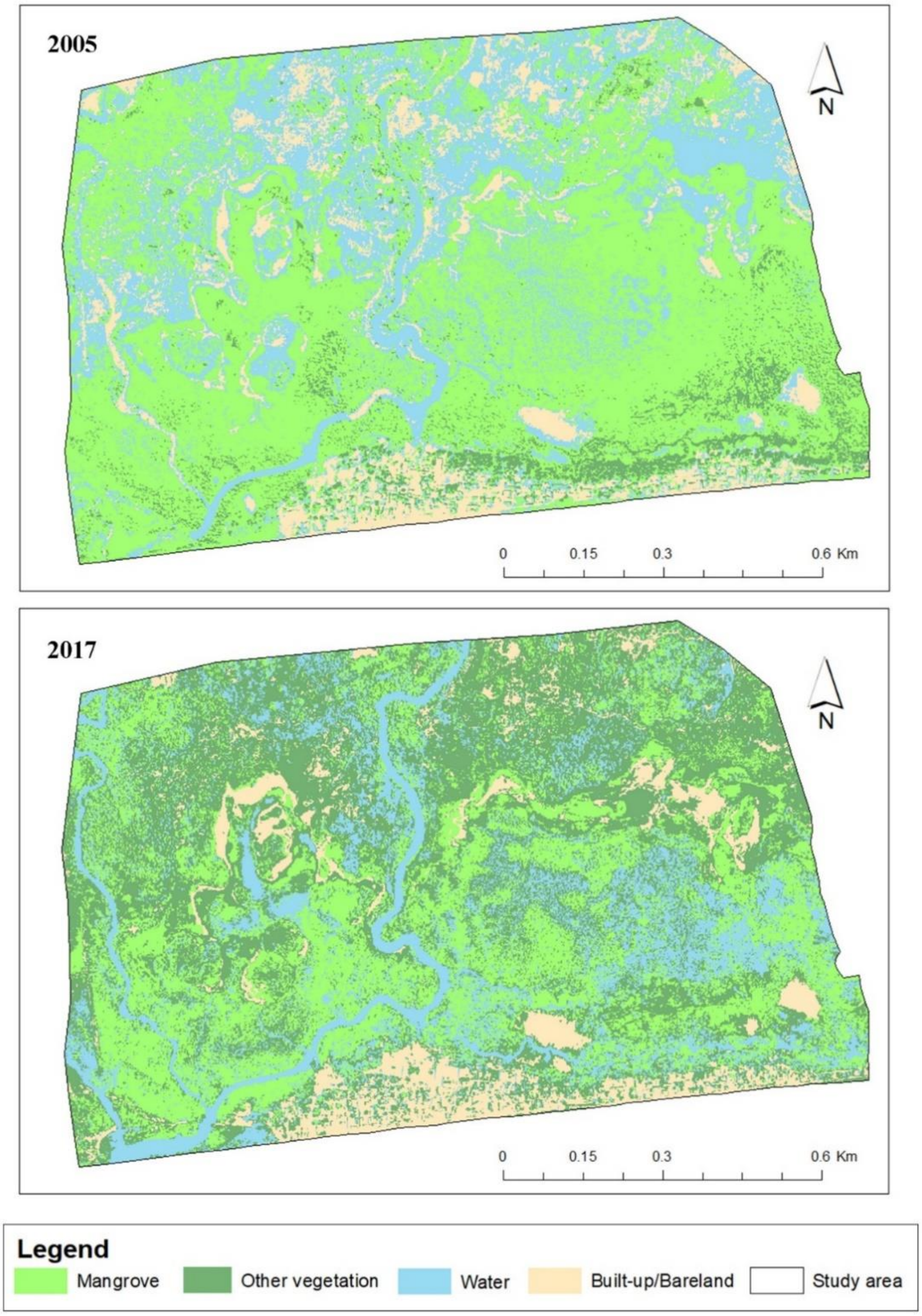

Figure 4.5: Land use/cover maps of Kakum Estuary for 2005 and 2017

4.2.2 Land use type and cover at the Pra Estuary

Table 4.9 shows the various land use types and changes in their respective areas between 2005 and 2017. The mangrove cover increased from 574.10 ha in 2005 to 646.10 ha in 2017, indicating a gain of 72.00 ha (representing 12.54 % increase in cover), while the area covered by water also increased from 200.46 ha in 2005 to 303.00 ha (a gain of 51.15 %) in 2017. On the other hand, other vegetation cover and built/bare-land areas reduced by 67.35 % and 29.28 % respectively.

Table 4.9 - *Land Use/cover in Pra Estuary Between 2005 and 2017*

Land use/cover	**2005**		**2017**		**Change in Area**	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**
Mangrove	574.10	51.34	646.10	57.78	72.00	12.54
Other Vegetation	194.13	17.36	63.38	5.67	-130.75	-67.35
Water	200.46	17.93	303.00	27.10	102.53	51.15
Built/bare-land areas	149.52	13.37	105.74	9.46	-43.78	-29.28
Total	**1118.21**	**100**	**1118.21**	**100**	-	-

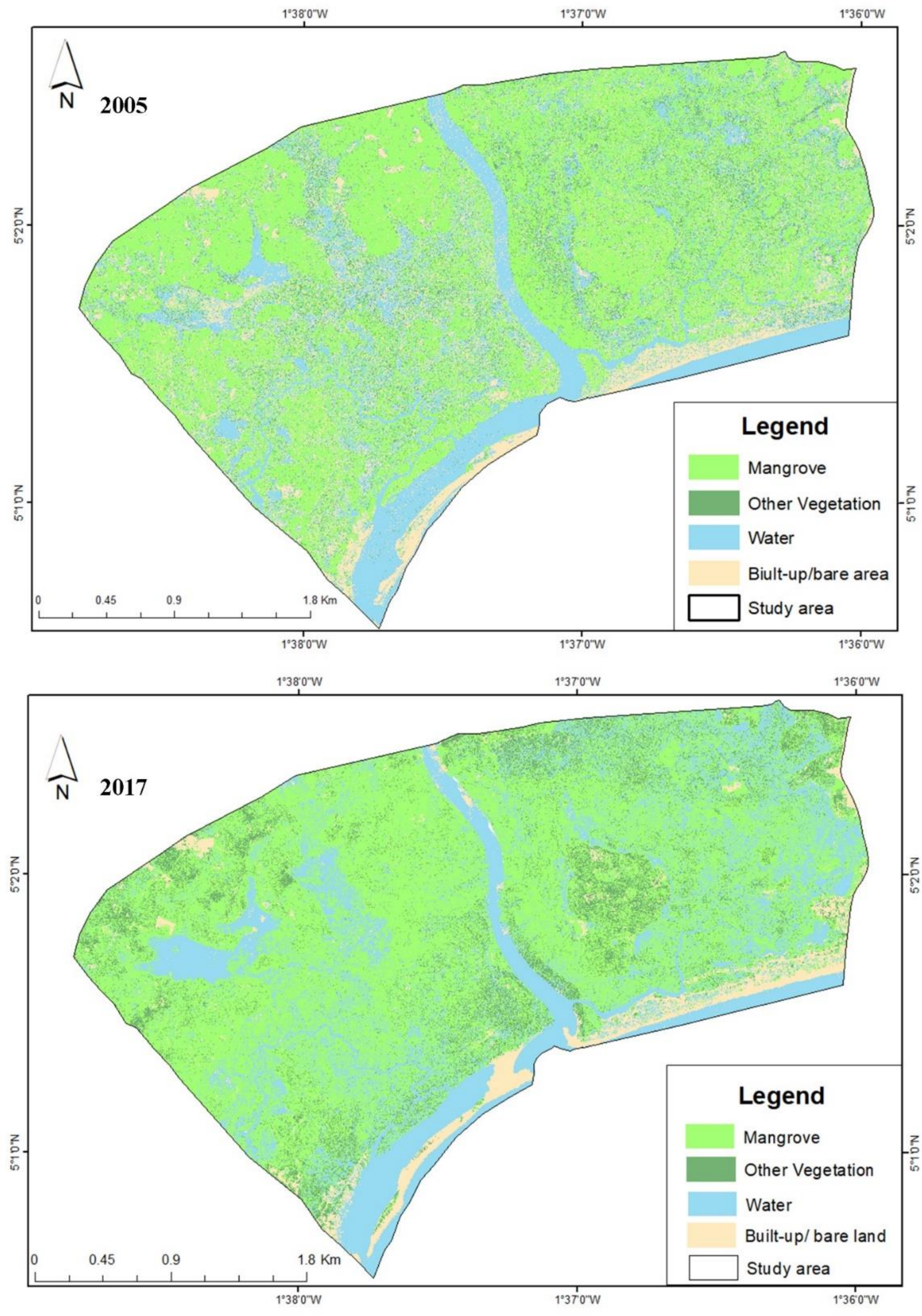

Figure 4.6: Land use/cover maps of Pra Estuary for 2005 and 2017

4.3 Inventory of Plant Species in the Kakum and Pra Mangrove Forests

Table 4.10 presents a list of plant species encountered at Kakum and Pra mangrove forests. A total of 23 plant species comprising five true mangroves and 18 non-mangroves or mangrove affiliates were encountered in Kakum mangrove forest. The five true mangroves were *Avicennia germinans*, *Rhizophora racemosa*, *R. mangle*, *R. harrisonii* and *Laguncularia racemosa*. The 23 plant species belonged to 14 families and 21 genera. Papilionaceae was represented by five species, while most of the families including Pteridaceae, Salicaceae, Sapindaceae, Scrophulariaceae and Verbanaceae registered only one species each. Sixteen of the plant species were woody while six were herbaceous, and one species, a mangrove fern.

In the Pra mangrove forest, the total number of plant species encountered were 20 and these comprised three true mangroves-- *A. germinans*, *R. racemosa* and *L. racemosa*, and 17 non-mangroves or mangrove affiliates. There was however, an unidentified species that was common in the mangrove forest. The identified plant species belonged to 13 families and 15 genera. Like Kakum mangrove forest, Papilionaceae was the family with the highest number of species (five).

Table 4.10 - *List of Plant Species in the Mangrove Forests of the Kakum and Pra Estuaries*

Type of plants	Family	Species	Mangrove forest Kakum	Pra	Habit
	Acanthaceae	*Avicennia germinans* L. (L.)	+	+	Tree
	Combretaceae	*Laguncularia racemosa* (L.) C. F. Gaertn	+	+	Tree
True mangroves	Rhizophoraceae	*Rhizophora harrisonii* Leechm.	+	-	Tree
		Rhizophora mangle L	+	-	Tree
		Rhizophora racemosa G. F. W. Meyer	+	+	Tree
	Acanthaceae	*Ruellia tuberosa* L.	+	+	Herb
	Aizoaceae	*Sesuvium portulacastrum* (L.) L.	+	+	Herb
	Combretaceae	*Terminalia catappa* Linn.	+	+	Tree
	Loranthaceae	*Tapinanthus bangwensis* (Engl. & K Krause) Danser	+	+	Shrub
		Abutilon mauritianum (Jacq.) Medik.	+	+	Shrub
	Malvaceace	*Thespesia populnea* (L.) Soland ex Corrêa	+	+	Tree
		Crotalaria retusa Linn.	+	+	Herb
		Indigofera hirsuta Linn.	+	+	Herb
		Pterocarpus santalinoides DC	+	+	Tree
	Papilionaceae	*Sesbania pubescens* DC	+	+	Woody herb
Mangrove associates		*Sophora tomentosa var. occidentalis* L.	+	+	Tree/shrub
	Poaceae	*Paspalum vaginatum* Sw.	+	+	Herb
	Pteridaceae	*Acrostichum aureum* Linn.	+	+	Fern
	Rutaceae	*Fagara zanthoxyloides* Lam	+	-	Tree
	Salicaceae	*Oncoba spinosa* Forssk.	+	+	Tree
	Sapindaceae	*Leucaniodiscus cupaniodes* Planch. ex Benth	+	+	Tree
	Scrophulariaceae	*Capraria biflora* Linn.	+	+	Herb
	Verbenaceace	*Lantana camara*	+	+	Shrub

+ = present, - = absent

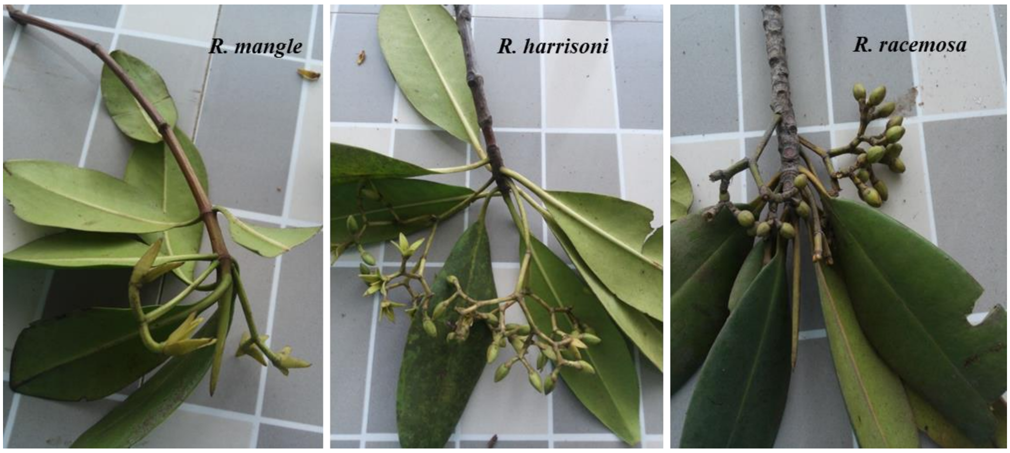

Figure 4.7: Inflorescence of *Rhizophora* species in the Kakum mangrove forest

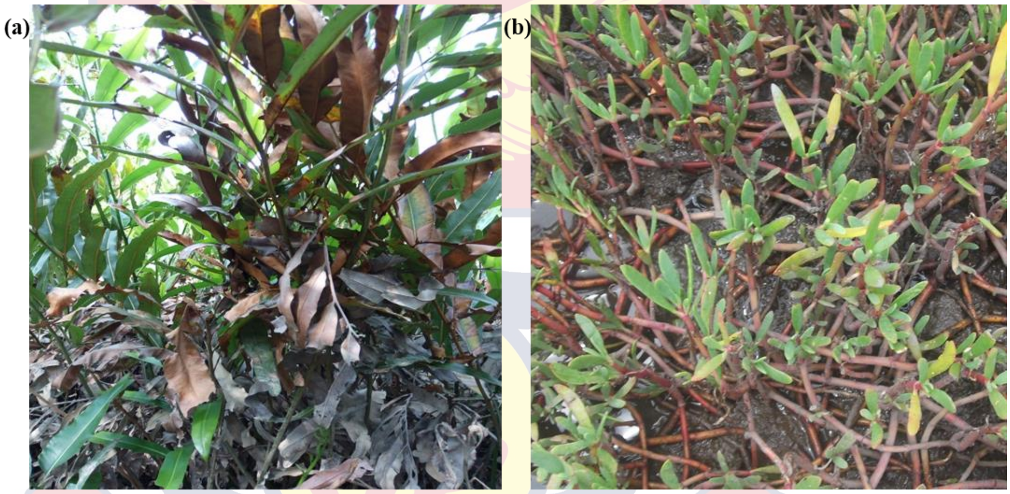

Figure 4.8: Examples of mangrove associates – (a) *Acrostichum aureum* and (b) *Sesuvium portulacastrum*, of the Kakum and Pra estuaries

4.4 Structural Parameters of the Mangrove Species

Information on the structural parameters of the three mangroves namely *Avicennia*, *Rhizophora* and *Laguncularia* is presented in Table 4.11. It was observed that *Avicennia* in the Kakum mangrove forest had a higher density of trees (3,131 ± 1619 ha^{-1}) than that of the Pra mangrove forest (2182 ± 1038 ha^{-1}). However, the densities of *Rhizophora* and *Laguncularia* in the Kakum mangrove forest. The total densities of all species at the Kakum and Pra mangroves were 5,361 ha^{-1} and 6,955 ha^{-1} respectively. Although Kakum mangrove had a lower species density than the Pra mangrove forest, there was however, no statistical difference between the densities of the two mangrove forests, $t = -0.71$, $p > 0.05$. In both mangrove forests, the number of individuals of *Laguncularia* was the least among the three mangrove species.

The mean diameter at breast (DBH) of *Avicennia* at Kakum mangrove forest (3.22 ± 0.02) was significantly lower than ($t = -45.05$, $p < 0.05$) that of Pra mangrove forest (4.09 ± 0.12). There was a significant difference between DBH of *Rhizophora* at the two mangrove forests ($t = -14.60$, $p < 0.05$); the mean DBH at Kakum mangrove forest was 3.52 ± 0.04 cm and that of Pra mangrove forest was 2.95 ± 0.02 cm. *Laguncularia* in the Kakum mangrove forest had significantly lower DBH ($t = 10.99$, $p < 0.05$) from that of Pra mangrove forest, with mean DBH of 2.94 ± 0.03 and 3.32 ± 0.02 respectively.

Apart from *Rhizophora* which was significantly taller at the Kakum mangrove forest than at the Pra mangrove forest ($t = -6.07$, $p < 0.05$), the other mangrove species were significantly shorter at the Kakum mangrove forest than at the Pra mangrove forest. Statistically, there were significant differences between the heights of each species from both forests - *Avicennia* ($t = -45.05$, $p < 0.05$), and *Laguncularia* ($t = 32.77$, $p < 0.05$).

Table 4.11 - *Structural Parameters of Mangrove Species in the Kakum and Pra Estuaries (Mean ± S.E)*

	Avicennia		***Rhizophora***		***Laguncularia***	
Parameter	**Kakum**	**Pra**	**Kakum**	**Pra**	**Kakum**	**Pra**
Total number of individuals	3131	2182	1269	2514	961	2249
Density (number/ha)	3131 ± 1619	2182 ± 1038	1269 ± 558	2514 ± 549	961 ± 336	2249 ± 866
Mean DBH (cm)	3.22 ± 0.02	4.09 ± 0.12	3.52 ± 0.04	2.95 ± 0.02	2.94 ± 0.03	3.32 ± 0.02
Mean Height (m)	3.21 ± 0.01	4.35 ± 0.02	4.49 ± 0.03	4.27 ± 0.02	2.85 ± 0.02	3.79 ± 0.02

4.4.1 Mangrove tree diameter distribution

The size distribution of the mangrove species at both study sites is presented in Figure 4.9. It can be noticed that more than 90 % of the individuals of the mangrove species in both forests were small in size and fell within the 0.00 - 4.99 cm class interval. For *Laguncularia*, almost all the individuals (> 97%) at both sites had relatively small diameters. However, few *Avicennia* trees at both study sites were ≥10 cm in diameter.

