ASSESSMENT OF THE ABOVEGROUND CARBON STOCK IN THE DISTURBED PART OF KANONGE LOCAL FOREST OF KAPUTA DISTRICT IN NORTHERN PROVINCE, ZAMBIA

BY

AMOS NYIRENDA

A dissertation submitted to The University of Zambia in partial fulfilment of the requirements of the Degree of Master of Science in Environmental and Natural Resource Management

THE UNIVERSITY OF ZAMBIA

LUSAKA

2023

DECLARATION

I, Amos Nyirenda (20019070), hereby declare that this dissertation is my original research and that it has not been previously submitted for the award of any academic qualification at the University of Zambia or any other university. All published work or material from other sources used in this dissertation has been acknowledged, and appropriate citations have been given.

Signature: ……………………… Date: …...……………………

CERTIFICATE OF APPROVAL

This dissertation by Amos Nyirenda has been approved as a partial fulfilment of the requirements of the award of the degree of Master of Science in Environmental and Natural Resources Management by the University of Zambia.

……………………….…… ……………………… …………………..…

Examiner 1 Signature Date

…………………………….. …………….…… ………………..

Examiner 2 Signature Date

……………………………… ……….………. ..…..……………….

Examiner 3 Signature Date

……………………..………. ……………...… ……………...…

Chairperson Board of Examiners Signature Date

……………………………… ……………………… ………………….

Supervisor Signature Date

DEDICATION

I dedicate this work to my family and friends who rendered their help during the time of study.

ACKNOWLEDGEMENTS

I'd like to express my gratitude to Jehovah God for all of the abundant blessings and power that have sustained me during my studies. I'd also like to express my gratitude to Mukuka Kasonde Nyirenda for her unwavering support.

Dr. P.H. Nyanga, my supervisor, deserves special thanks for his time, support, and advice in this research. Thank you for always encouraging me to reach higher.

ABSTRACT

The sequestration and storage of additional atmospheric carbon from anthropogenic sources by forests contribute significantly to the mitigation of climate change. There are several factors that can alter the carbon store in forest ecosystems, some of which change over time, including climatic factors, insect or disease outbreaks, as well as anthropogenic factors. Therefore, by planting, managing, and rehabilitating forests sustainably, forest carbon stocks can be preserved and enhanced. The use of a sequential explanatory design allowed the quantitative data to be collected and analysed first and the qualitative data to be collected and analysed later to explain the variable linkages. As a result, 15 sample plots were used in the forest, 266 households were sampled in villages adjacent to the forest, and 30 key informants were purposively sampled from the Forestry Department and Zambia Forestry and Forest corporations (ZAFFICO). The quantitative data was collected using forest inventories and household surveys, while the qualitative data was collected using key informants' interviews. The allometric equations were used to analyse forest inventory data; logistic regression was used to analyse household survey data; and the key informant interviews were analysed using thematic analysis. The results show that the above-ground biomass and carbon stock were 347.22 t ha^{-1} and 195.81 t ha^{-1}, respectively. The logistic regression results show that forest product use, farm size, household size, and forest clearing were the significant predictors of the aboveground carbon stock loss. The results further reveal that there is inadequate intersectoral coordination at the district and local levels. Further study should be done to find strategies to sustain carbon stocks in the forest while maintaining the use of the forest by the local communities. This study provides accurate estimates of forest and tree carbon stocks and supports the development of the district integrated plan in accordance with decentralized policy. This information can therefore be used at the district and national levels in various carbon programs like REDD+, offering the district the chance to participate in the fight against climate change and global warming.

Keywords: *Aboveground Biomass and Carbon Stock, Kanonge Local Forest, Anthropogenic Factors, Forest Policy, Household Survey*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND

Biomass estimation for tropical forests has received a lot of attention in recent years (Sun and Liu, 2020). For a better understanding of the effects of deforestation and forest degradation on global warming and environmental degradation, accurate biomass estimation is required (Taghavi et al., 2011). Natural forests store a considerable amount of carbon, which is transformed into carbon dioxide and released into the atmosphere when they are removed and burned (Williams *et al.*, 2018). The estimation of forest ecosystem carbon stocks has been a focus of research on the subject of global climate change.

Forests play a crucial role in the global carbon cycle and are major contributors to the mitigation of climate change. In recent years, there has been a growing concern about the negative impact of anthropogenic activities and unsustainable forest management practices on forest carbon stocks ((Kambayi, 2017). Forest degradation and deforestation as a result of human activities such as logging, land-use change, charcoal production, and forest fires have resulted in significant carbon emissions, affecting both the global climate and local ecosystems (Chomba et al., 2014). Estimating the above-ground carbon stock of forests affected by anthropogenic activities and unsustainable management practices is therefore critical in informing forest management, carbon accounting, and climate change mitigation efforts (Tamene *et al.*, 2016).

However, the accurate estimation of above-ground carbon stock is challenging and requires the integration of multiple data sources, models, and techniques. This research aims to investigate the current state of above-ground carbon stock estimation, and assess the impact of anthropogenic and unsustainable forest management practices on the carbon cycle.

1.1 **Statement of the problem**

Despite the crucial role of forests in mitigating climate change, anthropogenic activities and unsustainable forest management practices continue to cause a decline in forest cover and carbon stocks in many regions of the country (Matakala et al, 2015) . The lack of accurate estimation of above ground carbon stock due to anthropogenic activities and unsustainable forest management practices, has led to misinterpretation of the carbon sequestration potential of forests and hinder effective climate change mitigation efforts (Gebeyehu *et al.*, 2019). Furthermore, accurate estimations of the above-ground carbon stocks held within forests is crucial for developing effective strategies for forest conservation and carbon management (Kambayi, 2017).

However, the prevalent situation is that Zambia's forest cover has been declining due to deforestation and degradation caused by unsustainable logging practices, charcoal production, and agricultural expansion (Chomba *et al.*, 2014). Therefore, the loss of forests due to anthropogenic activities such as deforestation and unsustainable forest management regimes has resulted in significant reductions in forest carbon stocks (Vinya *et al.*, 2012).

This has significant consequences for the forest and the global climate, including increased greenhouse gas emissions, loss of biodiversity, and reduced ecosystem services (Giliba et al., 2011). Furthermore, according to forecasts, between 10 and 20 percent of the world's forest area would be converted for other uses by 2050, having a significant impact on the carbon cycle (Karousakis, 2007). While these studies have been carried out at global and national levels, this study is more focused on providing comprehensive data on carbon stocks in the local forest as a result of anthropogenic activities and unsustainable management practices at the district level. It will be possible to make comparisons of the results with previous studies based on a methodology and with practical field-based evidence.

1.2 Aim

The aim of this research is to assess the aboveground carbon stocks in the disturbed part of Kanonge Local Forest.

1.3 Objectives

i. To evaluate the above ground carbon stock in Kanonge Local Forest.
ii. To examine the anthropogenic factors that influence the above ground carbon stocks in Kanonge Local Forest.
iii. To identify the forestry policy implementation challenges that hinder the management of the aboveground biomass in Kanonge local forest.

1.4 Research Questions

i. What is the current status of above-ground carbon stocks in the Kanonge local forest?
ii. What are the main human activities that have influenced the above-ground carbon stocks in Kanonge local forest?

iii. How do forest management regimes influence above-ground carbon stocks in Kanonge local forests?

iv. What are the barriers that hinder the implementation of the forest policy in the management of the above-ground carbon stocks?

1.5 Research hypothesis

The research hypothesis states that the anthropogenic activities have a significant influence on the aboveground carbon stocks in Kanonge local forest.

1.6 Significance of the study

Forests are an essential component in the global carbon cycle which helps regulate the Earth's climate. Anthropogenic activities and unsustainable forest management regimes have negative impacts on carbon removals and emissions from forestlands, which contribute to climate change. The study highlights the importance of sustainable forest management regimes in mitigating climate change by improving carbon sequestration and reducing carbon emissions.

Unsustainable Forest management practices, such as deforestation, result in forest degradation, biodiversity loss and above ground carbon stocks. The study highlights the negative impacts of unsustainable forest management regimes and anthropogenic activities on the ecological values of forests, and highlights the need for effective forest conservation measures.

The study provides valuable information to stakeholders such as policy makers, foresters, and conservationists for developing effective policies to combat anthropogenic activities and unsustainable forest management regimes. It also provides crucial evidence for considering large-scale efforts to reduce greenhouse gas emissions from deforestation and degradation.

Overall, this study highlights the critical importance of adopting sustainable forest management practices in conserving above ground carbon stock, mitigating climate change and promoting sustainable development.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Forests play a critical role in mitigating climate change by absorbing and storing carbon dioxide from the atmosphere. However, deforestation driven by human activities, such as logging, charcoal production, and conversion of forest to agriculture, has contributed to approximately 10-20% of global carbon emissions (Matakala et al, 2015). These activities have resulted in significant losses of above-ground carbon, altering the ecological balance of forest ecosystems. This literature review aims to provide an overview and evaluation of the existing literature on the estimation of above-ground carbon in forests in the context of anthropogenic activities and unsustainable forest management regimes. The review will explore current methods for estimating above-ground carbon, the impact of anthropogenic activities on carbon stocks, and the effectiveness of sustainable forest management regimes in mitigating carbon losses from forests. By synthesizing the available evidence, this review aims to provide insights into how the forest can be managed better to optimize carbon storage and mitigate the impact of anthropogenic activities on the environment.

2.2 Carbon stock estimation models

Carbon estimation models are essential tools for monitoring and managing forest ecosystems and providing critical information to inform policies to mitigate climate change (Kambayi, 2017). However, it is important to use appropriate models that incorporate local site characteristics, species composition, and management practices to obtain accurate carbon estimates. The development of newer models that incorporate multidisciplinary datasets would help in improving accuracy and reducing uncertainties.

2.2.1 Allometric equations

Miombo woodlands are the largest dry forest ecosystem in southern Africa, covering approximately 2.7 million km^2 (Chidumayo et al., 2013). These woodlands are characterized by a high diversity of tree species and a variable tree density, which makes it challenging to estimate their aboveground and belowground biomass and carbon stocks accurately. Allometric equations provide a non-destructive and low-cost method to estimate these parameters, making it possible to develop forest inventories and carbon accounting systems for miombo woodlands.

Kambayi, (2017) developed an Allometric equation that estimates the aboveground biomass density (AGBD, in kg/m^2) of miombo woodlands based on the diameter (D, in cm) and wood density (WD, in g/cm3) of trees. This equation has been applied to estimate AGBD in various miombo woodland locations in southern Africa, such as Zambia, Tanzania, and Mozambique. Kaonga et al., (2010) developed an Allometric equation that estimates the aboveground biomass (AGB, in kg) of miombo woodlands trees based on the diameter at breast height (DBH, in cm). This equation has been used to estimate AGB of individual trees and to inform forest inventories in Zimbabwe and Malawi.

Kalaba et al., (2013) developed an Allometric equation that estimates the belowground biomass (BGB, in kg) of miombo woodlands trees based on DBH (in cm). This equation has been used to estimate total tree biomass and carbon stocks of miombo woodlands in Mozambique and Zambia. Gebeyehu et al., (2019) developed an Allometric equation that estimates the carbon stocks (in t/ha) in miombo woodlands based on AGB (in kg) and wood density (in g/cm3). This equation has been used to estimate the carbon stocks of miombo woodlands in Tanzania and Mozambique.

Despite the usefulness of Allometric equations, there are some limitations and uncertainties associated with their use. For instance, the accuracy of Allometric equations often depends on the tree species and their growth conditions, and not allometric equations have been developed or validated for all the tree species present in miombo woodlands. Additionally, Allometric equations may underestimate the biomass or carbon stocks of large or uncommon trees, such as lianas or thick-barked species.

Despite these limitations, Allometric equations represent a valuable tool for estimating the biomass and carbon stocks of miombo woodlands, which is crucial for developing sustainable forest management practices and informing climate change policies in southern Africa.

2.2.2 Remote sensing-based model

A study by Puliti et al., (2021) used LiDAR data to estimate the aboveground biomass and carbon stocks of miombo woodlands in Tanzania. They found that LiDAR was an accurate and efficient tool for estimating carbon stocks, and could potentially be used for REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiatives. A study by Ene et al., (2017) used SAR data to estimate the aboveground biomass of miombo woodlands in Tanzania. They found that the backscatter signal from vegetation was strongly correlated with biomass, and that SAR offered a cost-effective alternative to LiDAR for estimating biomass.

A study by (Lu, 2006) used MODIS data to estimate the aboveground biomass and carbon stocks of miombo woodlands in Tanzania. They found that MODIS-derived vegetation indices such as NDVI and EVI were good predictors of biomass and carbon, and could be used to monitor changes in miombo woodlands over time. A study by used ALOS data to estimate the aboveground biomass and carbon stocks of miombo woodlands in Mozambique. They found that ALOS-derived canopy height and cover data were good predictors of biomass and carbon, and could be used to support sustainable forest management practices.

A study by (Phiri *et al.*, 2020) used Landsat data to estimate the aboveground biomass and carbon stocks of miombo woodlands in Zambia. They found that Landsat-derived NDVI was a good predictor of biomass and carbon and could be used to monitor deforestation and forest degradation in miombo woodlands.
Overall, these studies demonstrate that LiDAR-based models are highly effective for estimating biomass and carbon stocks in miombo woodlands. These models have the potential to improve forest management and conservation efforts by providing accurate data on forest resources and carbon sequestration rates.

2.2.3 Process-based model

One process-based model for estimating biomass and carbon stocks in miombo woodlands is the "WBE-CBM" model. This model was developed by Janssens et al. (2005) and integrates two different models: the "WBE" model, which estimates tree biomass based on tree diameter and height, and the "CBM" model, which estimates carbon stocks using inputs such as biomass, litter production, and decomposition rates.
The WBE-CBM model has been applied in several studies, including those by Sedano et al., (2022)) in miombo woodlands in Zambia and Malawi. These studies found that the WBE-CBM model was effective in estimating biomass and carbon stocks in miombo woodlands, and highlighted the importance of accurate estimates for effective carbon accounting and conservation efforts.

Ns et al., (2021) conducted a study to determine the suitability of using process-based models to estimate above-ground biomass (AGB) in Miombo woodlands. The authors developed a process-based model used the individual-based forest model called FORMIND to analyse the carbon balance in the miombo woodlands of Niassa Special Reserve (NSR), northern Mozambique. The authors concluded that process-based models are essential tools for estimating biomass in Miombo woodlands due to their ability to incorporate the complex dynamics of this forest ecosystem.

In a similar context, Saito et al., (2014) examined the accuracy of different models for estimating AGB in a Miombo woodland. The model was developed based on observations of tree top kill rates in individual tree size classes for fire intensity and resprouting. The authors found that the inclusion of spatial heterogeneity and remote sensing data in the process-based model significantly improved the accuracy of the AGB estimates.

Process-based models such as the WBE-CBM and FORMIND models have proven effective in estimating biomass and carbon stocks in miombo woodlands and can provide valuable information for conservation and climate change mitigation efforts. However, further research is needed to refine these models and improve their accuracy, particularly in areas with high variability in miombo woodland structure and composition.

2.3 Anthropogenic activities

Anthropogenic activities are a significant threat to the Miombo woodlands in Zambia, affecting above-ground carbon stocks. Wood extraction, agriculture expansion, charcoal production and firewood, have all been identified as contributing factors influencing aboveground carbon stocks in this region.

2.3.1 Wood extraction

Zambia's forests play a crucial role in regulating the global climate by sequestering carbon from the atmosphere. However, the increasing demand for wood products in Zambia has led to extensive logging of forest trees, resulting in the loss of carbon stocks and the deterioration of forest ecosystems (Wathum et al., 2016). Wood extraction is one of the major anthropogenic activities that influence above-ground carbon stocks in Zambia.

Studies have shown that wood extraction has a significant impact on above-ground carbon stocks in Zambia. For instance, a study by (Chidumayo et al., 2013)found that selective logging of trees had a negative impact on above-ground carbon stocks in the forest. Similarly, a study by (Giliba et al., 2011) found that logging activities in Zambia led to a net loss of carbon stocks in the forest.

Furthermore, wood extraction has led to the conversion of forests and woodlands into agricultural land, resulting in further loss of carbon stocks (Vinya *et al.*, 2012). The increasing demand for wood and agricultural expansion has also led to the degradation of forest ecosystems and the loss of biodiversity (Chidumayo et al., 2013).

Another study by (Matakala et al, 2015) found that timber extraction was also a significant contributor to deforestation in the Miombo woodlands. The study found that illegal logging for timber extraction was the primary cause of forest loss, leading to a decline in above-ground carbon stocks

Despite the extensive research on the impacts of wood extraction on above-ground carbon stocks in Zambia, little attention has been given to the impact of other anthropogenic activities, such as charcoal production, on carbon stocks. Charcoal production is a major source of energy in Zambia, with over 90% of households relying on charcoal for cooking and heating (Wathum et al, 2016). However, charcoal production has been associated with deforestation, soil degradation, and loss of carbon stocks (Vinya *et al.*, 2012). As such, there is a gap in understanding the extent to which charcoal production influences above-ground carbon stocks in Zambia. Future research should focus on the impact of charcoal production on carbon stocks in Zambia.

