ESTIMATING ECOSYSTEM CARBON STOCK IN A DIVERSIFIED TREE BASED SYSTEM IN UNIVERSITY OF BENIN, EDO STATE, NIGERIA.

BY

Victor IFEANYI

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DEPARTMENT OF FOREST RESOURCES AND WILDLIFE MANAGEMENT

FACULTY OF AGRICULTURE

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BENIN CITY

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF FOREST RESOURCES AND WILD LIFE MANAGEMENT, UNIVERSITY OF BENIN, BENIN CITY

A FINAL YEAR PROJECT SUBMITTED TO THE DEPARTMENT OF FOREST RESOURCES AND WILDLIFE MANAGEMENT, FACULTY OF AGRICULTURE, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF FORESTRY AND WILDLIFE DEGREE OF THE UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

JANUARY, 2023

CERTIFICATION

This is to certify that this project was carried out by Ifeanyi Victor of the Department of Forest Resources and Wildlife Management, University of Benin City, Benin City, Nigeria

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DR. (Mrs.) CHIOMA OKWU-ABOLO	**Prof. (Mrs) G. E. Oboho**
(Project Supervisor)	(Head of Department)

Date: ____________________ Date:____________________

DEDICATION

This work is dedicated to God Almighty for his love grace favour and guidance and assurance all through the period of my study. It is also dedicated to my wonderful Family.

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I wish to express my piece of thanks to my siblings May God bless you all. I will not fail to mention the love and concern shown to me by my friends Afolabi Jeremiah, Trust Esosa Ahmed, Kelly Ogbodu. For all the love shown to me. I will not fail to mention the concern shown by my course mates. God bless you all.

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ABSTRACT

Diversified tree-based system are practices that intentionally include functional biodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control and pollination. This system is a component of social-ecological systems that depend on certain combinations of traditional and contemporary knowledge, cultures and practices. As ecosystem services are generated and regenerated within a tree-based system, it was imperative to estimate carbon stock in a diversified tree-based system in an arboretum in Forest Resources and Wildlife Management Department, University of Benin. This study determined the tree biomass and predicted the carbon pool in the study area. The biomass carbon accumulation was evaluated using non-destructive method in a completely randomized design. A total of 87 trees were sampled from 8 sample plots measuring 15 x 15 m with an area of 0.22 ha in the study using two input variables (diameter and height). Mean tree height and diameter were pooled together and the best fit allometric regression model was used to estimate Aboveground biomass (AGB) in this study. The result showed that the largest DBH was 64.9 cm while the tallest tree was 26.79 m. In estimating the AGB in the diversified tree-based system, Ketterings *et al.*, 2001 model (AGB=aDb (0.066D2.59) indicated the highest modelling efficiency (R^2=1.000, AIC=-40.25, Std. error 1.34). Regression analysis also revealed that most of the carbon was stored in the aboveground biomass with an estimation of 137,216.81 kg ha^{-1} in the study area. Furthermore, the total carbon stock (AGB + BGB) and carbon sequestered were 77,390.28 and 284,022.3 Mg C ha^{-1} respectively. Furthermore, to predict the monetary values to be derived from Kyoto carbon credit scheme, the tons of CO_2 sequestered in the tree based diversified system amounted to $8,520,669. This study concluded that for the Department to benefit from the carbon credits scheme (Kyoto protocol), it is recommended that an ecosystem services payment policy should be in place in order to sustain the environmental benefits derivable from the tree-based systems.

CHAPTER ONE

1.0 INTRODUCTION

Forest ecosystems are areas of the landscape that are dominated by trees and consists of biologically integrated communities of plants, animals, microbes, together with the local soils and atmosphere with which they interact (Kimmins, 2003). These ecosystems provide provisioning, regulatory, supporting, and cultural services that are important to the lives and livelihoods of humans. Forest ecosystems play an important role in maintaining habitats that support important global biodiversity (Raich *et al*. 2014; Escobedo *et al*. 2011) and mitigation of global climate change (Miller *et al*. 2007). Amongst the three major ecosystems, the rainforests store the most carbon (Pan *et al*. 2011), with the majority of sequestered carbon held in woody biomass (Scott *et al*. 2004).

