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CLIMATE CHANGE AND BLUE CARBON: ABOVE-GROUND CARBON STOCK OF MANGROVES IN THE LOWER VOLTA AREA

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DECLARATION

I hereby declare that I have under supervision, undertaken this study herein submitted for the award of a Master of Philosophy in Environmental Science. This study is my own production and has not been presented anywhere for another degree whatsoever. The thesis report has been prepared and presented in accordance with academic rules and ethical conduct. I have fully cited, referenced and acknowledged all material and results that are not original to this work

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DEDICATION

This work is dedicated to my mother, Elizabeth.

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ABSTRACT

Mangroves and other blue carbon systems are under high pressure due to population pressure and coastal development. The continuous degradation of mangroves leads to the loss of the carbon stocks stored in the mangrove ecosystem. In this study, GIS based analysis using Landsat images and allometric equations were used to estimate the above-ground carbon stock of mangroves in the Lower Volta area in Ghana. The Landsat images were classified to obtain the mangrove area. An ASTER GDEM covering the mangrove was calibrated to obtain mangrove heights and the above-biomass and above-ground carbon stock was estimated using a global allometric equation. The study identified socio-economic factors that influenced mangrove exploitation as well as assessed the willingness of local residents to use Liquefied Petroleum Gas (LPG) as an alternative energy source. The carbon stock for the study area in 2014 was estimated to be 269,379.5 Mg and the carbon stock per hectare was found to be 50.102 Mg. A time series analysis of changes in carbon stock revealed that the study area has lost 161,428.65 Mg of its carbon stock between 1991 and 2014.The results indicated that increased income, commercial supply of fuel wood and supply of fuel wood for domestic use were significant factors that influenced the exploitation of mangroves. The local residents preferred mangroves as an energy source and were less likely to use LPG as an alternative due to price and safety considerations. It is recommended that all major stakeholders contribute towards the effective management and protection of the mangrove resource.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASTER	Advanced Space borne Thermal Emission and Reflectance
CDM	Clean Development Mechanisms
DBH	Diameter at breast height
DEM	Digital Elevation Model
FAO	Food and Agriculture Organisation
GDEM	Global Digital Elevation Model
GIS	Geographical Information Systems
GHG	Green House Gas
GLAS	Geoscience Laser Altimeter System
ICESAT	Ice Cloud and Land Elevation Satellite
IPCC	Inter-governmental Panel on Climate Change
ISME	International Society for Mangrove Ecosystems
ISODATA	Iterative Self-organizing Data Analysis
ITTO	International Tropical Timber Organisation
LPG	Liquefied Petroleum Gas
NASA	National Aeronautics and Space Administration
PES	Payment for Ecosystem Services
PWC	Price Waterhouse and Coopers
REDD	Reduced Emissions from Deforestation and Degradation
SRTM	Shutter Radar Topography Mission

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CHAPTER ONE

1.0 BACKGROUND

Mangroves refer to a type of tropical vegetation positioned at the interface between land and sea. They are found along the coast and estuaries throughout the tropics and subtropical regions of the world and are uniquely adapted to thriving in soils with high salinities (Joshi & Ghose, 2003). Although mangroves account for approximately 1 % of the total area of tropical forest they are among the most carbon-rich forest in the tropics containing on average of 1023 Mg carbon per hectare (Spalding *et al*., 2010; Donato *et al*., 2011). With the effects of climate change on the environment becoming more apparent, there is an urgent need for significant reductions in greenhouse gases emissions. In line with such measures is the need to properly manage habitats such as mangroves, which act as critical carbon sinks in order to reduce their potential of becoming sources of greenhouse gas emissions to the atmosphere (Smith & Gattuso, 2009). Mangroves are globally being lost at rates 3-5 times greater than average rates of forest loss (Jan-Willem *et al*., 2014) and estimates of carbon emissions resulting from mangrove loss are uncertain owing part to a lack of broad-scale data on carbon stocks in these ecosystem (Smith & Gattuso, 2009). The potential economic impacts due to the release of carbon to the atmosphere are felt globally. These impacts are often seen in the effects of associated increase in drought, sea level and frequency of extreme weather events which are often acute in developing countries (Tol, 2009). In order to explicitly address the role of blue carbon systems in climate change mitigation and human well-being, particularly through policy and implementation frameworks, there is the need to create carbon inventories by measuring the carbon stock of these coastal ecosystems.

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In Ghana, mangroves are mainly found along the fringes of lagoons on the western coast and bordering the lower reaches and deltaic areas of the Volta River. They are best developed along a stretch on the west coast between Cote d'Ivoire and Cape Three Points (FAO, 2005). Mangroves are very important because they provide ecosystem services including protection of coastlines from storms, floods and erosion; providing nursery grounds for juvenile fish, crabs and molluscs as well as supporting livelihoods by providing goods such as wood fuel, timber and non-timber forest products (Alongi, 2002). A wide variety of organisms depend on the habitat mangroves provide, these include hundreds of migratory birds and several endangered species (RAMSAR-MAVA-UNEP, 2012) According to Gordon *et al.* (2009), Ghana's estimated value of mangrove related harvesting and contribution to marine fisheries is well over $ 6,000,000 per year. This estimate excludes other ecosystem services such as coastline protection and the provision of nesting sites for migratory birds. The inclusion of these and other ecosystem services would bring to proper perspective, the ecological and economic significance of mangroves.

Despite these important values, mangroves continue to face degradation with increasing population pressures and environmental variability serving as major drivers especially in developing countries. In Ghana, mangroves are threatened by population growth, hydrological and land use change as well as land based sources of pollution. The country's mangrove area fell by 24 % between 1980 and 2006; from 181 km^2 to 137 km^2 (Corcoran *et al.*, 2007). Such continuous degradation of mangroves increases the risk of stored carbon that has been accumulating in place for thousands of years to be released into the atmosphere and result in increased CO_2 concentration (Kauffman *et al.*, 2014). An area becomes a carbon sink when it is able to store more carbon that

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it releases and conversely a carbon source is an area which releases more carbon than it stores. An area functions as either a sink or a source depending on the balance between the rate of photosynthesis and the combined rate of respiration and burning (Trumper *et al.*, 2009).

The role of mangroves as efficient carbon sinks has been recognised more in recent times and they are incorporated into climate change mitigation efforts. These mitigation efforts focus on the reduction of CO_2 and other GHGs through the conservation and restoration of natural systems such as mangroves. For example, the International Panel on Climate Change (IPCC) has predicted that in order to mitigate about 12-15% of CO_2 emissions from fossil fuel by 2050, there is the need for a global program that involves the protection, conservation and enhancement of tropical forests, such as mangroves, in order to sequester 60-87 Gt of atmospheric carbon for that period (Trumper *et al.*, 2009). Mangrove forests, salt-mashes and seagrass meadows have been reported to be amongst the world's most intense carbon sinks (Nellemann *et al.*, 2009).

The loss of mangroves not only results in the loss of their functioning as carbon sinks but also results in an increased potential to become huge sources of carbon emissions when degraded. For example, the conversion of one hectare of mangrove to shrimp farming can release about 330 Mt CO_2 per hectare per year (Yee, 2010). Experts estimate that emissions from the degradation of mangroves constitute as high as 10-20% of total emissions from deforestation globally (Donato *et al.*, 2011; Jan-Willem *et al.*, 2014). This realization has led to financial mechanism programmes and incentives to stimulate conservation such as Reduced Emissions from Deforestation and Degradation (REDD) (Cohen *et al.*, 2013). REDD+, which is an extension of the

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REDD, goes beyond deforestation and forest degradation and considers other related concerns such as the conservation of forest carbon stock, sustainable management of forest and enhancement of forest carbon stocks (Vordzogbe *et al.* 2015) The REDD/REDD+ programme is an effort to assign monetary value to carbon stored in forests. This creates an incentive for developing nations to reduce emissions from forest lands and invest in low-carbon paths to sustainable development (REDD, 2011). This therefore requires developing countries to produce robust estimates of above-ground biomass (Cohen *et al*., 2013).

Blue carbon refers to the carbon stock stored in the world's oceans and coastal ecosystems; mangroves, salt tidal marshes and seagrass meadows. It includes the carbon stored within the soil, the living biomass above-ground (leaves, branches, stems), the living biomass below ground (roots) and the non-living biomass e.g. leaf litter and dead wood (Mcleod *et al*., 2011). Coastal ecosystems store more carbon compared to terrestrial ecosystems especially in the soil. This is because of the limited carbon storage potential in terrestrial soils due to an available supply of oxygen which allows the oxidation of carbon by bacteria resulting in its release back into the atmosphere (Schlesinger *et al.*, 2001). The soil in blue carbon systems is however usually saturated with water, keeping oxygen concentrations very low, this leads to a continual vertical accretion of carbon resulting in a high build-up over time (Chmura *et al.*, 2003). Soils in coastal ecosystems can therefore store carbon for long periods of time (centuries to millennia) compared to those in terrestrial ecosystems which can sequester carbon for decades or centuries at most (Chambers *et al.*, 2001)

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1.1 Problem Statement

Approximately one-third of the world's mangrove forests have been lost over the past 50 years due to anthropogenic activities such as agriculture, aquaculture, tourism, urban development and overexploitation (Alongi, 2002; Coleman *et al*., 2007; Giri *et al*., 2008). About 20% of global greenhouse emissions are from forest degradation and this is more than the entire global transportation sector and second only to the energy sector (REDD, 2011). Because mangroves are able to sequester high amounts of carbon, there is a high risk of such areas becoming a significant source of greenhouse gases when the mangroves are degraded (Alongi, 2002; Pendleton *et al*., 2012).

Ghana's mangroves and for that matter carbon stocks have decreased significantly over the past few decades and continue to diminish at an alarming rate even in Ramsar designated sites (Mensah, J., 2013; Spalding *et al*., 2010). Although there is a wide range of literature on the effects of loss of mangroves on ecosystem services (Ajonina, 2011; Dankwa & Gordon, 2002; FAO, 2005) there is still the need for more work on carbon stocks in coastal ecosystems, especially in Africa and Ghana.

An emerging body of literature recognizes the importance of coastal habitat loss to climate change (Chtmura *et al*., 2003; Duarte *et al*.2005; Nellemann *et al*., 2009). However these researches have focused mainly on the lost carbon sequestration potential overlooking the conversion of standing carbon pools associated with vegetated coastal ecosystems.

In situ measurements of mangrove carbon stock pose a challenge due to the physical environments in which mangroves are found, therefore large-scale field measurements of blue carbon stocks and emissions are rare or non-existent particularly in coastal

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ecosystems in Africa, South America and South-east Asia (Howard *et al*., 2014; Pendleton *et al*., 2012). Soares & Schaeffer-Novelli (2005) state that deriving accurate estimates of biomass are crucially important in determining forest status, modelling the impacts of climate change as well as be an integral component of carbon sequestration estimation.

Blue carbon sinks are said to lose between 0.7-7% of their area annually (Duarte *et al*., 2005; Spalding *et al*., 2010; Waycott *et al*., 2009). Such losses reduce the capacity of such ecosystems to sequester carbon and also have serious implications for human populations that depend on these ecosystems for their food and livelihoods. Pendleton *et al.* (2012) estimates that 0.15-1.02 billion tons of CO_2 are being released annually and result in economic damages of $6-42 billion annually. The human and climate-driven threats to these coastal ecosystems make it imperative that we improve our understanding of how they function as carbon sinks and how they are likely to be affected by future changes. There is also the need for additional mapping of converted, degraded and revegetated blue carbon ecosystems and the quantification of the associated changes in their carbon stock.

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1.2 Justification

Mangroves have been shown to have high above-ground and below-ground biomass, productivity and high rates of carbon sequestration despite their small global area (Donato *et al*., 2011; Komiyama *et al.* 2008; Mcleod *et al*., 2011). Approximately 2000 Mg/ha of carbon are stored in the mangrove ecosystem, one hundred fold more than tropical high forests (PWC, 2015).The understanding of the spatial variations in forest biomass and carbon stocks is therefore important to inform global climate

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change models and developing policies, plans and programmes to mitigate their climate change effects (Grabowski & Chazdon, 2012; Nepstad *et al.* 2011), especially since mangroves are highly threatened, with over a third of the world's mangroves lost through conversion into aquaculture and agriculture (Alongi, 2002).

The mapping of mangrove areas and the estimation of their carbon stocks would prove relevant for databases such as the IPCC Emission Factor Database. It would also provide empirical evidence to show how human activities may serve as a driver of ecosystem degradation as well as their subsequent effect on potential emission rates.

Through the adoption of Clean Development Mechanisms (CDM) under the Kyoto Protocol (IPCC, 2007), developing countries can receive funding as an incentive to maintain their forest resources as carbon sinks based on their carbon credits. Carbon credits however can only be assigned after carbon stocks have been quantified (Mcleod *et al.*, 2011).This kind of knowledge is therefore important to support mangrove inclusion in Payment for Ecosystem Services (PES) schemes such as the REDD+ that offers financial benefits to local communities and governments to better manage their natural resources.

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1.3 Research Questions

1. What is the carbon stock of mangroves in the Lower Volta Basin?

2. Have there been any changes in the mangrove cover in the past 25 years?

3. How have these changes in the mangroves impacted the livelihood of the local people?

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1.4 Aim

- To estimate the above-ground carbon stock of mangroves in the Lower Volta Basin

1.5 Specific Objectives

1. To map out the mangrove area with the study area and determine the land cover features.
2. To estimate the above-ground biomass and carbon stock using allometric equations and determine the changes over the past 25 years
3. To assess the perception of change by the local community in the mangrove area
4. Identify socio-economic factors that drive mangrove exploitation and assess the willingness to use alternative energy sources such as LPG

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mangroves

Mangroves refer to a diverse group of woody plants and ground ferns that grow in inter tidal zone between land and sea along tropical and sub-tropical coastlines of the world. Soils in such areas are often wet, with salinities ranging from brackish to shoreline estuaries (Clough, 2013; Joshi & Ghose, 2003). The term ‘mangrove’ describes both the plant communities as well as the ecosystem as a whole including other plants and animals (Tomlinson, 1994).

Mangroves are distributed globally across 123 countries and territories within the tropical and subtropical regions. Despite this broad spread, approximately 70% are found in 12 countries with Indonesia accounting for 20% (Spalding *et al*., 2010). Their highest in abundance is however found between latitudes 5°N and 5°S (Giri *et al*., 2011). The total mangrove area in Africa is estimated to be 3.2 million hectares representing about 19% of the global coverage (Spalding *et al*., 2010).

In Africa, they are distributed as follows: 63% on the Atlantic coast and 37% on the Indian Ocean and Red Sea coasts. There are 9 species of mangroves in the Indian Ocean coast, 6 species in the Atlantic coast and 4-5 species in the Red Sea coast (Armah *et al*., 2009). Nigeria has the highest mangrove extent in Africa, spanning 653,669 hectares in area (Giri *et al*., 2011).

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2.2 Mangroves in Ghana

Ghana has a total forest area of 81,342 km^2 of which mangroves cover about 140 km^2 (Gordon & Ayivor, 2003). The estuaries of major rivers and lagoons along the coast of southern Ghana possess the characteristics that allow the development and adaptation of mangroves (Akpalu, 2007) thus the mangroves are restricted in area and distributed along the fringes of lagoons on the west coast and bordering the lower reaches and delta of the Volta River (FAO, 2005).

Mangroves in Ghana belong to 3 main genera; *Rhizophora, Avicennia* and *Laguncularia*. The species represented are *Rhizophora racemosa, R. mangle, R. harrisonii, Avicennia germinans* and *Laguncularia racemosa*. They are however often associated with other plant species that include *Conocarpus erectus, Acrostichum aureum, Phoenix reclinata, Sesuvium portulacastrum, Hibiscus tiliaceus, Thespesia populnea, Canavalia rosea, Ipomoea pes-caprae, Dalbergia escastophyllum, Drepanocarpus lunatus, Cardiospermum grandiflorum, Paspalum vagintaum* and sometimes *Terminalia catappa* (Armah *et al*., 2009; Gordon *et al*., 2009).

2.2.1 *Distribution and Structural characteristics*

In the International Tropical Timber Organisation (ITTO) Pre-Project final report by Akpalu (2007), mangroves with relatively high density occurred in the far West and East of the county that is within the Evergreen and Moist Evergreen respectively and the Savanna Ecological Zones, the highest concentration of mangroves in the Savanna zone occurred in the Volta Region, recording an average of 30 trees within a 100m^2 area. High values for parameters such as height and diameter were associated with all 3 ecological zones. The mangroves exhibited an average tree height of 5m above the

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ground level with mature trees reaching heights of above 10m. Mangrove vegetation in the other ecological zones was sparse and the poor height and diameters observed in such zones were attributed to unsustainable harvesting (Akpalu, 2007).

In a study on structural parameters of mangroves by Aheto *et al.* (2011) at Iture in the Central Region, *Rhizophora mangle* were found to be significantly larger in terms of mean height (5.19m), diameter at breast height (3.08cm) and basal area (8.55cm^2) compared with *Avicennia germinans* with mean height of 3.05m; diameter at breast height of 2.86cm; and basal area of 7.90 cm^2 and *Laguncularia racemosa* with mean height of 2.34m, diameter at breast height amounting to 2.42m and basal area of 5.36cm^2. Such structural differences among mangrove species was also reported by Friends of The Nation (2014) in the Anlo beach area where *Rhizophora mangle* was found to be greater than *Avicennia germinans* and *Laguncularia racemosa* in mean height. There were however some differences when it came to other parameters such as diameter at breast height and basal area for which *Laguncularia racemosa* had the highest values when compared with *Avicennia germinans* and *Rhizophora mangle*.