2.3.2 Agricultural expansion

Chomba et al., (2014) investigated the influence of land use change on above ground carbon stocks in the miombo woodland savannah of Zambia. The study found that agricultural expansion had a significant impact on above ground carbon stocks, with a loss of up to 20 tC/ha in some areas. The study concluded that there is a need for policies and practices that promote sustainable land use to mitigate the impacts of agricultural expansion on above ground carbon stocks.

Another study byHandavu et al, (2019) focused on the impact of land use on carbon stocks in Zambia's miombo woodlands. The study found that agricultural expansion resulted in a significant loss of above ground carbon in the miombo woodlands. The study recommended the promotion of sustainable land use practices to mitigate the loss of above ground carbon in agricultural expansion areas.

A study by Lembani et al., (2020) explored the relationships between land use, carbon stocks, and tree diversity in Zambia. The study found that agricultural expansion had a significant negative impact on above ground carbon stocks, with a loss of up to 15 tC/ha. The study suggested that the promotion of sustainable land use practices should be prioritized, especially in areas where agricultural expansion is high.

A study by Kazungu et al., (2021) evaluated the impacts of land use change on carbon stocks in Zambia. The study found that agricultural expansion had a significant impact on above ground carbon stocks, with a loss of up to 12 tC/ha. The study also recommended the implementation of sustainable land use practices to mitigate the negative impacts of agricultural expansion on above ground carbon stocks.

While the studies reviewed here provide significant insight into the impact of agricultural expansion on above ground carbon stocks in Zambia, there is a gap in the literature. None of these studies specifically examined the impact of agricultural expansion on the contribution of soil organic carbon to the above ground carbon stock. This is an important area of inquiry, as soil organic carbon is a major contributor to the above ground carbon stock in Zambia's miombo woodlands. Further research is needed to determine the extent to which agricultural expansion in Zambia affects the contribution of soil organic carbon to above ground carbon stocks.

Studies reviewed demonstrate that agricultural expansion has a significant impact on above ground carbon stocks in Zambia. Sustainable land use practices are essential for mitigating the negative impacts of agricultural expansion on above ground carbon stocks. However, more research is needed to investigate the impact of agricultural expansion on the contribution of soil organic carbon to above ground carbon stocks.

2.3.3 Charcoal production

Charcoal production is an important source of energy for millions of people in Zambia, but it also has negative impacts on above ground carbon stocks. This literature review explores the impact of charcoal production on above ground carbon stocks in Zambia and identifies gaps in the existing literature.

One study by Matakala, et al, (2015) investigated the impact of charcoal production on above ground carbon stocks in Zambia's miombo woodlands. The study found that charcoal production had a negative impact on above ground carbon stocks, with a loss of up to 20 tC/ha in some areas. The study recommended the promotion of sustainable charcoal production practices to mitigate the negative impacts on above ground carbon stocks.

Another study by Wathum et al, (2016) explored the contribution of charcoal production to deforestation in Zambia. The study found that charcoal production was a significant driver of deforestation in Zambia, which in turn led to a loss of above ground carbon stocks. The study recommended the implementation of policies that promote sustainable charcoal production and alternative sources of energy. According to a study by Vinya et al., (2012), charcoal production is the most significant driver of deforestation in the Miombo woodlands of Zambia. The study found that charcoal production accounted for approximately 53% of the total forest loss.

A study by Deuteronomy et al, (2019) investigated the impact of charcoal production on above ground carbon stocks and soil fertility in Zambia's miombo woodlands. The study found that charcoal production had a negative impact on above ground carbon stocks, with a loss of up to 25 t C/ha. The study also found that charcoal production led to a decrease in soil fertility, thus affecting the regeneration of miombo woodlands. The study recommended the implementation of sustainable charcoal production practices to mitigate the negative impacts on above ground carbon stocks and soil fertility.

While the studies reviewed here provide significant insight into the impact of charcoal production on above ground carbon stocks in Zambia, there is a gap in the literature. None of these studies specifically examined the impact of charcoal production on the contribution of soil organic carbon to the above ground carbon stock. Soil organic carbon is an important component of the above ground carbon stock, and charcoal production has been shown to affect soil fertility. Further research is needed to determine the extent to which charcoal production in Zambia affects the contribution of soil organic carbon to above ground carbon stocks.

Studies reviewed demonstrate that charcoal production has a significant impact on above ground carbon stocks in Zambia. Sustainable charcoal production practices and the promotion of alternative sources of energy are necessary to mitigate the negative impacts on above ground carbon stocks. However, more research is needed to investigate the impact of charcoal production on the contribution of soil organic carbon to above ground carbon stocks.

2.3.4 Firewood

One study by (Kamwi *et al.*, 2015) investigated the impact of firewood use on above ground carbon stocks in the miombo woodlands of Zambia. The study found that firewood harvesting had a negative impact on above ground carbon stocks, with a loss of up to 15 t C/ha in some areas. The study recommended the promotion of alternative energy sources to mitigate the negative impacts on above ground carbon stocks. Another study by Deuteronomy et al, (2019) explored the impact of deforestation on above ground carbon stocks in Zambia. The study found that firewood harvesting was a major driver of deforestation in Zambia, which in turn led to a loss of above ground carbon stocks. The study recommended the implementation of policies that promote sustainable firewood harvesting and alternative sources of energy.

A study by Wathum et al, (2016) investigated the impact of firewood harvesting on above ground carbon stocks and biodiversity in Zambia's miombo woodlands. The study found that firewood harvesting had a negative impact on above ground carbon stocks, with a loss of up to 12 t C/ha. The study also found that firewood harvesting led to a decrease in biodiversity, which further affected the health of miombo woodlands. The study recommended the implementation of sustainable firewood harvesting practices to mitigate the negative impacts on above ground carbon stocks and biodiversity.

While the studies reviewed here provide significant insight into the impact of firewood use on above ground carbon stocks in Zambia, there is a gap in the literature. None of these studies specifically examined the impact of traditional cooking practices on above ground carbon stocks. Traditional cooking practices typically involve the use of three stones or simple stoves which consume firewood at a faster rate thereby demanding for more, which may have different levels of impact on above ground carbon stocks compared to modern stoves. Further research is needed to determine the extent to which traditional cooking practices in Zambia affect above ground carbon stocks.

Studies reviewed have shown that firewood harvesting has a significant impact on above ground carbon stocks in Zambia. Alternative energy sources and sustainable firewood harvesting practices are needed to mitigate the negative impacts on above ground carbon stocks. However, more research is needed to investigate the impact of traditional cooking practices on above ground carbon stocks in Zambia.

2.4 Forest management practices

Forest management regimes in Zambia involve the sustainable management and utilization of forest resources to cater to the needs of both present and future generations (Matakala et al., 2015). The government of Zambia has adopted various policies and legislations that govern the management of forest resources in the country. These policies and legislations are aimed at promoting sustainable forest management practices, conserving biodiversity, and enhancing the livelihoods of local communities (Ministry of Lands & Natural Resources, 2018).

One of the key policies implemented by the government is the National Forestry Policy, which outlines the objectives and principles that guide the management of forest resources in the country. The policy promotes the use of participatory approaches in forest management, whereby local communities are actively involved in decision-making processes (Maxwell et al, 2009). These measures include the promotion of tree planting, the establishment of agroforestry systems, and the enforcement of regulations to prevent illegal logging and trade in forest products.

The forest management regimes in Zambia are aimed at promoting sustainable forest management practices, conserving biodiversity, and enhancing the livelihoods of local communities.

2.4.1 Joint Forest management

According to Bwalya et al., (2015), Joint Forest Management (JFM) is a collaborative approach in forest protection that involves the participation of forest-dependent communities and government entities. In Zambia, JFM's evolution began when the Forest Act was amended in 1999, paving the way for the implementation of community-based forest management (CBFM) and Joint Forest Management (JFM) (Kokwe, 2012).

The successful implementation of JFM depends on the level of community participation in decision-making processes related to forest management (Bwalya et al., 2015). The participation of communities in JFM programs has been shown to improve forest conservation efforts in Zambia (Matakala et al, 2015).

Leventon et al., (2014), found that JFM has contributed to improved forest governance in Zambia through the promotion of community empowerment, the creation of rules and regulations for forest resource use, and the establishment of mechanisms for revenue sharing. The study further noted that the success of JFM may be attributed to a diverse range of factors, including political commitment, effective stakeholder coordination, and the establishment of strong monitoring and evaluation frameworks.

Although JFM has shown promise in improving forest management in Zambia, certain challenges exist. Bwalya et al., (2015) noted the lack of adequate human and financial resources to support

JFM programs, limited community participation due to the perception that these programs are government-driven, and a lack of clear legal and regulatory frameworks guiding JFM implementation.

Joint Forest Management has the potential to improve forest conservation efforts in Zambia through collaborative approaches involving forest-dependent communities and government entities. However, there is a need for an enabling environment that promotes community participation and provides adequate resources for the successful implementation of JFM programs.

2.4.2 Community Forest management (CFM)

Community Forest Management (CFM) is an approach to forest management based on local communities' involvement in forest preservation and management activities. The National Forestry Policy, 2014, the Forests Act, 2015 (specifically sections 29 to 35) and the Regulations on Community Forest Management, 2018, combined with the Government policy of promoting decentralisation, provide the policy, legal and institutional basis for greater community involvement in forest management (Ministry of Lands & Natural Resources, 2018) .

Several studies have evaluated the effectiveness of CFM programs in Zambia. For instance, (Jumbe et al., 2018) found that CFM programs have contributed to sustainable forest management through the promotion of community participation, improved rule-making processes for forest management, and strengthened monitoring and evaluation mechanisms.

Similarly, a study by (Kalaba, 2016) established that CFM has been instrumental in promoting community participation in forest management activities and empowering local communities to manage their forest resources sustainably. The study also pointed out that the success of CFM programs depends on the development of strong institutional arrangements, effective communication channels, and the provision of adequate financial and technical support.

However, challenges to the implementation of CFM programs in Zambia have also been documented. For instance, (Zulu, 2016) highlighted a lack of clarity in the legal and policy framework guiding the implementation of CFM programs, inadequate mechanisms for revenue sharing, and limited access to appropriate technologies and financial resources.

CFM programs have shown potential in enhancing sustainable forest management and community livelihoods in Zambia. Still, there is a need for an enabling environment that promotes effective community participation, strengthens institutional frameworks, and provides adequate financial and technical support to ensure their successful implementation.

2.4.3 Private Forest

Private forest management is an important aspect in the maintenance of forest reserves, timber production, and carbon sequestration. In Zambia, private forest management is performed by the Forest Stewardship Council (FSC), an international organization that promotes sustainable forest management (Kalinda *et al.*, 2008). Private forest management practices in Zambia have gained attention in recent years due to the need for conservation and sustainable utilization of natural resources (Kalinda *et al.*, 2008). Thus, this literature review aims to provide an overview of the current state of private forest management in Zambia. According to (Kalinda *et al.*, 2008), private forest management in Zambia faces several challenges, such as limited financing, inadequate policy frameworks, lack of awareness on forest management, and inadequate institutional capacity. The authors argue that these challenges can be mitigated through proper financing mechanisms, institutional strengthening, and awareness campaigns.

In a similar vein, Karsenty et al, (2012) contend that private forest management requires effective legal frameworks, stakeholder participation, and technical capacity building to ensure sustainability. The authors further argue that institutional collaboration among various stakeholders can improve private forest management in Zambia.

Several studies have highlighted the potential of private forest management in mitigating climate change. For instance, (Kalaba, 2016) argue that private forest management can contribute to carbon sequestration, thus reducing the carbon footprint of the country. Additionally, private forest management can promote sustainable wood and non-timber forest product production, which can support the livelihoods of local communities.

Private forest management in Zambia faces numerous challenges, but there is potential for sustainable forest management, carbon sequestration, and livelihood support. To achieve these goals, effective legal frameworks, institutional strengthening, stakeholder participation, technical capacity building, and awareness campaigns are required.

2.5 Barriers in policy implementation in forest management

Carbon stocks and their management have become more critical topics in recent years due to the recognition of their impact on climate change mitigation (Ngoma *et al.*, 2021). Zambia's forest policy offers a framework for the management of carbon stocks. However, it does not specifically target above-ground carbon stocks, which restricts Zambian forest managers from focusing on specific management strategies that could increase above-ground carbon stocks (Karsenty et al, 2012). Furthermore, there is inadequate institutional support for the implementation of the policy to manage the carbon stocks effectively (Ongolo, 2015).

Zambia became a member of REDD+ in 2010, a UN program that aims to manage and reduce carbon emissions (Ministry of Lands and Natural Resources and Ministry of National Development Planning, 2019). In this program, Zambia aims to manage its carbon stocks by conserving its forests. However, the need for improved infrastructure, training of the local communities in sustainable agriculture, and the lack of involvement of the local communities in REDD+ program implementation is slowing progress (Ngoma et al, 2018)

Illegal logging and charcoal production are recognized as serious concerns in Zambia. The lack of clear policy direction on identifying, controlling, and enforcing regulations on illegal logging, and charcoal production in Zambia has led to a loss of large amounts of carbon stocks (Handavu et al, 2019)). A lack of understanding of the value of carbon stocks and limited enforcement mechanism have enabled this illegal activity (Chinasho, 2015).

Enhancing the capacity of personnel in the forestry sector is a critical challenge in Zambia. Training of personnel in forestry practices and management, monitoring of above-ground carbon stocks, and enforcement of regulations is fundamental in Zambia's management of its above-ground carbon stocks. The capacity is limited in local communities, charities, and the government (Kalaba, 2016).

Overall, the existing literature points to the need for significant action in tackling the problems related to policy implementation in management of above-ground carbon stocks. The current literature available, however, is limited in scope and scale due to the nation's regional context. Further research could focus on identifying suitable mechanisms and stakeholder partnerships to implement control policies efficiently and explore the potential of alternative livelihoods, such as ecotourism, to combat illegal logging and the unsustainable utilization of charcoal and timber

(Kalinda *et al.*, 2008)). Zambia seems to have taken significant steps in forest policy. However, a lack of specificity in above-ground carbon stocks, illegal logging, limited capacity building, insufficient institutional support, and the need for socio-environmental factors complicates the implementation of policy. Consequently, there is a need for further research and collaboration among stakeholders to come up with interventions that enhance Zambia's capacity to have a sustainable and legal system of land use and forest management.

2.5.1 Resource limitation

Several studies have evaluated the effects of resource limitations on forest management in Zambia. According to Kalinda et al., (2008), the lack of financial resources has resulted in an inadequate workforce, leading to a shortage of trained personnel with requisite skills to manage the forests. Additionally, the same authors noted that resource limitations have hindered the ability of forest managers to implement sustainable forest management practices.

Moreover, (Ngoma *et al.*, 2021) highlighted that resource limitations have also affected the development of forestry policies in Zambia. The authors argued that policymakers had failed to prioritize financial and human resource allocation towards forest conservation and management, leading to ineffective policy implementation. Similarly, Karsenty et al, (2012) noted that resource limitations such as financial constraints, inadequate technical expertise, and poor infrastructure had impacted community participation in forest management initiatives.

However, there is a gap in the literature regarding the impact of resource limitations on the integration of traditional and modern forest management practices in Zambia. Although some authors have noted the importance of using traditional knowledge to supplement modern forest management practices none of these studies has examined how resource limitations may affect the integration of these practices.

Resource limitations, such as financial constraints, a lack of skilled personnel, and inadequate infrastructure, have negatively impacted forest management and conservation efforts in Zambia. Although some studies have explored the effects of these limitations on forest management, the literature lacks research on the integration of traditional and modern forest management practices in the country, indicating a research gap.

2.5.2 Socio-economic factors

Several studies have examined the socio-economic factors that limit the management of forests in Zambia. For instance, Ongolo, (2015) identified poverty as a significant barrier to sustainable forest management in the country. The authors argued that many Zambians who rely on forest resources for their livelihoods lack alternative income-generating opportunities, thereby contributing to illegal logging and other unsustainable forest practices.

Similarly, Ngoma et al., (2018) observed that lack of tenure security was a significant socio-economic barrier to sustainable forest management in Zambia. The authors noted that unclear land tenure systems and land use policies resulted in conflicting interests between different stakeholders leading to degradation of forests.

Additionally, Chinasho, (2015) highlighted that social and economic factor such as infrastructure, access to markets and information, and inadequate funding have negatively impacted community-based forest management efforts in Zambia. According to the authors, disadvantaged households lacked the resources necessary to participate in forest management initiatives, thereby affecting the effectiveness of community-based forest management approaches.

However, there is a gap in the literature regarding the interaction between social-economic factors and gender in the management of forests in Zambia. While several studies have explored gender issues in forest management, few have examined how social-economic factors may affect gender roles, responsibilities, and opportunities in sustainable forest management initiatives.

Socio-economic factors are significant barriers to the management of forests in Zambia, including poverty, lack of tenure security, and inadequate funding. While several studies have examined these factors, more research is necessary to understand the interaction between social-economic factors and gender dynamics in sustainable forest management initiatives.

2.5.3 Technical matters

Several studies have examined the technical barriers impacting forest management efforts in Zambia. For instance, (Ngoma et al, 2018) noted that the lack of technical expertise in monitoring and controlling forest fires impeded forest management initiatives. The authors highlighted the need for technical training and capacity building to improve fire management in the country.

