WOODY SPECIES DIVERSITY, BIOMASS AND SOIL CARBON STOCK ALONG ALTITUDINAL GRADIENTS AND TOPOGRAPHIC ASPECTS: THE CASE OF KURA-CHALTE NATURAL FOREST, JIMMA ZONE, OROMIA REGIONAL STATE, SOUTH WEST ETHIOPIA

MSc THESIS

SAGNI OLANI LEMMI

HAWASSA UNIVERSITY, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCES, WONDO GENET, ETHIOPIA

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SAGNI OLANI LEMMI

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ADVISORS' APPROVAL SHEET 1

This is to certify that the thesis entitled "Woody Plant Diversity, Biomass and Soil carbon stock along altitudinal gradients and topographic aspects: The case of Kura-Chalte natural forest, Jimma Zone, Oromia Regional State, South West Ethiopia" Submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Forest Resources Assessment and Monitoring, Graduate Program of the Department of General Forestry, and has been carried out by Sagni Olani Id. No FrAM/R020/10, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence can submit the thesis to the Department.

Abdella Gure (PhD)	-------------------------	-------------------------------
Name of major advisor	Signature	Date
Fantaw Yimer (PhD)	--------------------------	-------------------------------
Name of co-advisor	Signature	Date

EXAMINERS' APPROVAL SHEET 2

We, the under signed, members of the Board of examiners of the final open defense by Sagni Olani have read and evaluated his thesis entitled "Ethiopia Woody Plant Diversity, Biomass and Soil carbon stock along altitudinal gradients and topographic aspects: The case of Kura-Chalte natural forest, Jimma Zone, Oromia Regional State, South West" and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science.

____________________	______________________	______________________
Name of the Chair person	Signature	Date
Dr. Abdella Gure	______________________	______________________
Name of Major Advisor	Signature	Date
Dr. Fantaw Yimer	______________________	______________________
Name of Minor Advisor	Signature	Date
____________________	______________________	______________________
Name of Internal Examiner	Signature	Date
____________________	______________________	______________________
Name of External Examiner	Signature	Date
____________________	______________________	______________________
SGS approval	Signature	

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Dedication

This thesis is dedicated to my beloved family affectionately, to my mother Ayantu Kitil, Mr. Desisa Olani, Ms. Bukura Olani and her family, Mr. Ferede Olani and his family, Mr. Merga Olani, Ms. Aleke Olani, Ms. Chaltu Olani, Mr. Deressa Abetu and my family and all my friends for their concern, pray, inspiration, love and support through out my life.