2.3 Adaptations of mangroves

The interface between land and sea is very dynamic and as such the prevailing conditions in such areas are harsh and thus require special adaptation for survival. Mangroves have morphological and physiological adaptations that enable them to tolerate high salt concentrations as well as survive in soils with low oxygen concentrations. For example, Red mangroves, *Rhizophora sp* which are often found in inundated areas prop themselves above the water level with stilt roots and can absorb air through pores (lenticels) in their bark. Black mangroves, *Avicennia sp* have aerial

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roots (pneumatophores) specialized for gaseous exchange as an adaption to survive in anoxic conditions. Other adaptations include mechanisms to actively remove salt such as salt excreting leaves and unique reproductive strategies such as the ability to produce live growing offspring which are naturally buoyant and capable of travelling great distances (Jan-Willem *et al*., 2014)..

2.4 Species Diversity in Mangroves

The location of mangroves at the interface between land and sea make them unique ecosystems that attract a host of species belonging to the terrestrial, freshwater, estuarine and marine environments (Blaber, 2013; Nagelkerken *et al*., 2008). There are other plants occurring within mangrove ecosystems which possess adaptations similar to mangroves and therefore mangrove plants are often classified as either true mangroves or mangrove associates (Tomlinson, 1994). Given their diversity, it is clear that mangroves are an ecological assemblage of very different species with many attributes in common rather than a single taxonomic group (Clough, 2013). There is therefore still no universal agreement on the number of mangrove species worldwide. For example, Saenger (2002) listed 84 mangroves species globally whiles Duke *et al*. (1998) and Spalding *et al*. (2010) list the global mangrove species as 70 and 73 respectively.

The mangrove ecosystem provides different types of habitats. These include the tree canopies, the branches and prop roots (Keith *et al*., 2013). Such habitat offers different types of niches that can be explored within the ecosystem thus making them a home to a wide range of animal species. These include mammals like deers, bats, and monkeys; reptiles including snakes such as the sea snake, mangrove snake and

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white bellied snake, crocodiles such as the Saltwater crocodile and lizards such as the Mangrove monitor and the Rusty Monitor (Hogarth, 1999; Ntyam, 2014).

A diversity of species also exists below the water surface within the mangrove community. The submerged parts of mangroves function as a nursery grounds for a number of fish species, offering them protection and abundant food supply especially during their juvenile stages. The submerged prop roots for example due to their interlocking nature form a habitat for juvenile fish and crustaceans such as shrimps, barnacles, prawns and crabs (Jan-Willem *et al*., 2014). Molluscs such as the Common Mud Whelk and the Mangrove Oyster are often seen in the muddy soil around the base of mangrove trees. Some animal species live primarily in mangroves while others move in and out of the mangroves seasonally or at different stages of their life cycles or even depending on level of the tide (Ntyam, 2014). For example, the fish, *Barramundi* spawns and spends its juvenile phase in creeks found in mangroves (Lamptey & Armah, 2008; Sackey *et al*., 2008)

Many bird species also depend on the mangrove ecosystem for food and shelter. These may be on a regular basis such as the Mangrove Heron, Jabiru and Mangrove Kingfisher which are considered mangrove specialists, or on a more seasonal basis such as the Mangrove honeyeaters which visit mangroves during flowering season for nectar, or the Torresian Imperial Pigeon which inhabits mangroves during breeding season (Ntyam, 2014). A number of migratory bird species rely on mangroves as wintering and roosting sites as they move along the migratory routes. Mangroves also become important refuge grounds during harsh weather conditions such as drought or winter (Jan-Willem *et al.* 2014; Lovelock *et al*., 2005; Sackey *et al*., 1996).

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Mangroves can also be seen as a life-support system without which a number of charismatic and endangered species would go extinct. Some of the critically endangered species supported by mangroves include the Goliath grouper, the Pygmy three-toed sloth and the Sapphire-bellied hummingbird (Jan-Willem *et al*., 2014)

2.5 Mangrove Ecosystem Services

Ecosystem services refer to the range of benefits (goods and services) derived from an ecosystem. The Millennium Ecosystem Assessment (2005) classified these benefits as provisioning services which include food, timber and water; regulating services that affect climate, disease, wastes, floods and water quality; cultural services that provide recreational and spiritual benefits or supporting services that in soil formation, photosynthesis and nutrient cycling.

Mangroves provide a wide range of ecosystem services, the continuous provision of these goods and services require not only the presence of the mangroves but also on the constituents of the ecosystem such as the species composition and other ecological factors (Barbier *et al*., 2011). A few examples of major goods and services provided by the mangrove ecosystem are shown below.

2.5.1 Timber and Non-Timber Forest Products

Wood or timber is one of the major products derived from mangroves. They have a wide variety of uses which include construction, wood fuel, charcoal, furniture, etc. Other products derived from mangroves, referred to as non-timber forest products include honey, fruits, medicine, wine and palm thatch used for roofing (Jan-Willem *et al*., 2014). Mangroves therefore form an integral component of coastal communities, sustaining the livelihoods and culture of millions of coastal dwellers by providing

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material for building, cooking and income through trade and employment (Ntyam, 2014).

The wood obtained from mangroves has qualities that make them the preferred choice even when other options are available. These qualities include: their resistance to termites making them very good materials for building poles for building frames and fishing structures (Taylor *et al.* 2003); high calorific value when burnt making mangrove charcoal the main source of fuel for cooking fires and smokehouses. The high demand for mangroves is demonstrated by the existence of commercial markets specifically created for mangrove wood and charcoal fuels (Barbier *et al.* 2011). Anyanui and Salo are examples of communities in Ghana with commercial markets specifically created for mangrove wood.

Other products from mangroves include tannins derived from the bark of some hardwoods of mangrove species such as *Rhizophora* and *Bruguier*. These are used for leather tanning and as decorative dyes (Jan-Willem *et al.*, 2014). The leaves, fruits, flowers and roots are used in some traditional medicine to treat a range of diseases and ailments such as leprosy and tuberculosis (Govindasamy & Kannan, 2012).

The dependence on mangroves by coastal communities varies widely. In a case study of a coastal community in Brazil by Jan-Willem *et al.* (2014), one of the major findings was that mangrove resources supported livelihoods by generating income in one community where as in another community such resources were used purely for subsistence and were therefore critical food sources for the poorest populations.

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2.5.2 Fisheries

Mangroves play an ecological role of providing habitats that support different kinds of fisheries. These include snappers, mullets, wrasses, parrotfish, sharks, rays, clams, crabs and mangrove fish. Dankwa & Gordon (2002) reported 38 finfishes and 14 shellfish species in the mangrove swamp of the Lower Volta. They also observed high species diversity in areas with more extensive mangrove cover compared with areas where mangroves were absent or sparse. The mangrove fisheries, many of which are of commercial importance are supported from subsistence foraging in the mangrove itself to industrialised, commercial offshore fisheries (Jan-Willem *et al.*, 2014). Mangroves may also provide an emergency food function when food is in short supply; some species of snails and bivalves which may have no market value are readily harvested for household consumption (Glaser, 2003).

The mangroves therefore play an important role of providing sources of protein as well as offer opportunities for trade and income for many coastal communities (Magalhãe *et al.*, 2007). A fish yield of between 450 and 500 Mt/y valued at about $400,000-450,000 is harvested in the mangrove swamps of the Lower Volta (Dankwa & Gordon, 2002)

Juvenile fish that nursed in mangroves replenish the offshore fish populations when they attain adult sizes and swim out to the open sea. A significant depletion in the population of some fish species is areas where nearby mangroves have been lost is a reflection of the importance of mangroves in the sustenance of such species (Dorenbosch *et al*., 2005; Jan-Willem *et al*., 2014; Nagelkerken *et al*., 2002).

The nurseries in mangroves also support populations of fish species in nearby ecosystems by providing prey species that form integral components of food chains

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and food webs. Others also functions as grazers which prevent coral reefs from being outcompeted by algae by feeding on them (Clark *et al.*, 2001; Mumby & Hastings, 2008; Nagelkerken *et al.*, 2012; Olds *et al.*, 2012; Olds *et al.*, Connolly, 2012).

Mangroves also buffer coastlines against storms and other extreme weather events and thus safeguard fishing grounds and fishing harbours (Williams *et al.*, 2007).

2.5.3 Coastal Protection and Shoreline Stabilization

Coastlines where mangroves are found are occasionally subjected to large waves including tsunamis, storm surges and high winds. Mangroves may serve as a barrier against these extreme weathers by reducing their impacts and thus saving lives and reducing damage to property. There is a growing interest in the potential use of mangroves as a natural and low-cost approach to reduce risks associated with natural disasters, especially in the wake of rising sea levels and variations in the frequencies and intensities of storms (Jan-Willem *et al.*, 2014). Mangroves also play an important role in the stabilization of shorelines. By reducing the height and energy of waves, they prevent coastal erosion by minimizing the erosive forces which act on sediments (Mazda *et al.*, 2006; Mcivor *et al.*, 2013; Quartel *et al.*, 2007). The roots bind the soil together and also slow the water flow rate causing sediment deposition and accumulation (Furukawa *et al.*, 1997).

The mangrove forest's extensive root structures acts as a shock absorber reducing current velocities and shear forces as well as enhance sedimentation and sediment retention (Ntyam, 2014). Mangroves can reduce storm surge levels by up to 50cm per km width of mangroves and this is important because a relatively small change in water depth may ameliorate the effects of tide particularly in low relief areas (Krauss

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et al., 2009; Mcivor *et al.* 2012; Zhang *et al.*, 2012). The effectiveness is however dependent on the density of the mangrove vegetation (Mazda *et al.*, 2006; Mcivor *et al.*, 2012).

2.5.4 Mangroves as carbon sinks

Mangroves are recognised as a significant global carbon sink with the largest average carbon stock per unit area of any terrestrial or marine ecosystem (Jan-Willem *et al.*, 2014). Mangroves are able to sequester up to 25.5 million tonnes of carbon per year according to Ong (1993). The carbon stock per hectare of mangroves exceeds those measured in tropical savannas, tropical dry forests and rainforest. Mangroves are among the most carbon-rich in the tropics with an average of 1023 tonnes per hectare. This includes both above-ground and below-ground carbon stocks (Adame *et al.*, 2013; Donato *et al.*, 2011; Jaramillo *et al.*, 2003; Kauffman & Donato, 2012). Tropical wetlands contain organic soils ranging from 0.5m to more than 3m in depth and are among the largest organic carbon reserves, accounting for 49-98% of carbon storage (Donato *et al.*, 2011). The effectiveness of mangroves as carbon sinks is affected by factors that include the hydrology i.e., tidal inundation, strength and frequency; salinity i.e., availability of freshwater; nutrient availability and climate. Equatorial areas characterized by lower soil salinity, higher rainfall and infrequent cyclones have larger carbon stocks (Jan-Willem *et al.*, 2014).

The degradation of mangrove areas may lead to the release of carbon that has been in storage for thousands of years either by burning or degrading organic matter (PWC, 2015). CO_2 emissions from degraded mangrove peat soils measured by Lovelock *et al.*, (2011) were in the order of 2900 tonnes CO_2 km^{-2} $year^{-1}$. Donato *et al.*, (2011) estimated CO_2 emissions to be within the range of 112-393 Mg released per hectare of

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mangrove forest and soils cleared. Pendleton *et al*. (2012) estimate that the conversion and degradation of blue carbon systems may ultimately lead to the release of 0.15-1.02 billion tons of CO_2 to the atmosphere. Emissions that result from mangrove losses are equivalent to 3-19% of global emissions from deforestation.

2.5.5 Recreational, Spiritual and Cultural Value of Mangroves

Some of the benefits that mangroves provide are intangible and therefore often difficult to assign value. Although difficult to determine, the recreational, spiritual and cultural values of mangroves are very important for human well-being (James *et al*., 2013). Mangroves are able to create scenery of nature's beauty that provides a recreational experience as well as cultural and artistic inspiration (Millennium Ecosystem Assessment, 2005). In some coastal communities, mangroves have been central to the people's livelihoods for decades, and are intertwined deeply with their historical, ethical and spiritual values of the people, their presence of mangroves in such areas today ensures the continuous transfer of ecological knowledge and mangrove-dependent fishing techniques (James *et al*., 2013). In Kenya for example, the local people worship in shrines in the mangrove forest and have the belief that the spirits of the shrine would punish those who cut surrounding trees by bringing death upon them (Kathiresan & Bingham, 2001).

Some mangrove areas have become eco-tourism sites, offering opportunities for leisure, education and recreational activities such as fishing, birdwatching and wildlife watching. Kayaking and snorkelling in mangrove channels are some of the recreational activities gaining ground in parts of the world where mangroves occur (Jan-Willem *et al*., 2014). Popular destinations such as the Dongchaigang nature reserve in China, the boardwalk in Cairns in Australia and Laguna de Resting in

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Venezuela receive around 60,000 visitors annually (Spalding *et al*., 2010). The Everglades National Park in Florida, USA has the largest mangrove ecosystem in the western hemisphere and close to a million visitors in 2010 alone spent $135.5 million in the park and in surrounding communities, supporting nearly 2000 local jobs in the area (Ramsar, 2012).

2.6 Threats to Mangroves and Drivers of Change

The dominance of man as a significant agent of change (Vitousek *et al*.,1997) is also reflected in the mangrove ecosystem. Although there is much debate over the statistics of mangrove cover loss in different countries, there is an agreed consensus of a global loss of mangroves (Spalding *et al*., 2010) with a significant portion attributable to anthropogenic activities (Nfotabong-Atheull *et al*., 2011).

An estimated 20% of mangroves, representing 3.6 million hectares was lost between 1980 and 2005 (FAO, 2007). Such declines are expected to continue into the future, Alongi (2002) predicted a continuous global decline up until the year 2025. Indonesia, which by far had the largest national stocks of mangroves in the year 2000 is predicted to lose substantial mangrove cover in the period up to 2050 and 35% of mangroves in South-East Asia to be lost within the same period (Brander *et al*., 2012).

The destruction of mangroves correlates positively with human population density; about 44% of the world's population reside within 150 km of a coastline (Cohen, 1997) and Jan-Willem *et al.* (2014) predicted that about 120 million people would live within 10 km of the remaining mangrove habitat by 2015 leading to increased mangrove degradation due to urban development, aquaculture and exploitation for timber. It is estimated that about 26% of mangrove forest worldwide are degraded due

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to fuelwood and timber production and about another 38% of global mangrove loss due to shrimp farming (Ellison, 2008; Valiela *et al*., 2001).The fundamental driver for the loss and degradation of these ecosystems arises when there is conflict between meeting human needs and conserving natural resources. Across Africa, there are four major drivers of change of the mangrove ecosystem according to Corcoran *et al.* (2007) ;

(i) Population growth and urban development

(ii) Economic and political trends

(iii) Climate change

(iv) Changes in upstream habitat.

2.6.1 Population growth and urban development

The Atlantic corridor borders many major towns and cities across western and central Africa, cities and towns characterized by high population densities. They include Dakar where over 60% of the national population live, Lagos, Port Harcourt and other coastal cities in Nigeria where about 20 million people representing about 23% of the population live. Other cities include Abidjan, Accra, Tema, Cotonou, Douala and Libreville (Corcoran *et al*., 2007; NOAA/NOS, 2002). Such high population densities puts pressure on coastal natural resources which end being treated as 'commons' (Hardin, 1968) leading to over-exploitation of mangroves and fisheries resources. Corcoran *et al.* (2007) reports that majority of West African countries are among the worlds least developed and have high dependencies on natural resources. Mangroves are used by coastal communities for both traditional and commercial purposes. Mangrove wood has always been used for cooking and heating, for building houses

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and hats. Other uses include tannins and resins for dying leather, making furniture, bridges, medicines, alcoholic beverages like *akpeteshie* and many other products (Gordon *et al*., 2009; Kathiresan & Bingham, 2001). Commercial practices such as felling mangrove forests are often due to increasing demand of mangrove products from outside the local community, such demands are usually larger than the local forests can sustain (Alongi, 2002)

Mangroves are known to occupy areas along the coast where there is high demand for development. Such development often requires the total clearance of the vegetation and the area subsequently drained and filled in order to support urban and residential development, tourism, golf courses, deep sea ports, oil refineries and other forms of industries. This is revealed in that about 60% of industries in West Africa are located in local coastal cities (Feka & Ajonina, 2011; Jan-Willem *et al*., 2014; Nfotabong-Atheull *et al*., 2011; NOAA/NOS, 2002)

2.6.2 Economic and Political trends

Africa has one of the highest levels of poverty in the world. When this is coupled with civil wars and political instability it is the environment that suffers. After the wars, governments focus on building the economy often places pressure on natural resources such as mangroves. Liberia and Sierra Leone are examples of countries where such trends have contributed significantly to deforestation (Van Asselt, 2003).

In some countries such as Nigeria, Cameroon and Gabon, mangroves are located in areas where important economic activities such as oil drilling occur (Corcoran *et al*., 2007). Oil spillage and other oil drilling activities such as gas flaring and canalization pose a significant threat to the health of the mangrove ecosystem. The quest to

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identify new sources across the West African sub-region also predisposes the mangrove ecosystem to pollution through activities that relate to prospecting

2.6.3 Climate Change

West Africa is described by Niasse (2002) as one of the regions of the world that is most vulnerable to climate change. Changes in rainfall pattern, extreme weather events and sea-level rise have been predicted to influence the distribution of mangroves (Corcoran *et al.*, 2007). Sea-level rise is reported to be the greatest threat to mangroves (Gilman *et al.*, 2008). This is because growth of mangroves are not able to keep pace with changing sea-level when the rate of accretion of the mangrove substrate is exceeded by the rate of change in sea-level (Gilman *et al.*, 2008). Sea-level rise would therefore alter the mangrove habitat and create new tidally inundated areas where some mangrove species may shift (Manson *et al.*, 2013).

Manson *et al.* (2013) reported a sea-level rise of 3.4mm/year along the Keta coastal zone of Ghana. This may either lead to a continuous increase in salinity due to the reduction of freshwater flowing into the mangrove ecosystem, thereby affecting their growth, or a complete inundation of the mangroves along the coast of Keta

2.7 Mangrove Restoration Projects

Given the importance of mangroves to both community and the environment, there have been a number projects aimed at a long-term sustainable use of the mangrove resource. These projects have been on different scales and in different communities. The Lower Volta Mangrove Project funded by the United Kingdom and the Mangrove Community restoration funded by the Netherlands are examples of restoration projects in Ghana.