Similarly, Kalinda et al., (2008) identified inadequate technical equipment and machinery as significant technical barriers to forest management. The authors noted that limited access to equipment such as chainsaws, vehicles, and communication equipment hindered forest managers' ability to carry out monitoring and protective measures effectively.

Moreover, observed that insufficient technical knowledge in forest restoration efforts had resulted in ineffective restoration initiatives in Zambia. The authors argued that successful restoration programs required a blend of technical knowledge in forestry, ecology, and land management to ensure the effective regeneration of degraded forests.

However, there is a gap in the literature regarding the role of emerging technologies such as remote sensing, geographic information systems (GIS), and unmanned aerial vehicles (UAVs) in facilitating sustainable forest management in Zambia. While several studies have examined the use of these technologies in forest management globally, few have explored their application in Zambia.

Technical matters such as inadequate technical knowledge, equipment, and machinery are significant barriers to sustainable forest management in Zambia. While several studies have examined these technical barriers, more research is necessary on the potential of emerging technologies in improving forest management in the country.

2.5.4 Legal and institutional barriers.

One of the major legal barriers to effective forest management in Zambia is the lack of clear, comprehensive and coordinated forestry laws and policies (Kamwi *et al.*, 2015)). The existing legislation is fragmented and inconsistent, and there is a lack of clear guidelines for implementation, monitoring, and enforcement (Ngoma *et al.*, 2021). Such legal inadequacy makes it difficult to regulate and manage the forest resources effectively. Thus, improved forestry laws and policies could contribute to better forest management practices.

Another institutional challenge to forest management in Zambia is the lack of institutional capacity and resources for managing forest resources. There is a need to strengthen forestry institutions such as the Forestry Department in terms of staffing, knowledge, skills, and budgetary resources (Chirwa & Syampungani, 2012). Furthermore, the various stakeholders involved in forest management, such as rural communities, traditional leaders, and government agencies, have different perceptions of forest management roles and responsibilities, which could create conflict (Kalaba, 2016). A more coordinated approach to forest governance is needed to ensure effective and sustainable forest management.

The lack of participation in forest management also poses a challenge in Zambia. The law provides for community participation in the management of forest resources (Kalinda *et al.*, 2008), but often this participation is limited and opportunities for stakeholder involvement are not always accessible. This can lead to a lack of ownership and responsibility for forests by local communities, thereby increasing the risk of overuse, degradation, and deforestation (Schielein et al, 2018). Therefore, a participatory approach to forest management that includes all stakeholders, particularly local communities, is necessary for sustainable forest management.

However, it is notable that most of the literature on forest management in Zambia focuses primarily on the challenges without providing much empirical evidence-based solutions to the challenges. A significant gap exists in terms of practical solutions for improving forest management in Zambia. Research that identifies effective measures for improving forest governance and management practices that address the regulatory, institutional, and socio-economic constraints of local communities is necessary. Furthermore, most of the current literature focuses on the challenges, thus obscuring the conjunctures where forest governance efforts in Zambia have been successful.

This literature review has highlighted the legal and institutional challenges that hinder effective forest management in Zambia. The review emphasized the need for comprehensive and coordinated forestry laws and policies, strengthened institutional capacity, increased stakeholder participation, and a more participatory approach to forest management, particularly in the context of local communities. Furthermore, the identified gap is the lack of empirical-based solutions to the challenges and limited exploration of successful forest governance efforts in Zambia, hence the necessity for further research.

CHAPTER THREE: DESCRIPTION OF THE STUDY AREA

3.1 Introduction

This chapter describes the physical and socio-economic characteristics of the study area. It describes the location, physical characteristics, social and economic activities, and the reasons for choosing the study area.

3.2 Location of the study area

Kaputa District is situated in the extreme of the north of the Northern Province, about 1030km form Lusaka at about 8°28'26.97"S south latitude and 29°40'12.65"E longitude. The area extent of the location of the study area is 29,100 hectares while area of interest covers 4,000 hectares (Figure 1). The international border with Congo DR is about 13 kilometres north of the central business development (CBD). It shares administrative boundaries with Mporokoso, Kawambwa and Nsama respectively.

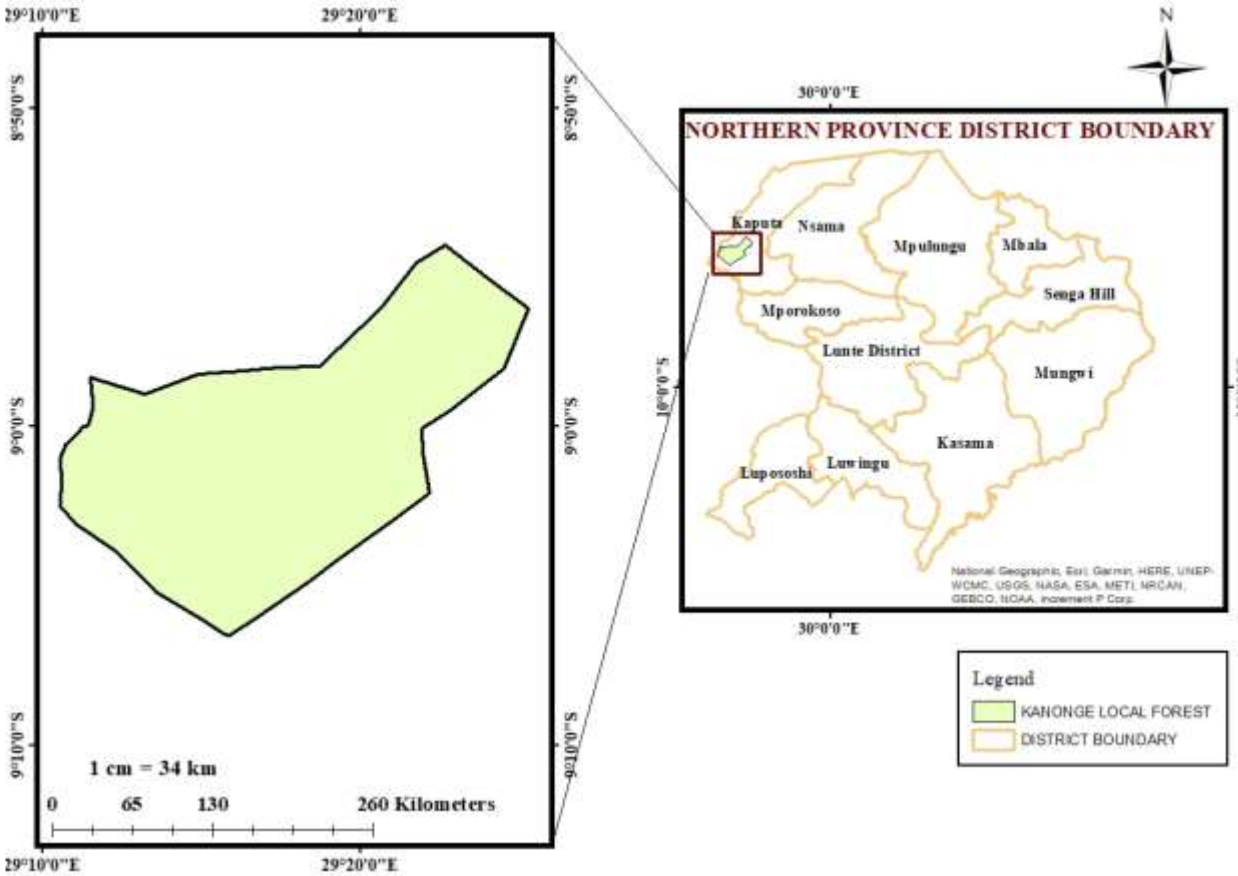

Figure 1: Location of the study area

3.3 Physical characteristics

3.3.1 Rainfall and temperature

The location of the study area has a range of minimum temperature is 5°C to 14°C, with a maximum temperature of 30°C to 34°C, the hottest month is October, while the coldest month is July (World Agroforestry Centre, 2012). Rainfall in the study area is caused by the Inter-Tropical Convergence Zone, which is created by the convergence of the North-east and South-east Trades (ITCZ). Smith, (2012) added that, the rainy season lasts about seven months, from October to April, with the wettest months being December, January, and February, and the driest months being October and April. The annual rainfall in the region varies between 1,000 and 2,000 mm (Musonda et al., 2013).

3.3.2 Soils and geology

The geology of the study region represents a Precambrian to early Paleozoic rock formation in Zambia (Japan International Cooperation Agency, 1995). Furthermore, in Kaputa, the Kibaran system's Precambrian basement complex consists of quartzites, grits, phyllites, slates, and schists. The location of the study area's rocks can also be found in Luapula and parts of Northern Province (Barry, 2016). These are divided into three classes, each with a distinct sequence that runs across the research field. Conglomerates, sandstones, and quartzites make up the lowest of the three, which is mostly arenaceous (Nyambe et al., 2010). The second and upper group consists of dolomites, shales, and limestone with thin sandstone beds, while the uppermost group consists of inter-bedded dolomites, shales, and limestone.

The rock groups have been structurally folded, resulting in a sequence of north-west/south-east trending anticlines and synclines that plunge to the north-west (Harrison' *et al.*, 1998). The higher parts of these systems were eroded away, and the sedimentary rocks are now represented by a series of Pedi-plains made up of synclinal basins and anticlines.

3.4 Social economic characteristics

The residents of Kaputa depend heavily on agricultural and fishing operations, as well as the collection of non-wood forest products, for their livelihood (World Agroforestry Centre (ICRAF)., 2012). The main crops grown in the region are maize (*Zea mays*) and cassava (*Manihot esculenta*). Groundnuts (*Arachis hypogaea*), beans (*Phaseolus vulgaris*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), and sweet potatoes (*Lopmoea batatas*) are among the other crops grown in small to medium quantities (Smith, 2012). While livestock is a source of income, it is only practiced on a small scale. Goats, pigs, chickens, and ducks are among the most commonly reared animals. Caterpillar, Masuku, honey, and mushroom selection are some of the people's off-farm income-generating practices. Forestry, charcoal processing, and reed collection are some of the other economic activities.

Forestry services, in general, are critical to the needs of households in the study area since they can be used for a variety of purposes, including food, fuel wood, charcoal, medicines, poles, dyes, and paints. These goods help to support the district's economy.

Another important economic activity in the study area is transportation, which is divided into three groups (Government of the Republic Zambia, 2005). The first form of transportation is motorized, which involves taxis and medium trucks. The bicycle is the second mode of transportation, followed by the water transport, which is used to transport agriculture produce, charcoal, firewood, and forest fruits from the study area to the other side of the river for sale.

3.5 Vegetation of the location of the study area

The Miombo type of vegetation, which extends into Zambia's northern area, is another characteristic of agroecological region III (Zulu, 2016). Therefore, the study area is part of this region, where Miombo woodland predominates in the northern districts of zambia, according to Chomba et al., (2014).

According to Ryan et al., (2012), the miombo is the most prevalent forest habitat type and formation in southern Africa. The majority of the forest in Zambia is miombo woodland, which makes up around 45% of the country's total land area (Stringer et al., 2017). According to Chidumayo et al., (2013), the provision of firewood, charcoal from miombo woods is significant for Zambia's economy. The dominant species include important species like *Brachystegia spiciformis,* and are represented by the genera Brachystegia, Isoberlinia, and Julbernardia., *B. boehmii*, *Julbernardia globiflora*, *J. paniulata*; and *Isoberlinia angolensis* as well as the dipterocarp, *Marquesia macroura.* Miombo woodland often has two stories and a 15–21 m–high open canopy. Species including *Dalbergia nitidula, Brachystegia stipulata, Anisophyllea boehmii*, and *Albizia antunesiana* can be found in the lower storey.

3.6 Reasons for choosing the study area

In zone III of the agricultural ecological region (Zulu, 2016), the study was undertaken in Kaputa District in Northern Province. The district is dominated by Miombo woodland and the most predominant species are *Pterocarpus angolensis, Brachystegia Spp, Afzelia quanzensis (Mupapa), Erythrophlem africanum, Faurea saligna, Khaya anthotheca and Mitragyna stipulosa.* Most of these tree species are at high risk because of their high economic value and the demand for charcoal, timber for construction, carpentry and joinery works (Chomba *et al.*, 2014) . Land in this zone is relatively abundant and shifting cultivation (slash and burn) is widespread in some areas. Selection of this areas was based on the timber harvesting, shifting cultivation and charcoal production activities taking place in the areas.

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This chapter discusses the methodological underpinnings of the methods used in this study, as well as the reasons for using them. The research approach, sampling strategies, data collection methods, and data analysis methods are all described in detail**.**

4.2 Philosophical basis of the study

This study employed a pragmatic approach as a philosophical basis for mixed-methods studies. Pragmatism allows for the employment of a wide range of techniques, worldviews, and assumptions, as well as various data collection and analysis methods and provides for quick changes in methodological techniques in response to uncertainty and to fit the obtaining situations as closely as possible while retaining quality (Creswell & Plano, 2017). Furthermore, it emphasizes practicality, usefulness, and results-oriented approach in the study. It suggests that knowledge and theories should be judged based on their practical value and impact on real-world situations, rather than their coherence with abstract concepts or metaphysical principles (Brierley, 2017).

Therefore, this helped the study to employ a wide range of data collection and analysis methods such as the forestry inventories, semi structured as well as key informant interviews. Further, allometric equations, descriptive statistics and thematic analysis were used as data analysis methods.

It also helped the study to focus on the practical implications of unsustainable forest management regimes and anthropogenic activities on above ground carbon stocks and aim to provide solutions. The implications have a far-reaching impact on the environment such as deforestation, land-use change, and forest degradation significantly contribute to greenhouse gas emissions, thus, exacerbating climate change.

Forests provide numerous economic benefits such as timber production, ecotourism, and the provision of non-timber forest products like honey and medicinal plants. Unsustainable forest management and anthropogenic activities such as illegal logging, fuelwood harvesting, and land-use conversion adversely affect these benefits, leading to significant economic cost.

4.2.1 Research design

The study used mixed methods procedures to answer the study research questions (Creswell and Vicki, 2011), which is a procedure for collecting, analysing, and mixing or integrating both quantitative and qualitative data at some stage of the research process within a single study. Creswell, (2009) posited that, the reason for combining quantitative and qualitative data is that neither quantitative nor qualitative methods are sufficient in and of itself to capture the trend and details of situations like carbon stock assessment in the local forest. Quantitative and qualitative approaches complement each other and create a fuller picture of research problems when utilized together (Ivankova, 2014).

The above ground carbon stock estimates and anthropogenic activities play a crucial role in informing forest management regimes in sequential explanatory design. This is because understanding the current carbon stock of a forest is important for developing a sustainable forest management plan that takes into account the impact of human activities on the forest ecosystem.

Anthropogenic activities, such as logging and agriculture, can have an impact on the above ground carbon stock of a forest. For example, deforestation and clear-cutting can result in a significant loss of carbon stored in trees and soil. By analysing the above ground carbon stock estimates and anthropogenic activities, forest managers can identify areas that are at risk of carbon loss and develop strategies to mitigate these impacts.

In sequential explanatory design, data was collected and analysed over time to create a comprehensive understanding of the forest. By incorporating above ground carbon stock estimates and anthropogenic activity data into this process, forest managers can develop more effective forest management plans that are based on real-world data and take into account the impact of human activities on the forest ecosystem.

For example, forestry managers could use the above ground carbon stock estimates to guide the timing and intensity of logging activities. By selectively harvesting trees with lower carbon stocks, they can reduce the impact of logging on the carbon stock of the forest. Furthermore, by analysing anthropogenic activities, forest managers can also identify areas that are at risk of degradation and take appropriate measures to limit the damage.

The above ground carbon stock estimates and anthropogenic activities are essential pieces of information that inform the forest management regimes in sequential explanatory designs. This data enables forest managers to make informed decisions that strike a balance between economic prosperity and environmental sustainability.

4.3 Sampling techniques

Mixed sampling methods were used in this study, (Kumar, 2011) argue that there are two types of sampling techniques: probability sampling and non-probability sampling. The authors argue that mixed methods studies usually necessitate the use of two types of samples and that this is sufficient in circumstances where mixed methods studies are related to two specific objectives. As a result, if a researcher wants to use quantitative data in a qualitative context, they must maintain a sufficient sample in order to make conclusions based on the quantitative data, and vice versa (Creswell and Clarck, 2011). In this study, probability and non-probability sampling approaches were used.

4.4 Systematic random sampling

To conduct a systematic random sampling method, the sample size or the sampling units was first calculated using. The number of sampling units required to produce an estimate of the mean with a specified acceptable error and probability was calculated using the following formular;

$$n = \frac{t^2 (\mathrm{CV})^2}{(E\%)^2}$$

Where the CV refer to the coefficient of variation of a preliminary sample was calculated by dividing the standard deviation by the sample mean which gave 39 indicated the variability of the population. *E* is an arbitrarily chosen level (often *E* was set at 20% because the forest inventory was being done in a natural forest where the variation is greater as compared to a single stand) and the *t*-value depends on the required probability (also was arbitrarily set at 2), where *n* refers to the number of sampling units in the preliminary sample which was calculated using the above formular giving 15 sample plots.