In a forest ecosystem, a component of the climate system which has the capacity to store, accumulate or release carbon is being referred as carbon pool. This accumulated carbon is usually stored up in five different pools namely; above ground biomass (leaves, trunks, limbs), belowground biomass (roots), deadwood, litter (fallen leaves, stems) and soil in natural sinks (IPPC, 2006).Examples of natural sinks includes grasslands, agricultural lands, boreal forests, tropical rainforests, freshwater lakes and wetlands, coastal ecosystems such as marshes and swamps. Forest carbon stock is the amount of carbon that has been sequestered from the atmosphere and is now stored within the forest ecosystem mainly as aboveground biomass, roots and soil at any specified time. While the rate at which the carbon is stored is referred to as the carbon sequestration rate.

When trees are cut down there are three destinations for the stored carbon: dead wood, wood products or the atmosphere. Decrease in tree carbon stock in a given area can either result in increased dead wood, increased wood products or immediate emissions. Dead wood stocks may be allowed to decompose over time or may after a given period, be burned leading to further emissions. When deforestation occurs, trees can be replaced by non-tree vegetation such as grasses or crops. In this case, the new land use has consistently lower plant biomass and often soil carbon, particularly when converted into annual crops.

Thus, the rainforest can be regarded as biodiversity hotspot by providing a wide array of goods and services that improves the well-being of the society as a whole in addition to its fundamental role in regulating the global climate (Asaah, 2012). Amongst the range of valuable goods provided includes marketed goods and environmental services (Frank and Pieter, 1997). These environmental services could relate to the reduction of climate changes and improvement of the local micro-climate which have become an important model for linking the functioning of ecosystems to human welfare (MEA, 2005 and Sukhdev, 2010).

In the light of the above, this study estimated the carbon stock in a tree based system and also predicted the monetary values that can be derived from Kyoto carbon credit scheme.

1.1 STATEMENT OF PROBLEM

Forests are the largest carbon pool on earth. It acts as a major source and sinks of carbon in nature. Thus, it has a potential to form a chief component in the mitigation of global warming and adaptation to climate change. The principal element for the estimation of forest's carbon stocks is the estimation of forest biomass. Although there has been numerous studies carried out to estimate the forest biomass and the forest carbon stocks, there is still a further need to develop robust methods to quantify the estimates of biomass of all forest components and carbon stocks more accurately. This study aimed at evaluating the quantity of carbon removed from the atmosphere and stored up in the tree-based system in the University of Benin arboretum.

1.2 JUSTIFICATION OF STUDY

It is important that research is carried out to monitor the development of forest ecosystem with regards to their productivity and environmental sustainability. Thus, this study aims to provide information on the estimation of the carbon stock sequestered in the trees in the University Benin arboretum.

1.3 OBJECTIVES

1.3.1 BROAD OBJECTIVES

The main objective of the study is to estimate ecosystem carbon stock in a diversified tree-based system in the Department of Forestry Resources and Wildlife, University of Benin with a view to providing empirical data for the amount of carbon sequestered in the study area.

1.3.2 SPECIFIC OBJECTIVES

The specific objectives of the study are to:

1. determine the best fit models for AGB Prediction
2. determine carbon stock in the tree-based system. In the University of Benin arboretum
3. determine the CO_2 equivalent (CO_2e) sequestrated in tree-based system. In the University of Benin arboretum to determine the carbon finance.

CHAPTER TWO

2.0 LITERATURE REVIEW

Deforestation and forest degradation influence the amount of carbon in the atmosphere, with deforestation and forest degradation contributing an estimated 18% of total global anthropogenic greenhouse gas emissions (Stern Review 2007). However, recent estimates of global carbon emissions from 2011 to 2015 point to a 25% reduction in emissions resulting from deforestation and forest degradation (i.e., from an annual average of 3.9 billion tons of CO2 in 2011 to 2.9 billion tones in 2015). This drop is linked to net growth in planted forest (FAO, 2015).

(MOFSC 2002), deforestation and forest degradation in Nepal is a diverse and complex issue. Nepal's Ministry of Forests and Soil Conservation has identified nine drivers of deforestation and degradation: high dependency on forests and forest products (timber, fuelwood, and other non-timber forest products); illegal harvesting of forest products; unsustainable harvesting practices; forest fires; encroachment; overgrazing; infrastructure development; resettlement; and the expansion of invasive species. The sustainable management of forests is essential to addressing these drivers of deforestation and forest degradation, reducing pressure on forests, and promoting biodiversity conservation. The amount of carbon stored in forests differs according to spatial and temporal factors such as forest type, size, age, stand structure and associated vegetation and ecological zonation (Raich *et al*. 2014; Escobedo *et al*. 2011;

Understanding these differences, and how they affect the degree to which the effects of greenhouse gas (GHG) emissions can be offset through afforestation and improved forest management, is important to informing forestry management programmes (Paoletti 2009).