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In the Mangrove Community restoration project, two communities with degraded areas undertook a replanting exercise of mangroves as well as the planting of *Cassia sp* as alternative source of fuel wood. The planting exercise was aided by the Resource and Environment Development Organisation (REDO) and the Forestry Commission in Winneba. Six thousand mangrove propagules and two plots of *Cassia sp*, at 10,000 per plot had been planted at the end of the project (Corcoran *et al*., 2007). A fire outbreak after poor rains however adversely affected the number of trees planted in the first year. The damage was minimized by the regenerative ability of *Cassia sp* after fires.

The Lower Volta Mangrove Project in an effort to achieve its aim of providing solutions to problems relating to mangrove exploitation conducted a socio-anthropological study. This study was conducted to acquire information on the socio-economic importance of the mangrove ecosystem within the study area and assess the social and economic potential for a community based management of the mangrove resource. Below is a summary of the major finding of the socio-anthropological study by Tsikata *et al*. (1997)

Education levels were generally low among the local people and poverty was wide spread. This had the implication of limiting economic opportunities and thus driving intensive exploitation of the limited natural resources in the area. The main occupation of the local people in level of importance was crop farming, mangrove related activities and petty trading. Mangrove related activities were found to be in two forms; main mangrove activities which include planting, harvesting, transportation and marketing (wholesale and retail) as well as mangrove by-product activities which included fishing and crab trapping, fish smoking, mat weaving,

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distilling and domestic use of mangrove fuel wood. The local people therefore perceived mangroves as a key economic resource.

The general perception of the local people were that mangroves were on the decline and attributable to a number of factors which included over-exploitation fuelled by limited economic opportunities and population pressure; the decline in fishery resource due to the damming of the Volta River at Akosombo and Kpong and the propagation of *Acrostichum aureum* and *Typha domingensis*.

2.8 Socio-economic drivers of mangrove resource exploitation

The dependence of the livelihood of coastal dwellers on mangroves is implied in the ecosystem services the mangrove provides them. Although mangroves provide both social and economic benefits, Tsikata *et al.* (1997) showed that the economic benefits outweighed the social benefits in the Lower Volta area. The harvesting of mangrove wood is observed to be a core economic activity for central and western Africa (Kjerfve *et al.*, 1997; Ajonina & Usongo, 2001; Macintosh & Ashton, 2005). The perception of mangroves as an economic resource by locals has in some instances led to replanting exercises either by individuals or community. Walton *et al.* (2006) through an economic analysis provided evidence to support the claim that income derived from mangrove timber is a driving factor for mangrove planting for sustainable harvesting. The household demand for construction wood as well as the use of mangroves as assets that can be liquidated in times of financial hardships was reported by Walters *et al.*, (2008) as a major factor for individuals to plant mangroves in the Philippines.

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Although the domestic use of mangrove as fuel wood has been a longstanding traditional practice among local communities, the existence of both local and external mangrove markets has become another livelihood option driving the harvesting of mangroves for commercial purposes. Arthurton *et al.* (2006) reports that markets are a major driver for the exploitation of coastal resources; influencing the intensity at which the resources are exploited. The existence of well-established commercial markets have resulted in the degradation and rapid deterioration of mangrove ecosystems (Din *et al*., 2008; Omodei Zorini *et al*., 2004).

Aheto *et al.* (2016) identified socio-economic factors that influenced the planting of mangroves to ensure sustainable harvesting. The factors in order of importance are:

(i) increase in income through harvesting and sale of mangrove wood,

(ii) granting of personal loans and credits

(iii)sustained supply of fuel wood

(iv)sustained supply for housing construction

(v) habitat restoration to support fisheries

(vi)protection against storms

(vii) protection of social relations

(viii) flood and erosion control

(ix)habitat for collecting bees and hunting wildlife'.

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2.9 National Policies and Multilateral Environmental Agreements relating to mangroves

The considerable differences in loss of mangroves that have occurred globally are indicative of the laws and policies that govern the use and management of mangrove resources. Very few countries have regulations and that specifically target mangrove management. In most countries, they are either entirely non-existent or implied in other environmental regulations. For example in Ghana, there are no specific policies on mangroves except that which is implied in the National Wetlands Conservation Strategy and Action plans (Derkyi, 2007).

At the international level, a number of conventions and treaties exist that promote the conservation and sustainable use of the mangrove resource (Jan-Willem *et al.*, 2014). Ghana is a signatory to a number of international conventions that include the Ramsar Convention. This obligates the country to ensure the wise usage of wetland resources such as mangroves. This convention inspired the formulation some national policies such as the National Environment Policy and National Wetland Policy (Derkyi, 2007). These international conventions however often lack the needed enforcement in countries especially when the conventions and treaties themselves lack penalties to discourage non-compliance. This is evident in the loss of mangroves even in areas designated as Ramsar sites (Mensah, J., 2013).

The Regional Seas programme provides a platform through which environmental challenges may be addressed through conventions and action plans (Jan-Willem *et al.*, 2014). One of such programmes in West Africa, Abidjan Convention has developed a protocol that would legally bind 22 countries including Ghana to protect mangroves and manage them sustainably (Abidjan Convention, 2015).

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2.10 Ghana's LPG Policy and promotion programme

Ghana, like many developing countries in struggling with meeting the energy demands of its citizenry in both rural and urban areas. Although there has been a steady rise in access to electricity, from 28% of the population in 1998 to 43% in 2000 (Bukari, 2012), only 26.9% of rural households have electricity for lighting purposes compared with 78.5% of urban households (Kemausuor *et al.* 2011).

In Ghana, wood fuel and charcoal accounted for 80% of the total energy consumed in 1987 with petroleum and electricity accounted for 14% and 7% respectively (Abakah, 1990). The reliance of majority of the population on wood fuel as an energy source mainly for cooking had implications on health and the environment. Wood fuel users were predisposed to acute respiratory infections, lung cancer, etc. (Bukari, 2012). Implications on the environment included increased deforestation (Akpalu *et al.* 2011) as well as an increase in CO_2 and other greenhouse gas emissions which impact air quality and contribute to climate change (Bailis *et al.*, 2005).

The quest to reduce the implications on human health and the environment led to the implementation of the national Liquefied Petroleum Gas (LPG) promotion programme in 1990 (Bukari, 2012) and the LPG Policy in 1992 (Energy Commission, 2010). Ghana adopted the policy as an intervention to deal with the cooking energy crisis as well as to help curb the associated dangers to human health and the environment (Energy Commission, 2010). LPG is a generic term for ethane to butane mixtures that exist as liquids under specific conditions of temperature and pressure (Totten *et al.*, 2003). The programme sought to promote LPG as a substitute to firewood and charcoal and thus reorient their choice of cooking energy source. The

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government at the time freely distributed 14.5 kg and 5 kg cylinders to the public (Bukari, 2012).

This led to a reduction in consumption of fuel wood form 80% in the early 1990's to 73% in 1996 (Bukari, 2012). The use of LPG in household also rose from 4% in 1998 to 9.5% in 2006 (Akpalu *et al.*, 2011).

There were however some unexpected outcomes of the LPG promotion programme. Aside that the programme was more inclined to urban households, the lower prices of LPG due to subsidies led to commercial vehicles particularly taxis and commercial buses switching to the use of LPG for fuel (Energy Commission, 2010). The Unified Petroleum Price Fund (UPPF) was initiated by the government in 2005 to correct the imbalance of the programme by increasing the availability of the product to the rural areas (Bukari, 2012). Despite the scheme, the use of LPG in rural areas was poor with consumption level rates standing at 1.5% (Ghana Statistical Service, 2008). This could be explained by the fact that the subsidy was not enough to alter the people's preference for fuel wood (Akpalu *et al.*, 2011) especially when fuel wood and charcoal are cheaper and more reliable compared with LPG which is not always available due to frequent shortages. The use of LPG also has an additional cost of acquiring a cylinder (Bukari, 2012).

The major source of energy for cooking in Ghana is still wood fuel. An estimated 11.7 million tonnes of biomass, mostly charcoal and firewood was consumed in 2008 (Ministry of Enegry, 2010). This represented 65.5% of Ghana's total primary energy consumption. According to Duku *et al*. (2011) the consumption of firewood and charcoal is reported to have increased by 58% and 50% respectively between 2004 and 2008. Ghana Statistical Service (2008) indicates that over 80% of rural dwellers

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depend on firewood. With the continuous increase in the consumption of firewood and charcoal, the country's consumption is projected to be 25 million tonnes by 2020 (Acharibasam & Apatinga, 2014).

2.11 Mapping of Mangroves Using Remote Sensing

Remote sensing has proven to be a useful tool in monitoring and mapping of mangrove ecosystems (Goetz & Dubayah, 2011; Green *et al.*, 1998; Kuenzer *et al.*, 2011; Mensah, J., 2013; Vaiphasa *et al*., 2006). Tropical and subtropical mangroves are among the world's most threatened and vulnerable ecosystems (Valiela *et al.*, 2001). There is therefore an urgent demand for conservation and restoration measures which require up-to-date information on the extent and condition of the mangrove ecosystem in order to inform management decisions and actions (Kuenzer *et al*., 2011).

Mangroves are inundated and located in areas with very restricted access (Fatoyinbo *et al*., 2008; Ill & Jensen, 1996), making traditional field observation methods very expensive and time consuming (Kuenzer *et al*., 2011). Remote sensing therefore serves as a tool for long term and cost- effective mapping and monitoring of large scale areas thus providing valuable information on vegetation structure and areal coverage that could not have been obtained otherwise (Howard *et al*., 2014).In addition, it is able to provide data at specific spatial and temporal scales that help in monitoring habitat inventories and assessing changes in the ecosystem (Kuenzer *et al*., 2011; Malthus & Mumby, 2003).

A Digital Elevation Model (DEM) is a quantitative model of a part of the earth's surface in a digital form (Burrough & McDonnell, 1998). DEMs consist of either a

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two dimensional array of numbers representing spatial distribution of elevation on a regular grid; a set of *x, y,* and *z* coordinates for an irregular of points or contour strings stored in the form of x,y coordinate pairs along each contour line of specified elevation (Walker & Willgoose, 1999).

DEMs have widespread applications and are particularly useful in areas that lack detailed topographic maps (Forkuor & Maathuis, 2012). DEMs serve as a useful tool for many areas of discipline including archaeology, forestry, geomorphometry and hydrology (Lane *et al*., 1994; Menze *et al*., 2006; Pike *et al*., 2009; Simard *et al*., 2006). The advances in space technology and satellites in producing stereoscopic images facilitates the extraction of DEMs which have the advantage of covering large and inaccessible areas (Forkuor & Maathuis, 2012).

The Shutter Radar Topographic Mission (SRTM) and the Advanced Space borne Thermal Emission and Reflectance Radiometer (ASTER) are two examples of satellites from which DEMs can be derived. SRTM and ASTER DEMs have been used for a wide range of applications due to their near global coverage. The DEMS can therefore be used to determine the significance of mangroves as carbon sinks by relating tree height to mangrove biomass at local scales (Cintron & Novelli, 1984).

Detailed *in situ* knowledge and field data are crucial for the proper use and understanding of all the remote sensing data sources discussed above and without any ground knowledge, it would be impossible to differentiate between mangrove species (Kuenzer *et al*., 2011). DEMs are inevitably subjected to errors which occur mainly from the methodologies used and the various post-processing steps they undergo such

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as interpolation. It is therefore important that errors are quantified in order to provide the accuracy of the DEM (Forkuor & Maathuis, 2012).

A number of works in Africa have used medium-resolution satellite imagery to map out mangrove ecosystems. These include work by Gang & Agatsiva (1992) who used SPOT XS imagery to map the extent and status of mangroves in Mida Creek, Kenya. Wang and Sousa (2009) identified changes in the distribution and total area of mangroves along the Tanzanian coast. Fatoyinbo *et al.* (2008) used Landsat ETM+ and SRTM elevation data to determine the spatial distribution and biomass of Mozambique's mangrove vegetation.

Fatoyinbo and Simard (2013) used ICESat/GLAS (Ice, Cloud and land Elevation Satellite/Geoscience Laser Altimeter System) and SRTM to determine the height and biomass of mangroves in Africa. Akpalu (2007) under the ITTO Pre-Project used Landsat TM to determine the quantity and spatial distribution of mangrove resources along the coast of Ghana. Coleman *et al.*, (2007) studied mangrove ecologies along the coast of Ghana using Landsat TM and Landsat ETM+.

A study by Mensah and Track (2013) used RapidEye and Landsat TM in addition to Aerial photos to map out past and present areal extent of mangroves in the Ellembelle district in the western region of Ghana.

2.11.1 Estimating Mangrove Coverage

The mapping of mangroves over alarge area has become easier due to advancement in remote sensing techniques and this has led to a number of studies on the global distribution and coverage of mangroves (Tang *et al*., 2014). Green *et al.* (1998) reports that the accuracy of a final map depends on the classification procedure used

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to discriminate between various vegetation types and this depends partly on the sensor's resolution and partly on the classification procedure used. The choice of an appropriate system and technique is informed by the study area and the budget.

The first comprehensive global mangrove map, *World Mangrove Atlas*, an initiative of ITTO and International Society for Mangrove Ecosystems (ISME) was published by (Spalding *et al*., 1997). This was followed by a revised edition in 2010 which had improved accuracy through analytical assessments of forest area and status at both regional and national levels. The total global mangrove area estimated by Spalding *et al.* (2010) was 152 360 km^2. An alternative estimate of 137 760 km^2 was published by Giri *et al.* (2011) a year later. Although the differences between the two is relatively minor on a global scale, Spalding *et al.* (2010) maintain that theirs is the most accurate since their data was partially supervised, and some of the large national data sets were fully supervised (ITTO, 2012).

On a regional scale, there are a number of studies conducted on the estimation and mapping of the spatial distribution of mangroves. Adams *et al.* (2005), in their study on the spatial distribution of mangroves along the coast of Transkei in South Africa used topographic maps and aerial photographs. The aerial photographs were digitised and calibrated using the topographic maps and field surveys. The mangrove area coverage was measured using image analysis software (analysis 3.0, ISAT).

A study by Dahdouh-Guebas *et al.*, (2004) also used aerial photography and field surveys to map out mangrove area coverage. In order to determine the spatial distribution of mangroves, a Maximum Likelihood classification was applied to Landsat images by Fatoyinbo *et al.*, (2008) using trained classes determined by GPS points and a Landover maps provided by Ministry of Co-ordination of Environmental

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Affairs, the National Remote Sensing Centre and Google Earth software. Kovacs *et al.* (2010) identified mangrove area using satellite imagery from IKONOS and QuickBird. The images were classified using an unsupervised classification approach; Iterative Self-organizing Data Analysis (ISODATA). In a later study by Fatoyinbo and Simard (2013), the estimation of mangrove area coverage on the African continent was achieved using an unsupervised ISODATA on Landsat images which were subsequently filtered using visual interpretation, the World Mangrove Atlas by Spalding *et al.* (2010) and Google Earth software.

2.12 Methods of Estimating the Above Ground Biomass of Mangroves

The estimation of mangrove biomass is crucial for studies relating to carbon cycle and climate change (Aheto *et al.* 2011; Soares & Schaeffer-Novelli, 2005). Ecologists have over the years developed ways to estimate the biomass of forests. These include the direct or harvest method, the mean-tree method used in forest with homogenous tree size and distribution as well as the allometric method (Komiyama *et al.*, 2008).

The direct method consists of harvesting the tree and determining the biomass from the dry weight of parts such as the stems, roots and leaves. This is not practical in mature mangrove forests where the total weight of an individual tree may reach several tons. Also, it is not reproducible as the trees are destructively harvested (Komiyama *et al.*, 2005; Segura & Kanninen, 2005). The allometric method estimates the whole or partial weight of a tree from measurable dimensions such as trunk diameter and tree height. This has the advantage of being non-destructive and causing minimal disturbance to the ecosystem under study (Gehring *et al.* 2008; Komiyama *et al.*, 2008). The site-specific and species-specific dependencies of allometric equations

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however pose a challenge to researchers because mangrove tree measurements is labour intensive (Komiyama *et al*., 2008).

The structure, biomass and carbon stocks of mangroves in Africa and other parts of the world have been studied and reported in literature (Steinke *et al.*, 1995; Fatoyinbo *et al*., 2008; Komiyama *et al.*, 2008; Aheto *et al*., 2011; Fatoyinbo & Simard, 2013; Adame *et al*., 2013; Rahman *et al*., 2015; Stringer *et al.*, 2015).

In estimating the above-ground biomass of mangroves, Aheto *et al*., (2011) measured the height and diameter at breast height (DBH) of mangroves which were then incorporated into allometric equations developed by Clough and Scott (1989) . The derived equations were subsequently applied to a select number of trees in sample quadrats and the best fit allometric equation was used as a model to derive the biomass. *Rhizophora mangle* recorded the highest standing biomass of 134.08 tonnes per hectare followed by *Avicennia germinans* and *Laguncularia racemosa* recording 35.02 tonnes per hectare and 22.08 tonnes per hectare respectively. Steinke *et al.*, (1995) in studying mangroves in South Africa, harvested the above-ground tree parts within 5m^2 sample plots and oven dried them to determine their biomass. The mean above-ground living biomass was calculated at 94.49±7.83 tonnes per hectare.

The biomass of mangroves in Mozambique, which has the third largest area of mangroves in Africa was estimated by Fatoyinbo *et al.*, (2008). This was done by applying stand-specific canopy height-biomass allometric equations. Landsat Enhanced Thematic Mapper Plus (ETM+) and SRTM data was used to estimate and map the spatial distribution of mangrove heights. The SRTM data was calibrated using height calibration equation from Simard *et al.* (2006). Field data based on previously published allometric equations were collected to develop a height-biomass

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relationship in order to estimate the above-ground biomass. The results showed that mangrove forests covered a total of 2909 km^2 in Mozambique; this was 27 % smaller than a previous estimate by Saket and Matusse (1994). The total mangrove dry aboveground biomass in Mozambique was 23.6 million tons and the total carbon was 11.8 million tons.