A systematic random sampling technique was used in this study. To determine the sampling frame, a map of the complete forest area was obtained from Forest Department and the area of interest obtained using the coordinates and converted into square grids of appropriate size to create the sampling frame. To determine the distance between sample plots when using systematic sampling, the formula was used:

d = A / n^-sqrt2

Where:
d = Distance between sample plots

A = Total area of the forest (4000 hectares)

n = Number of sample plots (15)

√2 = Square root of 2

Substituting the values, we get:

d = 4000 / 15^-sqrt2

d = 4000 / 3.87

d = 1033.6 meters

Therefore, the distance between the sample plots when using the systematic sampling method was approximated at 1033.6 meters which gives an area of 107 ha. Therefore, to get the total number of grids (*N)*, 107 ha was divided in to 4000 ha which gave N = 37. Furthermore, the number of grids was typically more than that of the sample plots. Grids were numbered from 1 to *37*.

To draw a systematic sample of size n from the forest, numbers between 1 and *37* are simply assigned to the grids. The sampling interval k was calculated using k = N/n where $N = 37$, $n = 15$, which gives k = 2 To locate the first sample unit, a random number nr between 1 and 2 was chosen. The second unit is (nr + k), the third is (nr + 2k), and so on until the required sample size was obtained.

Systematic sampling method was used because it provides the benefit of randomization within a defined pattern, which reduces the likelihood of bias in the samples. A random starting point was chosen, and subsequent trees were selected at a regular interval, ensuring that each tree in the population has an equal chance of being selected. Since systematic sampling covers the entire population of trees, it led to cost savings in comparison to other methods that require the measurement of all trees within a sample plot. Also ensured that results are more repeatable, and the same method can be employed in different areas of the forest. This can result in reliable and consistent data. Furthermore, it provided an unbiased estimate of forest resources, resulting in a more accurate estimate of forest conditions. This can help forest managers to make better decisions and manage forest resources more effectively. Overall, systematic sampling is a valuable method in forest inventory because of its efficiency, cost-effectiveness, and accuracy in estimating forest resources.

4.5 Simple random sampling

The villages adjacent to the forest were identified in order to get information from households that actually depend on the forest as well as assess how closely communities are related to the forest reserves and the resource use patterns that go along with them. This is supported by (Handavu et al., 2019) that people who live close to a forest reserve prefer to interact with it more regularly and deeply.

A total of 776 households were counted from the identified households. The number of participants required for the study was calculated using the software calculator G-Power. In order to do that, the effect size, alpha level, power, and population size were identified. A medium effect size of 0.5, an alpha level of 0.05, and a power of 0.80 were identified. This is how the sample size was calculated using G-Power: The ‘t-test ‘was selected from the left-hand panel of G-Power software. In the next window, ‘One-Sample t-test’ was selected, a sample size of zero under ‘Groups’ was entered, ‘A priori' was selected under ‘Type of power analyses," and the population size of 776 households was entered into the ‘Total sample size’ box. The effect size of 0.5 was entered into the ‘Effect size f to w’ box, then the alpha level was set to 0.05 and the statistical power to 0.80 in each of their respective boxes. Click ‘Calculate’ to get the required sample size. Based on the inputs, the necessary sample size was 266 households.

A simple random sampling with a sample size of 266 using was conducted using Excel, using the following: A new column next to the data set in Excel was created. In the first cell of the new column, the formula =RANDBETWEEN (1,776) was entered, and the first random number appeared in the first cell. The cell with the random number was dragged down to the other cells until 266 was reached as the sample size.

4.6 Purposive sampling

Purposive sampling, also known as judgmental sampling or selective sampling, is a non-probability sampling technique in which the researcher selects the sample based on specific characteristics or criteria (Tichapondwa, 2013). In the case of forest management regimes and the challenges in the implementation of the forestry policy. The respondents were selected based on the experiences with different forest management regimes and challenges they faced in the implementation process. Purposive sampling was conducted in the following way:

The population was defined as the group of people who have experience with different forest management regimes. In this case, it was the forest managers who have worked with different regimes. The sampling criteria was determined was by the specific characteristics or criteria that the researcher uses to select the sample.

The potential participants who fit the criteria for the sample were identified. This was done through a literature review, online searches, and by reaching out to professional organizations. From the pool of potential participants, the sample was selected based on the purposive sampling criteria. The sample size depends on the research question, but typically a smaller sample size of 30 was used in purposive sampling.
The selected participants were contacted and invited to participate in the study. The data was then collected using key informant interviews.

Overall, the goal of purposive sampling was to select a sample that is representative of the population in terms of the characteristics or criteria that are of interest to the study. In the case of forest management regimes, purposive sampling was a helpful technique for selecting forest managers who have experience with different regimes and provided valuable insights into their effectiveness.

4.7 Data collection methods

Several research methods, defined as procedures for gathering data (Bryman 2012), was used throughout the study. For such a multifaceted investigation, combining several data collection approaches was beneficial. Quantitative and qualitative data was collected for this study. The field assessment of biophysical data was included in the first quantitative phase, followed by the key informant interviews in the second qualitative phase.

4.7.1 Field assessment

Before the field work commenced, training was undertaken with the team members on how to capture and record data in the field. The field team was responsible for the collection of data in the field and the transmission of the field forms to the team leader. The field team consisted of a team leader, two enumerators (to handle biophysical measurements), and one botanist assisted by one community member. The tools that were used include the diameter tape for measuring diameter, the measuring tape for measuring distances, the hypsometer for measuring tree height, the Know Your Tree book for tree identification, and the recording forms.

A forest inventory was conducted with a total of 15 sampling plots for the research. This covered an area of 4000 ha in which the sampling plots were laid and parameters such as diameter at breast height (DBH), total heights of trees, and the lengths of the dead wood lying down were measured. The protocol used in this research was based on the field manual prepared for the Integrated Land Use Assessment (ILUA) project of the Zambian Forestry Department (Vesa, 2013). Nested plots were designed in which a set of sub-plots of different sizes for different size (diameter) classes were accommodated. Furthermore, a reasonable plot size was suggested based on the stocking density of the stand. The following are the shapes and sizes of the sample plots used:

Table 1: Size and shape of the sample plot

Unit Name	**Shape**	**Size (area)**	**Number**
Plot	Rectangle	50m x20m (1000m^2)	15
Subplot for samplings, 5 cm<DBH<10 cm	Rectangle	20m x10m (200m^2)	One per plot
Subplot for fallen deadwood	Rectangle	20m x25m (500m^2)	One per plot
Subplot for regeneration	Circle	Radius (r) = 4.99 m (50 m2)	One per plot

In all the sample plots, the total tree height and species were recorded except for the fallen dead wood. All trees with a DBH larger than 10 cm within the plots (20m wide and 50m long) were sampled, with sampling consisting of measuring the height and diameter at breast height. A rectangular subplot that measured 20 m by 10 m was used to measure trees with a diameter at breast height (DBH) of 5 to 10 cm. Another sub-plot measuring 20 m x 25 m was used to measure the dead-wood data that was collected on all fallen dead logs and branches in the plot area that have a diameter of 10 cm or greater (regardless of where they originated). The length of dead wood to be measured was at least 1 meter. All pieces of fallen wood having a diameter greater than or equal to 10 cm within the plot area had their length and diameter measured at both ends. Regeneration trees with a DBH of less than 5 cm were measured in a 4.9-m-radius sub-sample plot.

4.7.2 Household surveys

Questionnaires developed by the Central Statistical Office (CSO) were adapted and expanded to suit the objectives of this study. These questionnaires have been widely used in developing countries to collect data on people's dependence on natural resources. These questionnaires lasted an average of 50 minutes per household and were conducted in the local vernaculars (*Tabwa* and *Bemba*), in which the researcher was conversant. The questionnaire included questions that covered a range of topics such as forest product use, forest clearing, and farming. Before the survey was conducted, the questionnaire was pilot tested with a few households to test its effectiveness and get feedback on how to improve it. Simple random sampling was used to select the households for the survey. Therefore, after the selection of the households, the household survey was conducted. This was done both online and in person by going house to house. It was important to be clear about the purpose of the survey and to assure respondents that their responses would be kept confidential. After the data collection was done, it was analysed to identify patterns and trends in the anthropogenic activities of households.

4.7.3 Key informant interviews

Conducting key informant interviews with forest managers provided valuable insights into understanding the management strategies and practices implemented in the forest. The identification of the relevant forest managers to be interviewed was done based on their experience and expertise in forest management. Relevant and specific questions to ask during the interviews were developed. The questions were open-ended to allow the forest managers to elaborate on their responses. The identified forest managers were contacted and requested their participation in the interviews. The purpose of the interview, the questions to be asked, and how the information would be used were explained. The interviews were scheduled at a convenient time for the forest managers. The interviews were administered in person to build rapport and trust with the key informants. The interviews were conducted, and the responses were recorded. The collected data from the interviews was analysed, and common themes were identified. A total of 30 key informants were interviewed from the forest department and the local community.

Table 2 summary of expert interview participants

Category	Description of participants	Number of respondents
Government department	Department of Forestry	Provincial 10 District 10,
Non-governmental organisation	Zambia Forestry and Forest Industry (ZAFFICO)	District 10

4.8 Data analysis methods

4.8.1 Allometric equations

This research relied on mathematical relationships, often known as allometric equations, to link the aboveground biomass of individual trees to other tree traits that are more easily assessed in the field. These characteristics include diameter at breast height (DBH), total height, and wood density (Chidumayo, 2012). The wood density (g/cm^3) values were obtained from Handavu et al, (2021) and the ICRAF database www.worldagroforestry.org/wd/genus. The average wood density of the genus species was estimated for species that were not immediately recoded in the data sets. The best-fit models constructed by (Handavu *et al.*, 2021) (($AGB = 0.093(\rho D^2 H)^{0.97}$) was used to calculate above-ground biomass estimates. Then, using the mean tree C % value of 0.564, the tree biomass estimates were converted to C stock (Handavu et al., 2021). Were AGB is the aboveground biomass, 'D' is the tree diameter at breast height and 'H' is the total tree height.

Newton's formula was used to determine the volume of dead pieces of wood lying on the ground (> 10 cm mid-diameter) (Kershaw et al., 2016).

$$V = \frac{L}{6(Ab + 4A\mathrm{m} + \mathrm{At})}$$

where, V = Volume (m3), L = Length of log (m), *Ab* = Area at the base (m2), *Am* = area at the middle (m2), and *At* = Area at the top (m^2) of the wood lying on the ground.

This volume, along with the wood density and expansion factor of the sampled trees, was used to calculate the biomass of dead wood. $AGB = \frac{L}{6(Ab+4Am+At)}$ x SWD x *ExpF*

The biomass values were converted from kilograms to tons/hectare using the following the procedure:

The total biomass values were converted into metric tons by dividing by 1,000 kilograms. Then the biomass value was then converted to tons/hectare using the formular:

$AGB_h = (A_h / A_p) * AGB_p$

where AGB_h is the estimate of aboveground biomass in metric tons per hectare, A_h is the area of one hectare in square meters, A_p is the area of the plot in square meters and AGB_p is the plot level estimate of aboveground biomass in metric tons.

4.8.2 Statistical analysis

The primary statistical approaches used to analyse quantitative data were both descriptive and inferential statistical methods. These techniques were employed to analyse the household survey data by using descriptive statistics, such as frequency counts and percentages of observed variables.

To determine the dependent and independent variables of the logistic regression, the research hypothesis under investigation was considered. The independent variables were determined based on their potential to influence the dependent variable. The independent variables were analysed using logistic regression as part of an inferential data analysis. The binary dependent variable of this study was 'aboveground biomass and carbon stocks' which was assigned the value '1' if there is loss local forest and '0' if it is not the case. The independent variables were forest product use, farm size, education, household size, forest clearing and period of residence. Logistic regression model presented in equation (1) was used: Yi=1/1+ez………………….……………………. (1) Where, Yi = is a binary variable with the value of 1 if the anthropogenic factors contribute to the reduction of the aboveground biomass and carbon stocks in the reserve and 0 if otherwise; Z = β0 +β1 X1 + β2 X2 + β3 X3 + ...+ βn Xn β0, β1 to βn = coefficients of independent variables showing marginal effect (positive or negative) of the unit change in the independent variables on the dependent variable; X1 to Xn = independent variables; e = natural logarithm base (2.718); i = 1, 2 …. n; where n is the total number of variables. Therefore, the following where the test hypothesis of the study:

H_0: Anthropogenic factors have no significant influence on the aboveground biomass and carbon stocks.

H_A: Anthropogenic factors have a significant influence on the aboveground biomass and carbon stocks.

4.8.3 Thematic analysis

Researchers begin by becoming familiar with the data. This involves reading through transcripts of interviews, reviewing field notes, or listening to audio recordings. During this stage, researchers may take notes, highlight key words or phrases, and make initial observations about the data.

Coding: Researchers then begin to apply codes to the data. Codes are labels that identify important or relevant elements within the data. For example, an interviewer may use codes such as "challenges", "successes", "resources", and "public opinion" to categorize the data.

Theme development: Researchers then begin to develop themes by grouping related codes together. This helps identify larger patterns within the data and can reveal underlying meanings. For example, a theme may emerge from the codes related to "challenges" and "resources" that highlights the difficulty of implementing policy in resource-scarce environments.

Researchers review the themes, ensuring they encompass the data comprehensively and accurately. This helps ensure that the themes reflect the complexity of the data and capture the nuanced experiences and perspectives of research participants.

Refining themes: the researcher refines themes as they return to the data and engage in deeper analysis. This ensures that the themes remain responsive to the data and reflect changes or new insights that emerge during analysis.

Reporting findings: Finally, the researcher reported the findings by summarizing the themes and how they relate to the research question or objective.

Through thematic analysis, researchers identified and analysed patterns and themes within qualitative data, providing a rich and deep understanding of the data. The use of codes and themes helps to organize the data and make it understandable, while also providing a framework for analysis that allows researchers to explore the complexity of research participants' experiences and perspectives.

4.9 Quality assurance

The adoption of research methods was well established, which provided both information from secondary and primary data collected. Systematic, simple random, and key informants were used to collect data. On questions for the key informants, the researcher avoided questions that could make the respondent uncomfortable, as the research itself is sensitive. Thereafter, the researcher ensured honesty in informants during data collection, which made the researcher evaluate the study. The qualifications and experience of the investigator and constant checking of the description and scrutiny of the study were considered for the examination of previous research findings.

Validity and reliability concerns were addressed in the quantitative portion of this study by correctly applying tools and following suggested methods. The research team attended pre-field survey training sessions to ensure that everyone on the team understood how to utilize the various data collection tools and what they were used for. In order to identify representative situations that typified the study communities for the qualitative portion of the research, great effort was made in selecting respondents.

4.9.1 Ethical obligations

Protection of study participants was ensured by ensuring that no injury or bad effect happened, and that participation was voluntary. By not writing the names of respondents on the interview form or the interview schedules, the study will maintain privacy, anonymity, and secrecy. All bibliographical sources shall be credited as correctly and comprehensively as feasible. The District Forest Officer will grant written approval to conduct the study through the District Commissioner.

The participants in the study were informed about the study's purpose. Those who refuse to participate were assured that they will not lose any privileges. Participants were asked to sign a permission form if they agree to participate in the study. To guarantee anonymity, no documents including the names of the respondents were used; instead, codes was used.

CHAPTER FIVE: FINDINGS OF THE STUDY

5.1 Introduction

This chapter presents the results and discussion of findings as per research objectives. The basic forest information is presented first followed by the Diameter distribution of the stand. This is followed by presentation of the above ground biomass and carbon stocks. The result will also present factors influencing the above ground biomass and carbon stocks. Finally, this section will present the identified challenges in the implementation of the forestry policy.