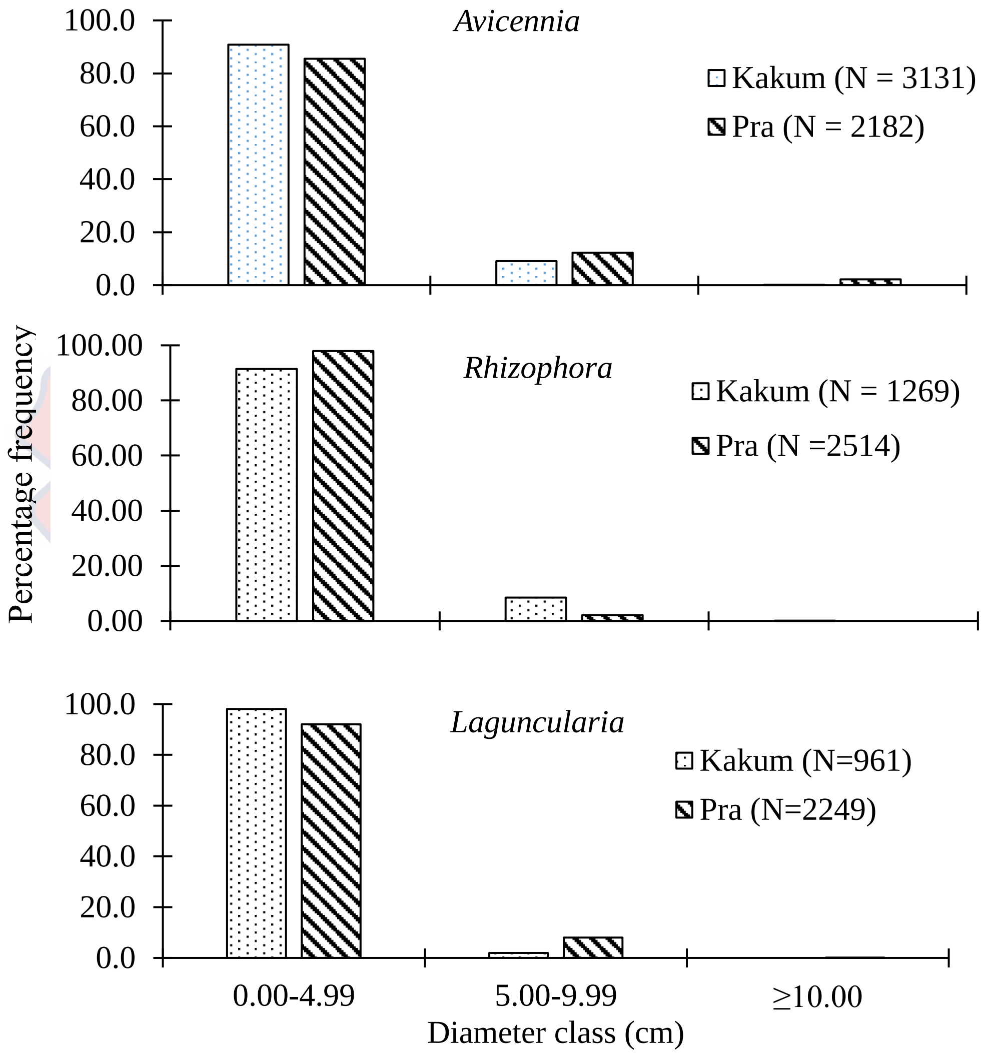

Figure 4.9: Diameter distribution of mangrove species in the Kakum and Pra mangrove forests

4.4.2 Height distribution of the mangrove tree species

Figure 4.10 indicates the percentage height distribution of individuals of mangroves in the two mangrove forests. Most of the individuals of *Avicennia* in the Kakum mangrove forest occurred within the 3.00-3.99 m height class, followed by the 2.00-2.99 m class, and only few fell in the other height classes. On the other hand, greatest percentage of individuals in the Pra mangrove forest occurred within the 4.00-4.99 m height class. The next height class with high percentage of individuals was 3.00-3.99 m and this is followed by 5.00-5.99 m. It was observed that more individuals in Pra mangrove forest occurred in the higher classes (4.0 to >6.0 m) than individuals in the Kakum mangrove forest.

It was noticed that a greater percentage of individuals of *Rhizophora* from both forests fell between the 3.00-3.99 m and 5.00-5.99 m height classes. Nonetheless, there was higher percentage of individuals of height >6.0 m class in the Kakum mangrove forest than in the Pra mangrove forest.

Regarding the percentage height distribution of individuals of *Laguncularia*, majority of those in the Kakum mangrove forest reached a height of 2.00-2.99 m, followed by 3.00-3.99 m and only few fell within the other height classes. Most of the individuals in the Pra mangrove forest fell within 3.00-4.99 m. In addition, higher percentage of individuals in the Kakum mangrove forest occurred in the 5.00-5.99 m than individuals in the Pra mangrove forest.

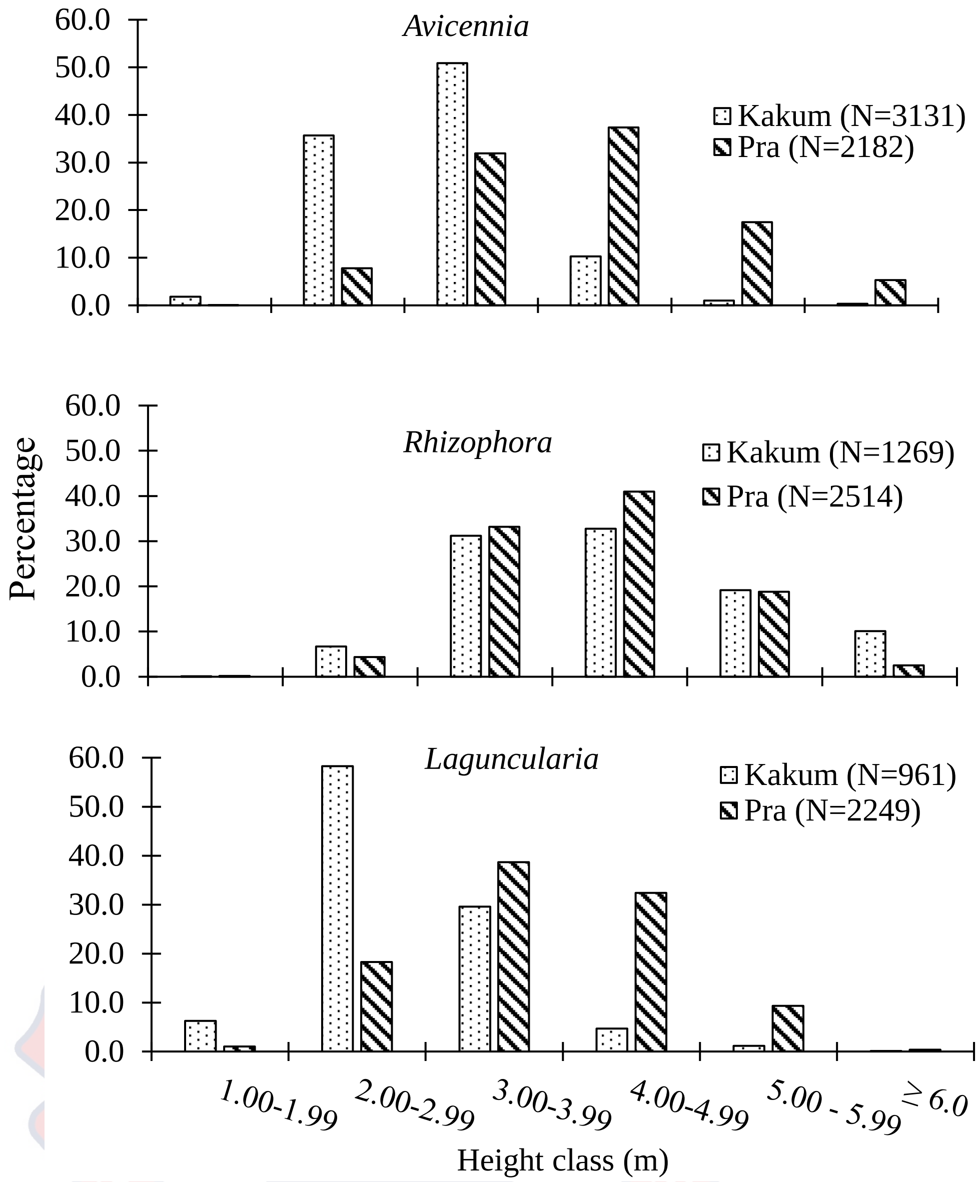

Figure 4.10: Height distribution of trees in the Kakum and Pra mangrove forests

4.4.3 Relationships between height and DBH of mangrove trees

The relationships between tree height and DBH of the mangrove species are illustrated in Figure 4.11. There was a very strong linear relationship between the diameter and height (Height = 0.50DBH + 1.62) of *Avicennia* at the Kakum mangrove forest, with coefficient of correlation (r) of 0.95. The relationship at the Pra mangrove forest was however fairly strong (r = 0.64).

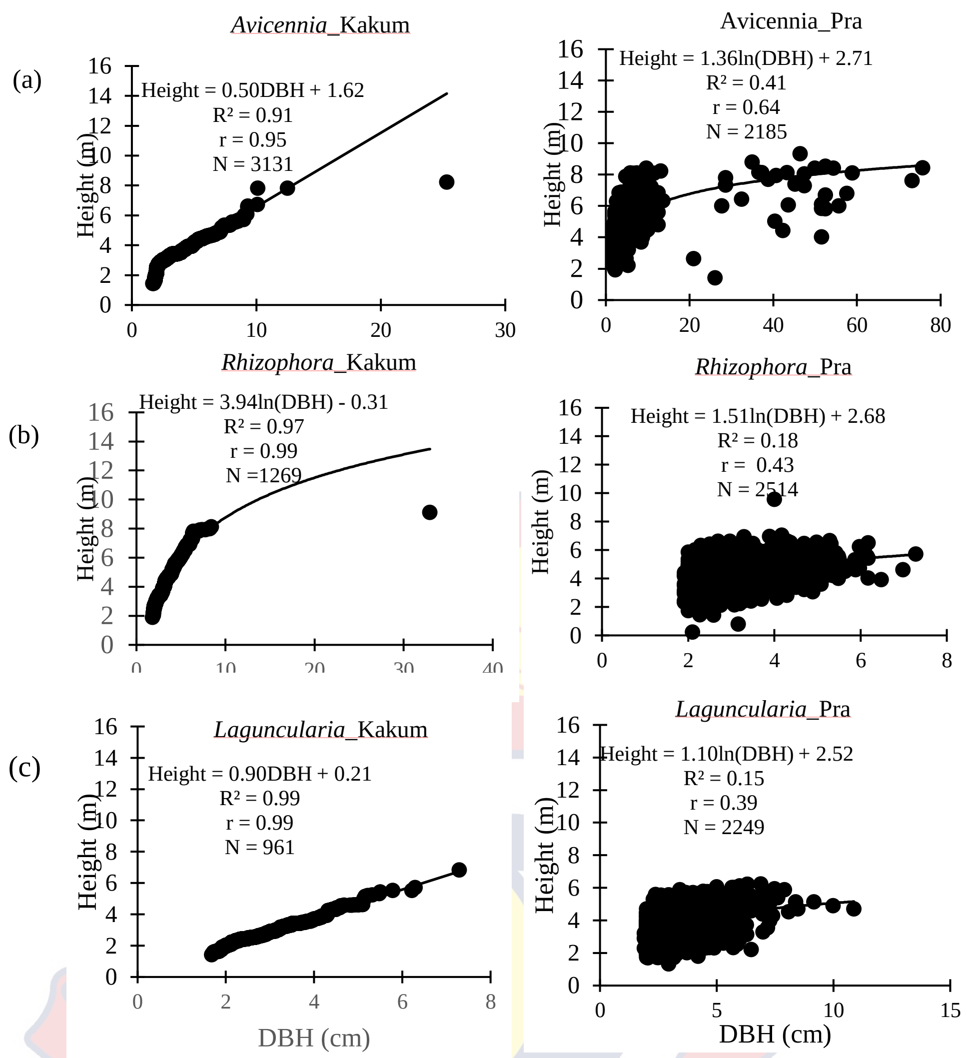

Figure 4.11: Relationships between height and DBH of (a) *Avicennia*, (b) *Rhizophora* and (c) *Laguncularia* in Kakum and Pra mangrove forests

Whilst the height and DBH of *Rhizophora* in the Kakum mangrove forest had a strongly correlated (r = 0.99) logarithmic relationship (Height = 3.94ln (DBH) - 0.31), that of the Pra mangrove forest was weak (Height = 1.51ln (DBH) + 2.68, r = 0.43). With respect to *Laguncularia*, there was highly correlated (r = 0.99) linear relationship (Height = 0.90DBH + 0.21) in the Kakum mangrove forest but weak logarithmic relationship (Height = 1.10ln (DBH) + 2.52) in the Pra mangrove forest. Generally, the relationships for all species were linear and very strong in the Kakum mangrove forest, and logarithmic and weak in the Pra mangrove forest.

4.5 Litter Production in the Kakum and Pra Mangrove Forests

The variations in mean rate of monthly litter production in both the Kakum and Pra mangrove forests are shown in Figure 4.12. The rate of litter production varied between 50.35 ± 6.24 g m^{-2} $month^{-1}$ - 105.40 ± 12.04 g m^{-2} $month^{-1}$ and 63.84 ± 5.88 g m^{-2} $month^{-1}$ - 128.51 ± 15.29 g m^{-2} $month^{-1}$ respectively in the Kakum and Pra mangrove forests. The highest mean rate of litter production in the Kakum mangrove forest occurred during the dry season in April 2018, whilst that of the Pra mangrove forest occurred during the wet season in July 2018.

The lowest rate of production in both mangroves however, took place in June 2018. The rates of annual litter production were 959.96 g m^{-2} y^{-1} (9.60 t ha^{-1} y^{-1}) and 1071.51 g m^{-2} y^{-1} (10.72 t ha^{-1} y^{-1}) respectively for the Kakum and Pra mangrove forests. T-test analysis revealed that there was a significant difference between the rate of litter production between the two mangrove forests, t = 2.91, P<0.05. ANOVA also showed that litter production varied significantly within the sampling months and study plots (P<0.05).

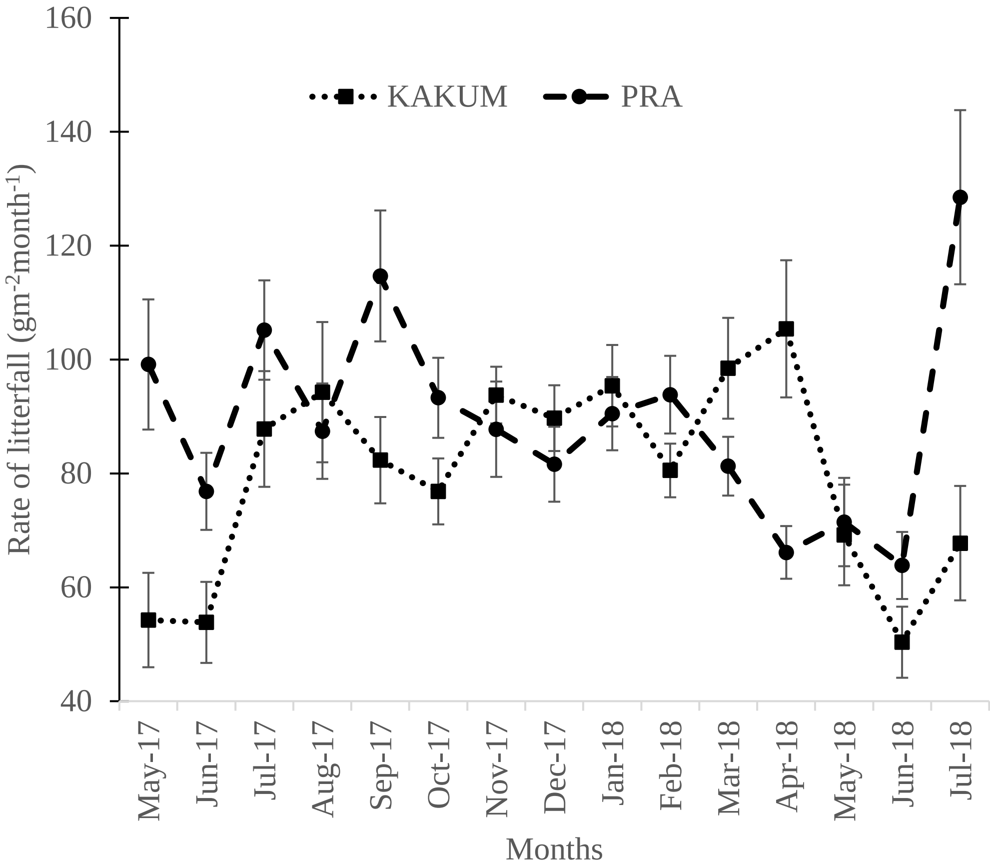

Figure 4.12: Variations in monthly litter production in the Kakum and Pra mangrove forests

4.5.1 Composition of litter in the mangrove forests

Figure 4.13 presents the percentage composition of litter fall in the Kakum and Pra mangrove forests. The major components of the litter produced in both forests were leaves. The composition of leaf litter from the Kakum mangrove ranged from 61.26 % (in April 2018) to 97.85 % (in September 2017). In the Pra mangrove forest, leaf litter composition varied between 75.87 % in August 2017 and 99.45 % in March 2018. Twigs were the least represented in litterfall in both mangrove forests. Whilst the twig composition values in the Kakum mangrove forest ranged from 0.28 % in December 2017 to 6.294 % in

May 2018, that of the Pra mangrove forest ranged between 0.210 % (November 2017) and 3.224 % (May 2017).

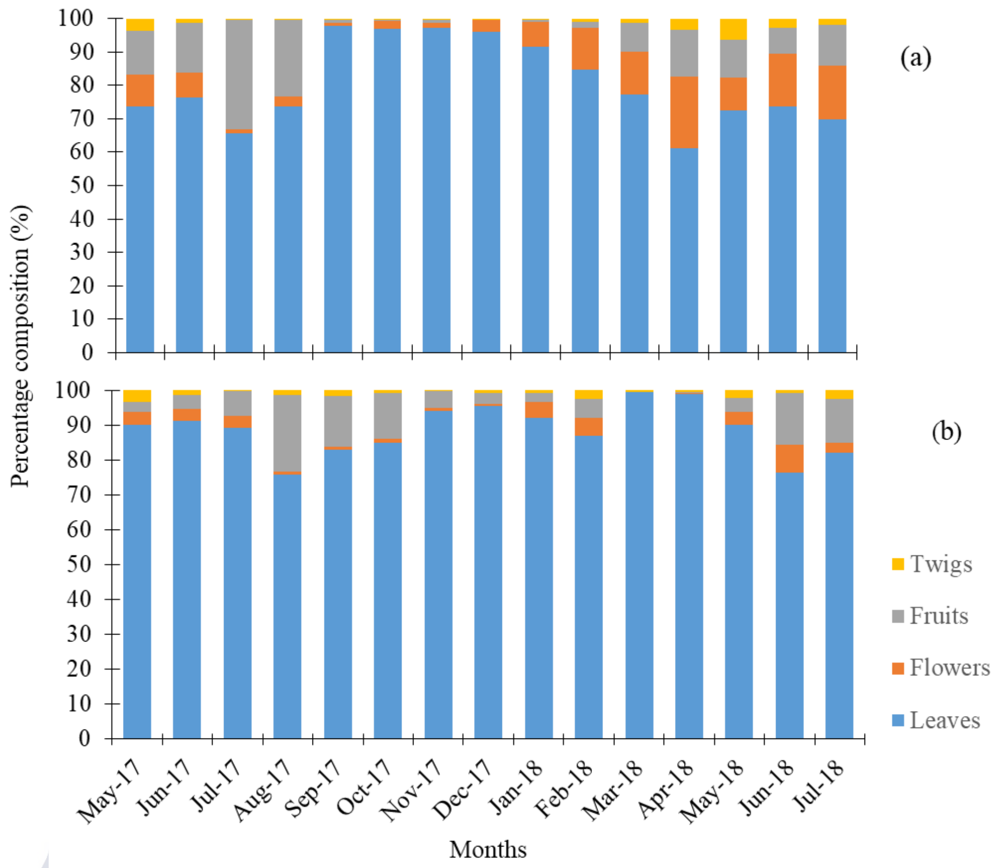

Figure 4.13: Percentage composition of litter fall in mangrove forests at (a) Kakum and (b) Pra estuaries

At both sites, the highest percentage production of fruits/propagules and twigs occurred in the wet season. The highest leaf fall occurred in the wet season at Kakum whereas that at Pra occurred in the dry season. One way ANOVA showed that there were significant differences between the production of leaves and flowers ($p<0.05$), but no significant differences were observed between the twig and fruit production ($p>0.05$) between the two mangrove forests (Appendix C1). Also, the composition of the various parts of litter within the sampling months differed significantly, $p<0.05$.