Fatoyinbo and Simard (2013) estimated the height and biomass of mangroves of the entire African continent. This was done using Lidar canopy height estimates from ICESaT/GLAS and elevation data from STRM. The Lidar measurements were used to derive local estimates of canopy height and calibrate SRTM data. They then applied a global allometric equation developed by Saenger and Snedaker (1993) that related canopy height to biomass in order to estimate the above-ground biomass. The total mangrove area of Africa was estimated to be 25,960 km2 with 83% accuracy. The area of mangrove cover and mean biomass for Ghana was found to be 76 km^2 and 97 tonnes per hectare.

Adame *et al.* (2013) measured carbons stocks in 3 strata of mangrove vegetation classified according to mean heights (H_m) along the coast of Mexico. Measurements were taken for tree height, crown volume and DBH. The estimation of biomass was done using allometric equations developed by Smith & Whelan (2006) and Ross *et al.*, (2001).Tall mangroves (H_m >5m) had the highest carbon stocks of 987±338 Mg/ha. This was followed by medium mangroves (3m≤H_m≤5m) with a carbon stock of 623±41 Mg/ha and dwarf mangroves (H_m<1.5m) with a carbon stock of 381±52 Mg/ha. Soil carbon contributed majority of the carbon stock (78-99%) as indicated by the aboveground carbon stocks which ranged from 1.5-88 Mg/ha.

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Tang *et al.* (2014) estimated the biomass and carbon stocks of West African mangroves using data sets including canopy height obtained from NASA and allometric equations developed by Saenger & Snedaker (1993). They reported a mean aboveground biomass and mean aboveground carbon of 113.14 Mg/ha and 56.57 Mg/ha respectively,

Stringer *et al.* (2015) in estimating the carbon stocks of the mangroves within the Zambezi River Delta applied a random sampling inventory design based on forest canopy heights derived from ICESat/GLAS and SRTM data adopted from Fatoyinbo and Simard (2013). Wood density and DBH measurements of trees were measured and the above and below ground biomass were estimated using allometric equations developed by Komiyama *et al.* (2005) .The average above-ground biomass C per hectare range from 75.4 Mg/ha to 206.0 Mg/ha. This included biomass contributed by leaf litter, downed wood debris, standing dead trees and ground vegetation.

Rahman *et al.* (2015) estimated the ecosystem carbon stocks in the Sundarbans, the world's largest mangrove forest found in Bangladesh. Tree height and DBH were measured and the above-ground biomass was estimated using allometric equations developed by Chave *et al.* (2005) . The above-ground carbon stocks of the mangrove trees ranged from (45.24 -152.57) Mg/ha. Results from the study revealed that a significant amount of carbon is stored in the soil irrespective of the mangrove heights.

2.12.1 Estimating the biomass of mangroves using allometric equations

The theory behind allometric equations is in the fact that in many organisms, the growth rate of one part is proportional to that of another part of the organism. For example, tree weight can be estimated from independent variables such as the trunk

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diameter and height that can be measured during field surveys (Komiyama *et al.*, 2008). A regression equation can therefore be derived to predict tree weight after a range of tree measurements have been taken. The sampling of dominant tree species in order to obtain allometric relationships is very tedious and not practical due to the destructive harvesting of trees. Allometric equations for mangroves have been developed over several decades to estimate the biomass and subsequent growth (Komiyama *et al.*, 2008). These equations however according to Clough *et al.*(1997) and Smith and Whelan (2006) often show site-or species-dependency. Ong *et al.* (2004) however applied similar equations to different sites of *Rhizophora apiculata* to determine their biomass.

On the issue of species-site dependency of allometric equations, Chave *et al.* (2005) and Komiyama *et al.* (2005) proposed the use of a common allometric equation for mangroves. The pipe model by Shinozaki *et al.* (1964) and static model of plant form by Oohata & Shinozaki (1979) formed the basis of the common allometric equation proposed by Komiyama *et al.* (2005) and Chave *et al.* (2005).

The common equation for above-ground biomass by Komiyama *et al.* (2005) is found below:

$$W = 0.251pD^{2.46} \quad \text{(Eq. 1)}$$

The common equation for above-ground biomass by Chave *et al.* (2005) is found below:

$$W = 0.168pDBH^{2.47} \quad \text{(Eq. 2)}$$

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These common equations have the advantage of requiring only two parameters; diameter at breast height (DBH) or trunk diameter (D) and mean tree density *p* (Komiyama *et al*., 2005).

Komiyama *et al.* (2008) compared the common equations to some site-specific ones such as Clough and Scott (1989) and Ong *et al.* (2004) to check their applicability and found a relative error of 10%. They also suggested that per their finding, the allometric equation of mangrove species was more species-specific than site-specific.

A common equation proposed by Saenger and Snedaker (1993) was used by Fatoyinbo *et al.* (2008) and Fatoyinbo and Simard (2013) to estimate the above-ground biomass of mangroves in Mozambique and Africa, respectively. This equation was based on a review of 43 articles and reports on biomass of mangroves. It showed that there was a strong correlation between biomass and tree height. Komiyama *et al.* (2005) in their study report that for a total understanding of forest biomass, the allometric equations for root weight are essential. This is however limited due to existence of few equations because of the tedious extraction roots from mangrove soils.

The common equation proposed by Saenger & Snedaker (1993) is found below:

$B_H = 10.8 \times H + 35$ RMSE 43.8 (Eq.3)

(B_H = above-ground biomass; H = tree height)

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CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

The area comprised sections of the Keta Municipal area and the South Tongu districts of the Volta Region of Ghana where the highest concentration of mangroves in the savannah zone occurs (Akpalu, 2007). It lies within latitude 5°46 N and 5°57 N and longitude 0°41 E and 0°53 E and covered an area of about 280 km^2. It covered a number of towns and villages that include Dzelukope, Tegbu, Salo, Woe, Anyako, Tsiame, Sesieme, Anyanui, Hawui, Gamenu, Tunu and Bomingo

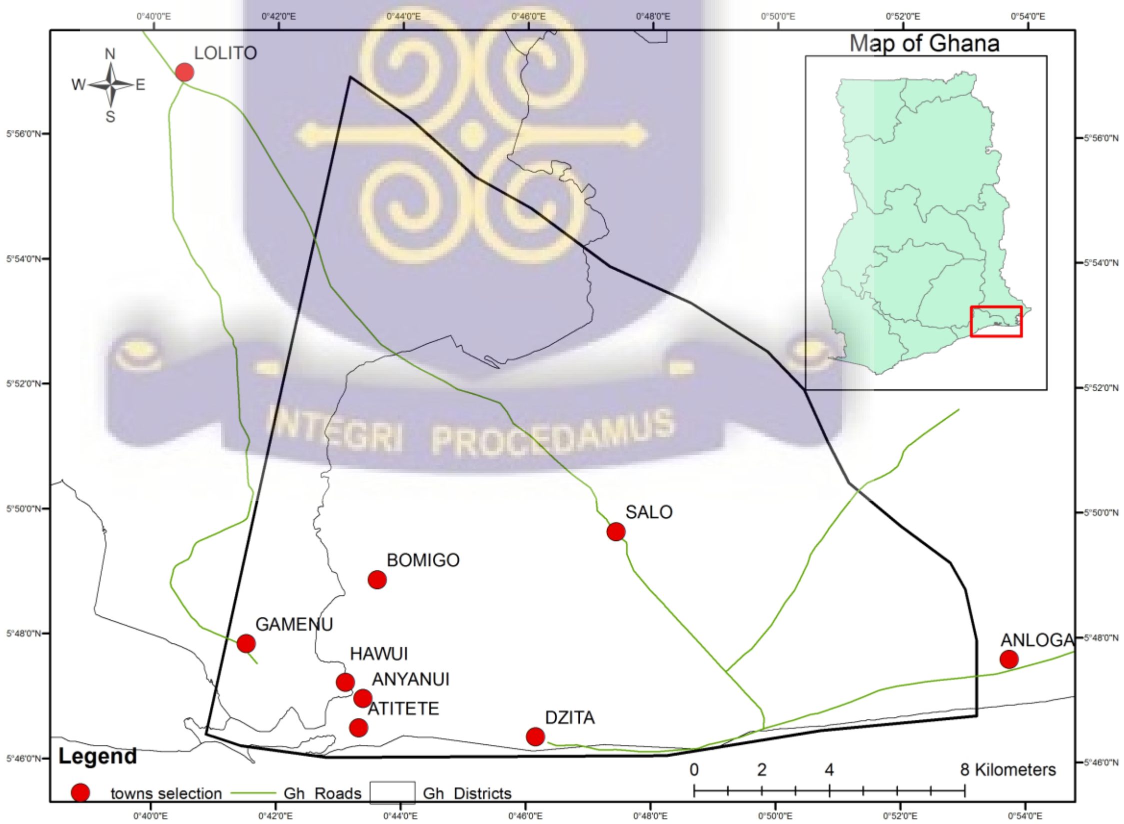

Figure 3.1 Map of the Study Area in the Volta Delta

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The vegetation within the study area includes tall grasses interspersed with medium sized trees occurring at the northern part and the middle part has the occurrence of short grasses and some short trees. The southern part is characterized by mangroves along the Volta Estuary and tall grasses. It experiences a double maximum rainfall pattern with the major season being between March and July and the minor season beginning in September and ending in November. It has an annual rainfall between 800-1000 mm.

A continuous stretch of mangrove vegetation is found at the south-western end of the municipality, from Anyanui to Bomigo. This formed the basis of the selection of the area.

3.2 Data Collection

3.2.1 Satellite Imagery

Landsat Thematic Mapper (TM) imagery of the study area was obtained from the Global Land Cover Facility of the United States Geological Survey (http://earthexplorer.usgs.gov/) at a spatial resolution of 30m × 30m. This was to determine the mangrove area, determine the land cover features and estimate the above-ground carbon stocks in the mangroves.

A total of three Landsat TM images; 1991, 2002 and 2014 were obtained for the classification of mangroves to determine the areal coverage of the mangroves within the study area. The selected data sets were cloud free images acquired between January and March as shown in Table 3.1.

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Table 3.1 Dates of Landsat images acquired

Year	Month	Satellite
1991	March	Landsat 4
2002	January	Landsat 7
2014	March	Landsat 8

The Advanced Space borne Thermal Emission and Reflectance Radiometer (ASTER) Global Digital Elevation Model (GDEM) version 2 was obtained from the NASA's Land Processes Distributed Active Archive Centre. The ASTER GDEM is a map of the earth surface derived from an optical stereo instrument that observes the landscape including its land cover. The data was generated at a sample space of 30 meters. It was obtained in order to estimate mangrove heights. This is based on an assumption that mangroves are located at sea level and elevation measurements can be calibrated to estimate canopy height of mangroves (Simard *et al.* 2006)

3.2.2 Questionnaire Administration

Field work was carried out in February, 2016 in two villages (Bomingo and Hawui) in the Lower Volta Area. These settlements were selected because they were villages in which mangroves were harvested extensively. The objectives of the study were to access the perception of the change in mangroves area, identify socio-economic

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drivers of mangrove exploitation and assess the willingness to use LPG as an alternative energy source.

The total population of the two communities reported by (Ghana Statistical Service, 2012) was about 1000. With an annual growth rate of 2.5 % per annum, the population was projected to be about 1200 in 2016 and a sample size of 120 was selected.

A total number of 120 questionnaires were administered by purposive sampling to residents belonging to the two mangrove harvesting communities. Data gathered from respondents covered the following:

- Demographics
- Occupation
- Benefits derived from mangroves and how these benefits have changed
- Socio-economic factors that drive mangrove exploitation
- Willingness to use Liquefied Petroleum Gas as an alternative energy source

3.3 Data Analysis

3.3.1 Pre-Processing and Spatial sub-setting of Landsat images

Three clear, cloud free Landsat images were selected to classify the study area: March, 1991; January, 2002 and March, 2014. These periods also coincided with

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Ghana's dry season making field sampling and ground truthing relatively easy compared with the wet season. The study area is contained within Landsat path 193 and row 56.

The Landsat images were subset using the spatial/spectral tool in ENVI 4.7. The tool was used to obtain a region of interest with a high concentration of mangrove vegetation.

3.3.2 Analysis Using ENVI 4.7 and ArcMap 10.1

The methods for data analysis included image classification (supervised and unsupervised), an accuracy assessment (confusion matrix), development of land cover classes and change detection analysis.

In order to obtain natural/true colour of the images, the following bands were loaded: bands 7, 5 and 3 for Landsat 8 and Landsat 4, bands 3, 2 and 1 for Landsat 7.

3.3.3 Unsupervised Classification

An unsupervised classification using Iterative Self-organizing Data Analysis (ISODATA) in ENVI 4.7 was carried out initially to determine the coverage of mangroves in the study area. This was to help in the field validation and later supervised classification (Fatoyinbo *et al*., 2008; Fatoyinbo & Simard, 2013). Unlike the K-mean method which required prior knowledge in order to estimate the number of cluster, the ISODATA creates as many class as possible based on the data by automatically calculating class means evenly distributed in the data space and then iteratively clustering the remaining pixels using minimum distance techniques. Each iteration process recalculates means and reclassifies pixels with respect to new means. The pixels are then classified to the nearest class unless a standard deviation or

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distance threshold is specified. The iteration process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations reached (Tou & Gonzalez, 1974)

3.3.4 Supervised Classification

This classification method is used to cluster pixels in a data set into classes corresponding to user defined training areas. Different regions of interest (ROIs) were carefully selected as training areas for a supervised classification in ENVI 4.7. The Maximum Likelihood supervised classification, which assumes that the class statistics in each band is normally distributed and determines whether a pixel belongs to a specific class based on the highest probability (maximum likelihood).

ENVI implements maximum likelihood classification by calculating the following discriminant functions for each pixel in the image (Richards, 1999)

$$g_i(x) = \ln p(\omega_i) - \tfrac{1}{2} \ln |\Sigma_i| - \tfrac{1}{2}(x - m_i)^T \Sigma_i^{-1} (x - m_i) \qquad \text{(Eq. 4)}$$

Where: i = class

x = n-dimensional data (where n is the number of bands)

$p(\omega_i)$ = probability that class ω_i occurs in the image and is assumed the same for all classes

$|\Sigma_i|$ = determinant of the covariance matrix of the data in class ω_i

Σ_i^{-1} = its inverse matrix

m_i = mean vector

Data from World Atlas Earth scan by Spalding *et al.* (2010) and high-resolution imagery from Google Earth aided in the identification of mangroves during the classification.

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The resulting classes were combined into a final classification with four land cover types:

(i) Mangroves

(ii) other vegetation,

(iii) water

(iv) bare ground).

3.3.5 Confusion Matrix

A confusion matrix also known as the error matrix was used to assess the accuracy of the image classification. It does so by comparing the image classification to the ground truth information. The result of an accuracy assessment provides an overall accuracy of the map based on an average of the accuracies for each class in the map.

$$\text{Overall accuracy} = \frac{\text{Number of pixels correctly classified}}{\text{Total number of pixels}} \qquad \text{(Eq.5)}$$

Kappa is used to measure the agreement or accuracy between the classification map and the reference data as indicated by the major diagonals and the chance agreement indicated the row and column totals (Jensen, 2003). The kappa co-efficient is given by the formula below:

$$\text{Kappa (k)} = \frac{P_0 - P_e}{1 - P_e} \qquad \text{(Eq.6)}$$

Where P_0 : the proportion of correctly classified cases

P_e : represents the proportion of correctly classified cases expected by chance

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3.3.6 Change Detection Analysis

After each image belonging to the respective years was classified, a multi-date post comparison and change detection algorithm was used to determine changes in the land cover in the intervals; 1991-2002 and 2002-2014. The change detection computed class or pixel change, change in area and percentage change for all classes

3.3.7 Field Measurements

A survey of mangrove sites within the study area was conducted from the 10^{th} to 13^{th} of February, 2014. This period was within the range of time the satellite images of the study were acquired and also within the dry season making the mangroves fairly accessible. Field visits were based on preliminary maps of mangrove areas that had been obtained for initial visits and classifications.

A total number of 14 sites were visited during the field survey. GPS readings of mangrove locations were taken as ground control points across the study area covering towns including Salo, Dzita, Atitete, Anyanui and Bomingo.