5.2 Basic forest information

It was discovered that the Kanonge forest stand in which the study was conducted had a dense, three-storey vegetation type with a closed canopy. *Pseudolachnostylis maprouneifolia, Baphia massaiensis*, and *Brachystegia wangermeeana* are sub-dominant species in the forest where the plots were located, while *Brachystegia spiciformis* subsp. *Diplorhynchus condylocarpon* is the dominating species. While the forest floor is primarily covered in mosses, the understorey has species like *Diplorinchus condylocarpon, Combretum zeyheri, Combretum molle, and Byrsocarpus orientalis.*

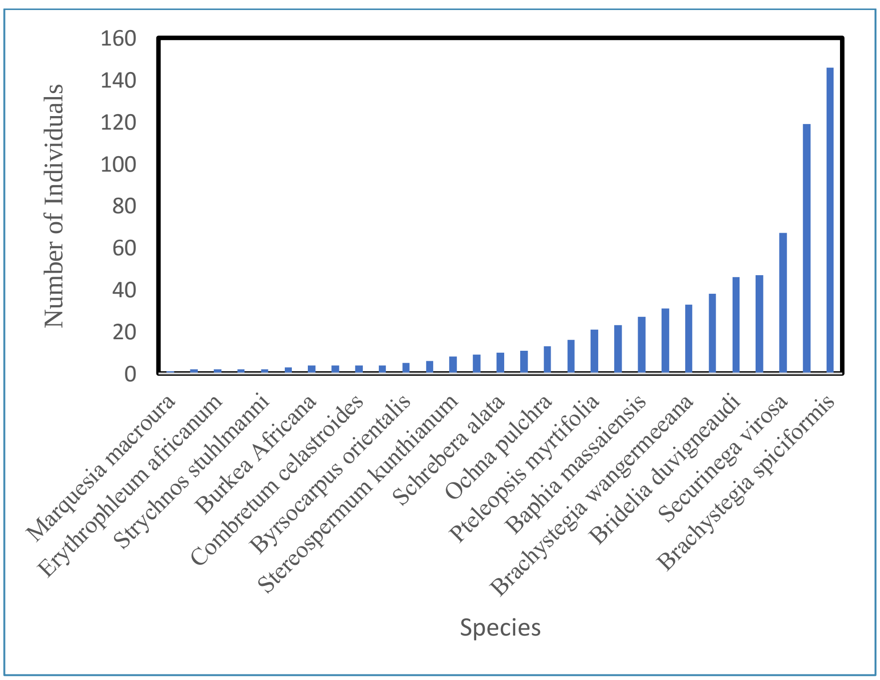

Figure 2: Number of individual tree species

5.3 Diameter distribution

Populations of the sampled vegetation exhibited a structure with both diameter and height, with a high frequency of small plants that are proportional (in the diameter class 1–5 cm) to the larger ones. This, therefore, indicates that the forest is in an early stage of succession, as younger trees are typically smaller than older ones. This can mean that the forest is still recovering from some kind of disturbance, such as logging or a natural disaster. As the forest matures and older trees grow larger, the structure of the forest may change, with taller trees dominating and creating a more closed canopy. This can lead to changes in the overall vegetation composition and biodiversity of the forest. This signifies that the vegetation on the study sites is stable and that the young plants are ready to replace the older ones.

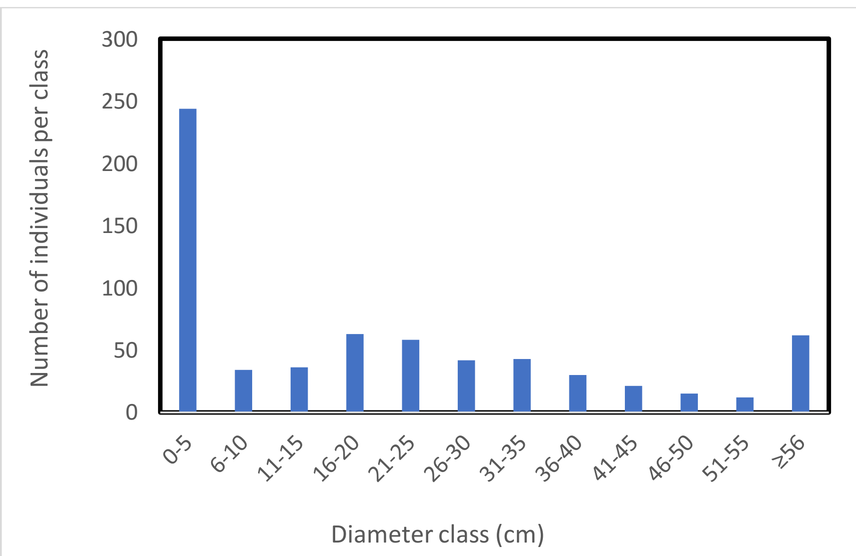

Figure 3:Diameter classes in the forest

5.4 Aboveground biomass and carbon stocks

A total of 704 individuals, representing 22 species, were identified and measured in all the sample plots. The density of trees varied among all sample plots, ranging from 280 to 802 stems/ha. The stem diameter and height of individual trees varied among plots, with a mean of 22.67 cm and 6.6 m, respectively. The aboveground biomass (AGB) and carbon stocks varied greatly, reflecting an increase from the smaller diameter classes to the bigger ones. When there are more small trees in the forest, the above-ground biomass and carbon stocks may be relatively low. This is because younger trees are typically smaller and have not yet reached their full growth potential. However, the amount of above-ground biomass and carbon stocks may increase over time as the forest matures and older trees grow larger. This is because larger trees generally have higher levels of above-ground biomass and carbon stocks than smaller trees. As the forest canopy becomes more closed and dominated by larger trees, the amount of above-ground biomass and carbon stocks may continue to increase until the forest reaches a stable or climax stage. Therefore, the calculated aboveground biomass (AGB) and carbon stocks (AGC) in Kanonge local forest was 347.2 t ha^{-1} and 195.8 t ha^{-1}.

5.4.1 Estimates of the biomass of dead wood

The results of the study indicate that dead wood was observed in only 13 out of 15 sample plots. The total above-ground biomass was estimated at 706.408 kilograms, or 0.7064 tons. This translates to 0.543 t ha^{-1} of deadwood above ground biomass. These results indicate the amount of deadwood above-ground biomass present in the studied area. This information is important for understanding the contribution of deadwood to the overall biomass of the forest ecosystem as well as its potential role in carbon stocks and nutrient cycling. Furthermore, this can help inform forest management and conservation strategies aimed at preserving these valuable resources.

Table 3: Biomass for dead wood

Sample plot no.	AGB (Kg)	AGB (tons)
1	0.013514	1.35137E-05
2	51.74776	0.051747764
3	136.4869	0.136486942
4	0.020396	2.03962E-05
5	202.0305	0.202030506
6	28.05166	0.028051665
7	61.48149	0.061481494
8	7.597722	0.007597722
9	47.39277	0.04739277

	10	144.9953	0.144995292
	11	0.02074	2.07404E-05
	12	0.026376	2.63762E-05
	13	26.543	0.026542999
Total		**706.4082**	**0.70640818**

5.5 Anthropogenic factors influencing the above ground biomass stocks in the local forest

In order to determine the possibility of the factors influencing the aboveground biomass in the forest reserve, the variables were entered into the logistic regression model and checked, and the insignificant factors were discarded from the prediction model.

The goodness of fit of the model was found to fit well with the findings of this study (69%). A chi-square value of 33.9 with a degree of freedom of 6 was highly significant at the 5% probability level (p = 0.00), meaning that the independent variables affected the dependent variable very well. Likewise, the -log likelihood (-2LL) value of 281.9 indicated that the model fitted the data well.

Table 5 shows that Wald statistics have non-zero values, which implies that there is interaction between the dependent and independent variables. According to Pallant (2020), the non-zero Wald statistic values indicate the presence of relationships between the dependent and explanatory variables. Therefore, the null hypothesis is rejected and we accept the alternative hypothesis, which states that anthropogenic factors have a significant influence on the aboveground biomass and carbon stocks.

Table 4: Factors influencing the above ground biomass and carbon stocks in Kanonge local forest.

Variable	β	*S.E.*	*Wald*	*df*	*Sig.*	*(Expβ)*
Forest product use	5.737	1.667	11.846	1	0.001 *	3.213
Cultivated land size	0.031	0.263	0.013	1	0.908 ns	0.970
Period of residence	3.547	1.527	5.394	1	0.020 *	34.726
Household size	0.477	0.318	2.248	1	0.134 ns	0.621
Forest clearing	0.174	0.091	3.653	1	0.046 *	1.19

Constant	3.256	2.754	1.398	1	0.237	0.039

Number of cases = 266, Model Chi-square= 85.88 (p=0.000), -2LL = 36.17; Overall percentage = 98.8%, Exp (β) **=** *odds ratio (probability of success/probability of failure), SE= standard error of the estimate, *Statistically significant at 0.05 level of significance, ns = statistically non significant at 0.05 level of significance, Sig = significance, β = regression coefficients which stand for the odds ratio of probability of success to the probability of failure and Wald statistics = $\beta/(SE)^2$, df = degree of freedom.*

5.5.1 Forest products use.

The results show that the use of forest products by households in the study area has a positive regression coefficient and the corresponding odds ratio, which are statistically significant in the table above. This, therefore, means that a unit increase in the use of forest products will increase the likelihood of above-ground carbon stock loss in the forest. Figure 9 shows the use of forest products by the households identified in the study area. Like many places in rural areas, charcoal is the most commonly used forest product, with 47%, followed by firewood (31.34%), wood poles (12.31%), industrial wood (4.8%), and wood carvings (4.48%), respectively. Therefore, households entirely depend on the local forest resources, which indicates that the use of forest products is impairing the Miombo woodlands of Kanonge local forest.

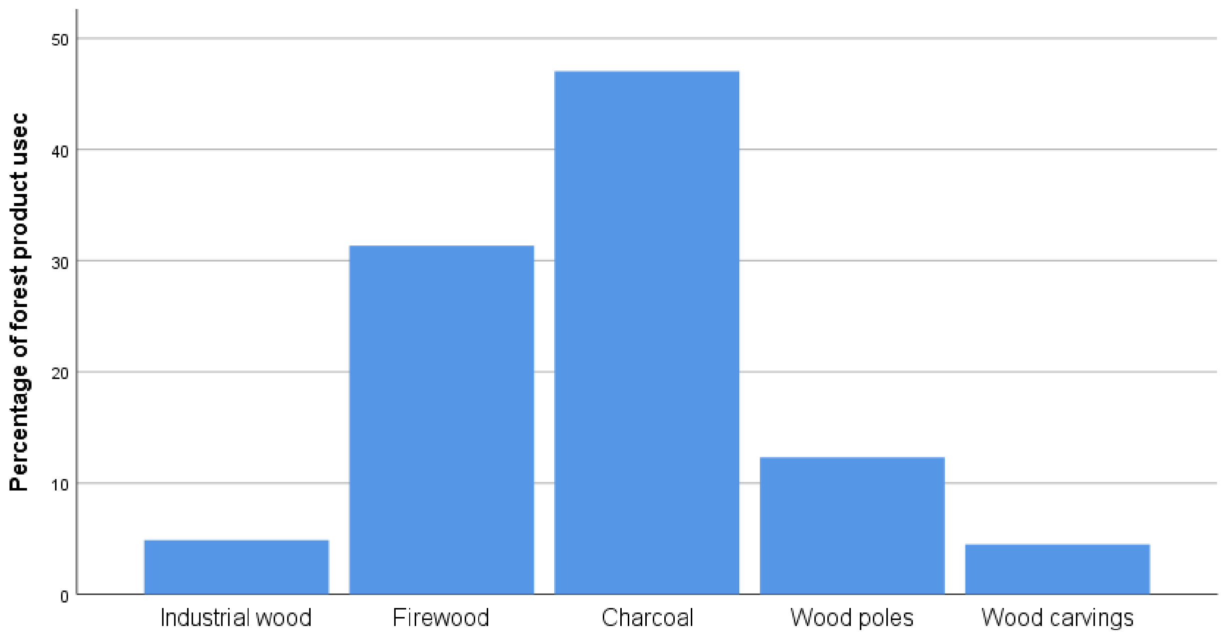

Figure 4: Forest product use

5.5.2 Farm size.

The results show that the cultivated land size by households in the study area has a positive regression coefficient and the corresponding odds ratio, which are statistically not significant as shown in the table above. This, therefore, means that a unit increase in the cultivated land will increase the likelihood of above-ground carbon stock loss in the forest. Figure 10 shows the cultivated land sizes by the households in the study area. Most households in the study area cultivate in the local forest with the mean value of 3 hectares per household. Therefore, most of the households in the study area rely on the local forest resources for their agricultural activities, which shows that the cultivated land size causes negatively affect the above ground carbon stocks in Kanonge local forest.

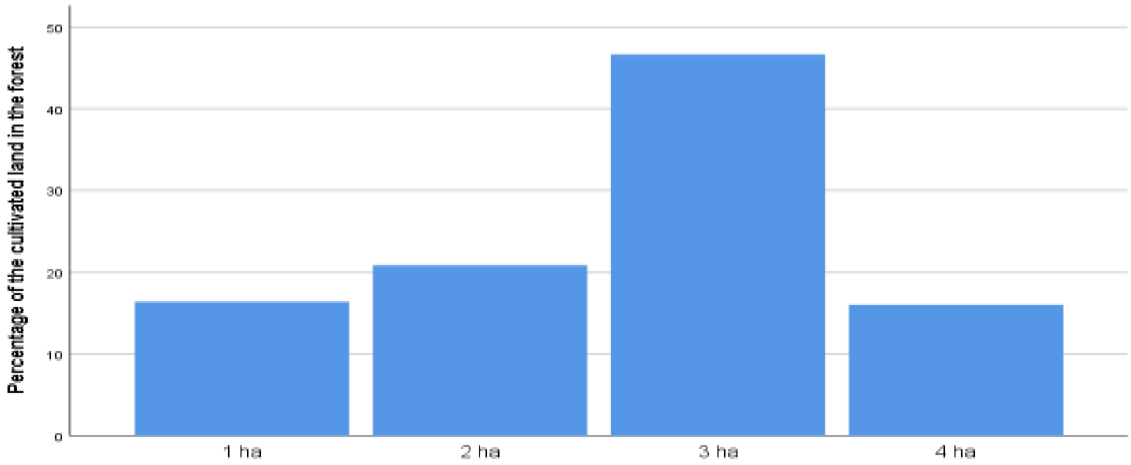

Figure 5: Cultivated land size

5.5.3 Household size

The findings demonstrate a positive regression coefficient and associated odds ratio for household size in the study area, both of which are statistically significant in the table above. As a result, an increase in the size of a household will increase the likelihood that the above-ground carbon stock in the local forest will be lost. The size of a household in the research area is depicted in (Figure 12). The chart below indicates that the average household size was 4, suggesting that a greater household size would only lead to an overuse of the resources in the local forest reserve to meet needs for subsistence. Because of this, the size of the households in the research area makes it easier for them to contribute to the depletion of the above-ground carbon stock.

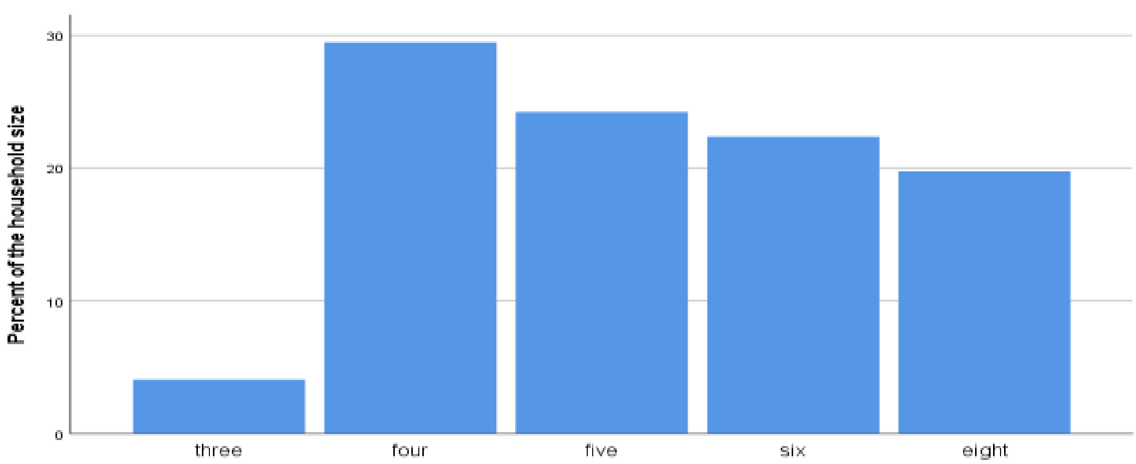

Figure 6: Household size

5.5.4 Forest clearing

The findings demonstrate a positive regression coefficient and associated odds ratio for forest clearing in the study area, both of which are statistically significant in the table above. As a result, an increase in forest clearing will increase the likelihood that the above-ground carbon stock in the local forest will be lost. The forest clearing in the research area is depicted in (Figure 7). The chart below indicates that there is much forest clearing in terms of settlement in the local forest. The increasing demand for land among members of the community who would want to expand their communities has resulted in the conversion of the local forest into settlements, leading to the loss of above-ground carbon stocks in the forest. Implying that when forests are cleared for settlements, the trees and other vegetation that store carbon are cut down or removed, resulting in the loss of the above-ground carbon stock.