4.5.2 Environmental factors in the Kakum and Pra forest areas

Figure 4.14 illustrates variations in environmental factors around the Kakum and Pra forest areas during the study period. There were minimal variations in average monthly air temperature around both study areas. The monthly average air temperature for the Kakum and Pra mangrove areas ranged from 24.9 °C to 29.1 °C and 25.1 °C to 28.6 °C respectively. Least temperatures were recorded in August 2017 during the wet season and highest temperatures occurred in April 2018 at the end of the dry season for both mangrove forests. Temperatures of the two mangrove areas did not differ significantly (t = -0.23, p>0.05).

Average relative humidity was fairly constant for the entire study period at both study sites. Generally, the Kakum mangrove area had slightly higher relative humidity than the Pra mangrove area, except in April 2018--82.1 % and 83.1 % respectively. Both study sites had the highest relative humidity of 92.1 % (Kakum) and 90.0 % (Pra) in July, 2018. Statistically, there were significant differences between the relative humidity of the two mangrove areas, t = -0.23, p<0.05.

There were notable variations in monthly total rainfall pattern, with the Kakum area having lower amounts of rainfall (0.0-144.14 mm) than the Pra area (0.0-270.25 mm). At the Kakum mangrove forest area, rainfall was highest in June and October 2017 with a smaller peak in May 2018. At the Pra mangrove area, the highest amount of rainfall was recorded in May-June 2017, and a significant peak occurred in May 2018. However, the amount of rainfall around the two forests did not differ statistically, t = -1.87, p>0.05.

Monthly wind speeds varied from 3.9 Km/h to 7.3 Km/h at the Kakum mangrove forest area, and 6.0 Km/h to 11.7 Km/h at the Pra mangrove forest area. Clearly, lower wind speeds prevailed at the Kakum area than the Pra area during the study period. The highest wind speeds were recorded in April 2018 at both study sites. The wind speeds varied significantly between the two study sites ($t = -6.46$, $p<0.05$).

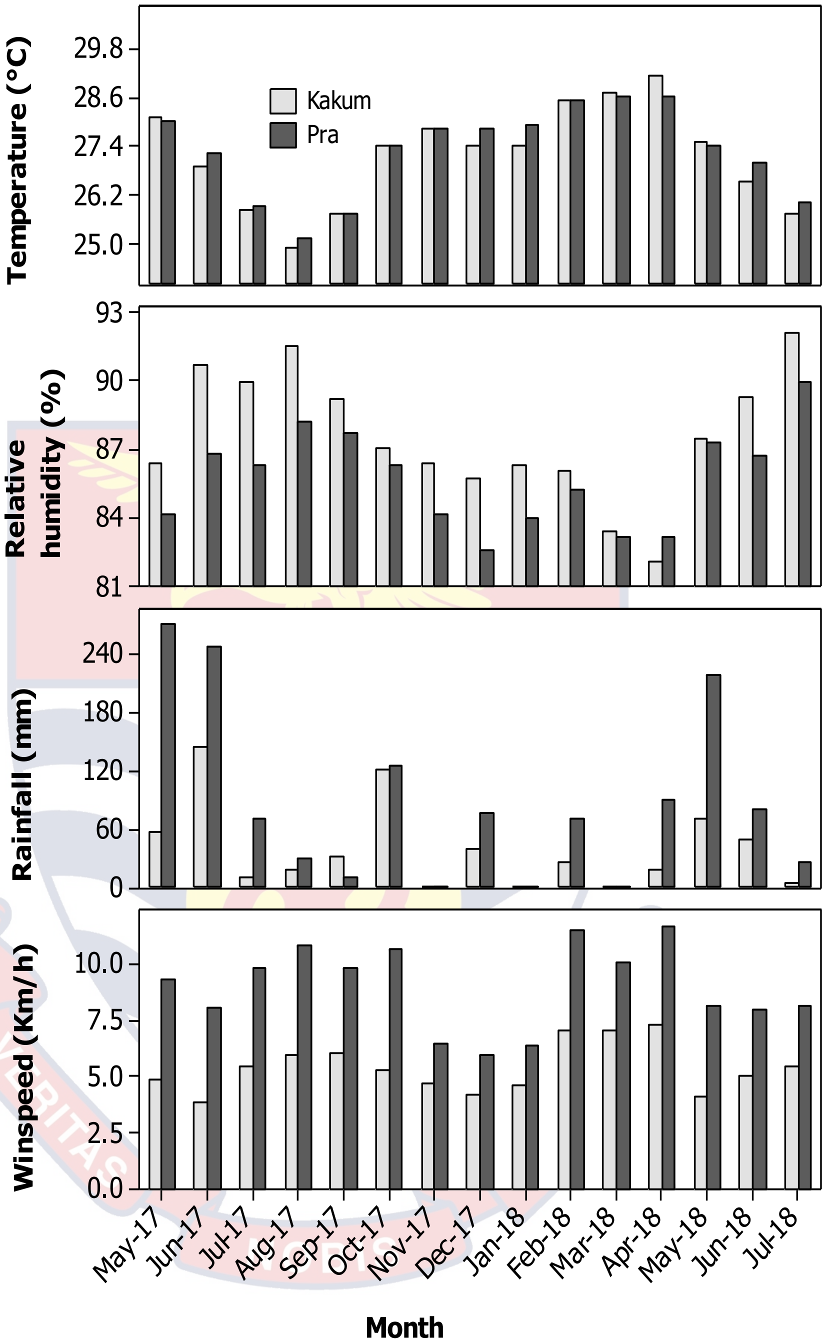

Figure 4.14: Variations in climatic factors around the Kakum and Pra mangrove forests
Source: Tutiempo Network (2018)

4.5.3 Relationships between litter production and environmental factors, structural parameters and soil nutrients

The relationships between litter production and environmental factors, structural parameters and soil nutrients have been established (Appendix D). The analysis suggested there was weak correlation between litter production and environmental factors at both mangrove forests. In Kakum, air temperature and wind speed appeared to have positive effects on litter production but the relationships were not significant ($r = 0.034$, $p>0.05$ and $r = 0.129$, $p>0.05$ respectively). Litter production was negatively correlated with relative humidity and rainfall ($r = -0.134$, $p<0.05$ and $r = -0.221$, $p<0.05$ respectively). While the correlations between litter production and relative humidity and wind speed at Pra were positive, those of temperature and rainfall were negative; having significantly different relationship with temperature ($r = -0.176$, $p < 0.05$) and relative humidity ($r = 0.169$, $p < 0.05$).

Litterfall correlated non-significantly with DBH ($r = 0.020$, $p > 0.05$ and $r = -0.07$, $p > 0.05$) and height ($r = -0.012$, $p > 0.05$ and $r = -0.08$, $p > 0.05$) in the Kakum and Pra mangrove forests respectively.

There were also significant correlations of litter with nitrogen ($r = 0.159$, $p < 0.05$), phosphorus ($r = -0.406$, $p < 0.05$) and potassium ($r = 0.168$, $p < 0.05$) in Kakum mangrove forest. In the Pra mangrove forest however, no significant correlations were observed between litter production and the soil nutrients.

4.6 Physico-chemical Parameters of the Kakum and Pra Estuaries

Results of water quality parameters measured at the Kakum and Pra estuaries from May 2017 to July 2018 are shown in Figure 4.15. Results of statistical analysis (ANOVA) conducted on the variations in physico-chemical parameters within the sampling months and study plots are presented in Appendix E.

4.6.1 Salinity

Average monthly salinity ranged from 0.16 ± 0.03 PSU to 28.55 ± 1.66 in the Kakum estuary and 0.04 PSU to 24.65 ± 2.64 PSU in the Pra estuary. Salinity remained fairly low in both estuaries from May-December 2017. Salinity of the Kakum estuary rose significantly in February 2018, and remained high till April 2018 (27.72 ± 1.70-28.55 ± 1.66 PSU). On the other hand, salinity of the Pra estuary increased gradually from December 2017 to a peak in February 2018 (7.80 ± 2.94-24.65 ± 2.64 PSU), and began to reduce till July 2018. Results of ANOVA revealed there were significant differences in salinity among the sampling months and stations ($p<0.05$). However, there were no significant differences between the salinities of the two estuaries (t = -0.22, $p>0.05$).

4.6.2 Conductivity

Monthly average conductivity of the Kakum estuary varied between 192.25±19.07 µS/cm and 37,908.33± 1,266.14 µS/cm whereas that of the Pra estuary ranged from 88.25±3.92 µS/cm to 33,391.67 ± 4,736.02 µS/cm. The pattern of fluctuations in conductivity is similar to that of salinity, with low conductivities coinciding with the wet period and peak conductivity corresponding with dry season in both estuaries. Statistically, there were differences in the conductivity values of the two estuaries, $t = -1.73$, $p<0.05$. Additionally, ANOVA established that there were significant differences among the months for both estuaries and sampling stations at the Pra estuary ($p<0.05$), but not within the sampling stations in the Kakum estuary ($p<0.05$).

4.6.3 Total dissolved solids

Average monthly total dissolved solids (TDS) fluctuated from 101.5 ± 11.05 to 27,116.67 ± 1,043.37 ppm in the Kakum estuary and 39.42 ± 1.71 to 23,650.00 ± 2,273.91 ppm in the Pra estuary. The fluctuations in the TDS were similar to fluctuation patterns in salinity and conductivity for both estuaries, with low values coinciding with the wet period and peak in TDS corresponding with dry season. There was no significant difference between the TDS of the two estuaries ($t = -0.51$, $p>0.05$). Like conductivity, ANOVA established that there were significant differences among the months for both estuaries and sampling stations at the Pra estuary ($p<0.05$), but not within the sampling stations in the Kakum estuary ($p>0.05$).

4.6.4 Turbidity

The Pra estuary was more turbid than the Kakum, with turbidity ranging from 24.15±3.13 NTU to 281.21±47.03 NTU in the former, and 5.00 ± 0.16 NTU to 81.19 ± 2.38 NTU in the latter, but their fluctuation patterns were similar (Figure 4.15). Unlike the pattern of fluctuations in conductivity, salinity and TDS, high turbidities coincided with the wet period whilst low turbidities corresponded with dry season in both estuaries. The differences in the turbidities between the two estuaries were highly significant, t = -12.46, $p < 0.05$. Again, ANOVA showed significant differences among the sampling months for both estuaries as well as sampling stations in the Pra estuary ($p<0.05$). However, no significant differences occurred in the sampling stations of the Kakum estuary ($p>0.05$).

4.6.5 Dissolved oxygen

Fluctuations in the monthly dissolved oxygen (DO) levels in the Kakum estuary ranged between 1.22 ± 0.07 mg/L and 13.57 ± 0.33 mg/L whereas the levels in the Pra estuary varied from 1.01 ± 0.06 mg/L to 9.65 ± 0.80 mg/L. Concentrations of DO in the two estuaries increased from May to a maximum in September-October 2017; this was followed by a steady decline until July 2018. Statistically (ANOVA), the concentrations of DO in both estuaries differed significantly within the sampling months and sampling stations ($p < 0.05$). On the other hand, there were no significant differences between the concentrations of DO of the two estuaries (t = -1.62, $p > 0.05$).

4.6.6 pH

The pH of the Kakum and Pra estuaries varied from 6.174 and 6.355 respectively to 8.272 and 7.732 respectively. Clearly the fluctuations and values in both estuaries were similar. Alkaline conditions (pH >7) noticeably prevailed in the estuaries in all months except July 2017 when acidic conditions (pH < 7) were recorded. Also, the difference between the pH of the two estuaries was not significant, t = 0.69, $p > 0.05$. The pH however, differed significantly among the sampling months for both estuaries and sampling stations at Pra estuary ($p<0.05$), but not among the sampling stations of the Kakum estuary ($p>0.05$).

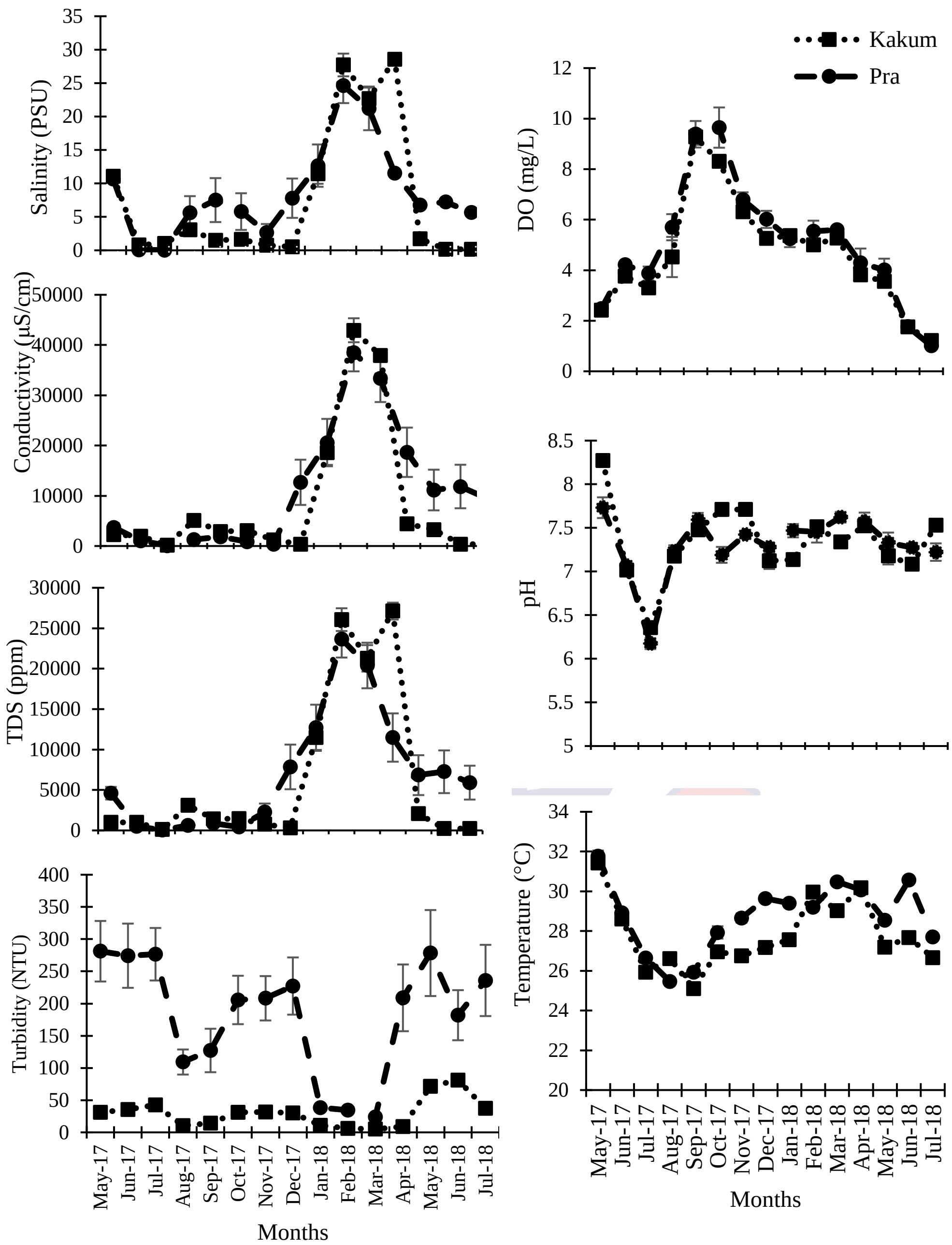

Figure 4.15: Monthly variations in physico-chemical parameters of the Kakum and Pra estuaries

4.6.7 Temperature

The variations in monthly average temperature were 25.11 ± 0.17 to 31.43 ± 0.21 for the Kakum estuary, and 25.47 ± 0.17 to 31.77 ± 0.29 for the Pra estuary. Fluctuations in monthly temperature of both estuaries were seemingly similar and there was no significant difference in temperature between the two estuaries t = -2.18, $p > 0.05$). Significant differences were observed within the various months for both estuaries and sampling stations at Pra estuary ($p < 0.05$). No significant difference was observed among the temperatures within the sampling stations at Kakum estuary ($p > 0.05$).

4.6.8 Water quality indices of the Kakum and Pra estuaries

From the PCA, the three most important parameters used for the determination of the water quality indices for both the Kakum and Pra estuaries were pH, DO and TDS. These parameters explained 86.48 % and 86.63 % of the total variance at the Kakum and Pra estuaries respectively (Appendix F). The respective indices for Kakum and Pra estuaries were 0.06 and 0.05, implying moderate water quality.

Table 4.12 - *Comparison of Physico-chemical Parameters with Previous Studies*

	Kakum estuary		Pra estuary	
Parameter	**Present study**	**Dzakpasu & Yankson (2015)**	**Present study**	**Okyere (2015)**
Salinity (PSU)	0.16 ± 0.03 - 28.55 ± 1.19	0.00 ± 0.00 - 25.39 ± 1.11	0.04 ± 0.00 - 24.65 ± 2.64	1.1 ± 0.2 - 29 ± 2.4
Conductivity (µS/cm)	192.25±19.07 - 37,908.33± 1,266.14	-	88.25 ± 3.92 - 33,391.67 ± 4,736.02	2,300 ± 0.9 - 38,600 ± 1.1
TDS (ppm)	101.5 ± 11.05 - 27,116.67 ± 1,043.37	-	39.42 ± 1.71 - 23,650 ± 2,273.91	-
Turbidity (NTU)	5.00 ± 0.16 - 81.19 ± 2.38	9.33 ± 0.63 - 12.36 ± 0.21	24.15 ± 3.13 - 281.21 ± 47.03	60 ± 3 - 1000 ± 0
DO (mg/L)	1.22 ± 0.07 - 13.57 ± 0.33	2.43 ± 0.03 - 4.31 ± 0.05	1.01 ± 0.06 - 9.65 ± 0.8	4.0 ± 0.3- 7.1 ± 0.2
pH	6.36 ± 0.07 - 8.27 ± 0.06	6.10 ± 0.10 - 6.77 ± 0.04	6.17 ± 0.06 - 7.73 ± 0.12	6.9 - 8.0
Temperature (°C)	25.11 ± 0.17 - 31.43 ± 0.21	26.59 ± 0.12 - 29.21 ± 0.04	25.47 ± 0.17- 31.77 ± 0.29	24.3 ± 0.8 - 31.5 ± 0.3

4.7 Physico-chemical Parameters of the Kakum and Pra Mangrove Soils

Figure 4.16 shows the variations in soil physico-chemical parameters in the two mangrove forests. Statistical analysis (ANOVA) conducted on the variations in physico-chemical parameters within the sampling months and study plots are provided in Appendix G.

4.7.1 Soil salinity

Salinity of soil samples from the Kakum and Pra mangrove forests ranged from 2.31 ± 0.44 PSU to 8.30 ± 0.59 PSU, and 1.15 ± 0.24 PSU to 6.31 ± 0.39 PSU, respectively. The trends in variations were similar; soil salinity reduced from May 2017 to low levels in October-November 2017 at Kakum mangrove and October 2017 at Pra mangrove, followed by a gradual increase till March 2018. Low soil salinities were recorded from May to July 2018 in the Kakum system and April to July 2018 in the Pra system. Salinity was significantly higher in the soils from Kakum system than the Pra system (t = 6.12, $p < 0.05$). The ANOVA also showed significant differences in soil salinities among the sampling months and within the study plots in both forests, $p < 0.05$.

4.7.2 Soil conductivity

Soil conductivity from the Kakum and Pra mangrove forests ranged respectively from 2179.04 ± 823.28 µS/cm to 4,672.67 ± 1038.71 µS/cm, and 2015.83 ± 461.73 µS/cm to 6,902.5 ± 709.21 µS/cm. Maximum conductivity of soils in the Kakum mangrove forest was recorded in January 2018 whilst a clear peak occurred in February 2018 for soil samples from the Pra mangrove forest.

Generally, conductivity was stable at both sites from May to September 2017, and March to July 2018. No significant differences were observed in conductivity of soils from the two mangrove forests (t = -1.19, $p > 0.05$). Nonetheless, the ANOVA showed that soil conductivity differed significantly within the study plots at each mangrove forest and within the sampling months of the Pra mangrove forest ($p < 0.05$). No significant differences were observed within the sampling months at the Kakum mangrove forest ($p > 0.05$).