Trees in forest (including plantation), if well stocked typically sequester carbon at a maximum rate. Forests (Including plantation) play an important role in the global carbon (C) cycle and sequestering carbon dioxide to mitigate climate change. They are major sinks for atmospheric carbon. accounting for 50% of the aboveground carbon in the vegetation (Hunter *et al*., 2013).

They play an important role in the biodiversity conservation and provision of ecosystem services (Spracklen and Righelato 2014). Forests create opportunities for the mitigation of climate change. They stored a considerable amount of carbon stocks if appropriate conservation and management systems existed in the forest sector. The current carbon stock in the world's forests is estimated to be 861 Gt of carbon of which 363 and 383 Gt of carbon are stored in the living biomass and soil (up to 1 m), respectively (Pan *et al*. 2011).

A larger amount of carbon is stored in aboveground biomass (56%) compared to the soil (32%) (Pan *et al*.2011). This figure indicates that biomass and soils have a large potential for temporary and long-term carbon storage (Houghton 2005). However, carbon storage in global forests varies greatly in both its magnitude and within-system distribution, depending on conservation and management (Chen *et al*. 2014).

Forests also create a threat and can release CO_2 to the atmosphere in places where deforestation and forest degradation continue. Thus, forest carbon can be a threat in the global C cycle depending on the management systems. Deforestation has altered the concentration of greenhouse gases in the atmosphere, thereby affecting climate and biodiversity, and become a threat by changing the global C cycle (Harris *et al*. 2012). In contrast, the reduction of the rates of deforestation and forest degradation (REDD) as well as promote sustainable forest management (REDD+) activities, which are targeted to enhance carbon (C) sequestration and maintain in situ C stocks, underlines the importance of mitigating the effects of climate change (UNFCCC 2010; Goetz *et al*.2015).

Forest disturbances often lead to changes in stand biomass, productivity, and carbon cycling (Gautam and Mandal 2016). The previous estimation reported that tropical deforestation contributes approximately 15–25% of the annual global greenhouse gas emissions (Houghton 2005). Similar to deforestation, timber extraction and logging are responsible for just over half of forest degradation (52%), followed by fuelwood collection and charcoal production (31%), uncontrolled fire (9%), and livestock grazing (7%) in the tropics (Hosonuma *et al*. 2012). This indicates that deforestation and forest degradation are the largest sources of greenhouse gas emissions in most tropical countries. This suggested that a small disruption in forests might result in a significant change in the global C cycle. Therefore, the estimation of biomass is an important means for understanding the function of a forest ecosystem and the effect of disturbances on productivity and carbon storage of forest stands.

To understand the impacts of anthropogenic and environmental disturbances on ecosystem services, particularly carbon sequestration in the forests (Including plantation) most previous studies have focused quantifying carbon stocks in protected areas (Moges *et al*. 2010; Simegn and Soromessa 2015).

Thus, the main objectives of this study is to determine the aboveground and below ground carbon stock in a Tree-based system.

2.4 BIOMASS ESTIMATION

Estimation of the accumulated biomass in the forest ecosystem is important for assessing the productivity and sustainability of the forest. It also gives us an idea of the potential amount of carbon that can be emitted in the form of carbon dioxide when forests are being cleared or burned. Biomass estimation of the forest ecosystem enables us to estimate the amount of carbon dioxide that can be sequestered from the atmosphere by the forest. The accurate assessment of biomass estimates of a forest is important for many applications like timber extraction, tracking changes in the carbon stocks of forest and global carbon cycle. Forest biomass can be estimated through field measurement and Remote sensing and GIS methods.

2.4.1 USING REMOTE SENSING

Remote sensing is a process of acquiring data from a distance of an object, area or a phenomenon by analyzing the data through instruments without being in contact with the object or area which is/ are being examined. Remote sensing technology provides a synoptic view of the surface area of interest, thereby capturing the spatial variability in the attributes of interest. But remote sensing is mostly used in natural forest.

