ABOVEGROUND BIOMASS CHANGE AND TERRESTRIAL CARBON STOCK IN THE FOREST AND WOODLAND AREAS OF SOUTHWESTERN NIGERIA

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DEDICATION

This thesis is dedicated to the memory of my late parents (Kevin and Cecelia Udofia) who left me as a child and would be so proud to see educational achievement.

The Thesis is also dedicated to the honour of the Blessed Virgin Mary who has always been my succour in difficult times.

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Samuel Kevin Udofia

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LIST OF ACRONYMS

AGB	Aboveground Biomass
CASA	Carnegie-Ames-Stanford Approach
CBFM	Community Based Forest Management
CHM	Canopy height models
CO_2	Carbon Dioxide
CPA	Canopy projection area
DBH	Diameter at Breast Height
DN	Digital Number
ENVI	Environment for visualizing Iage
ETM+	Enhanced thematic mapper
FAO	Food and Agriculture Organization
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FLEGT	Forest Law Enforcement, Governance, and Trade
GHGs	Greenhouse Gases
GIS	Geographic Information System
GPP	Gross Primary Production

GPS	Global Positioning System
IPCC	Intergovernmental Panel on climate change
kg/m^2	Kilograms per meters square
LIDAR	Light Detection and Ranging
LST	Land Surface Temperature
LUE	Light Use Efficiency
LULC	Land Use Land Cover
LULCC	Land use/ land cover change
MAXLIKE	Maximum Likelihood
MgC/ha	Mega Grams Carbon per Hectare
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Vegetation Index
NDWI	Normalized Difference Water Index
NEP	Net Ecosystem Productivity
NPP	Net Primary Production
OLI	Operational Land Imager
PAR	Photosynthetically Active Radiation

RADAR	Radion Detection and ranging
REDD+	Reduce Emissions from Deforestation and Forest Degradation
SAVI	Soil Adjusted Vegetation Index
SFM	Sustainable Forest Management
SOC	Soil Organic Carbon
SR	Simple Ratio
SSP	Shared Socioeconomic Pathway
STSM	State Transition Simulation Model
SW	Southwestern
TM	Thematic mapper
UAVs	Unmanned Aerial Vehicles
USGS	United States Geological Surveys
VPA	Voluntary Partnership Agreement

Abstract

The forest ecosystem is a significant global carbon sink, but anthropogenic activities such as deforestation and forest degradation have led to increased carbon emissions, thereby contributing to climate change. This study examines changes in aboveground biomass and carbon fluxes in Southwest Nigeria's forest and savannah woodland from 1986 to 2016. Southwest Nigeria was chosen for its high number of forest reserves, enhancing the study's empirical validity. Using the concepts of the carbon cycle and socio-ecological theory, the research employed remote sensing data and field sampling to assess land use/land cover changes, biomass, and carbon. The CASA model was used for carbon estimation, and the STsim model projected future patterns. Results revealed that savannah woodland lost 17,743.97 km^2, agriculture gained 3,407.95 km^2, and forests lost 2,316.99 km^2 at an annual rate of 35.66 km^2. Savannah woodland biomass declined from 141 g/m^2 in 1986 to 70 g/m^2 in 2016. The CASA model indicated a carbon loss of 140 g/m^2 in forests and 119 g/m^2 in savannah woodland between 1986 and 2016. Field measurements showed natural forests had the highest carbon stock (3646.26 MgC/ha) and biomass (8038.63 tons/ha), followed by cocoa plantations. Grasslands had the lowest carbon stock and biomass. Future projections predict a decline in carbon stock from 200 MgC/ha in 2016 to 80 MgC/ha in 2066. The study highlights significant biomass loss due to deforestation, underscoring the need to preserve forest resources and mitigate climate change impacts in Southwest Nigeria.

Keywords: Biomass, Carbon Sequestration, Carbon stock, Climate Change, Remote Sensing

CHAPTER ONE

INTRODUCTION

1.1 Background to Study

The diversity of plant species within an ecosystem is intricately linked to environmental factors such as climate, soil, and geology. These variables collectively shape the floristic composition of plants, influencing the biomass and carbon makeup of natural forests and savannah woodlands. Vegetation encompasses all plant species and ground cover, forming distinct clusters that characterize the spatiotemporal attributes of a location and the growth forms of dominant plant species. The floristic composition of an area plays a pivotal role in determining the rate of carbon sequestration in ecosystems. It directly influences the capacity of the ecosystem to sequester and store carbon within the Aboveground Biomass (AGB). The carbon sequestration rate is closely tied to the floristic composition of the forest (Pareta & Pareta, 2011). This process is essential for maintaining and balancing the carbon dioxide (CO_2) stock within the forest environment. In essence, forests are crucial for upholding environmental equilibrium on Earth. By sequestering and storing carbon, the floristic composition of the forest contributes significantly to the overall carbon balance in the ecosystem. This underscores the vital role of forests in mitigating the impact of CO_2 emissions and sustaining a balanced and healthy environment.

Forest loss can arise from both human activities and natural phenomena, although human-induced causes are more prevalent. Agricultural and urban expansion stand out as major contributors to the diminished carbon sequestration capacity of vegetation and the subsequent reduction in carbon stocks. Fasona, Adeonipekun, Agboola, Akintuyi, Bello, Ogundipe, Omojola (2020) have pinpointed key drivers of deforestation and forest degradation in Southwest Nigeria, including activities like lumbering, pole extraction, fuelwood and charcoal production, crop cultivation, urban growth, and animal grazing, all of which result in significant carbon emissions. While human activities predominantly drive forest loss, natural causes such as climate change, wildfires, and flooding played a role in tropical deforestation during the 1980s and 1990s. In the case of Nigeria, the primary forests have dwindled to 13,944 km^2, with a staggering 95% loss due to deforestation at an annual rate of 5% between 2010 and 2015. Presently, only 10% of the original forest in Nigeria remains (Oyebo, Bisong, & Morakinyo, 2010). This extensive loss, resulting from deforestation and forest degradation, has significantly compromised the vegetation's ability to sequester carbon, leading to increased carbon emissions. Monitoring vegetation biomass is essential for understanding ecosystem responses and its role in the global carbon cycle. Recognizing forests as potent carbon sequestration agents, various studies have focused on estimating aboveground biomass or carbon stocks across diverse land uses (Sun & Liu, 2020). Commonly employed methods for assessing forest biomass include harvesting samples and field measurements of plant parameters like diameter at breast height (dbh) and tree height. These approaches contribute to our understanding of how forests contribute to carbon sequestration and help in devising strategies for sustainable forest management.

Recent advancements in high-resolution space-borne and air-borne satellite data present an opportunity for improved estimation and mapping of Aboveground Biomass (AGB) across diverse spatial and temporal scales. Unmanned Aerial Vehicles (UAVs) contribute to super-fine resolution biomass estimation for specific applications. The utilization of remote sensing data, including satellites like Sentinel 2, Landsat OLI, and SPOT, offers spectral advantages for comprehensive descriptions of vegetation types based on species composition, canopy density, and site conditions

(Roy and Kumar 1986). This investigation into alterations in Aboveground Biomass (AGB) and carbon fluxes holds significance, as it sheds light on the estimation of biomass in southwestern (SW) Nigeria. This estimation not only quantifies the carbon losses resulting from deforestation and forest degradation but also establishes the baseline for carbon stocks. This, in turn, positions the region to potentially access global green carbon funds and other incentives.

1.2 Statement of Problem

In recent decades, deforestation and forest degradation have emerged as pressing environmental concerns, profoundly affecting global carbon cycles. These processes involve the clearing of forests, either for agricultural expansion, urban development, or unsustainable logging, leading to a significant release of stored carbon into the atmosphere. The released carbon compounds, primarily in the form of carbon dioxide (CO_2), contribute to the greenhouse effect, exacerbating climate change and its associated consequences in southwestern Nigeria. Therefore, the major issues faced are the ability to quantify the amount of forest loss over a very large area like southwest Nigeria and quantifying the forest of past years.

Accurately quantifying and understanding the scale of carbon fluxes has been the paramount challenge in the field of environmental science. The core issue at hand is the need to precisely measure and monitor the net carbon emissions and sequestration dynamics over a very large study area without having to employ the traditional method of measuring individual trees. The quantification of carbon fluxes is vital for several reasons. Firstly, it aids in assessing the immediate environmental impact on forest ecosystems and their biodiversity. Secondly, it is indispensable for gaining insights into the broader global carbon budget, essential for addressing climate change. Carbon trading represents a sector within the global economy that channels financial support to countries capable of establishing their carbon baseline. Despite the abundance of forest resources in southwest Nigeria, the region has been unable to benefit from this opportunity due to its reliance on traditional field survey methods for estimating carbon stock, hindering the establishment of a carbon baseline.

Plate 1.1: Uncoordinated logging in the study area (source: Author 2017)

Furthermore, the escalating concerns of deforestation and forest degradation (as shown on Plate 1.1) pose critical challenges to global carbon cycles. This study aims to tackle the issue by focusing on the accurate quantification of carbon fluxes. To achieve this, the research leverages remote sensing technology and biomass estimation models. By utilizing these advanced tools, the study seeks to enhance the precision and efficiency of measuring carbon fluxes, providing valuable insights into the dynamics of carbon emissions and sequestration in the context of the studied region.

Remote sensing technology offers a non-invasive and cost-effective approach to monitor changes in land cover and land use, including deforestation and forest degradation. Satellites equipped with various sensors can capture images of the Earth's surface at regular intervals, allowing for the detection of changes over time. These images can be processed using sophisticated algorithms to classify different land cover types and estimate forest biomass and carbon stocks. By analyzing remote sensing data, researchers can identify areas experiencing deforestation or degradation and quantify the associated carbon emissions.

In addition to remote sensing, biomass estimation models play a crucial role in quantifying carbon fluxes. These models use a combination of field data, remote sensing imagery, and environmental variables to predict the biomass of forests and other vegetation types. By calibrating and validating these models with ground-truth data, researchers can accurately estimate carbon stocks and track changes in forest carbon over time. Furthermore, advances in machine learning and artificial intelligence techniques have improved the accuracy and scalability of biomass estimation models, allowing for more precise carbon accounting at regional and global scales.

The application of remote sensing technology and biomass estimation models in southwestern Nigeria presents an opportunity to enhance the understanding of carbon dynamics in the region. By leveraging these tools, researchers can overcome the limitations of traditional field surveys and achieve a more comprehensive assessment of forest carbon stocks and fluxes. This, in turn, can inform decision-making processes related to forest management, conservation, and climate change mitigation efforts.

Moreover, the establishment of a robust carbon monitoring system in southwestern Nigeria is essential for the region's participation in international carbon trading mechanisms. By accurately quantifying carbon stocks and fluxes, the region can demonstrate its contribution to global efforts to reduce greenhouse gas emissions and combat climate change. This can attract financial incentives and investment opportunities for sustainable forest management practices, thereby promoting economic development while preserving the region's valuable forest resources.

In conclusion, the accurate quantification of carbon fluxes in southwestern Nigeria is crucial for addressing the challenges of deforestation, forest degradation, and climate change. By harnessing the capabilities of remote sensing technology and biomass estimation models, researchers can improve our understanding of carbon dynamics in the region and inform evidence-based policy decisions. Through collaborative efforts between government agencies, research institutions, and local communities, southwestern Nigeria can establish a comprehensive carbon monitoring system that supports sustainable forest management and contributes to global climate change mitigation efforts.

1.3 Aim and Objectives of the Study

This research examines the changes in the aboveground biomass and the carbon stock in forest and savannah woodland of Southwest Nigeria between 1986 and 2016.

The specific objectives are to:

i. Analyse the trend and pattern in forest and savannah woodland conversion in the years 1986, 2006, and 2016
ii. Examine the trend and pattern in aboveground biomass induced by vegetal conversion and degradation
iii. Determine accurate carbon stock in the forest and Savanna woodland between 1986 and 2016
iv. Predict the changes in future carbon stock between 2016 to 2066

1.4 Research Questions

i. What is the trend and pattern of forest and savannah woodland conversion from 1986 to 2016 in southwestern Nigeria?
ii. What has been the trend and pattern in aboveground biomass induced by vegetal conversion and degradation between 1986 and 2016?
iii. What is the accurate extent of carbon fluxes in the forest and savanna woodland of SW Nigeria, between 1986 and 2016?
iv. How will carbon fluxes evolve from 2016 to 2066?

1.5 Significance of the Study

This research delivers direct and substantial benefits to the communities, stakeholders, and policymakers intricately linked to the ecosystems of SW Nigeria. By offering crucial insights into the abundant carbon resources within the region's forests and woodlands, the study empowers local communities and forest managers to make informed decisions about sustainable forest management practices. Armed with this knowledge, forest managers can assess the impact of various management approaches on carbon storage, allowing them to optimize resource utilization while ensuring the long-term health of these crucial ecosystems. The data generated serves as a potent tool for crafting evidence-based policies that directly influence the region's development trajectory and will help policymakers. This information supports policymakers at both regional and national levels in designing initiatives for forest conservation, sustainable land use, and carbon sequestration.

Furthermore, it aids in making well-informed decisions about forest management strategies, carbon pricing mechanisms, and climate change mitigation efforts in Southwest Nigeria.

Furthermore, this study will provide support to initiatives like REDD+ (Reducing Emissions from Deforestation and Forest Degradation), which aim to mitigate climate change by preserving forests. By establishing a baseline of carbon storage within Southwest Nigeria's forests and savannahs, the research enhances the region's eligibility for international forest carbon policies and support initiatives. Biodiversity conservation is another integral aspect of this study's significance. By identifying regions with high aboveground biomass and carbon storage, the research assists in pinpointing priority zones for conservation efforts. This directly contributes to the protection of biodiversity within the region, preserving unique flora and fauna. These critical habitats benefit both the ecosystem and the local communities reliant on these natural resources.

The research provides invaluable insights into future land cover and carbon trends in Southwest Nigeria. This forward-looking perspective is indispensable in the face of uncertainty surrounding vegetation patterns and carbon dynamics. It equips researchers and environmentalists with the foresight needed to develop proactive climate change mitigation strategies, strengthening resilience against anticipated climate change impacts in the region. In essence, this study transcends academic boundaries to directly benefit local communities, forest managers, policymakers, conservationists, international initiatives, and the broader field of environmental science. It serves as a cornerstone for informed decision-making and proactive measures, safeguarding the ecosystems and the well-being of SW Nigeria while contributing to global effort in climate change mitigation and environmental conservation.

1.6 Scope and Delimitation of the Study

The study focuses on aboveground biomass (AGB) change and terrestrial carbon fluxes in the forest and woodland areas of southwest Nigeria. AGB was chosen as the focal point of the study because it represents the most visible and quantifiable component of the ecosystem, encompassing trees, shrubs, and herbs, which can be effectively captured by remote sensing satellites. Southwest Nigeria was selected as the study area due to its abundance of forest reserves, making it an ideal candidate for examining carbon dynamics in Nigerian forests compared to other regions.

The decision to focus solely on carbon dioxide (CO_2) emissions, rather than considering other greenhouse gases (GHGs), stems from the recognition that CO_2 is the primary contributor to global warming, particularly through deforestation activities (USEPA, 2022). By narrowing the scope to CO_2 emissions, the study aims to address a significant driver of climate change in the region.

The study period spans from 1986 to 2016, chosen based on the understanding that significant changes in land cover typically require a timeframe of over 30 years to become noticeable on a medium resolution (30 meters spatial resolution) satellite image like the Landsat used for the study (Hansen *et al*. 2013). Additionally, Landsat satellite imagery, which became available in 1986, facilitated the analysis. Notably, a data gap occurred in 1996 due to the decommissioning of the Landsat 5 mission from space due to a fault during that period, resulting in the unavailability of data for that specific year.

Given the vast extent of the study area, a combination of remote sensing data and existing base maps was utilized. This approach was supplemented with limited field verification and measurement conducted in selected sampling locations across the study area. Consequently, the study's findings heavily relied on interpreted proxies derived from satellite imagery alongside the limited field measurements. The approach is only limited to the spatial resolution of the Landsat image which is 30m, which is not suitable for species identification.

Although several carbon pools are crucial for comprehensive carbon flux estimation, the study primarily focused on AGB and its associated carbon pools due to their significance in forest and woodland carbon dynamics. Notably, soil carbon and wetland carbon pools were not considered in this study, which may impact the completeness of the carbon flux assessment.

Field data collection primarily involved biomass estimation and carbon measurement to quantify AGB and associated carbon stocks accurately. Land use change projections were analyzed using the ST-Sim model, the model used land cover change matrix, the land cover change rate, the biomass indices, the model did not incorporate proximate drivers due to insufficient available data on economic factors such as population growth and land consumption rates.

In conclusion, the study provides valuable insights into AGB change and terrestrial carbon fluxes in southwest Nigeria's forest and woodland areas. By focusing on AGB and CO_2 emissions over a significant period, the research sheds light on critical aspects of forest dynamics and their contributions to climate change. However, limitations such as data gaps and the exclusion of certain carbon pools highlight areas for further research and refinement of carbon flux estimation methods in the region.

1.7 Study Area

1.7.1 Geographical Location

The study area encompasses the southwestern states of Nigeria, including Ogun, Osun, Oyo, Ondo, and parts of Ekiti. As shown in figure 1.1, the study area is delineated by longitude 3° 05' to 5° 25' East and Latitude 6° 05' North to 9° 10' North, covering an expansive area of approximately 6,364,030 hectares (63,641 km2). Spanning from the northern savannah grasslands and woodlands to the lush southern forested regions, the study area boasts a diverse range of ecosystems. Bordered by the Republic of Benin to the west, Edo State to the east, Kwara State to the north, and Lagos State to the south, it occupies a strategic position within Nigeria's geographical landscape.

The choice of this study area is guided by several factors, chief among them being its substantial forest reserves, which represent some of the largest in Nigeria. This makes it an ideal location for investigating forest dynamics, carbon fluxes, and Land use changes. Moreover, the region is experiencing alarming rates of deforestation, making it a focal point for research aimed at understanding and mitigating this phenomenon. The urgency of addressing deforestation in the study area is underscored by reports from the Food and Agriculture Organization (FAO, 2017) highlighting the rapid pace of forest loss in the region.

Geologically, the landscape of the study area is characterized by a dissected plain developed on tertiary sediments. This geological setting influences soil composition, topography, and hydrology, shaping the distribution and characteristics of vegetation across the region. Understanding the geological context is essential for interpreting Land use patterns, ecosystem dynamics, and carbon sequestration potential within the study area. Overall, the study area's unique blend of ecological diversity, extensive forest reserves, and pressing environmental challenges makes it a compelling subject for scientific inquiry and conservation efforts. By conducting research in this region, scholars and policymakers aim to generate insights that can inform sustainable land management strategies, mitigate deforestation, and safeguard the region's invaluable natural heritage for future generations.

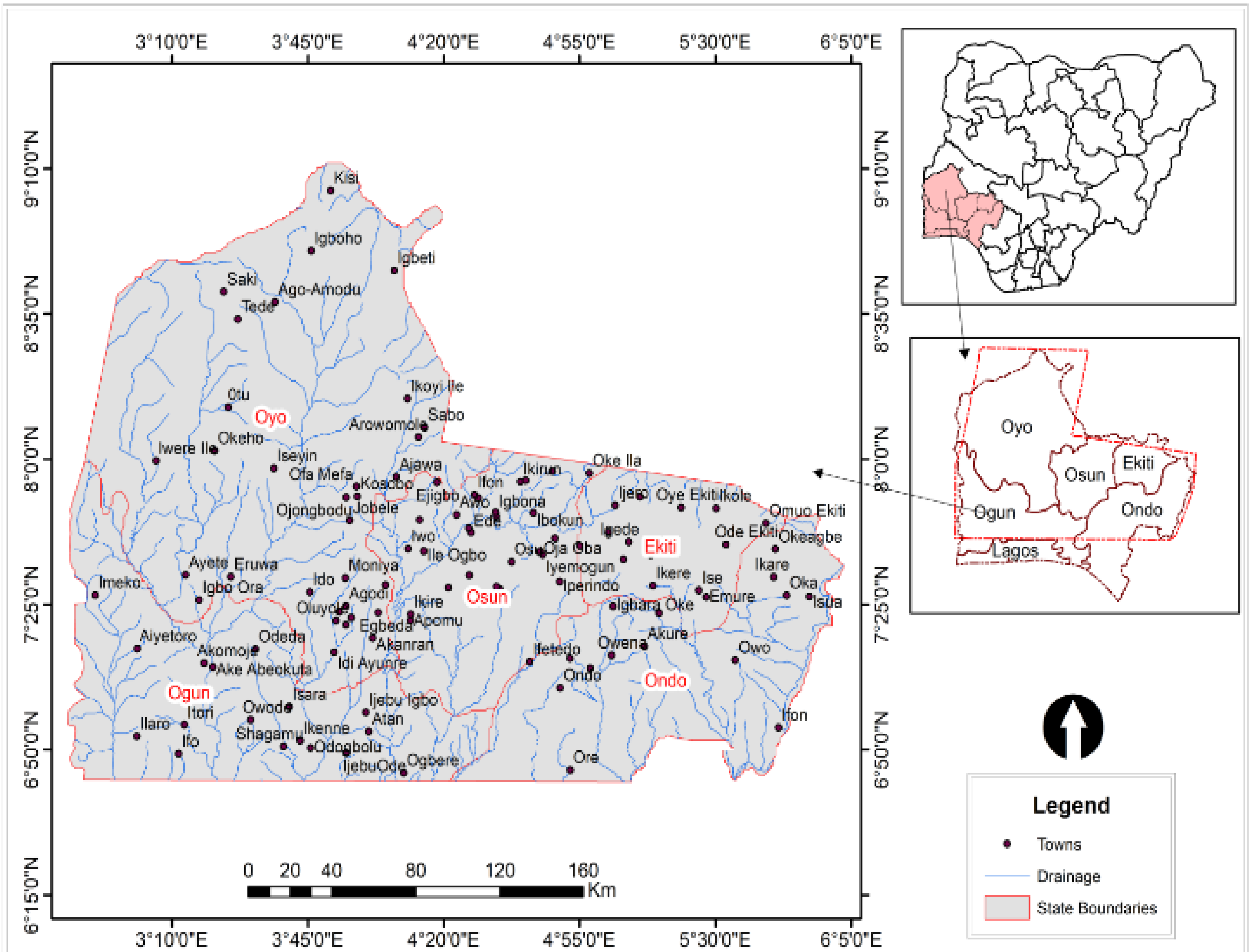

Figure 1.1: Study Area map (Source: Author 2017)

1.7.2 Physical Setting

1.7.2.1 Landforms and Soils

The southwestern region of Nigeria is characterized by a diverse geological landscape shaped by igneous and metamorphic rocks of the basement complex, as documented by Jones and Hockey

(1964). These geological formations provide the foundation for the region's topography and soil composition. Lateritic outcrops, resulting from intense chemical weathering processes in previous geological ages, are prevalent across the area, contributing to the unique soil characteristics observed in the region. The landscape of the study area is characterized by varieties of features, including dense forests, expansive plantations, vibrant wetlands, and vast savannahs. This mosaic of ecosystems contributes to the region's rich biodiversity and ecological significance. The presence of extensive forest reserves underscores the area's importance for conservation efforts and sustainable land management practices. However, despite its ecological value, the region is facing unprecedented environmental challenges, particularly concerning deforestation.

The topography as shown on figure 1.2 is predominantly characterized by gentle to moderate slopes, ranging from two to six percent, as described by Udo (1970). These slopes create a varied terrain that influences water drainage patterns, soil erosion rates, and vegetation distribution. Notably, numerous inselbergs and quartzite ridges punctuate the landscape, particularly in areas such as Ado Awaiye, Eruwa, Oke Iho, Iganna, and Iwere Ile, as noted by Moss (1963). These geological features add to the scenic beauty of the region while providing habitats for unique flora and fauna.

As one moves northward and north-eastward within the study area, the elevation gradually increases. Starting from approximately 200 feet (60.96 m) in Ijale-Ketu, Imeko axis of Ogun State, the land rises to over 1000 feet (304.8 m) around Shaki, with peaks reaching as high as 1600 feet (487.68 m) and 1660 feet (505.968 m) in Ighoho. This elevation gradient contributes to variations in climate, vegetation, and land use practices across the region.

Conversely, the eastern axis of the study area exhibits undulating terrain, characterized by a gradual descent from approximately 1600 feet (487.68 m) around Ekiti State to about 400 feet (121.92 m) farther south in locations such as Ore, Ago Iwoye, and Ijebu Igbo. This topographical variation influences the distribution of vegetation zones, with changes in elevation corresponding to shifts in ecological habitats and biodiversity hotspots.

Inselbergs, prominent rocky outcrops formed through weathering and erosion processes, are prevalent throughout the region, particularly around Ado Ekiti, Akure, and Ondo. These inselbergs vary in size and shape, with some reaching considerable heights. Notably, the Idanre hills stand out as one of the region's iconic geological landmarks, rising to heights well above 3,000 feet. These geological formations serve as important cultural and ecological sites, attracting tourists and researchers alike.

The western part of the study area is characterized by a network of major rivers, including the Okpara, Ofiki, Oyan, and Ogun rivers. These water bodies play a crucial role in the region's hydrological cycle, providing water for agricultural activities, domestic use, and supporting aquatic ecosystems. Additionally, the presence of rivers influences land use patterns, with fertile floodplains and riverine habitats supporting diverse flora and fauna.

In the southern part of the eastern axis, the landscape is heavily forested, with dense vegetation covering vast areas. These forests harbor a wealth of biodiversity, including endemic species and rare plant communities. The lush greenery of these forests contributes to the region's ecological resilience and provides essential ecosystem services such as carbon sequestration, soil stabilization, and habitat provision for wildlife.

Overall, the geological and topographical features of southwestern Nigeria contribute to its ecological richness and cultural diversity. Understanding the complex interplay between geology, topography, and ecology is essential for effective land management, conservation planning, and sustainable development in the region.

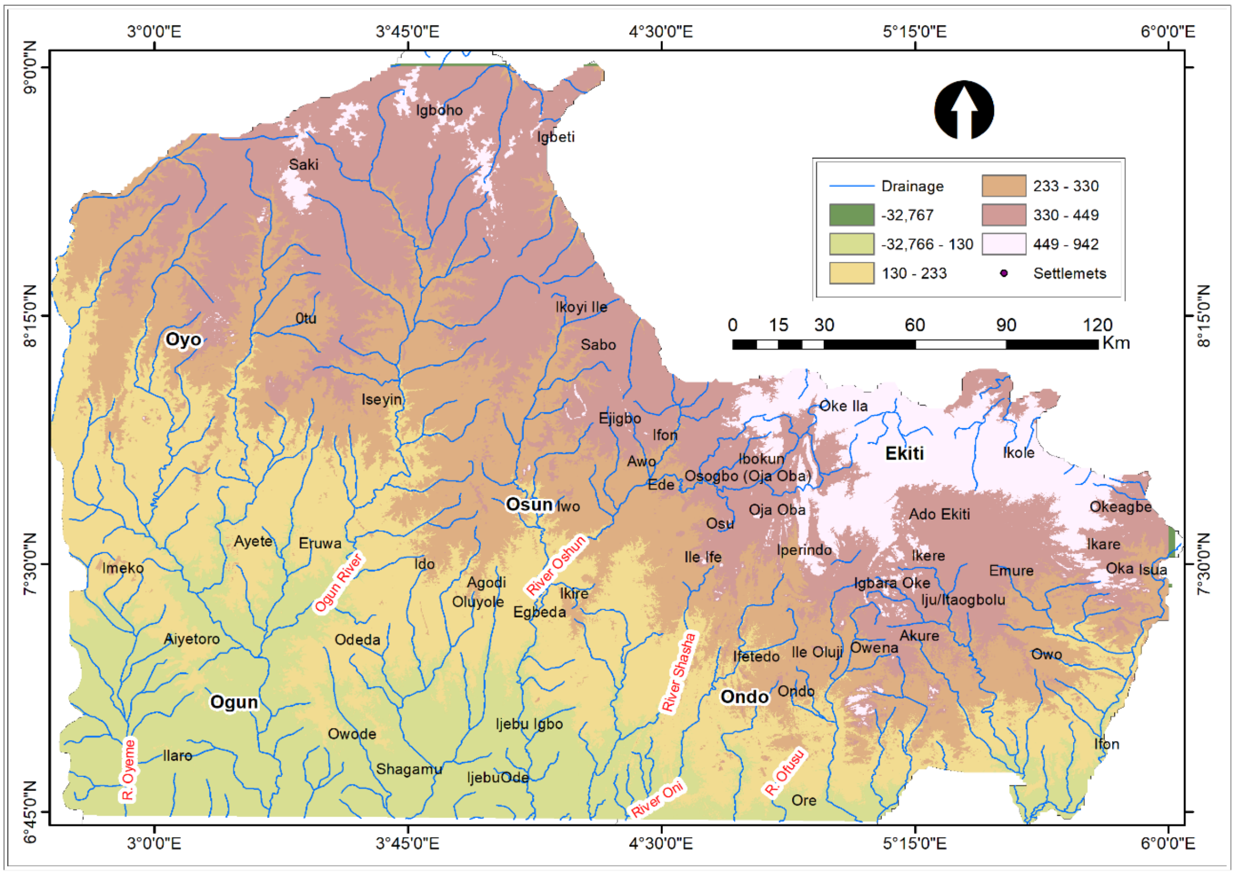

Figure 1.2: Topography of the study area (source: Author 2017)

1.7.2.2 Climate and Vegetation

The Southwestern region of Nigeria boasts a rich tapestry of climatic patterns that profoundly influence various aspects of life in the area, from agricultural practices to infrastructure development and socio-economic activities. Among the most notable climatic features defining the region is its mean annual rainfall, which exhibits significant variability across different locales. On average, the mean annual rainfall hovers around 1236.77 mm, 1418.8 mm, and 1507 mm in Abeokuta, Ibadan, and Lagos, respectively, as documented by Fasona *et al*. (2014). This diversity in rainfall intensity reflects the region's heterogeneous topography and geographical characteristics, with coastal areas typically receiving more rainfall compared to inland regions.

The rainfall distribution pattern as shown on the map on the figure 1.3 in the study area displays distinct characteristics, characterized by two peaks throughout the year. The first peak occurs in the northern axis around September, coinciding with the apex of the rainy season in the region. Conversely, the southern parts of the study area experience their highest rainfall around July, marking another peak in precipitation. This bimodal distribution of rainfall is a defining feature of the region's climate, providing essential water resources for agricultural activities and sustaining ecosystems throughout the year. However, there is usually a break in rainfall during August, commonly referred to as the "August Break," allowing for some respite from the wet conditions and facilitating agricultural activities such as planting and harvesting (Fasona *et al*., 2014).

Temperature conditions in the southwestern region of Nigeria exhibit relatively minor fluctuations throughout the year, with a prevailing trend of warm temperatures across the area. Maximum temperatures in the southern regions average around 28°C, while temperatures rise to approximately 36°C in the northern regions. The months of February and March typically register as the hottest periods, characterized by scorching temperatures and intense sunlight, which can have implications for both human health and agricultural output. Conversely, the lowest temperatures are usually experienced during August, offering a reprieve from the heat during the peak of the dry season.

Relative humidity represents another critical climatic parameter influencing the overall comfort and well-being of inhabitants in the southwestern region. Generally, relative humidity levels tend to be higher in the southern parts of the region compared to the northern areas. In the south, relative humidity averages around 85% in the morning hours, creating a humid and often muggy environment. This elevated humidity can contribute to discomfort and may exacerbate heat-related health concerns. On the other hand, relative humidity decreases slightly in the northern regions, where it averages approximately 26% at 9 a.m. (Fasona *et al*., 2014). While this lower humidity level may provide some relief from the oppressive heat experienced in the north, it can also lead to dry conditions, particularly during the dry season.

The climatic conditions prevalent in the southwestern region of Nigeria have significant ramifications for various sectors, including agriculture, water resource management, and urban planning. The distribution of rainfall plays a pivotal role in shaping crop cultivation practices and determining the viability of different agricultural activities in the region. Farmers rely heavily on the timing and intensity of rainfall to plan their planting and harvesting schedules, with fluctuations in rainfall patterns directly impacting crop yields and overall agricultural productivity.

Moreover, temperature variations and humidity levels exert a notable influence on human comfort and health, especially during periods of extreme heat and humidity. Adequate infrastructure and urban planning strategies are imperative for mitigating the adverse effects of climatic conditions, such as flooding, heatwaves, and water scarcity, which can pose significant challenges to both residents and infrastructure in the region. Therefore, sustainable development initiatives that prioritize climate resilience and adaptation are crucial for ensuring the long-term viability and resilience of communities in the southwestern region of Nigeria.

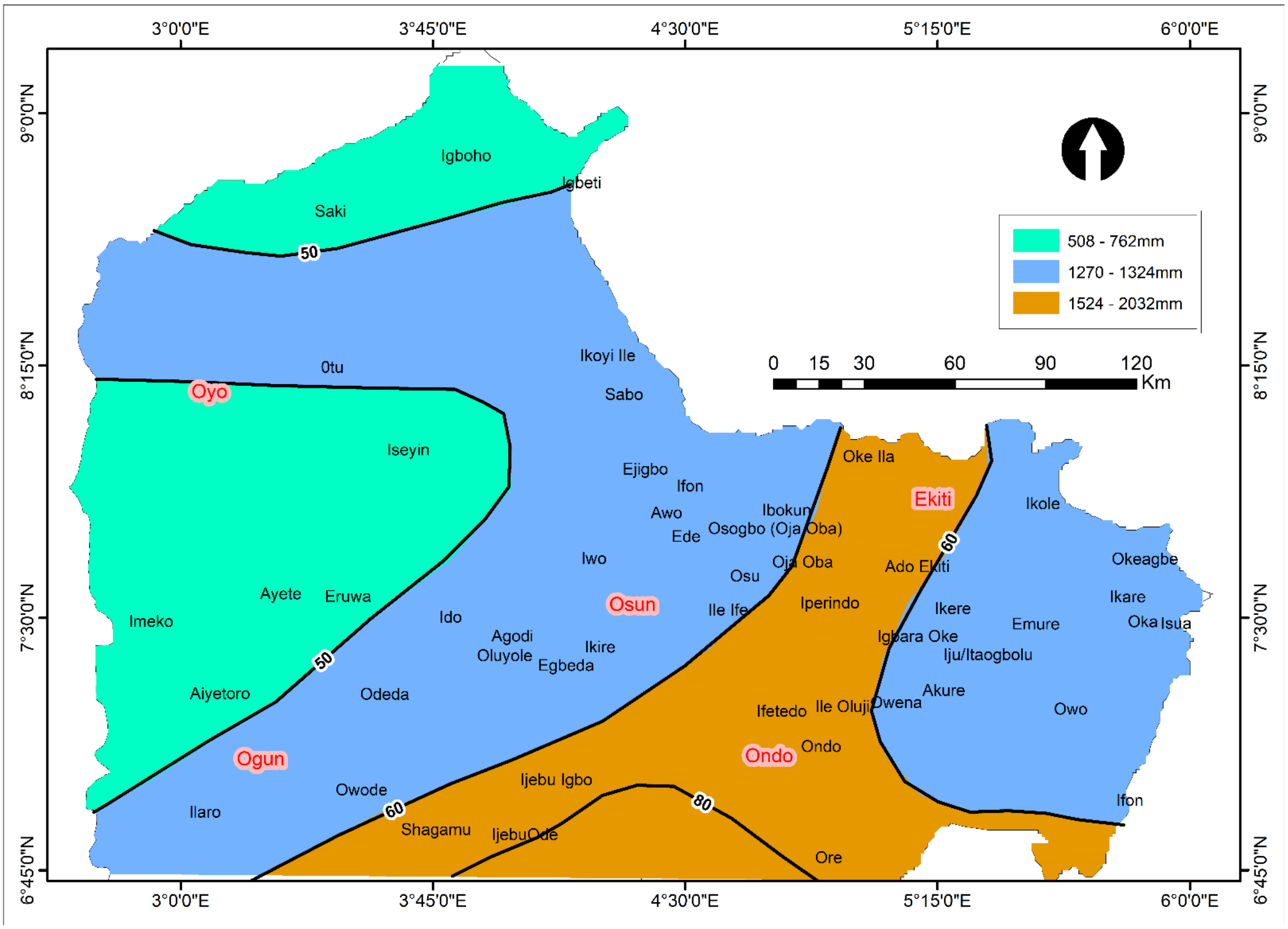

Figure 1.3: Rainfall pattern of the study area (source: Author, 2017)

The study area, spanning from south to north, encompasses a diverse range of ecological zones, each characterized by distinct vegetation types and landscape features as shown on figure 1.4. Starting from the south, the region is marked by lowland rainforests, which are characterized by dense vegetation, towering trees, and rich biodiversity. These rainforests are often interspersed with riparian swamps along major rivers, further adding to the region's ecological diversity and providing vital habitats for various aquatic and semi-aquatic species.

Moving northwards from the lowland rainforests, the landscape gradually transitions into the Southern Guinea Savanna, particularly evident in areas like Meko, Ogun State. The Southern Guinea Savanna is characterized by a mixture of grasslands, shrubs, and scattered trees, with a more pronounced dry season compared to the humid conditions of the rainforest zone. This transition zone represents a shift in both vegetation composition and ecological dynamics, reflecting the influence of climatic factors and soil characteristics on the local flora and fauna.

Within the forest zone, the natural succession process has been frequently disrupted and disturbed, preventing the development of a mature, three-layer forest structure. This disturbance can be attributed to various human activities, including logging, agriculture, and urbanization, as well as natural phenomena such as wildfires and land degradation. As a result, the forest ecosystem in this area may exhibit signs of degradation, with altered species composition, reduced biodiversity, and impaired ecosystem functioning (Kortmann *et al*., 2018).

The impact of human activities on the forest ecosystem is particularly pronounced in areas where land use practices have intensified, leading to widespread deforestation and habitat fragmentation. This fragmentation can have detrimental effects on forest-dependent species, limiting their access to resources and increasing their vulnerability to predation and competition. Additionally, the loss of forest cover can disrupt vital ecosystem services such as carbon sequestration, water regulation, and soil stabilization, further exacerbating environmental degradation and contributing to climate change.