Abbreviation/ Acronyms

AGB--------------Above ground biomass

AGC--------------Above ground Carbon

BA-----------------Basal area

BGB--------------Below ground biomass

CRGE-------------Climate Resilient Green Economy

CSA---------------Central Statistics Authority

FAO---------------The Food and Agriculture Organization of the United Nations

GHG--------------Green House Gases

GPS---------------Geographical Positioning System

IPPC--------------Intergovernmental Panel on Climate Change

IVI----------------Importance Value Index

MEFCC----------Ministry of Environment, Forest and Climate Change

NBSAP---------- National Biodiversity Strategy and Action Plan

NMA-------------National Meteorology Agency

RBA--------------Relative Basal Area

RD-----------------Relative Density

REDD+-----------Reducing Emissions from Deforestation and Forest Degradation

RF------------------Relative Frequency

SOC---------------Soil Organic Carbon

SOM---------------Soil Organic Matter

UN-----------------United Nations

UNFCCC ---------United Nations Framework Convention on Climate Change

WANRO----------Woreda Agriculture Natural Resource Office

WEFCCO---------Woreda Environment, Forest and Climate Change Office

Table of Contents

List of Tables

List of Figures

Abstract

Ethiopian tropical forests presents a great geographical diversity with high and rugged mountains, flat-topped plateaus, deep gorges, river valleys and plains and as a result it has different species diversity, biomass and soil carbonstock. The study was conducted in Kua-Chalte moist afromontane natural forest located in Limmu Seka Woreda, Jimma Zone, Oromia Regional State, and Southwest Ethiopia. The aim of the study was to assess the woody species composition, diversity, structure and to determine carbon stocks of the forest. A total of 60 plots, each within 20m × 20m were laid systematically at 100m interval along the altitude and aspect to collect vegetation and soil data. In each of the plots, all woody species were recorded; cover abundance of woody species estimated; and their height and DBH were measured. Five subplots, each with 1m × 1m were laid at the four corners of the main plots for collecting *composite soil samples and middle of each plot for bulk density analysis. Similarly, foursubplots of 1m × 1m were laid at the four corners of each plot to collect litter data. A total of 67 woody tree species belonging to 35 families and 56 genera was recorded and identified. in The most dominant families were Fabaceae, followed byMoraceae, Oleaceae, Asteraceae, Rubiaceae,and Rutaceae respectively. The total basal area and IVI of the forest were 48.17* m^2*/ha and 300.01respectively. Forests play an important role in keeping greenhouse effect and carbon cycle working naturally by reducing* CO_2 *emissions and increasing the* CO_2 *pulled out of the atmosphere and stored as carbon that helps for climate change mitigation. With this importance, altitude and aspect affect the carbon sock of the study area. The mean above and below ground carbons were increased as altitude increase, whereas carbon along aspects was not statistically significant. The other pools of carbons were showing an increasing or decreasing pattern along altitude, while soil organic carbons along lower, middle and high altitude resulted in 162.02, 216.77 and 190.72 t/ha respectively, and SOC along aspect was 133.53, 172.61, 152.67 and 169.61 t/ha within the respective direction of W, S, N and E independently.*

Key words: Altitude, Aspect, Kura-Chalte natural forest, Biomass carbon, Floristic composition and Soil carbon.

Declaration

I hereby declare that this MSc Specialty or equivalent thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name____

Signature: ____

This MSc Specialty or equivalent thesis has been submitted for examination with my approval as thesis advisor.

Name____

Signature: ____

Place and Date of Submission: ______________________________

1. INTRODUCTION

1.1. Back Ground of the Study

Ethiopia covers a land area of around 1,120,000 km2, stretching between 3^0 and 15^0 N latitude and 33^0 and 48^0 E longitude (Thomas and Million Bekele, 2013). Ethiopia presents a great geographical diversity with high and rugged mountains, flat-topped plateaus, deep gorges, river valleys and plains. Its diverse topography has given rise to a wide range of diversities of flora and fauna and in rich endemic species. Ethiopia has about 6,000 species of higher plant taxa of which 10% are endemic due to its diversity in topography (Ensermu Kelbessa and Sebsebe Demissew, 2014).

Tropical forests are among the most complex and species rich ecosystems of the world (Primark and Corlett 2005) and store 40–50% of carbon in terrestrial vegetation (Lewis *et al.*, 2009). Tree diversity is fundamental to tropical forest biodiversity because it provides the resources and habitats for almost all other forest species. In tropical forests, tree diversity varies from place to place mainly due to differences in biogeography, habitat and disturbances (Whitmore 1989).

Ethiopia adopted a new forest definition as follows: “Land spanning at least 0.5 ha covered by trees and bamboo), attaining a height of at least 2m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course” (Minutes of Forest sector management (MEFCC, 2015). Forest has multipurpose by nature, it also provides a home for biodiversity and aesthetic values, and serve as the basis for developing local entrepreneurial opportunities, tourism, recreation, rural livelihoods, fuel woods, fodder, fiber, fruit and herbal medicines (Maria *et al.*,2012). Forests are ecologically important in influencing climate and maintaining global balances of carbon and atmospheric pollutants (Maria *et al.*, 2012).