2.4.2. FIELD MEASUREMENT

Measuring tree parameters

2.4.3 Diameter at Breast height (DBH)measurement

In measuring the diameter of a tree, it is important to maintain a constant point of measurement. Ideally, for matured trees, diameter is measured at 1.3 m from the ground. However, for saplings and coffee trees, the point of measurement should be 30 cm from the ground. Inaccuracies in measurement can result from vines entangled around the stem, slope, irregular trunk shape, including hollow trees, human error, as well as improper use of equipment. In situations where one encounters an irregular shaped or hollow tree at the 1.3 m point, it is ideal to move further upwards to the relatively most cylindrical point. With stems entangled with vines, attempt must be made to pass the tape between the vine and the stem of the tree. Breast height in flat terrain, non circular trees are to be measured in two perpendicular diameters.

Instruments for this Measurement

(i)Diameter tape

(ii)Veneer Caliper

2. 4.4 Height Measurement

Tree height is a fundamental geometrical variable for trees. Unfortunately, most measures are based on visual inspection, and they are almost always considerably biased, as it is difficult to assess the size of vertical objects 10-40 m in height. One no-biased height estimate makes use of automated distance measurement tools, as reported here.

Tree height measurement

Instruments for height measurement

(i)Christen hypsometer

(ii)Meritt hypsometer

(iii) Klasner hypsometer

(iv) Chapman hypsometer

(v) JAL hypsometer

(vi)Laser hypsometer

Instruments Based on Trigonometry are

a. Abney level

b. Haga altimeter

c. Sunnto clinometer

d. Spiegel Relaskop

2.5 ESTIMATION OF ABOVE GROUND Biomass

The above-ground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous undergrowth. For agricultural lands, this includes crop and weed biomass. To measure the biomass of vegetation which includes trees is not easy, especially in mixed, uneven-aged stands. It requires considerable labor and it is difficult to obtain an accurate measurement, given the variability of tree size distribution. The focus of this section will be on estimating carbon stocks of forests that are subject to deforestation and degradation. The mean carbon stock in aboveground tree biomass per unit area is estimated based on field measurements in fixed area sample plots or temporary sample points that are selected randomly or systematically.

It is hardly ever possible to measure all biomass on a sufficiently sample area by destructive sampling, However allometry models are used to estimate the biomass of individual trees to an easily measured property such as its stem diameter and height

For biomass estimation of woody vegetation any live plant greater than or equal to 2 cm DBH will be treated as above ground woody plant. Experience to date with the development of generic regression equations has shown that measurements of DBH explains more than 95% of the variation in tree biomass even in highly species rich tropical forests.

2.1 FOREST REGENERATION:Forest regeneration is the process by which new tree seedlings become established after forest trees have been harvested or have died from fire,insects, or disease. Regeneration is key to sustainable forestry.

2.1.1 Natural Regeneration: natural regeneration, occurs when new seedlings or sprouts are produced by trees left on or near the site

2.1.2 Artificial regeneration: Artificial Regeneration is the establishment of young trees through planting seedlings or seed.

2.2 Arboretum: An arboretum is a place where trees, shrubs, and sometimes herbaceous plants are cultivated for scientific and educational purposes.

2.2.3 Functions of an arboretum : An arboretum is a place where many varieties of trees are grown for research, educational and ornamental purposes.

2.3 Ecosystem services: This can be defined as a community of living organisms (Plant and animals) sharing an environment.

2..3.1Categories of ecosystem services: The Millennium Ecosystem Assessment (MA), a major UN-sponsored effort to analyze the impact of human actions on ecosystems and human well-being, identified four major categories of ecosystem services: provisioning, regulating, cultural and supporting services.

2.3.1.1 Provisioning services: the provision of food, fresh water, fuel, fiber, and other goods;

2.3.1.2Regulating services: This includes climate, water, and disease regulation as well as pollination

2.3.1.3Cultural services: This includes educational, aesthetic, and cultural heritage values as well as recreation and tourism.

2.3.1.4Supporting services: This includes soil formation and nutrient cycling.

2.2.2.Tree assessment: This are visual assessment of a tree's health by a certified arborist. They are done to determine the likelihood of failure of branches or the whole tree and the consequences of a failure.

2.4 Measurement of total height: This is the measurement total height of a tree from its stump to its tiptop

2.4.1Measurement of tree diameter at breast height: Diameter is generally measured 1.3 m (4.5 feet) above the ground, which is roughly at breast height. DBH is measured on standing trees outside of the bark. Diameter can be calculated by measuring the circumference of the tree, then divide circumference by π (3.1416).