A total of 20 sample plots of 0.01 ha (10m × 10m) were assessed in five mangrove sites. Parameters that were taken included GPS readings, mangrove heights, mangrove species and number of trees found within a sample plot. The mangrove height was determined by measuring the distance from tree and angle of elevation using a range finder and clinometer respectively. The height of the tree was computed using obtained tree distance and angle of elevation. The tree height measurements was used to estimate the above ground mangrove biomass

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3.3.8 Estimating the Above-ground biomass of Mangroves

Using the land cover map, all the areas that were not within the mangrove area on the GDEM were masked. This included areas with heights above 15 m. This is because the tallest trees recorded from field measurements was 12 m similar to the tallest mangrove tree observed by Ntyam (2014) at Songhor which is also located in the coastal savanna zone. An assumption of maximum tree height of 15 m was therefore established

The ASTER GDEM was calibrated using equation (1) derived from Simard *et al.*(2006). The equation was applied based on the assumption of low tree diversity and similar structural and zonation patterns observed in mangrove ecosystems worldwide (Chapman, 1944, 1970; Smith, 1992). For this study, it was assumed that mangroves grow at sea level and therefore topography was not taken into account. This is because the ASTER GDEM has a positive bias to land cover features such as woody wetlands and mixed forests (Meyer & ASTER-GDEM-Validation-Team, 2011).The elevation measured by GDEM correlates with canopy height and can therefore be calibrated to estimate the canopy height of mangroves ((Simard *et al*., 2006).

$$\mathbf{H = -2.19 \times 1.12\, H_{GDEM}} \qquad \text{(Eq. 7)}$$

The above ground biomass was estimated using a global allometric equation (7) developed by Saenger & Snedaker (1993) which was used by Fatoyinbo *et al.* (2008) and Fatoyinbo & Simard (2013) in estimating the biomass of mangroves in Mozambique and Africa respectively .

$$\mathbf{B_H = 10.8 \times \boldsymbol{H} + 35 \quad RMSE\ 43.8} \qquad \text{(Eq. 8)}$$

Where B_H : above-ground biomass

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H : mangrove canpopy height

RMSE: root mean square error

The carbon stock was then computed from the above-ground biomass using the conversion factor of 0.5 (Tang *et al*., 2014) as shown below.

$$\mathbf{C = 0.5 \times ABG} \quad \text{(Eq. 8)}$$

(Where C is the carbon stock and ABG is the above-ground biomass)

3.3.9 Socio-economic factors that drive mangrove exploitaitoin and the willingness to use LPG as an alternative energy source

In order to determine whether the identified socio-economic factors were significant in influencing the decision to exploit mangroves, a multiple regression analysis was conducted using the equation given below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + e \quad \text{(Eq.9)}$$

Where Y : decision to exploit mangroves

β_0 : constant of regression

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$: respective regression co-efficient

X_1, X_2, X_3, X_4, X_5 : respective independent variables (factors that influence mangrove exploitation)

e :error of regression

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A logistic regression using odds ratio was used to determine the willingness of the local people to use LPG as an alternative source of energy using the equation given below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + e \qquad \text{(Eq. 10)}$$

Where Y : willingness to use LPG as alternative energy source

$\beta_1, \beta_2, \beta_3$: respective regression co-efficient

X_1, X_2, X_3 : respective independent variables of price, safety and preference

e : error of regression

3.4 Limitations of Study

A major challenge during field sampling was accessibility to mangrove areas due to lack of roads necessitating movement by boat in some instances. Field plots were therefore established along the road from Salo down to Anyanui. The sizes of plots were significantly smaller than the spatial resolution of satellite images. It was therefore assumed that the natural height variability of mangroves in the study area was not fully represented and therefore could not be used to calibrate the ASTER DEM (Simard *et al*., 2008)

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CHAPTER FOUR

4.0 RESULTS

4.1 Land-Use/Cover features

For the purpose of this study, four land cover features were identified in the Lower Volta area. These were Mangrove (*Rhizophora sp and Avicennia sp*), Water, Other Vegetation and Bare Ground. The description of each land cover feature is listed in the Table 4.1found below

Table 4.1 Land-Use/Cover features

Land Cover Feature	Description
Mangrove	All mangrove tree species mainly Rhizophora sp and *Avicennia sp*
Water	Natural water sources including rivers and lakes (Volta lake)
Bare Ground	Bare land areas and other areas with patches of grass
Other Vegetation	All other vegetation types apart from mangroves

The proportion and distribution of land cover features by area and percentages is shown for the years 1991, 2002 and 2014 in Tables 4.2, 4.3 and 4.4 and Figures 4.1, 4.2 and 4.3 respectively. There was a continuous decline in, mangrove area from 1991-2014, the areas for bare ground and other vegetation increased within the period. There was a significant decrease in the area covered by water between 1991-2002.

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4.2 1991 Land Cover Accuracy Assessment

An accuracy assessment was conducted with ground reference points and randomly generated points to produce an overall accuracy of 85.43% with a kappa coefficient of 0.787

Table 4.2 Distribution summary of land cover features (1991)

Land Cover Feature	Points	Percentages	Area/ m^2
Mangrove	106.616	34.22%	95, 954,400
Water	36,981	11.87%	33,282,900
Bare Ground	119,962	38.51%	107,965,800
Other Vegetation	47,983	15.40%	43,184,700

INTEGRI PROCEDAMUS

4.3 Distribution of Land cover features (1991)

The total subset representing the Lower Volta covered about 280 km^2. Out of this total, approximately 34.22% was classified as mangroves representing an area of 95.954 km^2. Other land cover types that were classified included water mainly the Volta Lake. This covered 11.87%, representing 33.283 km^2, bare ground which included some settlement areas and covered 38.51% representing 107.966km^2, and other vegetation types covered 15.40% representing 43.185 km^2. This is summarised in the Table 4.2.

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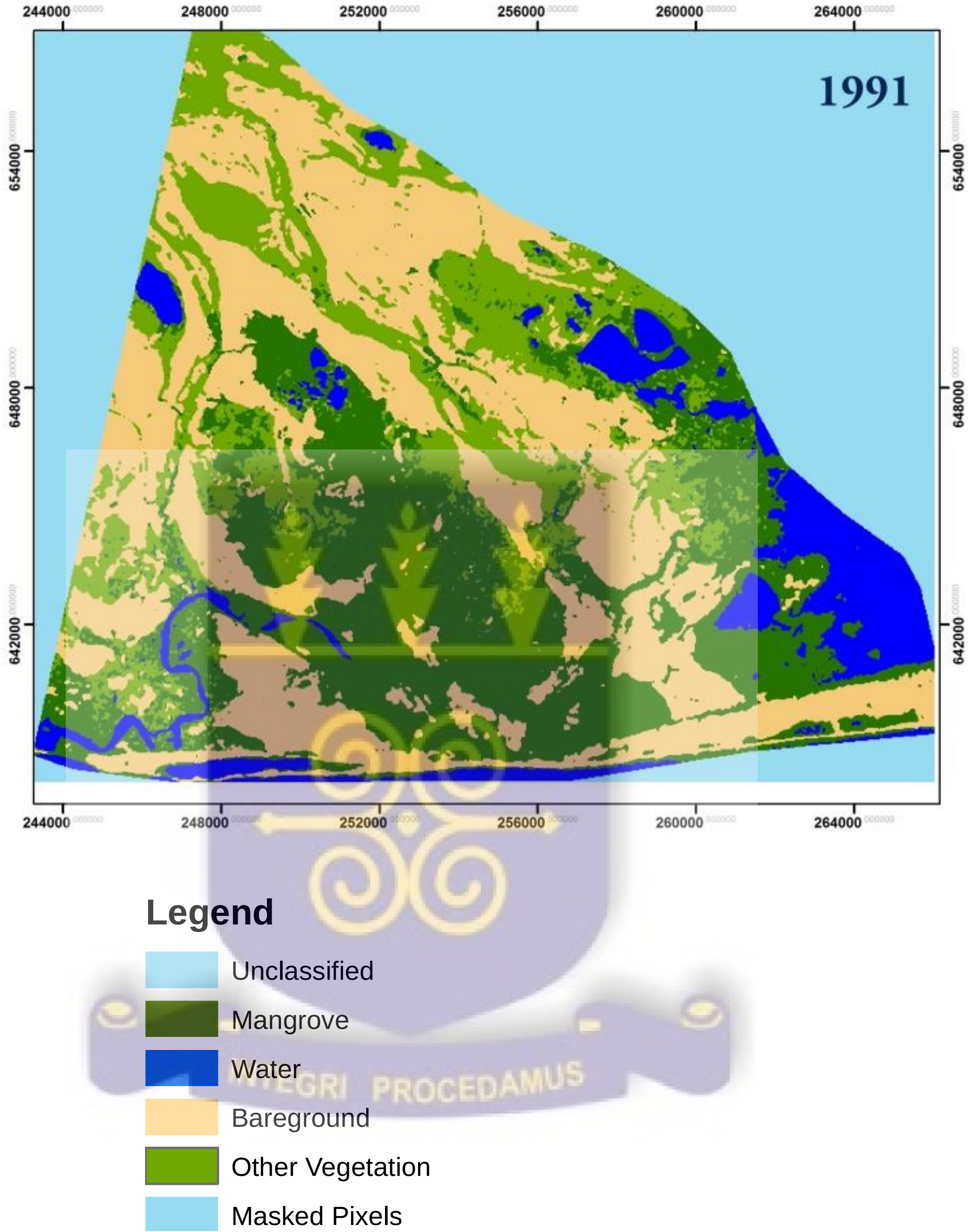

Figure 4.1 Map of land cover features (March, 1991)

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4.4 2002 Land Cover Accuracy Assessment

An accuracy assessment was conducted with ground reference points and randomly generated points to produce an overall accuracy of 90.09% with a kappa coefficient of 0.864

Table 4.3 Distribution summary of Land cover features (2002)

Land Cover Feature	Points	Percentages	Area/m^2
`Mangrove	97.445	35.00%	87,700,500
Water	23, 655	8.50%	21, 289, 500
Bareground	125,002	44.91%	112,501,800
Other Vegetation	56, 404	23.51%	58, 863,600

4.5 Distribution of Land cover features (2002)

Out of the total area covered by the study area. Approximately 35% were classified as mangroves accouting for 87.700km^2. Water which was mainl contributed by the Volta lake contributed 8.50% , representing 21.190km^2. The bareground class which included some settlement areas covered 44.91% of the study area representing 112.502km^2. The other vegetation covered 23.51% representing 58.863km^2.

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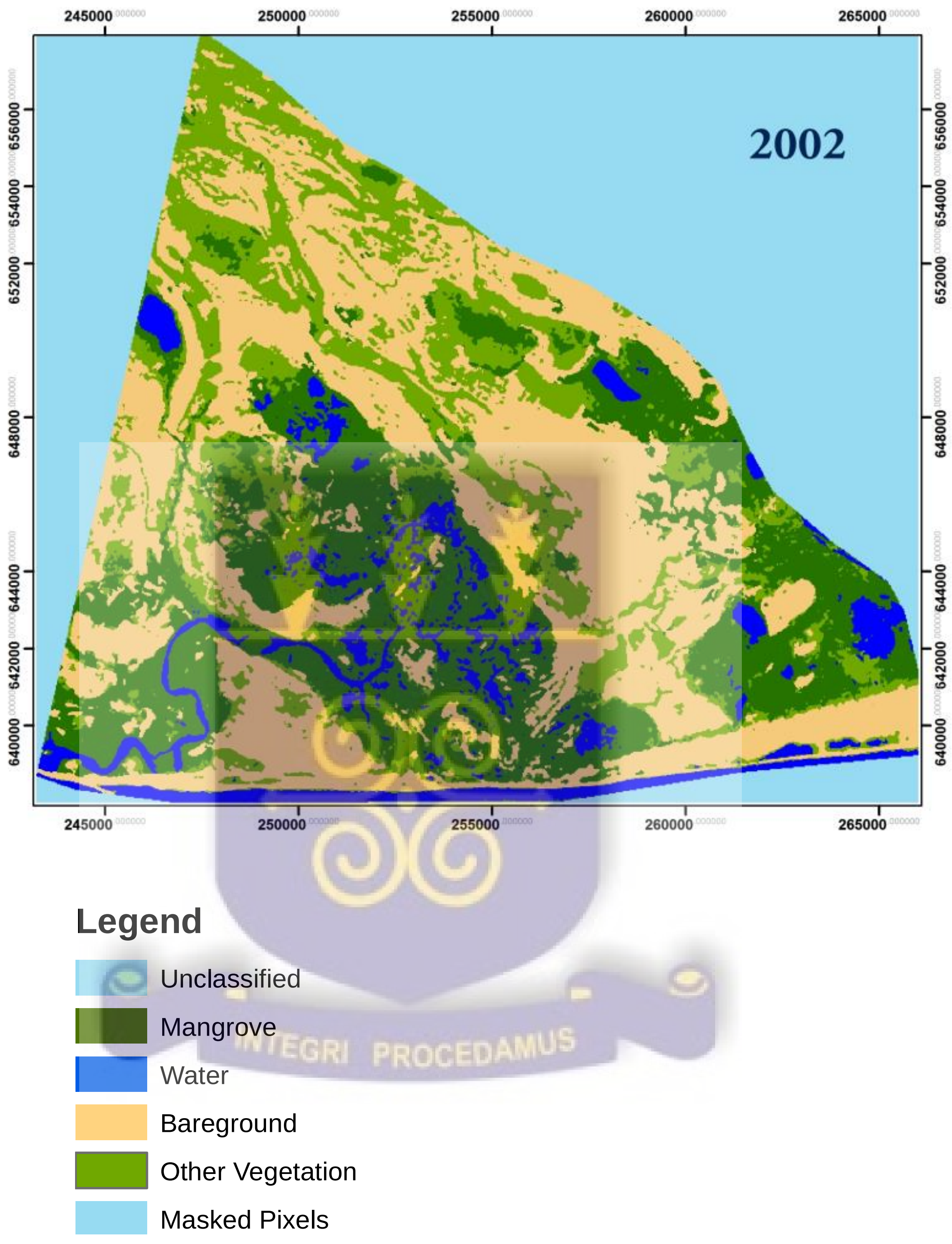

Figure 4.2 Map of land cover features (January, 2002)

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4.5 Land Cover Accuracy Assessment (2014)

An accuracy assessment was conducted with ground reference points and randomly generated points to produce an overall accuracy of 85.18% with a kappa coefficient of 0.7957

Table 4.4 Distribution summary of Land cover features (2014)

Land Cover Feature	Points	Percentages	Area/ m^2
Mangrove	70,810	22.73%	63,729,000
Water	26,200	8.41%	23,580,000
Bare Ground	135,492	43.49%	121,942,800
Other Vegetation	79,048	25.37%	71,143,200

4.6 Distribution Summary of Land cover features (2014)

Out of the total classified area , approximately 22.73% was classified as mangroves representing an area of 63.729 km^2. Water covered 8.41% of the area representing 23.580km^2, bare ground which included some settlement areas covered 43.49% representing 121.943km^2 and other vegetation types covered 25.37% representing 71.143km^2

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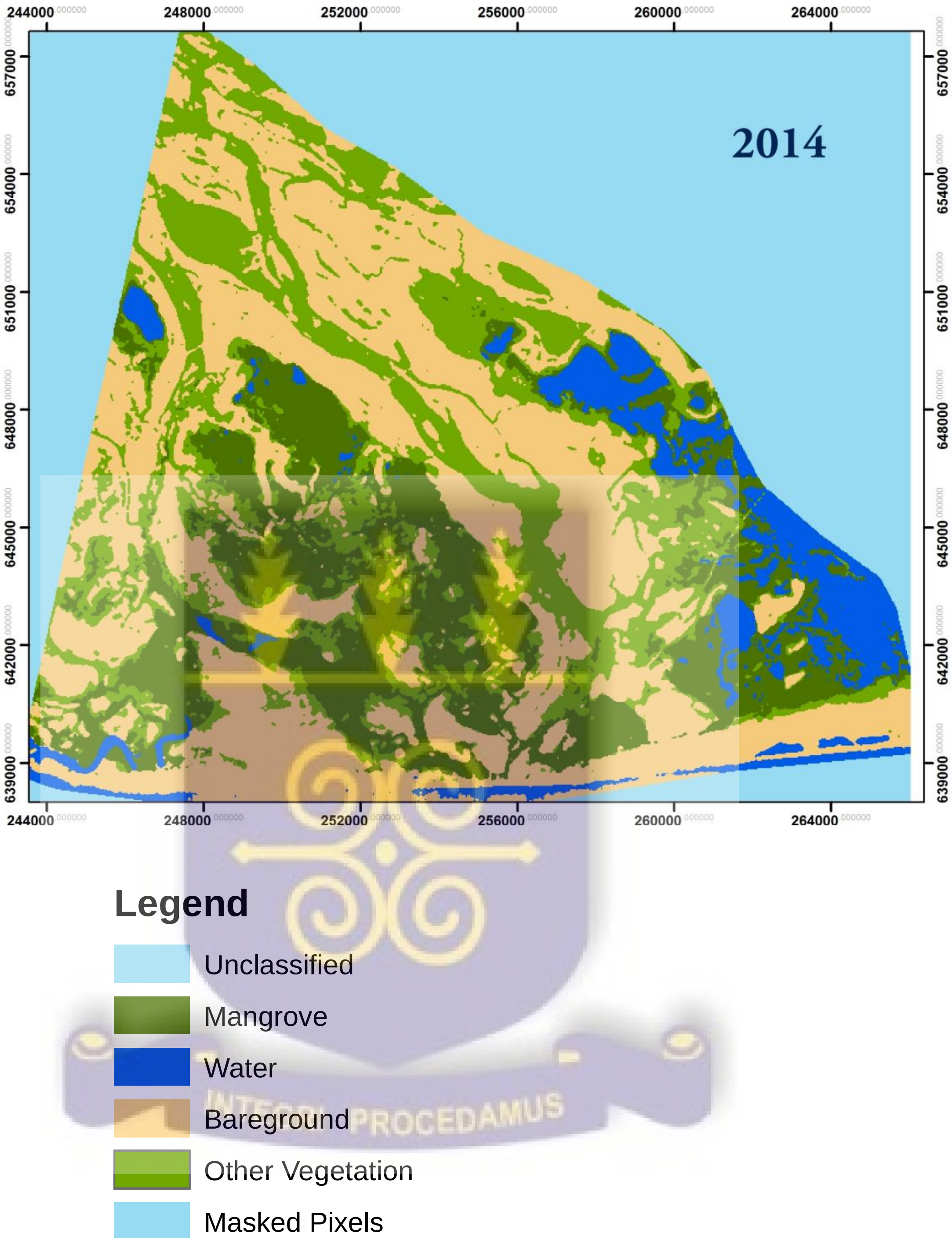

Figure 4.3 Map of land cover features (March, 2014)

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4.6 Patterns of changes in land cover features from 1991 to 2002

Table 4.6 shows the changes in land cover features between 1991 and 2002 in both percentages and area. The mangrove area in 2002 reduced by about 8.6% compared with the area covered in 1991. The area covered by water showed a similar pattern of change, decreasing by about 36.0% compared with the area covered in 1991. Within this same period, there was an increase in the area covered by bare ground and other vegetation. The bare ground area cover increased by about 4.2% and the other vegetation area increased by about 36.3%. The pattern of change over the 10 year period showed the conversion of about 40% of the mangrove area into other classes; bare ground, water and other vegetation accounting for about 14%, 7% and 18% respectively. The changes in area coverage of each of the land cover features from 1991-2002 is shown in Table 4.6 below.