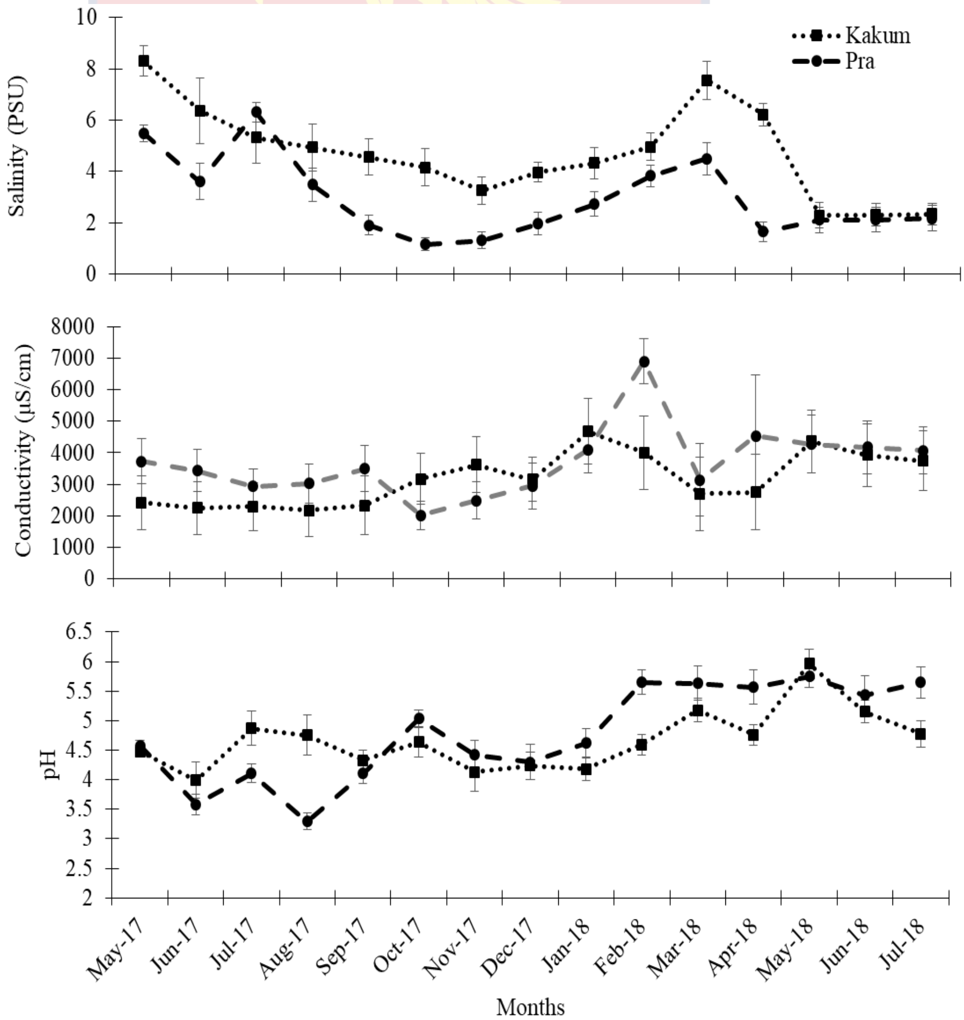

Figure 4.16: Monthly variations in salinity, conductivity and pH of the Kakum and Pra mangrove soils

4.7.3 Soil pH

The monthly pH of soils from the Kakum and Pra mangrove forests ranged from 3.99 ± 0.31 to 5.96 ± 0.25 and 3. 29 ± 0.17 to5.75 ± 0.18 respectively. The pH of soils from the Kakum mangrove forest fluctuated from May 2017 to January 2018, increased marginally to a maximum in May 2018 and later declined till July 2018. The pH of the soils from the Pra mangrove forest also fluctuated from May 2017 to February 2018 and remained fairly stable up to July 2018. The highest pH of soils from both forests was recorded in May 2018, but the least mean pH values were recorded in different months--June and August, 2017 respectively for Kakum and Pra mangrove forests. The pH values between the two mangrove forests differed significantly, $t = -1.28$, $p < 0.05$. In addition, the ANOVA showed there were significant differences in the monthly pH values within the months, and study plots in both mangrove forests ($p < 0.05$).

4.7.4 Correlations between water and soil physico-chemical parameters

Apart from the negative correlations between pH of soil and water in the Kakum estuary, the other physico-chemical parameters including salinity and EC of water and soil correlated positively in both estuaries (Appendix H).

4.8 Concentrations of Nutrients in the Sediments of the Kakum and Pra Mangrove Forests

Quarterly variations in concentrations of some macronutrients in the two mangrove sediments are presented in Figure 4.17. The statistical analysis

(ANOVA) conducted on the variations in concentrations of nutrients within the quarters (sampling months) and study plots are provided in Appendix I.

4.8.1 Carbon

Mean percentage organic carbon in the sediments ranged from 0.14 ± 0.12 % to 1.06 ± 0.12 % and 0.14 ± 0.12 % to 2.07 ± 0.62 % in the Kakum mangrove forest and Pra mangrove forest respectively. Percentage carbon was high within the first two quarters, June and September 2017 and reduced drastically to the lowest in March 2018 in both mangrove forests. While the highest mean percentage carbon in Kakum mangrove forest was recorded in September 2017, the highest average percentage carbon was recorded in June 2017 in the Pra mangrove forest. Additionally, no significant difference was observed between the percentage carbon in the mangrove sediments from both forests, $t = -1.54$, $p > 0.05$. The ANOVA however showed that the concentration varied significantly among the sampling quarters and study plots ($p < 0.05$).

4.8.2 Nitrogen

The mean concentration of nitrogen in sediments in the Kakum and Pra mangrove forests varied respectively from 1.47 ± 0.44 to 17.37 ± 3.40 mg/L, and 0.90 ± 0.13 mg/L to 17.56 ±1.71 mg/L. The patterns of variations were basically similar in both forests--concentrations were highest in June 2017, and lowest in June 2018, with a marginal increase in August 2018. Furthermore, there were no significant differences between the nitrogen concentrations in both mangrove forests ($t = 1.11$, $p > 0.05$). However, the ANOVA confirmed there were significant differences among the sampling quarters at both sites and study plots at Kakum ($p < 0.05$). The concentrations did not differ within the study plots in Pra mangrove forest ($p > 0.05$).

4.8.3 Phosphorus

The average quarterly concentrations of phosphorus in the soil at Kakum mangrove forest were between 0.27 ± 0.05 mg/L and 0.57 ± 0.10 mg/L, whereas that of Pra mangrove forest varied from 0.13 ± 0.05 mg/L to 0.31 ± 0.05 mg/L. The concentration of phosphorus was stable at both sites from June 2017 to March 2018. While the concentration of phosphorus in the Kakum mangrove forest increased in June and August 2018, a decrease was apparent in the Pra mangrove forest, $t = 3.56$, $p < 0.05$. The ANOVA results indicated quarterly concentrations also differed significantly among the study plots and within the quarters ($p<0.05$).

4.8.4 Potassium

Average potassium concentration in soil sediments from the Kakum mangrove forest ranged from 17.7 ± 2.284 mg/L to 42 ± 4.470 mg/L, and that of the Pra system varied between 11.26 ± 1.385 mg/L and 48.78 ± 5.182 mg/L. There was a general increase in the potassium content of soil from both forests during the study period, except for a significant decrease in June 2018 at the Pra. There were no significant differences between the concentrations of potassium in the two mangrove forests ($t = 0.17$, $p > 0.05$). However, the ANOVA established there were significant differences among the sampling months and study plots ($p<0.05$).

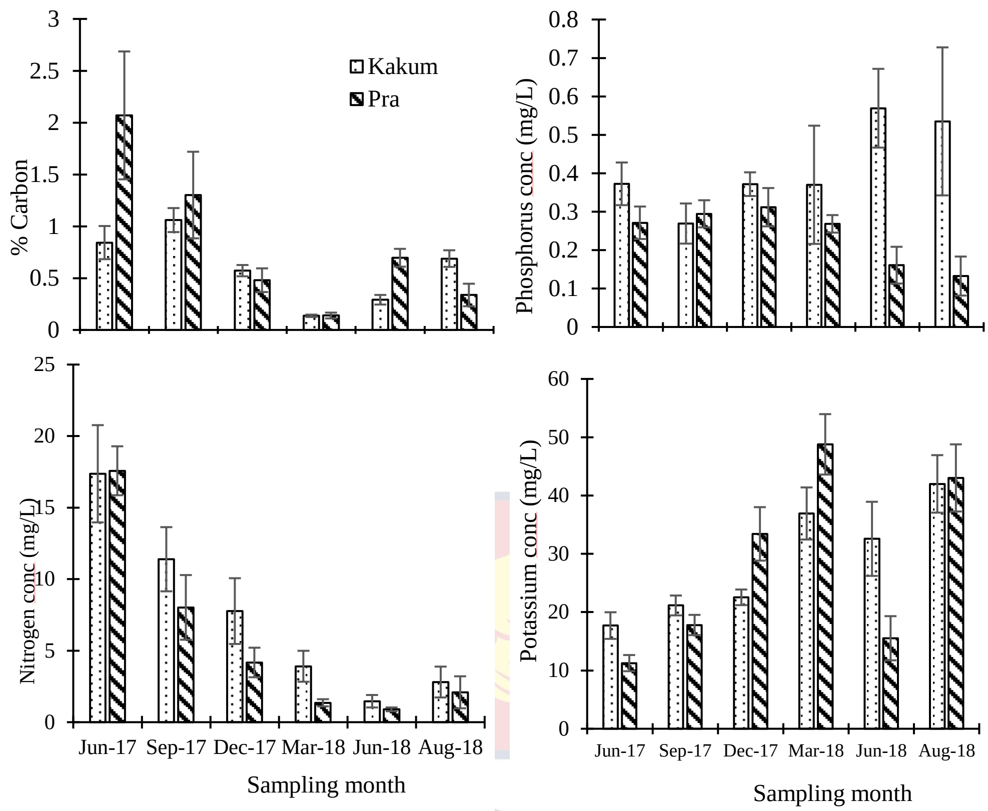

Figure 4.17: Variations in concentration of nutrients in sediments of the Kakum and Pra mangrove forests

4.8.5 Sediment quality indices of the Kakum and Pra mangrove forests

Three important sediment parameters including salinity, potassium and phosphorus for the Kakum mangrove as well as pH, organic carbon and phosphorus for the Pra mangrove were the most important factors that determined the quality of the respective mangrove sediments. This shows that phosphorus is essential at the two mangrove forests. These parameters explained 71.66 % and 63.21 % respectively of the total variances (Appendix J). The sediment quality index was -0.01 for both mangroves, indicating moderate sediment quality.

4.9 Concentrations of Heavy Metals in the Sediments of the Kakum and Pra Mangrove Forests

The variations in the average concentrations of heavy metals measured quarterly during the study are shown in Figure 4.18. Nonetheless, the concentrations of cadmium at both mangrove forests were below detectable limits, hence no data has been presented on it. Results of statistical analysis (ANOVA) conducted on the variations in concentrations of heavy metals within the quarters (sampling months) and study plots are provided in Appendix I.

4.9.1 Arsenic

The mean concentrations of arsenic in the Kakum mangrove forest fluctuated from 4.14 ± 0.08 mg/kg to 4.35 ± 0.07 mg/kg, whereas that of the Pra mangrove forest varied from 2.51 ± 0.05 mg/kg to 4.63 ± 0.59 mg/kg. The mean concentrations from both forests remained fairly stable in all the sampling quarters, except for a sharp decline in the concentration at Pra in the last quarter (August 2018). Both mangrove forests had their highest concentrations in June 2018. Statistically, there was no significant difference between the levels of arsenic at both forests, $t = 0.59$, $p > 0.05$. The ANOVA suggested that differences in the concentrations among the quarters at both mangrove forests and the study plots at Kakum were highly significant ($p < 0.05$). No differences were observed within study plots at Pra mangrove forest ($p > 0.05$).

4.9.2 Mercury

Quarterly average concentrations of mercury in the sediments in the Kakum and Pra mangrove forests fluctuated respectively between 0.33 ± 0.05 - 0.39 ± 0.05 mg/kg and 0.36 ± 0.05 - 0.49 ± 0.04 mg/kg. Even though the average concentrations of mercury at the Kakum mangrove forest were higher than those at the Pra mangrove forest, the concentrations from the two forests did not differ significantly (t = -1.19, p>0.05). Also, ANOVA showed there were significant differences among sampling stations (p<0.05), but not within quarters (p>0.05).

4.9.3 Zinc

The average concentrations of zinc in the sediments of the Kakum and Pra mangrove forests ranged respectively from 1.18 ± 0.20 to 2.31 ± 0.60 mg/kg and 1.39 ± 0.14 to 2.46 ± 016 mg/kg. The concentrations of zinc in sediments from the Pra mangrove forest decreased gradually from the first quarter (June 2017) to the fourth quarter (March 2018) but rose again through June to August, 2018. Conversely, at Kakum, the concentrations of zinc decreased from June 2017 to December 2017, then increased to June 2018 and decreased again in August 2018. The zinc concentrations in the sediments from the two forests differed significantly (t = -2.15, p<0.05). There were also significant differences in the concentrations within the sampling months for both mangrove forests and study plots at Kakum mangrove forests, based on ANOVA (p<0.05). No differences were observed within study plots at Pra mangrove forest (p>0.05).

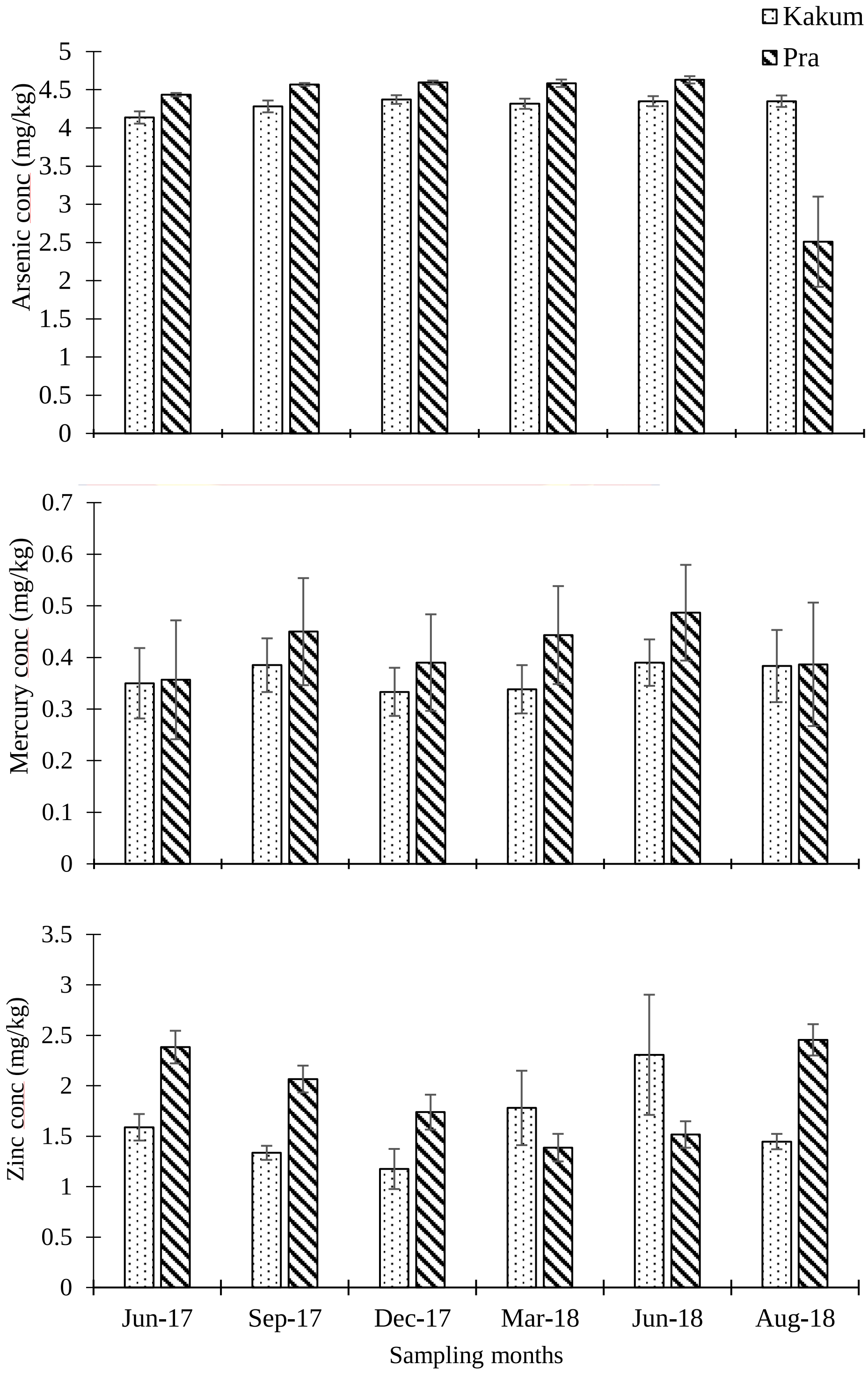

Figure 4.18: Variations in concentrations of heavy metals in sediments of the Kakum and Pra mangrove forests

4.9.4 Ecological risk indices of the Kakum and Pra mangrove forests

Table 4.13 presents the risk potentials of each heavy metal and the ecological risk index of each study plot in the two mangrove forests. In both forests, risk potential of heavy metals decreased in the sequence: Hg>As>Zn. Of the three heavy metals investigated, Hg contributed more than 96 % of the ecological risk in both forests. Mercury posed the highest risk at Plot IV and Plot II respectively, in the Kakum and Pra mangrove forests. While the risk potential of Hg was considerable at Kakum, that of the Pra was high, with respective indices of 106.44 and 164.00. Overall, all the plots in both mangrove forest were with low risk, with the exception of Plot II at Pra mangrove forest which was with moderate risk, with ERI of 166.66. Thus, on average, ecological risk posed by heavy metals to the mangrove forests was low with ERI of 75.56 ± 14.28 and 86.61 ± 29.40 for the Kakum and Pra mangrove forests respectively.

Table 4.13 - *Ecological Risk Indices of the Kakum and Pra Mangrove Forests*

Mangrove forest	Sampling plots	Risk potential of heavy metal			Ecological risk index (ERI)	ERI categories
		As	**Hg**	**Zn**		
Kakum	I	2.74	82.22	0.02	84.98	Low
	II	2.75	62.89	0.02	65.66	Low
	III	3.04	39.11	0.02	42.17	Low
	IV	2.93	106.44	0.03	109.40	Low
	Mean	**2.87 ± 0.07**	**72.67± 14.30**	**0.02**	**75.56± 14.28**	**Low**
Pra	I	2.61	73.78	0.03	76.42	Low
	II	2.63	164.00	0.03	166.66	Moderate
	III	2.98	75.33	0.02	78.33	Low
	IV	3.03	22.00	0.02	25.05	Low
	Mean	**2.81 ± 0.11**	**83.78± 29.47**	**0.02**	**86.61 ± 29.40**	**Low**

4.10 Mangrove Health Indices of the Kakum and Pra Mangrove Forests

The criteria used to determine the mangrove health indices (MHI) were as follows:

1) Excellent (85-100%) = 272 ≤ MHI ≤ 320

2) Good (70-84.7%) = 224 ≤ MHI ≤ 271

3) Moderate (55-69.7%) =176 ≤ MHI ≤ 223

4) Bad (40-54.7 %) = 128 ≤ MHI ≤175

5) Worst (<40%) = MHI < 128

The MHI for the Kakum and Pra mangrove forests are provided in Table 4.14. Whereas the Kakum mangrove forest had MHI of 175 (out of maximum of 320), Pra mangrove forests had MHI of 190. This implied that the Kakum mangrove forest fell within bad health category, while the Pra mangrove forest was within moderate or medium health.