Despite these challenges, efforts are underway to conserve and restore forest ecosystems in the study area. Conservation initiatives, such as the establishment of protected areas and the implementation of sustainable land management practices, aim to mitigate the impacts of deforestation and promote the recovery of degraded habitats. Community-based conservation approaches, involving local stakeholders in decision-making processes and resource management activities, are also gaining traction as effective strategies for biodiversity conservation and sustainable development.

Overall, the study area's ecological diversity and environmental significance underscore the importance of conservation efforts and sustainable land use practices. By protecting and restoring forest ecosystems, stakeholders can safeguard biodiversity, mitigate climate change, and promote the well-being of both human communities and natural habitats. However, achieving these goals will require collaborative action, innovative solutions, and long-term commitment from governments, NGOs, local communities, and other relevant stakeholders.

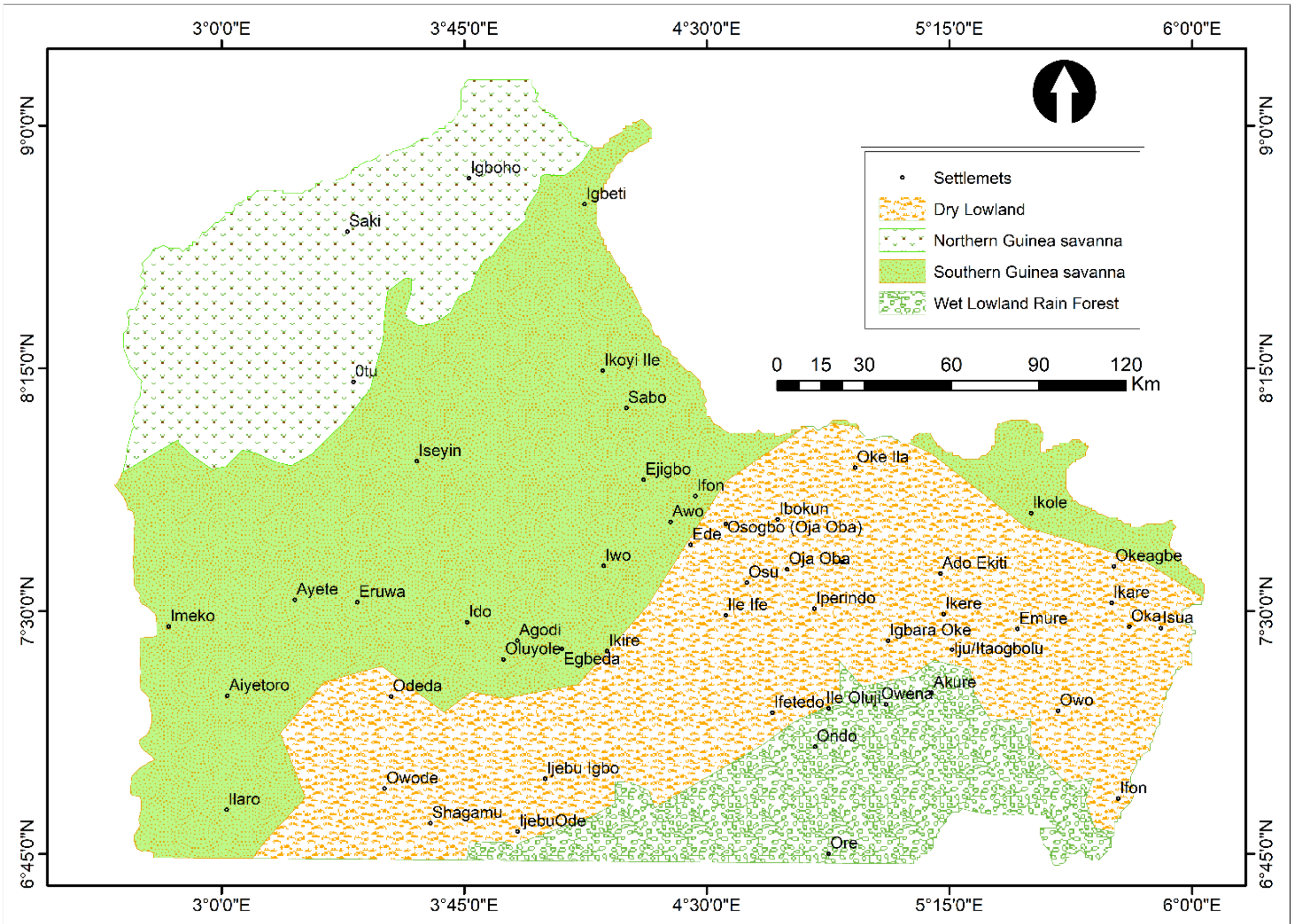

Figure 1.4: Vegetation of the study area (Source: Author 2017)

1.7.3 Human Setting

The study area is typically agrarian settlements which are majorly rural. The major cash crops in the study area include Cocoa in Osun and Ekiti state, tobacco, and yam in Oyo State. The zone is well-known for its commerce and trading activities, with a preponderance of micro, small, and medium indigenous industries that are into manufacturing, fabrication, and agro-allied produce. Agriculture still serves as the mainstay of economic activity for most rural communities. Because the area is blessed with fertile terrain, agriculture does quite well there. Yam, cassava, cocoyam, and maize are the principal food crops farmed in the region, while rubber, cocoa, bananas, and different fruits are the cash crops.

Iseyin is known for its large-scale cultivation of cash crops such as cotton and tobacco, as well as staple food crops like yam and cassava. The fertile soil and favorable climate of Iseyin make it an ideal location for agriculture, sustaining the livelihoods of thousands of residents. Ikere-Ekiti in Ekiti State is Situated amidst lush greenery, Ikere-Ekiti is famed for its cocoa plantations, which have been a cornerstone of the local economy for generations. The town's economy revolves around cocoa farming, with numerous smallholder farmers tending to their cocoa trees across vast stretches of land. The annual cocoa harvest season brings a flurry of activity to Ikere-Ekiti, as farmers gather their produce for sale and export, contributing significantly to the region's agricultural output.

In addition to its agrarian communities, southwestern Nigeria boasts several bustling commercial and trading centers that drive economic growth and prosperity in the region. Ibadan, is the capital of Oyo State and one of the largest cities in Nigeria. Ibadan is a vibrant hub of commerce and industry, with numerous markets, shopping centers, and business districts catering to the needs of its burgeoning population. The city's Oje Market is a bustling trading hub where a wide array of goods, ranging from fresh produce to clothing and electronics, are bought and sold by merchants and shoppers alike. Ado-Ekiti, the capital of Ekiti State is another prominent commercial center. It is renowned for its thriving business community, with numerous indigenous industries engaged in manufacturing, fabrication, and agro-allied produce. The city's Oja Oba Market is a bustling marketplace where traders from across the region converge to buy and sell goods, creating a vibrant atmosphere of commerce and entrepreneurship. Ado-Ekiti's strategic location and well-developed infrastructure make it an attractive destination for businesses and investors seeking opportunities for growth and expansion.

Urban and sub-urban settlements are found only in capital cities, commercial centres, and local government headquarters. The residents of these urban and suburban centres are chiefly civil servants and traders. The Nigerian Bureau of Statistics projected the population of the states from the 2006 census to 2016 to 3.2 million (490.7 persons/km^2) for Ekiti state, 5.2 million (269.3 persons/km^2) for Ogun state, 4.6 million (272.7 persons/km^2) for Ondo state, 4.7 million (475.9 persons/km^2) for Osun state, and 7.8 million (242.3 persons/km^2) for Oyo state. The study area has a growth rate of 3.2% annually (NBS, 2012).

The socio-economic significance of southwestern Nigeria lies in its resilience and cultural vibrancy, exemplified by cities like Ijebu-Ode in Ogun State. Ijebu-Ode is rich in cultural heritage and historical significance, serving as a center of trade and commerce for centuries. The city's bustling markets, ancient landmarks, and vibrant festivals attract visitors from far and wide, contributing to its economic prosperity and cultural identity. Ijebu-Ode's traditional industries, such as pottery and weaving, showcase the ingenuity and creativity of its people, underscoring the region's socio-economic importance as a hub of culture and heritage. Ado-Awaye is famed for its breathtaking landscapes, including the renowned Oke-Ado-Awaye Suspended Lake and the mysterious Iyake Suspended Stone. These natural wonders draw tourists and visitors to the city, generating revenue and employment opportunities for local residents. Ado-Awaye's cultural festivals, such as the Olojo Festival and the Egungun Festival, celebrate the city's rich heritage and traditions, fostering a sense of community and pride among its inhabitants. Through sustainable tourism and cultural preservation efforts, Ado-Awaye exemplifies the socio-economic significance of southwestern Nigeria as a region steeped in history, culture, and natural beauty.

1.8 Operational Definition of Terms

In this section, operational definitions of key terms relevant to the study are provided to ensure clarity and consistency in their usage throughout the research. These definitions offer concise explanations of concepts such as forest degradation, carbon fluxes, remote sensing, and land use classification, elucidating their significance within the context of the study's objectives and methodology. By establishing clear definitions, the study aims to enhance understanding and facilitate effective communication of findings within the academic community and among stakeholders involved in forest management and environmental conservation efforts. These terms include the following:

i. Aboveground Biomass: all living vegetal matter above the soil, including stem, stump, branches, bark, seeds, and foliage.
ii. Carbon Emissions: Carbon emission is the release of carbon from the forest into the atmosphere.
iii. Carbon Flux: the amount of carbon exchanged between the earth's atmosphere and the aboveground carbon pool, which includes Living Plants, dead plants, litter, and grasses.
iv. Floristic Composition: Floristic composition refers to the plant species or vegetation types that make up a particular geographical area or ecosystem.

v. Forest carbon stock: The amount of carbon sequestered from the atmosphere and stored in a forest ecosystem, mainly within living biomass and deadwood and litter.

vi. Fraction of Absorbed Photosynthetically Active Radiation (FAPAR): FAPAR refers to the total dry weight of organic plant material, typically expressed in grams per square meter (g/m^2).

vii. Photosynthetically Active Radiation (PAR): PAR, represents the amount of photosynthetic plant material produced through the absorption and utilization of Photosynthetically Active Radiation (PAR) during the process of photosynthesis.

viii. Carbon Sequestration: The process of capturing CO_2 from the atmosphere through the process of photosynthesis.

ix. Terrestrial carbon: This is the carbon which stored in the various land uses on the earth surface.

CHAPTER TWO

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.0 Introduction

Studies on biomass and carbon estimation have developed over the past years, thus, generating more than enough literature materials. As regards this research, a large amount of existing literature was consulted and reviewed to critiquing their gaps in terms of location, research design, findings, and result accuracy. This chapter is done in two sections- the literature review and the conceptual framework. Literature review was achieved under the following subheadings; Global Forest and woodland deforestation and degradation and Carbon emission estimation, Remote Sensing and Land use Classification, Remote Sensing for Carbon and Biomass Estimation, and Modelling Present and Future Biomass and Carbon**.** Then the conceptual framework upon which this study was based was the concept of the carbon cycle concept and the Social-Ecological Systems theory**.** These concepts were discussed in direct relationship with this study and the study location.

2.1 Literature Review

2.1.1 Deforestation and forest and woodland degradation

The total global net change in forest area in the period 2000–2010 is estimated at -5.2 million hectares per year, equivalent to either a loss of more than 140 km^2 of forest per day or an area slightly more significant than the size of Costa Rica (FRA, 2010). However, the current (2020) annual net loss of forest is about 37% lower than in the 1990s and equals a loss of 0.13% of the remaining forest area each year during this period. An estimated 420 million hectares of tropical forest cover have declined through deforestation substantially since 1990–2000. During 2015–2020, the rate of deforestation was estimated at 10 million hectares per year, from 16 million hectares per year in the 1990s (FAO and UNEP, 2020). According to Trumper, Bertzky, Dickson, Heijden, Jenkins., & Manning, (2009), Savannah vegetation makes up part of the land cover on the earth's surface. They are primarily found in sub-Saharan Africa and parts of South America. Unlike the forest ecosystem, it is described by the presence of reduced trees compared to the forest. Most of the savannah areas are natural ecosystems; others result from the degradation of tropical forests from burning, grazing, and deforestation. Carbon sequesters on the aboveground in a savannah ecosystem is a function of tree cover density (Trumper *et al*., 2009). Due to the natural nature of Savannah to attract frequent fire, the event, therefore, can release a large amount of carbon to the atmosphere, approximately 0.5-4.2Gt C annually (Grace, San Jose, Meir, Miranda, & Montes, 2006).

Oyebo *et al*., 2010, carried out a desk-based assessment of forest and carbon sequestration issues, policies, institutions, projects, and stakeholders at both Federal and Cross River State Government levels. The rate of deforestation in Nigeria is one of the highest in the world, less than 10% of Nigeria's original forest cover remains (Oyebo *et al.*, 2010). Cross River state has over 50% of what is remaining of the tropical High Forest, showed that in Cross River state between 1978 and 1995 the natural forest decreased from 23,429,100 hectares to 15,097,900 hectares (25.7% to 16.0%); and an increase in degraded forest from 284,500 ha to 2,650,900 ha (0.4% to 0.7%). Though the study did not quantify the carbon emissions, it made recommendations as to how the carbon emissions can be estimated using GIS and remote sensing. This specifically creates a gap that the current study will cover.

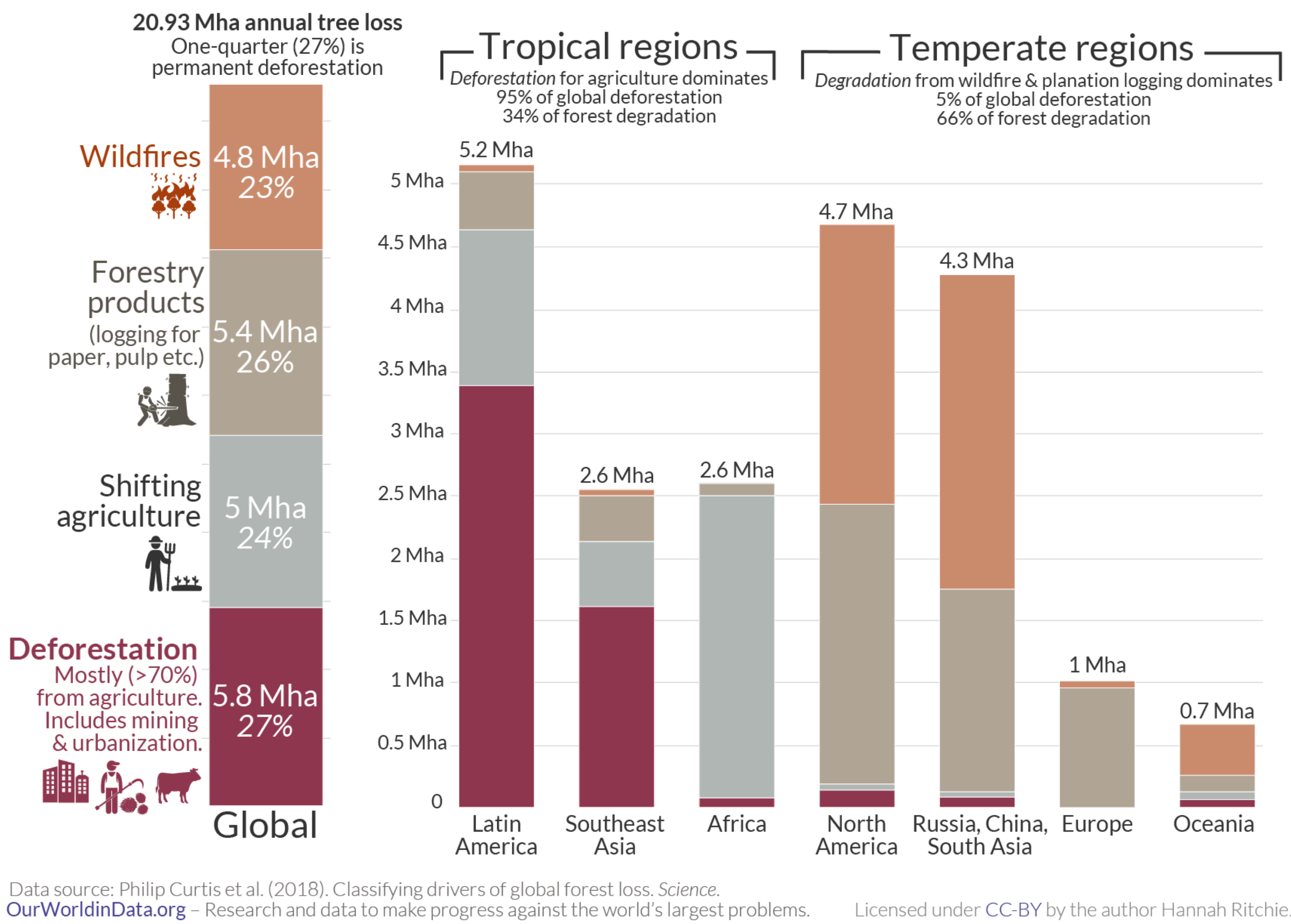

Figure 2.1: Global drivers of forest loss (Source: IPCC, 2006)

According to FAO (2005), for every 2 cubic meters of wood growth in forests, approximately 1 ton of carbon from the air is captured, highlighting the crucial role of forests and woodlands as carbon sinks. Figure 2.1 shows the area losses of the forest area through deforestation and other drivers across the major continents of the world. Forests and woodlands sequester carbon primarily through their aboveground biomass (AGB), which encompasses all living vegetation biomass, including woody and herbaceous components such as stems, branches, foliage, and stumps (IPCC, 2006). This process is facilitated by the high canopy density and soil organic carbon content within forest ecosystems (Banskota *et al*., 2007). As trees and vegetation grow, they absorb carbon dioxide from the atmosphere during photosynthesis and store it in their biomass, effectively removing carbon from the air and contributing to mitigating climate change. Understanding the dynamics of aboveground biomass and carbon sequestration in forests and woodlands is essential for assessing their role in the global carbon cycle and implementing effective strategies for climate change mitigation and forest conservation.

Dengsheng *et al*. (2014) argue that field measurements represent the most accurate method for estimating forest biomass. However, this approach is associated with significant challenges, including its time-consuming and labor-intensive nature. Additionally, conducting field measurements across large geographic areas is often impractical and unfeasible (Segura and Kanninen, 2005; Seidel *et al*., 2011; Wang *et al*., 2011a). Despite its accuracy, field measurement-based biomass estimation encounters constraints related to data sources, spatial resolution, and model inaccuracies, leading to considerable uncertainties in biomass estimates (Rivington *et al*., 2006; Verbeeck *et al*., 2006; Larocque *et al*., 2008; Zhang *et al*., 2012). These uncertainties can arise from various factors, including limitations in climate data availability, soil characteristics, and topographical features.

To mitigate the limitations of field measurements and address the challenges associated with biomass estimation, complementary approaches are often employed. For instance, the IPCC tier 3 inventories recommend supplementing field measurements with data on tree parameters, litter, and the herbaceous component of vegetation (IPCC, 2006). By integrating multiple data sources and methodologies, researchers can enhance the accuracy and reliability of biomass estimates while minimizing uncertainties.

Furthermore, advancements in remote sensing technology and geospatial analysis have provided alternative methods for estimating forest biomass over large spatial scales. Remote sensing techniques, such as LiDAR and satellite imagery, enable researchers to assess forest structure and biomass remotely, offering valuable insights into forest dynamics and carbon sequestration processes (Mitchard *et al*., 2013; Mascaro *et al*., 2014).

Overall, while field measurements remain a cornerstone of biomass estimation, their limitations necessitate the adoption of complementary approaches, including remote sensing and modeling techniques, to overcome challenges and improve the accuracy of biomass assessments in forested ecosystems.

Trumper *et al*. (2009) delineate savannah vegetation as a significant component of the Earth's land cover, predominantly distributed across sub-Saharan Africa and parts of South America. Unlike dense forest ecosystems, savannahs are characterized by a sparser tree cover, interspersed with grasslands and shrubs. While many savannah areas represent natural ecosystems, others arise from the degradation of tropical forests due to factors such as burning, grazing, and deforestation.

Carbon sequestration in savannah ecosystems predominantly occurs aboveground and is closely tied to tree cover density (Trumper *et al*., 2009). The presence of trees plays a crucial role in capturing and storing carbon within the ecosystem. However, the natural propensity of savannahs to experience frequent fires poses a significant risk to carbon sequestration efforts. These fires can release substantial amounts of stored carbon into the atmosphere, contributing to carbon emissions and exacerbating climate change.

Research by Grace *et al*. (2006) suggests that savannah fires have the potential to emit significant quantities of carbon annually, ranging from 0.5 to 4.2 gigatons of carbon (Gt C). This underscores the importance of understanding the dynamics of carbon fluxes in savannah ecosystems and implementing measures to mitigate the risk of fire-induced carbon emissions. Sustainable land management practices, including fire management strategies and reforestation efforts, are essential for maintaining the carbon balance in savannah regions and mitigating the impact of wildfires on carbon sequestration. Overall, savannah ecosystems represent critical components of the global carbon cycle, influencing both carbon storage and emissions. Effective conservation and management of savannah vegetation are essential for preserving biodiversity, maintaining ecosystem services, and mitigating climate change impacts.

However, the carbon lost is mostly regained during the subsequent period of plant regrowth (afforestation), unless the area is converted to pasture or grazing land for cattle (Grace *et al.,* 2006). The Tropical savannah ecosystem is considered a carbon sink by taking up an estimated 0.5 Gt C per year (Scurlock and Hall 1998). As human pressure on the savannah vegetation increases, more than one percent of the global savannah is lost annually to anthropogenic activities such as fires, cattle raising, and agricultural activities (Trumper *et al*., 2009). Deforestation and forest degradation often result from a complex interplay of both direct drivers (operating at local or regional levels) and indirect drivers (operating at local, regional, national, and international levels). Currently, commercial and subsistence agriculture are the direct drivers of more than 70% of deforestation, and logging and fuelwood extraction are the major direct drivers of forest degradation (Hosonuma *et al*., 2012). Increasing international trade and commodity flows resulting from economic globalization are exacerbating this complex relationship (Lambin and Meyfroidt, 2011). In light of this, some call for a hybrid approach to addressing drivers, whereby REDD+ projects target local and direct drivers, and national REDD+ policies and strategies target national and indirect drivers. One advantage of such a strategy would be that targeted local interventions that respond well to local drivers would be less likely to result in so-called ‘‘leakage’’ or a shift of unsustainable practices to other locations (Fisher *et al*., 2011)

According to (Kissinger, 2012) any economic growth that is fully dependent on the exportation of primary commodities and accelerated demand for forest products and agricultural products can be singled out as the main drivers of deforestation and forest degradation (Rademaekers *et al*., 2010). This fact is further buttressed by the use of the modern remote sensing data which when overlayed on population and economic trends of agricultural production as the primary drivers of deforestation and forest degradation. (DeFries *et al*., 2010) Population growth is synonymous with an increase in demand for agricultural land, thereby exerting pressure on the demand for forest products. (Rademaekers *et al*., 2010) According to (Kissinger, 2012) Poor governance, corruption, low capacity of public forestry agencies, land tenure uncertainties, and inadequate natural resource planning and monitoring can be important underlying factors of deforestation and forest degradation; regarding the enforcement of forest policies and combating illegal logging (Rademaekers *et al*., 2010). Analysis of the underlying drivers shows weak forest sector governance and institutions, with conflicting policies are the underlying drivers of deforestation and degradation. Population growth is the next underlying driver, followed by poverty and insecure tenure, market forces, particularly commodity markets, prices, and foreign direct investment as key underlying drivers. (Kissinger, 2012)

In the study of Kipkemoi *et al* 2018 which entails detecting forest degradation and modeling future scenarios using GIS and remote sensing, in Elgeyo/Marakwet County, (Embobut forest), reveals that forests have been managed for several years in the world, but in most cases especially in the developing world, various regimes have tried to come up with institutional to guide forest management with no much success, in many countries, there is no regular monitoring system that collects information about the situation of the forests and trends of the distribution. This makes it difficult to quantify the status of the existing forest cover. High-resolution satellite imagery, as well as GIS and remote sensing software (ArcGIS and ENVI) with mathematical models, were used to project the forest status, apart from satellite images ground truthing using Global positioning system (GPS) as a data collection tool, as well as the use of Auxiliary data, was employed; with Socio-economic data for 1980, 1990, 2000 and 2010. The study found that the total forest loss was 7,172.31 hectares; this represents a loss of 28% of the total forested area that existed in 1986 which corresponds to an annual forest loss of 286.892 hectares. According to the study, as the population increased the rate of deforestation also increased. The future scenarios from the studies were based on a fixed annual deforestation rate and a conclusion is made that Bare land & rocky and water bodies classes increased in area while Mixed *Podocarpus latifolius*, *Juniperus-Nuxia-Podocarpus factus*, Tree ferns *Cyathea manniana & Bamboo, Acacia abyssica* & Scrubby grassland classes decreased in size. As Population grew forestry loss increased, between 1986 and 2011, the total forest loss was 7,172.31 hectares. Future Scenario found that with the same trend, there will be no forest remaining natural forest block by the year 2038 in the study area.

Remote sensing data has been instrumental in estimating carbon emissions resulting from deforestation and forest degradation in various regions across the globe. One notable study conducted by Hansen *et al*. (2013) utilized high-resolution satellite imagery to assess forest cover loss on a global scale from 2000 to 2012. Their findings revealed alarming trends, particularly in tropical forests, which experienced significant losses during the study period. The researchers estimated a total loss of 2.3 million square kilometers of forest cover worldwide, highlighting the extensive impact of deforestation on forested landscapes. In addition to Hansen *et al*. (2013), another noteworthy study by Gibbs *et al*. (2018) focused on estimating carbon emissions associated with forest loss in 30 tropical countries between 2001 and 2015. This comprehensive analysis aimed to identify the countries responsible for the highest carbon emissions resulting from deforestation and degradation. The study identified Brazil, Indonesia, and the Democratic Republic of Congo as the primary contributors to carbon emissions from forest loss during the study period.

The findings of these studies underscore the critical importance of remote sensing technology in monitoring and quantifying forest cover changes and associated carbon emissions. High-resolution satellite imagery provides researchers with a powerful tool for detecting and mapping changes in forest cover over large geographic areas with high accuracy and precision. By analyzing changes in forest cover over time, researchers can assess the extent and magnitude of deforestation and degradation, as well as the associated carbon emissions. The use of remote sensing data in estimating carbon emissions from deforestation and degradation offers several advantages over traditional ground-based methods. Remote sensing allows for the rapid and cost-effective assessment of forest cover changes on a large scale, providing valuable insights into global forest dynamics. Additionally, remote sensing data can be used to identify areas of rapid forest loss and prioritize conservation efforts in regions facing the greatest threats from deforestation and degradation.

Moreover, the integration of remote sensing data with advanced modeling techniques enables researchers to estimate carbon emissions associated with forest loss more accurately. By combining satellite-derived data on forest cover change with carbon density maps and emission factors, researchers can estimate the amount of carbon released into the atmosphere as a result of deforestation and degradation. These estimates contribute to our understanding of the drivers of deforestation and degradation and inform policy decisions aimed at mitigating their impacts on climate change. Overall, studies utilizing remote sensing data to estimate carbon emissions from deforestation and degradation play a crucial role in informing global efforts to address climate change and conserve forest ecosystems. By providing accurate and timely information on forest cover changes and associated carbon emissions, remote sensing technology contributes to the development of effective strategies for forest management, conservation, and climate mitigation on both regional and global scales.

Several studies have delved into estimating carbon emissions specifically from forest degradation, complementing research on deforestation. One notable study conducted by Venter *et al*. (2018) utilized remote sensing data to assess forest degradation in the Congo Basin, a region known for its rich biodiversity and extensive forest cover. The findings of this study revealed that forest degradation in the Congo Basin was a significant contributor to carbon emissions, underscoring the importance of addressing degradation alongside deforestation in efforts to mitigate climate change. Similarly, a study by Tyukavina *et al*. (2015) focused on estimating aboveground carbon losses resulting from selective logging activities in the Amazon Basin. Leveraging satellite data and advanced modeling techniques, the researchers quantified the carbon emissions associated with selective logging, providing valuable insights into the environmental impact of this widespread practice. The study highlighted the substantial contribution of selective logging to carbon emissions, emphasizing the need for sustainable logging practices and forest management strategies to mitigate its adverse effects on carbon stocks and climate change.

These studies shed light on the significant role of forest degradation in contributing to carbon emissions and climate change, alongside deforestation. While deforestation involves the complete removal of forest cover, degradation refers to the deterioration of forest ecosystems due to human activities such as logging, fire, and unsustainable land use practices. Despite the distinct nature of these processes, both deforestation and degradation result in the release of carbon stored in vegetation and soils into the atmosphere, contributing to greenhouse gas emissions and climate change. The findings of these studies underscore the importance of accurately estimating carbon emissions from both deforestation and degradation to inform policymaking and conservation efforts. By quantifying the carbon losses associated with these processes, policymakers can develop targeted strategies to address the drivers of forest loss and degradation, promote sustainable land use practices, and mitigate climate change impacts. Remote sensing techniques play a crucial role in this endeavor, providing valuable data and insights into forest dynamics and carbon stocks over large spatial scales.

Moreover, the results of these studies have significant implications for forest conservation and climate change mitigation efforts on both regional and global scales. By identifying hotspots of forest degradation and quantifying the associated carbon emissions, policymakers can prioritize conservation interventions in areas facing the greatest threats. Additionally, incorporating estimates of carbon emissions from degradation into climate change mitigation strategies can enhance the effectiveness of efforts to reduce greenhouse gas emissions and achieve emission reduction targets.

Overall, these studies highlight the complex interplay between forest degradation, carbon emissions, and climate change, emphasizing the need for integrated approaches to forest management and conservation. By understanding the drivers and impacts of both deforestation and degradation, stakeholders can work towards sustainable land use practices that promote forest health, biodiversity conservation, and climate resilience. Through continued research and collaboration, remote sensing techniques can continue to contribute to our understanding of forest dynamics and support informed decision-making for a sustainable future.

2.1.2 Land Use/Land Cover Change Studies

Human populations and their use of land have transformed most of the terrestrial biosphere into anthropogenic biomes. Such transformation has caused a variety of new ecological patterns and processes to emerge and has been significant for more than 8000 years (Ellis, 2011). Recently, issues related to LULC change have gained interest among a wide variety of researchers, ranging from those who favor modeling spatio-temporal patterns of land conversion to those who try to understand the causes, impacts, and consequences (Verburg *et al*. 1999; Brown *et al*. 2000;

Theobald, 2001). Land use affects land cover and changes in land cover affect land use. A change in either however is not necessarily the result of the other. Changes in land cover by land use do not necessarily imply degradation of the land. However, many shifting land use patterns driven by a variety of social causes, result in land cover changes. These changes affect biodiversity, water and radiation budgets, and other processes that come together to affect climate and biosphere (Riebsame *et al*. 1994). Human activities which are mainly driven by socio-economic factors bring out changes in non-built-up and built-up land despite restrictions by physical conditions (Long *et al*. 2007). Land use change, including land transformation from one type to another and land cover modification through land use management, has altered a large proportion of the earth's land surface. The aim is to satisfy mankind's immediate demands for natural resources (Meyer and Turner, 1992; Vitousek *et al*. 1997). The worldwide changes to forests, farmlands, waterways, and air are being driven by the need to provide food, fiber, water, and shelter to more than six billion people. Global croplands, pastures, plantations, and urban areas have expanded in recent decades. This expansion is accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity (Foley *et al*. 2005). Land cover can be altered by forces other than anthropogenic. For instance, Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem changes may also initiate modifications upon land cover. There are also incidental impacts on land cover from other human activities such as forests and lakes damaged by acid rain from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Meyer, 1995). Kuemmerle (2009) observed the conversion of cropland to grassland in Arges¸ County in Romania which he related to the rapid changes in socio-economic, demographic, and institutional conditions after 1989.

Similarly, Brown (1995) states that more recent changes in land use have been dominated by losses of agricultural land. In eastern China, there has been an unprecedented conversion of arable land into built-up uses following rapid industrialization. While Kebrom and Hedlund (2000) reported increases in the size of open areas and settlements at the expense of shrublands and forests in twenty-eight years (between 1958 and 1986) in Kalu District. Similarly, Woien (1995) reported an increase in homesteads in studies made in the central highlands, during 1957 and 1986 attributing it to an increase in population density. Mark and Kudakwashe (2010) in a study in Shurugwi district in Midlands Province of Zimbabwe observed the increase in cropland. He attributed this increase to the Land Reform and Resettlement Program. Large areas of forests were cleared for different farm-related activities like opening new farming plots, wood for fuel, and poles for building both homes and cattle pens, among other activities. The built-up area around the water bodies in Davangere city, Karnataka, India has almost doubled between 1970 and 2005, at the cost of the agricultural land and scrubland (Begum *et al*. 2010). Prakasam (2010) studied land use/land cover change over a period of 40 years in Kodaikanal taluk, Tamil Nadu. In this study major changes have been observed like area under built-up land and harvested land has increased whereas the area under forest and water bodies has decreased. Javed and Khan (2012) studied land use land cover change due to mining activities from 2001 to 2010. The study revealed that a significant decrease has been observed in dense forest areas, cultivated land, and water bodies, however settlement, wasteland land, and uncultivated land have increased mainly due to anthropogenic activities. Bisht and Kothyari (2001) have carried out a land cover change analysis of Gurur Ganga watershed in Uttaranchal.

The study from 1963 to 1996 and 1986 to 1996 revealed that the area under agriculture and settlement has increased whereas the forest and barren land show a decline in the area. Dhinwa *et* *al*. (1992) studied land use change in Bharatpur district, the analysis in the study revealed that forest cover has been depleted whereas wasteland undulating terrain with or without scrub and rock-out crops increased during 1986 to 1989. Different land use changes may affect one another. Most of the ecological consequences of land use change reflect interactive effects under different land use changes. For example, deforestation has led to the degradation of freshwater habitat due to the siltation of rivers. Similarly, the role of the Asian forest as a carbon sink and source varies from year to year or from place to place as a result of interactive effects between deforestation, afforestation and reforestation. Therefore, the interactions of different land uses along their change trajectories represent a 53 challenge for a better understanding of the land use change issue. Changes in land and ecosystems and their implications for global environmental change and sustainability are a research challenge for the human environmental sciences (Omenn, 2006; Turner *et al*. 2007).

2.1.3 Land Use/Land Cover Studies Using Remote Sensing and GIS Techniques

To use land optimally, it is necessary to have information on existing land use land cover. It is also important to have the capability of monitoring the dynamics of land use resulting out of both changing demands of increasing population and forces of nature acting to shape the landscape. Land is in a continuous state of transformation as a result of various natural and man-made processes. The study of spatio-temporal patterns of intra and inter-urban form and understanding of the evolution of urban systems are still primary objectives in urban research. Therefore, change information is necessary for updating land cover maps and the management of natural resources (Xiaomei and Rong Qing, 1999). Land use/land cover change detection process identifies the differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Change detection is an important process in monitoring and managing natural resources and urban development because it provides a quantitative analysis of the spatial distribution of the population of interest. Macleod and Congation (1998) list four important aspects of change detection when monitoring natural resources. They include; firstly, detecting the changes that have occurred; secondly, identifying the nature of the change; thirdly, measuring the area extent of the change and lastly, assessing the spatial pattern of the change. The basis of using remote sensing data for change detection is that changes in land cover result in changes in radiance values which can be remotely sensed. Techniques to perform change detection with satellite imagery have become numerous as a result of increasing versatility in manipulating digital data and increasing computer power. Conventional ground methods of land use mapping are labor-intensive, time-consuming, and are done infrequently. These maps soon become outdated over time in a rapidly changing environment.

In recent years, satellite remote sensing techniques have been developed, which have proved to be of immense value 54 for preparing accurate land use/land cover maps and monitoring changes at regular intervals of time. Despite the spatial and spectral heterogeneity challenges of urban environments, remote sensing seems to be a suitable source of reliable information about the multiple facets of the urban environment (Jensen and Cowen, 1999; Herlod *et al*. 2003). So, the analysis of dramatic changes in land use/land cover at global, continental, and local levels and further to explore the extent of future changes, the current geospatial information on patterns and trends in land use/land cover is playing an important role. Remotely sensed imageries provide an efficient means of obtaining information on temporal trends and spatial distribution of urban areas needed for understanding, modelling, and projecting land changes (Elvidge *et al*. 2004). In the case of inaccessible regions, this technique is perhaps the only method of obtaining the required data on a cost and time-effective basis (Olorunfemi, 1983). Satellite imagery can provide more frequent data collection regularly unlike aerial photographs. Although aerial photographs may provide more geometrically accurate maps, they are limited in terms of coverage and expenses. The importance of remote sensing technique was realized by Olorunfemi in 1983 while using the traditional method of surveying i.e., aerial photographic approach to monitor urban land use in developing countries with Ilorin in Nigeria as the case study. A remote sensing device records response which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses the elements of tone, texture, pattern, shape, size, shadow, site, and association to derive information about land cover. The generation of remotely sensed data/images by various types of sensors flown aboard different platforms at varying heights above the terrain and at different times of the day and the year does not lead to a simple classification system. It is often believed that no single classification could be used with all types of imagery and all scales.