Ecological and environmental problems such as soil degradation, soil erosion and alteration of natural resources are some of the negative effects resulting from the destruction of natural vegetation (Kitessa Hundera *et al*., 2007). Furthermore, biodiversity resources along with their habitats are rapidly disappearing in the country (Feyera Senbeta and Denich, 2006). Loss of such forest resources would have great implication for the environment, biological diversity and socioeconomic setup of the communities. So, this study estimate carbon stock of Kura-Chalte natural forest and made an analysis of plant woody diversity along the altitude and topographic aspects. According to the IPPC (2006) carbon pools in forest ecosystems comprises of carbon stored in the living trees (aboveground) and belowground (roots); in dead matter, including standing dead trees, down woody debris and litter; in non-tree understory vegetation and in the soil organic matter.

Tropical forest lands are a natural forest type that is an important source of biodiversity, food and carbon storage, and comprise the largest proportion of the world's forests at 44%, FAO (2011); they also contain one of the largest carbon pools and have a significant function in the global carbon cycle. Deforestation and forest degradation contribute 15%–20% of global carbon emissions, and most of this contribution comes from tropical regions.

Approximately 60% of the carbons sequestered by forests are released back into the atmosphere via deforestation. Scholars have also determined that tropical deforestation releases 1.5 Giga tons of carbon into the atmosphere each year Gullison, R. *et al.,* (2007). The amount of carbon sequestered by a forest can be inferred from its biomass accumulation because approximately 50% of forest dry biomass is carbon Brown, (1997). When trees are cut down there are three destinations for the stored carbon- dead wood, wood products or the atmosphere. The decreased tree carbon stock can either result in increased dead wood, increased wood products or immediate emissions. Deadwood stocks may be allowed to decompose over time or may after a given period, be burned leading to further emissions.

Assessment of biomass provides information on the structure and functional attributes of a forest and is used to estimate the quantity of timber, fuel and fodder components (Brown, 1997). With approximately 50% of dry forest biomass comprised of carbon (Westlake, 1966), biomass assessments also illustrate the amount of carbon that may lose or sequestered under different forest management regimes. According to Richard (2008), terrestrial ecosystems, especially forests, are increasingly valued because of their ability to sequester carbon. Much of this carbon uptake is being attributed to increased rainfall associated with the warming trend in temperature. Therefore, a carbon sink occurs when carbon sequestration is greater than carbon releases over some time period (Mathews and Robertson, 2002).

The soil landscape of Limu Seka was characterized under four soil types because of landforms, topography, slopes, parent materials, soil morphology and physico-chemical properties. These were Leptosols 44.8 %, Gleysols 28.2 %, Nitisols 21.8 % and Cambisols 5.2 % according to Alemayehu Regassa (2016). The study was focuses on the first three soil types of the study area.

Soil organic carbon (SOC) is defined as carbon in soils derived from the decay of plant and animal residues, living and dead microorganisms, and soil biota (Jörn, P, *et al*., 2014). Global soils contain roughly twice as much carbon (C) as the atmosphere and three times the amount of C in above ground vegetation (Ontl, T. and Lisa, A., 2012). SOC content is important due to SOC's relationship with soil properties and functions ranging from the regulation of water runoff to reductions of erosion and greenhouse gas (GHG) emissions as targeted by Sustainable Development Goals (Goal 15: Sustainably Manage Forests, Biodiversity Loss. 2017). Size and changes in the soil organic carbon (SOC) pool are major uncertainties in global earth system models used for climate predictions. Accurate estimation of SOC stocks is vital to understanding the links between atmospheric and terrestrial carbon (Friedlingstein *et al.,* 2014).

However, these rich biological resources of Ethiopia are diminishing at an alarming rate due to extensive anthropogenic activities such as uncontrolled exploitation, expansion of agricultural land, grazing land, infrastructure, forest fire, industrialization and urbanization (Gessesse Dessie and Johan Kleman, 2007). According to the Ethiopian National Energy Steering Committee (1986), 94.5% of the nation's total energy comes from biomass sources, and 77% of it is derived from wood and tree residues. Loss of forest biomass through deforestation and forest degradation makes up 12% to 20% of annual greenhouse gas emissions (Saatchi *et al.*, 2011); which is more than all forms of transport combined together in the world.