Table 4.14 - *Mangrove Health Indices of the Kakum and Pra Mangrove Forests*

Ecological indicators	Weighted score (%)	Rank/Score		Weight × Score	
		Kakum	Pra	Kakum	Pra
DBH	15	1	1	15	15
Ecological risk	5	3	3	15	15
Water quality	5	3	3	15	15
Human Pressure	5	1	1	5	5
Litter production	15	2	2	30	30
Mangrove cover change	15	1	3	15	45
Sediment quality	5	3	3	15	15
Species richness	5	3	2	15	10
Tree density	15	2	2	30	30
Tree height	15	1	1	15	15
MHI				**170**	**195**

4.11 Chapter Summary

The chapter highlighted the major findings of the research. The socioeconomic data showed that a total of 136 mangrove users made up of 53.7 % females and 46.3 % males (60.8 % and 39.2 %, 49.4 % and 50.6 % from Kakum and Pra areas respectively) were engaged in the study. These mangrove users exploited fish products – crabs, periwinkles and tilapia, and forest products – fuel wood and timber (poles). Land use and land cover change analysis indicated that the mangrove cover at Kakum estuary reduced by 41.58

% from 2005 to 2017, while that of Pra estuary increased by 12.54 % within the same period.

The floristic analysis revealed that 23 plant species comprising five true mangroves and 18 mangrove associates, distributed in 13 families and 16 genera were encountered in the Kakum mangrove forest. In the Pra mangrove forest, 20 plant species that comprised three true mangroves and 17 non-mangroves were recorded. The Kakum mangrove forest had a lower total density of all species (5,361 ha^{-1}) than Pra mangrove forest (6,955 ha^{-1}). Again, the Kakum mangrove forest had a lower annual litter production rate of 959.96 g m^{-2} y^{-1} (9.60 t ha^{-1} y^{-1}) than the rate recorded in the Pra mangrove forest -1071.51 g m^{-2} y^{-1} (10.72 t ha^{-1} y^{-1}).

The results of the sediment analyses showed that heavy metals posed low ecological risks in both mangrove forests, although moderate and considerable risks were registered at some sampling stations. Also, water and mangrove sediments from both locations were of moderate quality. In all, the health of the Kakum mangrove forest was bad whereas that of the Pra mangrove forest was moderate.

CHAPTER FIVE

DISCUSSION

The previous chapter presented the various results obtained in the study. This chapter has been organised to explain the results of the study under six major subthemes including socioeconomic characteristics; land use types; floristic composition and structural parameters; litter production; and water and mangrove sediment quality, in relation to the health of the Kakum and Pra mangrove forests. The findings have also been related to relevant literature.

5.1 Soccioeconomic Characteristics of Mangrove-dependent Population

5.1.1 Demography and mangrove resource use

Coastal inhabitants depend greatly on mangroves to meet their livelihood and other economic needs (USAID, 2014). A total of 136 mangrove users made up of 54 % females and 46 % males were encountered during the survey, indicating that more females depend on the mangrove resources than males. This is in line with the suggestion by Forselius (2013) that most of these mangrove exploitations are performed by women.

These respondents were made of all age groups including children under 18 years and adults who were 56 years and above, with middle adults aged between 36 - 55 years forming the majority. This shows that these mangroves serve as source of income for people of all ages. Most of these users (56.5 - 82.4%) were engaged in other occupations and used mangrove resource harvesting as a part-time occupation. Earlier researchers also reported that direct harvest of mangrove wood and plants is rarely a full-time occupation for the users (Walters et al., 2008).

On the type of mangrove resource utilization, majority of the respondents (82.4 %) from the communities around the Kakum mangrove forest harvested fish products which comprised periwinkles and crabs while few of them harvested forest products, mainly for fuel wood. Whereas harvesters of the fish products were both migrants and natives of Abbina, Atonkwa, Koful and Ntranoa, all the mangrove wood harvesters were migrants resident at Abakam. These migrants are all from various communities in the Volta Region. It was found that the inhabitants of Iture no longer harvested mangrove resources but rather did fishing in the sea.

Conversely, more respondents exploited forest products than fish products from the Pra mangrove forest, while few of them exploited both products. Also, respondents obtained tilapia in addition to periwinkles and crabs from the Pra mangrove area. Mangrove wood harvesting from the Pra mangrove forest was predominantly done by mangrove users from Anlo Beach (71 %) and Shama-Apo. This again, indicated that the mangrove wood exploitation was being done mostly by migrants from the Volta Region.

Overall, as high as about 70 % of the mangrove resource users were migrants and only few of them were natives of the communities around these mangrove forests. This trend confirms assertion that, the number of people migrating and settling in the coastal areas keeps increasing (Moller-Jensen & Knudsen, 2008). This is because the well-being of coastal inhabitants is typically much better than that of people living inland communities (MEA, 2005).

In terms of mangrove resource harvesting and gender, more men harvested forest resources, while fish resources were harvested more by women. The forest products comprised basically of wood for fuel-wood and timber or poles for construction. This confirms the claim by Walters et al. (2008) that wood for fuel and construction are the two most widespread uses of mangrove wood. Nonetheless, fuel wood is harvested daily, but woods for construction (poles) were harvested infrequently and only upon need.

Traditionally, mangroves are believed to provide better quality wood for fuel wood for smoking fish, charcoal production and construction materials (USAID, 2014). This study revealed that *Avicennia* was the most exploited mangrove species for fuel wood, followed by *Rhizophora*, while *Laguncularia* was the least exploited species. It was also found out that more females (19) harvested *Avicennia* than males (14), however, males dominated (20) harvesting of *Rhizophora*. Varying reasons were cited for the preference for harvesting a particular species. Reasons cited for harvesting *Avicennia* were that it was readily available, easy to harvest and did not cause any bodily injury to the harvester. These made *Avicennia* the preferred choice for women, while its availability at the Kakum mangrove forest also contributed largely to it being the most preferred mangrove species for fuel-wood.

The reasons given by mangrove harvesters for harvesting *Rhizophora* included the fact that it dries and burns fast, it gives nice aroma when used for smoking fish as well as makes the fish very attractive. There is also, ready market for it, therefore, it is more lucrative. Hence, although the men attested to the fact that the harvesting of *Rhizophora* is very difficult and demanding, they prefer to harvest it since it is more lucrative and readily sold for fuel wood. The few who harvested mangroves for poles also preferred *Rhizophora*, indicating that it is the most durable mangrove species for construction. Wang'ondu et al. (2014) established that *Rhizophora* is widely utilised in fuel wood and construction industry in Kenya, hence, is the most preferred species in many restoration projects.

The typically short and distorted nature of stems of *Avicennia* makes them unsuitable for large, commercial-sized lumber (Walters et al., 2008). A similar study by Dahdouh-Guebas et al. (2006) in India revealed that *Avicennia* spp. were the most frequently used mangrove species for firewood and for construction. They however reiterated that harvesting for construction wood, is both species-and size-specific.

5.1.2 Mangrove ecosystem services

The principal provisioning services derived from the mangrove forests by the respondents were wood for fuel wood and poles, and fisheries including periwinkles (mollusc), crabs (crustacean) and tilapia. This is in agreement with other workers who indicated that the mangrove ecosystem supports diverse local fisheries such as fishes, crustaceans and molluscs, and serves as a source of income for nearby communities (Barbier et al., 2011; Santos et al., 2014; Walters et al., 2008).

Ahammad, Stacey and Sunderland (2019) pointed out that perceived indirect services of benefits of forests are crucial, especially for forest management. The respondents perceived regulating services in the following order of importance: climate regulation; pollution control; flood protection; erosion control; and disease control. Thus, it can be said that the respondents recognised the importance of mangrove ecosystems in maintaining favourable environmental conditions.

The role of mangroves in serving as nursery grounds for fish and nesting grounds for birds were important supporting ecosystem services stated by respondents in this study. Nutrient cycling was the least (7.80 %) supporting ecosystem service cited by the respondents. Perhaps, this is so because the respondents observe the fishes and birds breeding and nesting in the mangrove forests, hence, they recognise these supporting roles played by the mangrove ecosystems, as compared to the nutrient cycling. Most respondents also indicated that the mangroves provide shades for the fishes, especially the young ones, confirming the supporting ecosystem services provided by mangrove ecosystems. Nonetheless, nutrient cycling is an ecological function and not a final (ecosystem) service (Boyd & Banzhaf, 2007).

Cultural services are services from ecosystems which provide spiritual and aesthetic appreciation to human beings (Fischlin et al., 2007). Aesthetic benefit was the most important cultural service derived by the respondents surveyed in this study, while education was the least. Most respondents indicated that mangrove forest stands especially, the undisturbed forests looked so beautiful, giving them aesthetic values. There was however, less educational and spiritual values attached to these mangrove forests. They explained only few folks visit the mangrove forest for spiritual purposes whereas few students undertake educational tasks in these mangrove forests. A recent work on global patterns in mangrove recreation and tourism by Spalding and Parrett (2019) indicated that out of the number of mangrove attractions mentioned in broad geographic region, only 28, representing 0.71% was found in Central and West

Africa. It can therefore be inferred that mangrove cultural ecosystem services are not well recognised in Ghana and other West African countries.

5.1.3 Conflicts and other issues related to mangrove resource use

Complex property rights - be it traditional, historical or commercial - do exist in many coastal areas commonly with unclear boundaries which sometimes generate conflicts (Pauly et al., 2005). In this study, 48 (35.29 %) respondents indicated that they and/or their communities have ever had conflicts with other people from different communities over the mangrove resources use. The inhabitants from Anlo Beach attributed the conflict to claim of ownership, whereby the natives of the communities mainly Shama-Apo, felt the mangrove ecosystems are on their land and denied them from harvesting the mangrove resources. This finding agrees with FoN (2014) report that there are instances of conflicts between the “landowners’ (the Fantes from Shama) and the Ewes (migrant settlers at Anlo Beach) because the landowners (the Fantes) perceived the migrants to be “pilfering” resources belonging to them.

Likewise, few of them (16.70 %), mainly inhabitants surrounding the Kakum mangrove forest attributed the cause of conflict to trivial issues such as seizure of their attires and mistaking them for thieves. According to the respondents from communities around the Pra mangrove forest, these conflicts do not occur these days, though little misunderstandings sometimes arise. But, at Kakum mangrove forest, trivial conflicts still go on and this is not healthy for the mangrove ecosystem resource uses. Consequently, engagements with stakeholder groups help to resolve resource conflicts and as well, help them come into agreement on resource management strategies (Brown et al., 2001).

Few of the respondents, that is 21.3 %, claimed they have had health conditions associated with mangrove forests and majority cited malaria as the health condition they normally got from mosquito bites in the mangrove forests. A report by CRC/FoN (2010) cited malaria as one of the most prevalent diseases recorded in the coastal districts in the Western Region in 2009. This may imply that the respondents might not have necessarily acquired the malaria from the mangrove forests, but rather from the communities, due to the prevalence of malaria in these coastal areas.

Virtually, all the respondents opposed alternative use of the entire mangrove forest area for developmental projects and preferred the continuing existence of the mangrove forests. All of these respondents emphasised alternative use would result in loss of their livelihoods, since the mangrove resources serve as their only source of livelihood. This finding supports a similar work in Tanzania which reported that most coastal people rely on natural resources around them for their livelihood, with households depending on mangrove vegetation for their survival (Peter, 2013). This finding is also in agreement with earlier reports that indicated that the coastal inhabitants insisted they must explore the mangrove resources because they had no other source of income to survive (Santos, Gasalla, Dahdouh-Guebas, & Bitencourt, 2017). They added that the people who agreed with alternative use indicated that the alternative use must go on along with the mangrove resource exploitation.

5.1.4 Respondents' perception on mangrove cover change and restoration

Globally, there have been reports on land use changes especially in relation to mangrove cover (FAO, 2007; Valiela et al., 2001). This study reports that almost all the respondents (99.20 %) established that there had been reductions in the mangrove cover or extent and majority (83.30 %) stated that these reductions occurred within the last 10 years ago. Even though respondents from the various age groups indicated that the mangrove reduction occurred within the past ten years, the older age groups reiterated that decline started more than a decade ago, but has increased rapidly within the last decade. This implies that the mangrove degradation is accelerating while the ecosystem services they provide are also vanishing. This agrees with Duarte et al. (2008) assertion that loss of ecosystems results in reduction in the provision of valuable ecosystem services provided by them. This result is in line with the findings of similar works in Ghana that pointed out that mangrove communities perceived or observed that 50 % of mangroves have been lost over the past two decades (Ajonina, 2011; Asante et al., 2014).

Deforestation was cited as the major cause of decline in mangrove cover, in addition to minor causes comprising flooding, invasive plants, illegal mining, sand winning and natural causes. These causes of mangrove loss have been reported by earlier workers (Ajonina, 2011; Asante, et al., 2014; Gordon et al., 2009; Nortey, 2014).

The rapid rate of mangrove loss necessitated numerous international agreements to help in the protection of large areas of mangrove forests globally (Romañach et al., 2018). Besides these international arrangements, individual efforts by nations and other groups to protect or restore mangroves have been made. Some of the respondents from communities around the Pra mangrove forest indicated there had been replanting efforts and 62.0 % of these respondents affirmed that replanting efforts brought about changes. The remaining respondents were of the view that the replanting efforts did not yield any results, because flooding of River Pra resulted in the death of the replanted trees.

Of the respondents who indicated absence of replanting in their areas, 69.20 % of them agreed that there was a need for replanting to help improve mangrove cover, as well as the mangrove resources. They experienced decline in the mangrove resources they exploit, hence, replanting of the degraded areas will help improve the mangrove resources they harvest. Conversely, of respondents who indicated there were no replanting efforts at their localities, 30.8 % indicated that replanting efforts were not necessary. Almost all of them (95.0 %) emphasised that natural regrowth would occur, while the rest of them felt replanting efforts might result in restriction of access to the mangrove forests and resources. These results can be compared with the results of a study carried out in the Western Region of Ghana which reported that most of respondents (83.3 %) at Whin indicated the need to improve the state of the mangrove cover whilst 70.0 % respondents at Nyan disagreed (Nortey, 2014). These disparities towards replanting efforts could be due to the fact that some mangrove users are unconcerned about conservation and are only interested in short-term benefits they derive now, at the expense of the future generation.

It must be noted that natural regeneration of cut-down stumps of *Avicennia* was observed in most of study plots especially in the Pra mangrove forest, but, this may not be enough to replace the degraded portions of the ecosystems. Moreover, Hoppe-Speer et al. (2015) cautioned that although mangroves recover naturally from interference by recruitment of propagules and seedling, while some species like *Avicennia* are able to regrow from stumps, excessive harvesting resulted in the death of the overharvested trees. Thus, assisted or aided regeneration is required at locations with inadequate natural regeneration (Walters et al., 2008), hence, replanting efforts should be implemented in these mangrove forests to effectively conserve them.

5.2 Land Use Types and Mangrove Cover Change

Global environmental change, and sustainability has revitalized research to address the human impact on and interactions with the surface of the Earth (Rindfuss, Walsh, Turner, Fox & Mishra, 2004). Land-Use and Land Cover Change (LULCC) is therefore, a result of natural processes, human activities and human-nature interactions that occur in space and over time (Rindfuss et al., 2004; Turner, Lambin & Reenberg, 2007).

The land use types identified in this study were mangrove, other vegetation (i.e. non-mangrove species), built/bare-area and water (estuary). At Kakum mangrove forest, it was found out that with exception of other vegetation which gained as much as 577.99 % cover area, all the land types, lost cover areas from 2005 to 2017. The mangrove forest area reduced by about 42 %, while the estuary also experienced about 34.34 % cover loss. The LULCC results on the reduction of the mangrove area supports the observation of the respondents from the various communities that there had been decline in the mangrove area. This supports the assertion that local people mostly observe changes in their neighbouring ecosystems and could indicate whether there is an increase or a decrease in the resources they provide (Satyanarayana, Mulder, Jayatissa & Dahdouh-Guebas, 2013).

The general trend observed in the LULCC may be largely attributed to the increasing clearing of mangroves and invasion of mangrove affiliates such as *Sesuvium portulacastrum and Paspalum vaginatum*. These species have the ability to colonise available space quickly, and prevent its colonisation by mangroves (Rubin, Gordon & Amatekpor, 1998). They as well, tolerate any changes in environment (John & Lawson, 1990). Blasco (1984) indicated that *Rhizophora* species - *R. racemosa* and *R. mangle* were incapable of recovering from the effects of dryness, hence, simply disappeared from disturbed and dry areas and have been replaced by patches of *Paspalum vaginatum* and *Sesuvium portulacastrum*. This may have accounted for the reduction in mangrove cover and increase in other vegetation cover. The reduction in the water cover too might have caused dryness of the area which in turn resulted in the reduction of mangrove cover.

Over all, the observed anthropogenic activities such as waste disposal, plastic pollution, sand winning and more importantly, the excessively logging of mangroves are causing the reduction in estuarine water cover and mangrove cover, and this can result in the total collapse of the mangrove ecosystems. Although earlier workers reported decline in the Kakum mangrove cover (Adotey, 2015; Aheto et al., 2011; Sackey et al., 2011; SGP, 2012), the results of this current study is a wakeup call for urgent conservation and restoration strategies to ensure the sustainability of this vital ecosystem.

Contrary to the results of the remote sensing on the LULCC at Kakum, the mangrove cover at Pra increased from 574.10 ha in 2005 to 646.10 ha and the water cover increased from 200.46 ha to 303.00 ha in 2017, indicating gains of 12.54 % and 51.15 % in cover respectively. The increase in the mangrove cover from the remote sensing is in disagreement with the observations of the respondents that the mangrove cover had reduced especially within the last decade. The increase may be attributed to the replanting exercises that took place at the mangrove area. Although some of the respondents also indicated the replanting efforts contributed to an increase in the mangrove areas that were replanted, the results from the remote sensing however could have resulted from the misclassification of other vegetation as mangroves, as some plants have similar reflectance values as that of mangrove vegetation (Agyeman et al., 2007). This may be so due to substantial invasion of woody mangrove associates most especially an unidentified plant species (Figure 3.3b). Admittedly, Dahdouh-Guebas, Hiel, Chan, Jayatissa and Koedam (2005) highlighted that there are limitations to remote sensing on the canopy layer, particularly in dense forests.

The increase in the water coverage might be due to the flooding that occurred in the Pra estuary in 2017. This may have also resulted in the reduction in both other vegetation and built/bare-land cover loss because the flood water might have covered the herbaceous and shrubby plants as well as the bare-land. The flooding also resulted in the washing away of built/bare-land (including houses) and other vegetation (including coconut trees) along the bank of the estuary particularly at the seaward side.

5.3 Floristic Composition and Structural Parameters of Mangrove Species

Information on the floristic composition of mangroves in an area is a basic and a significant prerequisite to understanding both the structure and function of mangroves, in addition to their conservation and management strategies (Jayatissa, Dahdough-Guebas & Koedam, 2002). In this study, five true mangrove species - *Avicennia germinans*, *Rhizophora racemosa*, *Rhizophora mangle*, *Rhizophora harrisonii* and *Laguncularia racemosa* were encountered in the Kakum mangrove forest. This is a confirmation of the findings of Sackey, et al. (2011) and DeGraft-Johnson (2010) that the Kakum estuary mangrove forest contains five true mangrove species and the most diverse mangrove forest in Ghana. This also confirms that Ghana has five true mangrove species contrary to four reported by FAO (2007) which indicated absence of *R. mangle* in Ghana. Adotey (2015) confirmed the existence of *R. mangle* in Ghana in an earlier study, although the other two species of *Rhizophora* were not reported.

At the Pra mangrove forest however, only three true mangrove species including *A. germinans*, *R. racemosa*, and *L. racemosa* were encountered. Sackey et al. (2011) stated that although there are three main mangrove genera - *Rhizophora*, *Avicennia* and *Laguncularia* in Ghana, not all the three genera are present at all the mangrove areas. Thus, the Pra estuary is one of the areas in Ghana where all the three genera of mangroves are found.