The successful attempt to develop a general-purpose classification scheme compatible with remote sensing data was carried out by Anderson in 1976, which is also referred to as the United States Geological Survey (USGS) classification scheme. Ever since the launch of the first remote sensing satellite (Landsat-1) in 1972, land use/land cover studies have been carried out on different scales for different users. For instance, wasteland mapping of India was carried out on 1:1 million 55 scales by NRSA using 1980-82 Landsat multi-spectral scanner data. About 16.2% of wastelands were estimated based on the study. It has been noted over time through a series of studies that Landsat Thematic Mapper is adequate for general extensive synoptic coverage of large areas. As a result, this reduces the need for expensive and time-consuming ground surveys conducted for the validation of data. The State of Maryland Health Resources Planning Commission used Landsat TM data to create a land cover data set for inclusion in their Maryland Geographic Information (MAGI) database. In 1985, the U.S. Geological Survey also carried out a research program to produce 1:250,000 scale land cover maps for Alaska using Landsat MSS data (Fitzpatrick *et al*. 1987). All seven TM bands were used to produce a 21-class land cover map (EOSAT, 1992). Georgia Department of Natural Resources in 1992 used Landsat Thematic Mapper data to complete mapping the entire State of Georgia to identify and quantify wetlands and other land cover types (ERDAS, 1992). Similarly, The State of Southern Carolina Lands Resources Conservation Commission carried out a detailed land cover map composed of 19 classes from TM multi-temporal and multi-spectral data (EOSAT, 1994).

In Indonesia combination of MSS Landsat and land use map was carried out for land use/land cover pattern analysis (Dimyati, 1995) using remote sensing techniques to calculate the index of changes. This was done by the superimposition of land use/land cover images of 1972, and 1984 and land use maps of 1990. Adeniyi and Omojola (1999) in their land use land cover change evaluation in the Sokoto –Rima Basin of North–Western Nigeria used remote sensing and GIS techniques to study changes in the two dams (Sokoto and Goronyo) between 1962 and 1986. The work revealed that land use/land cover classes changed but with settlement still remaining the largest. In India, the National Remote Sensing Agency (NRSA) of the Department of Space under the National Urban Information System (NUIS) scheme used Cartosat-1, Resourcesat-1, and LISS-VI+PAN merged satellite data to carry out national-level urban land use thematic mapping at 1:10,000 scale of 564 cities/towns including State capitals and Union Territories; 23 cities with

Million plus population; NCR towns; and one town from each class (from Class I to Class VI) from each State and Union Territories (NRSA, 2008). 56 For this urban land use mapping a classification standard was designed with classes hierarchically arranged with increasing information content as the levels increase from Level I to Level V. The classification also consists of certain land cover classes up to Level II designed to accommodate the rural classes noticed within the urban administrative limits.

2.1.4 Remote Sensing and land use classification for carbon and biomass estimation

The functions for which lands are being used are commonly associated with types of cover, from the forest, agricultural, residential, to industrial. Intergovernmental Panel on Climate Change's (IPCC) good practice guidance on carbon estimation states that: (1) land use should be adequate, capable of representing carbon stock changes (2) consistent, i.e., capable of representing management and Land use change consistently over time. (3) Complete, which means that all land areas within the study area should be included, with increases in some areas balanced by decreases in others (IPCC 2007) (See figure 2.2). IPCC (2007) states that satellite remote sensing products may also be appropriate for assessing biomass and carbon fluxes at different ecosystem levels (grassland and forest). Carbon stocks in forests have been estimated using correlations between spectral image data and biomass, provided that adequate data are available to represent the range in forest biomes for which estimates are required. Mapping aboveground carbon density over large regions includes work with MODIS (Houghton, Greenglass, Baccini, Cattaneo, Goetz, Kellndorfer, Laporte, Walker, 2010), multiple satellite data, radar, lidar, and Landsat (Baccini *et al.*, 2012). Houghton *et al.* (2010) stated that while the accuracy of remote sensing estimation is lower than site-based inventory measurements, inventory data are generally used to validate satellite algorithms. However, satellite data are far less intensive to collect, can cover a wide spatial area, and thus can better capture the spatial and temporal variability most suitable for a time series analysis of aboveground carbon and biomass analysis.

Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) has been used to describe the vegetation biomass (Diouf, Brandt, Verger, Jarroudi, Djaby, Fensholt 2015). This information shows the biomass index of the Land use class per pixel. So many vegetation indices have been used in remote sensing for the estimation of biophysical properties of the environment.

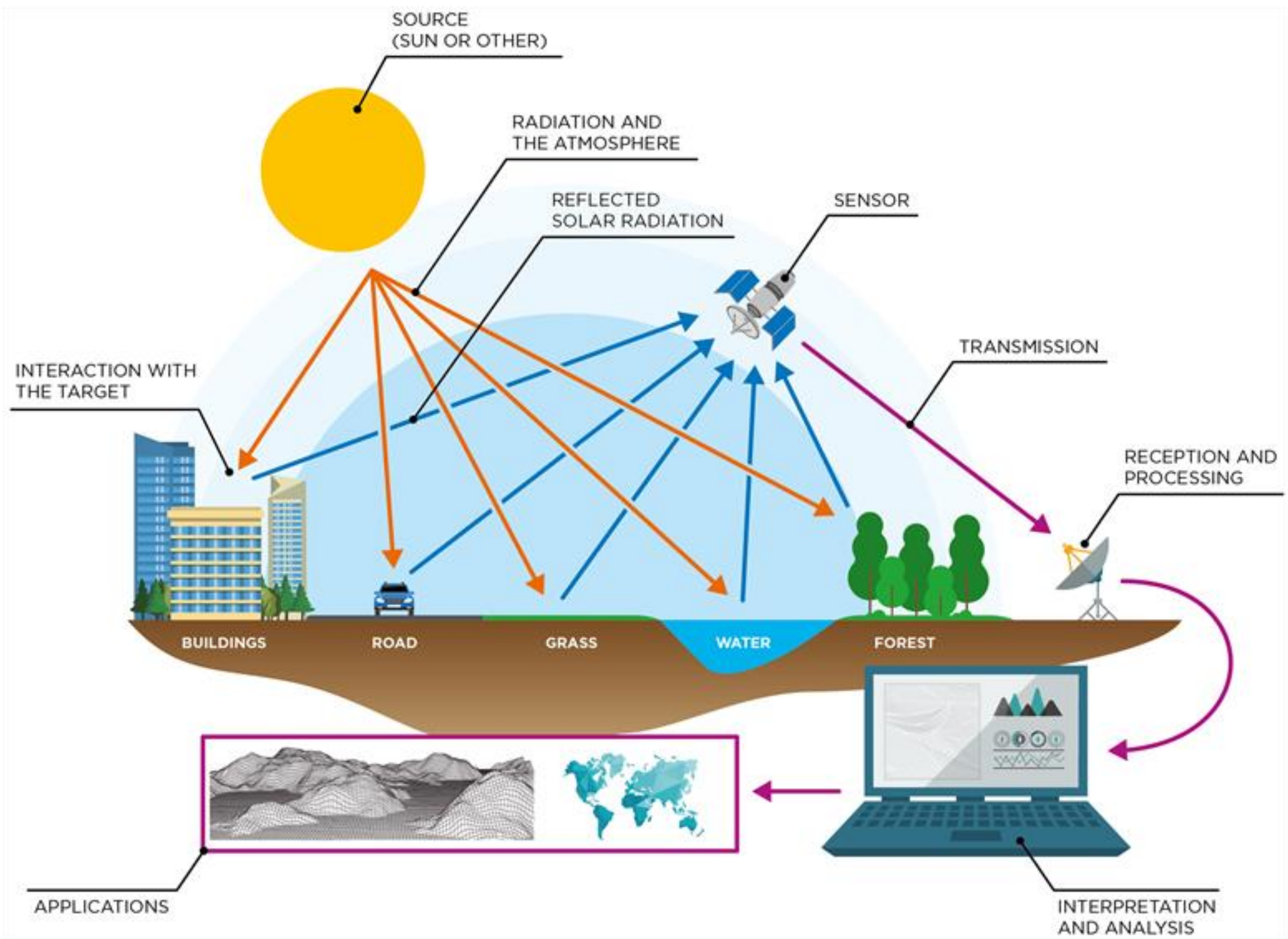

Figure 2.2: Remote sensing application and Land use classification. (Source: IPCC, 2007)

2.1.5 Remote Sensing for Carbon and Biomass Estimation

According to IPCC (2003), Satellite, remote sensing products may also be appropriate for assessing biomass and carbon fluxes in different ecosystems. Carbon stocks in forests have been estimated using correlations between spectral image data and biomass, provided that adequate data are available to represent the range in forest biomes for which estimates are required (Trotter *et al*. 1997).

New satellite techniques are being applied to estimate aboveground carbon densities. Mapping aboveground carbon density over large regions include work with MODIS (Houghton *et al*., 2007), multiple satellite data (Saatchi *et al*., 2007, 2011), radar (Treuhaft *et al*., 2009), and lidar (Baccini *et al*., 2012), Landsat (Gizachew *et al*., 2016). Houghton *et al*. (2012) stated that while the accuracy of remote sensing estimation is lower than site-based inventory measurements, inventory data are generally used to validate satellite algorithms as shown in figure 2.3. However, satellite data are far less intensive to collect, can cover a wide spatial area, and thus can better capture the spatial and temporal variability most suitable for a time series analysis of aboveground carbon and biomass analysis.

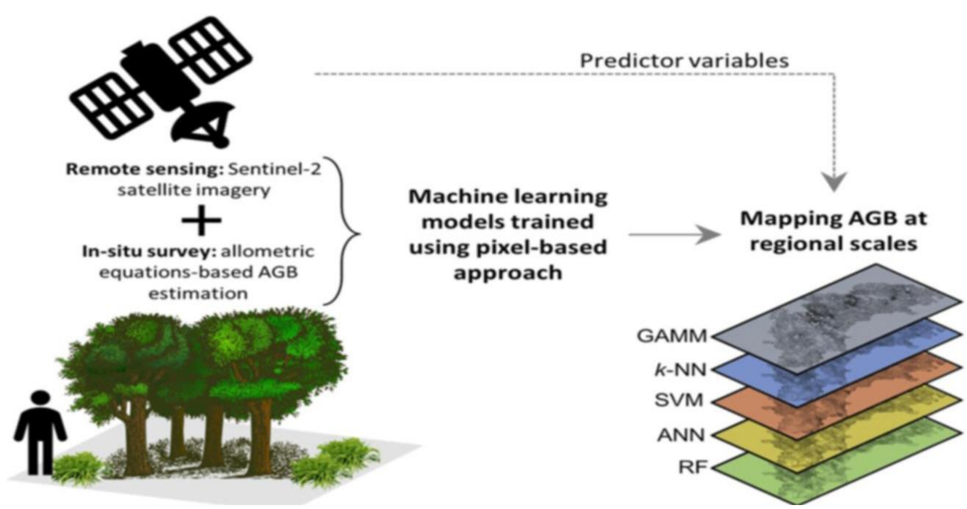

Figure 2.3: Remote sensing and Carbon estimation (Source: Houghton, 2011)

According to Houghton (2011), the capability of estimating the dynamics in carbon density by monitoring is not yet advanced. Still, this capability would enable methods to estimate carbon sources and sinks before identifying disturbance and then examining carbon density or change in carbon density (Houghton and Goetz, 2008). The approach requires models and ancillary data to calculate changes in soil, slash, and wood products. Furthermore, the estimation of change does not discriminate between LULCC by anthropogenic or natural drivers. Nevertheless, the estimation of change in aboveground carbon density has clear potential for improving calculations of sources and sinks of carbon.

For confidence in the outcomes of biomass estimation and mapping from remotely sensed data some form of ground calibration/validation data is required (Goetz *et al*., 2009) including (i) field measurement; (ii) remotely sensed data; or (iii) ancillary data used in GIS-based modelling. Estimation from field measurements may entail destructive sampling or direct measurement and the application of allometric equations. Biomass is commonly estimated by applying conversion factors (biomass expansion factors) to tree volume (either derived from field plot measures or forest inventory data) or applying allometric regression equations to forest stand tables. Landsat TM and ETM+ data are the most widely used sources of remotely sensed imagery for forest biomass estimation. Numerous studies (Roy *et al*., 1996; Kazadi *et al*., 2012) have generated stand attributes from LIDAR data and then used these attributes as input for allometric biomass equations. Other studies have explored the integration of LIDAR and RADAR data for biomass estimation.

According to Karma *et al*, 2012 Forests play a major role in global warming and climate change issues through their unique nature of carbon sinks and sources. Therefore, precise estimation of carbon stock is crucial for the mitigation and adaptation of these issues through the REDD+ carbon incentive program. The study aims to develop a species-specific regression model using canopy projection area (CPA) and LiDAR-derived tree height for accurate estimation and mapping of carbon stock in tropical forests of Chitwan, Nepal. Pan-sharpened WorldView-2 image and canopy height models (CHM) were used for tree crown delineation to extract the CPA and height of the individual trees. Species-wise multiple regression models were developed using CPA, Lidar height, and field-measured carbon stock for carbon estimation of the study area. The study used the Shannon diversity index of each community forest (CF) to find out the relationship between tree species diversity and the carbon stock of CF. LiDAR-derived tree height was able to explain 76% of the variability in field height measurement. Multi-resolution segmentation resulted in overall accuracy of 76% in 1:1 correspondence. Tree species classification resulted in an overall accuracy of 58.06% and Kappa statistics of 0.47 for classifying six tree species. On average correlation coefficient of CPA and carbon, height and carbon, and CPA and height were found to be 0.73, 0.76, and 0.63 respectively for five dominant tree species.

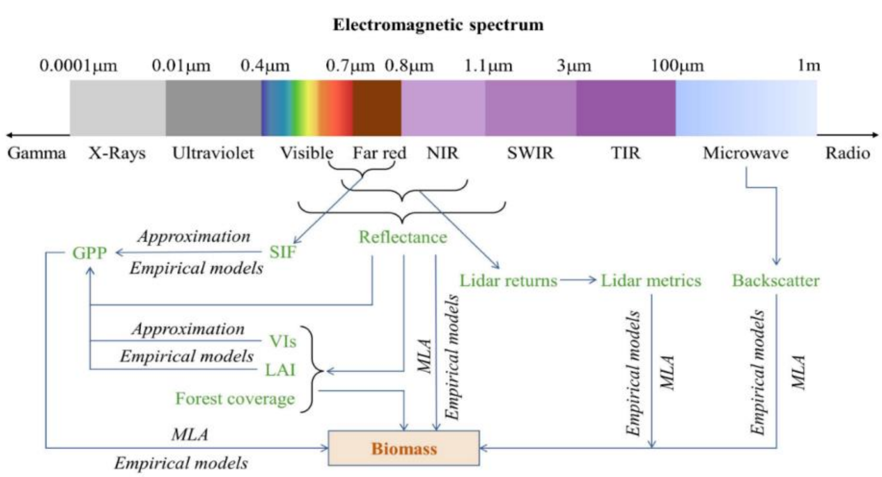

Figure 2.4: Electromagnetic spectrum of forest aboveground biomass (AGB)

The study employed species-wise multiple regression models, incorporating canopy cover percentage (CPA) and Light Detection and Ranging (LiDAR) height data, to estimate carbon stocks for individual tree species. Remarkably, these models successfully accounted for over 75% of the variation in carbon estimation for each species. However, the analysis revealed that the relationship between tree diversity and carbon stock at the community forest (CF) level was insignificant, suggesting a weak correlation. Utilizing WorldView-2 satellite imagery and airborne LiDAR data proved to be highly promising for estimating and mapping species-specific aboveground carbon stocks in tropical forests. These remote sensing technologies offer valuable insights into forest structure and composition, facilitating more accurate carbon stock assessments. Moving forward, further research is recommended to delve into the broader relationship between tree diversity and carbon stock across various forest types. Exploring this relationship on a larger scale could enhance our understanding of ecosystem dynamics and inform conservation and management strategies aimed at maximizing carbon sequestration potential in forests.

2.1.6 Modelling Present and Future Biomass and Carbon

Since Terrestrial ecosystem production cannot be directly measured at the regional or global scales, thus its estimation by computer models has become very necessary (Cramer *et al*., 1999). Models have been developed to estimate biomass at large scales. According to Randerson *et al*. (2002), the CASA biogeochemical model predicts net ecosystem productivity (NEP) through net primary production (NPP) to aboveground and belowground pools, which have turnover rates governed by specified rate constants. According to Masek *et al*., (2006), The Modeling results indicated that forests have average net ecosystem productivity (NEP) of 80 GC m_2 yr^{-1} reflecting the young age structure of rapid rotation forests. The global landscapes are spatially heterogeneous and temporally dynamic.

Most of these landscape models were developed for specific purposes or regions, resulting in a proliferation of landscape models (Keane *et al*., 2004; National Research Council, 2014). This makes most existing models unsuitable for use as a general landscape modeling framework (Wimberly *et al*., 2015). There are a few models that are different from the more general models. The exceptions include SELES (Fall & Fall, 2001) and the state-and-transition simulation model (STSM) approach for forecasting landscape change (Daniel *et al*., 2016). State-and-transition simulation models (STSM) provide a general framework for forecasting landscape dynamics, including projections of both vegetation and land use/land cover (LULC) change. However, a current limitation of the STSM method is that all of the state variables must be discrete (Colin *et al.,* 2017).

In a study of Historical and future carbon stocks in forests of northern Ontario, Canada Ter-Mikaelian *et al* 2021 used a combination of field and remotely sensed observations with a land surface model to estimate forest C stocks in the FNO forests and to project their future dynamics. The study was to simulate historical C stocks for 1901–2014 and future C stocks for 2015–2100 for five shared socioeconomic pathway (SSP) scenarios selected as high-priority scenarios for the 6th Assessment Report on Climate Change. The result reveals that Carbon stocks in live vegetation in the FNO forests remained relatively stable between 1901 and 2014 while soil organic carbon (SOC) stocks steadily declined, losing about 16% of their initial value.

At the end of the historical simulation (in 2014), the stocks were estimated at 19.8, 46.4, and 66.2 t Cha−1 in live vegetation, SOC, and total ecosystem pools, respectively. Projections for 2015–2100 Effectively indicated no substantial change in SOC stocks, while live vegetation C stocks increased, accelerating their growth in the second half of the twenty-first century. These results were consistent among all simulated SSP scenarios. Consequently, the increase in total forest ecosystem C stocks by 2100 ranged from 16.7 to 20.7% of their value in 2015. Simulations with and without wildfires showed the strong effect of fire on forest C stock dynamics during 2015–2100: inclusion of wildfires reduced the live vegetation increase by half while increasing the SOC pool due to higher turnover of vegetation C to SOC.

2.1.7 Forest Management Policies

Historically, Nigeria has undergone several phases in its forest policy development since the 1900 Forest Ordinance which was primarily focused on revenue generation and the exploitation of timber resources (Obi, (2020) but neglected the ecological, social, and cultural aspects of forest management. Critiques point out that the historical approach prioritized economic gains at the expense of environmental sustainability and the rights of forest-dependent communities (Aiyeloja, Oladipo, & Olasupo, 2018).

In response to growing environmental concerns, Nigeria began transitioning towards sustainable forest management (SFM) in the late 20th century. The 1988 National Forestry Policy emphasized conservation, afforestation, and community involvement (Obioha, Muchapondwa, & Leiman, 2019). This shift towards SFM aligns with international agreements such as the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change (Ola-

Adams, Ajayi, & Ajayi, 2015). However, critics argue that while policies have evolved theoretically, challenges persist in translating these principles into effective on-ground practices (Okali, Tagg, & Hawtin, 2017). A notable development in Nigeria's forest policies is the promotion of community-based forest management (CBFM). The Forest Law Enforcement, Governance, and Trade (FLEGT) Voluntary Partnership Agreement (VPA) process initiated in 2010 seeks to empower communities and enhance transparency in the forestry sector. While CBFM is lauded for its potential to foster sustainable resource use and local livelihoods, critiques highlight challenges in the equitable distribution of benefits and insufficient capacity building for communities (Kanu, Adebote, & Adegun, 2017). Despite policy reforms, issues like illegal logging, encroachment, and inadequate enforcement persist. Inconsistencies between federal and state-level policies also hinder effective forest governance (Nigeria REDD+ Programme, 2016). The lack of integration between forestry, agriculture, and Land use planning policies exacerbates deforestation (Aiyeloja, *et al*., 2018). These issues in forest management policies in Nigeria have continued to create problems in managing carbon emissions in southwestern Nigeria.

In conclusion, the literature review shows that there is a knowledge gap on the relationship between deforestation, biomass changes, carbon fluxes, and the forest management strategies that are vital for developing policies to protect forest areas and reduce carbon emissions by reducing deforestation and forest degradation. There is also a knowledge gap in the proper methods of accurately quantifying carbon stock in the study area. The research therefore intends to cover these gaps and add to the body of knowledge in forest carbon management.

2.1.8 Forest Area, Governance, and Exploitation in Nigeria

The history of forest exploitation and governance in Nigeria dates back to the 19th century, with the establishment of the first forestry department in 1908 (National Forest Policy, 2006). According to the National Forest Policy (2006), Nigeria's forest estate spans five main ecological zones: Freshwater/Mangrove, Lowland Rainforest, Derived Savannah, Guinea Savannah, and Sudan/Sahel Zone. Forest reserves cover approximately 10% (96,043 km^2) of Nigeria's land area, comprising 20,746 km^2 of high forest, 3,208 km^2 of derived savannah, and 72,089 km^2 of savannah. This forest estate is a legacy inherited from colonial forest administrators. The National Forest Policy (2006) highlights the undeniable degradation of Nigeria's forests, attributing it to the current level of wood demand surpassing the sustainable supply. The projected wood demand for 2020 is estimated at 180 million m^3, exceeding the sustainable supply level of less than 100 million m^3. This rapid deforestation rate, approximately 5% annually, ranks Nigeria as the top country for forest loss globally, resulting in an average degradation of 410,000 ha of forest cover annually (FAO, 2016). Moreover, reports from 1976/78 to 1993/95 indicate a continual decline in Nigeria's forest status, accompanied by an increase in land allocated for agricultural purposes (Olayele & Ameh, 1999). This trend contradicts government policies aiming to maintain 20-25% forest cover on the country's land surface for the well-being of the national, regional, and global environment.

2.1.9 Effect of Forest Decision Making and the Rights of the Indigenous People

Lindblom (1959) contended that decisions made by a select few individuals hold significant implications, as they reflect the goals agreed upon within the political system. This approach to forest administration in Nigeria poses a threat to achieving common goals, potentially benefiting certain powerful groups at the expense of others. This is evident in Nigeria's Millennium Development Goals End-Point Report (2015), which highlighted impressive economic growth rates in the 2000s. However, this growth was not inclusive and did not effectively reduce poverty or create employment opportunities. Disparities in welfare across geopolitical zones persist, with rural areas experiencing higher levels of poverty despite possessing resources that could enhance their well-being.

The United Nations Declaration of the Rights of Indigenous Peoples (UNDRIP, 2008) emphasizes the rights of indigenous peoples, including their rights to own lands, territories, and natural resources traditionally or historically acquired. It stipulates that governments must consult and cooperate in good faith with indigenous peoples through their representative institutions to obtain their free and informed consent before implementing measures that may affect them. In Nigeria, an estimated 20,625,200 indigenous people exist, with 90% of the rural population relying on forests and woodlands for fuel (Chao, 2012).

However, current forest management practices in Nigeria undermine the rights of indigenous peoples, highlighting a disconnect between policy formulation and implementation. This may be attributed to the absence or failure to integrate community representatives during policy formulation. The World Commission on Environment and Development (WCED, 1987) stressed the importance of a political system that ensures effective citizen participation in decision-making to achieve a more prosperous, just, and secure global future.

The National Forest Policy (2006) acknowledges the absence of a National Forest Act in Nigeria to date. The enactment of such an Act is crucial to legally enforce the forest policy and ensure its implementation. The proposed Act, currently under review by the Attorney-General's office, includes provisions aimed at protecting communities, regulating access to materials, and recognizing community rights in forest estates. It also outlines penalties for trespassing or violating forestry regulations. The absence of this Act poses a threat to ecological sustainability, the welfare of Nigerian citizens, and the well-being of global citizens.

2.1.10 Forest Policies in Nigeria and the Role of Communities

As per the National Forest Policy (2006), the overarching aim of the policy is to achieve sustainable forest management, ensuring sustainable economic, social, and environmental benefits from forests and trees for both current and future generations, including marginalized groups. The policy outlines specific objectives and strategies aimed at reducing inequality, preserving cultural heritage, and maintaining ecological balance in an appealing manner. It delineates thirty priority areas, each accompanied by policy statements, objectives, and strategies for their achievement. Among these priorities, community participation within and outside forest reserves and game reserves stands out as crucial for attaining sustainable forest management in Nigeria. The primary objective is to foster collaborative partnerships with rural communities to sustainably manage forest resources, ensuring the continued provision of goods and services from forests for present and future generations. This involves promoting sustainable forest management in both designated forest reserves and areas outside formal forest boundaries, often referred to as free areas.

2.2 Conceptual Framework

2.2.1 Carbon Cycle

The concept of the carbon cycle (Figure 2.4) is intricately linked to the dynamic exchange of carbon between various Earth reservoirs, playing a pivotal role in regulating environmental processes. Within this cycle, the aboveground carbon pool is a crucial component that connects terrestrial ecosystems, deforestation activities, and carbon emissions. The aboveground carbon is primarily stored in vegetation, including trees, shrubs, and other plant structures. They absorb CO_2 from the atmosphere through the process of photosynthesis, converting it into organic compounds. This mechanism forms a link in the carbon cycle and establishes the initial connection between atmospheric carbon and the aboveground carbon pool. Trumper *et al* (2019). The large-scale removal of forests disrupts this delicate balance by directly impacting the aboveground carbon pool. When forests are cleared for various purposes such as agriculture, logging, or urban development, the stored carbon within trees and vegetation is released into the atmosphere. Consequently, deforestation becomes a significant source of carbon emissions, contributing to the increase in atmospheric CO_2 concentrations. The link between deforestation and carbon emissions is of paramount concern due to its far-reaching implications for climate change. As trees are removed, not only is the aboveground carbon pool depleted, but the capacity of the remaining ecosystems to sequester carbon is also compromised. Understanding the consequences of disrupting the aboveground carbon pool through deforestation is crucial for addressing climate change mitigation efforts. By preserving existing forests and restoring degraded landscapes, it is possible to enhance the sequestration potential of the aboveground carbon pool and mitigate the impact of human-induced carbon emissions on the global carbon cycle. This provides the basis for which deforestation in southwest Nigeria must be estimated and the carbon emissions from forests estimated since the forest and woodland removals contribute to forest carbon emissions to the atmosphere.

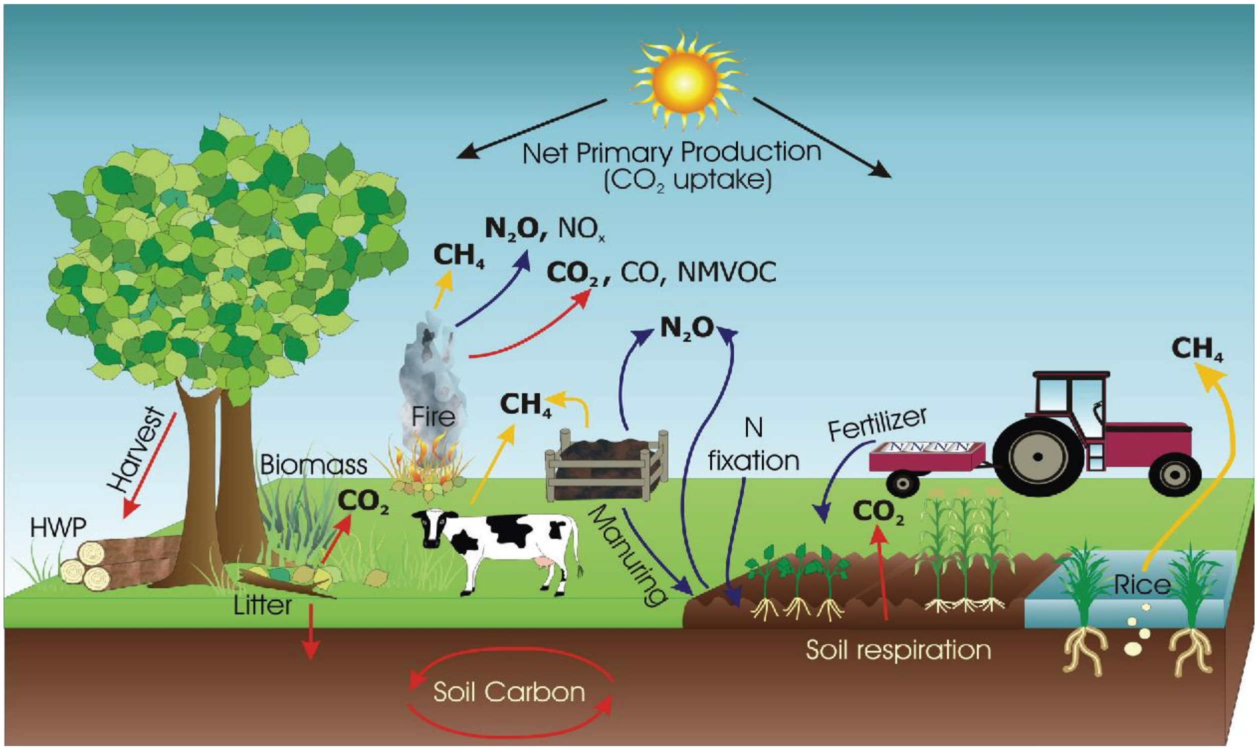

Figure 2.5: Global Carbon cycle (Source: Trumper *et al*, 2019).

Carbon dioxide is removed from the atmosphere by photosynthesis and released back by respiration and combustion of fossil fuels. Photosynthetic uptake and respiratory release are essentially in equilibrium in prevailing climates, except where large-scale deforestation and forest degradation have resulted in increased transfer of carbon to the atmosphere. Land use changes also tend to increase the amount of atmospheric carbon through the conversion of natural ecosystems to areas of human use (agriculture, pasture, building land, and so forth) typically involving a transition from an area of relatively high carbon storage (often forest or woodland) to one of lower carbon storage (Figure 2.4). The clearing of forest for agricultural and construction purposes results in an estimated 90% decrease in carbon held in living tissues. Because of the widespread use of fossil fuels and deforestation, the concentration of carbon dioxide is increasing at an annual rate that now exceeds 1 ppm. Local concentrations may exceed 400 ppm (Cowie *et al*. 2007; Eliasch 2008) on a daily basis in areas with high level of fossil fuel combustion and topographic conditions that may reduce atmospheric mixing.

According to Barbour *et al*., 1987, Increasing CO_2 levels support higher photosynthetic fixation rates by C_3 plants (most green plants). The competitive interactions of some plant species may change due to CO_2-induced changes in their photosynthetic rates or to temperature-related responses caused by fluctuations in atmospheric CO_2, which traps solar energy much like the glass of a greenhouse does. We might expect subtle changes in physiological response, vegetational structure, and vegetational composition as the carbon cycle fluctuates and finally reaches equilibrium as shown in Figure 2.6. The carbon cycle involves the process whereby there are fluxes in carbon stocks as a result of continuous processes which include; growth and decay, discrete events such as disturbances like harvest, fire, insect outbreaks, Land use change, and other events. The continuous processes can affect carbon stocks in all areas in each year, while discrete events cause emissions and redistribute ecosystem carbon in specific areas and in the year of the event. For practicality, the Tier 1 method estimates the decay of dead organic matter left after a disturbance for several years as part of the current year of the event.

Under Tier 1, it is assumed that the average transfer rate into dead organic matter (dead wood and litter) is equal to the average transfer rate out of dead organic matter so the net stock change is zero. This therefore assumes that dead wood and litter carbon stocks need not be quantified under Tier 1 for land areas that remain in a Land use category. This approach assumes that dead organic matter stocks, particularly dead wood, are very dynamic and depend on the site conditions, which include forest type and age, disturbance history, and management. Countries with significant changes in forest types or disturbance or management regimes in their forests are encouraged to develop local data to estimate the impact of these changes using Tier 2 or 3 methodologies and report the carbon stock changes and removals. Estimates of changes in carbon stocks such as growth, internal transfers, and emissions, are in units of carbon such that all calculations are consistent. Data on biomass stocks, increments, harvests, etc. can initially be in units of dry matter that need to be converted to tonnes of carbon for all subsequent calculations.

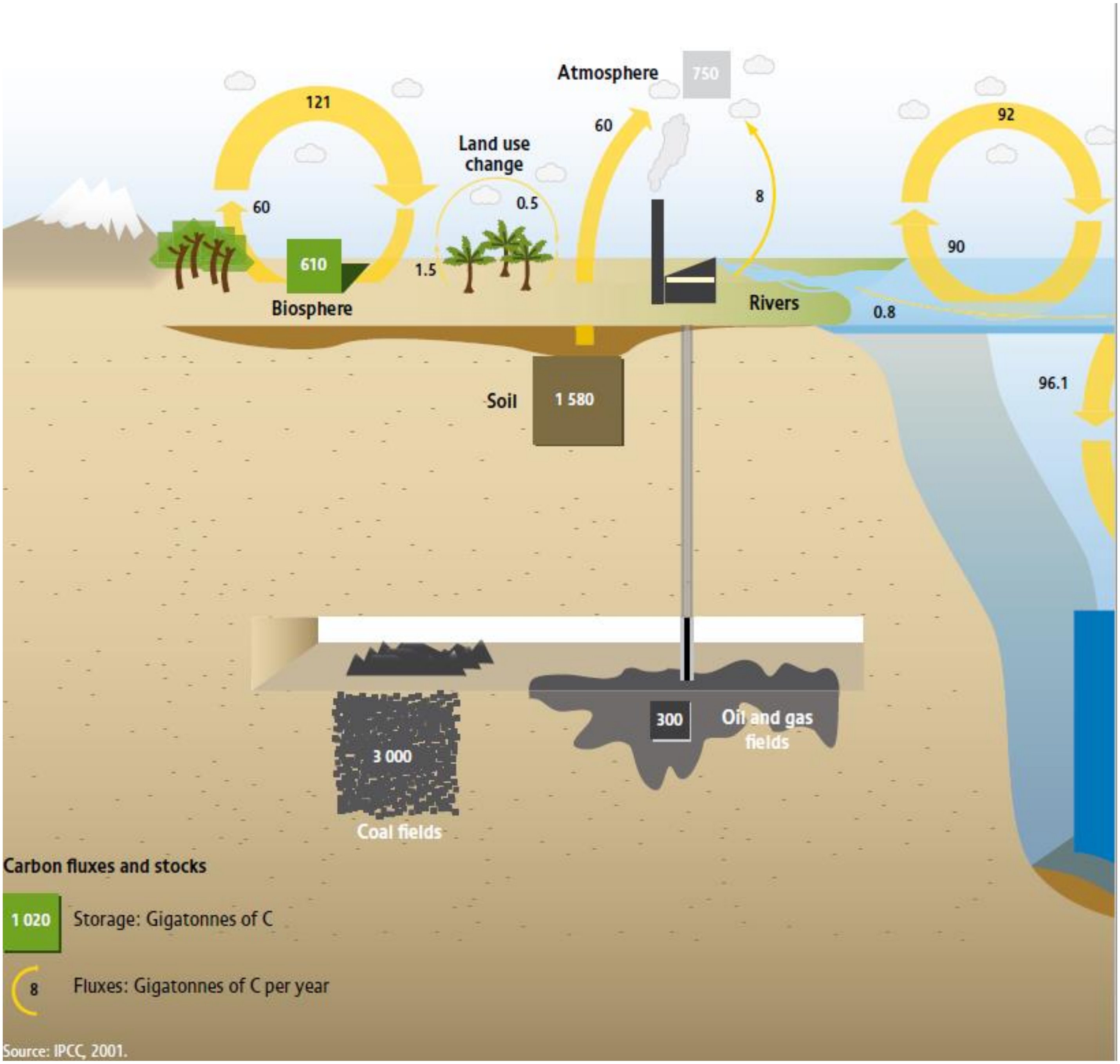

Figure. 2.6: Carbon Cycle in the Natural Ecosystem (Source: Trumper *et al* 2019)

2.2.2 Social-Ecological Systems Theory

According to Kleindl, 2018, Social-ecological theory states that observations, assessment, theory, and their integration with management and policy currently exist at local, and regional landscape scales; (Arthur *et al*., 2015; Loreno 2015; Bixler *et al*., 2016), (Kleindl *et al*., 2015). Social-ecological systems, proposed either conceptually or as a means of analysis, have been developed across many of these scales (Heffernan, *et al*, 2014, Binder, 2013, Folke, 2011; Rose, 2017). The social-ecological system framework integrates ecosystems, goods, and services, with management and policy forming linkage through monitoring and assessment as a means to theorize these relationships. Monitoring and assessment are the interfaces between social and ecological components that should be integrated into any theory of macrosystems because they influence our perception of ecological structure and function.

The trans-disciplinary research gives a view to concepts that bring to focus the ecological and societal impacts of human activities on forests which either leads to biomass and carbon sink or emissions in southwest Nigeria. The ecological structure of the forest in the southwest has given the community a source of livelihood through the exploitation of the forest resources. However, societal management of forest exploitation is of tremendous concern to the environment, due to the weak forest management policies which affect the net production and rate of carbon cycling and energy flow of the study area which is described by the condition of the forest and its quality.