Table 4.5 Changes in area cover of land cover features (1991-2002)

Land cover feature	Area (1991) (km^2)	Area (2002) (km^2)	Change (km^2)
Mangrove	95.95	87.70	-8.25
Water	33.28	21.29	-11.99
Other Vegetation	43.18	58.86	+15.68
Bare ground	107.97	112.5	+4.54

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Change Detection (1991-2002)

Table 4.6 Changes in land cover features (1991-2002)

Percentages (Final 2002)	Bare ground	Mangrove	(Initial 1991) Other Vegetation	Water	Row Total	Class Total
Mangroves	2.288	60.999	24.748	48.073	99.988	100
Water	1.134	7.368	0.634	38.222	99.996	100
Bare ground	84.095	13.996	16.525	3.38	99.985	100
Other Vegetation	12.461	17.63	58.039	10.262	99.977	100
Masked Pixels	0.022	0.008	0.054	0.062	0.042	100
Class Total	100	100	100	100	0	0
Class Changes	15.905	39.001	41.961	61.778	0	0
Image Difference	4.201	-8.602	36.307	-36.035	0	0

Area (Square Km)	Bare ground	Mangrove	Other Vegetation	Water	Row Total	Class Total
Mangroves	2.47	58.53	10.69	16	87.69	87.7
Water	1.22	7.07	0.27	12.72	21.29	21.29
Bare Ground	90.79	13.43	7.14	1.13	112.48	112.5
Other Vegetation	13.45	16.92	25.06	3.42	58.85	58.86
Masked Pixels	0.02	0.01	0.02	0.02	0.07	177.24
Class Total	107.97	95.95	43.18	33.28	0	0
Class Changes	17.17	37.42	18.12	20.56	0	0
Image Difference	4.54	-8.25	15.68	-11.99	0	0

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4.7 Patterns of changes in land cover features from 2002 to 2014

Table 4.7 shows the changes in land cover features from 2002-2014 in both percentages and area. There was a 27% decline in the mangrove area in 2014 compared with area covered by mangroves in 2002. In contrast to the previous period between 1991and 2002, the area covered by water increased by about 11% in 2014. The area covered by bare ground and other vegetation showed a similar pattern of increase. The area covered by other vegetation showed the greatest increase of 20.1% and the bare ground area increased by about 8.4%.

There were also some significant changes between classes. Other vegetation area has about 41% its area being converted into other classes including bare ground and mangroves accounting for 24% and 11% respectively. The mangrove area also had about 47% of its area being converted into other vegetation and water, these accounted for 26% and 12% , respectively. The area covered by water had the highest amount of area (58%) being converted into other classes. About 40% was converted to mangroves and 15% into bare ground.

Table 4.8 Changes in area cover of land cover features (2002-2014)

Land cover feature	Area (2002) (km^2)	Area (2014) (km^2)	Change (km^2)
Mangrove	87.70	63.73	-23.97
Water	21.29	23.58	+ 2.29
Other vegetation	58.86	71.14	+12.28
Bare ground	112.5	121.94	+9.44

Change Detection (2002-2014)

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Table 4.9 Changes in land cover features (2002-2014)

Percentages			Initial (2002)			
Final (2014)	Mangroves	Water	Bare Ground	Other Vegetation	Row Total	Class Total
Mangroves	53.238	40.279	1.592	11.334	99.999	100
Water	12.233	41.907	0.485	5.721	99.927	100
Bare ground	8.740	15.642	86.062	23.937	99.970	100
Other Vegetation	25.772	2.16	11.853	58.986	99.966	100
Masked Pixels	0.016	0.013	0.008	0.021	0.022	100
Class Total	100	100	100	100	0	0
Class Changes	46.762	58.093	13.938	41.014	0	0
Image Difference	-27.333	10.759	8.392	20.861	0	0
Area (Square Km)						
	Mangroves	Water	Bare Ground	Other Vegetation	Row Total	Class Total
Mangroves	46.69	8.58	1.79	6.67	63.73	63.73
Water	10.73	8.92	0.55	3.37	23.56	23.58
Bare Ground	7.67	3.33	96.82	14.09	121.91	121.94
Other Vegetation	22.6	0.46	13.34	34.72	71.12	71.14
Masked Pixels	0.01	0	0.01	0.01	0.04	177.2
Class Total	87.7	21.29	112.5	58.86	0	0
Class Changes	41.01	12.37	15.68	24.14	0	0
Image Difference	-23.97	2.29	9.44	12.28	0	0

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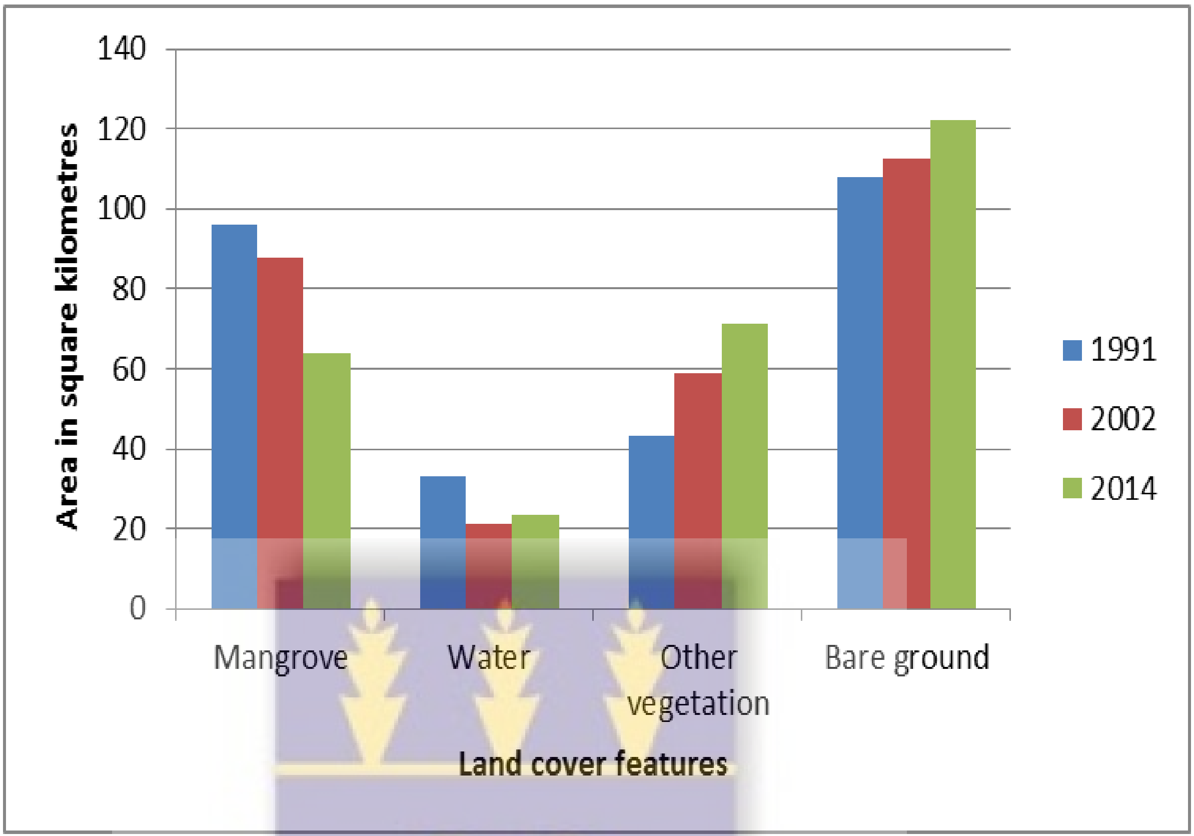

Figure 4.4 Changes in land cover features from 1991-2014

4.8 Patterns of changes of land cover features from 1991-2014

Figure 4.4 shows the changes in terms of area coverage of the land cover features over a 23-year period. The mangrove area reduced from 95.95 km^2 in 1991 to 87.7 km^2 in 2002. This represented a decline of 8.6 %. The decline continued from 87.7 km^2 to 63.73 km^2 representing a 27.3% reduction in mangrove area. A comparison of the mangrove area from 1991 to 2014 showed a significant decline of 33.6% in mangrove area. There was a significant reduction of the area covered by water from 33.28 km^2 in 1991 to 21.29 km^2 in 2002. In contrast, there was a small increase of 2.29 km^2 in the area covered by water from 2002 to 2014. The area coverage of the bare ground and other vegetation increased steadily from 1991 to 2014. The other vegetation area cover increased from 43.18 km^2 to 58.86 km^2 in the 1991-2002 period and then from 58.86 km^2 to 71.14 km^3 in the 2002-2014 period. The bare ground increased from

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107.97 km^2 to 112.5 km^2 in the 1991-2002 period and then from 112.5 km^2 to 121.94 km^{2}in the 2002-2014 period, representing an overall increase of 13.8%

4.9 Mangrove Height and Biomass estimation

Mangrove height represented in Figure 4.5 ranged from 1.19 m to 14.61 with a height average of 6.9m. Height values are represented on a grey scale with low values gradating form dark regions to high values in lighter regions

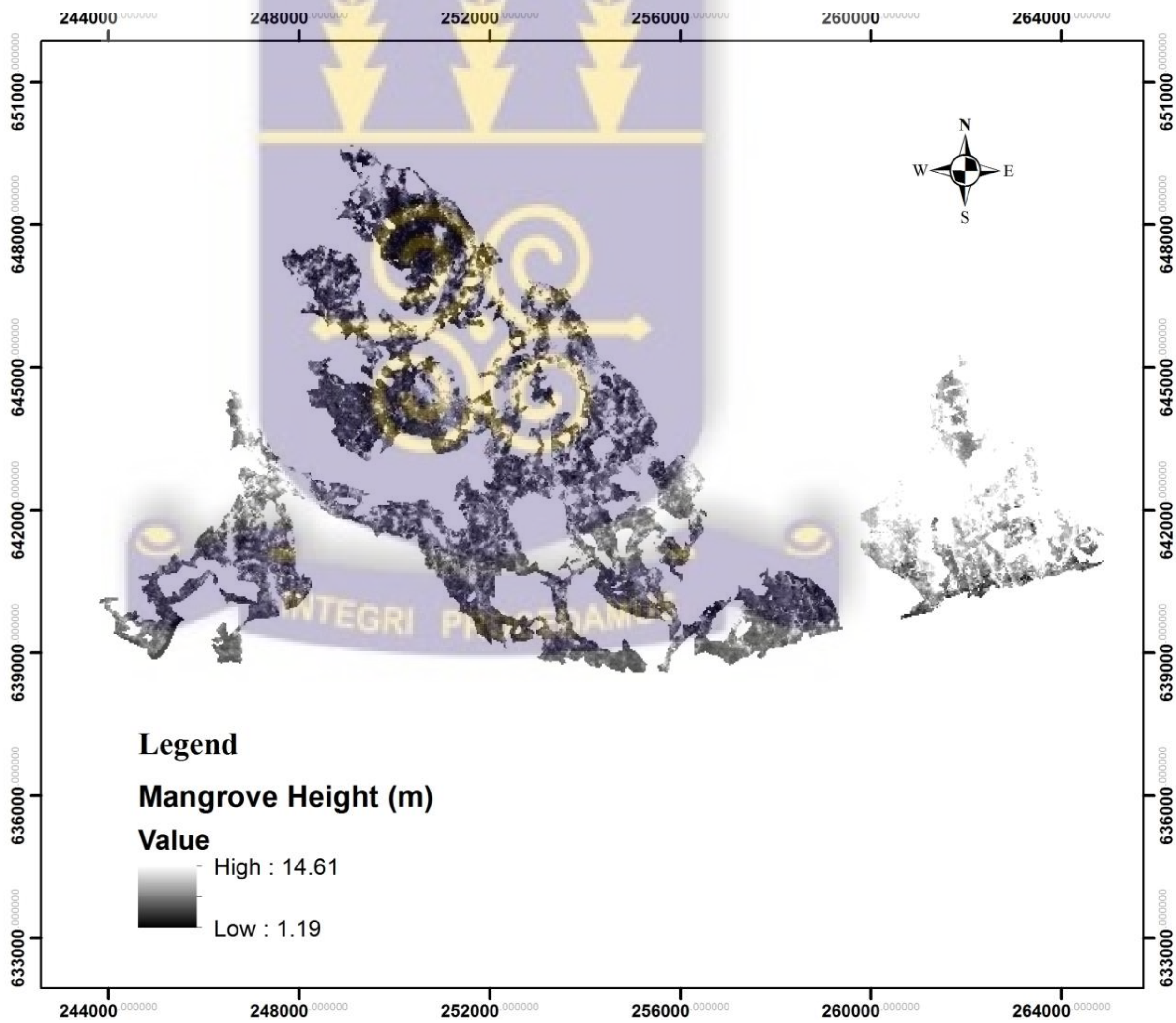

Figure 4.5 Map of mangrove heights

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The above-ground biomass of mangroves represented in Figure 4.6 ranged from 46.9 Mg to 192.788 Mg with an average of 109.8 Mg. The total above-ground biomass and carbon is shown below in Table 4.10. Height values are represented on a grey scale with low values gradating form dark regions to high values in lighter regions

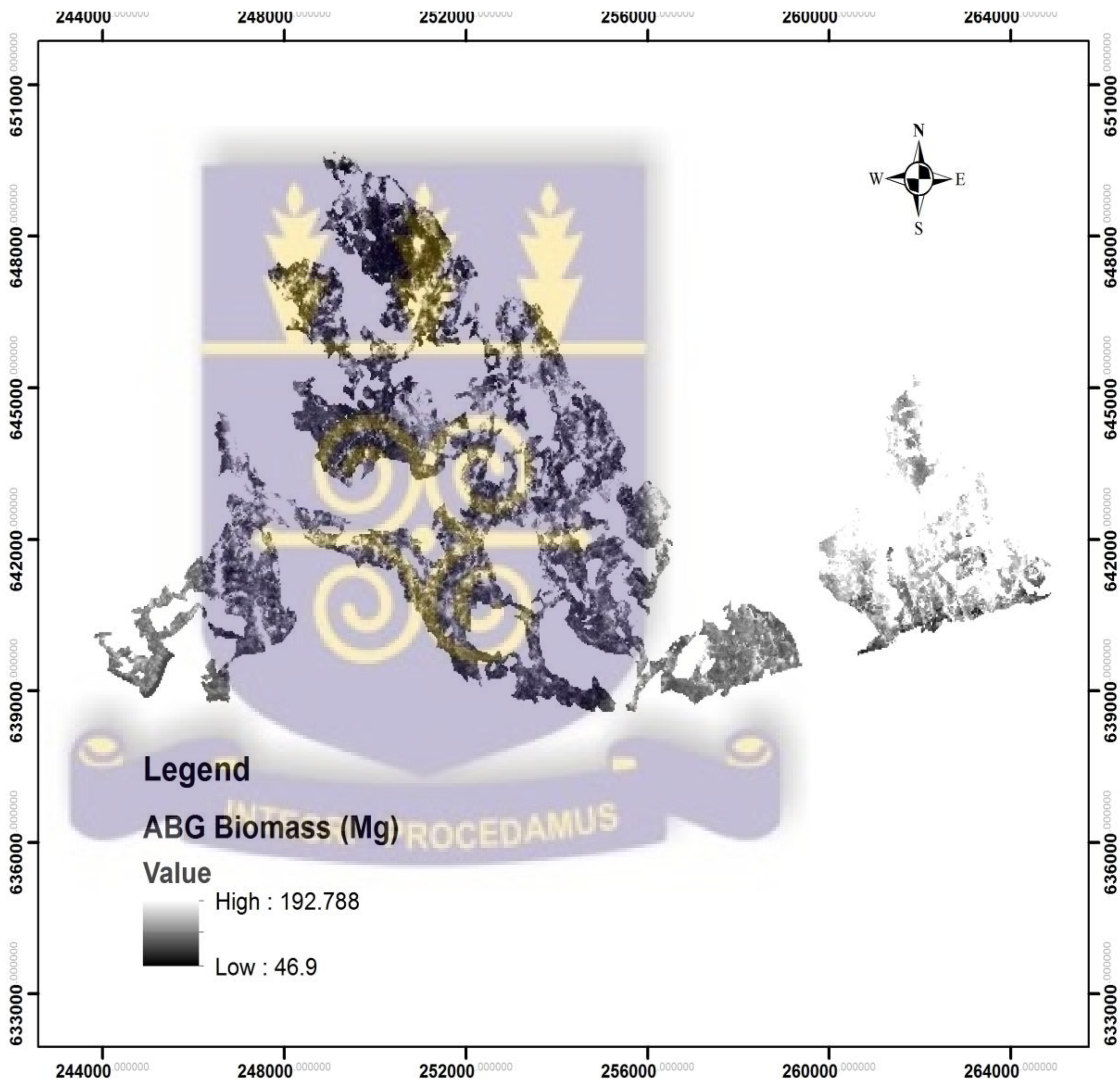

Figure 4.6 Map showing the above-ground biomass of mangroves (2014)

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Table 4.10 Above-ground biomass and carbon stock of mangroves (2014)

Area (km^2)	Total Biomass (Mg)	Biomass per hectare (Mg/ha)
53.766	538,759.00	100.204
Area (km^2)	Carbon (Mg)	Carbon per hectare (Mg/ha)
53.766	269,379.50	50.102

Table 4.11 Changes in Above-ground biomass and carbon from 1991-2014

Year	1991	2002	2014	Change (1991-2014)
Mangrove				
Area (km^2)	95.95	87.70	63.73	-32.22
Biomass (Mg)	961,457.38	878,789.08	638,600.09	-322857.29
Carbon (Mg)	480,728.69	439,394.54	319,300.05	-161428.65

Table 4.12 Potentially lost CO2 from 1991-2014

Carbon Stock Lost (Mg)	Potentially lost CO_2 (Mg)
161,428.65	602,352.15

Table 4.13 Average changes in carbon stocks and average rate of change

Period	Change in Carbon (Mg)	Rate of Change per year (Mg/yr)
1991-2002	- 413,34.15	- 3757.65
2002-2014	-120,094.49	- 10007.87
Average	-807,14.32	-6882.76

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4.10.1 Perception of Change

There was a consensus on the general decline of mangroves in the Lower Volta area. However with respect to the mangroves area in the two communities, opinions were divided. In Bomingo, about 77% of respondents from Bomingo reported that the mangrove area in their community had increased. Of these respondents, 44% were male and 56% were female. In terms of occupation, about 4% of those who observed an increase in mangrove coverage were fishermen, mangrove harvesters and people who engaged in both fishing and mangrove harvesting accounted for 65% and 30%, respectively. Seventy-seven percent of those who reported an increase in mangrove area coverage attributed the changed to excessive planting of mangroves. The remaining 23% had no idea as to the cause of the increase in mangroves. About 17% of respondents in Bomingo reported a decrease in mangrove area. Of this, 60% were male and 40% were female. In terms of occupation, 40% were mangrove harvesters and the remaining 60% engaged in both mangroves harvesting and fishing.