2.5 Methods for estimating aboveground biomass: Above ground biomass is the above ground standing dry mass of live or dead matter. There are 2 method of estimating above ground biomass. They are Non-destructive and the destructive.

2.5.1 Destructive biomass estimation: This method is the most direct method, it is also known as the harvest method. This methods involves the harvesting of trees in a particular area and measuring the weight of the different components of the harvested trees.

2.5.1 Non-destructive biomass estimation: This estimate the biomass of a tree without falling.

Models developed from allometric equation

2.5 Belowground biomass estimation: All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter. (IPCC, 2006; GL FRA, 2005)

2.7Carbon stock: The quantity of carbon in a “pool”, meaning a reservoir or system which has the capacity to accumulate or release carbon. (FRA, 2005)

2.8 Soil organic carbon: Soil organic carbon is a measurable component of soil organic matter. It refers only to the carbon component of organic compounds

2.9 Carbon sequestration:

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Research area

The research was carried out in the Department of Forest Resources and Wildlife Management Arboretum, located in the Faculty of Agriculture, University of Benin, Benin city, Edo state, Nigeria (Fig. 3.1). The arboretum lies between longitudes 05^0 37' 25"E and latitudes 06^0 24' 03"N and an altitude of 134 (sat). It covers a land mass of 0.22 hectare. The annual rainfall in the area varies between 1500 mm and 2500 mm with a temperature range of 27 – 35ºC. Relative humidity ranges from 75 % at mid-day to 95 % at dawn. The general topography of the study area is regarded as low and the terrain is sloppy and gentle. The natural vegetation of the area is rainforest zone which supports growth of tropical hardwood trees such as *Terminalia spp., Khaya spp., Ceiba pentandr*a, shrubs, woody vines etc.

3.2 Method of Data Collection for Aboveground and Belowground biomass

The following materials were used for the purpose of this study; Suunto clinometer, measuring tape, Camera, wooden pegs, rope, cutlass, pen and note book.

3.3 Experimental design

Total enumeration of trees in the arboretum was used to estimate the aboveground biomass (AGB) and belowground biomass (BGB). A total of 8 sample plots of 15 x 15 m were randomly laid in the arboretum. Assessment was carried out on two (2) aboveground tree growth variables (tree height (Ht.) and Diameter at Breast Height (DBH).

The height and diameter were used for estimating the tree biomass using non-destructive sampling. Three (3) allometric regression models were identified and tested to predict Aboveground biomass (AGB) estimation, the best fit model was selected for biomass estimation using three (3) model evaluation statistics (coefficients of determination (R^2), Adjusted R^2, Akaike info criterion (AIC) and F-statistics.