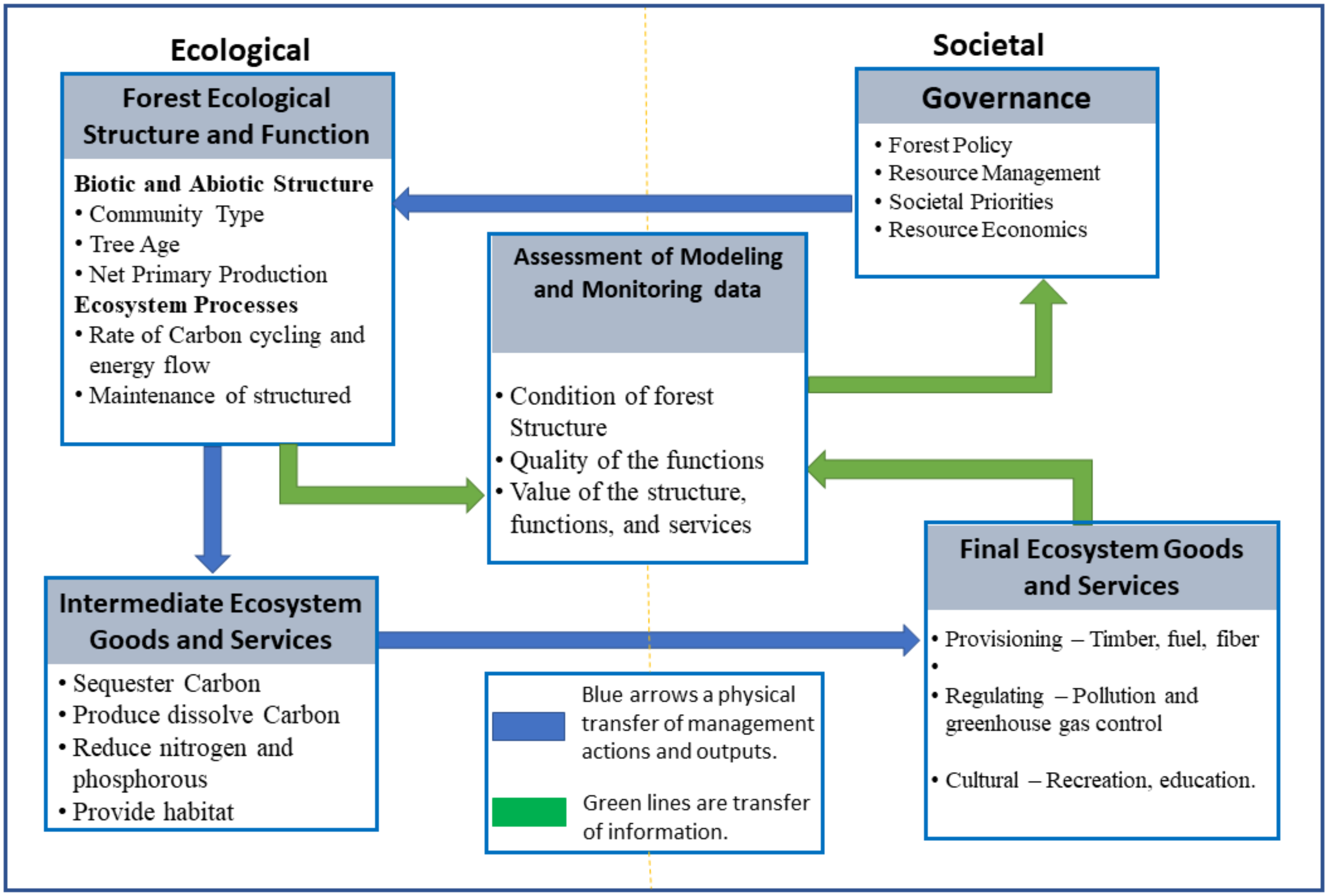

Figure 2.7: A conceptual model representing a coupled social-ecological forest/human

Source: (Kleindl *et al.*, 2018)

Ecological elements in the framework are the core of the theoretical relationship between ecological structure and function (Figure 2.7) (Odum 1962). Our understanding of ecosystems' structural attributes has been defined among ecologists as the biotic community's composition, including physical and species composition, distribution, biomass, and the quantity and distribution of abiotic materials. These structural attributes interact to support various ecosystem functions like energy flow rates and nutrient cycling (Odum, 1962; Brinson, 1993). In addition, ecologists have examined the resilience and stability of systems across scales through the disturbance and recovery fluxes driven by natural disturbance dynamics (Stanford *et al*., 2005; Stanford *et al*., 2001). This dynamic interaction between structure and disturbance regimes results in either a sink or source of products that support other ecosystems. Some of these products are transferred through direct connections across ecotones, like the exchange of carbon from terrestrial to aquatic systems (Tranvik, 2002), like Amazonian deforestation's influence on global climate (Stark *et al*., 2016).

These sink and source products which are vital to create ecosystem equilibrium, are recognized and classified in the Millennium Ecosystem Assessment of Ecosystem Services (MEM, 2005) as supporting services. Ecosystem services are the goods and benefits that ecosystems provide to support human well-being (MEM, 2005). However, other research work suggested that, although supporting services produce natural capital, they do not translate to human well-being support and are therefore considered 'intermediate services' which are fundamentally necessary for final provisioning, regulating, and cultural services (Boyd, 2007). When the natural resources produced by ecosystems is combined with the opportunity, humans gain ecological benefits such as; provisioning, regulating, and cultural services. (MEM, 2005; Boyd, 2015) then ecological-based goods and benefits are produced that make Ecological services essential for economic prosperity (Daily, 1997), and their maintenance is central to policy and management directives. In many ways, these directives attempt to control ecological perturbations that occur when disturbances exceed the adaptive range of ecosystems (Collins *et al*., 2011) through rules and regulations limiting or mitigating disturbances that are considered damaging (Bosselman, 1993). Some resource-based forest management approaches use perturbations (timber harvest) and recovery (replanting) in an attempt to mimic these natural disturbances (Bergeron, 1999; Lindenmayer, 2006), further emphasizing the link between ecosystem theory and economic outcomes. Global change can alter the flow of benefits from ecosystem services (Nelson *et al*., 2013). Through our new capability (Satellite remote sensing) to view forests at large scales, modern research in forest ecology is abundant with accounts of the alteration of forested ecosystems resulting from anthropogenic drivers (Westerling *et al*., 2006; DeSantis *et al*., 2013; Weed *et al*., 2013) and projections of future consequences, (Trumbore *et al*., 2015, Miler *et al*., 2015).

The monitoring and assessment of the ecological response to management decisions stands at the focal point to the relationship within the ecological science, ecological management and policy, and the quality and quantity of services the system produces. Assessment explains the intricacy of ecological data to aid policy and management decisions (Barbour *et al*, 1999, Turnhout *et al*, 2007). To enable this process, several methodologies on assessment have been established that rely on indicators to measure how components of ecological structure recover toward a state relatively free of the effects of human activities (Karr *et al* 1998, Collins *et al*, 2008). Ideally, these assessments measure the system's ability to sustainably support the production of desired ecological goods and services and economic benefits (Boyd *et al*, 2015). Just as the awareness of the complexity and scale of environmental problems has increased spatio-temporally, the complexity and scale of the assessment tools is also expanding. There is a long history of assessment approaches developed to facilitate regulatory actions at site and ecosystem scales, and recently, an emergence of landscape-to-macroscale assessment approaches in the satellite era (Tierney *et al*., 2009, USDA, 2011). Today, these assessments are applied throughout the world to provide resource managers with ecological information relevant to decision-making for the public (Dramstad, 2009), and support the refinement of the regulatory process (Holder *et al* 2007).

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

The nature of the study drives the methods to be adopted in analyzing and resolving environmental issues. Ecosystems have multidimensional traits that epitomize a typical geographical problem with a spatio-temporal nature. As a result, this study employs an inductive approach whose inquiry is to establish and define the relationship, create a synthesis, and establish a logical conclusion. Therefore, multidisciplinary tools of remote sensing, GIS, and change in spatial environmental modeling were employed for the data analysis of this research.

3.1 Methodological Framework

This study investigates the carbon fluxes from deforestation and forest degradation using remote sensing and biomass estimation models. The three critical outputs are Land use can cover change, biomass estimation, and estimation of carbon stocks in living plants. The methodology framework has two planks, as shown in Figure 3.1. In the first part, archived-based maps and multi-date Landsat imageries were assembled. The types and sources of these datasets are shown in Table 3.1. The datasets were inspected to ascertain their qualities. This was followed by digital conversion of the base map and extraction of required data layers from the base maps. The Landsat data were analyzed for Land use change, soil-adjusted vegetation index, normalized water index, and land surface temperature. Biomass estimation was estimated from the deforestation and forest degradation analysis.

The second part deals with biomass and carbon estimation through biophysical field measurement to validate the modelled data. The fieldwork involved measuring tree parameters, including Diameter at Breast Height, Tree Height, and stem core, and taking samples from the litters and herbs. The processing of the field data provides an estimate for the Aboveground Biomass at the field scale. During the fieldwork, a questionnaire was administered to assess the policies on forest and woodland management practices. The remote sensing processes and fieldwork results were used as variables in the LUE-Biogeochemical model to generate spatially explicit carbon fluxes within the study area and ultimately produce the carbon maps.

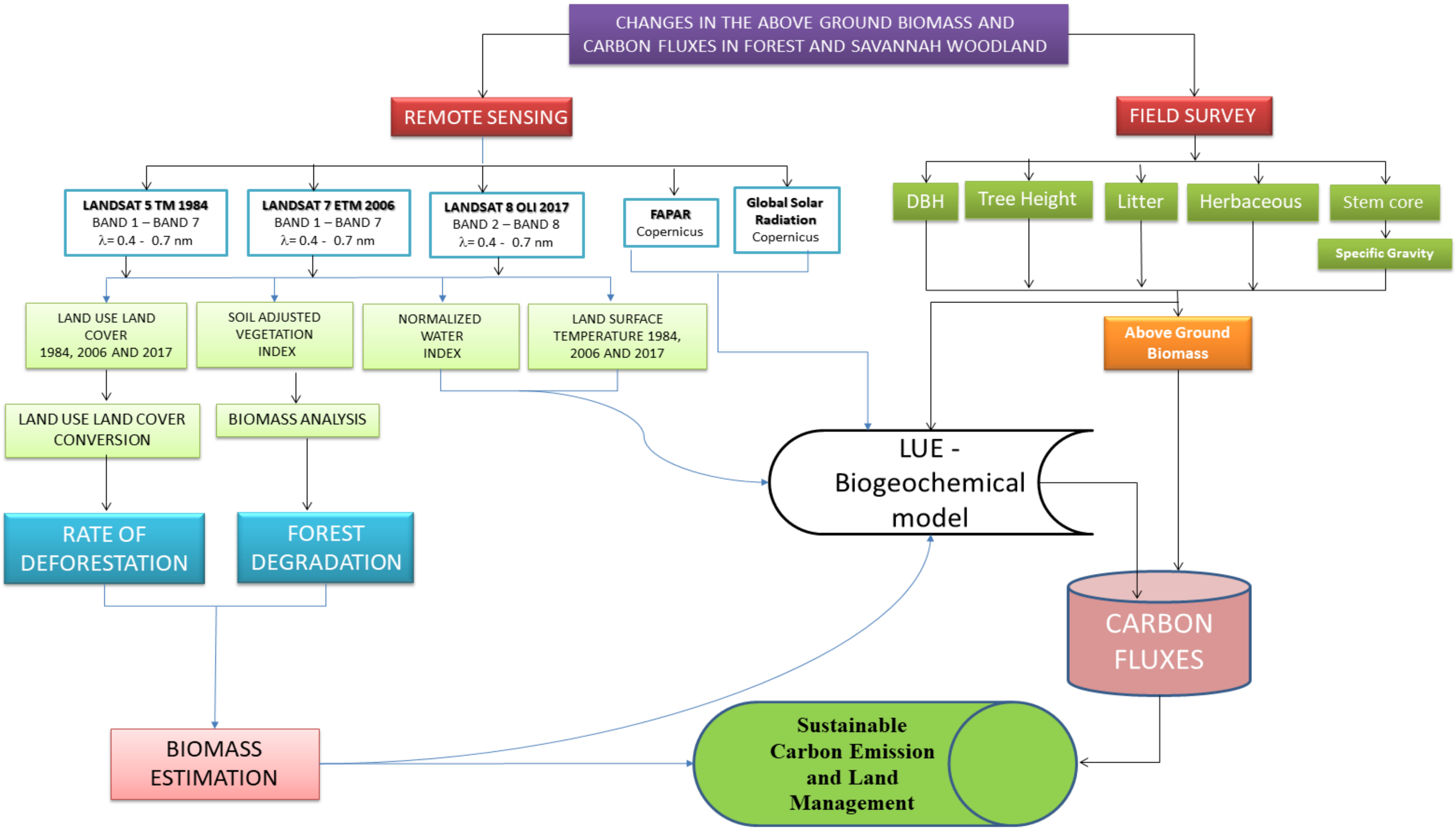

Figure 3.1: Methodological Framework employed for the research.

3.2 Data types and sources

Data used for this study were obtained from various sources, as shown in Table 3.1. The data collected from the primary sources included field measurements, plant sampling, and enumeration. The other data collected from secondary sources included satellite images. The satellite images were obtained from the United States Geological Surveys (USGS) for 1986, 2006 and 2016. In contrast, the Radiation data and the fraction of the absorbed photosynthetically active radiation (FAPAR) were obtained from the cds.climate.Copernicus. eu.

Table 3.1: Characteristics and Sources of Data

Sensor	**Identification**	**Spatial Resolution**	**Date**	**Source**	**Application**
Landsat 5 Tm	Path 191 Row 055, Path 191 Row 054, Path 190, Row 055	Spatial resolution – Pan – 15m B-IR 30mx30m TIR – 60m Spectral resolution – 8 bands	1986	US geological Surveys, glovis.usgs.gov	Land use change Analysis, LST, VI, NDWI
Landsat 7 ETM+	Path 191 Row 055, Path 191 Row 054, Path 190, Row 055	Spatial resolution – Pan – 15m B-IR 30mx30m TIR – 60m Spectral resolution – 8 bands	2006	US Geological Surveys, glovis.usgs.gov	Land use change Analysis, LST, VI, NDWI

Landsat 8 OLI	Path 191 Row 055, Path 191 Row 054, Path 190, Row 055	Spatial resolution – Pan – 15m B-IR 30mx30m TIR – 60m Spectral resolution – 8 bands	2016	US Geological Surveys, glovis.usgs.gov	Land use change Analysis, LST, VI, NDWI
Fraction of Absorbed Photosynthetically Active Radiation	Global Data	1 km by 1 km	1986, 2006, & 2016	www.cds.climate. Copernicus.eu	Variable in CASA Model
Solar Radiation	Global Data	1 km by 1 km	1986, 2006, & 2016	www.cds.climate.Copernicus.eu	Variable in CASA Model
Administrative map	Southwest	1:250,000		GIS & Remote Sensing Lab, Depart of Geography, Unilag	State Boundary delineation
Questionnaire	NA	NA	2017	Fieldwork	Forest Management Practices

3.3 Remote Sensing Data Processing for Land cover analysis

3.3.1 Land use/Land cover classification

The classification was done in line with the IPCC's good practice guidance. Stacking and mosaicking of the image bands to generate a composite image was carried out within the ArcMap GIS environment. For the Landsat TM imagery of 1986, ETM of 2001, the band combinations 2, 4, and 7 (blue, near-infrared, and far-infrared) gave the best band combination for extraction of vegetation and Land use classes while the OLI of 2016 was 3, 5, and 8 (blue, near-infrared and far-infrared). To carry out a detailed ecosystem classification that will reveal the various subclasses of the land cover, the third level of Anderson *et al.,* 1976 schema was employed. A supervised/unsupervised classification method was carried out; training sites established according to spectral reflectance were developed into signature files. The signature classes were subjected to a soft classifier algorithm in the Image classification plugin on ArcGIS 10.3 Software. The Hybrid classification was used for this study due to the large extent of the study area, which the entire locations could not be visited. Thus, Maximum likelihood (MAXLIKE) was employed. MAXLIKE is a powerful classification technique that acts on the differences between the classes of the spectral radiance and the variability and degree and type of correlation between bands (covariance matrices) (Eastman 2001). This method entailed using the Linear Pixel Unmixing. This method was employed when pixels integrate with discrete areas and conceptually fuzzy classes that arise from variability in the underlying classes (Borsoi *et al*., 2021).

Table 3.2: Classification schema

S/N	Level I	Level II
1	Urban or Built-up Land	• Residential • Commercial and Services • Industrial • Transportation, Communications, and Utilities
2	Agricultural Land	• Cropland • Plantation • Scattered Cultivation
4	Forest Land	• Heavy Forest • Light Forest • Disturbed Forest

5	Water	• Streams and River • Lakes • Reservoirs
6	Wetland	• Mangrove • Marsh
7	Open Surface	• Sandy Areas • Bare Exposed Rock • Quarries • Recreational • Construction area

The land use / land cover of the study area was classified using the schema presented on table 3.2. this was adopted and modified from the USGS classification schema of 1969. The classes presented on the table was used and it is reflected on the land uses of this project.

3.3.2 Land use and Landcover Change Analysis

A post-classification approach utilized in this research involves the interpretation and classification of vector land use/land cover data derived from satellite imagery, as outlined by Fichera *et al*. (2012). This methodology is essential for understanding changes in land use and land cover over time, providing valuable insights into landscape dynamics and environmental trends. Change detection analysis plays a pivotal role in this process, allowing researchers to identify and quantify alterations in land cover types between two or more time periods.

In the context of this study, change detection for land use and land cover entails comparing pixels from multi-date satellite images of the same location to detect changes, as elucidated by Vivekananda *et al*. (2021). This involves aligning and overlaying images acquired at different time points, enabling the detection of differences in pixel values indicative of land cover changes. The application of change detection algorithms within Geographic Information Systems (GIS) software, such as ArcGIS 10.8, facilitates the automated identification and analysis of land cover changes across the study area.

The process begins by preprocessing the satellite images to ensure consistency and accuracy in the data. This may involve geometric correction, radiometric calibration, and atmospheric correction to remove distortions and artifacts introduced during image acquisition. Once preprocessed, the images are classified into discrete land cover classes using supervised or unsupervised classification algorithms. Each pixel in the image is assigned to a specific land cover category based on its spectral characteristics, as captured by the satellite sensors.

After classification, change detection is performed by comparing the classified images from different time periods. This comparison involves identifying pixels that have undergone changes in land cover type between the two dates. Change detection algorithms analyze the spectral signatures of corresponding pixels in the two images, flagging areas where significant differences occur. These differences may include land cover conversions, such as the transition from forest to agricultural land, urban expansion, or deforestation.

ArcGIS 10.8 provides a robust platform for conducting change detection analysis, offering a range of tools and functionalities specifically designed for this purpose. The DN (digital number) values of corresponding pixels in the images acquired at time t_1 and t_2 are compared using these tools, allowing for the identification of areas where land cover changes have occurred. The output of the change detection process is typically a thematic map highlighting the locations and extent of land cover changes across the study area.

To further analyze and interpret the detected changes, researchers generate a land change matrix table. This table provides a systematic overview of the different types of land cover changes observed, categorizing areas that have remained stable and those that have undergone conversion to a different land cover class. By quantifying the extent and nature of land cover changes, researchers can assess the drivers and impacts of land use change, informing land management strategies and environmental policy decisions.

3.3.3 Simulation of LULC and Carbon from 2016 to 2066

The State Transition Simulation Model (STSim) (Daniel *et al*, 2016) application was used to simulate the land use and land cover change within the study years as depicted in Figure 5. The state variables are the landcover type, X_t, of the cell at time t, such that (X_t: $t \geq 0$). For example, in a simple model of forest vegetation, the state type might represent the cell's dominant vegetation community, such as grassland, woodland, Natural Forest, Plantation, Agricultural, and Built-up area. The variables used for this model included; the classified land use/landcover as raster data, the transition type, and the change probability for each of the land classes, the probability was set according to the rate of change for the land covers from the base year (1986) to the current year (2016), the minimum age for each of the land cover to recover from disturbance was set. The model used Lumbering, Farming, construction, and succession as drivers of the Land use change. To achieve the STsim carbon projection, a time series maps estimating biomass, at a resolution of 30m x 30m, for the years 1984, 2006, and 2016, to characterize the temporal variability in our growth flows over time for future simulations (2016–2066). The baseline growth flow amounts for each cell and time step were simulated to temporal variability in growth across future years, to make land use type, match the temporal variability in the time series of historical biomass; Note that the same sampled historical year, for each time step, to select historical lumbering probabilities in our LULC change model, thus capturing any covariance that might exist between the variation in historical NPP and land use change.

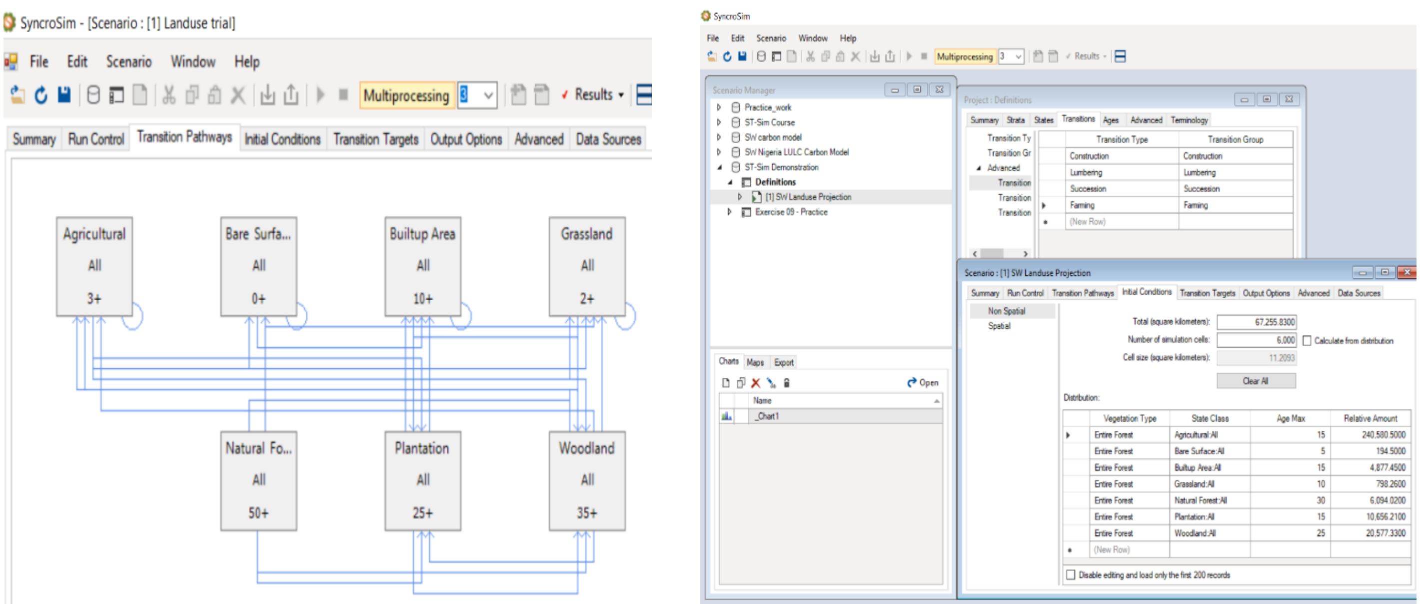

Figure 3.2: Land use Probability Pathway and change drivers shown in the STsim Model

3.4 Aboveground Biomass and Carbon Estimation from Remote Sensing

The soil adjusted Vegetation Index (SAVI) was used to estimate the biomass content of the forest (Barbour *et al.*, 1987); this was used to measure forest degradation for the given study period. The choice of this algorithm is because of its ability to eliminate the effect of the soil reflectance on the vegetation. In addition, this method estimates the biomass and can account for the differing transmission of different wavelengths in the atmosphere as conditions change.

$$SAVI = \frac{nir - rb}{nir + rb + L} \quad \textbf{[1]}$$

Where nir is the near-infrared,

Rb is red and blue wavelength

Then the L is the canopy background adjustment factor that accounts for differential red and near-infrared extinction through the canopy (Huete, 1988; Huete *et al*., 1992; Karnieli *et al*., 2001). An L value of 0.5 in reflectance space minimised soil brightness variations and eliminated the need for additional calibration for different soils (Huete and Liu, 1994). This was on all the years of study, after which the probability matrix was gotten from the processed pixels of the image to determine the extent of change of the AGB of the study area.

3.4.1 Estimation of PAR and FAPAR

PAR is measured as the amount of light within the wavelengths that plants can absorb and use for photosynthesis (400 to 700 nm) and can be calculated using weather and climate data (Pfeifer *et al*., 2012). This means that PAR measures the Gross Primary Productivity (GPP), while the FAPAR measures the Net primary productivity (NPP) which is the same as biomass. The FAPAR is calculated as a linear function of the NDVI simple ratio (SR)

ε is the conversion efficiency of absorbed energy of 0.5, which is then fixed as carbon within an ecosystem.

Is mathematically expressed as

$$\varepsilon = \varepsilon_{max-npp} \times W_{scalar} \times T_{scalar} \quad \textbf{[2]}$$

$\varepsilon_{max-npp}$ is usually a biome-specific variable representing the maximum ability of a particular biome to convert absorbed radiation into dry matter.

W_{scalar} was estimated by using the NDWI (Normalized Difference Water Index)

T_{scala} was estimated by the LST (Land Surface Temperature)

3.5 Field Data Sampling for Remote Sensing Validation

The sampling locations (Table 3.3) were carefully considered using a map during the pre-field briefing with the team (see plate 3.1) to ensure sampling from the major ecosystems in the study area: forest plantations, savannah woodland, and natural forest. The vegetation metrics measured on the field include tree height and diameter at breast height (DBH). Samples were also collected for stem core, dry litter, and fresh herbs.

Plate 3.1: Pre field briefing

The process of this data collection is shown on plate 3.2, where the researcher and the assistants were collecting liter, and herbaceous samples. The data collected on the field was used for the LULC validation and also used to compute and analyze field-based biomass and carbon.

Table 3.3: Sampling Plots for the study area

S/N	Land cover	Community	State
1	Savannah woodland	Erifun-Ilaro	Ogun
2	Savannah woodland	Awo	Osun
3	Natural Forest	Orile Owu	Osun
4	Natural Forest	Okeluse	Ondo
5	Cocoa Plantation	Igbara Oke	Ekiti
6	Teak Plantation	J4 Junction	Ogun
7	Savanna woodland	Okeagbe-Akoko	Ondo
8	Natural Forest	Erin Camp	Ogun
9	Savannah Woodland	Ottu	Oyo
10	Natural Forest	Shasha	Osun
11	Cocoa Plantation	Ibokun	Osun
12	Grassland	Igbetti	Oyo
13	Oil Palm	Ijebu Igbo	Ogun
14	Woodland	Igboho	Oyo
15	Gmelina	Odigbo	Ogun
16	Savanna	Odo Ayedun	Ekiti
17	Savanna woodland	Ikoyi-Ile	Oyo
18	Gmealina/Teak	Ikeji	Osun

Two plots of 25 m by 25 m were marked out in each ecosystem with a 50-meter Measuring Tape. From the sample plots, 5 quadrat plots of 1m by 1m (see plates 3.3 and 3.4) were marked for dry litter and fresh herbs sample collection. Complete identification of all plant species of all life forms (herbs, trees, climbers, shrubs) was done. The woody plants were enumerated, and their girths at breast height (GBH 1.3 m) of trees greater than or equal to 3 m high and those < 3 m height at midpoint were measured using a diameter tape (Plate 3.9). The height of the trees was determined using the clinometer instrument (Plate 3.10). The Stem core of the trees was extracted using the increment borer. The herbaceous and litter were weighed, then blended and the weight was measured again after blending as shown on plates 3.5, 3.6, and 3.7. To estimate the Specific gravity from the stem-core, the samples were analyzed at the Institute for Soil, climate, and Water, Pretoria, South Africa.

Plate 3.2: Litter collection on field

Plate 3.3: Herbaceous collection on field on the 1m x 1m quadrangle set

Plate 3.4: Labelling of samples

Plate 3.5: Samples Separation in the Lab

Plate 3.6: Samples Cataloguing in the Lab

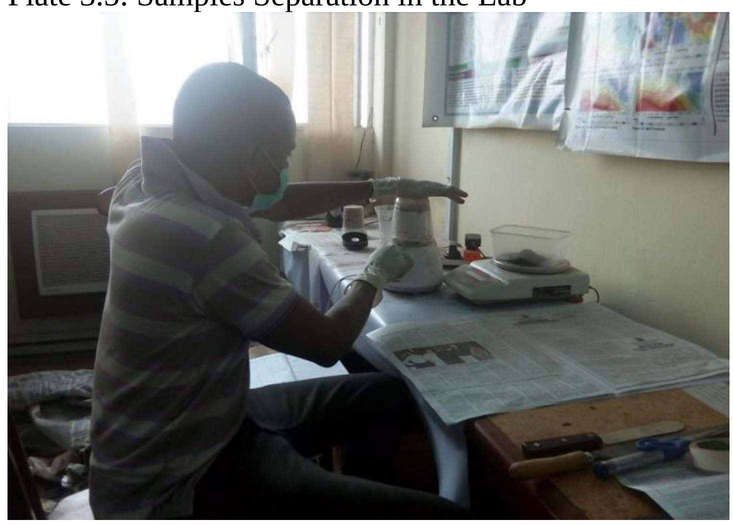

Plate 3.7: Samples Blending and weighing in the lab

Plate 3.8: Field team on the field

Plate 3.9: DBH measuring tape

Plate 3.10: Clinometer for measuring tree height

3.6.1 Field Estimation of Aboveground Biomass and carbon

Aboveground biomass and carbon stock was estimated in each plot across the different ecosystems. The girth sizes of all trees (GBH-1.3 m) greater than or equal to 10 cm in size was enumerated, measured with a tape rule, and identified to species level was converted to DBH using the equation.

$$DBH = \frac{GBH}{\pi} \quad \textbf{[3]}$$

Where: GBH = Girth at Breast Height and π = 22/7

Aboveground biomass was calculated using allometric equations developed from the different tree variables: DBH, specific gravity, and total tree height as predictors using the IPCC 2003 model for the 18 study sites across the study area (Table 1). In addition, the allometric equations developed for Cameroon forest, an African tropical moist forest, by Djomo *et al*. (2011) were used to estimate aboveground biomass in the studied sites.

$$AGB(kg) = exp\ (-2.29 + 0.17\ (InD)2 + 0.66\ In\ (D2H + 0.13In(p)) \quad \textbf{[4]}$$

Where, D is the diameter at breast height, ρ is the specific gravity, and H is the height of the individual tree species. The aboveground biomass was determined by oven drying each woody stem core at 80^{0}C to constant dry weight (Bernard *et al*., 2011). The result from the measurement of AGB on the field was integrated with the biomass result of the remote sensing data to estimate the carbon density of the other land use that could not be sampled. With the spectral signature library created and the carbon content of each plant species on the field.

To validate the carbon result from remote sensing, spearman correlation was used to analyse the degree of relationship between remote sensing and field measured carbon. The correlation used was that which the data does not have a tied rank.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \qquad \textbf{[5]}$$

*Where d_i = difference in paired ranks and n = number of case*s

3.7 Modelling carbon fluxes and estimating the extent of carbon emissions resulting from LULCC, deforestation, and forest and woodland degradation

3.7.1 Carbon Fluxes Estimation

The CASA model was first introduced by Potter *et al.* (1993) based on Monteith's equation (1972) and was expanded by Field *et al*. (1995) using a combination of ecological principles, satellite data, and surface data to predict terrestrial NPP. The remote sensing data and field data were incorporated into the calculation's CASA model to examine the carbon stock. The model controls photosynthetic efficiency in response to spatiotemporally varying stress constraints resulting from temperature and water. (Goroshi *et al.*, 2014) Based on plant production as the primary carbon cycling source, the CASA model is calibrated to connect daily and seasonal patterns in soil nutrient mineralisation and soil heterotrophic respiration (Rh) of CO_2 from soils (Figure 3.3). The flow chart below was designed to model using remote sensing data to estimate the AGB and carbon accumulation of the area using the remote sensing technique.

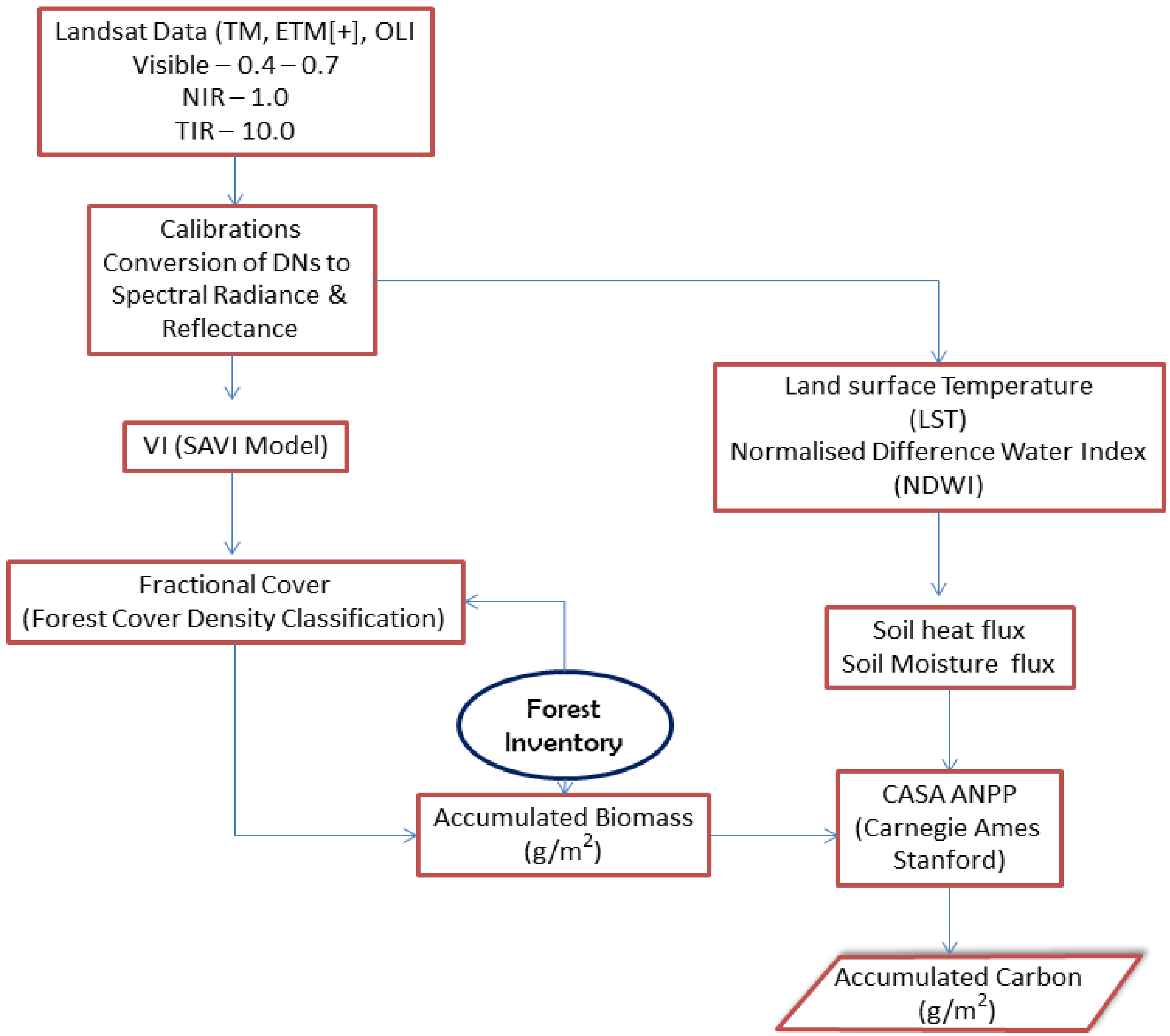

Figure 3.3: Flow chart for estimating carbon (source: Adapted from Eugenia *et al.*, 2018)

The diagram in figure 6 above shows the procedure that was adopted for estimating carbon in the ecosystem. (Potter, 2010) The formula for the CASA model was developed by (Monteith 1977; Hilker *et al.,* 2008):

$$NPP_{(x,t)} = FAPAR_{(X,t)} \times PAR_{(X,t)} \times \varepsilon_{(X,t)} \times T_{(X,t)} \times W_{(X,t)} \qquad \textbf{[6]}$$

Where NPP is the Net Primary Productivity which is the rate of carbon flow in plant and is expressed as grams of biomass per unit time (Barbour *et al*., 1987), the NPP is estimated by GPP minus plant autotrophic respiration.

PAR is the total photosynthetically active radiation incident on the vegetation, and fPAR is the fraction of photosynthetically active radiation absorbed by vegetation,

Solar radiation is converted to PAR by multiplying by a 0.5 constant

The product of fPAR and PAR is sometimes given as APAR (Absorbed Photosynthetically Active Radiation). In many Light Use Efficiency (LUE) models, fPAR is modelled as a function of a vegetation index and is assumed to have a linear relationship with the Vegetation index (Huemmrich *et al*., 2010). Diof *et al*. (2015) have used this in their study of Fodder Biomass Monitoring in Sahelian Rangelands Using Phenological Metrics from FAPAR Time Series

3.8 Field estimated Carbon in Land use / Land cover area

For carbon stock per land use estimation within the study area, the area of the land use was converted to the land use per plot using the following formula.

Land use/plot = LU /625(25 m*25 m) **[7]**

where the LU is the area for the land use and 25m*25m is the plot area.

Carbon/land use = LU/plot * Plot Area **[8]**

CHAPTER FOUR

LAND USE /LAND COVER CHANGE ANALYSIS

4.0 Introduction

This chapter reveals the result and discusses the changes in the land use/land cover of southwest Nigeria from 1986 to 2016. Precisely, this chapter is divided into 3 sections; section 1 deals with the land use /land cover characteristics, which reveal the land use classes and its statistics for the three study period of 1986, 2006 and 2016. The second section reveals the change detection in land use within the three study years to uncover which land use changed more, or which one gave up more to which one. The last section reveals the projection of the land use classes till 2066.