1.2. Statement of the Problem

Ethiopia is a country of great geographical diversity with high and rugged mountains, flat-topped plateau and deep gorges, river valleys and rolling plains. This gives the country a highly diversified climatic conditions and topography with a wide range of habitats and vegetation types. However, the forest cover of Ethiopia is diminishing over times due to an ever increasing demand for farmlands, the increasing livestock population, and an increasing demand for firewood and charcoal with the illegal harvesting of the forest and its products (Teshome Soromessa *et al.,* 2004).

Most of the remaining forests in Ethiopia are confined to the south and the southwestern parts which are less accessible (Kumilachew Yeshitela and Tamrat Bekele, 2002). However, now a day the remnant natural forests in these areas are also continually threatened by anthropogenic activities and the existing ones are in a secondary state of development. Therefore, detailed biodiversity and ecological studies are desirable to draw the attention of policy makers to understand the ecosystem services of this biodiversity assemblage and undertake appropriate conservation measures and mitigate climate change.

Ecologically and economically, the forest gives invaluable environmental benefits and sources of income to the country by providing watershed protection services, carbon sink service and by providing habitats for a multitude of animal and plant life and production functions (food, raw materials and genetic resources). So, the current study was carried out on assessment of plant woody diversity, biomass and soil carbon stock in Kura-Chalte natural forest in relation to altitudinal gradient and topographic aspect that was not studied before and keep some management activities for continuous development of this natural forest.

1.3. Objectives of the study

1.3.1. General objective

The general objective of the study was to assess the woody species diversity, biomass and carbon stock along altitudinal gradients and topographic aspects in the study area.

1.3.2. Specific objectives

i. To assess and document woody species diversity along altitudinal gradients and topographic aspects of Kura-Chalte natural forest,
ii. To determine plant community types and vegetation structure of the forest along altitudinal gradients and topographic aspects in the study area, and
iii. To determine biomass and carbon stocks along altitudinal gradients and topographic aspects of the Kura-Chalte natural forest

1.4. Significance of the Study

The result of study generated information on woody species diversity and carbon stock of Kura-Chalte natural forest and thus its significance in climate change mitigation due to its carbon sequestration function. The study also highlight the conservation status and threats to the forest in the study area. The findings of the study would serve as a source of empirical data that could be used to convince local administration and regional government to make better efforts to protect the forest from various types of pressures being posed by the local communities.. Particularly the findings of the study is of relevance to all stakeholder institutions, partularly for the Ethiopian Biodiversity Institute, the Environment, Forest and Climate Change Commission, Ministry of Agriculture and other governmental and nongovernmental organizations that directly or indirectly contribute to the conservation and utilization of the forest. Besides, the study will be used as a baseline for other researchers who were interested to conduct related research deeply in this forest area.

1.5. Research Question

1. What does the woody species composition and diversity of the Kura-Chalte natural forest look like?
2. What are the dominant woody species in the natural forest in the study area and what is their population structure?
3. What does the different carbon stocks of the forest look like, and do they show variation along altitudinal gradients and aspects?

2. LITERATURE REVIEW

2.1. Afromontane Moist forest of Ethiopia

The moist evergreen montane forest consists of high forests of the country, mainly the southwest forests, wet and also humid forest in the southeastern plateau known as the Harenna forest. This forest occurs mainly in the southwestern part of the country (Wollega, Illubabor and Kafa). Afromontane forests are among the most species rich ecosystems on earth (Schmitt *et al.,* 2010). They are under severe land use pressure, because the same environmental conditions that foster high species diversity also render tropical montane forest areas suitable for agricultural uses**.**

The moist forest ecosystem is the most diverse ecosystem in composition, structure and habitat types (NBSAP, 2005); consequently it is rich in biodiversity with a number of endemic species. In the southwest part of Ethiopia forest are major sources of coffee production and timber for saw log, plywood and chip wood and paper industries during the last century. Moreover, forests of the country, particularly the montane moist forests are important components of the planet to sequester CO_2 gases in the atmosphere.