Fig. 3.1 GIS of the study area

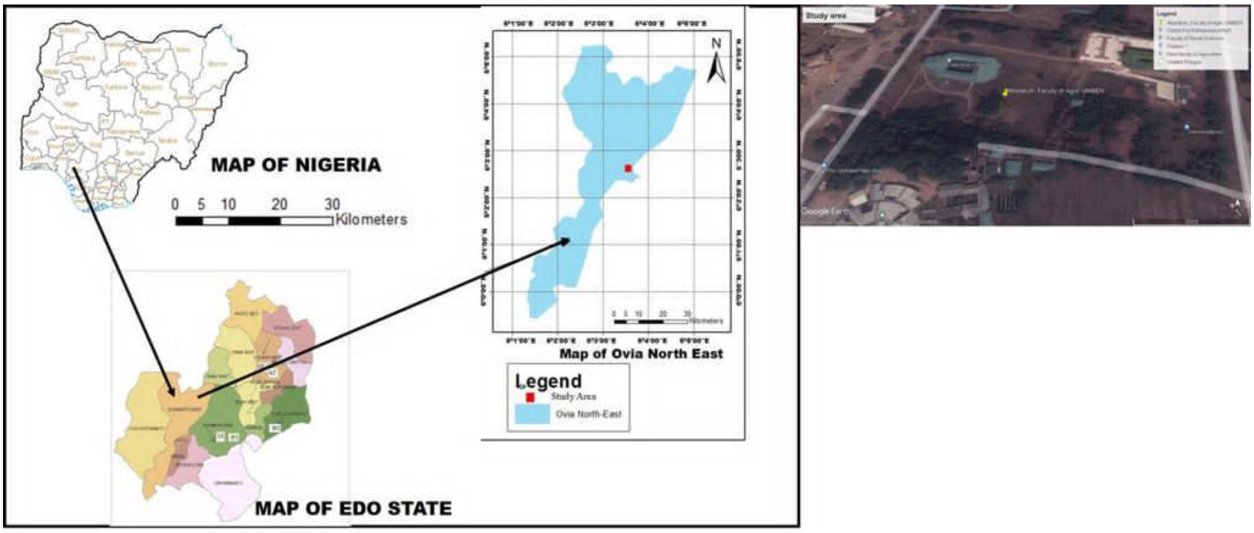

Fig. 3.2: Map of the study area

3.4 Biomass assessment

Tree height, diameters, crown spread, biomass loss are indicators to express differences in the growth attributes of trees (MacDicken *et al*., 1991), however, these growth attributes are influenced by some factors which are not limited only to site quality, season, age of stand, shade and companion crops (Okwu, 2019).

Tree height is the total stem length measured from the ground level to the highest growing point (MacDicken *et al*., 1991) while the diameter of a tree is the lateral growth expressed by the main trunk diameter which is usually measured at 1.3 m above the ground level.

The Stem diameter was measured using a measuring tape as described by MacDicken *et al*., (1991) while the tree height (H) was obtained using a suunto clinometer by taking the reading from point 'O' in the clinometer to the highest growing point of the tree (a) and again from point 'O' to the base of the tree (b). The formula used to obtain the total height of the tree using the suunto clinometer was;

Tree height for elevated ground; $H = a - (-b)$

$$H = a + b$$

Tree height for depressed ground; $H = a - (b)$

$$H = a - b$$

3.3.3 Above Ground Biomass (AGB) estimation

To estimate the aboveground biomass in the diversified tree-based system, non-destructive sampling was used. Growth parameters such as the height and diameter of the stands were computed into allometric regression models that converted individual tree inventory data to estimates of AGB (Ketterings *et al*., 2001 and van Breugel *et al*., 2011). To determine the best fit model to estimate the aboveground biomass, three allometric regression models developed by Brown (1997) model 1, Brahma *et al*., (2017) model 2 and Ketterings *et al*., (2001) model 3 were used to determine the best fit equation using three model evaluation statistics.

Table 3.1: Allometric regression models adopted for the study

S/N	Author	Model	Parameters
Model 1	Brown, 1997	AGB = exp {-2.134 + 2.530 x ln(D)}	where; AGB=Aboveground biomass(kg) D= Diameter at breast height(cm)
Model 2	Brahma *et al*., 2017	AGB = (exp (-3.31 + 0.95 (lnD^{2}H))) x 1.02	AGB = Aboveground biomass ln = Logarithm D = Diameter H = Height
Model 3.	Ketterings *et al*., 2001	AGB=aDb (0.066D2.59	AGB =Aboveground Biomass D = Diameter at breast height α and β = are parameters to be estimated

3.3.4 Belowground biomass estimation

The knowledge body on belowground biomass (BGB) estimation is limited as compared to that on aboveground biomass estimates. However, regression models for non-destructive sampling of trees has been developed which can predict root biomass based on aboveground measurement data have been developed (Cairns *et al*., 1997; Mokany *et al*., 2006) especially in even-aged plantations. However, this study is carried out in an uneven aged tree system where the root system is known to weigh 20 % of the aboveground biomass. Thus, to determine the belowground biomass (BGB) of the uneven aged tree system, data obtained from the AGB was multiplied by 20 %.,

3.3.5 Carbon stock assessment

Carbon content in standing trees has been reported as an essential element in quantifying forest carbon stocks (Martin and Thomas, 2011). There is a generic assumption of biomass consisting of 50 % carbon (Asaah *et al*., 2012) and this weight is known to be constant across a wide variety of tissue types and species. Although, it could vary between 45 and 50 % by oven – dry mass (Schlesinger,1991). Thus, the Land use, Land-use change and forestry (LULUCF) value of 0.47 C fraction approved by IPCC (2006) was adopted for this study.

To estimate the carbon stock of the diversified tree-based system, C fraction (0.47) was multiplied by the aggregate of AGB and BGB.