4.1 Static Land use and Land cover 1984 to 2017

The study area covers a land area of about 67,255.83 km^2. The distribution of the static Land use/Land cover for the area in 1986 is shown in table 4.1 and figure 4.1. The data in table 4.1 shows that the primary class of savannah dominates the landcover in 1986. Savannah grassland and woodland cover 12,089.99 km^2 and 10,355.38 km^{2,} respectively. In the natural forest class, highly disturbed forest covered an area of 12,611.37 km^2, while the intensive arable cultivation in the Agriculture primary class covered 8,537.40 km^2, thereby accounting for 17.98% and 15.4%, 18.75% and 12.69% of the study area, Other ecosystem classes in increasing order included fallow (Scattered cultivation) (8.72%), Tree crop/secondary forest (8.03%) undisturbed forest (6.1%), Rock/Montane forest (3.57%), minimally disturbed forest (3.17%), swamp (1.49%), urban (1.32%), sandbar (0.35%), Oil palm (0.68%) River/Lake (0.1%) and Coastal grassland (0.07%)

respectively. The Land use statistics for 2006 show that savannah woodland had an area of about 17,743.97 km^2 (26.38%). It is closely followed by highly disturbed forest with a total area of about 12,390.57 km^2 (18.42%), intensive arable cultivation follows the highly disturbed forest with about 11,330.40 km^2 (16.85%). The table reveals that the land use classes with the lowest land area are rubber 9.34 km^2 (0.01%) quarry 4.37 km^2(0.01%), coastal grassland 39.32 km^2(0.06%), and other ones as shown in table 4.1 above. The table reveals that some other land uses such as oil palm, marshland, Banana was no longer available in 2006. The Land use statistics for 2016, as shown on the table, reveals that savannah woodland had the highest land area of about 20,577 km^2 (30%), intensive arable cultivation had a land area of 14,064 km^2 (20.9%), Teak/Gmelina plantation has a land area of 10,625.85 km2 (15.8%). On the other hand, the table shows that banana plantations had the lowest land area, of 0.47 km^2(0%). The statistics show that Oil palm land use had no record area.

The analysis of Land use data spanning from 1986 to 2016 reveals dynamic changes in land cover within the study area. These changes have significant implications and reflect the complex interplay between environmental and anthropogenic factors. Initially, savannah grassland and woodland dominated the land cover in 1986, but subsequent years witnessed substantial shifts in their areas, indicating the sensitivity of these ecosystems to various influences. These findings align with research by Hirota *et al*. (2011), which emphasizes the susceptibility of savannah ecosystems to environmental and human-induced changes. Moreover, the emergence of new land cover classes such as Teak/Gmelina plantation and bare surfaces underscores the impact of human activities, including afforestation initiatives and land degradation processes. These changes reflect broader trends in land use and highlight the need for sustainable land management practices, as discussed by Chazdon *et al*. (2009) and Veldkamp *et al*. (2001).

Agricultural transitions and land use intensification are evident from the significant increase in intensive arable cultivation area over the years. This suggests shifts in agricultural practices characterized by intensification or expansion, as noted by Verburg *et al*. (2019). However, the loss of certain land cover types like oil palm and banana plantations raises concerns about the underlying factors driving these changes, such as market dynamics and policy shifts impacting agricultural practices, as highlighted by Gibbs *et al*. (2010) and Carlson *et al*. (2012).

Forest dynamics and conservation challenges are also prominent themes in the Land use data analysis. The observed changes in forest cover, including declines in highly disturbed forests and increases in plantation forests, underscore the ongoing challenges of deforestation, forest degradation, and afforestation efforts. Addressing these challenges requires effective conservation strategies that promote sustainable land management practices, as advocated by Gaveau *et al*. (2014). Urbanization and infrastructure development have contributed to the expansion of urban areas, leading to habitat fragmentation and loss of natural ecosystems. These trends underscore the need for integrated Land use planning approaches that balance economic development with environmental sustainability, as emphasized by Seto *et al*. (2012) and McDonald *et al*. (2008).

The dynamic changes in land use and land cover observed in the study area highlight the complexity of interactions between human activities, environmental processes, and policy interventions. Addressing these challenges requires interdisciplinary approaches informed by ecological, social, and economic considerations as portrayed in the conceptual framework of this study. Foley *et al*. (2005) and Lambin *et al*. (2003) emphasize the importance of integrated Land use planning and stakeholder engagement in promoting sustainable land management practices.

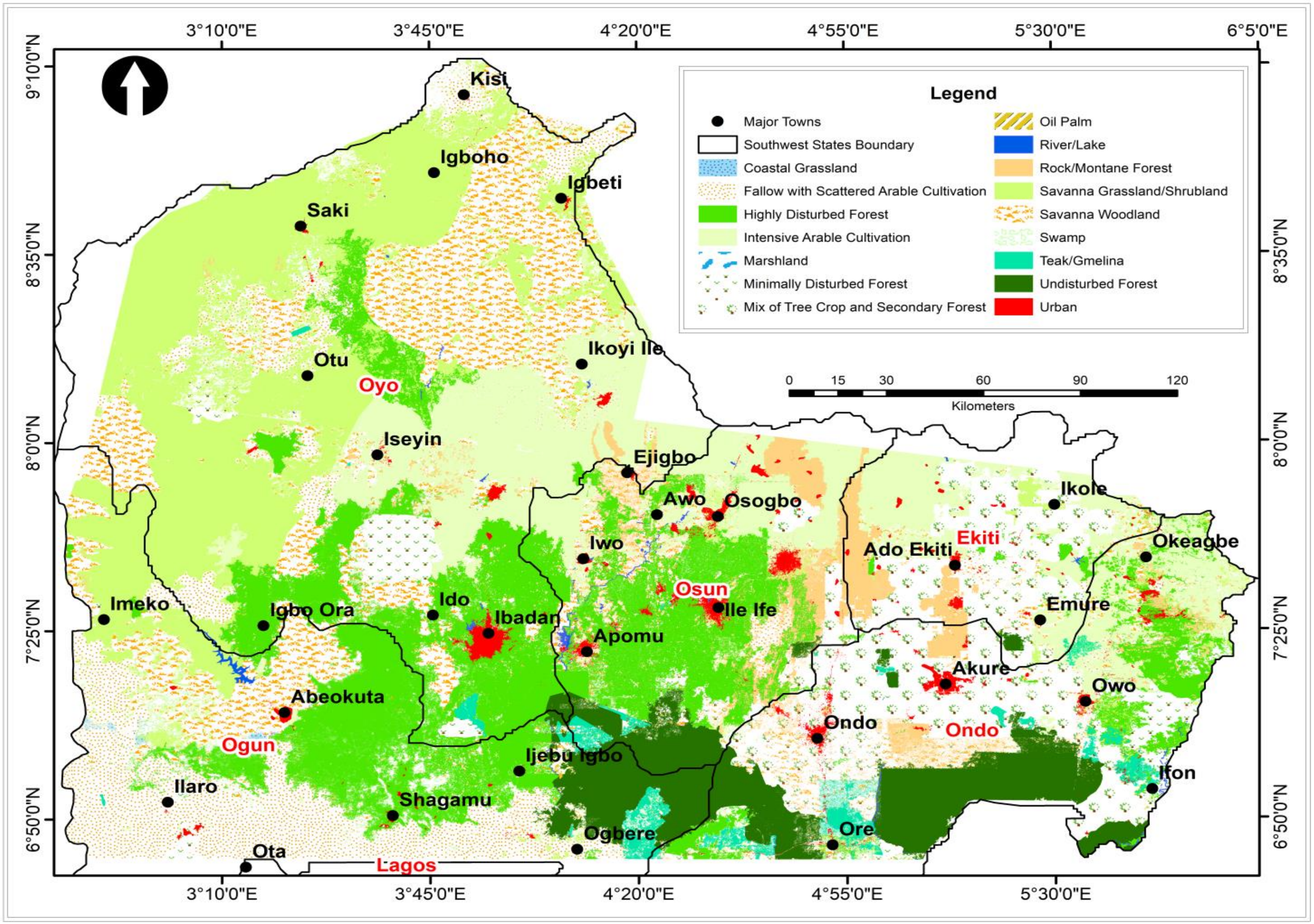

Figure 4.1: 1986 land use characteristics

Table 4.1: LULC Characteristics of 1986, 2006 and 2016

S/N	**Primary Class**	**Secondary Class**	**1986 (km²)**	**%**	**2006 (km²)**	**%**	**2016 (km²)**	**%**
1	Agriculture	Banana					0.47	0
2	Agriculture	Fallow (Scattered Cultivation)	5,864.70	8.72	6,022.36	8.95	1,626.17	2.42
3	Agriculture	Intensive Arable Cultivation	8,537.40	12.69	11,330.40	16.85	14,064.09	20.91
4	Agriculture	Tree Crop/Secondary Forest	5,583.14	8.3	4,993.49	7.42	8,367.32	12.44
5	Bare Surface	Quarry			4.37	0.01	2.58	0
6	Bare Surface	Rock/Montane Forest	2,400.93	3.57	3,692.08	5.49	191.92	0.29
7	Built-up Area	Urban	890.44	1.32	1,944.15	2.89	4,877.45	7.25
8	Natural Forest	Highly Disturbed Forest	12,611.37	18.75	12,390.57	18.42	3,817.42	5.68
9	Natural Forest	Minimally Disturbed Forest	2,130.66	3.17	2,433.65	3.62	1,770.13	2.63
10	Natural Forest	Undisturbed Forest	4,104.14	6.1	1,272.74	1.89	7.13	0.01
11	Plantation	Oil Palm	456.62	0.68				
12	Plantation	Rubber			9.34	0.01	30.37	0.05
13	Plantation	Teak/Gmelina	874.49	1.3	4,961.81	7.38	10,625.84	15.8
14	Savanna	Savannah Grassland	12,089.99	17.98	127.16	0.19	798.26	1.19
15	Savanna	Savannah Woodland	10,355.38	15.4	17,743.97	26.38	20,577.33	30.6
16	Water	River/Lake	68.09	0.1	129.56	0.19	93.99	0.14
17	Wetland	Coastal Grassland	47.98	0.07	39.32	0.06	6.15	0.01
18	Wetland	Marshland	1.25	0			171.61	0.26
19	Wetland	Sand bar	234.01	0.35	105.65	0.16	0.02	0
20	Wetland	Swamp	1,005.24	1.49	55.21	0.08	227.57	0.34
	Total		**67,255.83**	**100**	**67,255.83**	**100**	**67,255.83**	**100**

Table 4.1 shows the natural forest ecosystem class facing competition from agriculture and savannah ecosystems. New landcover classes such as bare surface also emerged. Savannah woodland, highly disturbed forest, and intensive arable cultivation were the most important classes in 2006 with 17743.97 km^2, 12390.57, and 11330.40 km^2 (26.38%, 18.42%, and 16.85 km^2) of the area, respectively. Fallow, tree crop and Teak/ Gmelina accounts for 6022.36 km^2 (8.95%), 4993.49 km^2 (7.42%) and 4961.81 km^2 (7.38%) respectively. Other ecosystem classes mapped for the area in 2006 in order of increase include Quarry 4.37 km^2 (0.01%), rubber plantation 9.34 km^2 (0.01%), coastal grassland 39.32 km^2 (0.06) swamp 55.21 km^2 (0.08%) sandbar 105.65 km^2 (0.16%), savanna grassland 127.16 km^2 (0.19%) undisturbed forest 1272.74 km^2 (1.89%), urban 1944.15 km^2 (2.89%), Minimally disturbed forest 2433.65 km^2 (3.62%) and rock/montane forest 3692.08 km^2 (5.49%). Rubber plantation land use and cover classes emerged in 2006, while oil palm lost in an area.

The distribution of land use and cover classes in the study area in 2006 provides valuable insights into the patterns of human-environment interactions and land management practices.

The dominance of savannah woodland, highly disturbed forest, and intensive arable cultivation underscores the extensive conversion of natural ecosystems for agricultural purposes. These land cover classes are indicative of deforestation, land clearance, and agricultural expansion, driven by socio-economic factors such as population growth, urbanization, and agricultural intensification (Lambin & Geist, 2006). Fallow land, tree crops, and Teak/Gmelina plantations represent areas undergoing various stages of land use transition. Fallow land may result from shifting cultivation practices or temporary abandonment of agricultural fields, while tree crops and plantations reflect efforts to diversify agricultural production or promote agroforestry systems (Turner II *et al*., 2007).

The emergence of rubber plantations highlights shifts in land use priorities and economic activities. Rubber cultivation may be driven by market demand, government policies, or incentives for cash crop production, leading to changes in land cover and land use intensity (Mertens *et al*., 2002). The decline in oil palm plantation area suggests changes in the dynamics of palm oil production, influenced by factors such as market trends, land availability, and environmental regulations. This trend underscores the need for monitoring and sustainable management of oil palm plantations to mitigate environmental impacts and ensure the long-term sustainability of palm oil production (Gibbs *et al*., 2010). Overall, the distribution of land use and cover classes reflects the complex interactions between human activities and environmental processes shaping the landscape of the study area. Understanding these dynamics is essential for sustainable land use planning, conservation efforts, and natural resource management strategies.

Table 4.1, also depicted in Figure 8, shows the emergence of a Banana Plantation of 0.47 km^2 to the ecosystem of the study area in 2016. the savannah woodland and intensive arable cultivation submerged other landcover ecosystems and claimed an area of 20577.33 km^2 (30.6%) and 14064.09 km^2 (20.91%) of the total area respectively, Another land use and landcover ecosystem that also had a relatively high increase rate in 2016 were Teak/Gmelina and Tree crop/ secondary forest with an area of 10625.84(15.8%) $km^2$and 8367.32 km^2 (12.44%) respectively.

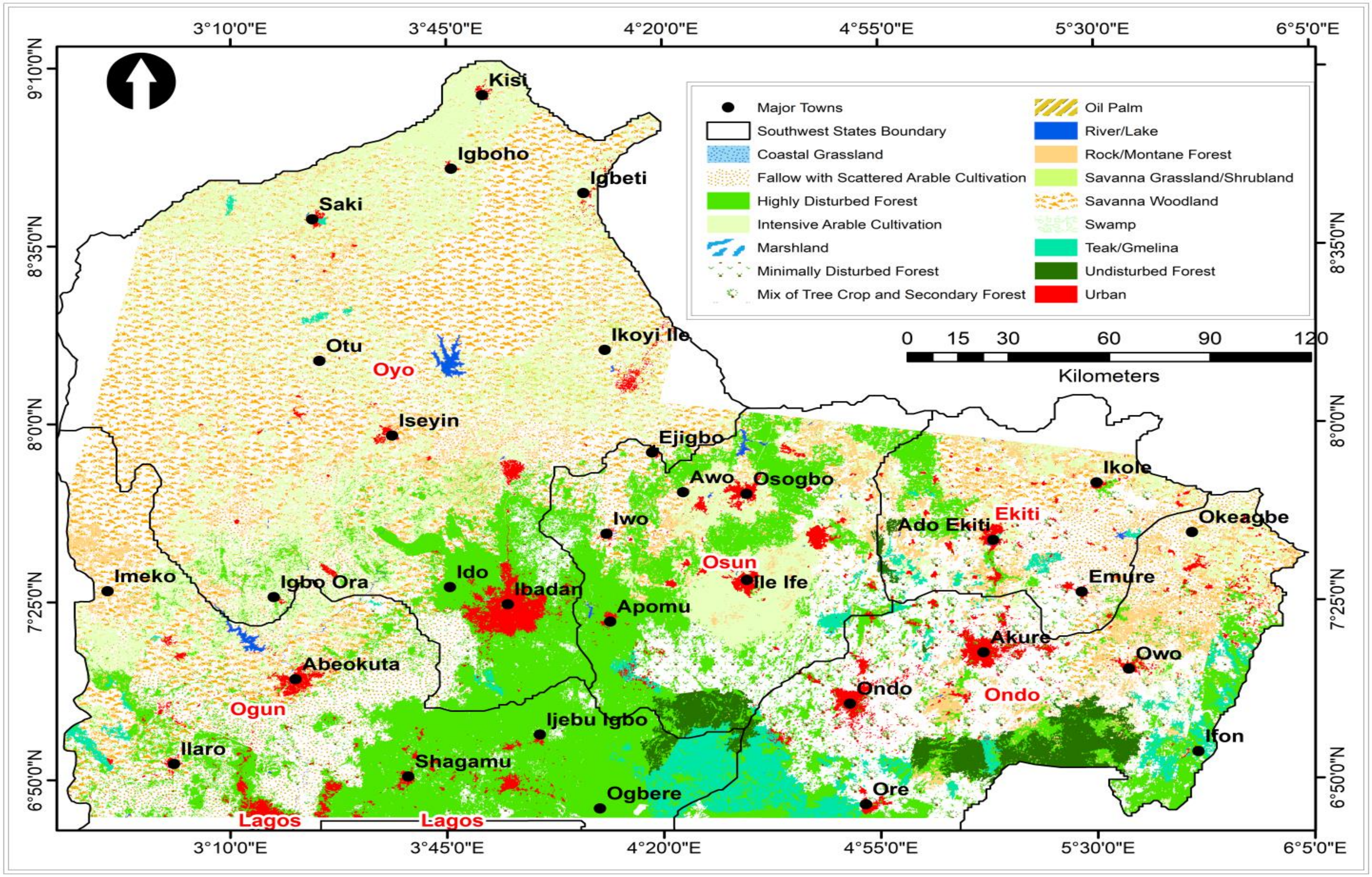

Figure 4.2: 2006 land use characteristics

The emergence of a Banana Plantation in the study area in 2016, as depicted in Table 4.1 and Figure 8, highlights the dynamic nature of land use and land cover changes in response to various socio-economic and environmental factors. The expansion of agricultural activities, particularly intensive arable cultivation and plantation crops such as bananas, reflects shifts in land use priorities, market demands, and agricultural practices. The substantial increase in savannah woodland and intensive arable cultivation areas, accounting for 30.6% and 20.91% of the total area respectively, underscores the extensive conversion of natural ecosystems for agricultural purposes. This expansion may be driven by factors such as population growth, urbanization, agricultural intensification, and government policies promoting agricultural development (Lambin & Geist, 2006). Additionally, the notable increase in Teak/Gmelina plantations and Tree crop/secondary forest areas further illustrates the diversification of agricultural production and land use intensification strategies. Plantation forestry, including Teak and Gmelina cultivation, may be promoted for timber production, agroforestry systems, or reforestation efforts, contributing to landscape transformation and ecosystem services provisioning (Mertens *et al*., 2002). These changes in land use and land cover patterns have significant implications for biodiversity conservation, ecosystem services provision, and socio-economic development. Understanding the drivers and impacts of these changes is essential for informing land use planning, environmental management strategies, and sustainable development initiatives aimed at balancing agricultural production, conservation objectives, and socio-economic priorities.

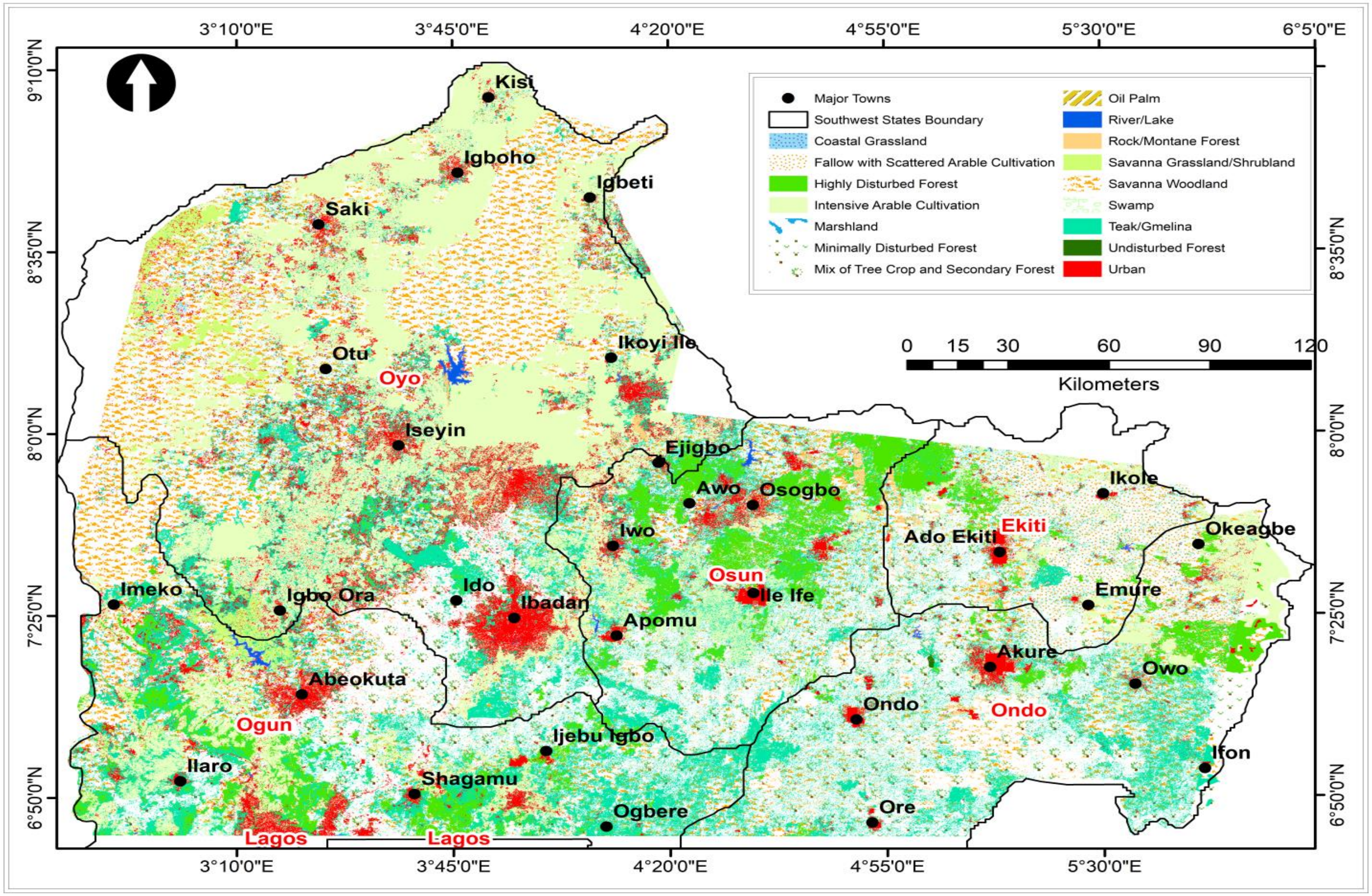

Figure 4.3: 2016 Land use characteristics

4.1.1 Trend of Landcover Change between 1986 and 2016

The analysis of land cover changes presented in Table 4.1 provides valuable insights into the dynamics of land use transformations in the study area over two distinct time periods: 1986 to 2006 and 2006 to 2016. These findings highlight both positive and negative changes in various land cover types, reflecting the complex interplay of natural and anthropogenic factors shaping the landscape (Lambin *et al*., 2003).

During the period from 1986 to 2006, the study reveals substantial changes in land cover, with savannah grassland experiencing the most significant decrease in area, amounting to 11291.73 km^2 or a reduction of 17.79%. This decline may be attributed to factors such as agricultural expansion, urbanization, and deforestation, which often result in the conversion of natural habitats to croplands or settlements (Foley *et al*., 2005). Conversely, savannah woodland exhibited a positive change, with an increase in area by 7388.59 km^2 or 10.00%. This could be indicative of afforestation efforts or natural regeneration processes occurring within the study area (Hirota *et al*., 2011).

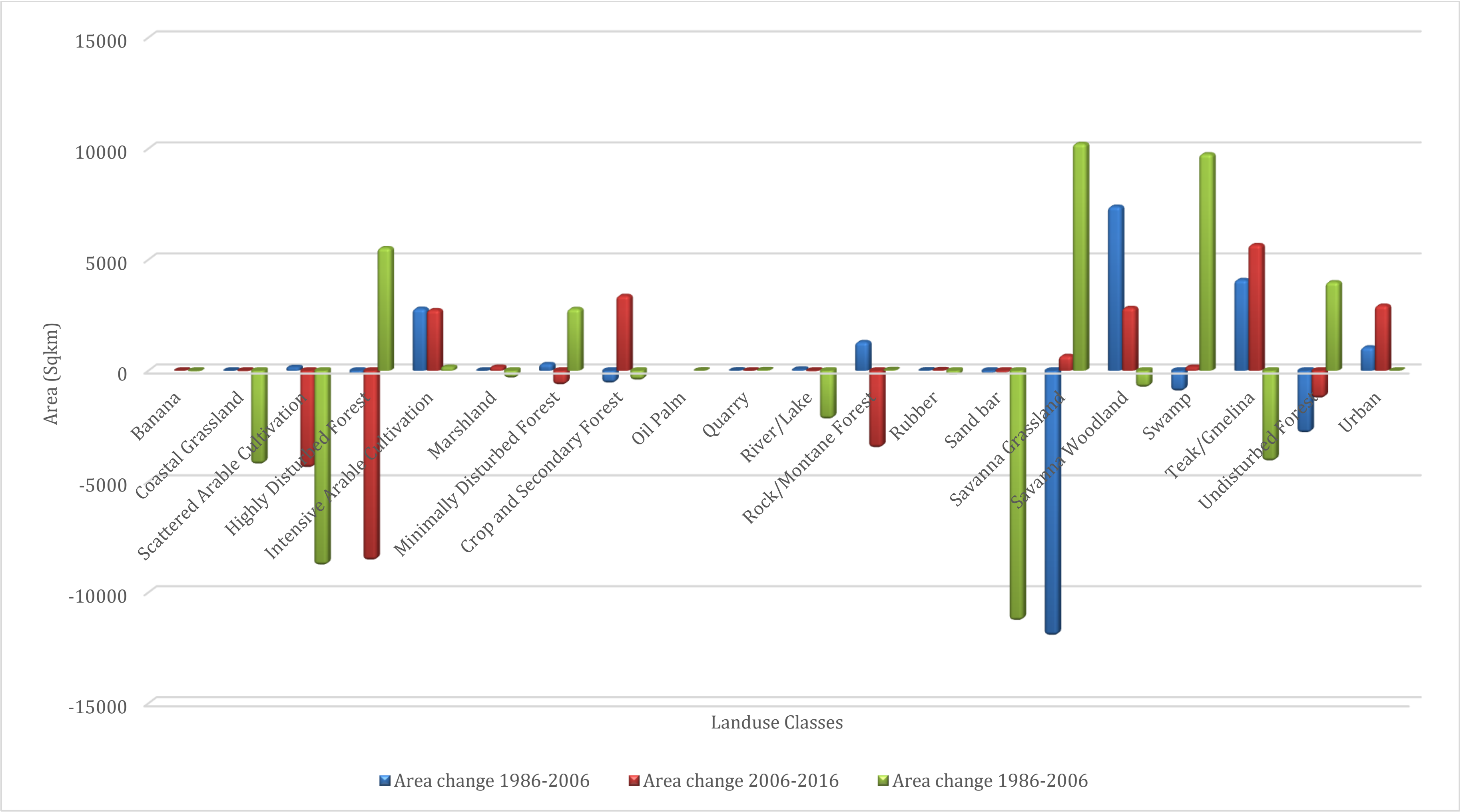

Figure 4.4: Land use/land cover change between 1986 and 2016

However, not all land cover types experienced significant changes during this period. Coastal grassland, for instance, showed a minimal loss of only 8.66 km² or 0.01%. Similarly, quarry and rubber plantation areas recorded negligible gains, indicating relatively stable land use patterns in these categories (Gaveau *et al*., 2014). These findings underscore the importance of considering local context and specific land cover dynamics when assessing landscape changes and their drivers. The analysis further extends to the period between 2006 and 2016, revealing continued shifts in land cover composition. Highly disturbed forests emerged as the most affected category, experiencing a substantial loss of -8573.14 km² or 12.75%. This trend is concerning as it suggests ongoing deforestation and land degradation processes, likely driven by factors such as logging, agricultural expansion, and infrastructure development (Sodhi *et al*., 2010). Similarly, fallow and shifting cultivation land cover recorded significant losses, highlighting the vulnerability of these areas to Land use changes and degradation (Gibbs *et al*., 2010).

In contrast, certain land cover types demonstrated notable gains during the same period. Teak and Gmelina plantation, for example, exhibited the highest increase in area, with a gain of 5664.03 km² or 8.42%. This expansion could be attributed to reforestation initiatives, agroforestry practices, or commercial plantation establishment aimed at meeting timber demand (Chazdon *et al*., 2009). Additionally, urban areas and intensive agriculture witnessed considerable growth, reflecting urbanization trends and agricultural intensification efforts in response to population growth and economic development (Lambin & Meyfroidt, 2011).

Overall, the findings underscore the dynamic nature of land cover changes in the study area and highlight the complex interactions between human activities and environmental processes.

Conservation efforts, sustainable land management practices, and effective monitoring mechanisms are essential for mitigating the adverse impacts of land cover changes, preserving critical habitats, and promoting ecosystem resilience in the face of ongoing global environmental changes.

Table 4.2: Land cover change detection

LAND USE CLASS	LULC 1986(SqKm)	%	LULC 2006(SqKm)	%	LULC 2016(SqKm)	%	Area change 1986-2006	% change 1986-2006	Area change 2006-2016	% change 2006-2016	Area change 1986-2006	% change 1986-2016
Banana	-	-		0	0.47	0			0.47	0	-41.83	-0.06
Coastal Grassland	47.98	0.07	39.32	0.06	6.15	0.01	-8.66	-0.01	-33.17	-0.05	-4238.53	-6.3
Fallow (Scattered Cultivation)	5,864.70	8.72	6,022.36	8.95	1,626.17	2.42	157.66	0.23	-4396.19	-6.54	-8793.95	-13.08
Highly Disturbed Forest	12,611.37	18.75	12,390.57	18.42	3,817.42	5.68	-220.8	-0.33	-8573.14	-12.75	5526.69	8.22
Intensive Arable Cultivation	8,537.40	12.69	11,330.40	16.85	14,064.09	20.91	2793	4.15	2733.69	4.06	170.36	0.25
Marshland	1.25	0		0	171.61	0.26	-1.25	0	171.61	0.26	-360.53	-0.54
Minimally Disturbed Forest	2,130.66	3.17	2,433.65	3.62	1,770.13	2.63	302.99	0.45	-663.52	-0.99	2784.18	4.14
Tree Crop and Secondary F.	5,583.14	8.3	4,993.49	7.42	8,367.32	12.44	-589.66	-0.88	3373.83	5.02	-456.62	-0.68
Oil Palm	456.62	0.68	-		-	0		-0.68		0	2.58	0
Quarry	-	-	4.37	0.01	2.58	0	4.37	0.01	-1.79	0	25.9	0.04
River/Lake	68.09	0.1	129.56	0.19	93.99	0.14	61.47	0.09	-35.57	-0.05	-2209	-3.28
Rock/Montane Forest	2,400.93	3.57	3,692.08	5.49	191.92	0.29	1291.15	1.92	-3500.15	-5.2	30.37	0.05

Rubber	-	-	9.34	0.01	30.37	0.05	9.34	0.01	21.03	0.03	-233.99	-0.35
Sand bar	234.01	0.35	105.65	0.16	0.02	0	-128.36	-0.19	-105.63	-0.16	-11291.72	-16.79
Savannah Grassland	12,089.99	17.98	127.16	0.19	798.26	1.19	-11962.83	-17.79	671.1	1	10221.95	15.2
Savanna Woodland	10,355.38	15.4	17,743.97	26.38	20,577.33	30.6	7388.59	10.99	2833.36	4.21	-777.67	-1.16
Swamp	1,005.24	1.49	55.21	0.08	227.57	0.34	-950.03	-1.41	172.36	0.26	9751.35	14.5
Teak/Gmelina	874.49	1.3	4,961.81	7.38	10,625.84	15.8	4087.32	6.08	5664.03	8.42	-4097.01	-6.09
Undisturbed Forest	4,104.14	6.1	1,272.74	1.89	7.13	0.01	-2831.41	-4.21	-1265.6	-1.88	3987.01	5.93
Urban	890.44	1.32	1,944.15	2.89	4,877.45	7.25	1053.71	1.57	2933.3	4.36	0	0

The information on table 5 and 6 shows the matrix of transition the various land use classes between 1986 and 2006, and 2006 and 2016. The tables diagonal values on the table represents the area of the land use that was stable between the two study epochs, while the horizontal shows the values of land use that was available for 2006/2016 and the vertical for 1986/2006. The cells with 0 values show that those land uses did not gain or lost any area.

4.1.2 Pattern Savannah and Forest Conversion

The analysis of land cover changes from 1986 to 2016 reveals significant transformations in various land cover categories, reflecting the complex interactions between human activities and environmental processes (Gaveau *et al.*, 2014). Highly disturbed forest areas witnessed a substantial decline from 12,611.37 km² in 1986 to 3,817.42 km² in 2016, indicative of intensive Land use changes likely driven by urbanization, industrialization, or logging activities (Gaveau *et al.*, 2014; Sodhi *et al.*, 2010).

Conversely, undisturbed forest areas experienced a drastic reduction from 4,104.14 km² to 7.13 km² over the same period, highlighting severe environmental degradation and the encroachment of human activities into previously pristine forest landscapes (Gaveau *et al.*, 2014). This decline in undisturbed forest areas underscores the urgent need for conservation efforts to protect remaining forest habitats and preserve biodiversity (Sodhi *et al.*, 2010).

In contrast, minimally disturbed forest areas exhibited moderate stability, suggesting relatively lower levels of human disturbance compared to highly disturbed and undisturbed forest ecosystems (Gaveau *et al*., 2014). The stability in minimally disturbed forest areas may indicate the effectiveness of conservation measures or land management practices aimed at mitigating environmental impacts (Gaveau *et al*., 2014; Sodhi *et al*., 2010).

Furthermore, savannah grassland areas remained relatively stable with a slight increase by 2016, indicating resilience to significant land cover changes observed in other ecosystems (Gaveau *et al*., 2014). This stability in savannah grassland areas may be attributed to natural ecological processes or sustainable land management practices that maintain ecosystem integrity (Gaveau *et al*., 2014).

Overall, the dynamic patterns in land cover changes highlight the complex dynamics of human-environment interactions and the need for integrated approaches to land management and conservation (Sodhi *et al*., 2010). Addressing the drivers of land cover changes, such as urbanization, deforestation, and agricultural expansion, requires coordinated efforts involving policymakers, stakeholders, and local communities to promote sustainable development and biodiversity conservation (Gaveau *et al*., 2014).

Table 4.3: Land covers statistics of Forest and Savannah

Landcover	**1986 (km2)**	**2006 (km2)**	**2016 (km2)**
Highly Disturbed Forest	12611.37	12390.57	3817.42
Minimally Disturbed Forest	2130.66	2433.65	1770.13
Undisturbed Forest	4104.14	1272.74	7.13

Savannah Grassland	12089.99	127.16	798.26
Savannah Woodland	10355.38	17743.97	20577.33

The savannah woodland areas within the study region showed notable fluctuations over the three-decade period, with significant implications for land cover dynamics and environmental sustainability. The area covered by savannah woodland expanded considerably from 10,355.38 km² in 1986 to 20,577.33 km² in 2016. This substantial increase suggests potential afforestation efforts or changes in land management practices during the study period. These fluctuations underscore the dynamic nature of land cover changes within the study region and the complex interactions between human activities and natural ecosystems. The expansion of savannah woodland areas may be influenced by various factors, including reforestation initiatives, natural regeneration processes, or shifts in land use practices such as agricultural abandonment or land restoration efforts.

However, these trends also highlight the urgent need for conservation efforts, sustainable land management practices, and effective monitoring mechanisms to safeguard critical habitats, preserve biodiversity, and mitigate the adverse effects of human activities on the environment. While the expansion of savannah woodland areas may indicate positive changes in land cover, it is essential to ensure that these changes are sustainable and do not lead to unintended consequences such as habitat fragmentation, loss of biodiversity, or degradation of ecosystem services.

Furthermore, ongoing monitoring and assessment of land cover dynamics are essential to track changes over time, identify emerging threats, and inform adaptive management strategies. By implementing proactive conservation measures, promoting sustainable land use practices, and engaging stakeholders in participatory decision-making processes, it is possible to achieve a balance between human development and environmental conservation objectives.

Overall, the fluctuations observed in savannah woodland areas underscore the dynamic nature of land cover changes and the importance of proactive conservation efforts to maintain ecological integrity, promote biodiversity conservation, and enhance the resilience of ecosystems in the face of environmental change.

Table 4.3 presents the statistical overview of forest and savannah areas within the study region. In 1986, the highly disturbed forest covered an extensive area of 12,611.37 km2. However, by 2016, this area had undergone significant reduction, shrinking to 3,817.42 km2. This substantial decrease indicates a profound conversion of highly disturbed forest within the study area over the three-decade period.

Figure 4.5 provides a visual representation of land cover conversions within the study area. It reveals that savannah grassland experienced the most substantial conversion, with an area reduction of approximately 13,000 km2. Following closely behind, the highly disturbed forest underwent a conversion of about 9,000 km2. Interestingly, the figure illustrates that the lowest conversion rate for forest occurred between 1986 and 2006, suggesting a period of relatively slower forest loss during this timeframe compared to other periods.