On a whole, a total of 18 (Kakum) and 17 (Pra) non-mangroves or mangrove affiliates recorded in the two mangroves indicates that species richness of plants is quite high in these mangrove forests. Five of these mangrove associates including *Thespesia populnea*, *Acrostichum aureum*, *Paspalum vaginatum*, *Sesuvium portulacastrum* and *Tapinanthus bangwensis* had been recorded earlier in the Kakum mangrove forest (Sackey et al., 2011). The high numbers of these mangrove associates may not be healthy for these mangrove ecosystems because some authors consider these species to be a major problem to the native mangrove species. For example, *A. aureum* can rapidly occupy deforested mangrove areas because it is well adapted to occupying sunlight spaces in the forest, and in turn causes a significant ecological impact, making it difficult for mangrove propagules to get established (Hogarth, 2007; Romañach et al., 2018).

The family Papilionaceae had five species and represented the family with the highest number of species. This is in consonance with the fact that members of Papilionaceae have an essentially worldwide distribution, found in all climates and are abundant in tropical and subtropical regions (Ali, Shah, Khan & Hussain, 2014; Baro & Borthakur, 2017; Sharma & Kumar, 2013).

Densities of *Avicennia*, *Rhizophora* and *Laguncularia* in the Kakum forest were respectively 3,131 ha^{-1}, 1269 ha^{-1} and 961 ha^{-1}, which were higher than densities of 2,327.5 ha$^{-1,}$ 894.4 ha^{-1} and 680.7 ha^{-1} recorded by Sackey et al. (2011). The difference in these two results could be attributed to the difference in the minimum diameter of the two studies – the former considered individuals with ≥ 2.5 cm in diameter while the current study considered individuals with ≥ 2.0 cm in diameter. Hence, smaller individuals were included in this study which resulted in higher densities. A similar study conducted in the same study area recorded lower densities (range of values ha^{-1}) for *Rhizophora* and *Laguncularia* but higher density of 3,627.7 ha^{-1} for *Avicennia* (Adotey, 2015). So far, the results from the study area indicated that *Avicennia* has the highest density and it is the mangrove species with the highest individuals, thus, the most dominant mangrove species in terms of distribution, at the Kakum mangrove forest.

The densities recorded at the Pra mangrove forest for *Avicennia* and *Laguncularia* in this study were lower compared to the results from a previous study (FoN, 2014). However, the density recorded for *Rhizophora* in the current study, was higher (2,514 ha^{-1}) than what was recorded earlier (1, 900 ha^{-1}). *Laguncularia* had a higher density in Pra than in Kakum, signifying the population of *Laguncularia* in Pra far exceeded that of Kakum. Generally, individuals of the various mangrove species were relatively fairly distributed at Pra than at Kakum, thus, the species showed codominance. This is contrary to the finding that mangrove forest at Pra stuary was dominated *Avicennia* (FoN, 2014). Although the total density of all the mangrove species at Kakum was lower than (5,361 ha^{-1}) that of Pra (6,955 ha^{-1}), it can be established that the two mangrove forests were moderately dense, because their densities fell within 1,000 -10,000 ha^{-1} category (Hoppe-Speer et al., 2015).

Diameter at breast height (DBH) is a suitable standard for studying large plants (Gehring, Park & Denich, 2008) whereas tree height is also a useful measure in stand forest classification (FAO, 1994). The mean DBH and mean height for all the mangrove species from the Kakum and Pra mangrove forests were less than 4.5 cm and 5.7 m respectively (Table 4.11). The mean DBH and height for mangrove stands at Kakum and Pra consequently, fell within a category of forests with low structural development - DBH between 1.6 and 4.5 cm, and mean height between 2.4 and 4.7 m (Pellegrini, Soares, Chaves, Estrada & Cavalcanti, 2009). It can therefore be deduced that the mangrove forests at both the Kakum and Pra estuaries were of low structural development. This conforms with the findings of earlier workers (Aheto et al., 2011; FoN, 2014).

The size structure distributions of the mangrove species show that more than 90 % of the mangroves at both study sites fell within the 0.0 - 4.99 cm class interval, underscoring the fact that almost all the species were small in size. However, few individuals of *Avicennia* sp. occurred within diameter size range ≥ 10 cm. This observation could be attributed to regeneration of trees from stumps of *Avicennia* sp. stems. It was also observed that higher percentage of individuals of *Rhizophora* in the Kakum mangrove forest were of height >6.0 m than individuals in the Pra mangrove forest. This could be attributed to fact *Rhizophora* is the most preferred mangrove species harvested for fuel wood at the Pra area, hence may be under severe exploitation and not be allowed to attain high height.

There were strong relationships between the diameter and height of all the mangrove species recorded at Kakum mangrove forest with coefficients of correlation (r) of 0.95 and above. These relationships were however, weak for mangrove species encountered at Pra. This suggests that there was a generally uniform structural development in mangrove species at Kakum in contrast to mangrove species at Pra mangrove forest that show a non-uniform structural development (Aheto et al., 2011). The differences observed in the relationship between the two study areas could be due to variations in growing conditions and environmental characteristics between the two study areas.

Generally, *Avicennia* and *Laguncularia* had better structural parameters at Pra, whereas *Rhizophora* had improved structural parameters at Kakum. The abundance and availability of individuals of *Avicennia* and *Rhizophora* respectively at Kakum and Pra may have influenced the preference of these species for wood harvesting at their respective locations, since availability was one of the reasons cited by the harvesters for their choices for wood for fuel wood. Furthermore, harvesting pressures on these species at their respective sites might have accounted for their low structural parameters. Day et al. (2018) pointed out that large trees occur, only when the ecosystem remains stable enough over a long period. Hence, these mangrove ecosystems must be left intact for some time to enable the species to grow to maturity.

5.4 Litter Production in the Kakum and Pra Mangrove Forests

The litter production of mangroves provides the contribution of organic input to the mangrove ecosystem (Conacher, O'Brien, Horrocks & Kenyon, 1996), and as well as, indicates the conditions of growth of mangrove forests (Saenger & Snedaker, 1993). Globally, the rate of litter production for mangrove forests range from approximately 1.3 to 18.7 t ha^{-1} y^{-1} (Saenger & Snedaker, 1993; Twilley, Robert & Day, 1999). Recently, a wider range of between 1.0 and 20.3 t ha^{-1} y^{-1} was stated by Rafael and Calumpong (2018). The rates of annual litter production of 959.96 g m^{-2} y^{-1} (9.60 t ha^{-1} y^{-1}) and 1071.51 g m^{-2} y^{-1} (10.72 t ha^{-1} y^{-1}) for the Kakum and Pra mangrove forests respectively fell within the global range. A total annual litter production of 30.3 t ha^{-1} y^{-1} was reported for mangroves of Ada Songor Ramsar Site in Ghana (Ntyam et al., 2014) - this is higher compared to the current study. This possibly was due to the restricted access to the Ramsar site which might have enhanced high productivity.

Litter production was significantly different between the two mangrove forests and within the sampling months. There are several reports on spatial and seasonal variations in mangrove litter production (Cunha, Tognella-de-Rosa &

Costa, 2006; Ntyam et al., 2014; Rafael & Calumpong, 2018). The litter production peaked during the dry and wet seasons in the Kakum and Pra mangrove forests respectively. Peak litter fall in the wet seasons has been reported in other studies elsewhere (Arreola-Lizárraga et al., 2004; Bernini & Rezende, 2010; Conacher et al., 1996; Cunha et al., 2006; Sharma et al., 2010). Nonetheless, Ntyam et al. (2014) and Wang et al. (2014) also reported peak litter fall in the dry seasons. The peak litterfall during the dry season might have been caused by the response of the mangroves to water stress (Rani et al., 2016).

Leaf litter formed the principal component of the litter production in both forests ranging from about 61 to 99 %. This is in line with numerous studies indicating leaf as a major component of litter production (Hemati et al., 2017; Hoque et al., 2015; Rafael & Calumpong, 2018; Rani et al., 2016; Wang et al., 2014). Generally, the order of the litter component was in the decreasing order of leaves, reproductive parts (flowers, fruits and propagules) and twigs. This outcome is similar to that of earlier studies by Mchenga and Ali, (2017) and Rani et al. (2016). In both forests, the highest percentage production of fruits and propagules occurred in the wet season. This agrees with the findings of Bernini and Rezende (2010) and Sharma et al. (2010), who reported highest fruit production during wet seasons. This can be related to the phenology of mangroves where fruiting and flowering occurred in the wet season.

Dharmawan, Guangcheng, Pramudji and Bin (2019) stated that changes in environmental and weather conditions influence mangrove productivity. In this study, moderate to weak correlations existed between litter production of both mangrove forests and environmental factors. Wind speed has been observed to be the common environmental factor that showed positive correlation with litter production in both mangrove forests, although its correlation in the Pra mangrove forest was not significant. This is in agreement with the findings of Mohit & Appadoo (2009). Rainfall and temperature correlated negatively but significantly with litter production in Kakum and Pra mangrove forests respectively. This is an indication of the reason why litter production peaked during the dry and wet seasons respectively in Kakum and Pra mangrove forests. Dharmawan et al. (2019) detailed that in the course of the dry season, higher temperatures raise cellular metabolism, which in turn activate more litter production to enable mangroves to cope with the higher salt concentration.

According to Cunha et al. (2006), Hogarth (2007), Mulya and Arlen (2018), as well as Rafael and Calumpong (2018), litter fall showed affinities of correlation with various structural attributes of mangroves. Yet, no significant correlation was observed between litter and DBH and height in both mangrove forests. Similarly, Hoque et al. (2015) found no significant correlations between litterfall and forest structure.

Besides climate and structure, adequate nutrient availability coupled with site fertility have also been cited as factors contributing to litter production (Bernini & Rezende, 2010; Saenger & Snedaker, 1993). Litter production had significantly positive correlations with N and K, but negative correlation with P in Kakum mangrove forest, while there were no significant correlations between litter production and all the four nutrients – C., N., P. and K in the Pra mangrove forest.

It can be inferred from the correlations of litter production with the various factors that several other parameters influence mangrove litter production. For instance, anthropogenic activities have been identified to have reduced litter production (Shunula & Whittick, 1999). Bernini and Rezende (2010) concluded that the pattern of litter production is influenced by the distinctiveness of each mangrove forest, because a particular factor can be the most significant for a given location but less influential in another mangrove.

5.5 Quality of Estuary Water and Mangrove Sediment

5.5.1 Physico-chemical parameters of estuaries

The physico-chemical parameters play a significant role in the distribution, survival and regeneration of mangroves (Srilatha, Varadharajan, Chamundeeswari & Mayavu, 2013). For instance, water temperature is of great significance because it controls the biological activities and directs solubility of gases in water (Dattatreya, Madhavi, Satyanarayana, Amin & Harini, 2018). The average temperatures recorded in this study are a bit higher than what was reported in previous studies (Dzakpasu & Yankson, 2015; Okyere, 2015). These relatively high estuarine temperatures may not have negative effects on the mangroves because Kathiresan and Bingham (2001) pointed out that mangroves have special features that help them to overcome transpiration triggered by high temperatures. It was stipulated that, relatively high temperatures increase the growth rate and the rate at which mangroves spread (Alshawafi, Analla, Aksissou & Triplet, 2016). However, Gregory, DeVivo, DiDonato, Wright and Thompson (2013) confirmed that many of organisms in the estuary have a narrow tolerance range of temperature.

Salinity is considered the important principal factor which governs the composition and distributions of living organisms in the mangrove ecosystems

(Dattatreya et al., 2018). Significant differences in salinities were observed within the sampling months. These variations in salinities could be due to differences in rainfall and freshwater inflow from land, as well as differences in evaporation rates. Soil salinity and water salinity correlated positively in both estuaries.

Electric conductivity (EC) can either be defined as the quantity of dissolved salts in water or the number of ions in water and the ability of water to pass electrical currents (Dattatreya et al., 2018). The EC values of the Pra Estuary were lower than what were recorded earlier (Okyere, 2015). There were highly significant differences in EC values among the months. There were also significant positive correlations between EC of the soil and water of both the Kakum and Pra estuaries.

The entire aerobic aquatic life in the mangrove ecosystems depends solely on DO for the respiratory metabolism (Dattatreya et al., 2018). The DO concentrations reported for both the Kakum and Pra estuaries were less than a range of 5–12 stated for estuaries (Gregory et al., 2013). The low DO recorded may be generally caused by high temperatures which reduced the solubility of oxygen. Both estuaries had their lowest DO concentrations in the same month, July 2018. This may probably be due to high turbidity caused by runoffs from rains, resulting in less photosynthetic activities by aquatic plants. Aksornkoae (1993) explained DO levels vary according to locations as well as zonation of plants.

The pH values of water of Kakum and Pra estuaries are lower and higher respectively than what was recorded earlier (Dzakpasu & Yankson, 2015; Okyere, 2015). The pH values differed significantly among the sampling months in both estuaries. Generally, seasonal variations in pH values through the year is attributable to factors such as bicarbonate degradation resulting from removal of CO_2 by photosynthesis, dilution of seawater via freshwater influx, reduction of temperature and salinity and organic matter decomposition (Rajasegar, 2003). The lowest pH values recorded in this study occurred in the wet season and this might be due to higher mangrove run-off (Atwell, Wuddivira & Gobin, 2016).

Turbidity indicates the level of fine particles or phytoplankton in the water (Gregory et al., 2013). They gave turbidity range of estuarine water to be 0–10 NTU and indicated that a value above 20 NTU calls for concern. Thus, turbidity values reported in this study were of concern. There were seasonal variations in the turbidities of both estuaries and this possibly could have resulted from changes in climate, with runoff from rains during the wet seasons making the estuaries more turbid. Turbidity of the Pra Estuary was about four to five times higher than the turbidity of the Kakum Estuary. The very high turbidity recorded for the Pra Estuary throughout the study period could be generally attributable to high sediment deposition that probably occurred due to illegal mining activities in the river upstream. Nonetheless, the turbidity range recorded for the Pra Estuary was far less than what was observed by Okyere (2015). This may be due to differences in the sampling stations, since some of the stations were located at tributaries that are far away from the flow of the river, as well as, perhaps the perceived reduction in illegal mining activities. Lovelock et al. (2015) found that turbidity and soil surface elevation are closely related, where an increase in turbidity resulted in increase in soil surface elevation and accretion in mangroves at sites where water column had abundant fine sediment.

Total dissolved solids (TDS) affect the growth of aquatic plants and animals. There were significant seasonal differences in TDS in the months, with the highest and lowest TDS values recorded for dry and wet seasons respectively. The TDS followed a similar seasonal pattern as salinity and they are both influenced by temperature. High TDS levels possibly from dissolved ions affect the pH of the body of water, whereas high TDS levels due to dissolved salts causes dehydration the skin of aquatic animals (LEO EnviroSci Inquiry, 2011)

Apart from turbidity and temperature, all the other physico-chemical parameters were higher at the Kakum Estuary than at the Pra Estuary. In a similar study by Atwell et al. (2016) to determine how abiotic water quality control mangrove distribution, *L. racemosa* dominated areas with higher turbidity and temperature. This might have accounted for the high density and distribution of *L. racemosa* in the Pra Estuary.

5.5.2 Sediment quality of the mangrove forests

Several factors such as nutrients, physico-chemical characteristics and heavy metal contamination are used in determining the sediment quality for optimum growth of mangroves. This is because, soil properties, most importantly nutrient concentrations, have a major influence on nutrition and growth of mangroves (Kathiresan & Bingham, 2001). Hence, enough supply of nutrients is vital in maintaining the stability of the mangrove ecosystems (Aksornkoae, 1993).

There were no significant differences in the concentrations of nutrients in the sediments from both mangrove forests, except for phosphorus. Potassium showed significant spatial variations in concentrations within the sampling plots. This confirms the notion that although the availability of potassium in mangrove sediments is variable, and may be limited in some mangroves (Ukpong, 1997).

Reef, Feller and Lovelock (2010) stated that even though mangrove ecosystems are considered rich in carbon, they are in a contradiction, often poor in nutrient. Apart from the first two quarters, that is, June and September 2017, that percentage organic carbon was very high (>1.0), the rest of the quarters recorded moderate (0.41 to 0.60) and very low (< 0.20) levels (Pawar et al., 2009). The levels of organic C recorded in this study is very close to the levels reported by Ataullah, Chowdhury, Hoque and Ahmed (2017), who documented a mean C of 0.832 % and minimum and maximum values of 0.292 % and 1.54 % respectively.

Organic C above 10 % is reported in a mangrove forest in Wildlife Sanctuary Sibuti Mangrove Forest in Malaysia (Rambok, Gandaseca, Ahmed & Majid, 2010) which is indicative of the peaty soils (Ataullah et al., 2017). Kaseng (2018) and Bangroo, Dar, Itoo, Mubarak and Malik, (2018) also reported organic carbon content of the mangrove sediment ranging from 2.53% to 2.60% and 1.52% to 2.78% respectively, which fall in the low category. It can therefore be said that the organic content reported in this study is very low. Ataullah et al. (2017) elucidated that organic C less than 1 % shows soils of the mangrove forests are poor in nutrients. Consequently, some of the stations in the two mangrove forests have poor nutritional levels.

Inorganic nutrients including calcium, magnesium, sodium, phosphorus, nitrogen and potassium are needed for the survival of mangroves and other organisms (Aksornkoae, 1993). Singh and Mishra (2012) also emphasised that N, P and K are essential elements that control soil fertility and plant yields.

Nitrogen is considered by Kekane, Chavan, Shinde, Patil and Sagar (2015) as the most critical element that is obtained by plants in the soil for proper growth. Nitrogen and P are found in fertilizers, animal and human wastes and yard waste (Gorde & Jadhav, 2013). They explained that while N also occurs in the air, P has no atmospheric form. Nonetheless, N and P are known to be limiting nutrients within mangrove forests (Reef et al., 2010; Rodríguez, 2008; Twilley, Robert & Day, 1999) and this may explain why low concentrations of these nutrients were obtained in this study. Alongi (1996) attributed the generally low concentrations of N and P in mangrove forests to intermittent anaerobic condition. These mangrove forests are notwithstanding, adapted to the lack of soil N and P of the mangrove forest soil (Gandaseca et al., 2016).

Potassium is essential for flowering purpose, fruit quality, building of protein, photosynthesis and reduction of infections (Addis & Abebaw, 2015). In this study, the levels of potassium in the sediments were higher than that of the other inorganic nutrients. This supports the idea that potassium is abundant in many minerals (Wheet, 2004). The results of this study are also in line with the view that inorganic nutrients usually occur in sufficient amounts, with the exception of phosphorus and nitrogen only, that are often limited in quantities (Aksornkoae, 1993). However, although Yates, Ashwath and Midmore (2002) stated that there is no literature indicating that potassium limits productivity of mangrove. Kathiresan and Bingham (2001) opined that levels of potassium may be essential in some regions, explaining that limiting nutrients may differ with individual mangrove ecosystems. Bangroo, Shabir, Dar, Itoo, Mubarak and Malik (2018) explained relationship between nutrient availability and the physico-chemical characteristic is a vital indicator of health of the soil in addition to plant nutrition.

Assessment of soil physico-chemical parameters is very important since it is essential for plant growth as well as proper soil management (Addis & Abebaw, 2015). Several studies confirmed the impact of physico-chemical properties on the distribution of mangrove (Alshawafi, Analla, Aksissou & Triplet, 2016).

According to Blasco (1984), salinity is a frequently used key factor for linking the physiology and patterns of spatial organization to the physical environment. Salinity is accordingly considered one of the most crucial factors causing stress in mangrove ecosystems (Ukpong, 1991). In this study, significant differences were observed in monthly salinities and between the two mangrove forests ($p < 0.01$), with Kakum recording a statistically higher salinity. The variations in sediment salinity could be attributable to freshwater inputs, tidal incursions, as well as the remoteness from the coast (Ukpong, 1991). This affirmation might have accounted for the lower and higher salinities observed in the wet and dry seasons. Ataullah et al. (2017) pointed out that variations in soil salinity of the mangrove forests are observed worldwide.