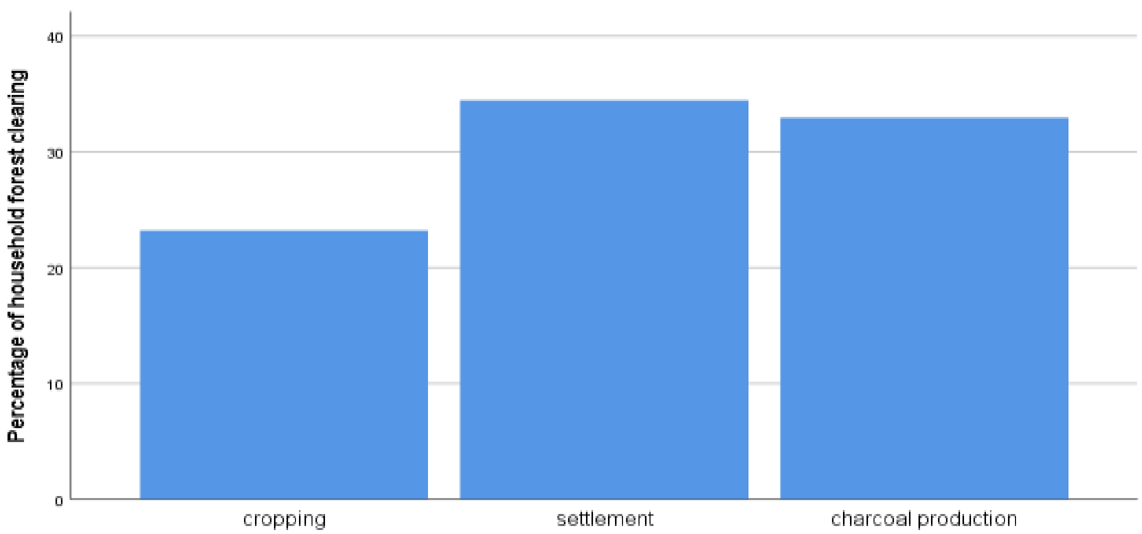

Figure 7: Household Forest clearing

5.5.6 Period of residence

Duration of residence in the area has a positive regression coefficient (β) of 0.122 with odds ratio of 1.13 which was statistically insignificant at probability level of 5% (p=0.42) (Table 4). This indicates that for a unit change in this variable, the risk of a drop in biomass in the forest reserve rises by a factor of 1.13. In other words, the likelihood that a home in a community next to a forest reserve may perceive a disturbance grows with the number of years the household has lived their increases. Families expand in size the longer they stay in a location. As a result, they use more of the forest products.

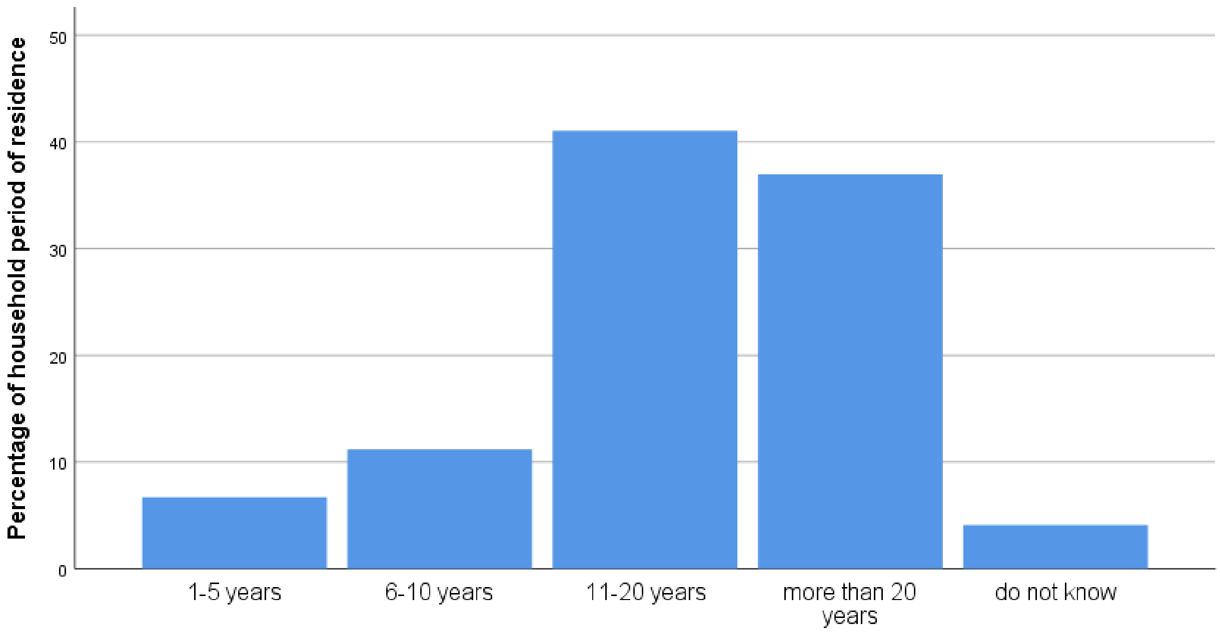

Figure 8: Period of residence.

5.6 Challenges in the implementation of the forestry policy

Forestry policies are essential tools for providing a framework for sustainable management of the above ground carbon stock, but their implementation can face various challenges. The study identified some of the challenges in the implementation of the forest policy for sustainable management of the above ground carbon stock. The table below presents the themes that were generated during thematic analysis, their sub-themes.

Table 5: Themes and sub-themes

Themes	Sub-themes	Frequency

Policy Implementation	Inadequate policy frameworks	lack of enforcement mechanisms	8
Resource Limitations	Inadequate funding,	deficient human capacity	7
Insufficient institution structures	Conflicts of interest,	conflicting sets of values	5
Technical Matters	Insufficient technology	data gaps	10

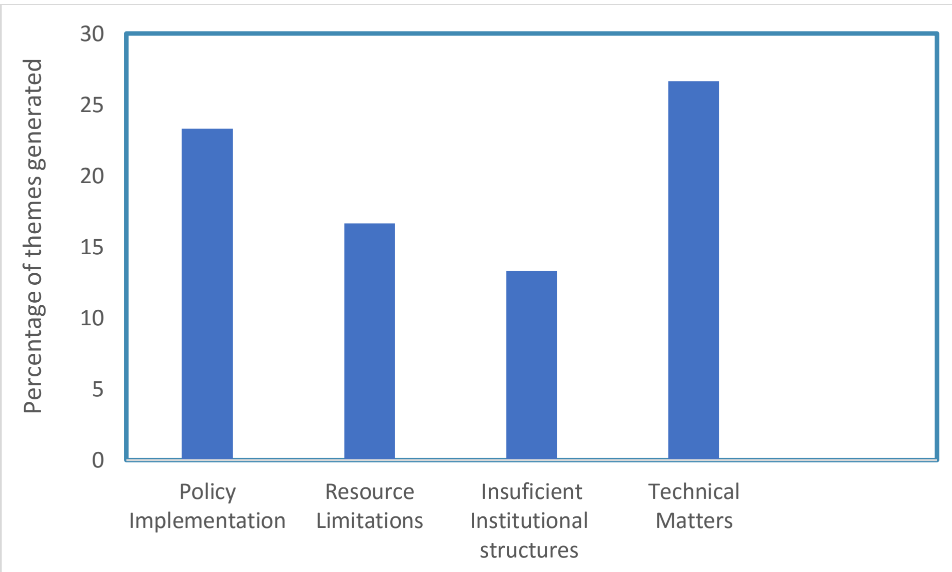

Figure 9: Themes generated

5.6.1 Policy implementation

According to interviews with different forest managers, the following issues are the main obstacles to the implementation of policies meant to reduce the loss of the aboveground carbon stock.

5.6.2 Inadequate implementation framework

A non-supportive implementation framework in terms of coordination between different agencies limits the execution of policies, according to interviews with government organizations, academia, and NGOs. The Forest Department, for instance, is unable to involve stakeholder participation in forest management, even though local communities are heavily involved in managing forests for a variety of purposes involve stakeholder participation in forest management, even though local communities are heavily involved in managing forests for a variety of purposes. Although the requirement of stakeholder interaction in the 2014 Forest Policy, which also promotes community participation in forest management decision-making, has not trickled down to the community level in some areas. The results also reported that inadequate frameworks have led to limited institutional capacity, meaning that government institutions such as the Forest Department fail to hire and train skilled personnel to work with the policy, as well as the absence of political will.

5.6.3 Inadequate intersectoral coordination at district and local level

Despite increased focus on coordination and collaboration between government ministries and other stakeholders, cross-sectoral policy level discussions have not trickled down from national to sub-national and district levels, according to interviews with policy actors at the district level. A representative of the district government emphasized the lack of ongoing coordination between the many environmental-related sectors at the district and village levels.

One of the respondents observed that:

> "*Projects are what drive sector coordination, and the project's duration determines how long it lasts." (Government forest officer).*

Despite national pronouncements to the Rio Conventions that emphasized integrated planning, district government officials highlighted a lack of integrated planning and a lack of communication within sectors. A district-level official from the Ministry of Agriculture emphasized the absence of cross-sectoral coordination with the forestry and energy sectors.

> *"We don't hold combined discussions with the forestry and energy industry stakeholders" (Government agricultural officer).*

Although the activities planned to reduce deforestation and forest degradation are overlapped in policy papers, there is no information sharing, joint meetings, or joint activities among the many actors mandated to implement policies, despite the similarities in the activities offered. There are no formal guidelines for intersectoral coordination, and government ministries in these sectors lack structures to encourage communication with one another, despite the energy policy mandating reforestation and afforestation activities, which are essentially a mandate of the forest department.

Like this, there is no coordination between the agriculture and forest sectors for advising on conservation farming practices or offering extension services to communities.

Conflicting extension services have resulted from poor communication between autonomous sectors, particularly between extension professionals in agriculture and forestry. For instance, due to their ignorance about the borders of the designated forest reserve, agricultural extension workers have offered agricultural subsidies (seeds and fertilizer) and extension services to farmers farming there.

> *"The quantity of crops produced throughout a farming season serves as our key success indicator; the manner and location of production are of minimal relevance to us" (Government agricultural officer).*

5.6.4 Resource limitation

The forestry policy requires a significant number of resources to be implemented effectively. However, the results of the study show that there was a shortage of resources, which hampered the essential activities from being carried out effectively. The following were identified as resource limitations during the interviews:

5.6.4.1 Poor funding for policy implementation

Inadequate funding makes it difficult to implement recommended actions to reduce deforestation. The implementation of suggested measures to minimize deforestation is hampered by inadequate finance. Inadequate institutions for governance and insufficient financing for activities were identified as issues with forest management in expert interviews with government officials at the district level. The study also revealed the lack of equipment at the forestry department. Forestry activities require specific equipment such as chainsaws, tractors, geographic positioning systems, suuntos, and excavators. There was a shortage of equipment due to resource limitations, which has made it difficult to implement the forestry policy.

5.6.5 Insufficient institutional structures and capacity

In terms of formal institutional frameworks, the Ministry of Agriculture has management structures from the national to village level, while the Forest Department has management structures carrying out management responsibilities from the national to district level. The Forest Department's insufficient institutional structures, which do not exist at the village level and have low employee levels at all levels, have been partially blamed for the loss of forest (i.e., district, provincial and national). A forest officer's interview revealed that;

> *"In comparison to the tasks necessary to implement activities for sustainable forest management, there are not enough human resources available." (Government forest officer).*

Forest officers at the district level noted that, in addition to having insufficient personnel levels, they lacked the necessary tools and technology to undertake forest assessments in their local forest reserves and create the necessary forest management plans.

Another respondent stated that:

> *"Lack of basic information regarding forest boundaries, harvestable stock, and forest area is the cause of the lack of forest management plans. We haven't conducted the national forest inventory at either the local or the national levels because we don't have the funds, people, or equipment to do it." (Government forest officer).*

Another respondent added that:

> *"There is a lack of forestry inventory equipment at the Forestry Department, including measuring tapes, suunto clinometers for measuring tree height, calliper diameter tape for measuring diameter, GPS for measuring geographic coordinates, bush nails for measuring distances, and geographic information system (GIS) facilities for image analysis and change detection." (Government forest officer)*

Another respondent added that:

> *"In order to create the forest management plans, the data from the Integrated Land Use Assessment Project (ILUA) Phase II, which had taken stock of the biomass and carbon stocks of the nation, needs to be updated." (Government forest officer)*

5.6.6 Technical aspects

The study reported that there were inadequate tools and technologies: Forestry policy implementation requires the use of proper tools and technologies for data collection, analysis, and reporting. Lack of adequate tools and technologies can affect the accuracy and reliability of data and make it difficult to monitor and report on the progress of the policy implementation.

The study also reported limited knowledge and expertise: Effective implementation of forestry policies requires specialized knowledge and expertise in various fields such as forestry, ecology, and carbon accounting. A lack of skilled personnel with the right expertise can hinder the implementation of policy goals. Forestry policy implementation requires access to proper infrastructure such as transportation, communications, and data management systems. The lack of adequate infrastructure can hinder the smooth implementation of policy goals.

Inadequate monitoring and reporting: Forestry policy implementation requires regular monitoring and reporting to assess progress and determine if adjustments are necessary. Inadequate monitoring and reporting can make it difficult to track progress and adjust course when needed.

Overall, these and other technical matters can pose challenges to the implementation of forestry policies. It is important to address these technical challenges in order to ensure effective implementation and ultimately achieve the desired outcomes of the policies.

CHAPTER SIX: DISCUSSION OF FINDINGS

6.1 Overview

The findings of the study are discussed in this chapter in relation to the study's prime aim and its specific research objectives. These results have been connected to both the concept guiding the study and the literature review reported in the second chapter.

6.2 Vegetation Structure.

The vegetation structure in which the study was undertaken was similar to that described by Handavu et al. (2021), which is composed of primarily deciduous trees that can reach up to 25 meters in height. The trees are commonly used for their valuable timber. Kambayi (2017) also conducted a study in a similar vegetation type in which the intermediate layer is composed of smaller trees and shrubs that are generally 5 to 15 meters in height and that provide additional support to the canopy layer, and the herbaceous layer is comprised of grasses and small herbaceous plants that make up the ground cover. These grasses are critical for soil stability and help reduce soil erosion. The underground layer is comprised of different root systems, including tap roots and surface roots. Deep tap roots are significant for nutrient acquisition and exchange with the trees, while surface roots are significant for soil stabilization.

The study reported a small number of species abundances in Miombo; *Brachystegia spiciformis* and *J. paniculata* were the most prevalent species on the study site, which were also reported by Chomba *et al. (*2014). The study conducted by Handavu et al. (2021) reported similar species in their study area that are of commercial value and attract loggers (Chomba et al., 2014). A number of previous studies in the Miombo woodlands have revealed distributions of size classes, with smaller diameter classes having an abundance with a comparable range, according to Kalaba et al. (2012), who also suggest the possibility of woodland recovery following disturbances. The most prevalent species (Brachystegia spiciformis), which is present in all size classes, is therefore expected to maintain its population without requiring a substantial change in carbon management.

6.3 Above-ground biomass distribution per diameter at breast height (DBH) class

The study reported an increase in biomass as tree diameters increased. The study conducted by Slik *et al.* (2013) reported similar results: the larger trees (with sizes starting at around 70 cm DBH) store a lot of biomass because of their huge wood volumes, and they are responsible for more than two-thirds of sample-based variation in the aboveground biomass. The middle DBH classes from 21 to 40 cm were found to have the maximum accumulation of biomass (20.73%) in this study. The biomass buildup in the DBH classes from 5 to 20 cm (4.3%) was marginally lower than that observed in the classes from 40.1 to 60 cm (23.36%). This result is consistent with what has been noticed in prior research (Baishya et al., 2014).

In this study, very few trees with a DBH greater than 60 cm were recorded. A similar study was conducted by (Matakala, et al, 2015) who suggested that if the forest is relatively young, it is possible that there are just a few trees that have grown bigger than the rest. Over time, as the forest ages, more trees will grow to larger diameters, and the distribution of diameters should become more even.

Another study conducted by (Kalaba *et al.*, 2013) stated that different tree species may have different growth rates and maximum sizes. If the forest is dominated by a species that grows relatively quickly and reaches a large size, then it is possible that there will be a few trees of that species that are much bigger than the other trees in the forest.

A study conducted by Vinya et al., (2012) suggested that management practices can also influence the diameter distribution of trees in a forest. For example, if trees are selectively harvested for timber, then the remaining trees may be primarily those that are larger in diameter. Similarly, if a forest is managed to promote the growth of certain tree species, those species may end up dominating the forest and contributing to the larger diameter classes.

Even though these mature forests do not contribute considerably to carbon uptake, it is crucial to remember that they are essential for regeneration and maintaining biodiversity (Baishya et al., 2014). In terms of management, research has revealed that larger trees may be more vulnerable to climate change than smaller trees, which could lead to a decrease in the storage of forest biomass (Slik *et al.*, 2013). For instance, a protracted drought may cause a disproportionately higher rate of massive tree death relative to smaller DBH trees. As a result, any effects caused by either global climate change or human disturbances like logging, clearing land for agricultural purposes, or large-scale mining that reduce the abundance or persistence of these larger DBH trees are likely to have noticeable and significant effects on the forest (Lewis *et al.*, 2013)

6.4 Comparison of *Kanonge* aboveground biomass (AGB) and carbon stocks (AGC) levels with other forests

The results of the study provided estimates of AGB (347.8 t ha^{-1}), which are higher than values reported in other studies in the Miombo but lower than the 243.6 million tons reported by Shakachite et al. (2016) for the northern province in the integrated land use assessment phase II (ILUA). In other studies, Handavu et al. (2021) reported 222.2 mg $ha^{-1.}$ Kalaba et al. (2013) reported 79.2 mg ha^{-1} AGB and 39.6 mg C ha^{-1}, while Chidumayo (2012) reported 123.4 mg ha^{-1} AGB for old-growth miombo woodlands. Similar studies have been conducted in southern African countries; Tamene et al. (2016) reported 119.9 mg ha^{-1} and 56.4 mg C ha^{-1}. The differences in estimated AGB and C stocks are probably due to differences in management and anthropogenic factors. The carbon stocks estimated in this study were biomass C storage (195.59 t ha^{-1}), which is larger than those reported in other Miombo woodlands. The carbon stock estimates of this study are relatively lower than estimates from, for example, South Africa's (Lisboa *et al.*, 2018), which reported 350.1 mg ha^{-1}.