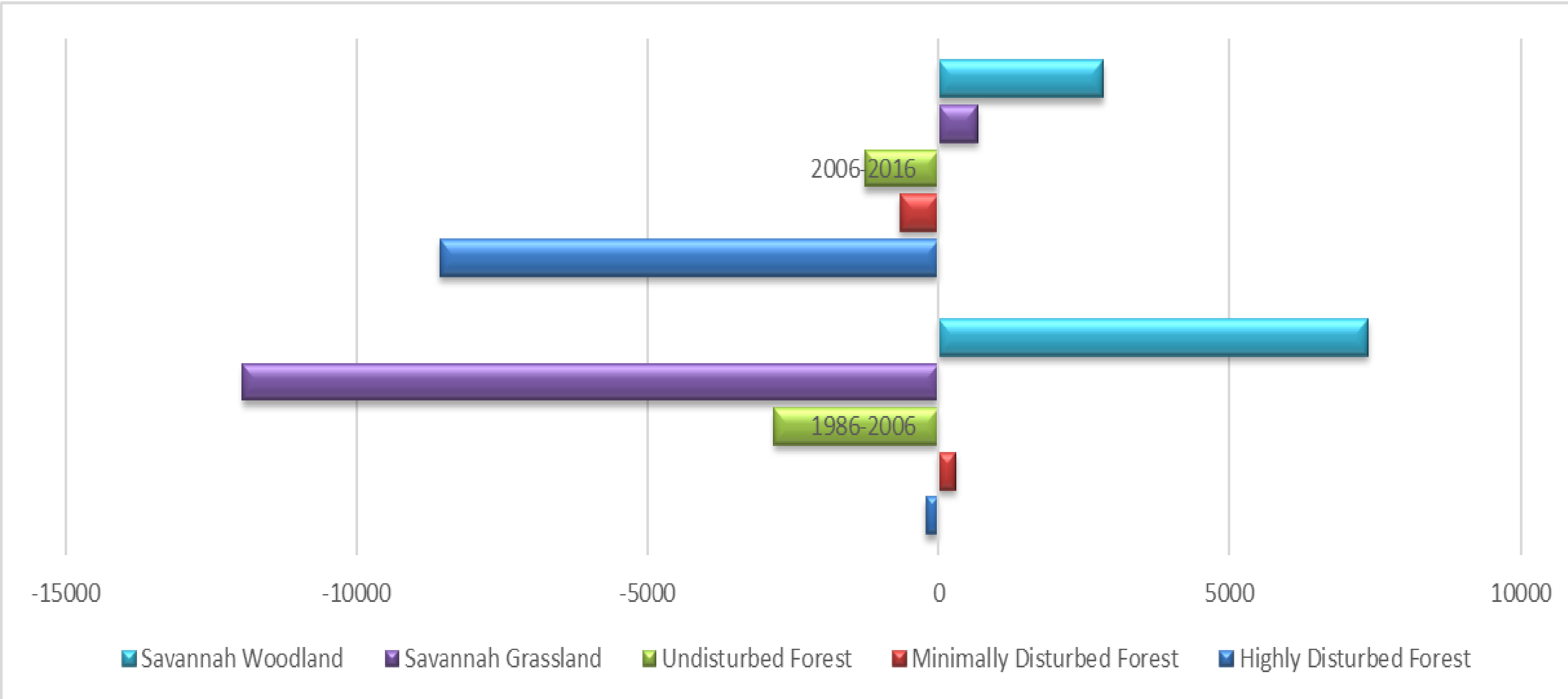

Figure 4.5: Forest and savannah conversion pattern

These findings underscore the significant changes in land cover dynamics within the study region over the past three decades. The considerable reduction in highly disturbed forest area highlights the extensive conversion of forested land for various purposes such as agriculture, urbanization, and infrastructure development. Similarly, the substantial conversion of savannah grassland underscores the pressures faced by natural ecosystems due to human activities and land use changes.

Understanding these land cover conversions is crucial for assessing the impacts on biodiversity, ecosystem services, and carbon stocks within the study area. Furthermore, these findings can inform land management strategies, conservation efforts, and policy interventions aimed at mitigating further land degradation and promoting sustainable land use practices. By monitoring land cover changes and their associated impacts, stakeholders can work towards preserving valuable ecosystems, protecting biodiversity, and mitigating the adverse effects of land cover change on the environment and society.

Table 4.4: Land use change Matrix 1986 and 2006

LULC Class (sqkm)	Coastal Grassland	Fallow (Scattered Cultivation)	Highly Disturbed Forest	Intensive Arable Cultivation	Marshland	Minimally Disturbed Forest	Tree Crop and Secondary F.	Oil Palm	River/Lake	Rock/Montane Forest	Sand bar	Savannah Grassland	Savanna Woodland	Swamp	Teak/Gmelina	Undisturbed Forest	Urban	1986
Coastal Grassland	8.66	11.2	0	0	0	0	0	0	0	0	0.57	0	0	5.7	0	0	21.52	47.98
Fallow (Scattered Cultivation)	0.89	157.66	0	2487.25	0	0	942.3	0	0	0	0	0	0	0	523.74	0	1724.96	5864.7
Highly Disturbed Forest	0	927.3	220.80	5083.21	0	213.3	1425.36	0	0	0	0	0	4741.85	0	0	0	0	12,611.37
Intensive Arable Cultivation	0	836.78	1100.69	2,793.00	0	940.9	591.5	0	0	631	0	0	1801.69	0	0	0	0	8537.4
Marshland	0	0	0	0	1.25	0	0	0	0	0	0	0	0	0	0	0	0	1.25
Minimally Disturbed Forest	0	0.897	806.58	0	0	302.99	0	0	0	0	0	0	1020.36	0	0	0	0	2130.66
Tree Crop and Secondary F.	0	0	2009.24	0	0	0	589.65	0	0	0	0	0	1053.47	0	1727.99	0	0	5583.14
Oil Palm	0	0	0	0	0	0	0	0	0	0	0	0	456.6	0	0	0	0	456.62
River/Lake	0	0	0	0	0	0	0	0	61.47	0	0	0	0	0	0	0	6.6	68.09
Rock/Montane Forest	0	393.21	605.9	0	0	0	0	0	0	1,291.15	0	0	110.4	0	0	0	0	2400.93
Sand bar	29.7	0	0	10.3	0	0	0	0	59.98	0	105.36	0	0	32.9	0	0	0	234.01
Savannah Grassland	0	2857.25	7103.25	0	0	875.6	0	0	0	0	0	127.69	56.25	0	1027.5	0	0	12,089.99
Savanna Woodland	0	658.3	569.23	717.6	0	0	0	0	0	0	0	0	7,388.59	0	1007.6	0	0	10,355.38
Swamp	0	0	0	0	0	100.6	0	0	0	890.25	0	0	0	18	0	0	0	1,005.24
Teak/Gmelina	0	0	0	99.5	0	0	0	0	0	0	0	0	123.3	0	674.98	0	0	874.49
Undisturbed Forest	0	0	0	13	0	0	997.6	0	0	879.6	0	0	988.3	0	0	1,258.66	0	4,104.14
Urban	0	256	0	0	0	0	446.98	0	0	0	0	0	0	0	0	0	191.64	890.44
2006	39.32	6,022.36	12,390.57	11,330.40		2,433.65	4,993.49	-	129.56	3,692.08	105.65	127.16	17,743.97	55.21	4,961.81	1,272.74	1,944.15	

Table 4.5: Land use Change Matrix between 2006 and 2016

Landcover Class (sq Km)	Banana	Coastal Grassland	Fallow (Scattered Cultivation)	Highly Disturbed Forest	Intensive Arable Cultivation	Marshland	Minimally Disturbed Forest	Tree Crop and Secondary F.	Quarry	River/Lake	Rock/Montane Forest	Rubber	Sand bar	Savannah Grassland	Savanna Woodland	Swamp	Teak/Gmelina	Undisturbed Forest	Urban	2006
Banana	0.47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Coastal Grassland	0	6.15	0	0	0	2.98	0	0	0	11.2	0	0	0.95	0	0	10.08	0	0	0	39.32
Fallow (Scattered Cultivation)	0	0	1,653.69	1436.6	2493.4	0	345.6	0	0	0	0	0	0	0	213.69	0	0	0	0	6,022.36
Highly Disturbed Forest	0	0	0	921.56	1569.87	0	102.6	1763.5	0	25.6	0	0	0	165.36	1479.3	0	5763.8	5.1	596.56	12,390.57
Intensive Arable Cultivation	0	0	0	0	2,733.69	0	94.2	0.98	0	0	0	0	0	183.9	5907.6	0	457.69	0	1641.34	11,330.40
Marshland	0	0	0	0	0	171.61	0	0	0	0	0	0	0	0	0	0	0	0	0	
Minimally Disturbed Forest	0	0	0	0	563.4	0	663.52	0	0	0	0	0	0	0	1026.54	0	0	0	0	2,433.65
Tree Crop and Secondary F.	0	0	0	912.46	0	0	0	3,373.83	0	0	0	0	0	164.7	0	0	542.5	0	0	4,993.49
Quarry	0	0	0	0	0	0	0	0	1.79	3.2	0	0	0	0	0	0	0	0	0	4.37
River/Lake	0	0	0	0	0	0	0	0	0	35.57	0	0	0	0	0	0	0	0	95.6	129.56
Rock/Montane Forest	0	0	0	0	1227.6	0	0	0	0	0	191.65	0	0	157.6	1056.36	0	997.25	0	45.3	3,692.08
Rubber	0	0	0	0	0	0	0	0	0	0	0	21.03	0	0	0	0	0	0	0	9.34
Sand bar	0	0	0	0	0	0	0	0	0	0	0	0	105.63	0	0	0	0	0	0	105.65
Savannah Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	127.16	0	0	0	0	0	127.16
Savanna Woodland	0	0	0	0	5423.4	0	0	1472.5	0	0	0	0	0	0	7,674.36	0	2369.5	0	823.6	17,743.97
Swamp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	172.36	0	0	0	55.21
Teak/Gmelina	0	0	0	562.64	0	0	0	2100.5	0	0	0	0	0	0	1596.45	0	702.22	0	0	4,961.81
Undisturbed Forest	0	0	0	0	658.95	0	0	0	0	0	0	0	0	0	996.36	0	0	2.15	0	1,272.74
Urban	0	0	0	0	149.9	0	0	0	0	0	0	0	0	0	798.95	45.7	0	0	949.60	1,944.15
LULC 2016 (SqKM)	0.47	6.15	1,628.17	3,817.42	14,084.09	171.61	1,770.13	8,387.32	2.58	93.99	191.92	30.37	0.02	798.28	20,577.33	227.57	10,625.84	7.13	4,877.46	

Table 4.6: Land use Change Matrix between 1986 and 2016

Landcover Class (sqKm)	Banana	Coastal Grassland	Fallow (Scattered Cultivation)	Highly Disturbed Forest	Intensive Arable Cultivation	Marshland	Minimally Disturbed Forest	Tree Crop and Secondary F.	Quarry	River/Lake	Rock/Montane Forest	Rubber	Sand bar	Savannah Grassland	Savanna Woodland	Swamp	Teak/Gmelina	Undisturbed Forest	Urban	1986
Banana	0.47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Coastal Grassland	0	6.15	0	0	0	2.98	0	0	0	11.2	0	0	0	0	0	14.08	0	0	12.47	47.98
Fallow (Scattered Cultivation)	0	0	653.69	1436.6	2493.4	0	345.6	0	0	0	0	0	0	0	213.69	0	0	0	0	5,864.70
Highly Disturbed Forest	0	0		921.56	1569.87	0	102.6	1763.5	0	25.6	0	0	0	195.36	1479.3	0	5763.8	5.1	596.56	12,611.37
Intensive Arable Cultivation	0	0	0	0	120.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10,557.40
Marshland	0	0	0	0	0	1.61	0	0	0	0	0	0	0	0	0	0	0	0	0	1.25
Minimally Disturbed Forest	0	0	0	0	563.4	0	543.90	0	0	0	0	0	0	0	1026.54	0	0	0	0	2,130.66
Tree Crop and Secondary F.	0	0	0	912.46	0	0	200.7	3,002.74	0	0	0	0	0	164.7	705.87	0	542.5	0	0	5,583.14
Quarry	0	0	0	0	0	0	0	0	2.58	3.2	0	0	0	0	0	0	0	0	0	
River/Lake	0	0	0	0	0	0	0	0	0	53	0	0	0	0	0	0	0	0	95.6	68.09
Rock/Montane Forest	0	0	0	0	1227.6	0	0	0	0	0	191.65	0	0	157.6	56.36	0	797.25	0	45.3	2,400.93
Rubber	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Sand bar	0	0	0	0	0	0	0	0	0	0.99	0	0	0.02	0	0	0	0	0	0	234.01
Savannah Grassland	0	0	1002.78	0	1981.75	0	0	0	0	0	0	0	0	277.16	6034.56	0	0	0	1102.77	12,089.99
Savanna Woodland	0	0	0	0	5423.4	0	0	1472.5	0	0	0	30.37	0	0	7,674.36	0	2369.5	0	823.6	10,355.38
Swamp	0	0	0	0	0	166.7	0	0	0	0	0	0	0	0	0	170	0	0	980.4	1,005.24
Teak/Gmelina	0	0	0	562.64	0	0	0	2100.5	0	0	0	0	0	0	1596.45	0	702.22	0	0	874.49
Undisturbed Forest	0	0	0	0	658.95	0	577.66	0	0	0	0	0	0	0	996.36	0	0	2.15	0	4,104.14
Urban	0	0	0	0	149.9		0	0	0	0	0	0	0	0	798.95	45.7	0	0	949.60	890.44
LULC 2016(SqKM)	0.47	6.15	1,626.17	3,817.42	14,064.09	171.61	1,770.13	8,367.32	2.58	93.99	191.92	30.37	0.02	798.26	20,577.33	227.57	10,625.84	7.13	4,877.45	

4.1.3 LULC Projection model from 2016 to 2066

The land use and land cover projection of the study area for the primary classes is shown in table 4.6 below, and the result reveals that the projection statistics urban area has a progressive expansion from 3209.75 km^2 in 2016 to 4042.35 in 2066. On the other hand, the forest area had a sharp reduction in 2020 and might become 0 from 2022 till 2066. This result is evident due to the fact that the population of the study area will continue increase, while this increasing population depends on the forest resources for livelihood, the forest will continue to reduce due to over exploitation which is enhanced by weak polices.

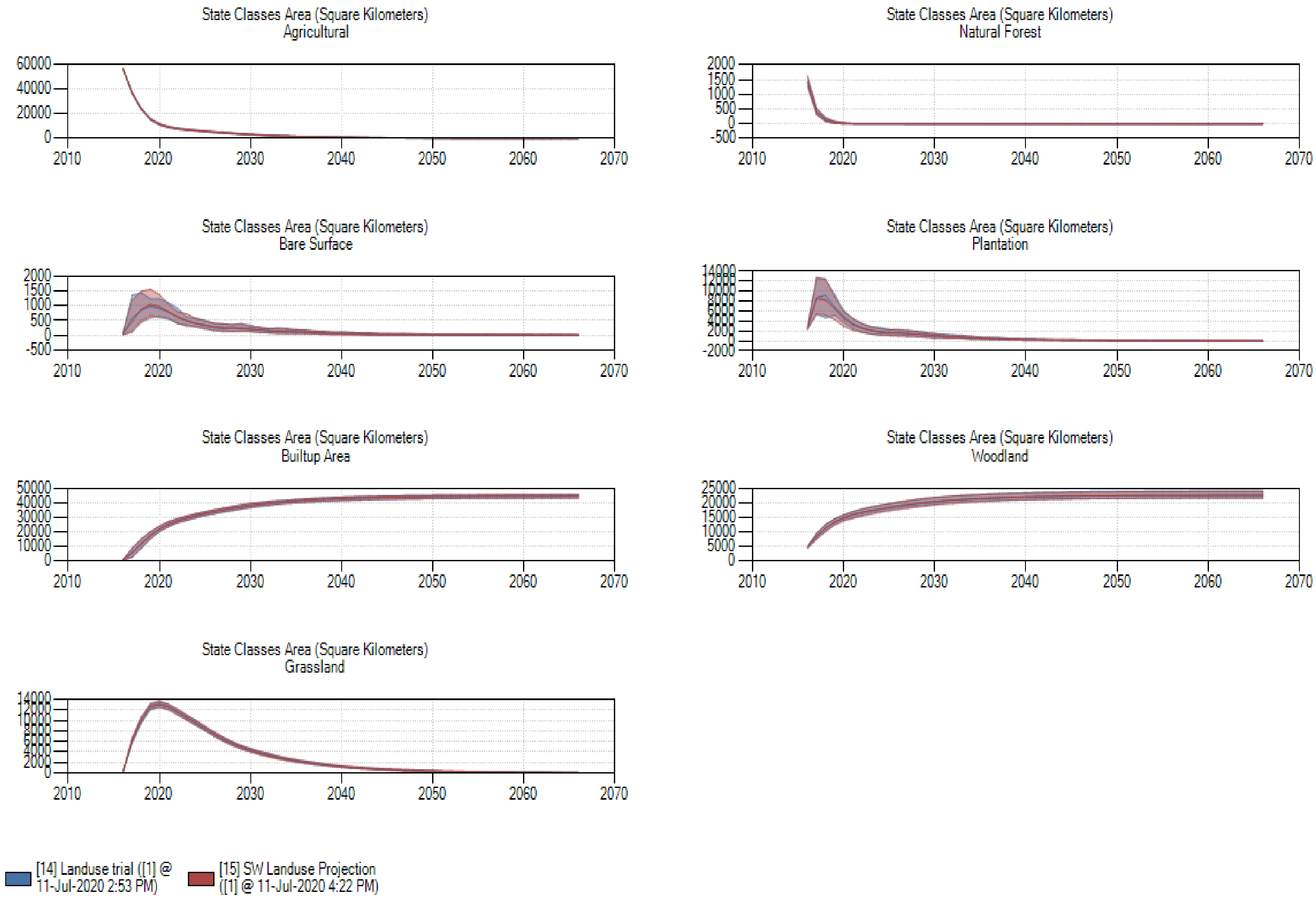

Figure 4.6: Future land use projection for the study area from 2016 to 2066

The analysis of land cover changes over the period from 1986 to 2016 reveals significant trends with profound implications for environmental health and biodiversity conservation. Firstly, there has been a notable decline in highly disturbed forest areas, amounting to 8573.14 km² during this period. This decline underscores the severity of environmental degradation and Land use changes within the study area, likely influenced by factors such as urbanization, logging activities, and agricultural expansion. These findings align with research by Gaveau *et al*. (2014) and Sodhi *et al*. (2010), highlighting the urgent need for conservation efforts and sustainable land management practices to mitigate further degradation.

Table 4.7: Simulated land use land cover from 2026 to 2066 for STsim

Primary Land cover classes (sqkm)	**Time step**				
	2026	**2036**	**2046**	**2056**	**2066**
Agricultural	5117.27	1444.43	410.71	115.90	29.14
Bare Surface	293.24	96.85	26.90	6.95	3.81
Builtup Area	33930.34	41711.84	43909.54	44523.58	44699.79
Grassland	7403.07	2025.97	562.26	158.05	43.04
Natural Forest	0.45	0.45	0.45	0.45	0.45
Plantation	1652.70	510.70	137.43	36.99	8.74
Woodland	18858.76	21465.59	22208.55	22413.90	22470.85

Source: Author, 2020

Similarly concerning is the drastic decline in undisturbed forest areas, shrinking from 4104.14 km² to 7.13 km² over the same period. This loss of pristine forest habitats poses significant threats to biodiversity and ecosystem services, emphasizing the importance of conservation strategies aimed at protecting remaining forested areas and restoring degraded landscapes. This aligns with the findings of Gibbs *et al*. (2010) and Chazdon *et al*. (2009), highlighting the critical need for biodiversity conservation and habitat restoration efforts.

On a contrasting note, the analysis reveals substantial fluctuations in savannah woodland areas, with an increase from 10355.38 km² in 1986 to 20577.33 km² in 2016. These dynamic changes suggest the influence of afforestation efforts or alterations in land management practices, highlighting the potential for ecosystem restoration and reforestation initiatives to mitigate deforestation and land degradation. This resonates with the research of Hirota *et al*. (2011) and Gibbs *et al*. (2010), emphasizing the role of afforestation in promoting landscape resilience and biodiversity conservation.

The observed land cover changes underscore the importance of conservation efforts, sustainable land management practices, and effective monitoring mechanisms to protect critical habitats and preserve biodiversity. Integrated approaches that consider ecological, social, and economic dimensions are essential for addressing the drivers of land cover change and promoting sustainable development. These findings align with the research of Foley *et al*. (2005) and Lambin *et al*. (2011), emphasizing the need for comprehensive strategies to mitigate the adverse impacts of human activities on the environment and promote the long-term health and resilience of ecosystems.

CHAPTER FIVE

ABOVEGROUND BIOMASS

5.0 Introduction

This chapter discusses the aboveground biomass estimated within the study area between 1986 and 2016. As a fall out of the analysis in chapter four which showed the continual reduction in forest area from 1986 to 2016. The biomass was estimated from Landsat images for the study period and the spatial distribution of the density across the study area. The chapter shows the relationship between the biomass densities and the fresh and dry weight biomass.

5.1 Trends in Aboveground Biomass Induced by Vegetal Conversion and Degradation

5.1.1 Pattern and Extent of AGB change.

Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) has been used to describe the vegetation biomass. (Diouf *et al.*, 2015) This information shows the biomass index of the Land use class per pixel. The table below shows that the higher the values of FAPAR, the higher the biomass content of the vegetation. So many vegetation indices have been used in remote sensing for the estimation of biophysical properties of the environment (Boyd, 2002); (Thenkabail, 2002) akin to the above researches, where the vegetation Index (VI) was used to estimate the biomass of the study location.

Table 5.1: Average Biomass changes within the study area within the study period

LANDCOVER CLASSES	**1986(g/m^2)**	**2006(g/m^2)**	**2016(g/m^2)**
Woodland	0.637756	0.418756	0.358756
Grassland	0.551595	0.332595	0.272595
Natural Forest	0.868481	0.649481	0.589481
Rubber Plantation	0.852348	0.833348	0.773348
Cocoa Plantation	0.785204	0.766204	0.716204
Teak Plantation	0.709055	0.490055	0.430055
Swamp Wetland	0.820912	0.601912	0.541912

From table 5.1 above, the woodland biomass reduced from 0.63 g/m^2 to 0.42 g/m^2 between 1986 and 2006. This result thus agrees with the land use analysis where the woodland savannah is being rapidly converted to farmlands due to the lack of vegetation cover, and the soil open for a more significant part of the year (Fasona *et al., 2015;* Udofia *et al*., 2020*)*. The table above shows that as of 1986, the grassland had a biomass density of 0.55 g/m^2, reduced to 0.33 g/m^2 in 2006 and 2016, and dropped to 0.27. The natural forest has the highest biomass density; in 1986, it had a biomass of 0.86 g/m^{2,} and dropped to 0.64 g/m^2 in 2006 and then 0.58 g/m^2 in 2016. The reduction in the forest biomass results from the continual lumbering activities and the exploitation of other forest resources. This result was found from the field visit where lots of forest degradation was actively carried out through either tree cutting or cultivation.

Woodland, characterized by its trees and shrubs, exhibited a gradual decrease in grams per square meter over the years, from 0.638 g/m^2 in 1986 to 0.359 g/m^2 in 2016. This reduction may indicate factors such as deforestation, urbanization, or Land use changes in the region. The decline in Woodland is a concerning trend, as it could have implications for biodiversity and ecosystem services. Grassland, another landcover class, also experienced a decline in grams per square meter over the years, from 0.552 g/m^2 in 1986 to 0.273 g/m^2 in 2016. Changes in Grassland cover can result from agricultural expansion, urban development, or natural ecological shifts. Such alterations in Grassland can impact local wildlife habitats and affect the balance of the ecosystem.

Conversely, Natural Forest, a critical component of ecosystems, demonstrated a reduction in grams per square meter from 0.868 g/m^2 in 1986 to 0.589 g/m^2 in 2016. This decline in Natural Forest area could be attributed to deforestation, logging, or land conversion for agriculture or infrastructure development. The loss of Natural Forest has ecological consequences, including habitat loss and reduced carbon sequestration.

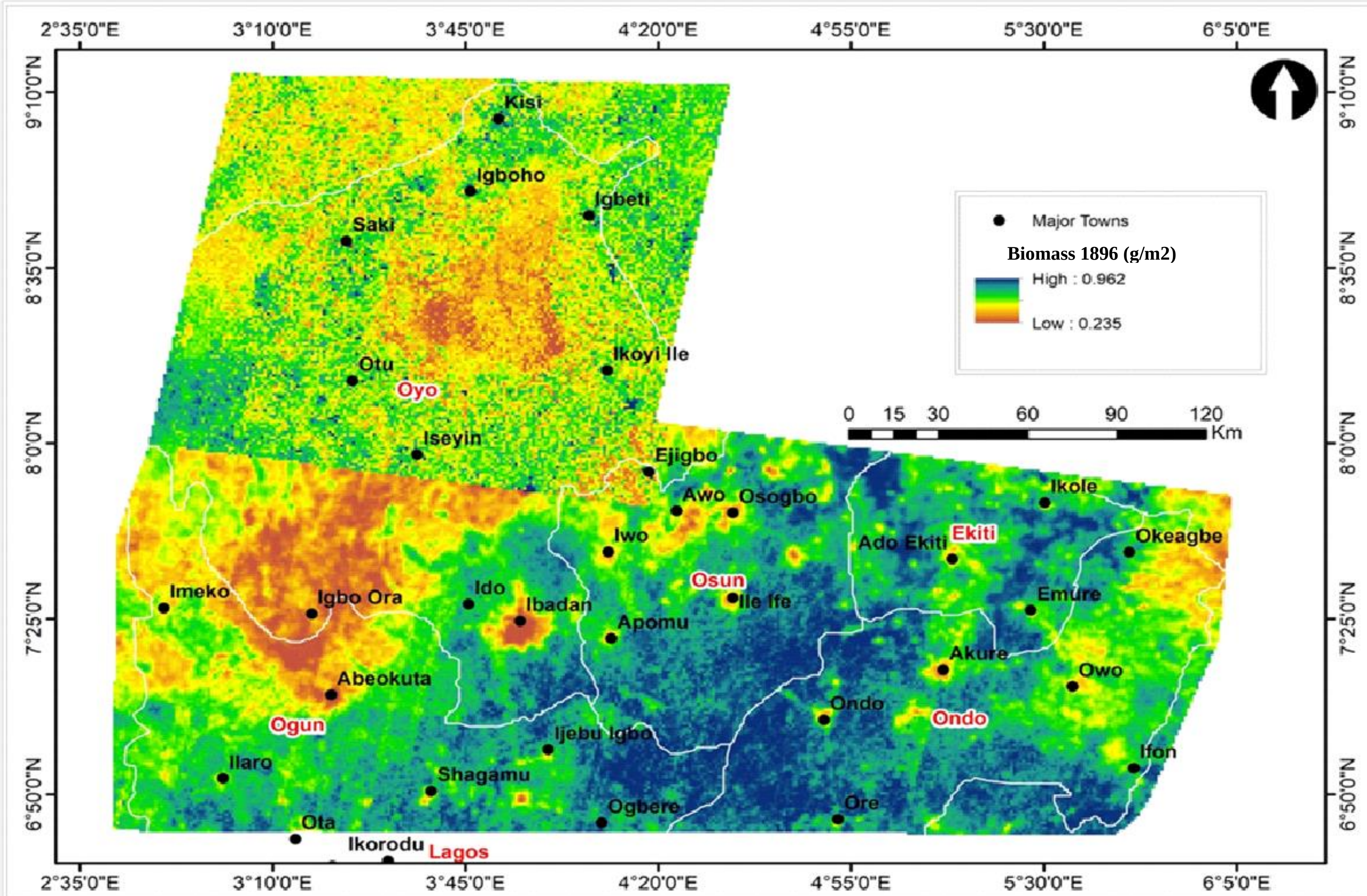

Figure 5.1: 1986 Biomass Status

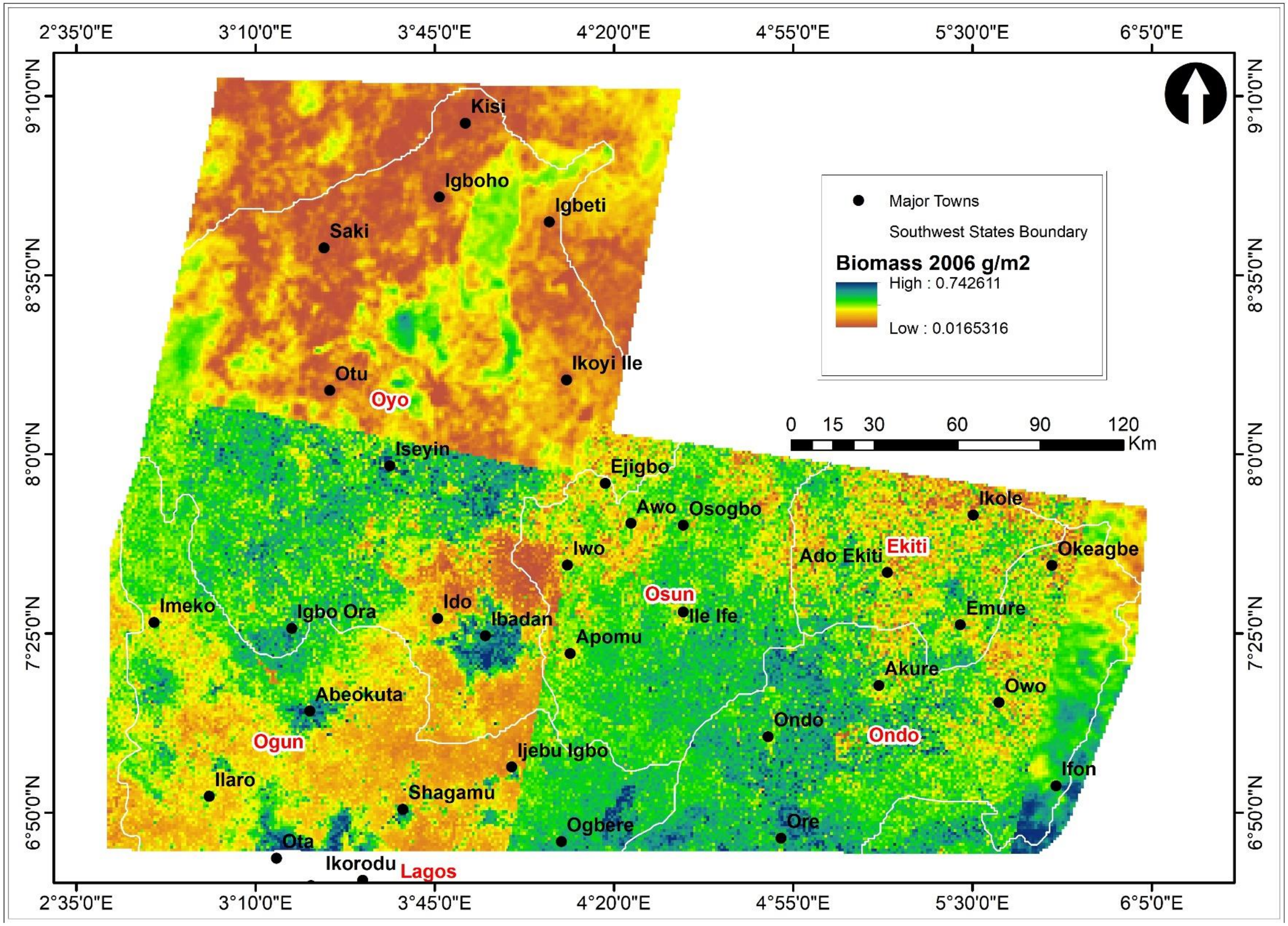

Figure 5.2: 2006 Biomass Status

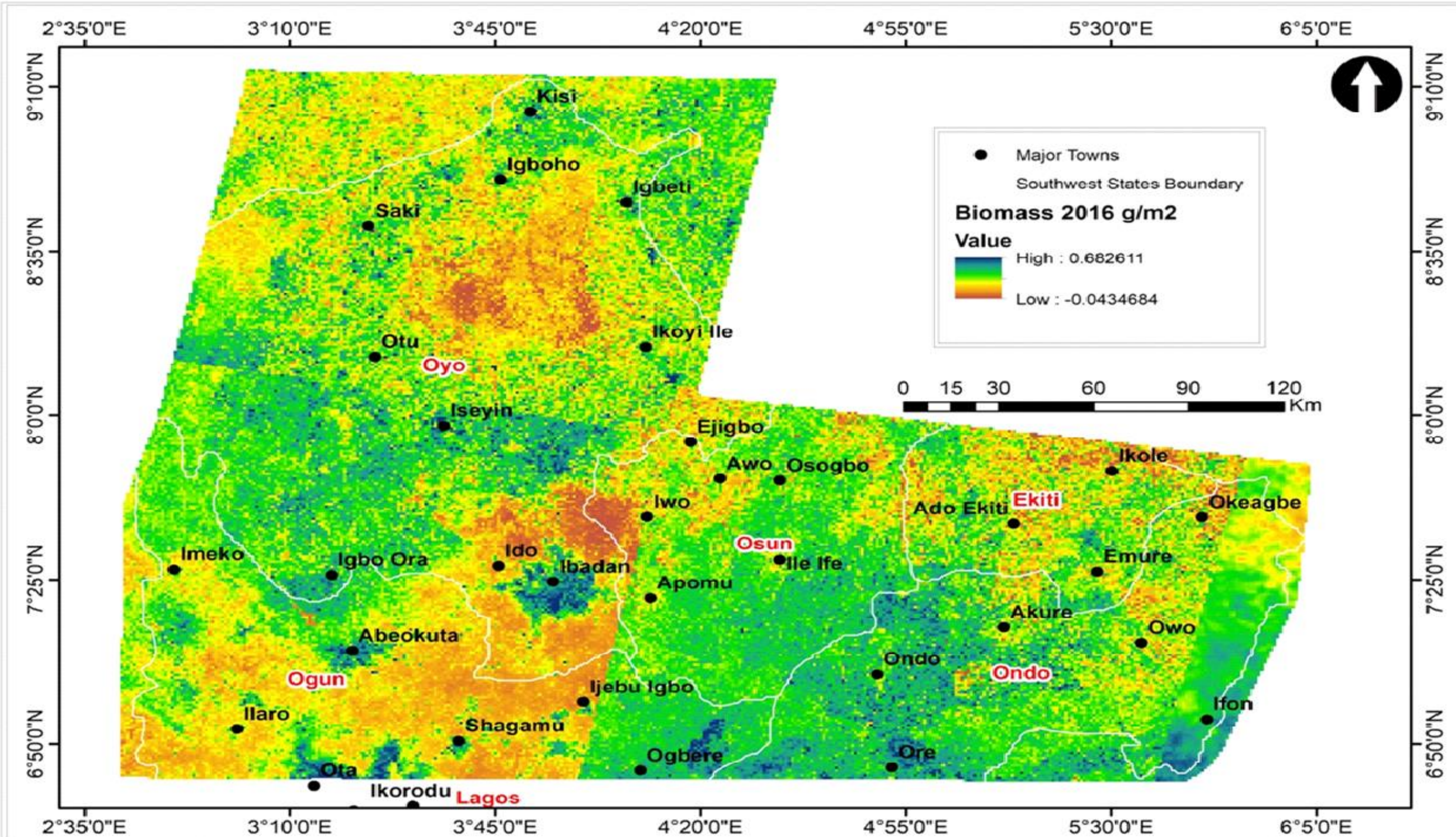

Figure 5.3: 2016 Biomass status (g/m^2)

Rubber Plantation and Cocoa Plantation are two agricultural landcover classes that displayed relatively stable measurements over the years. Rubber Plantation exhibited minor fluctuations, while Cocoa Plantation showed a slight decrease in grams per square meter. These landcover classes reflect human activities related to agriculture, and their stability may indicate sustainable practices or land management in these sectors. Teak Plantation, another agricultural landcover class, exhibited a gradual decline in grams per square meter over the years. The reduction in Teak Plantation cover could result from changes in timber demand, Land use policies, or shifts in market dynamics. Swamp Wetland, an important ecosystem for biodiversity and water regulation, also experienced a decrease in grams per square meter from 0.821 g/m^2 in 1986 to 0.542 g/m^2 in 2016. This decline may be attributed to drainage, land reclamation, or alterations in hydrological patterns. Loss of Swamp Wetland can have implications for water quality, flood control, and habitat availability for aquatic species.

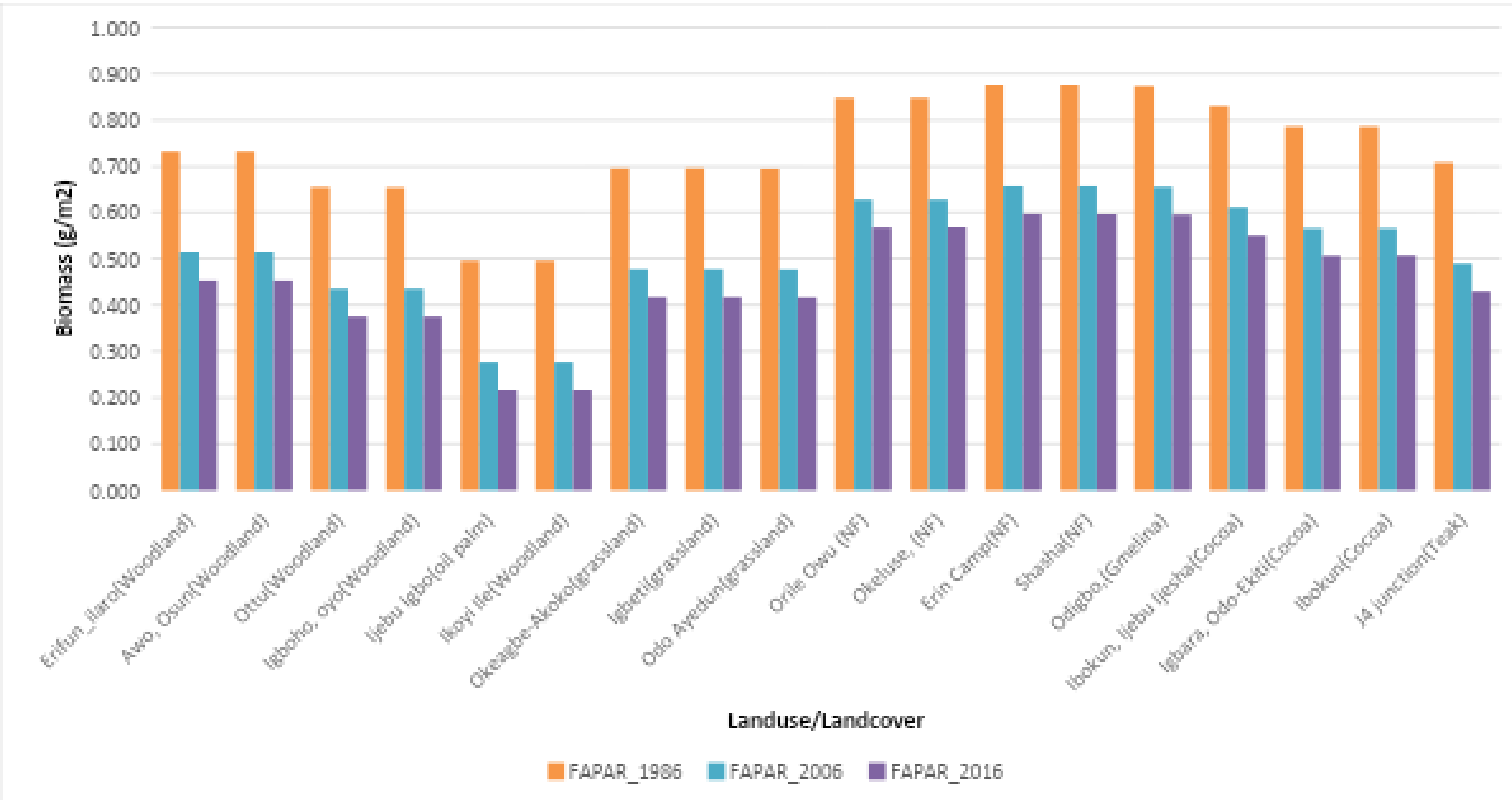

Figure 5.4: Pattern of biomass change across the land use within the 3 study periods

The landcover class data highlights significant changes in the landscape over the three decades. These changes may be influenced by a range of factors, including urbanization, agricultural practices, deforestation, and Land use policies. The implications of these landcover shifts on ecosystem health, biodiversity, and environmental sustainability warrant further investigation and conservation efforts.