Carbon stock = 0.47 * (AGB + BGB)

3.3.6 Carbon Sequestration Potential

Carbon dioxide equivalent (CO_2e) sequestrated by the diversified tree-based system was estimated from the combination ratio derived from the atomic weights of the elements making up the CO_2 molecule to that of carbon C, i.e. 44/12 or approximately 3.67 (Asaah *et al*., 2012; Kauffman and Donato, 2012). This is used as a standard for reporting carbon stock estimates in the carbon market. The ratio (3.67) was multiplied by both carbon stock obtained in AGB and BGB in the diversified tree-based system to estimate CO_2 equivalent (e) (CO_2e) sequestrated.

Thus, CO_2e sequestrated = 3.67 * (C.AGB + BGB).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Variability in tree growth attributes in the tree-based system

The values of diameter and height as measurable characteristics related to the subset of trees that were sampled for Aboveground and Belowground biomass estimation using non-destructive sampling are summarized in Figure 1.

The result shows the average diameter of tree species in the study area. Plot 6 had the highest mean diameter (64.9 cm), plot 1 (49.58 cm) and the least diameter was recorded in plot 4 (25.52 cm). From the figure, it was also observed that the highest height was recorded in plot 8 (27.34 m) while the lowest was recorded in plot 2 (16.96 m).

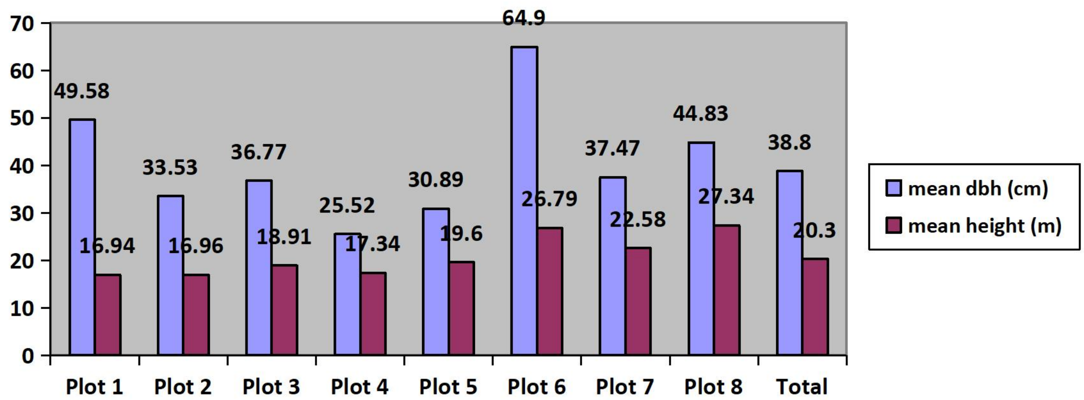

Figure 4.1 Mean tree height and diameter in the diversified tree-based system

4.1.2 Allometric Regression Analysis

In this study, allometric regression models were used to estimate the total Above Ground Biomass (AGB) and Below Ground Biomass. Three predictor variables were employed in this study and were tested (Table 4.1). In all cases AGB was subjected to a natural log transformation to normalize its distribution.

For the trees investigated, the model selected was a logarithmic model of Ketterings *et al*., 2001, using diameter as the predictor variable (i.e. Model 3: (AGB=aDb (0.066D2.59) indicated the highest modelling efficiency (R^2=1.000, AIC=-40.25, Std. error 1.34).

Table 4.1 Model evaluation statistics for allometric regression models in the estimation of Above ground biomass in the study area.

Model		**Model evaluation Statistics**			
#	**Author**	**R^2**	**Adj. R**	**AIC**	**F. Statistics**
1	Brown, 1997	75 %	1.20 %	19.65	0.385
2	Brahma *et al*., 2017	99.95 %	99.96 %	8.28	120708
3	Ketterings *et al*., 2001	100 %	100 %	-40.25	6.62

4.1.3 Biomass Estimation and Carbon Stock in a Diversified Tree-based System

The height and diameter of 87 trees were measured to determine the AGB of trees employing allometric regression models (Table 4.2).

Results from the table below shows that the total biomass recorded in the tree-based system was 164,660.17 Mg C/ha while the total amount of CO_2e sequestrated was 284,022.31 Mg C/ha.