The study also reported the above-ground biomass for deadwood at 0.54 t ha^{-1}, which is less than the estimates from the Republic of Zambia, (2021) with 1.7 t ha^{-1}. Chidumayo, (1994) reported 1.1 t ha^{-1} of deadwood biomass that was ready to be converted into charcoal. Low values of deadwood biomass in a study area indicate that there is a lack of deadwood left behind by trees that have died or fallen or that the forest has been subject to repeated human disturbance. Deadwood is a critical resource for sustaining the above ground carbon stocks and fuelling local ecosystem services. Low deadwood biomass can lead to a decrease in the aboveground carbon stocks.

6.5 Factors influencing the above ground biomass stocks in the local forest

6.5.1 Forest product use

The results of the study show that under the category of forest product use, charcoal was the mostly used forest product followed by firewood which both makes up 78.35%. The results are similar to study conducted by (Matakala et al, 2015) who found that Charcoal and firewood make up over 70% of the national energy consumption in Zambia as only 20% of the population has access to electricity. Vinya *et al.* (2011) in the preliminary study on the drivers of deforestation in Zambia also found that fuelwood was among the most frequent forest product in nearly all the provinces.

A similar study was conducted by the Chidumayo et al, (2013) found that charcoal was the most consumed forest product in the country. The Food and Agriculture Organization of the United Nations (FAO) also reported a significant increase in charcoal production in Zambia in 2015 (FAO, 2015). Similarly, a study conducted by by Matakala et al, (2015) found that charcoal production was a major contributor to deforestation in the country. Another study conducted by Kalinda et al., (2008), reported that Forest degradation due to fuelwood extraction causes a change in a forest from undisturbed to disturbed state which has led to the loss of biomass. Another study by Wathum et al., (2016) indicated that the total annual fuelwood consumption (both firewood and charcoal) in the Eastern province has greatly contributed to the biomass loss. Another study conducted by Kalaba et al., (2013), reported that the loss in the above ground biomass is attributed to high firewood demand especially in rural areas for cooking and heating needs at household level and also among tobacco farmers especially those producing.

These studies and others like them suggest that charcoal and firewood consumption is a persistent challenge in Zambia which has led to the contribution of the loss of the aboveground carbon stocks, highlighting the need for continued efforts to promote sustainable forest management practices and alternative sources of energy.

6.5.2 Cultivated land size

The results of the study show that the cultivated land size increases the likelihood of the loss of the aboveground carbo stocks. A similar study was conducted by Matakala et al, (2015), the study reported that agricultural expansion is the second highest driver of forest loss in Zambia. A growing population has led to increased pressure for agricultural land in order to meet national and subsistence food requirements. Another study conducted by (Vinya *et al.*, 2012) stated that agricultural expansion is caused both by shifting subsistence cultivation and extensification of subsistence which is supports the results of this study.

Another similar study conducted by (Wathum et al., 2016), reported that Small-scale agricultural expansion is the principal driver of deforestation which contributes to the loss of the above ground carbon stocks. Another study conducted by Chomba et al., (2014), who reported that the pressure to clear forests is driven by the expansion of smallholder subsistence and cash crop systems and that traditional forest fallow land use systems has all but disappeared as more land is demanded for permanent conversion to agriculture thereby leading to the permanent loss in the aboveground carbon stock.

The study by (Ngoma et al, 2018) results asserted that most of the smallholder households' farmers expanded their cropland into the forest by clearing the average of 0.14 ha over one year which is lower than the results reported in this study. Its low adoption intensity, averaging 0.13 ha of cultivated land per farm household while (Shakachite *et al.*, 2016) reported Agriculture expansion in the forest which accounts for 60.78% of forest cover loss. These results are in line with research by (Kamwi *et al.*, 2015), which found that agriculture is the primary cause of declining forest cover. This is largely because agriculture is highly responsive to everyday life realities, such as communities' need for food on a daily basis and their desire to meet this need no matter the cost. The prevalence of agricultural expansion among other forest clearing activities may have been influenced by a number of variables, including increase in population and poverty.

6.5.3 Household size

A key indicator of a population's potential environmental impact is the size of each household. The results of this study reported a smaller average household size of 4 individuals, in contrast to the majority of studies in the field. Family size increases the likelihood that an area would have an increase in people, population, and population density. The average household size in rural sub-Saharan Africa is 5.3 people, following Bongaart's (2001) research. Similar findings were made by Alelign et al. (2011) and Teshome et al. (2015) for some regions of Ethiopia, where the average household size ranged from 5.6 to 7, and by Giliba et al. (2011), Kalaba et al. (2013), and Kamwi et al. (2015) for some regions of Zambia's Copperbelt province, where the average family size was 5.0 and 6.0, respectively. Results from additional studies undertaken in Uganda (Tugume et al., 2015), which discovered a connection between household size and reliance on forest resources, provide support for this. This demonstrates that large-family families are more dependent on forest resources to satisfy their basic needs, especially those with few work opportunities (Birben, 2022).

6.6. Intersectoral coordination and policy implementation

The results of this study have shown that the execution of policies in the forest sector is hampered by a lack of intersectoral coordination. Coordination is necessary for effective policy implementation both inside and outside of the forest sector (Dkamela *et al.*, 2014). A comprehensive policy cannot be implemented successfully if there is a lack of coordination

(Ongolo, 2015). The implementation of policies in linked sectors frequently has an impact on the implementation of policies in the sector in question. The sustainable management of forests is seriously threatened by the inability of two or more actor groups to coordinate their conflicting interests (Ongolo, 2015). In the instance of Zambia, the agriculture policy interacts negatively with the forest policy, which compromises the efficacy of the implementation of the forest policy. These results support research conducted in Cameroon by Dkamela et al. (2014) that identified inconsistencies between sectoral policies and rivalry for forest resources as barriers to the implementation of forest sector policy. In Zambia, expanding agriculture is the same as increasing agricultural productivity. In accordance with the national development plan, the agricultural strategy is focused on boosting agricultural productivity (i.e., Vision 2030). It is necessary to recognize explicitly the mutually beneficial connections between sectoral policies with regard to food security and agroforestry in order to increase the synergies between forestry and agriculture policies and policy implementation in the forest sector. National development plans give priority to ensuring food security, which is why the agriculture policy places a strong emphasis on raising food production, which is considered as exclusively enhancing food security. Despite the importance of forest products in the diets of the locals, the forest policy and national statements are silent on the function of forests in promoting food security. Forests may be taken into account with agriculture in national strategies for food security once the role of forests for food is acknowledged in policies, strengthening the synergy and coherence between the two policy instruments. The difficulty of increasing food production by enhancing agricultural crop production systems utilizing less expensive technology accessible to rural families persists since food insecurity issues persist in rural areas (Angelsen *et al.*, 2014). Promoting agroforestry, which is the management of trees in agricultural landscapes utilizing methods like enhanced fallow, rotational woodlots, and intercropping to increase soil fertility, could strengthen the synergy between the agricultural and forestry sectors (Quinion *et al.*, 2010). As farming systems become more intensive, integrated land use management is encouraged, and options for livelihood diversification are presented by trees in agroforestry systems. Agroforestry promotion has the potential to enhance sector cooperation and would assist in integrating extension services, which are now lacking.

6.7 Insufficient institutional structures in the forest sector

Weak institutional capability prohibits measures to address deforestation and forest degradation from being implemented in the forest sector (Karsenty et al., 2012) . This study's local-level data indicate that institutional frameworks for competing land uses have an impact on how policies are carried out. This is explained by the fact that implementing policy actions and monitoring is less expensive when formal mechanisms are present at the village level than when they only exist at the national or district levels. The effectiveness of policy implementation is influenced by institutional structure levels because institutional structures have a natural tendency to either assist or impede policy implementation (Dougill *et al.*, 2012). According to related studies, creating formal institutions to carry out village-level policies boosts the effectiveness of institutions in comprehending the local setting and their geopolitical contexts.

6.8 Political will and policy implementation

Lack of political commitment to stop deforestation and forest degradation appears to be impeding the implementation of policies in Zambia's forest sector. Although the nation has created laws and policies that could stop the loss of forests, execution is poor. Staffing levels are insufficient, and funding for the forest sector is still insufficient, making policy implementation difficult. Governments therefore rely substantially on outside resources (Ongolo, 2015). Therefore, some administrations create policies with a personal goal to acquire funding without intending to alter the path of events (Karsenty and Ongolo, 2012). The tendency of policy elites in developing nations to use ideas from international discourse, like sustainable forest management, in policy creation that frequently does not match activities at the national and local levels has been brought to light by Dkamela et al. (2014). While the genuine national willingness by political participants is truly lacking, politicians use this strategy to appease the international community by pretending to be conversant in international political vocabulary. In order to protect their own interests in national policies, some governments engage in cunning behavior (Ongolo, 2015). Because resources are externally managed and domestic policymakers have limited control, financial resources obtained in the form of foreign aid to various sectors frequently do not produce effects on the ground.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

The study has shown that the above-ground carbon stock of disturbed forest in the study area is higher than other studies in Miombo woodlands in other provinces but lower than the values reported for the northern province. This suggests that disturbance has a significant impact on carbon storage in Miombo ecosystems, which can have negative implications for carbon sequestration and climate change mitigation. Therefore, the findings of this study can contribute to the development of sustainable forest management practices that promote carbon storage and climate change mitigation in Miombo ecosystems.

The use of forest products (timber extraction, firewood and charcoal), forest clearing, household size, and period of residence in the study area have a cumulative effect on above-ground carbon stock, leading to deforestation, degradation, and loss of biodiversity. Unsustainable harvesting practices, deforestation, and changes in forest composition are the main causes of this loss. Forest clearing for agricultural, or settlement purposes leads to the conversion of forested areas into non-forested ones, resulting in habitat destruction, biodiversity loss, and the emergence of greenhouse gases. The size of households and time of residence are also critical factors in the loss of above-ground carbon, with larger families requiring more resources and longer periods of residence increasing the likelihood of unsustainable land use practices. Furthermore, the findings of this study can inform policy interventions that promote sustainable forest management and climate change mitigation in Miombo ecosystems.

The identified barriers to forest policy implementation in the management of above-ground carbon in the study area demonstrate the complexity of sustainable forest management. Efforts must be made to strengthen institutional structures and build the capacity of stakeholders to effectively implement forest policies.

Collaborative partnerships between stakeholders could help address resource limitations and provide solutions to technical issues faced during forest policy implementation. Consistent monitoring and evaluation of forest management practices are also crucial in ensuring that policies and regulations are effectively implemented.

Promoting sustainable forest management practices in Zambia requires a concerted effort from stakeholders to address the identified barriers and develop effective solutions to ensure the management of above-ground carbon for the wellbeing of present and future generations.

7.2 Recommendations

1. There is a need for conservation and restoration efforts to maintain and enhance carbon storage in Kanonge local forest.
2. Therefore, sustainable forest management practices that limit the use of forest products and minimize forest clearing should be promoted to maintain and enhance carbon storage in miombo forests
3. There is a need for a multi-stakeholder approach involving the government, local communities, civil society organizations, and private sector actors to work towards developing and implementing sustainable forest management practices

8.0 References

Angelsen, A. *et al.* (2014) Environmental Income and Rural Livelihoods: A Global-Comparative Analysis, *World Development, 64(S1), pp. S12–S28.* Available at: https://doi.org/10.1016/j.worlddev.2014.03.006

Baishya, R. and Upadhaya, K. (2014) *Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India All-India Coordinated Project on Preventing extinction and improving conservation status of threatened plants through application of biotechnological tools View project*. Available at: https://www.researchgate.net/publication/228977964.

Barry, J.J. (2016) The Mineral Industry of Zambia. *A craton to mobile belt sedimentary sequence, Transactions of the geological society of South Africa, 85, 155-165p.* Available at: https://www.cobaltinstitute.org/statistics.html

Birben, Ü. (2022) 'Socio-economic factors influencing household dependency on forests: *Empirical evidence from Turkey.', Cerne, 28(1), pp. 28–35*. Available at: https://doi.org/10.1590/01047760202228013043

Brierley, J.A. (2017) *The role of a pragmatist paradigm when adopting mixed methods in behavioural accounting research, Int. J. Behavioural Accounting and Finance*.

Bwalya, S.M. and Atlanta, C. (2015) *COMPETITIVE GRANTS PROGRAM Final Report Rural Livelihoods and Collective Action in Joint Forest Management in Zambia FIRST DRAFT Supporting institution & address Strategies and Analysis for Growth and Access (SAGA)*.

Chidumayo, E.N. (1994) *Zambian charcoal production Miombo woodland recovery*.

Chidumayo, E.N. (2012) *Assessment of Existing Models for Biomass Volume Calculations*.

Chidumayo, E.N. and Gumbo, D.J. (2013) The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis, *Energy for Sustainable Development*. *Elsevier B.V., pp. 86–94.* Available at: https://doi.org/10.1016/j.esd.2012.07.004

Chinasho, A. (2015) Carbon Stock in Woody Plants of Humbo Forest and its Variation along Altitudinal Gradients: The Case of Humbo District, Wolaita Zone, Southern Ethiopia, *International Journal of Environmental Protection and Policy, 3(4), p. 97*. Available at: https://doi.org/10.11648/j.ijepp.20150304.13

Chomba, B.M. *et al.* (2014) *Drivers of deforestation, identification of threatened forests and forest co-benefits other than carbon from REDD+ implementation in Zambia*. Available at: www.fao.org/publications.

Deuteronomy, K., Elijah, P. and Imasiku, N. (2019) Deforestation impact on ecosystem services in Kamfinsa sub-catchment of Kafue River Basin in Zambia, *Journal of Ecology and The Natural Environment*, *11(4), pp. 33–45*. Available at: https://doi.org/10.5897/jene2018.0692

Dkamela, G.P. *et al.* (2014) Lessons for REDD+ from Cameroon's past forestry law reform: A political economy analysis, *Ecology and Society*, *19(3)*. Available at: https://doi.org/10.5751/ES-06839-190330

Dougill, A.J. *et al.* (2012) Lessons from community-based payment for ecosystem service schemes: From forests to rangelands, *Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1606), pp. 3178–3190*. Available at: https://doi.org/10.1098/rstb.2011.0418

Emilie Smith, A.K.C.M.F.S. (2012) *FIELD MANUAL FOR TREE SELECTION AND MANAGEMENT AGROFORESTRY INTERVENTIONS TO REDUCE SEDIMENTATION AND IMPROVE LIVELIHOODS IN THE ZAMBIA CATCHMENT DEMONSTRATION SITES OF THE LAKE TANGANYIKA*. Available at : http://www.worldagroforestry.org

Ene, L.T. *et al.* (2017) 'Large-scale estimation of change in aboveground biomass in miombo woodlands using airborne laser scanning and national forest inventory data', *Remote Sensing of Environment*, *188, pp. 106–117*. Available at : https://doi.org/10.1016/j.rse.2016.10.046

Gebeyehu, G. *et al.* (2019) 'Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia', *Journal of Ecology and Environment*, *18, pp. 37–46*. Available at : https://doi.org/10.1186/s41610-019-0105-8

Giliba, R.A. *et al.* (2011a) The Influence of Socio-economic Factors on Deforestation: A Case Study of the Bereku Forest Reserve in Tanzania, *Journal of Biodiversity*, 2(1), pp. 31–39. Available at : https://doi.org/10.1080/09766901.2011.11884727

Giliba, R.A. *et al.* (2011b) The Influence of Socio-economic Factors on Deforestation: A Case Study of the Bereku Forest Reserve in Tanzania, *Journal of Biodiversity, 2(1), pp. 31–39*. Available at: https://doi.org/10.1080/09766901.2011.11884727

Government of the Republic Zambia (2005) *Lake Tanganyika Integrated Management Programme – Zambia Component (Catchment management through sedimentation control) PIMS 1941*.

Handavu, F. *et al.* (2021) Aboveground and belowground tree biomass and carbon stocks in the miombo woodlands of the Copperbelt in Zambia, *Carbon Management, 12(3), pp. 307–321*. Available at: https://doi.org/10.1080/17583004.2021.1926330

Handavu, F., Chirwa, P.W.C. and Syampungani, S. (2019) Socio-economic factors influencing land-use and land-cover changes in the miombo woodlands of the Copperbelt province in Zambia, *Forest Policy and Economics, 100, pp. 75–94*. Available at: https://doi.org/10.1016/j.forpol.2018.10.010

Harrison', D.J. *et al.* (1998) *LOCAL DEVELOPMENT OF AFFORDABLE LIME IN SOUTHERN AFRICA CJ Mitchelll, SDJ Inglethorpe', P TawodZera2, S Bradwel13 & EJ Evans' with contributions from*.

Imasiku Nyambe, B. and Phiri, C. (2010) *DATABASE OF MINERAL DATABASE OF MINERAL RESOURCES OF ZAMBIA RESOURCES OF ZAMBIA Introduction Regional Geological Setting Stratigraphy Geology and Mineral Resources Mining Administration Of Mineral Resource Regional Mapping Geochemical Survey Mineral Resource Exploration Mineral Resource Evaluation Mineral Potential Conclusion References*.