A saline environment is a necessity for stabilization of mangrove ecosystems, and there is an ideal salinity range which ensures maximum growth (FAO, 1994). However, excess salinity can be detrimental to the growth of mangroves (Day et al., 2018). Notwithstanding the obvious differences in the levels of salinity recorded in this study, it can be inferred that the salinity levels in the two mangrove sediments are suitable for mangrove growth. This assertion is deduced from the findings of Yates et al. (2002) that salinities close to 10–25% seawater are best for mangrove growths. Salinity significantly correlated positively with N and negatively with soil pH, as reported by Ataullah et al. (2017).

Another very important characteristics of the soil is EC, as it is useful in determining soil quality (Kekane et al., 2015). The highest EC values for both Kakum and Pra mangrove sediments were recorded in the dry season, that is 4672.667 µS/cm in January 2018 and 6902.5 µS/cm in February 2018 respectively. The conductivities recorded in this study can be categorised as moderately saline category and can restrict the yield of salt sensitive plants (JICA Expert Team, 2014).

According to Kekane et al. (2015), pH is most important property of soil, since it has effects on all other soil parameters. The assessment of soil pH is therefore, vital because it contributes greatly to nutrient availability to plants, as well as useful for classification of soil as either acidity or alkaline (basic) (Pawar, et al., 2009). The average pH of soils from the Kakum and Pra mangrove forests were less than 7, hence, the mangrove sediments from both forests were acidic. The pH of this study is similar to a range of 3.52 to 5.83 reported by Gandaseca et al. (2016), but lower than the range of 6.2 and 8.6, with overall mean of 7.34 recorded by Ataullah et al. (2017). Ramamurthy, Radhika, Amirthanayagi and Raveendran (2012) also recorded higher pH between 9.6 and 10.2 for Vedaranyam mangrove forest in India. Wheet (2004) specified that soil pH is between 3.5 and 11.0, while the best range for plant growth is 5.0 to 8.5.

In this study, soil pH showed significant negative correlation with N in the Kakum and Pra mangrove forests. A similar finding was reported by Bangroo et al. (2018). The positive correlation recorded between pH and P in this study also supports the finding of Ataullah et al. (2017), but contradicts the negative correlation reported by Bangroo et al. (2018).

Heavy metals and ecological risk

According to Marchand et al. (2006), some heavy metals are needed as essential nutrients for mangroves; but when they occur in excess, would cause adverse toxic effects on the mangrove communities. The average concentrations of Cd in the sediments in both the Kakum and Pra mangroves were below detectable limits. This is in support of the view of Maiti and Chowdhury (2013) that, Cd least has the least concentration in mangrove sediment out of all heavy metals accumulation. Similar studies by Balakrishnan, Sundaramanickam and Shekhar (2015) and Li et al. (2015) in India also recorded Cd as the heavy metal with the least concentration. The concentrations of As and Zn were within acceptable limits of 20.0 mg/kg and 90.0 mg/kg respectively, but that of Hg was above the acceptable limit of 0.2 mg/kg (AQSIQ, 2002).

The ecological risk potential of individual heavy metal however, decreased in the sequence: Hg>As>Zn at both mangrove forests. Thus, out of the four heavy metals analysed, Hg posed the highest ecological risk and contributed to more than 96 % of overall heavy metal potential ecological risk indices in both forests, confirming that Hg levels were above the acceptable limit. Mercury contamination at Pra could be attributed to mining activities taking place in the upstream of the Pra River. The Hg contamination at Kakum however, can be attributable to intrusion of water from rivers and sea and atmospheric deposition (Maiti & Chowdhury, 2013). A similar study conducted in Tanzania by Rumisha, Mdegela, Kochzius, Leermakers and Elskens (2016) reported that Hg contamination is threatening mangroves and called for effective measures against Hg emissions. Burke et al. (2001) reiterated that because heavy metals do exist in the environment naturally, it is sometimes challenging to distinguish whether variations originate from anthropogenic sources or the atmosphere and natural hydrological cycle.

On a whole, ecological risk posed by these heavy metals to the two mangrove forests was low, even though moderate risk was observed at Stations IV at Kakum forest whereas considerable risk was detected at Station II in Pra mangrove forest. According to Maiti and Chowdhury (2013), several investigations reveal that *Avicennia* is among the most tolerant mangrove species to heavy metals. This may explain why *Avicennia* was monospecific at Station IV in Kakum forest and constituted 64 % of the species composition at Station II at Pra mangrove forest, where moderate risk and considerable risk respectively were observed. Bodin et al. (2013) cautioned that heavy impact negatively on human health, hence, attention should be given to heavy metal contaminations.

5.6 The Health of the Kakum and Pra Mangrove Forests

Ecosystem health is defined and expressed in several ways, ranging from combination of biological, physical, human, and socio-economic components to a single component, on the common goal of ecosystem management and conservation (Mark et al., 2003). A variety of approaches which focus on different components of the ecosystem have been used in assessing ecosystem health (Roley et al., 2014) due to the non-existence of a comprehensive, all-encompassing framework for assessment (Roley et al., 2014). This is largely due to the uniqueness of every ecosystem, which makes it challenging to use a common framework, leading to case-specific methods being used in the assessment (Burkhard et al., 2008; Jørgensen, 2010; Roley et al., 2014).

Assessment of the ecological health of mangrove ecosystems is thus a very crucial way of monitoring mangrove ecosystems periodically. Diverse variables or parameters such as litter production, seedling regeneration, canopy cover, mangrove forest structure (Queensland Government, 2018) and socioeconomic factors are considered. Using MCDM approach based on ten different indicators, it was found out that the Kakum mangrove forest had MHI value of 175, implying a bad health state. Most of the health indicators were either low or moderate within this mangrove ecosystem and this is indicative of unsustainable uses of this mangrove ecosystem and its resources. This finding therefore suggests an urgent need for sustainable management of this mangrove ecosystem (Prasetya et al., 2017).

Unlike the Kakum mangrove forest, the Pra mangrove forest was found to be moderately healthy, with MHI value of 195, implying it was of a relatively better ecological health than the Kakum mangrove forest. This may be largely due to the increase in mangrove cover based on the remote sensing result, contrary to the respondents' perceived decrease in the mangrove cover. As discussed earlier, application of remote sensing to mangrove studies has limitations (Agyeman, et al., 2007; Dahdouh-Guebas, Hiel, Chan, Jayatissa & Koedam, 2005). Besides these, the MHI for the Pra mangrove forest was 195, which is close to the upper class of 175 for bad category. Hence, its health status should be taken with caution. Consequently, management efforts must be directed towards the conservation and sustainability of this vital ecosystem as well.

5.7 Chapter Summary

This chapter presented the discussion on the findings of this study and related these findings to relevant literature. It was concluded that the Kakum mangrove forest had MHI of 175 indicating a bad ecological health. The Pra mangrove forest had MHI of 195, implying moderate ecological health.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Mangroves are very essential to the livelihood of coastal communities and contribute immensely to coastal fisheries and shoreline stabilization among others. The rate at which mangroves are being degraded calls for concerted efforts in assessing the health of these mangroves for remediation in view of their direct and indirect benefits. This study is thus crucial for management and coastal policy development in relation to mangroves because it analysed ten different ecological indicators of health of two mangrove forests at the Kakum and Pra Estuaries in Ghana.

Socioeconomic characteristics were assessed for 136 of mangrove resource users made up of 54 % females and 46 % males in ten communities surrounding the Kakum and Pra mangrove forests through field surveys. These inhabitants depended heavily on the mangrove forests for fuel wood, poles for construction, crabs, periwinkles (*Tympanotonus* sp.) and tilapia as sources of protein.

Mangrove cover change analysis was done with remotely sensed data. The results of analysis showed that the mangrove cover at Kakum had reduced from 68.8 3ha in 2005 to 40.21 ha in 2017 (41.58% loss), while mangrove cover at Pra estuary had increased from 574.10 ha in 2005 to 646.10 ha in 2017 (12.54 % gain). However, almost all the respondents from the two mangrove areas, that is, 98 -100 % indicated that the mangrove cover had reduced considerably within the last decade.

A total area of 10,000 m^2 (1 ha) within each mangrove was also sampled for the inventory of plant species, ecological studies, litter production and soil analyses. Five mangrove species, black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and three species of red mangrove (*Rhizophora racemosa*, *R. mangle* and *R. harrisonii*) were encountered at Kakum Estuary while only three – *A. germinans, L. racemosa* and *R. racemosa* were encountered at Pra Estuary. *Avicennia* was the most dominant mangrove species at the Kakum mangrove forest, whereas at Pra mangrove forest, the three mangroves species exhibited codominance, where the individuals of the three species were relatively fairly distributed. It was established that the two mangrove forests were moderately dense.

More than 90 % of the mangrove species at both mangrove forests were small and generally less than 5cm in diameter. Also, only few individuals of the mangrove species encountered were above 6 m height.

Litterfall varied significantly between the two mangrove forests and within the sampling months. The rates of annual litter production were 959.96 g m^{-2} y^{-1} (9.60 t ha^{-1} y^{-1}) and 1071.51 g m^{-2} y^{-1} (10.72 t ha^{-1} y^{-1}) respectively for the Kakum and Pra mangrove forests.

The following physico-chemical parameters, temperature, salinity, conductivity, DO, pH, turbidity and TDS of the estuary water were measured at different locations close to the mangrove forests. Apart from turbidity and conductivity, no significant differences were observed in the other parameters between the two estuaries. Based on the PCA, the pH, DO and TDS were the determinants of water quality indices for both estuaries. The respective indices for Kakum and Pra estuaries were 0.06 and 0.05, implying moderate water quality.

Three soil physico-chemical parameters, pH, salinity and conductivity were measured and soil salinity and pH varied significantly between the two mangrove forests. Sediment analyses also showed phosphorus concentrations differed significantly between the two mangrove forests. Apart from potassium, which recorded high concentrations, the rest of the nutrients – carbon, nitrogen and phosphorus were low in concentrations. Three sediment parameters each including salinity, potassium and phosphorus for the Kakum mangrove as well as pH, organic carbon and phosphorus for the Pra mangrove were the determinants of the sediment quality. Both estuaries had an index of -0.01 each, indicating moderate water quality.

In terms of heavy metal contamination, there was low heavy metal contamination in both mangrove forests except for Hg which was above the acceptable limit. Risk potential of individual heavy metal decreased in the sequence: Hg>As>Zn at both mangrove forests, implying that Hg posed the highest ecological risk among all three heavy metals analysed. Accordingly, Hg contributed to more than 96 % of total ecological risk indices in both mangrove forests. On a whole, however, ecological risk posed to the mangrove forests was low, although some sampling stations were at higher risk.

Furthermore, the health of mangrove forests in the Kakum and Pra estuaries was assessed using the following ten indicators: tree density, DBH, tree height, species richness, litter production, sediment quality (nutrient and physico-chemical parameters), ecological health risk (heavy metal contamination), estuarine water quality, mangrove cover change and human pressures. The Mangrove health index of the Kakum mangrove forest was 175, and this indicated bad ecological health. The Pra mangrove forest had an index of 195, implying moderate ecological health status.

6.2 Conclusions

Based on the results of this study, it can be concluded that mangrove resources serve as one of the main economic survival bases of the inhabitants in the coastal communities neighbouring the Kakum and Pra estuaries.

Mangrove forest cover at Kakum Estuary reduced by about 42 % from 2005 to 2017, whereas the mangrove cover at the Pra Estuary increased by about 13 % within the same period.

Five and three true mangrove species were encountered and inventoried at the Kakum and Pra mangrove forests respectively. This confirms the existence of five true mangrove species in Ghana. The mangrove species in both mangrove forests were of low structural development, in terms of size and height. The rates of annual litter production in both mangrove forests were moderate and were within the globally estimated range.

The estuary water, as well as the mangrove sediments were of moderate quality, with low ecological risk from heavy metal contamination.

Overall, it can be stated that the health of the Kakum mangrove forest was bad while the Pra mangrove forest was moderately healthy.

6.3 Recommendations

With the current rapid degradation of coastal ecosystems, particularly mangrove forests, continual monitoring and evaluation of the socio-ecological characteristics of the mangrove forests are necessary for their sustainability. In line with this, the following are recommended:

i. This research should be replicated in other mangrove forests by researchers and if possible, by Forestry Commission of Ghana, in order to ascertain the health of these ecosystems. This would also contribute to the establishment of a national database on mangrove ecosystems in Ghana.

ii. Coastal inhabitants depend greatly on these mangrove resources for their livelihoods. Government agency and NGOs should therefore necessarily, provide alternative livelihoods to these mangrove harvesters to help reduce pressure on the mangrove resources.

iii. The reforested area at the Pra mangrove area helped to increase the mangrove area to some extent. The reforestation should be revisited and extended particularly to the locations with high proliferation of invasive plants at the Pra mangrove area to help improve the health of the mangrove forest. Furthermore, reforestation strategies should be put in place at the Kakum mangrove area as well, to prevent total collapse of this most diverse mangrove ecosystem in Ghana. These will in turn help to achieve the sustainable development in the coastal areas for long term benefits.

iv. In addition, there is a need to consider participatory approaches, involving local populations, scientists, other researchers and both governmental and non-governmental environmental agencies, to develop enhanced conservation management towards sustainability of the mangrove ecosystems.

v. Furthermore, in order to find means to ensure the long term sustainability of socio-ecological system in these coastal areas, there should be ‘Extractive Reserve’- mainly the establishment of a protected area for sustainable use based on rational exploitation of mangrove resources. This should be done by government in collaboration with local people.

vi. Finally, the establishment of ‘Mangrove Parks’ for recreational ecotourism could provide sustainable income for local dwellers to support conservation as against exploitation.

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APPENDICES

Appendix A: Interview Guide for Social Survey

UNIVERSITY OF CAPE COAST

DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES

INTERVIEW GUIDE FOR KAKUM AND PRA ESTUARIES' MANGROVE HEALTH PROJECT

This questionnaire is designed to evaluate the views of the mangrove dependent communities on the mangrove forest ecosystems at Kakum and Pra estuaries. You are assured that your response shall be used for the said purpose and your confidentiality is paramount to the researcher.

Serial Number:……………………… Date:……………….

Community:………………………….

Contact Information……………………

SECTION A: DEMOGRAPHIC INFORMATION

1. Gender:	2. Age:
3. Place of origin:	4. Household size:
5. Educational qualification:	6. Period of stay:
7. Main Occupation:	8. Part-time Occupation:

SECTION B: ECOSYSTEM SERVICES

I. Direct Values				
Resources	No. of trees per trip	Trip per week	Market price	Commercial or subsistence
1. Forest resources/s you derive from the mangrove forest				
Timber/poles				
Fuel wood/ Charcoal				
Fodder				
Thatch /Traps				
Other/s				
2. **Fish resources**				
Periwinkles				
Crabs				
Fishes (sp. name)				
Oysters				
Birds				
Other/s				

Appendix A *continued*

II Indirect Values

3.	**Regulating services**	Which regulating services are derived from the mangrove forest?	Climate regulation	
			Flood protection	
			Erosion control	
			Pollution control	
			Diseases control	
			Other/s	
4.	**Supporting services**	Which supporting services are derived from the mangrove forest?	Nutrient cycling	
			Nursery ground	
			Nesting ground or migratory site for birds	
			Other/s	
5.	**Cultural values**	Which cultural services /values are derived from the mangrove forest?	Recreational	
			Spiritual	
			Aesthetic	
			Other/s	

SECTION C: MANGROVE COVER CHANGE

6	In your view, has there been a change in the status or extent of the mangrove forest in your area?		No
			Yes
7	If Yes, indicate the nature of change	Increase in extent	
		Decrease in extent	
8	For how long have you noticed the change/s?		
9	What do you think might have caused the change/s in the status?		

SECTION D: OTHER ISSUES AND ALTERNATIVE USES

10	Do you experience any health problem related to the mangrove?		No
			Yes
11	If yes, specify		
12	Has there been any conflict between this community and another over the mangrove resource?		No
			Yes
13	If yes, give details		
14	Instead of reserving the mangrove forest, do you think it should rather be converted into other uses?		No
			Yes
15	If yes, what alternate use/s will you prefer?		
16	If no **Q14**, why do you oppose alternative use/s?		

Appendix B: Details of Mangrove Health Index Assessment

Indicators	Category	Rank / Score (Value)		Weight (%)
		Kakum	Pra	
Diameter at Breast Height (cm)	3) High = > 15.6 2) Intermediate = 4.5 - 14.8 1) Low = > 4.5 (Pellegrini et al , 2009)	1 (3.21 ± 0.02)	1 (4.14 ± 0.01)	15
Ecological risk	3) Low risk = ERI < 150 2) Moderate risk = 150 ≤ ERI <300 1) High/Very high risk=300≤ ERI ≥ 600 (Hakanson, 1980)	3 (75.56)	3 (86.61)	5
Water quality (Estuary)	5) Excellent = WQI > 1.5 4) Good = 0.5 ≤ WQI≤1.5 3) Moderate = - 0.5 WQI ≤ 0.5 2) Bad = - 1.5 QQI ≤ - 0.5 1) Worst = WQI < 1.5 (Ibrahim et al., 2019)	3 (0.06)	3 (0.05)	5
Human Pressures	3) Low human activities 2) Moderate human activities 1) High human activities	1	1	5
Litter production (t ha-1y-1)	3) High litterfall= ≥ 13.10; 2) Moderate litterfall = 9.35 - 13.09 1) Low litterfall = < 9.35	2 (9.60)	2 (10.72)	15
Mangrove cover change	3) Increase; 2) Same; 1) Decrease	1	3	15
Sediment quality	5) Excellent = SQI > 1.5 4) Good = 0.5 ≤ SQI ≤ 1.5 3) Moderate = -0.5 SQI ≤ 0.5 2) Bad = - 1.5 SQI ≤ - 0.5 1) Worst = SQI < 1.5 (Ibrahim et al., 2019)	3 (-0.01)	3 (-0.01)	5
Species richness	3) High = 5 species 2) Moderate = 3 species 1) Low = less than 3 species	3 (5)	2 (3)	5
Tree density (inds/ha)	3) Dense or High = >10,000 2) Moderate = 1,000 - 10,000 1) Low/sparse = < 1000 (Hoppe-Speer et al., 2015)	2 (5,361)	2 (6,945)	15
Tree height (m)	3) High = >11.8 2) Intermediate = 5.7 - 11.7 1) Low = < 5.7 (Pellegrini et al., 2009)	1 (3.32 ± 0.02)	1 (3.43 ± 0.04)	15

*Value refers to the result of the current study

Appendix C: ANOVA on litter production

Appendix C1: One way ANOVA for litter fall by Location

ONEWAY Leaves Flowers Fruit/Prop Twig Total BY Location

		Sum of Squares	Df	Mean Square	F	Sig.
Leaves	Between Groups	52.764	1	52.764	30.065	.000
	Within Groups	1470.689	838	1.755		
	Total	1523.453	839			
Flowers	Between Groups	3.765	1	3.765	30.310	.000
	Within Groups	104.094	838	.124		
	Total	107.859	839			
Fruit/Prop	Between Groups	.022	1	.022	.042	.838
	Within Groups	434.964	838	.519		
	Total	434.986	839			
Twig	Between Groups	.001	1	.001	.075	.785
	Within Groups	6.259	838	.007		
	Total	6.260	839			
Total	Between Groups	27.034	1	27.034	11.606	.001
	Within Groups	1951.932	838	2.329		
	Total	1978.966	839			

Appendix C3: One way ANOVA for litter fall, nutrients and climatic factors by Month