Table 4.2 CO_2 sequestered in a diversified tree-based system in the study area

	Biomass	Carbon stock	CO_2e (Mg C/ha)
Aboveground	137,216.81	64,491.90	236,685.26
Belowground	27,443.36	12,898.38	47,337.05
Total	164,660.17	77,390.28	284,022.31

4.1.4 Determine price ($) per ton of carbon dioxide in the diversified tree-based system

Carbon credits or green house gas offsets may be referred to as marketable certificates that represent reductions in gases (Pelemo, *et al.*, 2020), this might contribute to the warming of the atmosphere. One carbon credit is equal to 1 ton of CO_2 (www.pointcarbon.org). This is referred to as the carbon dioxide equivalent (CO_2e). Thus, 1 ton of carbon equals 3.67 Mg C/ha. Given that the price per ton of carbon dioxide is $30 (www.pointcarbon.org).

Thus, the tons of CO_2 sequestered in the tree based diversified system is 284,022.3 Mg C/ha.CO_2 per dollar ($) = 284,022.3 tons x $30 = **$8,520,669**

4.2 Discussion

4.2.1 Tree Height and Diameter in the Diversified Tree-Based System

The analysis on the plots in the arboretum as shown in figure 4.1 revealed that the trees in plot 6 has the highest mean DBH (64.9 cm) which is followed by the trees in plot 1 which has a mean DBH of (49.58 cm). and the trees in plot 4 has the lowest mean DBH (25.52 cm). This can be as a result of human activities or other environmental factors which might affect the growth of trees (Ducey, 2010). The highest mean tree height was observed in plot 7 which has a mean of 26.79 m, while the lowest mean tree height was observed in plot 1 which has a mean of 16.94 m. It was also observed that the mean tree height in plot 1 and 2 were closely related.

4.2.2 Model Evaluation Statistics for Allometric Regression Models in The Estimation of Aboveground Biomass

Tree species composition influences pattern of maximum forest biomass accumulation in the study area, mixed tree increases the storage of SOC and biomass accumulation in the forest (Augusto and Boca, 2020). To estimate the aboveground biomass in the study area, 3 regression models (Brown, 1997 which has an R^2 of 75% and AIC of 19.65, Brahma *et al.*, 2017 which has an R^2 of 99.95 and an AIC of 8.28 and Ketterings *et al.*, 2001 which has an R^2 of 100% and AIC -40.25) were used. The third model was the best fit for estimating the biomass in the tree-based system, this is because of the evaluation fit statistics that was employed.

4.2.3 CO_2e (Mg C/ha) sequestered in the diversified tree-based system

The total biomass of the study area was 164,660.17. This was gotten by the addition of AGB 137,216.81 and BGB 27,443.36. The ABG biomass in the study area was higher than the BGB. With this, it is proven that the above ground biomass has the tendency to store more carbon gotten from the atmosphere and the BGB has the tendency to store the least carbon.

CHAPTER FIVE

5.0 CONCLUSION

Greenhouse gas is a gas that absorbs and emits radiant energy within the thermal infrared range causing the greenhouse effect. The primary greenhouse gases in the atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone. A simple, common sense approach to this climate crisis is carbon sequestration which will sponge up carbon dioxide emission with trees and other plants.

Carbon sequestration according to the Intergovernmental Panel on Climate Change (IPCC) defines it as the amount of carbon absorbed from the atmosphere by plants but which can be lost in part to the atmosphere through subsequent decomposition of dead residues. Thus, playing an important role in the glo`bal carbon cycle. Carbon sequestration has the sole objective of managing the excess release of GHGs to the atmosphere. This continued increase in concentration of GHGs in the atmosphere if not curbed might likely lead to climatic change resulting in large changes in ecosystems leading to possible disruptions in livelihood, economic activities, living conditions and above all human health. Carbon sequestration has proven with empirical evidence to be a long-term storage of carbon in the terrestrial biosphere, underground, oceans so that the build-up of principal greenhouse gas (carbon dioxide) concentration in the atmosphere will reduce or slow down. Hence, the fact that we have temporarily thrown the global cycle out of balance suggest that we can also rebalance the system by improving vegetation management and natural sequestration of atmospheric carbon through photosynthesis. Measuring and predicting sequestration of carbon in the diversified based system was fundamental to providing the quantifiable unit of carbon that can be traded or claimed as offsets against emissions in the arboretum.

5.1 RECOMMENDATION

The study recommended that:

1. Conservation efforts should be centered in the study area to help the protection of the rare species. For example *Milicia excelsa* (iroko)
2. Estimation of sequestration generally should be accurate, measurable, easy to handle, cost effective and verifiable.
3. A further study should be carried out to estimate the physicochemical properties and organic carbon in the soil.

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