Japan International Coorperation Agency (1995) 'Final Report Supporting Dam Geology', pp. 6–7.

John W. Creswell and Vicki L. Planco Clarck (2011) *Designing and conducting mixed methods research*. 2nd edn. Edited by Vicki Knight et al.

Jumbe, C.B.L., Bwalya, S.M. and Husselman, M. (2018) *Contribution of dry forests to rural livelihoods and the national economy in Zambia 1 Introduction*.

Kalaba, F.K. *et al.* (2013) Floristic composition, species diversity and carbon storage in charcoal and agriculture fallows and management implications in Miombo woodlands of Zambia, *Forest Ecology and Management, 304, pp. 99–109.* Available at: https://doi.org/10.1016/j.foreco.2013.04.024

Kalaba, F.K. (2016) Barriers to policy implementation and implications for Zambia's Forest ecosystems, *Forest Policy and Economics, 69, pp. 40–44.* Available at : https://doi.org/10.1016/j.forpol.2016.04.004

Kalinda, T. *et al.* (2008) *Zambia Forestry Department Ministry of Tourism, Environment and Natural Resources Food and Agriculture Organization of the United Nations USE OF INTEGRATED LAND USE ASSESSMENT (ILUA) USE OF INTEGRATED LAND USE ASSESSMENT (ILUA) DATA FOR FORESTRY AND AGRICULTURAL DATA FOR FORESTRY AND AGRICULTURAL POLICY REVIEW AND ANALYSIS IN ZAMBIA POLICY REVIEW AND ANALYSIS IN ZAMBIA*.

Kambayi, M. (2017) *Estimating carbon sequestered in the Cryptosepalum forest in Mwinilunga District of North-western Province, Zambia, 12 (2), pp. 20–29* Available at : https://scholar.sun.ac.za

Kamwi, J.M. *et al.* (2015) Livelihoods, land use and land cover change in the Zambezi Region, Namibia, *Population and Environment, 37(2), pp. 207–230.* Available at: https://doi.org/10.1007/s11111-015-0239-2

Kaonga, M.L. and Bayliss-Smith, T.P. (2010) Allometric models for estimation of aboveground carbon stocks in improved fallows in eastern Zambia, *Agroforestry Systems, 78(3), pp. 217–232*. Available at: https://doi.org/10.1007/s10457-009-9253-7

Karsenty, A. and Ongolo, S. (2012) Can "fragile states" decide to reduce their deforestation? The inappropriate use of the theory of incentives with respect to the REDD mechanism, *Forest Policy and Economics, 18, pp. 38–45.* Available at : https://doi.org/10.1016/j.forpol.2011.05.006

Kazungu, M. *et al.* (2021) Household-level determinants of participation in forest support programmes in the miombo landscapes, Zambia, *Sustainability (Switzerland)*, 13(5), pp. 1–22. Available at: https://doi.org/10.3390/su13052713

Kokwe (2012) ‘Forest management practices with REDD+ in Zambia’, *FINAL REPORT* [Preprint].

Kumar (2011) *RESEARCH METHODOLOGY a step-by-step guide for beginners*. Available at: www.sagepublications.com.

Lauri Vesa (2013) ‘Integrated Land Use Assessment Phase II Zambia Biophysical Field Manual’, *book* [Preprint].

Lembani, R. *et al.* (2020) Quantifying spatial-temporal changes of aboveground carbon stocks using Landsat time series data: A case study of Miombo woodlands, *International Journal of Environmental Studies, 77(4), pp. 581–601*. Available at: https://doi.org/10.1080/00207233.2019.1698870

Leventon, J. *et al.* (2014) Delivering community benefits through REDD+: Lessons from Joint Forest Management in Zambia, *Forest Policy and Economics, 44, pp. 10–17*. Available at: https://doi.org/10.1016/j.forpol.2014.03.005

Lewis, S.L. *et al.* (2013) Above-ground biomass and structure of 260 African tropical forests, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 368(1625) *pp. 21–48*. Available at: https://doi.org/10.1098/rstb.2012.0295

Lu, D. (2006) The potential and challenge of remote sensing-based biomass estimation, *International Journal of Remote Sensing*. *Taylor and Francis Ltd*., *365(1520) pp. 1297–1328*. Available at: https://doi.org/10.1080/01431160500486732.

Matakala, P.W., Kokwe, M. and Statz, J. (2015a) *ZAMBIA NATIONAL STRATEGY TO REDUCE EMISSIONS FROM DEFORESTATION AND FOREST DEGRADATION (REDD+) Ministry of Lands, Natural Resources and Environmental Protection Forestry Department*.

Matakala, P.W., Kokwe, M. and Statz, J. (2015b) *ZAMBIA NATIONAL STRATEGY TO REDUCE EMISSIONS FROM DEFORESTATION AND FOREST DEGRADATION (REDD+) Ministry of Lands, Natural Resources and Environmental Protection Forestry Department*.

Maxwell Phiri, by and Chirwa, P.W. (2009) *Evaluation of the Performance of Joint Forest Management (JFM) Programme: Case of Dambwa Forest Reserve in Livingstone District, Zambia*.

Ministry of Lands & Natural Resources (2018) *NATIONAL GUIDELINES FOR COMMUNITY FORESTRY IN ZAMBIA.*

Ministry of Lands and Natural Resources and Ministry of National Development Planning (2019) *ZAMBIA'S FIRST REDD+ SAFEGUARDS SUMMARY OF INFORMATION 2019 GOVERNMENT OF THE REPUBLIC OF ZAMBIA-iii-Ministry of Lands and Natural Resources Ministry of National Development Planning*.

Musonda and Bathsheba (2013) *RAINFALL AND TEMPERATURE CHARACTERISTIC OVER ZAMBIA.*

Ngoma, H. *et al.* (2021) Climate-smart agriculture, cropland expansion and deforestation in Zambia: Linkages, processes and drivers, *Land Use Policy*, 112, pp 107. Available at: https://doi.org/10.1016/j.landusepol.2021.105482

Ngoma, H. and Angelsen, A. (2018) Can conservation agriculture save tropical forests? The case of minimum tillage in Zambia, *Forest Policy and Economics*, 97, pp. 153–162. Available at : https://doi.org/10.1016/j.forpol.2018.10.001

Ns, R. *et al.* (2021) *Prediction of Forest Parameters and Carbon Accounting under different Fire Regimes in Miombo Woodlands, Niassa Special Reserve, Northern Mozambique*.

Ongolo, S. (2015) On the banality of forest governance fragmentation: Exploring "'gecko politics'" as a bureaucratic behaviour in limited statehood, *Forest Policy and Economics, 53, pp. 12–20*. Available at : https://doi.org/10.1016/j.forpol.2015.01.005

Phiri, D. *et al.* (2020) Sentinel-2 data for land cover/use mapping: A review, *Remote Sensing*. *MDPI AG*. *52, pp. 13–26*. Available at: https://doi.org/10.3390/rs12142291

Puliti, S. *et al.* (2021) Above-ground biomass change estimation using national forest inventory data with Sentinel-2 and Landsat, *Remote Sensing of Environment*, *70(4), pp. 355–364*. Available at : https://doi.org/10.1016/j.rse.2021.112644

Quinion, A. *et al.* (2010) Do agroforestry technologies improve the livelihoods of the resource poor farmers? Evidence from Kasungu and Machinga districts of Malawi, *Agroforestry Systems*, *80(3), pp. 457–465*. Available at: https://doi.org/10.1007/s10457-010-9318-7

REPUBLIC OF ZAMBIA (2021) *REPUBLIC OF ZAMBIA FOREST REFERENCE EMISSIONS LEVEL (ZAMBIA)*.

Ryan, C.M. *et al.* (2012) Quantifying small-scale deforestation and forest degradation in African woodlands using radar imagery, *Global Change Biology*, 18(1), pp. 243–257. Available at : https://doi.org/10.1111/j.1365-2486.2011.02551.x.

Saito, M. *et al.* (2014) Fire regimes and variability in aboveground woody biomass in miombo woodland, *Journal of Geophysical Research: Biogeosciences*, 119(5), pp. 1014–1029. Available at: https://doi.org/10.1002/2013JG002505.

Schielein, J. and Börner, J. (2018) Recent transformations of land-use and land-cover dynamics across different deforestation frontiers in the Brazilian Amazon, *Land Use Policy*, 76*, pp. 81–94*. Available at : https://doi.org/10.1016/j.landusepol.2018.04.052.

Sedano, F. *et al.* (2022) Influence of Charcoal Production on Forest Degradation in Zambia: A Remote Sensing Perspective, *Remote Sensing*, 14(14) *pp. 85–97*. Available at : https://doi.org/10.3390/rs14143352.

Shakachite, O. *et al.* (2016) *Integrated Land Use Assessment Phase II-Report for Zambia. The Food and Agriculture Organization of the United Nations and the Forestry Department*.

Slik, J.W.F. *et al.* (2013) Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics, *Global Ecology and Biogeography*, *22(13), pp. 1260–1270*. Available at : https://doi.org/10.1111/geb.12092.

Stringer, L.C. *et al.* (2017) A New Dryland Development Paradigm Grounded in Empirical Analysis of Dryland Systems Science, *Land Degradation and Development*, *28(7), pp. 1952–1961*. Available at: https://doi.org/10.1002/ldr.2716.

Tichapondwa, S.M. (2013) *Pr eparing your Disser tation at a Distance: A Resear ch Guide*.

Vinya *et al.* (2012) *Preliminary study on the drivers of deforestation & potential for REDD+ in Zambia Republic of Zambia Ministry of Lands, Natural Resources and Environmental Protection*.

Wathum, G., Seebauer, M. and Carodenuto, S. (2016) *Drivers of deforestation and forest degradation in Eastern Province, Zambia Zambia Integrated Forested Landscape Program*.

World Agroforestry Centre (ICRAF). (2012) *REPORT ON THE DEVELOPMENT AND USE OF MANUALS AND ASSOCIATED SELECTION TOOLS FOR TREE SPECIES AND MANAGEMENT OPTIONS FOR AGROFORESTRY INTERVENTIONS IN THE LAKE TANGANYIKA BASIN*. Available at: http://www.worldagroforestry.org.

Zulu, P. (2016) *REPUBLIC OF ZAMBIA MINISTRY OF AGRICULTURE COUNTRY PRESENTATION ON AGRICULTURAL POLICY-ZAMBIA SECOND NATIONAL AGRICULTURAL POLICY (SNAP) PRINCIPAL AGRICULTURAL ECONOMIST-TRADE AND ENTREPRENEURSHIP*.

APPENDIX: 1 FOREST INVENTORY BOOKING SHEET

ENUMARATION FORM 2b

MAINPLOT/PERMANENT

ENUMARATOR……………………………………….. TIME START……………….

Province………………………………………………….

District ……………………………………………

Forest area………………………………………………

Date………………………………………………..

Plot number……………………………………………

Altitude……………………………………………

GPS-x (m)………………………………………………..

S………………………………………………………..

GPS-y (m)………………………………………………..

E………………………………………………………..

Potential land use……………………………………

Intensity of fire………………………………..

Degree of grazing…………………………………….

Undergrowth type…………………………..

Soil type………………………………………………..

Treatment suggestion……………………..

Treatment done……………………………………….

No.	CODE	NAME	DBH (cm)	HS	TECH	BOLE	HB (m)	TREEH	DIR DEGREE	D (cm)
1	49	Brachystegia Longifolia	32	H	SW	S	6	13		

Observention…………………………………………………………………………………………
………………………………………………………….

KEY

Health status **Tech. use** **Bo. Tech**

H health	M Medicinal	C Crooked

D Dead	FR Fruit	S Straight
B Burt	P Poles	
E Diseased	F Firewood	
	SW sown logs	
	O others	

APPENDIX: II RESEARCH APPROVAL LETTER FROM UNIVERSITY OF ZAMBIA

THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka10101 | Tel: +260-211-290 258/291 777

Fax: (+260)-211-290 258/253 952 | E-**mail**: director.drgs@unza.zm | Website: www.unza.zm

APPROVAL OF STUDY

IORG No. 0005376

NASREC IRB No. 00006465

8th April 2022, 2022

REF NO. NASREC-2021-APR-004

Mr Amos Nyirenda

The University of Zambia

School of Natural Sciences

Department of Geography and Environmental Studies

P.O. Box 32379

LUSAKA

Dear Mr. Nyirenda

RE: "ESTIMATION OF CARBON STOCK IN KANONGE LOCAL FOREST OF KAPUTADISTRICT OF NORTHERN PROVINCE, ZAMBIA."

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	**Ordinary Review**	**Approval No.** **NASREC-2021-APR-004**
Approval and Expiry Date	Approval Date: 8th April 2022, 2022	Expiry Date: 7th April 2022, 2022
Protocol Version and Date	Version - Nil.	8th April 2022, 2022
Information Sheet,	☐ English.	To be provided

Consent Forms and Dates		
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

Conditions of Approval

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.

- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.

- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.

- All protocol deviations must be reported to NASREC within 5 working days. □ All recruitment materials must be approved by NASREC prior to being used.

- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.

- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.

- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled “late submissions” and will incur a penalty fee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.

- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.

- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO),both NASREC

- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.

- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.

- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.

- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. E. M. Mwanaumo

CHAIRPERSON THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB

cc**:** Director, Directorate of Research and Graduate Studies

Assistant Director (Research), Directorate of Research and Graduate Studies

Assistant Registrar (Research), Directorate of Research and Graduate Studies

APPENDIX : III HOUSEHOLD INTERVIEW GUIDE

AREA IDENTIFICATION PARTICULARS	CODE NUMBER
1.0 STRATUM:	
1.1 CLUSTER:	☐☐☐
1.2 PROVINCE NAME:	☐☐
1.3 DISTRICT NAME:	☐☐☐☐
1.4 CONSTITUENCY NAME:	☐☐☐
1.5 WARD NAME:	☐☐
1.6 REGION: (I-rural 2=urban)	
1.7 CSA NUMBER:	☐☐
1.8 SEA NUMBER	
1.9 CHIEF / CHIEFTAINESS' AREA:____	
1.10 VILLAGE/LOCALITY NAME:____	
1.11 LAND USE / VEGETATION TYPE:	☐☐☐

GPS COORDINATES: 1.12 Latitude (S): □□ □□□□ 1.13 Longitude (E): □□ □□□□
1.14 INTERVIEWER(S):____
1.15 DATE OF INTERVIEW:.........../................/......... 1.16 ………………………… TIME START.... . . 1.17. END………………………… TIME —

FOREST ACCESS		Option codes & notes
2.1	Do you have access to forest or wooded area for harvesting or collecting wood and/or non-wood forest products? 1 Yes 2 Some members of the group have access 4 Not aware	
2.2	What is the distance to the forest/wooded area edge (time and km)	a. time____(by transport' code E) b. km ______ Forest/wooded area too far and thus not used by the user group/community (ifnoforest nearby and no one harvestsforest products, go to Q 2.6)
2.3	Do you need a permit to collect wood or non-wood forest products from this source? 1. Yes 2. Yes, for some products/ purposes (specify)	If'no' → go to Q 2.5

	4. Group is unclear	
2.4	In your opinion, is the permit granting process open and transparent? 1. Yes 2. No 3. Don't know Mark also down any comments	
2.5	Are there now more/less different wood and non-wood forest products available in that forest/wooded area than 10 years ago? 1. Now fewer products than 10 years ago (some products no more available) 2. No change (same products available now as 10 years ago) 3. Now more different products than 10 years ago 4. Don't know	
2.6	In general, has your access to forest /wooded land improved or deteriorated during the last 5 years? 1 Improved 2 Deteriorated 3 No change	If 'no change' 9 go to Q 2.8

Fuel wood
5. Is fuel wood utilized by the HH? *Yes=1, No=2*
6. On average, what is the quantity used per month?
7. Specify unit

8. How did you obtain fuel wood? *Self produce/collect = 1, Buy it= 2, Receive it as gift=3, Other=4 (specify)________ (multiple options possible) If not self-collected.*	
Ask only if collected / produced by the HH **9 How much time do the household members spend for the collection?** (including both travel and actual collection) *(hours)* ***Note! It is important that this question is asked from the person doing the collection (see answer to Q. 7.2)***	Hours:_________ per ________(*1=day, 2=week, 3=month)* Mark 1, if was answered by a person involved in collection. Mark 2, if was answered by a person not involved in collection.
Forest product collection (Household)	
10 Please specify all the wood and non-wood forest products you collected regularly during the last 12 months? *(Code A) Mark each product to a separate column. If person collected no forest products, mark N/A and end the interview.*	
11 What quantities have you collected during the last 12 months?	
12 Specify the unit	
13 For what are the different wood and non-wood forest products used? *Indicate proportions in percentage of the total quantity you collected during the last 12 months.*	

Charcoal
1. Is charcoal utilized by the HH? *Yes=1, No=2*
2. On average, what is the quantity used per month?
3. Specify unit

4. How did you obtain charcoal?*Self produce=1, Buy it=2, Receive it as gift=3, Other=4 (specify)***________** *(multiple options possible)****If bought, ensure that you have recorded the price paid per unit to Q***