Rubber plantation also showed a high level of biomass, from the table above showed that it has an annual mean value of 0.85 g/m^2 in 1986, however, the density reduced in 2006, this could be explained in the degradation of the plantation these have caused the biomass to drop to 0.83 g/m^2 in 2006 and the 0.77 g/m^2 in 2016.

Various factors may contribute to the observed decline in biomass density within rubber plantations. These could include soil degradation, nutrient depletion, disease outbreaks, or changes in climate patterns affecting plant growth and productivity (Montagnini & Nair, 2004; Fisher *et al*., 2017). Human activities such as improper land management, excessive harvesting, or conversion of rubber plantations to other land uses could also impact biomass dynamics within these ecosystems (Fox *et al*., 2017; Vijay *et al*., 2016). The reduction in biomass density within rubber plantations may have significant environmental and ecological implications. It could affect carbon sequestration rates, soil fertility, water retention capacity, and biodiversity within these agroecosystems (García-Orenes *et al*., 2009; Dent *et al*., 2017).

To address declining biomass density and mitigate associated environmental impacts, sustainable management practices within rubber plantations are crucial. This may include measures such as agroforestry integration, soil conservation techniques, biodiversity conservation efforts, and sustainable harvesting practices (van Kuijk *et al*., 2008; Danielsen *et al*., 2009).

5.2 Field Measured Biomass and Remote Sensing Biomass

The results of the analysis presented on Figures 5.2, 5.3, and 5.4 revealed a strong positive correlation between fresh weight and biomass across the sampled vegetation types. Regression analysis indicated a significant predictive relationship between the two variables, with fresh weight explaining a substantial portion of the variability in biomass. The relationship varied among vegetation types, with certain species exhibiting more consistent biomass-to-fresh weight ratios than others.

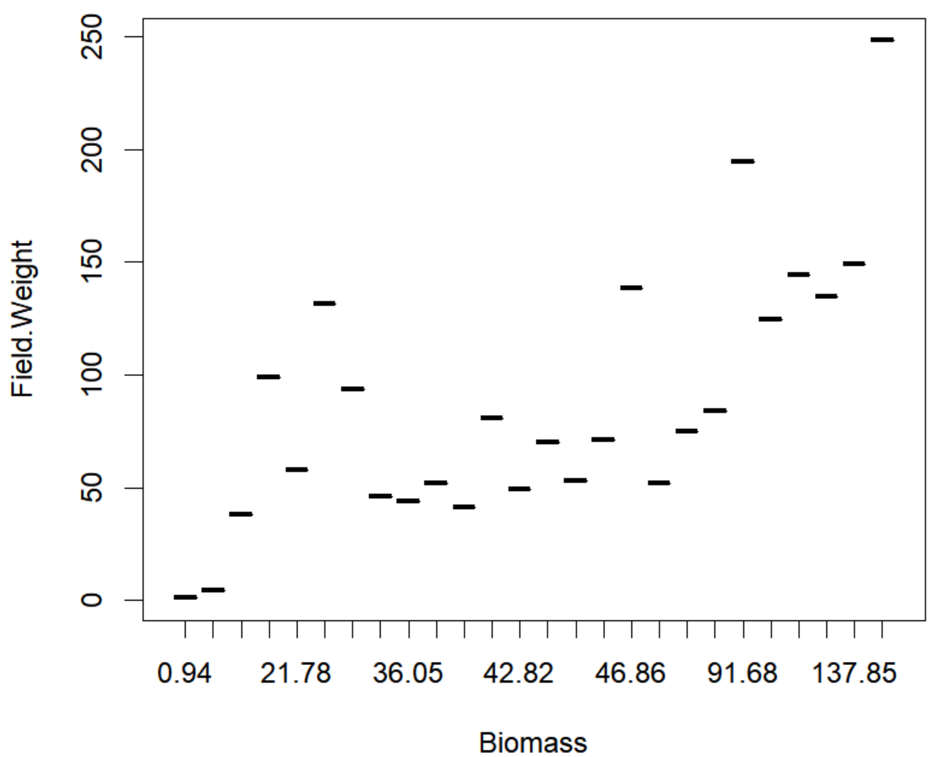

Figure 5.5: relationship between fresh weight and biomass

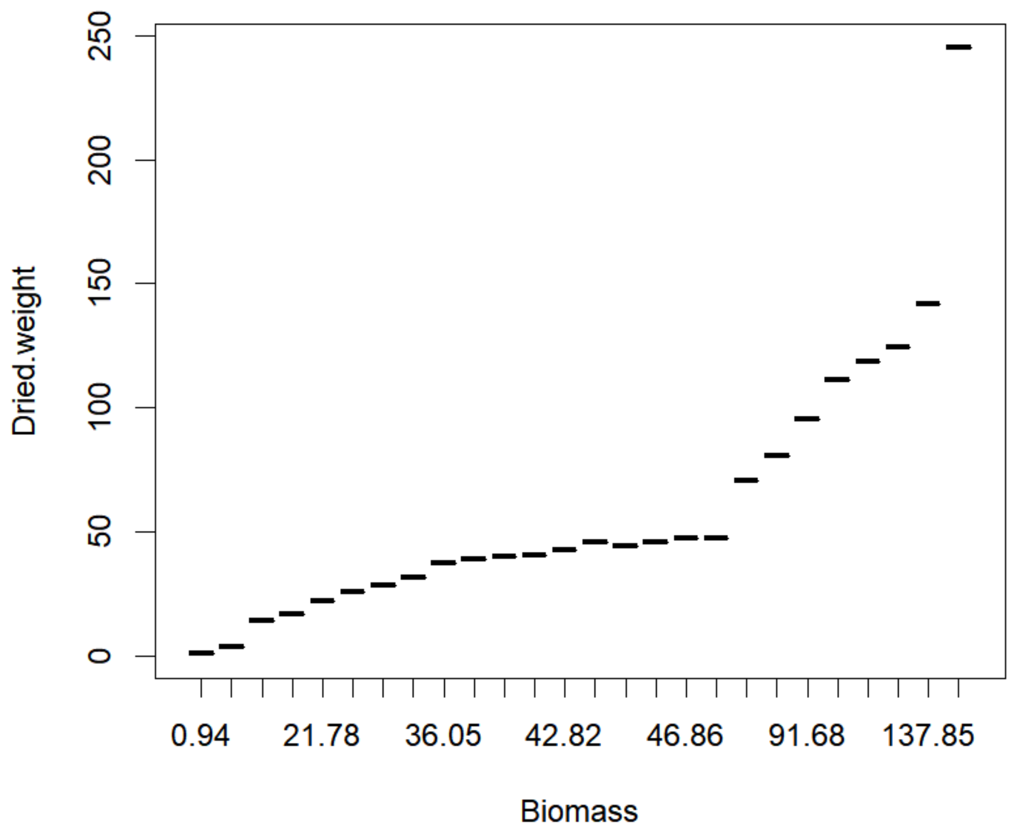

Figure 5.6: Relationship between dried weight and biomass

The findings underscore the potential utility of fresh weight measurements as a proxy for biomass estimation in southwest Nigeria shown in figure 5.5. While the relationship between fresh weight and biomass was generally positive and significant, variations among vegetation types highlight the importance of species-specific calibration. Factors such as moisture content, plant morphology, and growth stage may influence the accuracy of fresh weight-based biomass estimates. Figure 5.6 shows a more direct relationship between the dried weight and the Biomass of the study area. The chart reveals that there is a linear relationship between the two variables.

CHAPTER SIX

CARBON FLUXES IN THE FOREST AND SAVANNAH WOODLAND BETWEEN 1986 AND 2016

6.0 Introduction

This chapter establishes the carbon stock and the dynamics from 1986 to 2016 in the forest and savannah which is the fourth objective. The result of the biomass status of the study area analysed in the previous chapter (Chapter Five) with the Land use/landcover status discussed in Chapter Four shows a clear path of the future carbon stock in the study area. this chapter is sectioned into two sections. Section one discusses the carbon stock and flows in the Land use from 1986 to 2016 using the CASA model. The second section discusses the future pattern and fluxes of carbon in the study area from 2016 till 2066, this analysis employed the use of STSim model to achieve this analysis. This chapter reveals the relationship between the remote sensing measured carbon and field-measured carbon.

6.1 Carbon estimation from CASA Model

The carbon trends of the study area, as shown in Figure 6.1, reveals that carbon was high in natural forest areas throughout 1986, 2006, and 2016, though there has been a steady reduction in the biomass from 1986 to 2016. Figure 6.1 below shows that grassland recorded the lowest carbon of about 20 g/m^2 in 1986 and 0 g/m^2 in 2016. In general, there has been a steady reduction for over 30 years of the carbon from 141g/m^2 in 1986 to 80g/m^2 in 2006 and 70 g/m^2 in 2016.

The high carbon levels observed in natural forest areas throughout the study period, despite a steady reduction in biomass, underscore the importance of these ecosystems as carbon sinks (Montagnini & Nair, 2004; Chazdon *et al*., 2009). The decline in biomass and carbon density within natural forests over time may be attributed to deforestation, logging activities, or land conversion, highlighting the threats to forest carbon stocks and the need for conservation efforts (García-Orenes *et al*., 2009; Gibbs *et al*., 2010).

The lowest carbon levels recorded in grassland areas, particularly the shift from 20 g/m^2 in 1986 to 0 g/m^2 in 2016, reflect the significant impact of land cover change on carbon sequestration capacity (Danielsen *et al*., 2009; Dent *et al*., 2017). The steady reduction in carbon levels across all land cover types over three decades suggests widespread carbon loss and ecosystem degradation, driven by factors such as deforestation, agricultural expansion, and urbanization (Fisher *et al*., 2017; van Kuijk *et al*., 2008).

The findings underscore the urgent need for policy interventions and conservation strategies to mitigate carbon loss, preserve natural carbon sinks, and promote sustainable land management practices (Fox *et al*., 2017; Vijay *et al*., 2016). Integrated Land use planning, reforestation initiatives, and agroforestry practices are essential for enhancing carbon sequestration, restoring degraded ecosystems, and mitigating the impacts of climate change (Hartley *et al*., 2018; Fisher *et al*., 2017). The observed trends in carbon dynamics highlight the complex interactions between land cover change, carbon sequestration, and ecosystem health. By addressing the drivers of carbon loss and implementing proactive conservation measures, it is possible to safeguard carbon stocks, enhance resilience to climate change, and promote sustainable development.

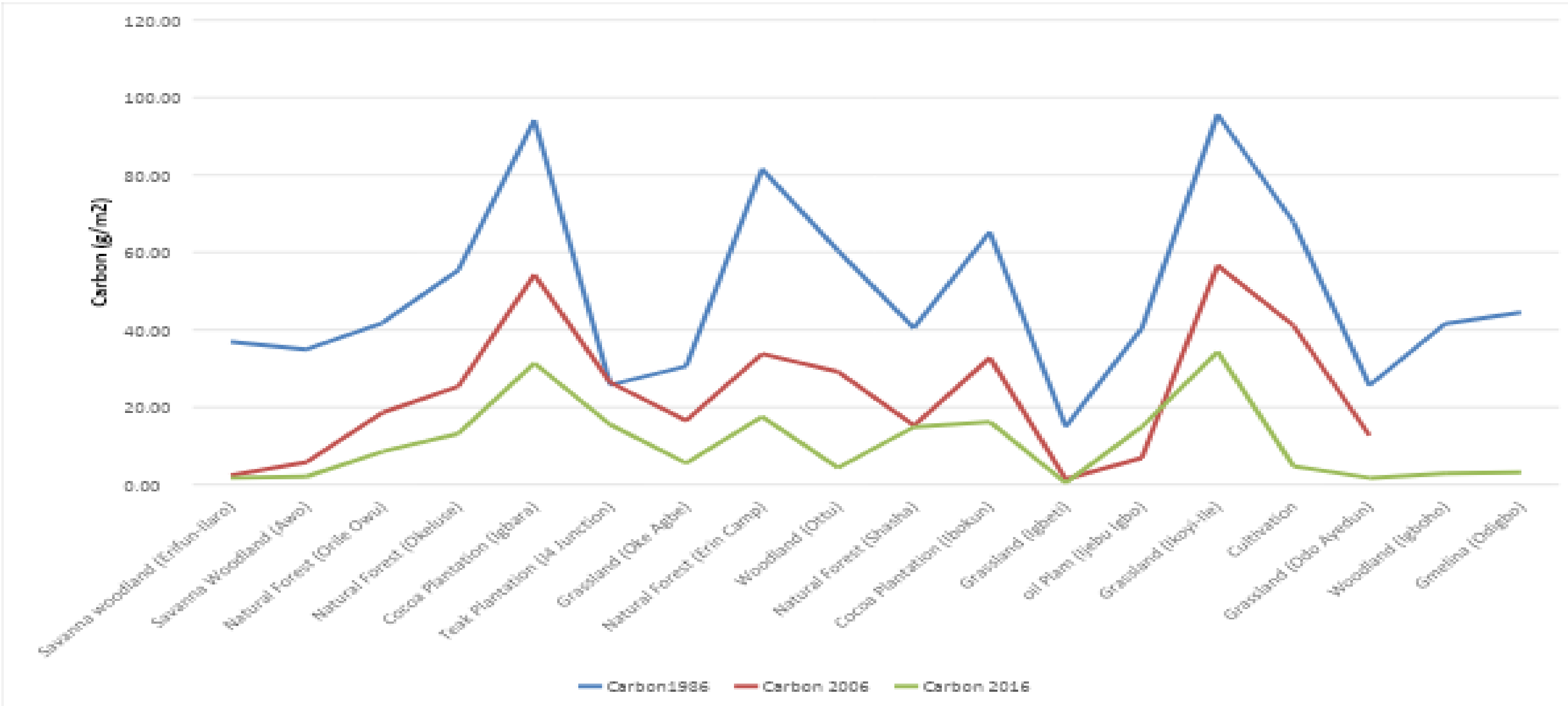

Figure 6.1: Landcover and carbon stock from CASA

The Net Primary Productivity also reduced significantly in the savannah areas of the study area. This is due to the continual cultivation of the savannah areas. Some natural forests are converted to farmlands, thus reducing the carbon in the natural forest and adding to the savannah areas. The NPP increase in agricultural areas could result from climate changes and agricultural activities such as increased farmlands and tree crops plantations in the recent several decades. Urban expansion has also caused the loss of Farmlands Li *et al*., 2003, and therefore resulted in the largest portion of areas with a significant decrease in NPP in the cultivated regions.

Conversely, the observed increase in NPP in agricultural areas may be influenced by climate changes and intensification of agricultural activities, including the expansion of farmlands and cultivation of tree crops (Xia *et al*., 2019; Asner *et al*., 2005). The adoption of modern agricultural practices and the introduction of high-yielding crop varieties could also contribute to enhanced productivity in these regions (Lobell *et al*., 2009; Mueller *et al*., 2012). However, the expansion of urban areas, driven by population growth and infrastructure development, results in the loss of farmlands and further exacerbates the decline in NPP in cultivated regions (Li *et al*., 2003; Seto *et al*., 2011).

The observed changes in NPP underscore the dynamic nature of Land use systems and their implications for ecosystem functioning and food security (DeFries *et al*., 2000; Foley *et al*., 2005). Sustainable land management practices and Land use planning strategies are essential to mitigate the adverse effects of Land use change on NPP and ecosystem services (Lambin *et al*., 2003; Verburg *et al*., 2019). Integrating ecological considerations into urban planning and promoting agroforestry practices could help reconcile competing Land use demands while maintaining or enhancing NPP levels (Zhang *et al*., 2018; Perfecto *et al*., 2009). The observed changes in NPP reflect the complex interactions between human activities, Land use change, and environmental factors. Addressing the drivers of NPP change requires interdisciplinary approaches that consider socio-economic dynamics, climate variability, and ecological resilience to ensure sustainable land management and food production systems.

6.2 Carbon Stock Fluxes

The changes in the carbon stock of the study area, as shown in the Figure above, reveals that most of the changes in the carbon stock within the study area took place between 1986 and 2006. The result indicates that the forest area alone gave up 140g/m^2; the next was savannah woodland that emitted about 119 g/m^2. This is a result of an increase in agricultural practices within the study area. Another significant change in carbon stock was from the Teak and Gmelina plantation giving up 79 g/m^2. Every other land cover had a carbon stock change of not over 45g/m^2; most of the other land cover is not subject to excessive change.

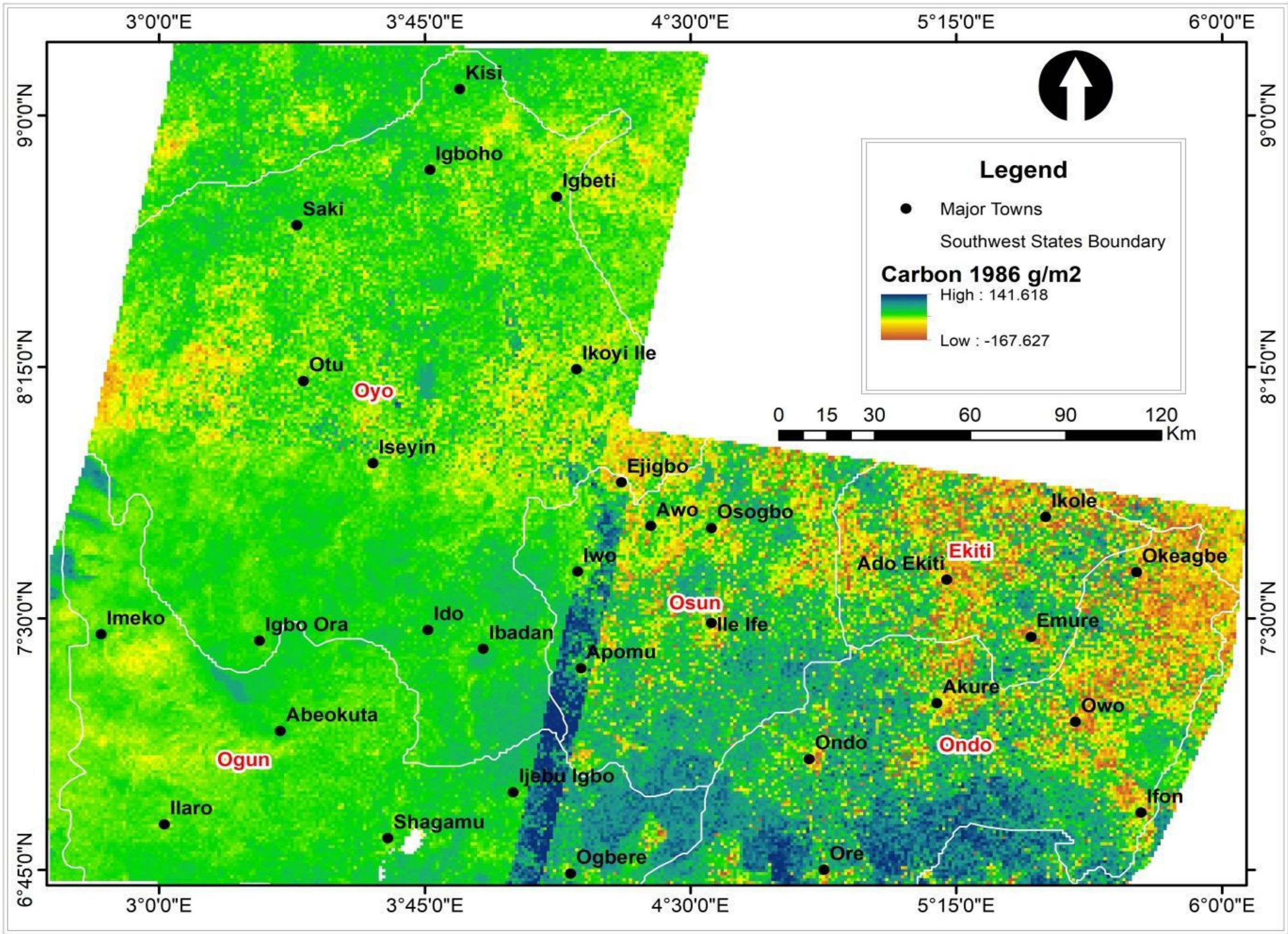

Figure 6.2: 1986 Carbon stock by CASA Model

The gradual and consistent decrease in the carbon of the study area, from the map on 1986, is apparent that the regions around Erin camp, Okeluse, Odigbo, and Shasha all had a very high carbon of 140 g/m^2. Still, as it goes up to the northern part of the study area, the density reduces because the land cover type changed from the forest to woodland and grassland. Locations like Igboho, Ottu, and Igbetti are savannahs, thus recording a lesser density. This trend continued to 2006, though the savannah gave up some lands to the urban area, while natural forest gave up some area to farmland and savannah. Consequently, the carbon concentration further reduces both in the forest areas to the savannah areas. In 2016, so much of the carbon has been lost to urbanization and timber cutting.

The map in Figure 6.2 shows the carbon stock in 1986, the result shows that carbon was high around the Okeluse and Erin Camp, while it reduces towards Igboho in Oyo state. The 2006 carbon map on Figure 6.3 shows that the carbon density around Erin Camp had reduced to 80 g/m^2 while moving towards the northern part the carbon reduced to about 50 g/m^2. Figure 19 reveals the spatial distribution of the carbon across the study area, which reveals that carbon density reduced from the southern area around Okeoluse, Erin camp from 70 g/m^2 to Igboho at the northern part of the map in Oyo state to 30 g/m^2.

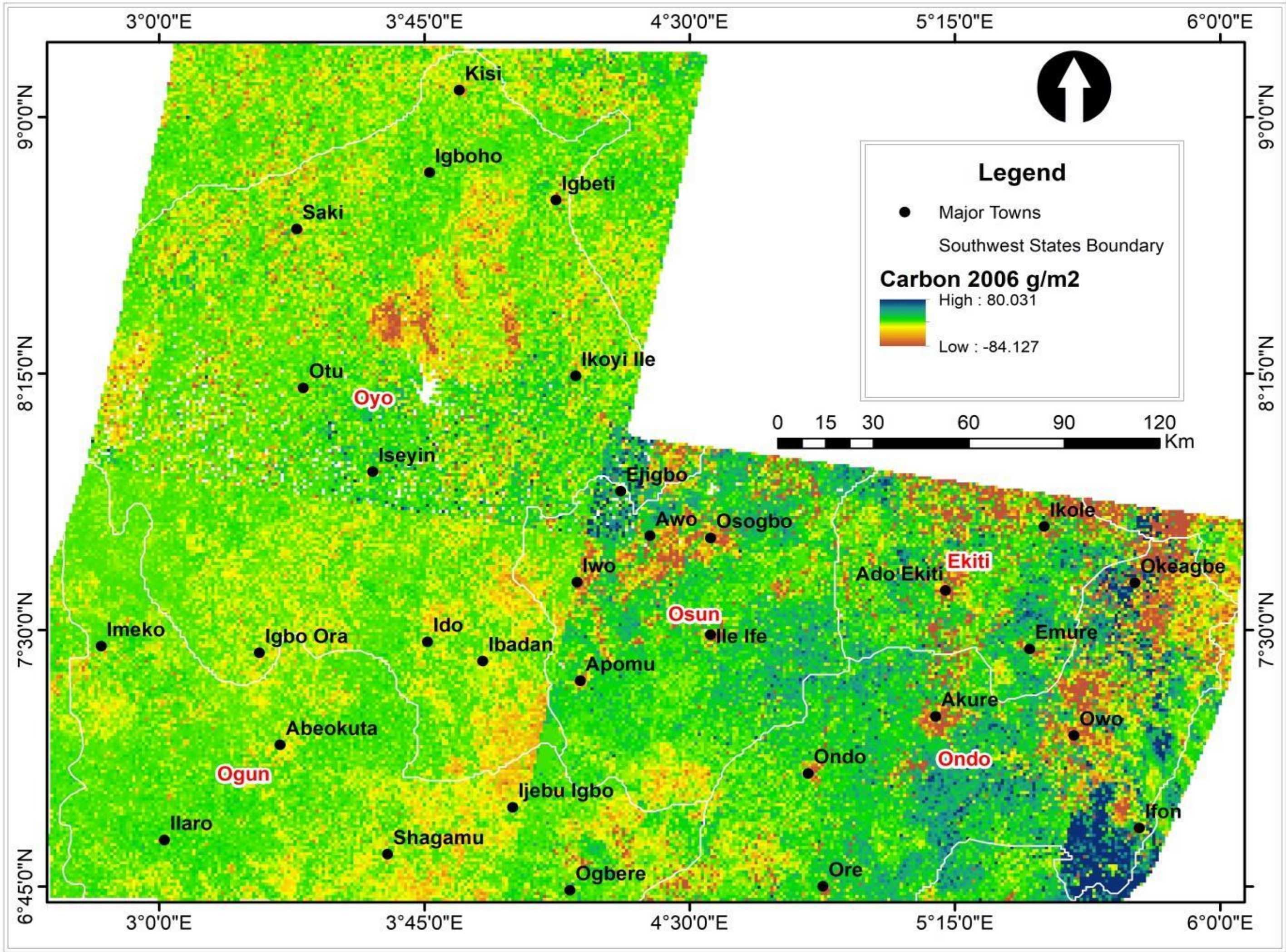

Figure 6.3: 2006 Carbon stock by CASA Mode

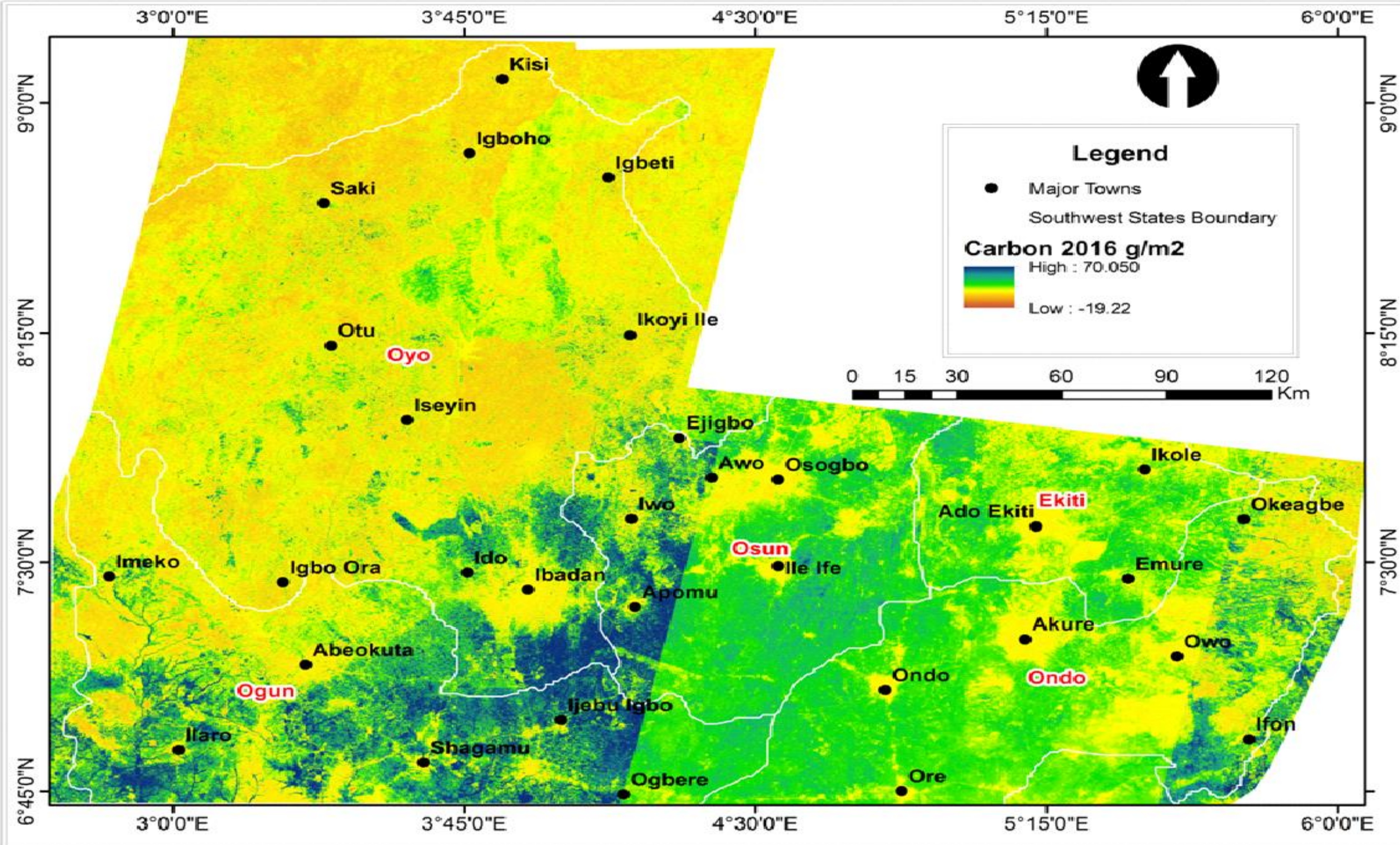

Fig 6.4: 2016 Carbon stock by CASA Mode

The observed changes in carbon stocks within the study area, particularly between 1986 and 2006, provide valuable insights into the dynamics of carbon sequestration and emissions associated with land cover changes (Harris *et al*., 2012; Gibbs *et al*., 2010). The substantial loss of carbon stocks in forest areas, amounting to 140 g/m², highlights the significant impact of deforestation and land conversion on carbon emissions (Houghton, 2005; DeFries *et al*., 2008). This loss is particularly concerning given the crucial role of forests as carbon sinks and their contribution to mitigating climate change (Bonan, 2008; Pan *et al*., 2011).

The emission of 119 g/m² of carbon from savannah woodland reflects the conversion of natural ecosystems to agricultural lands, leading to the release of carbon stored in vegetation and soil organic matter (Galford *et al*., 2010; van der Werf *et al*., 2009). Such land cover changes contribute to the loss of biodiversity, ecosystem services, and carbon sequestration capacity, exacerbating environmental degradation and climate change (Lambin & Meyfroidt, 2011; Foley *et al*., 2005).
The significant carbon stock change of 79 g/m² from Teak and Gmelina plantations highlights the role of plantation forestry in carbon dynamics and land use transitions (Montagnini & Nair, 2004; Sasaki & Putz, 2009). While plantations can sequester carbon through afforestation efforts, the harvesting of timber and land management practices may result in carbon emissions over time, affecting the net carbon balance (Nair *et al*., 2009; Danielsen *et al*., 2009).

Overall, the findings emphasize the need for integrated land management approaches that balance agricultural development with forest conservation and carbon sequestration objectives (Sodhi *et al*., 2010; Gaveau *et al*., 2014). Conservation strategies, such as forest protection, reforestation, and sustainable land use practices, are essential for maintaining carbon stocks, preserving biodiversity, and enhancing ecosystem resilience to climate change (Chazdon *et al*., 2009; Lambin *et al*., 2003).

6.3: Field Measured Carbon Estimation

Field estimated carbon in the study area is depicted in Table 6.1; the result reveals the carbon and biomass concentration in liters and herbs.

Table 6.1: Field Carbon parameters

Plot/ Location	Plot Dimension	Liter Biomass (g/m^2)	Herb Biomass (g/m^2)	Tree Biomass (g/m^2)	AGB ($gram/m^2$)	AGB (tons/ha)	AGC (Mg C)	AGC (Mg C/ha)
Woodland – Erifun	25mX25m	37.3	28.27	25648.26	25713.83	283.45	141.72	128.57
Woodland – Awo	25mX25m	47.35	124.38	9368.64	9540.37	105.16	52.58	47.70
Woodland - Igboho,	25mX25m	134.46	101	37013.69	37249.15	410.60	205.30	186.25
Woodland - Okeagbe-Akoko	25mX25m	39.95	14.31	46125.12	46179.38	509.04	254.52	230.90
Woodland-Ikoyi Ile	25mX25m	80.46	18.33	22680.27	22779.06	251.10	125.55	113.90
Woodland – Ottu	25mX25m	141.58	1.02	26121.93	26264.53	289.52	144.76	131.32
Natural Forest - Orile Owu	25mX25m	80.54	31.47	16465.06	16577.07	182.73	91.37	82.89
Natural Forest- Okeluse	25mX25m	70.6	3.93	170412.90	170487.43	1879.30	939.65	852.44
Natural Forest – Shasha	25mX25m	51.02	44.52	16798.40	16893.94	186.22	93.11	84.47
Natural Forest - Erin Camp	25mX25m	95.62	45.82	525153.61	525295.05	5790.38	2895.19	2626.47
Cocoa Plantation – Igbara Oke	25mX25m	111.09	22.2	136729.82	136863.11	1508.66	754.33	684.31
Cocoa Plantation – Ibokun	25mX25m	56.41	49.91	25651.86	25758.18	283.94	141.97	128.79

Cocoa Plantation – Ijebu Ijesha	25mX25m	94.46	45.39	42187.84	42327.69	466.58	233.29	211.64
Grassland – Igbeti	25mX25m	50.5	44	3299.87	3394.37	37.42	18.71	16.97
Grassland – Odo Ayedun	25mX25m	90.21	125.86	21165.56	21381.63	235.69	117.85	106.91
Oil Plam – Ijebu Igbo	25mX25m	102.3	95.8	33705.75	33903.85	373.73	186.86	169.52
Gmelina – Odigbo	25mX25m	102	45.64	29211.80	29359.44	323.63	161.82	146.80
Teak Plantation - J4 junction	25mX25m	42.95	39.1	48338.14	48420.19	533.74	266.87	242.10

The biomass and carbon concentration in the sampling locations was calculated after the algorithm of Chave *et al* 2014. The result shows that for the AGB, the natural forest at Erin Camp had the highest biomass of 5790.38 tons/ha. This was followed by Natural Forest at Okeluse with 1879.30 tons/ha. The Cocoa plantation at Igbara Oke showed a high biomass concentration of 1508.66 tons/ha. The analysis showed that the study location with the least biomass is the grassland at Igbeti with 37.42 tons/ha, followed by the woodland at Awo with a concentration of 105.16 tons/ha. Other locations had different biomass levels.

The carbon concentration at the study locations followed the same pattern with the biomass, as shown on table 6 the natural forest at Erin Camp had the highest carbon content of 2626.47 Mg C/ha, the natural forest at Okeluse had a carbon concentration of 852.44 MgC/ha, Cocoa plantation at Igbara Oke had a carbon concentration of 684.31 MgC/ha. The savanna woodland at Okeagbe had a carbon of 230.90 MgC/ha. On the other hand, the study locations with the lowest carbon were the Savanna grassland at Igbeti with 16.97 MgC/ha, followed by savanna woodland at Awo with only 47.70 MgC/ha, other carbon concentration at the study locations are shown on table 6.1.

These findings underscore the importance of land cover types in sequestering and storing carbon, with natural forests emerging as crucial reservoirs of carbon stocks. The results also highlight the potential of certain land cover types, such as cocoa plantations, in contributing to carbon storage. However, the comparatively low biomass and carbon concentrations observed in grasslands and woodlands signify the need for conservation efforts and sustainable land management practices to enhance carbon stocks in these ecosystems (Malhi *et al*., 2006; Pan *et al*., 2011; Chave *et al*., 2014).

In conclusion, the biomass and carbon concentration analysis provides valuable insights into carbon sequestration potential across different land cover types. These findings can inform Land use planning and conservation strategies aimed at maximizing carbon storage and mitigating climate change impacts.

6.4 Carbon across Land Use in the Study Area

The carbon storage in the various land cover is explained in Figure 20 below; the result shows that natural forests had the highest carbon storage in the study area. Natural forests had a carbon stock of 26.94 tons/ha, due to the density of the tree species (Steidinger *et al.* 2019; Lal 2005). It is followed by cocoa plantation (21.67 tons/ha). The savannah woodland has a carbon stock of 19.53 tons/ha. This is explained by the sizable land area of the savannah woodland. Teak and Gmelina planation have a carbon stock of 20.99 tons/ha. The small quantity of the carbon stock of this land cover is a result of the fact that it has the smallest area occupied.

Following natural forests, cocoa plantations demonstrate considerable carbon storage, with a stock of 21.67 tons/ha. This indicates the potential of agroforestry systems, such as cocoa plantations, in contributing to carbon sequestration while supporting agricultural productivity (Asare *et al*., 2010). The presence of trees in cocoa plantations enhances carbon storage and promotes ecosystem resilience.

Savannah woodlands exhibit a moderate carbon stock of 19.53 tons/ha, reflecting the substantial land area covered by this land cover type. While savannah woodlands may not store carbon as effectively as natural forests, their contribution to carbon storage remains notable, particularly considering their extensive spatial coverage (Mitra *et al*., 2019). Teak and Gmelina plantations, although occupying a smaller area compared to other land cover types, still contribute to carbon storage with a stock of 20.99 tons/ha. Despite their limited spatial extent, these plantations play a role in carbon sequestration and may serve as important carbon sinks within the landscape (Senthilkumar *et al*., 2018).

In summary, the carbon storage analysis underscores the significance of different land cover types in sequestering carbon and mitigating climate change impacts. Natural forests emerge as key carbon reservoirs, highlighting the importance of their conservation and sustainable management. Agroforestry systems, such as cocoa plantations, also demonstrate potential for carbon storage, emphasizing the importance of integrating tree-based farming practices into Land use strategies.