In Hawui, about 79% of respondents reported a reduction in mangrove coverage. Of these, about 67% were male and 33% were female. In terms of occupation, 33% were engaged in fishing and 67% engaged in mangrove harvesting. About 93% of respondents who observed a reduction in mangrove area attributed them to the harvesting of mangroves resources. The remaining 7% attributed the reduction in mangroves to changes in hydrology of the Volta River. Of the 21% of respondents who reported increase in mangrove area, about 64% was male and about 36% were female. In terms of occupation, about 27% engaged in fishing, 45% were mangrove harvesters and 27% engaged in both fishing and mangrove harvesting.

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4.10 Social Survey Results

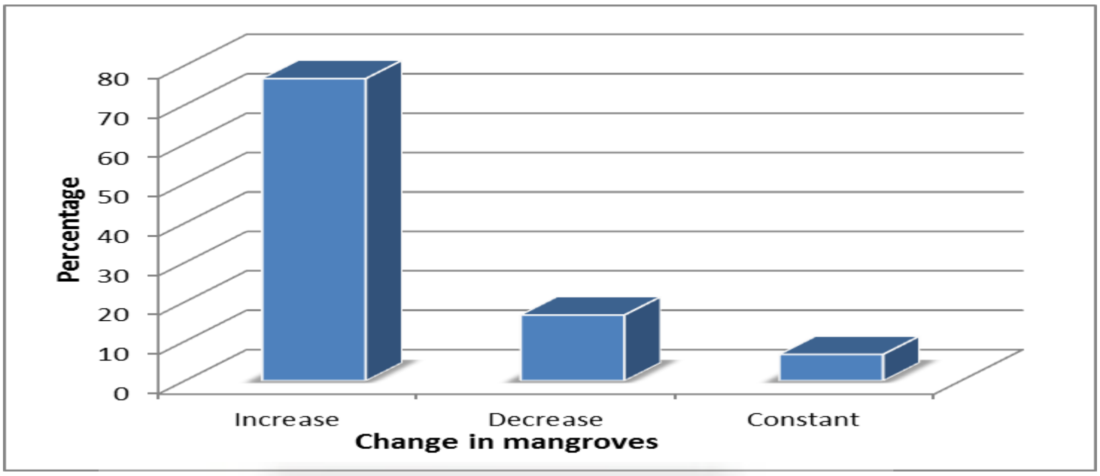

Figure 4.7 Perception of change in Bomingo

Figure 4 8 Gender Perceptions of Change in Bomingo

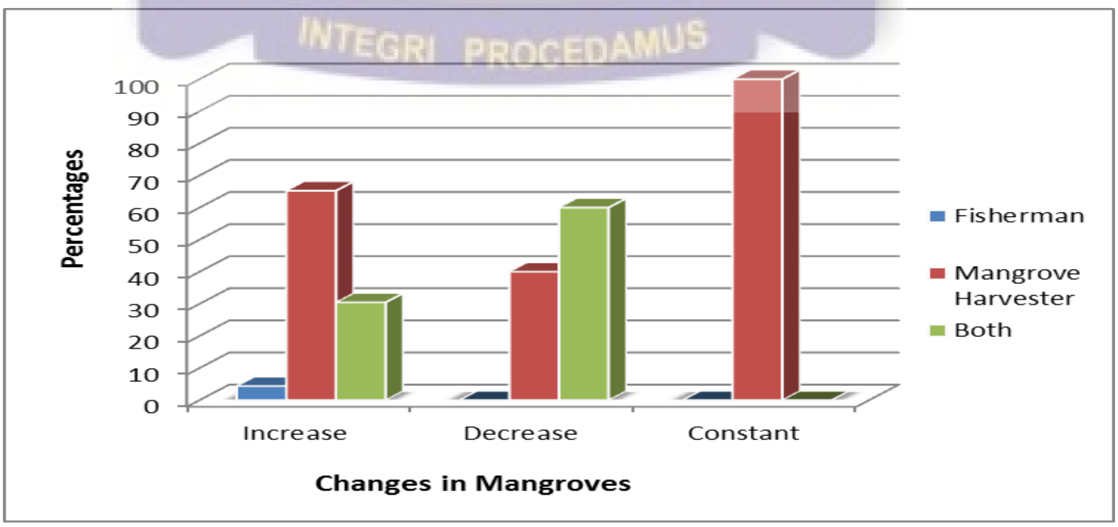

Figure 4 9 Perception of Change by Occupation in Bomingo

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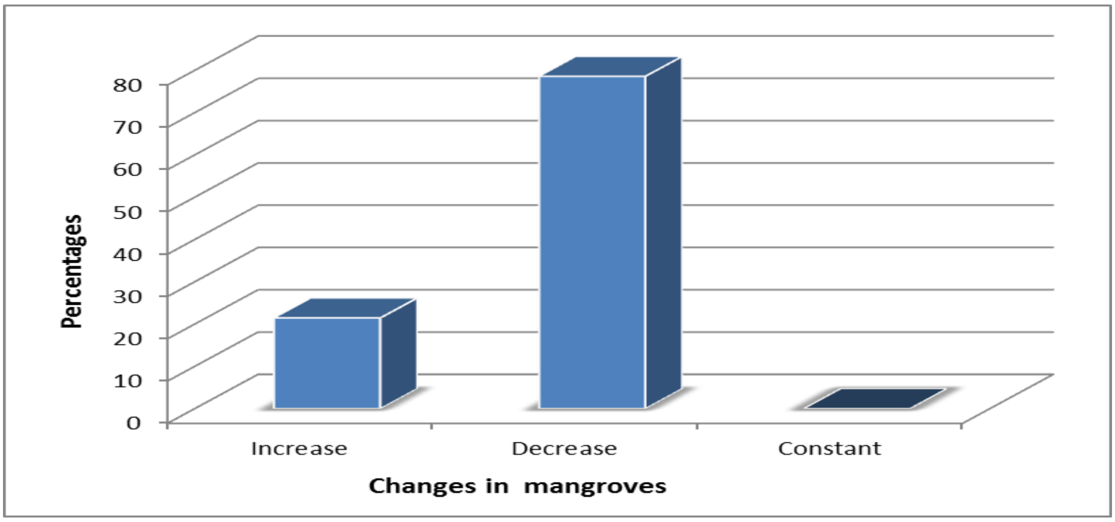

Figure 4.10 Perception of change in Hawui

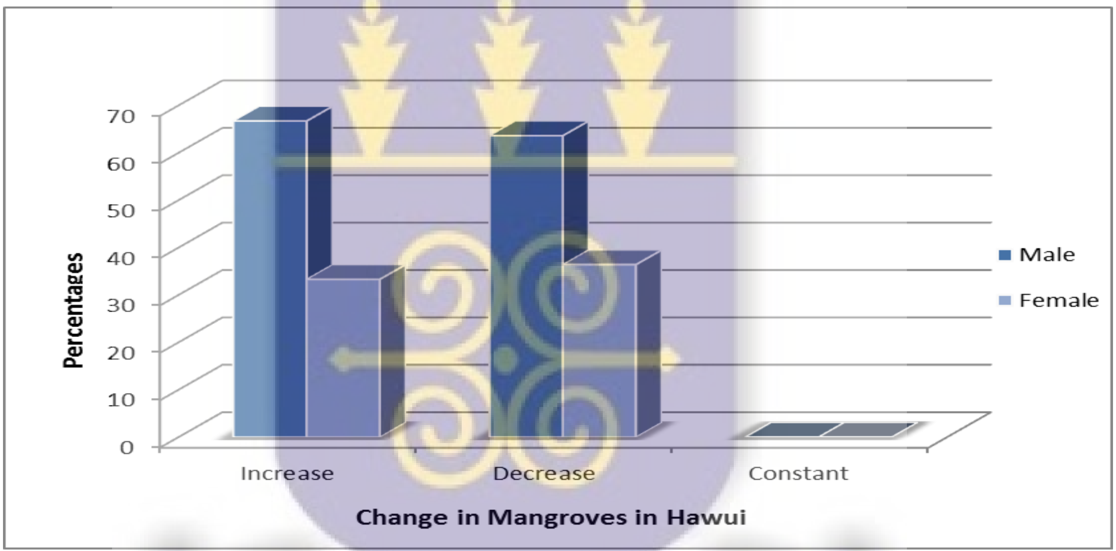

Figure 4 11 Gender Perceptions of Change in Hawui

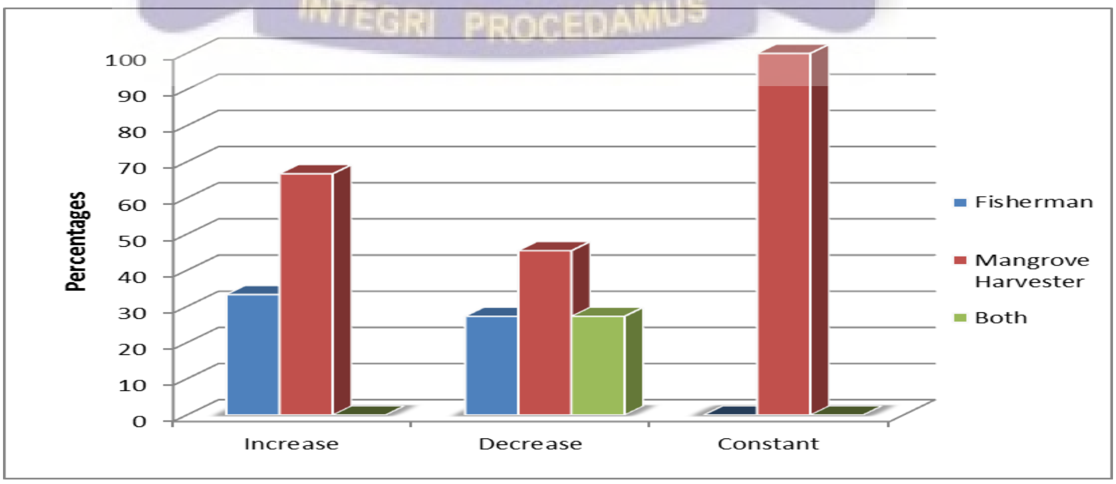

Figure 4.12 Perception of Change by Occupation in Hawui

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4.10.2 Socio-economic factors that drive mangrove exploitation

The major factors that influence the respondent's decision to exploit mangrove resources in the study area were identified as:

(i) Increased income (ii) wood for constructions

(iii) Medicinal purpose (iv) commercial supply of wood fuel

(v) Supply of wood fuel for domestic use

In order to establish whether these factors influenced the decision to exploit mangroves, a multiple regression analysis was conducted. The results showed that these factors significantly influence the decision to exploit mangroves at 95% confidence interval ($p = 0.035$).

An individual test of significance was conducted using a t-test statistic to determine the significance of individual factors in influencing the decision to exploit mangroves. The results revealed that the following factors were significant; increased income, commercial supply of fuel wood and supply of wood fuel for domestic use as show in Table 4.14 below with a $p < 0.05$. Lack of alternative energy sources and medicinal purposes were not significant factors to influence the decision to exploit mangroves.

The R^2 obtained from the regression output was 0.65. This means that about 65% of the total variation with benefits derived from mangrove harvesting is being attributed to the identified factors shown in Table 4.14. This indicates that about 35% of the variation is unaccounted for.

In terms of magnitude, increased income has the highest outcome with a co-efficient of 0.838. This was followed by commercial supply of commercial supply of wood

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fuel with a co-efficient of 0.525, supply of wood for domestic use with a co-efficient of 0.430,wood for construction with a co-efficient of 0.240, lack of alternative energy source with a co-efficient of 0.197 and medicinal purpose with a co-efficient of 0.142 respectively.

Table 4.14 Significance of socio-economic factors in influencing mangrove exploitation

Variable	Co-efficient	Standard Error	p-value	Confidence Interval
Increased income	0.838	0.304	0.001*	0.425-0.920
Commercial supply of fuel wood	0.525	0.341	0.002*	0.16-1.213
Supply of wood fuel (domestic)	0.430	0.242	0.023*	0.059-0.524
Wood for construction	0.240	0.330	0.125	0.150-0.320
Medicinal purpose	0.142	0.208	0.063	0.105-0.221
Lack of alternative energy source	0.197	0.202	0.03*	0.212-0.605

*significant at $P \leq 0.05$

The demographic characteristics of the respondents were also analysed to find out whether they influenced the decision to exploit the mangrove resource. The analysis showed that the demographic characteristics i.e. sex, age, marital status, number of

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children and education level did not have any significant influence on the decision to exploit the mangrove resource ($p > 0.05$) as shown in Table 4.15.

Table 4.15 Significance of demographic characteristics in influencing mangrove exploitation

Variable	Co-efficient	Standard Error	p-value	Confidence Interval
Age	-0.800	0.158	0.616	-0.067-4.703
Marital Status	0.255	0.255	0.323	-0.804-0.123
Sex	-0.340	0.229	0.146	-0.400-0.240
Educational level	-0.074	0.131	0.575	-0.339-0.191
Number of children	0.060	0.082	0.466	-0.105-0.226

In order to test the willingness to use LPG as an alternative energy source, a binary logistic regression analysis was conducted. The results showed that respondents are about 0.445 times less likely to use LPG because of price of the product. It also showed that the local people are 1.497 times more likely to use mangroves due to preference than to use LPG. It was also shown that the people were about 0.743 times less likely to use LPG as an alternative energy source due to safety. These results are shown below in Table 4.16.

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Table 4.16 Willingness to use LPG as alternative energy source

Variable	Co-efficient	Standard Error	Odds ratio	p-value	Confidence interval
Price	-0.809	0.907	0.445	0.030*	0.75-2.633
Preference	0.404	0.980	1.497	0.001*	0.219-10.221
Safety	0.298	0.966	0.743	0.758	0.112-4.932

*significant at $p \leq 0.05$

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CHAPTER FIVE

5.0 DISCUSSION

5.1 Image Classification Accuracy

The lowest overall accuracy was 85.18% for the 2014 classification and the highest was 90.09% for the 2002 classification. The highest kappa co-efficient was 0.864 for 2002 classification and 0.796 for the 2014 classification. According to Rahma *et al.*, (2004), kappa values greater than 80% represent a strong agreement between the classification map and ground reference points. The classification map generated from this study therefore has a strong agreement with ground information. Classification accuracy (confusion matrix) reports can be found in Appendix 1.

5.2 Change Detection

The decrease in mangrove vegetation within the period between 1991 and 2002 could be attributed to the exploitation of the mangroves by the local people. Tsikata *et al*., (1997) reported that the damming of the Volta River at Akosombo and Kpong resulted in the decline of economic opportunities such as marine and inland fishing. The construction of the dam resulted in changes in the hydrology and salinity of the water. These in addition to changes in climatic conditions, declined soil fertility and population pressure rendered the exploitation of the mangrove resource a major economic activity.

The conversion of 14% and 18% of mangroves to bare ground and other vegetation may be a reflection of the level of intensity of mangrove exploitation. A degraded mangrove area may be classified either as other vegetation or bareground depending

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on the degree of exploitation. The loss of mangrove area is consistent with the increase in area covered by bare ground (5%) and other vegetation (16%). The results also showed a significant decrease in the amount of water between 1991 and 2002. This change could be attributed the differences in dates of acquisition of Landsat images. The 2002 Landsat image was acquired in January, which is a dry month throughout the country whiles the 1991 Landsat image was acquired in March, which marks the beginning of raining season (Ghana Meteological Agency, 2016).

Within the period between 2002 and 2014, the mangrove vegetation area fell by 27%. This could be attributed to an increase in the intensity of mangrove exploitation. While the use of mangroves as fuel wood has been a traditional practice of the local people (Aheto *et al.* 2016), increased population with associated increase in demand for both domestic use (Ghana Statistical Service, 2008) and commercial markets (Arthurton *et al.*, 2006) may contribute to such significant decrease in mangrove area. The mangrove area loss is consistent with the observed conversion of about 47% of the mangrove vegetation into other classes, mainly other vegetation which accounted for 26%. Although there was a general increase in the area covered by water which could be attributed to rainfall that starts in the month of March, about 58% of the previous cover had been converted into other classes. A significant portion of the area covered by water (40%) was shown to have been converted into mangroves. This could be as a classification error as a result of the inability to discriminate between mangroves and mudflats that occur within the mangroves. The mudflats may occur as a result of the drying up of the waterbody.

Figure 4.9 provides a snapshot of changes that have occurred between 1991 and 2014. The observed 33% decline in mangroves area between 1991 and 2014 could be

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attributed to the progressive increase in mangrove exploitation alluded to by the Ghana Statistical Service, (2008), Arthurton *et al*., (2006) and Aheto et al., (2016). The decline in mangrove area was consistent with the increase in area covered by other vegetation and bare ground. This increase in area could be attributed to the inclusion of degraded mangroves areas as part of the other vegetation class. The increase in bare ground area could be as attributed to mangrove areas that have been totally degraded as well as an increase in human settlements as a result of increased human population.