ONEWAY Leaves Flowers Fruit/Prop Twig Total Temp R.H Rainfall Wind_Speed BY Month /MISSING ANALYSIS.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Leaves	Between Groups	149.632	14	10.688	6.418	.000
	Within Groups	1373.821	825	1.665		
	Total	1523.453	839			
Flowers	Between Groups	6.327	14	.452	3.672	.000
	Within Groups	101.532	825	.123		
	Total	107.859	839			
Fruit/Prop	Between Groups	27.537	14	1.967	3.983	.000
	Within Groups	407.449	825	.494		
	Total	434.986	839			
Twig	Between Groups	.630	14	.045	6.590	.000
	Within Groups	5.630	825	.007		
	Total	6.260	839			
Total	Between Groups	132.939	14	9.496	4.244	.000
	Within Groups	1846.027	825	2.238		
	Total	1978.966	839			
Temp	Between Groups	1065.176	14	76.084	3832.070	.000
	Within Groups	16.380	825	.020		
	Total	1081.556	839			
R.H	Between Groups	4624.256	14	330.304	239.709	.000
	Within Groups	1136.800	825	1.378		
	Total	5761.056	839			
Rainfall	Between Groups	3157286.629	14	225520.474	142.851	.000
	Within Groups	1302438.560	825	1578.713		
	Total	4459725.189	839			
Wind Speed	Between Groups	1562.307	14	111.593	30.487	.000
	Within Groups	3019.800	825	3.660		
	Total	4582.107	839			

Appendix D: Correlations between litter production and factors

Appendix D1: Correlations of Litter with environmental factors at Kakum mangrove forest

	Litter	Temp	R.H	Rainfall	Windspeed
Litter	1				
Temp	0.034	1			
R.H	-0.132**	-0.909**	1		
Rainfall	-0.221**	0.011	0.203**	1	
Wind speed	0.129**	0.229**	-0.356**	-0.463**	1

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

Appendix D2: Correlations of Litter with Environmental factors at Pra mangrove forest

	Total Litter	Temp	R.H	Rainfall	Windspeed
Total Litter	1				
Temp	-0.176**	1			
R.H	-0.169**	-0.805**	1		
Rainfall	-0.096*	0.181**	0.029	1	
Windspeed	0.019	-0.038	0.125*	0.041	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Appendix D3: Correlations of Litter with DBH and Height at Kakum mangrove forest

	DBH	Height	Litter
DBH	1		
Height	0.387**	1	
Litter	0.020	-0.010	1

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

Appendix D4: Correlations of Litter with DBH and Height at Pra mangrove forest

	DBH	Height	Litter
DBH	1		
Height	0.346**	1	
Litter	-0.007	-0.008	1

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

Appendix D5: Correlations between Litter and Nutrients at Kakum mangrove forest

	Total Litter	C	N	P	K
Litter	1				
C	-0.047	1			
N	0.159**	0.418**	1		
P	-0.406**	-0.196**	-0.340**	1	
K	0.168**	-0.456**	-0.291**	0.026	1

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

Appendix D6: Correlations between Litter and Nutrients at Pra mangrove forest

	Total	C	N	P	K
Total					
C	1				
N	0.548**	1			
P	-0.143**	-0.156**	1		
K	-0.510**	-0.292**	0.016	1	

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

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix E: ANOVA for physico-chemical parameters of water

Appendix E1: ONEWAY Turbidity pH DO Conductivity TDS Salinity Temperature BY Month for Kakum estuary

		Sum of Squares	df	Mean Square	F	Sig.
Turbidity	Between Groups	86460.472	14	6175.748	84.444	.000
	Within Groups	12067.116	165	73.134		
	Total	98527.588	179			
pH	Between Groups	30.528	14	2.181	50.476	.000
	Within Groups	7.128	165	.043		
	Total	37.655	179			
DO	Between Groups	822.316	14	58.737	69.647	.000
	Within Groups	139.153	165	.843		
	Total	961.469	179			
Conductivity	Between Groups	32060288539.167	14	2290020609.940	184.493	.000
	Within Groups	2048063326.833	165	12412505.011		
	Total	34108351866.000	179			
TDS	Between Groups	16621801449.952	14	1187271532.139	169.203	.000
	Within Groups	1157778619.845	165	7016840.120		
	Total	17779580069.797	179			
Salinity	Between Groups	23948.772	14	1710.627	7.490	.000
	Within Groups	37683.321	165	228.384		
	Total	61632.092	179			
Temperature	Between Groups	1179.474	14	84.248	8.529	.000
	Within Groups	1629.803	165	9.878		
	Total	2809.278	179			

Appendix E2: ONEWAY Turbidity pH DO Conductivity TDS Salinity Temperature BY Month for Pra Estuary

		Sum of Squares	df	Mean Square	F	Sig.
Turbidity	Between Groups	1428843.302	14	102060.236	5.272	.000
	Within Groups	3194450.921	165	19360.309		
	Total	4623294.223	179			
pH	Between Groups	22.368	14	1.598	19.096	.000
	Within Groups	13.806	165	.084		
	Total	36.174	179			
DO	Between Groups	987.792	14	70.557	38.104	.000
	Within Groups	305.525	165	1.852		
	Total	1293.316	179			
Conductivity	Between Groups	24957611118.073	14	1782686508.434	14.672	.000
	Within Groups	20047941815.557	165	121502677.670		
	Total	45005552933.631	179			
TDS	Between Groups	9019337112.960	14	644238365.211	14.055	.000
	Within Groups	7563019587.836	165	45836482.351		
	Total	16582356700.796	179			
Salinity	Between Groups	11124.371	14	794.598	5.410	.000
	Within Groups	24236.359	165	146.887		
	Total	35360.731	179			
Temperature	Between Groups	1224.666	14	87.476	8.104	.000
	Within Groups	1780.981	165	10.794		
	Total	3005.647	179			

Appendix E3: ONEWAY Turbidity pH DO Conductivity TDS Salinity Temperature BY Sampling Station for Kakum estuary

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Turbidity	Between Groups	610.588	3	203.529	.366	.778
	Within Groups	97917.000	176	556.347		
	Total	98527.588	179			
pH	Between Groups	1.013	3	.338	1.622	.186
	Within Groups	36.642	176	.208		
	Total	37.655	179			
DO	Between Groups	.642	3	.214	.039	.990
	Within Groups	960.826	176	5.459		
	Total	961.469	179			
Conductivity	Between Groups	515394192.756	3	171798064.252	.900	.442
	Within Groups	33592957673.244	176	190869077.689		
	Total	34108351866.000	179			
TDS	Between Groups	338790900.963	3	112930300.321	1.140	.335
	Within Groups	17440789168.834	176	99095393.005		
	Total	17779580069.797	179			
Salinity	Between Groups	3529.647	3	1176.549	3.564	.015
	Within Groups	58102.445	176	330.128		
	Total	61632.092	179			
Temperature	Between Groups	45.497	3	15.166	.966	.410
	Within Groups	2763.781	176	15.703		
	Total	2809.278	179			

Appendix E4: ONEWAY Turbidity pH DO Conductivity TDS Salinity Temperature BY Sampling Station for Pra estuary

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Turbidity	Between Groups	2119590.743	3	706530.248	49.666	.000
	Within Groups	2503703.480	176	14225.588		
	Total	4623294.223	179			
pH	Between Groups	1.991	3	.664	3.417	.019
	Within Groups	34.183	176	.194		
	Total	36.174	179			
DO	Between Groups	29.496	3	9.832	1.369	.254
	Within Groups	1263.820	176	7.181		
	Total	1293.316	179			
Conductivity	Between Groups	10105173269.796	3	3368391089.932	16.987	.000
	Within Groups	34900379663.835	176	198297611.726		
	Total	45005552933.631	179			
TDS	Between Groups	4058356811.719	3	1352785603.906	19.011	.000
	Within Groups	12523999889.077	176	71159090.279		
	Total	16582356700.796	179			
Salinity	Between Groups	6796.759	3	2265.586	13.960	.000
	Within Groups	28563.972	176	162.295		
	Total	35360.731	179			
Temperature	Between Groups	143.888	3	47.963	2.950	.034
	Within Groups	2861.759	176	16.260		
	Total	3005.647	179			

Appendix F: PCA for physico-chemical parameters of water

Appendix F1: Total Variance Explained by estuarine water at Kakum

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.553	50.763	50.763	3.553	50.763	50.763	3.305	47.215	47.215
2	1.414	20.202	70.965	1.414	20.202	70.965	1.425	20.351	67.566
3	1.086	15.510	86.475	1.086	15.510	86.475	1.324	18.909	86.475
4	.421	6.020	92.495						
5	.282	4.031	96.526						
6	.230	3.286	99.812						
7	.013	.188	100.000						

Extraction Method: Principal Component Analysis.

Appendix F2: Total Variance Explained by estuarine water at Pra

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.450	49.290	49.290	3.450	49.290	49.290	3.283	46.894	46.894
2	1.317	18.819	68.109	1.317	18.819	68.109	1.425	20.352	67.246
3	1.296	18.520	86.629	1.296	18.520	86.629	1.357	19.383	86.629
4	.471	6.730	93.358						
5	.319	4.550	97.909						
6	.134	1.916	99.825						
7	.012	.175	100.000						

Extraction Method: Principal Component Analysis.

Appendix G: ANOVA for soil physico-chemical parameters

Appendix G1: ONEWAY pH_Soil Salinity_Soil EC_Soil pH BY Month for Kakum

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH_Soil	Between Groups	47.176	14	3.370	4.967	.000
	Within Groups	111.943	165	.678		
	Total	159.119	179			
Salinity_Soil	Between Groups	619.367	14	44.241	7.555	.000
	Within Groups	966.260	165	5.856		
	Total	1585.627	179			
EC_Soil	Between Groups	123429360.195	14	8816382.871	.812	.655
	Within Groups	1791321259.171	165	10856492.480		
	Total	1914750619.366	179			

Appendix G2: ONEWAY pH_Soil Salinity_Soil EC_Soil pH BY Month for Pra

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH_Soil	Between Groups	110.740	14	7.910	12.843	.000
	Within Groups	101.625	165	.616		
	Total	212.364	179			
Salinty_Soil	Between Groups	405.139	14	28.938	10.967	.000
	Within Groups	435.391	165	2.639		
	Total	840.529	179			
EC_Soil	Between Groups	217131143.190	14	15509367.371	2.342	.006
	Within Groups	1092751652.778	165	6622737.290		
	Total	1309882795.968	179			

Appendix G3: ONEWAY EC_Soil Salinity_Soil pH_Soil BY Study plots for Kakum

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
EC_Soil	Between Groups	508168005.503	3	169389335.168	21.195	.000
	Within Groups	1406582613.863	176	7991946.670		
	Total	1914750619.366	179			
Salinity_Soil	Between Groups	362.517	3	120.839	17.388	.000
	Within Groups	1223.110	176	6.949		
	Total	1585.627	179			
pH_Soil	Between Groups	53.036	3	17.679	29.330	.000
	Within Groups	106.083	176	.603		
	Total	159.119	179			

Appendix G4: ONEWAY pH_Soil Salinity_Soil EC_Soil pH BY Study plot for Pra

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH_Soil	Between Groups	41.485	3	13.828	14.243	.000
	Within Groups	170.880	176	.971		
	Total	212.364	179			
Salinty_Soil	Between Groups	161.824	3	53.941	13.988	.000
	Within Groups	678.705	176	3.856		
	Total	840.529	179			
EC_Soil	Between Groups	211943089.234	3	70647696.411	11.325	.000
	Within Groups	1097939706.734	176	6238293.788		
	Total	1309882795.968	179			

Appendix F: Correlations between water and soil physico-chemical parameters

Appendix F1: Correlations between Soil and Water physico-chemical parameters at Kakum

	pH_Soil	Saly._Soil	EC_Soil	pH_Water	Sal._Water	EC_Water
pH_Soil	1					
Salinity_Soil	-0.422**	1				
EC_Soil	0.141	-0.233**	1			
pH_Water	-0.108	0.151*	-0.128	1		
Salinity_Water	0.002	0.263**	0.068	0.074	1	
EC_Water	0.147*	0.192**	0.139	0.161*	0.161*	1

Appendix F2: Correlations among Soil and Water physico-chemical parameters at Pra

	pH_Soil	Salinity_Soil	EC_Soil	pH_Water	Salinit_Water	EC_Water
pH_Soil	1					
Salinity_Soil	-0.275**	1				
EC_Soil	-0.064	0.346**	1			
pH_Water	0.250**	-0.281**	-0.095	1		
Salinity_Water	0.398**	0.257**	0.407**	0.021	1	
EC_Water	0.310**	0.148*	0.319**	0.130	0.579**	1

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

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix I: ANOVA for Soil Nutrients and Heavy Metals

Appendix I1: ONEWAY pH As Hg Zn C N P K BY Quarter for Kakum

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
As	Between Groups	.962	5	.192	3.476	.005
	Within Groups	9.629	174	.055		
	Total	10.590	179			
Hg	Between Groups	.106	5	.021	.673	.645
	Within Groups	5.477	174	.031		
	Total	5.583	179			
Zn	Between Groups	28.323	5	5.665	4.533	.001
	Within Groups	217.429	174	1.250		
	Total	245.752	179			
C	Between Groups	20.149	5	4.030	46.786	.000
	Within Groups	14.987	174	.086		
	Total	35.137	179			
N	Between Groups	3875.599	5	775.120	19.506	.000
	Within Groups	6914.318	174	39.737		
	Total	10789.917	179			
P	Between Groups	1.944	5	.389	3.271	.008
	Within Groups	20.687	174	.119		
	Total	22.631	179			
K	Between Groups	11273.717	5	2254.743	12.929	.000
	Within Groups	30344.873	174	174.396		
	Total	41618.590	179			

Appendix I2: ONEWAY As Hg Zn C N P K BY Quarter for Pra

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
As	Between Groups	48.224	5	9.645	34.673	.000
	Within Groups	48.401	174	.278		
	Total	96.625	179			
Hg	Between Groups	.344	5	.069	.596	.703
	Within Groups	20.094	174	.115		
	Total	20.438	179			
Zn	Between Groups	24.956	5	4.991	20.128	.000
	Within Groups	43.147	174	.248		
	Total	68.103	179			
C	Between Groups	70.023	5	14.005	13.578	.000
	Within Groups	179.461	174	1.031		
	Total	249.483	179			
N	Between Groups	5336.853	5	1067.371	54.781	.000
	Within Groups	3390.257	174	19.484		
	Total	8727.110	179			
P	Between Groups	.625	5	.125	6.050	.000
	Within Groups	3.593	174	.021		
	Total	4.218	179			
K	Between Groups	35346.865	5	7069.373	40.036	.000
	Within Groups	30724.113	174	176.575		
	Total	66070.977	179			

Appendix I3: ONEWAY As Hg Zn C N P K BY Study plot for Kakum

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
As	Between Groups	6.121	3	2.040	80.333	.000
	Within Groups	4.470	176	.025		
	Total	10.590	179			
Hg	Between Groups	2.466	3	.822	46.420	.000
	Within Groups	3.117	176	.018		
	Total	5.583	179			
Zn	Between Groups	35.841	3	11.947	10.017	.000
	Within Groups	209.911	176	1.193		
	Total	245.752	179			
C	Between Groups	1.221	3	.407	2.111	.100
	Within Groups	33.916	176	.193		
	Total	35.137	179			
N	Between Groups	2804.521	3	934.840	20.604	.000
	Within Groups	7985.396	176	45.372		
	Total	10789.917	179			
P	Between Groups	8.962	3	2.987	38.463	.000
	Within Groups	13.669	176	.078		
	Total	22.631	179			
K	Between Groups	2315.523	3	771.841	3.456	.018
	Within Groups	39303.066	176	223.313		
	Total	41618.589	179			

Appendix I4: ONEWAY As Hg Zn C N P K BY Study plot for Pra

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
As	Between Groups	1.707	3	.569	1.055	.370
	Within Groups	94.918	176	.539		
	Total	96.625	179			
Hg	Between Groups	11.096	3	3.699	69.682	.000
	Within Groups	9.342	176	.053		
	Total	20.438	179			
Zn	Between Groups	2.062	3	.687	1.832	.143
	Within Groups	66.041	176	.375		
	Total	68.103	179			
C	Between Groups	12.282	3	4.094	3.038	.031
	Within Groups	237.202	176	1.348		
	Total	249.483	179			
N	Between Groups	125.134	3	41.711	.853	.466
	Within Groups	8601.976	176	48.875		
	Total	8727.110	179			
P	Between Groups	.879	3	.293	15.446	.000
	Within Groups	3.339	176	.019		
	Total	4.218	179			
K	Between Groups	693.144	3	231.048	.622	.602
	Within Groups	65377.834	176	371.465		
	Total	66070.977	179			

Appendix J: PCA for Soil Physico-chemical Parameters and Nutrients

Appendix J1: Total Variance Explained at Kakum

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.623	37.465	37.465	2.623	37.465	37.465	2.165	30.932	30.932
2	1.346	19.227	56.692	1.346	19.227	56.692	1.426	20.374	51.306
3	1.048	14.968	71.660	1.048	14.968	71.660	1.425	20.355	71.660
4	.773	11.042	82.702						
5	.624	8.920	91.623						
6	.379	5.412	97.035						
7	.208	2.965	100.000						

Appendix J2: Total Variance Explained at Pra

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.048	29.257	29.257	2.048	29.257	29.257	2.019	28.850	28.850
2	1.288	18.400	47.657	1.288	18.400	47.657	1.290	18.431	47.281
3	1.088	15.547	63.205	1.088	15.547	63.205	1.115	15.924	63.205
4	.981	14.008	77.213						
5	.724	10.336	87.550						
6	.529	7.561	95.110						
7	.342	4.890	100.000						

Extraction Method: Principal Component Analysis.

Appendix K: Experts' Questionnaire

Dear Participant,

Thank you for accepting to participate in this survey.

My name is Gertrude L.A. Dali, a PhD (Integrated Coastal Zone Management) student of Department of Fisheries and Aquatic Sciences, University of Cape Coast, Ghana.

I am working on a PhD research entitled "Assessment of the Health of Mangrove Forests in the Kakum and Pra Estuaries in Ghana". As part of the research, I am employing Multi Criteria Decision Making (MCDM) approach in assessing the mangrove health. I am using expert view or judgement to prioritise the criteria or parameters for evaluating the health of the two mangrove forests. This survey is therefore, designed to seek scientific opinion from experts with in-depth knowledge on coastal especially mangrove ecosystems.

In MCDM approach, the various important parameters are ranked or weighted based on their relative impact on the health of mangroves. The sum of the weights of all identified factors is considered as 100% and the weights are thus assigned accordingly, based on the relative importance (in terms of ecological contribution) of that particular parameter on the health of mangroves. If all or some of the parameters have equal importance in your view, you may assign same weight to each parameter.

The questionnaire is in two parts: Part 1- Background information of respondent; and Part 2 – Assessment of mangrove health indicators.

MULTI CRITERIA DECISION MAKING QUESTIONNAIRE

Part 1: **Background of respondents** (*Please tick as appropriate*)

1.Sex	Male [ ] Female [ ]
2. Where do you work?	University/Research Institution [ ] Forestry Commission [ ] NGO/CSO [ ] MMDAs [ ]
3. What is your highest level of education?	Master's degree [ ] Doctoral degree [ ]
4. How long have you been working in mangrove related field?	

Part 2: Weighting of mangrove health indicators

Kindly weight these identified parameters based on the importance of individual parameters for mangrove health assessment.

Mangrove health indicators	Weight (%)
Tree density (inds/ha)	
Species richness	
Tree height (m)	
Diameter at Breast Height (cm)	
Litter production (t $ha^{-1}y^{-1}$)	
Sediment quality	
Ecological risk	
Water (estuarine) quality	
Mangrove cover change	
Human Pressures	
Total	

*****Definition of indicators as applies to this study:**

Tree density: Number of individuals of trees within a sampled area.

Species richness: Number of different species found in an ecological community.

Tree height: Vertical distance between the base of the tree and the apex of the tree.

Diameter at Breast Height: Diameter of the trunk of a standing tree measured at 1.3 m above the ground.

Litter production: Shedding of vegetative and reproductive structures of mangroves over, as a measure of productivity of the ecosystem.

Sediment quality: Quality of mangrove sediment using nutrient content and physico-chemical parameters of the sediment.

Ecological risk: The risks posed by the presence of heavy metals in mangrove environment.

Water (estuarine) quality: Quality of the estuarine water based on its physico-chemical parameters.

Mangrove cover change: Change in mangrove area or extent over time.

Human pressures: Impact of human activities such as logging on the mangrove ecosystems.