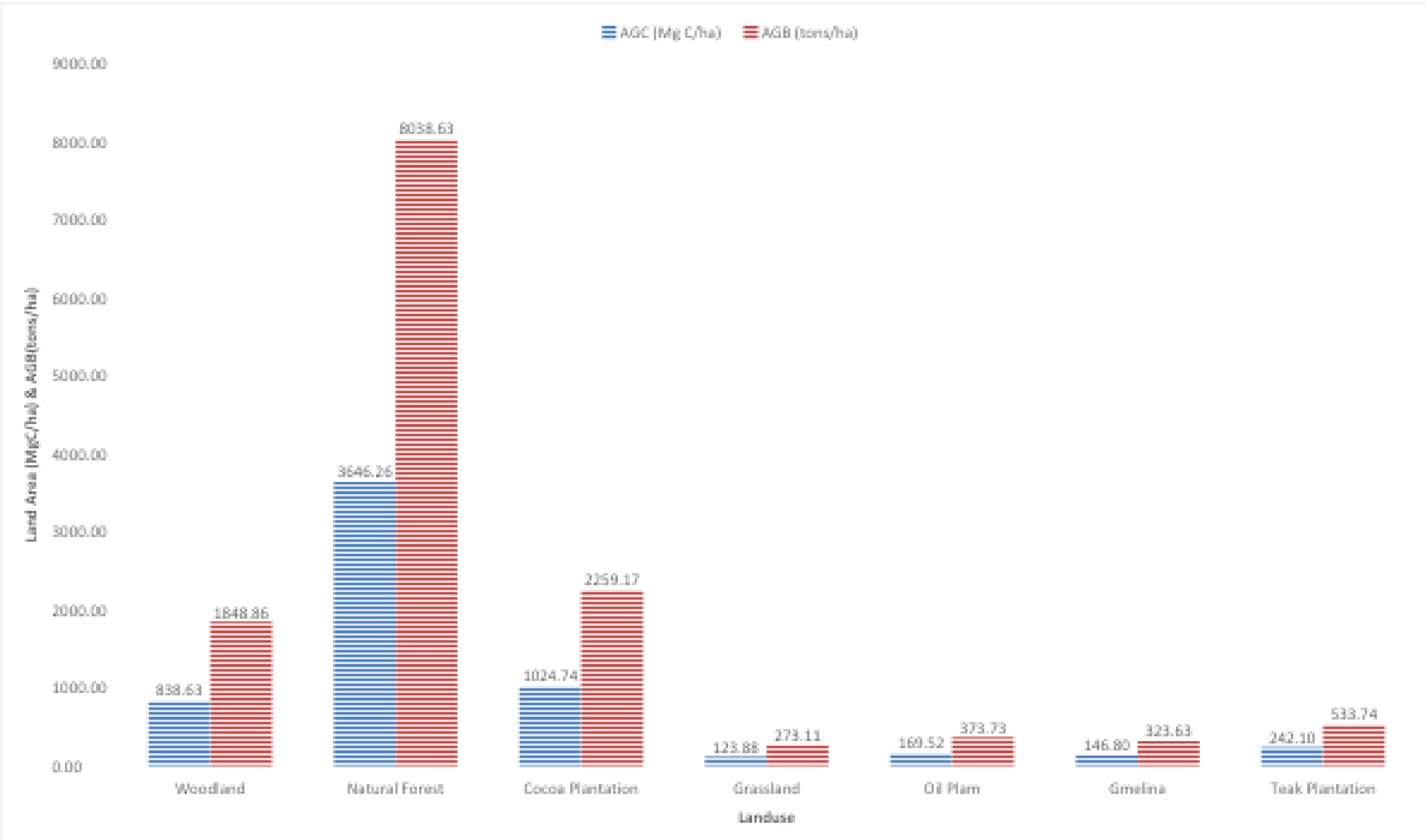

Figure 6.5: Carbon stock in land use

The relatively high carbon stock observed in cocoa plantations, with 21.67 tons/ha, suggests that agroforestry systems can contribute to carbon storage while supporting agricultural productivity (Montagnini & Nair, 2004; Danielsen *et al*., 2009). Agroforestry practices integrate tree crops with agricultural activities, enhancing biodiversity, soil fertility, and carbon sequestration potential (Nair *et al*., 2009; Galford *et al*., 2010).

Savannah woodland, despite its extensive land area, exhibits a slightly lower carbon stock of 19.53 tons/ha compared to natural forests. This may be attributed to differences in vegetation structure and biomass density between woodland and forest ecosystems (van der Werf *et al*., 2009; Galford *et al*., 2010). Nonetheless, savannah woodlands still play a role in carbon storage and ecosystem services provision within the landscape.

Teak and Gmelina plantations, characterized by their smaller spatial extent, show a moderate carbon stock of 20.99 tons/ha. While plantation forestry can contribute to carbon sequestration and timber production, their carbon storage potential may be limited compared to natural forests due to differences in species diversity and ecosystem complexity (Montagnini & Nair, 2004; Sasaki & Putz, 2009). Several studies have highlighted the complex interplay between land use changes, forest dynamics, and carbon sequestration. Angelsen *et al*. (2014) demonstrate how agricultural expansion, logging activities, and infrastructure development can contribute to deforestation and forest degradation, leading to significant losses in biomass and carbon stocks. Similarly, studies by Harris *et al*. (2012) and Hansen *et al*. (2013) underscore the role of land use policies, socioeconomic factors, and climate change in shaping forest carbon dynamics at regional and global scales.

Overall, the distribution of carbon stocks across different land cover types highlights the importance of ecosystem conservation, sustainable land management practices, and Land use planning strategies aimed at maximizing carbon sequestration potential and mitigating climate change impacts (Chazdon *et al*., 2009; Foley *et al*., 2005).

6.5 Carbon Stock Projection

The STsim projection showed the proportion of carbon stock for the various land uses. The blue line indicates Carbon stock for living biomass and land use carbon pools; coloured zones indicate the corresponding 95% Monte Carlo confidence intervals over 100 Monte Carlo realizations. Only those LULC classes with dynamic carbon are displayed.

The result indicates that agriculture reveals a continual decline in the carbon stock from 0.12 kg/m^2 to about 0.040 kg/m^2. Which is explained by the fact urban expansion will continue to take up the vegetation which stores the carbon. Again, the result is obvious due to the fact that the cultivated area will always have seasonal vegetation cover as a result of the annual harvest of the crops.

Then the grassland showed a reduction in carbon stock from 0.180 kg/m^2 to 0.120 kg/m^2 from 2016 to 2066. This situation is explained by the gradual conversion of grassland to agricultural land and builtup area, the projection thus reveals that from 2016 till 2066, there will be a consistent reduction in grassland thus leading to also a reduction in carbon stock of the land use. Natural forest being the highest store of carbon in the ecosystem revealed that it has a gradual increment in carbon stock from 0.470 kg/m^2 in 2016 to 0.485kg/m2 in 2066. The reason for this is because of the continual encouragement to support forest protection especially the natural reverses to reduce the level of deforestation in the study area.

The carbon stock in the woodland area shows a consistent increase from 2016 to 2066, the result is due to the reported conversion of some forested area into derived savannah woodland. The carbon stock increased from 0.90 $kgm/^2$ in 2016 to 0.120 kg/m^2 in 2066. while the plantation had a stable carbon stock of no increase and no reduction. This could be explained by the constant planting and harvesting of trees in the plantation area, thus not making the area to have a recorded loss or gain. The analysis also shows the carbon in the litter, wood product and living biomass, the result shows that is increasing from the base year to 2066.

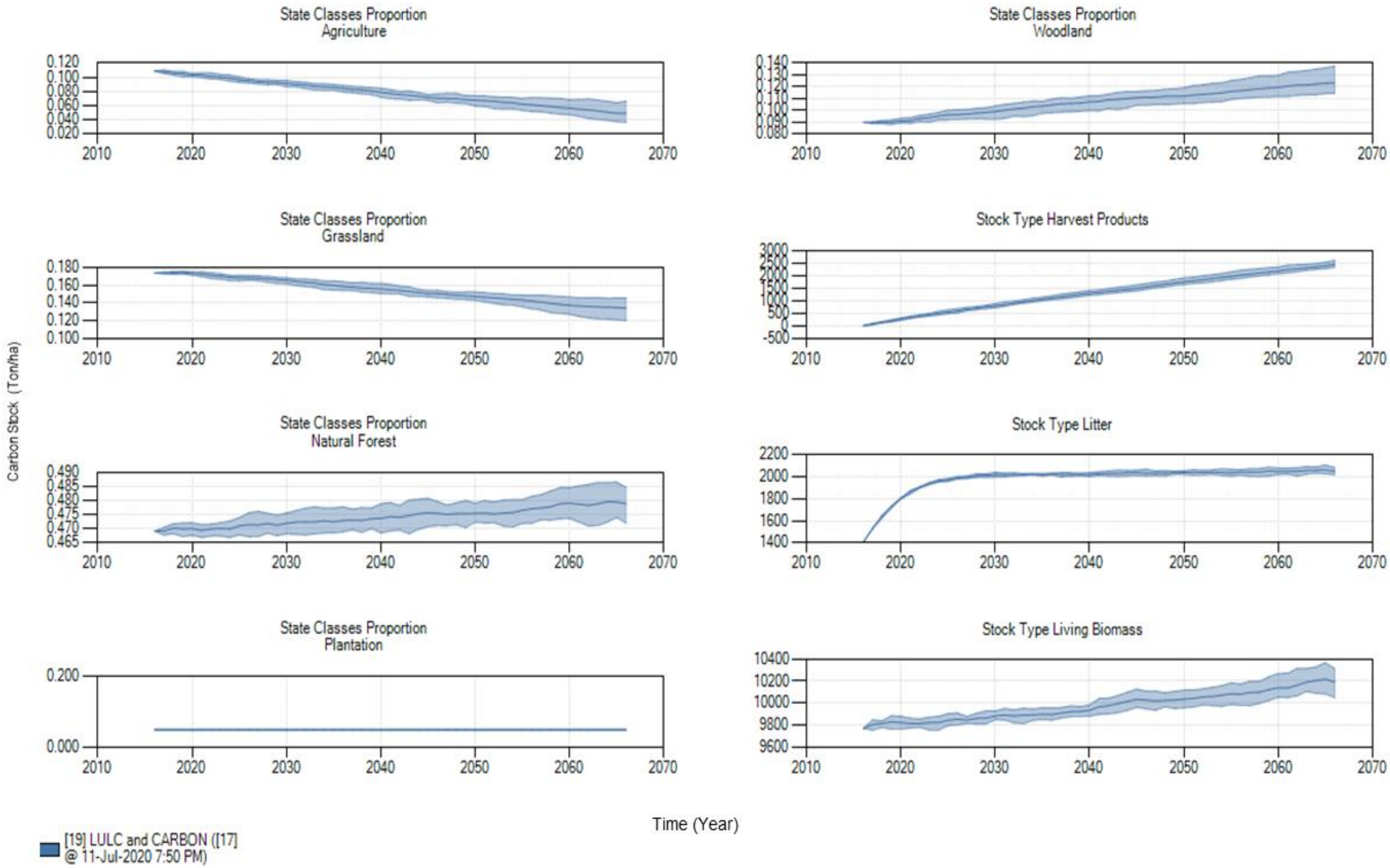

Figure 6.6: Carbon projection over the simulation period (*Source: Author, 2020)*

6.6 Result Validation: Remote Sensing Carbon and Field Measured Carbon

The analysis of the relationship between remote sensing (RS) estimated carbon and field-measured carbon, as depicted in Figure 4.7, provides valuable insights into the efficacy of RS-based methods for estimating carbon stocks in land use assessments. The findings indicate a strong correlation between RS biomass and RS estimated carbon, with adjusted r2 values consistently above 50% for all three years examined (1986, 2006, and 2016). Specifically, the adjusted r2 values of 80%, 79.05%, and 66.1% for 2016, 2006, and 1986 respectively suggest a robust relationship between RS-derived carbon estimates and field measurements (Chave *et al*., 2014).

This strong relationship underscores the potential utility of RS techniques as a viable alternative or complementary approach to traditional field-based methods for assessing carbon stocks in extensive forested areas. Particularly in cases where conducting comprehensive field measurements may be logistically challenging or economically prohibitive, RS offers a cost-effective and efficient means of estimating carbon stocks across large spatial scales (Asner *et al*., 2005). By leveraging satellite or aerial imagery coupled with advanced modeling algorithms, RS enables the extrapolation of carbon estimates from sampled locations to broader landscapes, providing valuable data for land management and conservation efforts (Mascaro *et al*., 2014).

Furthermore, the consistent performance of RS-derived carbon estimates across multiple years highlights the reliability and consistency of RS-based methodologies over time. This longitudinal stability reinforces the credibility of RS-derived carbon assessments and enhances their applicability for monitoring changes in carbon stocks and land use dynamics over extended temporal scales (Asner *et al*., 2009). Such continuity in RS-derived carbon assessments facilitates the identification of long-term trends, spatial patterns, and drivers of carbon sequestration or loss, thereby informing evidence-based decision-making in ecosystem management and climate change mitigation strategies (Asner *et al*., 2016).

However, it is essential to acknowledge the inherent limitations and uncertainties associated with RS-based carbon estimation techniques. Factors such as cloud cover, sensor resolution, and spectral saturation may introduce biases or errors in RS-derived carbon estimates, particularly in complex landscapes with heterogeneous vegetation cover or topography (Mitchard *et al*., 2012). Additionally, calibration and validation of RS models using ground-truth data are crucial for ensuring the accuracy and reliability of RS-derived carbon estimates, as discrepancies between RS and field measurements may arise due to variations in measurement protocols, sampling strategies, or environmental conditions (Asner *et al*., 2018).

The findings regarding the strong relationship between RS-derived carbon estimates and field-measured carbon underscore the potential of RS techniques as valuable tools for assessing carbon stocks in land use studies. While RS offers numerous advantages in terms of scalability, cost-effectiveness, and temporal continuity, it is essential to address methodological uncertainties and validation requirements to ensure the accuracy and reliability of RS-derived carbon assessments. By integrating RS with field-based approaches and adopting rigorous quality assurance measures, researchers and practitioners can harness the full potential of RS technology for advancing our understanding of carbon dynamics and supporting informed decision-making in environmental management and conservation initiatives.

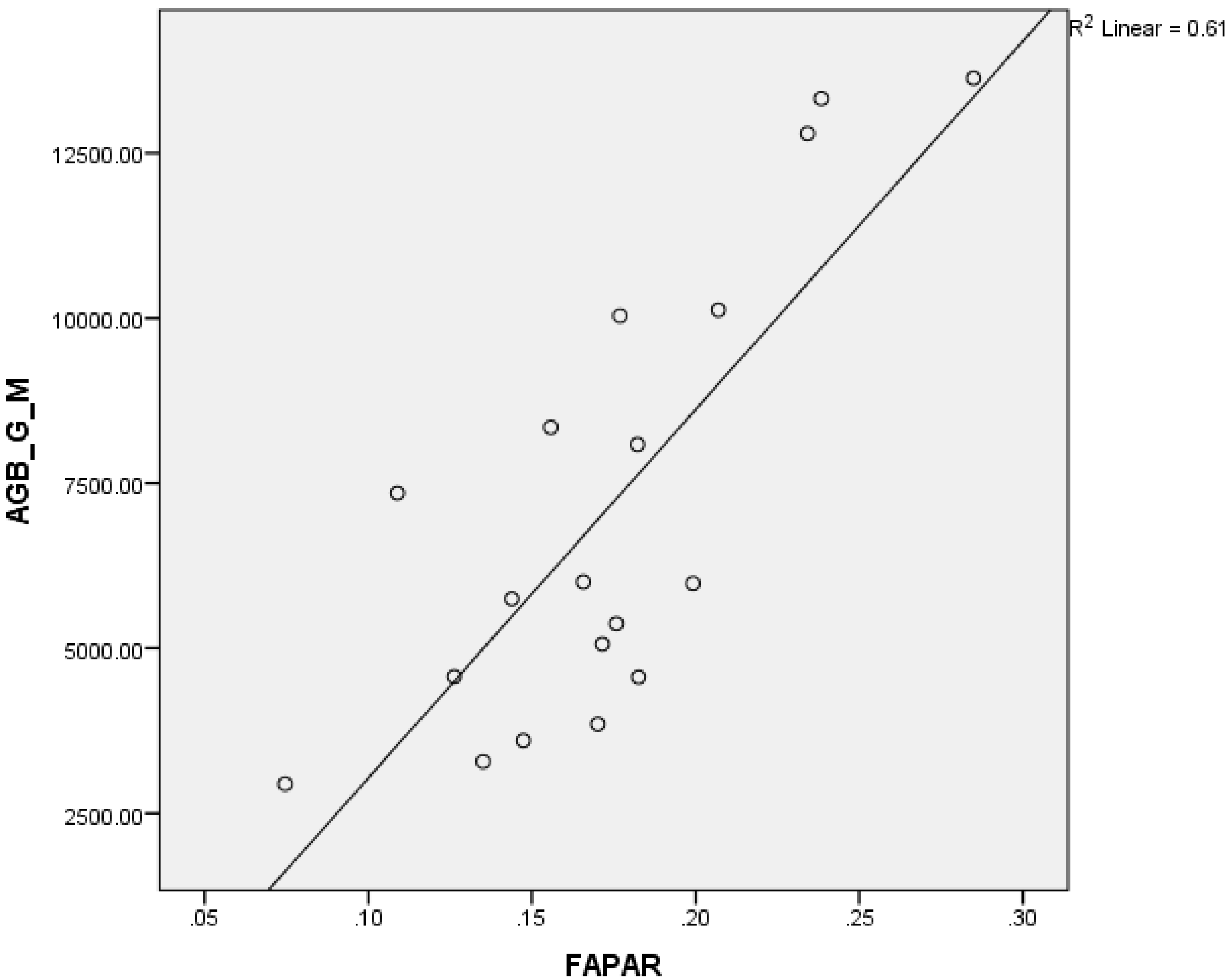

Figure 6.7: Relationship between Vegetation index and RS estimated Carbon stock in grams/m^2

The high percentage of the relationship between remote sensing estimated carbon and field estimated carbon across the three years (>50%) implies that remote sensing methods provide robust estimates that closely align with ground-truth data (Lu *et al*., 2016; Lucas *et al*., 2018). This suggests that remote sensing techniques offer a cost-effective and efficient means of monitoring carbon stocks over large spatial extents, facilitating comprehensive assessments of carbon dynamics and informing management strategies (Asner & Mascaro, 2014; Gibbs *et al*., 2007). The ability to accurately estimate carbon stocks using remote sensing holds significant implications for carbon accounting, climate change mitigation efforts, and ecosystem management (Baccini *et al*., 2017; Mitchard *et al*., 2013). By leveraging remote sensing technologies, researchers and policymakers can gain timely insights into carbon dynamics, monitor changes over time, and prioritize conservation and restoration actions in areas with high carbon sequestration potential (Asner *et al*., 2013; Mitchard *et al*., 2013).

The strong relationship between RS biomass and RS estimated carbon highlights the utility of remote sensing as a valuable tool for assessing carbon stocks in land use contexts. This finding underscores the importance of integrating remote sensing techniques into carbon monitoring and management strategies to enhance our understanding of carbon dynamics and support informed decision-making processes.

CHAPTER SEVEN

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

7.0 Introduction

The environment depends on the photosynthesis activities of the vegetation in our terrestrial environment to regulate the gasses in the atmosphere and thus, make the environment safe for human habitation. But with the increase in human activity on the earth's surface, man in a bit to create a livelihood has altered the vegetation ecosystem through deforestation for either construction of agricultural purposes thus, reducing its ability to sequester the carbon dioxide from the atmosphere, and making the environment not conducive to man. The study, hence, is aimed at assessing the biomass changes and carbon fluxes in the savanna and forest areas of the southwest Nigerian between 1986 and 2016. The specific objectives are to;

- Analyse the trend and pattern in forest and savannah woodland conversion from 1984 to 2016.
- Examine the trend and pattern in aboveground biomass induced by vegetal conversion and degradation.
- Estimate the carbon fluxes in the forest and Savanna woodland between the two epochs, 1984 to 2016.
- Predict the changes in future carbon fluxes up to 2066.

Therefore, this chapter summarizes all the chapters in the research and presents them under the following subheadings; summary of findings, policy implications for forest and biomass management, conclusion, recommendations, and contribution of knowledge.

7.1 Summary of Findings

From 1986 through 2006 to 2016, the land use/land cover in southwestern Nigeria has undergone tremendous changes. Savannah area had a total change of 27.79%, Agriculture recorded the highest net gain (3,407.95 km^2), while forests had the highest net loss (-2,316.99 km^2 with an annual net change of -35.66 km^2 per annum and the forest area lost 12.75% within the study years having a net reduction of -441.71 km^2 per annum). Fallow and shifting cultivation followed closely, with a combined loss of land area amounting to -4,396.19 km^2 (-6.54%). Teak and Gmelina plantations showed the highest gain during this period, increasing by 5,664.03 km^2 (8.42%). Urban areas expanded by about 2,933.30 km^2 (4.36%), Coastal grassland had the least change, with a loss of about -8.66 km^2 (-0.01%), and the smallest gains were observed in quarry and rubber plantation, each with approximately 4.37 km^2 (0.01%) and 9.34 km^2 (0.01%), respectively. Between 2006 and 2016, highly disturbed forests recorded the highest loss, totaling approximately -8,573.14 km^2 (-12.75%). Several studies and reports underscore the importance of data harmonization, expansion, and sharing for effective forest monitoring and management. For example, the Global Forest Resources Assessment (FRA) conducted by the Food and Agriculture Organization (FAO) emphasizes the need for countries to improve the accuracy and reliability of their forest data through standardized methodologies and data-sharing mechanisms. Similarly, initiatives such as the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) program highlight the importance of robust forest monitoring systems supported by comprehensive and up-to-date data for achieving sustainable forest management and climate change mitigation goals.

The land use projection for 2016 to 2066 Across the study period shows notable trends emerge in land cover dynamics. Agricultural land area steadily declines from 57,076.88 hectares in 2016 to 29.14 hectares by 2066. built-up area undergoes a remarkable expansion, skyrocketing from 1,174.51 hectares in 2016 to a staggering 44,699.79 hectares by 2066. Meanwhile, the area of bare surfaces experiences fluctuations, ranging from 44.39 hectares in 2016 to 3.81 hectares in 2066. Grassland area also shows variability over time, area oscillates between 185.85 hectares in 2016 and 43.04 hectares in 2066. Notably, the natural forest area remains relatively stable, hovering around 1,419.99 hectares in 2016 and maintaining a consistent 0.45 hectares in subsequent years. In contrast, plantation land witnesses fluctuations, starting at 2,525.90 hectares in 2016 and gradually declining to 8.74 hectares by 2066. Lastly, the woodland area remains relatively unchanged, with values ranging from 4,828.30 hectares in 2016 to 22,470.85 hectares in 2066.

The biomass trends in woodland for 30 years varied from 141g/m^2 in 1986, to 0.41 g/m^2 to 70 g/m^2 in 2016. Grassland had a biomass of 0.55 g/m^2 in 1986 reduced to 0.33 g/m^2 in 2006 and 0.27 g/m^2. Natural forest biomass of 0.86 g/m^2 in 1986 was reduced to 0.64 g/m^2 in 2006, finally in 2016 the biomass had further dropped 0.58 g/m^2. The gradual and consistent decrease in the biomass of the study area, in 1986 Erin camp, Okeluse, Odigbo, and Shasha all had 140 g/m^2 the density reduced towards Igboho, Saki, Alapo, and Igbetti which are savannahs. The natural forest exhibited the highest biomass density, with a biomass of 0.86 g/m2 in 1986, decreasing to 0.64 g/m2 in 2006 and 0.58 g/m2 in 2016. The decline in forest biomass could be attributed to ongoing logging activities and the exploitation of other forest resources.

The changes in carbon stock for the static years 1986, 2006, and 2016 highlight that most of the changes in carbon stock within the study area occurred between 1986 and 2006. the forest area experienced a loss of 140 g/m^2, and savannah woodland lost about 119 g/m^2 due to increased agricultural practices. Teak and Gmelina plantation lost 79 g/m^2. The gradual and consistent decrease in carbon across the study area is evident from 1986. Regions around Erin Camp, Okeluse, Odigbo, and Shasha exhibited very high carbon levels of 140 g/m^2 while moving northward, the density reduced due to the transition from forest to woodland and grassland. Igboho, Ottu, and Igbetti, characterized by savannahs, recorded lower carbon densities. This trend continued into 2006, the savannah lost some land area to urban areas, while natural forests yielded areas to farmland and savannah. carbon concentration is further reduced, both in forested areas and savannah regions. In 2016, substantial carbon loss occurred due to urbanization and logging. the carbon stock in 1986, with high carbon levels around Okeluse and Erin Camp, gradually decreasing towards Igboho in Oyo State. In 2006 carbon density around Erin Camp had reduced to 80 g/m^2, decreasing further to about 50 g/m^2 towards the northern part. The spatial distribution of carbon across the study area indicates a reduction in carbon density from the southern locations around Okeluse and Erin Camp (70 g/m^2) to Igboho in the northern part of Oyo state (30 g/m^2).

The study revealed Aboveground Biomass (AGB), Erin Camp's natural forest exhibited the highest biomass at 5,790.38 tons/ha, followed by Okeluse's natural forest with 1,879.30 tons/ha. The Cocoa plantation at Igbara Oke showed a notable biomass concentration of 1,508.66 tons/ha. The grassland at Igbeti had the lowest biomass at 37.42 tons/ha, followed by Awo's woodland with a concentration of 105.16 tons/ha. Other locations displayed varying biomass levels. Carbon concentrations at the study locations mirrored the biomass pattern. Erin Camp's natural forest had the highest carbon content at 2,626.47 Mg C/ha, followed by Okeluse's natural forest with 852.44 Mg C/ha. The Cocoa plantation at Igbara Oke had a carbon concentration of 684.31 Mg C/ha, while the Okeagbe savanna woodland registered a carbon content of 230.90 Mg C/ha. Conversely, the study locations with the lowest carbon were the Igbeti Savanna grassland at 16.97 Mg C/ha, followed by Awo's savanna woodland with only 47.70 Mg C/ha. Under the support of the Forest Carbon Partnership Facility (FCPF), significant progress has been made in establishing functional management frameworks for the national REDD+ (Reduced Emissions from Deforestation and Forest Degradation) process in Nigeria, both at the national and state levels. However, despite these achievements, the capacity for implementing REDD+ readiness initiatives remain relatively weak, particularly at the state level. This is largely due to the complex and technical nature of the REDD+ process, which requires robust institutional arrangements and technical expertise for effective coordination and implementation.

The carbon storage in the various land covers shows that natural forests had the highest biomass and carbon storage in the study area, and grassland had the lowest biomass and carbon. Natural forests had a carbon stock of 3,646.2 MgC/ha and biomass of 8,038.6 tons/ha, due to the density of the tree species. It is followed by cocoa plantation the result shows 1,024.7 MgC/ha for carbon and 2,259.2 tons/ha for biomass. Savannah woodland had a carbon stock of 838.6 MgC/ha and a biomass of 1,848.9 tons/ha. Teak and Gmelina planation have a carbon stock of 242.1 MgC/ha and 146.8 MgC/ha with biomass of 533.7 tons/ha and 323.6 tons/ha respectively. Grassland had the lowest carbon stock of 123.9 MgC/ha and 273.1 tons/ha in the study area.

The STsim projection showed the proportion of carbon stock for the various land uses indicates that agriculture reveals a continual decline in the carbon stock from 0.12 MgC/ha to about 0.040 MgC/ha. Then the grassland land use showed a reduction from 0.180 MgC/ha to 0.120 MgC/ha. Natural forests and woodland had a gain in carbon stock, while the plantation had a stable carbon stock of no increase and no reduction. The analysis also shows the carbon in the litter, wood product, and living biomass, the result shows that is increasing from the base year to 2066.

7.3 Recommendations

Thus, the following are recommended.

i. The study findings show a rapid decline in forest area. The findings underscore the urgency of implementing regular and systematic Land use change inventories to effectively manage ecosystems. With the high rate of forest area reduction identified in the study, establishing a periodic inventory schedule becomes imperative. Such inventories would provide essential data and insights into the dynamics of Land use changes over time, enabling policymakers and stakeholders to develop informed strategies for sustainable ecosystem management and conservation efforts.

ii. The study has revealed that biomass is reducing due to lumbering activities, it becomes imperative to enhance the Forest Wood Product (FWP) extraction policy to curb unregulated logging practices, which contribute to forest degradation. Strengthening this policy would involve implementing stricter regulations and enforcement measures to ensure sustainable harvesting practices and prevent overexploitation of forest resources. By enhancing FWP extraction policies, authorities can implement good tree planting campaigns to replace trees loses which were identified from the tree inventory campaigns.

iii. Regular projections of forest biomass are essential for effective tracking of forest carbon sinks and ensuring proper accountability for annual carbon growth in the region. Conducting periodic assessments of carbon storage, to identify trends in forest carbon, and evaluate the effectiveness of conservation and management strategies. These projections provide valuable insights into the trajectory of forest carbon sequestration, guiding policy decisions and management interventions aimed at optimizing carbon storage, mitigating climate change impacts, and promoting sustainable forest management practices.

iv. Adopting remote sensing techniques for carbon estimation has the potential to revolutionize Nigeria's understanding of its carbon resources and their role in climate mitigation efforts. By leveraging satellite imagery and advanced modeling algorithms, the country can conduct comprehensive assessments of carbon stocks across diverse landscapes, providing valuable insights into the spatial distribution and magnitude of carbon reservoirs. This information can inform evidence-based decision-making processes, enabling policymakers to develop targeted strategies for enhancing carbon sequestration, conserving vital ecosystems, and meeting international climate commitments. Remote sensing offers a cost-effective and scalable approach to carbon monitoring, facilitating informed environmental management practices and sustainable development initiatives.

7.3 Policy Implication for forest Biomass and Carbon Management

The management of forest ecosystem services is crucial for understanding the intricate relationships governing carbon flows within ecosystems, thereby informing effective resource management and policymaking strategies. By analyzing these relationships, resource managers and policymakers can gain valuable insights into the drivers of deforestation and forest degradation, and their impacts on biomass and forest carbon dynamics over time. This holistic approach identifies synergies and trade-offs between different environmental practices, allowing for the development of integrated management plans that promote carbon sequestration while addressing broader sustainability objectives.

By integrating insights from these studies, resource managers and policymakers can develop targeted interventions aimed at mitigating deforestation and promoting sustainable forest management practices. This may include implementing policies to incentivize afforestation and reforestation efforts, enhancing protected area management, and promoting agroforestry and sustainable land use practices. Additionally, the adoption of remote sensing technologies and ecosystem modeling tools can facilitate real-time monitoring of forest carbon stocks and fluxes, enabling adaptive management approaches that respond to changing environmental conditions and human pressures.

The study underscores the importance of adopting a holistic and interdisciplinary approach to forest ecosystem management and carbon sequestration. By understanding the complex relationship between land use, forest dynamics, carbon cycling, resource managers and policymakers can develop evidence-based strategies to safeguard forest ecosystems, mitigate climate change, and promote sustainable development. The institutional arrangements for REDD+ readiness and implementation in Nigeria are still evolving, with ongoing efforts to define and document roles, responsibilities, and institutional linkages at both national and state levels. Additionally, there is a need for enhanced coordination and support to strengthen the technical and institutional capacities of these arrangements, particularly in addressing new technical areas introduced by REDD+.

Key technical areas requiring attention include Social and Environmental Safeguards (SESA) and Environmental and Social Management Frameworks (ESMF), the establishment of reference levels for measuring emissions reductions, monitoring and evaluation (M&E) systems, data management, communication and outreach strategies, benefit-sharing mechanisms, and grievance and redress mechanisms. These areas are critical for ensuring the effective implementation of REDD+ initiatives and achieving the desired outcomes in terms of emissions reductions, forest conservation, and sustainable development. Several studies and reports have highlighted the importance of building institutional and technical capacities for successful REDD+ implementation.

Similarly, studies by organizations such as the Center for International Forestry Research (CIFOR) and the United Nations Development Programme (UNDP) have underscored the importance of addressing governance challenges and building technical capacities to overcome barriers to REDD+ implementation. While progress has been made in establishing institutional frameworks for REDD+ in Nigeria, there is a clear need for further capacity building and technical support, particularly at the state level, to effectively address the complex challenges associated with REDD+ readiness and implementation. Strengthening institutional arrangements, enhancing technical expertise, and promoting stakeholder engagement are essential steps towards realizing the full potential of REDD+ as a mechanism for climate change mitigation and sustainable forest management.

One of the primary challenges facing the NFMS is the lack of adequate hardware and software infrastructure for geospatial analysis and database management of satellite imagery. This includes the absence of robust systems for image processing and data management, which are essential for the accurate monitoring of forest cover change, carbon stocks, and greenhouse gas (GHG) emissions and removals. Without access to reliable hardware and software tools, the ability of the NFMS to generate accurate and timely information about forest resources is severely compromised.

The harmonization of historical data and the updating of Nigeria's National Space Research and Development Agency (NASRDA) country-wide data represent crucial steps toward enhancing the effectiveness of the National Forest Monitoring System (NFMS). By consolidating and standardizing historical data sets, including satellite imagery and other geospatial data, Nigeria can ensure the comprehensive coverage of its forest resources across the entire country. This harmonization process is essential for developing accurate and reliable baseline information on forest extent, composition, and dynamics, which forms the foundation for monitoring and managing forest resources effectively.

Moreover, the expansion of NASRDA's data coverage to encompass the entire country based on a standardized forest definition will facilitate the collation of in-country wood density values. Currently, efforts are underway at various universities in Nigeria to collect wood density data specific to local forest ecosystems. Integrating these localized wood density values into national databases will enable the refinement and improvement of existing Allometric Equations used for estimating forest biomass and carbon stocks. This, in turn, will enhance the accuracy of carbon stock assessments and support more informed decision-making regarding forest management and climate change mitigation strategies.

Institutionalizing a robust data-sharing mechanism among forest stakeholders' institutions is another critical component of strengthening the NFMS. By fostering collaboration and information exchange among government agencies, research institutions, non-governmental organizations, and other relevant stakeholders, Nigeria can maximize the utility of available data and resources for forest monitoring and management purposes. This collaborative approach promotes transparency, accountability, and efficiency in data collection, analysis, and reporting processes, ultimately enhancing the effectiveness of forest governance and conservation efforts.

The harmonization of historical data, expansion of NASRDA's data coverage, and institutionalization of data-sharing mechanisms are essential steps toward enhancing the effectiveness of Nigeria's National Forest Monitoring System. By leveraging these initiatives, Nigeria can improve the accuracy and reliability of its forest data, support evidence-based decision-making in forest management, and contribute to global efforts to combat deforestation, forest degradation, and climate change.

The training of stakeholders at both national and sub-national levels in various key areas is essential for strengthening capacities for demonstration and monitoring within Nigeria's forest sector. Training initiatives should encompass a diverse range of topics, including satellite data interpretation and analysis, accuracy assessment, transition matrix generation, GPS handling and navigation, compass reading, and forest equipment handling. These technical skills are critical for effectively utilizing geospatial technologies and field equipment in forest monitoring activities, such as mapping forest cover changes, delineating forest boundaries, and conducting field surveys.

In addition to technical skills, stakeholders should receive training in plot design and demarcation, data collection protocols, and data processing and analysis techniques specific to estimating tree biomass, carbon stocks, and carbon dioxide equivalent emissions. These skills are essential for conducting forest inventories, quantifying carbon sequestration rates, and assessing the impacts of forest management practices on carbon dynamics. Moreover, capacity-building efforts should focus on enhancing stakeholders' abilities to verify NFMS data, particularly through data quality control measures, to ensure the accuracy and reliability of forest monitoring information.

Technical training in specialized software tools, such as the ALU (Area, Loss, and Use) software, and in technical greenhouse gas (GHG) inventories reporting methodologies under various IPCC (Intergovernmental Panel on Climate Change) guidelines, is also crucial. These software platforms and reporting frameworks provide standardized methodologies and protocols for quantifying GHG emissions and removals associated with forest-related activities, enabling countries like Nigeria to fulfill their reporting obligations under international climate agreements and initiatives, such as the Paris Agreement and REDD+.

Furthermore, community engagement and participation in forest monitoring efforts are vital for the success of REDD+ initiatives and sustainable forest management practices. Training community members in mobile device handling for forest monitoring tasks can empower local communities to actively contribute to data collection, verification, and reporting processes. By equipping communities with the necessary skills and tools, such as mobile data collection applications, Nigeria can foster greater grassroots involvement in forest conservation and management efforts, thereby enhancing the effectiveness and sustainability of REDD+ interventions.

Several studies and reports emphasize the importance of capacity-building initiatives for enhancing forest monitoring and management capabilities. For instance, the UN-REDD Programme's Capacity Development Initiative provides technical assistance and training to support countries in strengthening their capacities for implementing REDD+ activities, including forest monitoring and reporting. Similarly, the FAO's Forest and Climate Change Programme promotes capacity-building efforts to improve countries' abilities to monitor and manage forests in the context of climate change mitigation and adaptation. These initiatives highlight the critical role of capacity development in enhancing the sustainability and effectiveness of forest management practices and climate change mitigation efforts.

7.4 Contribution to Knowledge

i. The research documented the patterns of land use and land cover changes in Southwest Nigeria spanning from 1986 to 2016.
ii. The study has projected the forthcoming trends in land use and land cover dynamics in Southwest Nigeria up to the year 2066.
iii. The research established baseline information on aboveground biomass and carbon stocks in the natural forest and savannah woodland of SW Nigeria.
iv. The study establishes the historical and projected patterns of carbon stock distribution in Southwest Nigeria up to the year 2066.
v. The study has demonstrated the effectiveness of remote sensing in estimating carbon stock in Southwest Nigeria.

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