5.3 Estimating Mangrove Height, Biomass and Carbon Stock

The ASTER DEM was calibrated with the equation (7) derived by (Simard *et al*., 2006). Calibrated ASTER DEM height estimates were compared with field estimates, this showed a positive correlation with a standard error of 2.3m was close to the ASTER DEM error reported for flat areas by Tachikawa *et al*. (2011). The ASTER DEM was therefore considered well calibrated.

The aboveground biomass for 2014 was estimated by applying equation (3) developed by Saenger & Snedaker (1993). This equation was used by Fatoyinbo *et al*., (2008) and Tang et *al*., (2014) in estimating aboveground biomass of mangroves. This equation is applicable to mangrove forest trees with heights up to 40m. The mangrove area reduced from 63.73 km^2 to 53.77 km^2 due to the masking of heights above 15m. The total aboveground biomass for the mangrove area was estimated to be 5.38759×10^5 Mg. The aboveground biomass of mangrove per hectare was found to be 100.204 Mg/ha. This is similar to the mean aboveground living biomass of 94.49 ± 78 Mg/ha reported by Aheto *et al,* (2011). This is also consistent with the

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mean aboveground biomass of 97 Mg/ha estimated by Fatoyinbo and Simard (2013). These findings, according to Aheto *et al.* (2011), is indicative of low structural development of mangroves compared with other areas like French Guiana where Komiyama *et al.* (2008) estimated the aboveground biomass to be 169.1 Mg/ha and 315.5 Mg/ha for *Avicennia sp* and *Rhizophora sp* trees respectively. Fatoyinbo and Simard (2013) reported that estuaries and deltas with extensive freshwater supply provide good conditions for mangrove growth in terms of height and cover.

Estimates of stand biomass provides an indication of allocation of carbon in plant tissues which is important for carbon accounting or sequestration (Kairo *et al*., 2008). The total aboveground carbon stock estimated for the study area was 2.693795×10^5 Mg. The carbon stock per hectare was found to be 50.102 Mg/ha. This was within the range of values reported by Adame *et al*. (2013), Tang *et al.* (2014) and Rahman *et al.* (2015). The estimated carbon stock recorded, 50.10 Mg/ha, is within the range of 1.5-88 Mg/ha reported by Adame *et al.* (2013) and 45.24 -152.57 Mg/ha reported by Rahman *et al*. (2015). The carbon stock per hectare estimated from this study is similar to the mean aboveground carbon of Ghana's mangrove (56.57 Mg/ha) reported by Tang *et al.* (2014). Higher values of aboveground carbon (75.4-206 Mg/ha) was reported by Stringer *et al.* (2015). These differences could be attributed to the inclusion of leaf litter, downed debris and standing dead trees in estimating the aboveground carbon stocks.

An examination of the changes in mangrove carbon stock revealed that the study area has lost about 161,428.65 Mg of its carbon stock due to the loss of mangroves between 1991 and 2014. Pendleton *et al.* (2012) expressed carbon stock in terms potential CO_2 emissions by multiplying carbon stock by a factor of 3.67 (molecular

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weight ratio of CO_2 to C). This gives a value of 602,352.15 Mg of CO_2 that may have been lost. This figure is however conservative as a number of studies have shown that majority of the ecosystem carbon is stored within the sediment. An analysis of the changes in carbon stock revealed an average rate of 6,882.76 Mg of carbon is being lost per year.

5.4 Perception of Change

The general consensus of a decline in mangroves in the Lower Volta is in agreement with the loss of mangroves in Ghana reported in literature (Spalding *et al.*, 2010; Mensah, J., 2013; Aheto *et al.*, 2016). This loss in mangroves could be attributed to the commercial harvesting of mangroves as a livelihood alternative. Such an alternative was resorted to when livelihoods related to fishing and farming were lost due to reduction in riverine flow into the Keta lagoon, caused by the damming of the Volta River.

In Bomingo, majority of the respondents (77%) reported an increase in the mangrove, attributed to excessive planting. It was reported that mangroves were formerly planted in order to meet its demand as wood fuel for smoking fish. There had however been a fall in the demand of mangroves for wood fuel because of a progressive reduction in fish catch in Bomingo since the mangrove wood was used in smoking fish. This was also worsened by the extensive growth of mangroves which prevented fishing canoes to access fishing areas. The abundance of mangroves in the area has attracted residents from neighbouring villages such as Hawui and Tunu who engage in mangrove harvesting.

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In Hawui, about 79% of the respondents reported a reduction in mangrove area. This was attributed to the intensive harvesting of mangroves. The sole dependence of mangroves for domestic energy needs as well as present economic hardships makes the mangrove resource an integral component of local economy and its harvesting an alternative livelihood option. This has led to a total depletion of the mangrove resource in Hawui resulting in local residents moving to Bomingo to harvest mangroves.

5.5 Socio-economic factors that drive mangrove exploitation

A number of factors, namely; increased income, commercial supply of fuelwood and wood fuel for domestic use were significant factors that influenced the decision to exploit mangroves. This may be attributed to the fact that the mangrove resource is viewed as an economic resource (Tsikata *et al*., 1997; Aheto et al., 2016) and each of these factors have direct economic benefits. The sole dependence on fuel wood as energy for cooking as well as the existence of mangrove markets at Anyanui also contributes to the significance of these factors. The availability of modern health care facilities may be a possible reason as to why 'medicinal purposes' was not a significant factor in influencing the decision to exploit mangroves. Further analysis also revealed that the demographic characteristics of respondents had no significance in influencing the decision to exploit mangroves. This could be attributed to the limited economic opportunities making mangrove exploitation the accessible means to sustain their livelihood.

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5.6 Willingness to use LPG as an alternative energy source

Respondents were less likely to use LPG due to price and safety considerations. This is because ,in addition to LPG being more expensive due to the added cost of buying a cylinder (Bukari, 2012), it could also expose users to severe burns and injuries in case of an accident. The results also indicated that the respondents were more likely to use mangroves as fuel wood over LPG due to preference. This is in agreement with Tsikata *et al*., (1997) who attributed the preference of mangroves as fuel wood to their high caloric value and the attractive gold colour they impart onto fish when used in fish smoking.

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CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

In this study, a GIS based analysis was combined with a global allometric equation in order to estimate the aboveground biomass and aboveground carbon stock of mangroves in the Lower Volta. The carbon stock of mangroves was estimated and an analysis of change was conducted to determine changes that had occurred in both mangrove area cover and carbon stock in the periods 1991-2002 and 2002-2014. A social survey was also conducted to identify socio-economic factors that drive mangrove exploitation as well as to assess the willingness of the local people to use LPG as an alternative energy source.

6.1 Conclusions

The land cover features of the study area were classified as mangroves, water, bare ground and other vegetation. Changes in land cover features from 1991 to 2014 included a significant decrease in mangrove area as well as a significant increase in both other vegetation and bare ground areas.

Results showed that mangroves have decreased in area from 95.95 km^2 in 1991 to 63.73 km^2 in 2014. This observed change in mangroves could be attributed to the increased harvesting of mangroves as an alternative livelihood strategy. The harvesting of mangroves is therefore expected to continue as long as prevailing conditions of lack of economic opportunities and a lack of alternative energy sources remains in the study area.

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The decrease in mangroves has therefore resulted in the loss of the carbon stock which would subsequently have negative implications on the environment due to increased CO_2 concentration. An amount of 602,352.15 Mg of CO_2 is estimated to have been lost from 1991 to 2014 due to the loss of carbon stock in the study area measuring 161428.65 Mg. The results also indicated that carbon stock in the study area is beings lost at a rate of 6,882.76 Mg/yr.

Respondents perceive that mangroves area in the Lower Volta were on the decline however perceptions of changes in mangroves area within communities visited differed between the two communities. The respondents from Hawui perceived that mangroves in the area were on a decline with majority attributing the decline to the harvesting of mangroves. Respondents from Bomingo perceived that mangroves in the area were on the increase with majority attributing the increase to excessive planting of mangroves.

The decision to exploit mangroves was shown to be significantly influenced by the following factors: increased income, commercial supply for fuel wood and wood fuel for domestic use. This is attributed to the limited economic opportunities that prevail in the study area. This makes mangrove exploitation a readily available economic resource and therefore a livelihood alternative.

With respect to the willingness to use LPG as an alternative energy source, the local people were less likely to use LPG due to price and safety considerations. The results also showed that the local people preferred to use mangroves as fuel wood over LPG.

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6.2 Recommendations

Conclusions from this study point show that mangroves are on a continuous decline in the study area leading to the loss of carbon stock stored in the mangrove ecosystem. In order to address the decline of mangroves in the area, there is the need for involvement by all major stakeholders. The following are recommended:

- The trend of a decline in the mangrove area could be reversed through replanting exercises by community members facilitated by the District Assembly.

- There is the need for developing an effective management and monitoring of mangroves and other coastal resources. Capacities of responsible agencies such as the Environmental Protection Agency (EPA) should be developed to complete carbon stock inventories especially for blue carbon systems.

- Further research should be carried out by research groups, NGOs and Universities to quantify below-ground mangrove carbon stocks especially the bulk of the carbon is stored in the mangrove ecosystem.

- There is therefore the need for policies specific to mangroves and other blue carbon systems to be developed by the Ministry of Environment, Science, Technology and Innovation to ensure the protection of mangroves and their function as carbon sinks amongst others.

- In order to address the challenges of lack of economic opportunities and lack of alternative energy sources and to curtail the continuous exploitation of mangroves, the Ministry of Tourism should harness the huge tourism potential

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within the study area in order to create economic opportunities and thus provide an alternative livelihood strategy.

- There is the need for massive public education programmes by the Energy Commission to educate the local people on the safe use of LPG.
- There is also the need for the Energy Commission to increase accessibility to LPG as well as introduce LPG subsidies that would target the poor rural residents in order to encourage patronage of the product.

INTEGRI PROCEDAMUS

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APPENDICES

Appendix I: Confusion Matrix for 1991 Classification

Overall Accuracy = 85.43%   Kappa Coefficient = 0.7878

Ground Truth (Pixels)

Class	Mangrove	Water	Bareground	Other Vegetation	Total
Mangrove	5627	227	11	175	6040
Water	310	1629	0	235	2174
Bareground	0	0	3191	31	3222
Other Vegetation	814	88	126	1382	2410
Total	6751	1944	3328	1823	13846

Ground Truth (Percent)

Class	Mangrove	Water	Bareground	Other Vegetaion	Total
Mangrove	83.35	11.68	0.33	9.60	43.62
Water	4.59	83.80	0.00	12.89	15.70
Bareground	0.00	0.00	75.88	1.70	23.27
Other Vegetation	12.06	4.53	3.79	75.81	17.41
Total	100.00	100.00	100.00	100.00	100.00

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Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Mangrove	6.84	16.65	413/6040	1124/6751
Water	25.07	16.20	545/2174	315/1944
Bareground	0.92	2.17	31/3222	137/3328
Other Vegetation	42.66	24.19	1028/2410	441/1823

Class	Producer Accuracy (Percent)	User Accuracy (Percent)	Producer Accuracy (Percent)	User Accuracy (Percent)
Mangrove	83.35	93.16	5627/6751	5637/6040
Water	83.80	74.93	1629/1944	1629/2174
Bareground	95.88	99.04	3191/3328	3191/3222
Other Vegetation	75.81	57.34	1382/1823	1382/2410

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Appendix II: Confusion Matrix for 2002 Classification

Over all Accuracy = 90.09% Kappa Co-efficient = 0.864

Ground Truth (Pixels)

Class	Mangrove	Other Vegetation	Bareground	Water	Total
Mangrove	1974	541	0	0	2515
Other Vegetation	0	1546	60	0	1606
Bareground	0	25	2699	0	2724
Water	175	0	0	1063	1238
Total	2149	2112	2759	1063	8083

Ground Truth (Percent)

Class	Mangrove	Other Vegetation	Bareground	Water	Total
Mangrove	91.86	25.62	0.00	0.00	31.11
Other Vegetation	0.00	73.20	2.17	0.00	19.87
Bareground	0.00	1.18	97.83	0.00	33.70
Water	8.14	0.00	0.00	100.00	15.32
Total	100.00	100.00	100.00	100.00	100.00

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Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Mangrove	21.51	8.14	541/2515	15/2149
Other Vegetation	3.74	26.80	60/1606	566/2112
Bareground	0.92	2.17	25/2724	60/2759
Water	14.14	0.00	175/1238	0/1063

Class	Producer Accuracy (Percent)	User Accuracy (Percent)	Producer Accuracy (Percent)	User Accuracy (Percent)
Mangrove	91.86	78.49	1974/2149	1974/2515
Other Vegetation	73.20	96.26	1546/2112	1546/1606
Bareground	97.83	99.08	2699/2759	2699/2724
Water	100	85.86	1063/1063	1063/1238

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Appendix III: Confusion Matrix for 2014Classification

Over all Accuracy = 85.18%   Kappa Co-efficient = 0.7957

Ground Truth (Pixels)

Class	Mangrove	Water	Bareground	Other Vegetation	Total
Mangrove	2147	14	8	898	3067
Water	0	1049	0	6	1055
Bareground	2	0	2680	199	2881
Other Vegetation	0	0	71	1009	1080
Total	2149	1063	2759	2112	8083\

Ground Truth (Percent)

Class	Mangrove	Water	Bareground	Other Vegetaion	Total
Mangrove	99.91	1.32	0.29	42.52	37.94
Water	0.00	98.68	0.00	0.28	13.05
Bareground	0.09	0.00	97.14	9.42	35.64
Other Vegetation	0.00	0.00	2.57	47.77	13.36
Total	100.00	100.00	100.00	100.00	100.00

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Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Mangrove	30.00	0.09	920/3067	2/2149
Water	0.57	1.32	6/1055	14/1063
Bareground	6.98	2.86	201/2881	79/2759
Other Vegetation	6.57	52.23	71/1080	1103/2112

Class	Producer Accuracy (Percent)	User Accuracy (Percent)	Producer Accuracy (Percent)	User Accuracy (Percent)
Mangrove	99.91	70.00	2147/2149	2147/3067
Water	98.68	99.43	1049/1063	1049/1055
Bareground	97.14	93.02	2680/2759	2680/2881
Other Vegetation	47.77	93.43	1009/2112	1009/1080

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Appendix IV: Field Data and DEM height

ID	GPS coordinates X	Y	Dem Height	Field Height
1	0.777	5.838	12.3	10.2
2	0.784	5.829	3.4	2.5
3	0.789	5.821	4.5	3.9
4	0.784	5.812	16	13.2
5	0.798	5.806	7.9	3.5
6	0.809	5.799	4.5	3.8
7	0.822	5.786	3.4	1.8
8	0.825	5.782	11.2	3.5
9	0.824	5.781	6.7	6
10	0.815	5.782	11.2	3.5
11	0.793	5.774	7.9	6.2
12	0.797	5.780	11.2	6.9
13	0.766	5.779	3.4	2.6
14	0.759	5.780	4.53	3.9
15	0.759	5.782	3.41	3.1
16	0.712	5.775	2.3	2.1
17	0.727	5.787	6.7	3.8
18	0.723	5.795	10.1	4.9
19	0.734	5.816	7.9	6.1
20	0.728	5.788	5.6	4.9

Appendix V: Mangrove Height and ASTER DEM Regression

R	R Square	Adjusted R	Standard Error
0.787	0.619	0.597	2.382

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Appendix VI: Survey Questionnaire

UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

INSTITUTE FOR ENVIRONMETAL SCIENCE AND SANITATION STUDIES

ENVIRONMENTAL SCIENCE PROGRAMME

QUESTIONNAIRE TO INVESTIGATE THE EFFECTS OF LOSS OF MANGROVES ON THE LIVELIHOODS OF THE PEOPLE

SECTION A- DEMOGRAPHICS

Community: ……………………………….…

1. Sex 1. Male [ ] 0. Female [ ]
2. Age 1. Under 20 [ ] 2. 21-40 [ ] 3. 41-60 4. 60+ [ ]
3. Marital status 1. Single [ ] 2. Married [ ] 3. Divorced/Separated [ ]

   4.Widow/Widower[ ]
4. How many children do you have? 0. None [ ] 1. 1 [ ] 2. 2 [ ] 3. 3[ ] 4. 4 [ ]

   5. 5 [ ] 6+ [ ]
5. What is your highest level of education? 1. No formal education [ ]2. Primary [ ]

   3.Secondary Education (SHS/Vocational/Technical school) [ ] 4. Diploma [ ]

   5.Bachelors [ ] 6. Post graduate [ ]
6. What is your occupation?

SECTION B-PERCEPTION OF VULNERABILITY CONTEXT

7. What are the benefits you obtain from mangroves?

   [ ] Fishing [ ] Collection of wood fuel [ ] Both [ ]

   Other……………………..…

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8. Is this your main source of income? Yes/No

   If No, What is your man source of income?

9. Have you noticed any changes in the mangroves during the last 10 years? 1.Yes [ ] 2.No [ ]

10. If yes, what changes have you noticed?

11. What do you think is the cause for the changes in thmangroves?

12. How have the changes affected the benefits/services you get from mangroves?

SECTION C-HOUSEHOLD

13. How many people do you have in your household?

14. Are you a household head? 1. Yes [ ] 0. No [ ]

15. How many people in your household depend on you

SECTION E- SOCIO-ECONOMIC FACTORS & WILLINGNESS TO USE LPG

16. Do you exploit mangroves? Yes [ ] . No [ ]

17. Which of these factors influence your decision to exploit mangroves

    [ ] increased income [ ] fuel wood (domestic) [ ] fuel wood (commercial)

    [ ] construction [ ] medicinal purpose [ ] lack of alternative energy source

18. Are you willing to use LPG as an alternative energy source? Yes [ ] No [ ]

19. Which factors influence you to use or not use LPG

    [ ] price

    [ ] Preference

    [ ] Safety