However, the destruction of natural forests as well as degradation of the various habitat types caused by different human activities in montane moist forests made the most vulnerable and threatened ecosystem. Therefore, an appropriate and effective law that is applied should be formulated to safeguard the protection and sustainable utilization of the remaining forest resources, otherwise the country losses one of its major 'Carbon Sink'.

2.2. Woody diversity of Ethiopia

Ethiopia is one of the tropical countries with diverse flora and fauna. This diversity results from its diverse topography and climatic conditions which led to the emergence of habitats that are suitable for the evolution and survival of various plant and animal species. The floras of Ethiopia are very heterogeneous and have rich endemic taxa. The number of species of higher plants (flowering plants, conifers and ferns) found in Flora of Ethiopia and Eritrea Volumes 1-8 is about 6000, of which about 10% are endemic to the country (Vivero *et al*., 2006).

The moist evergreen forest ecosystem is the most diverse ecosystem in composition, structure and habitat types (NBSAP, 2005). Forests worldwide are known to be important habitats in terms of the biological diversity they contain and in terms of the ecological functions they serve. Ecologically, the forest gives important environmental benefits by providing carbon sink/ carbon storage service, watershed protection services (protect soil erosion and flooding) and providing habitats for a large amount of animals (Sisay Nune *et al*., 2010).

Forests are basic resources for life. The forest serves as a source of food, household energy, construction and agricultural material, tourism and recreation values and medicines for both people and livestock (Vivero *et al.*, 2005). They also serve as biodiversity reserve, construction wood, ecological balance, eco-tourism, environmental benefits, fire protection, flora biodiversity, food, for wildlife conservation (fauna), fuel wood, gum and incense production, honey production, medicinal values, restoration of forest resources, seed source, soil conservation, spice sources, timber production, wildlife habitat, wildlife safe haven (protection), spring abundance by encouraging underground storage and recharge (Tamirat Bekele, 2002).

Plant diversity can be affected by different biotic and abiotic factors. The plant communities and their component species are exposed to changes in the environmental, physical, biological, technological, economic or social factors (Frankel *et al.*, 1995). Globally, patterns of plant species diversity are influenced by latitude, attitudinal and soil gradients. The other factors that highly influence plant diversity are human beings, as destructive factor (Ababu Anage, 2009).

2.3. Carbon sequestration potential of forests

The forest is the home of two-thirds of all plants and animals living on land, it is the most biodiversity terrestrial ecosystems (FAO, 2010; IUCN, 2010). Also it comprises diversity within and among species, and within and between each of the terrestrial and aquatic components of forest ecosystems. The services provided by forests cover a wide range of ecological, economic, social and Cultural considerations and processes. Hence, ecosystem services are the outcome from ecosystem functions that benefit human being (Nasir *et al.*, 2007).

Ecologists have more interest in potential functional relationships between diversity and carbon sequestration (Spehn *et al*., 2005; Srivastava and Vellend, 2005). In the former case, the relationship of tree species diversity to C sequestration is likely to be of greatest concern for managers interested in sequestering the maximum amount of C over the short term. In the latter case, understanding the relationship of tree species diversity to carbon storage will be critical to maintaining C stocks of protected forests over the long term.

2.4. Global carbon cycle

Forests play an important role in the global carbon balance. As both carbon sources and sinks, they have a potential to form an important component in efforts to combat global climate change. FRA (2010) estimated that the world's forests store 289 Gt of carbon in their biomass alone (www.fao.org/fra/fra2010/en/). Forest carbon flows comprise a significant part of overall global greenhouse gas emissions. While global forests as a whole may be a net sink, global emissions from deforestation contribute between 20 to 25 percent of all greenhouse gas emissions (IPCC, 2007).

For the world as a whole, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period of 2005-2010, mainly because of a reduction in the global forest area. Globally, forests act as a natural storage of carbon, contributing approximately 80% of terrestrial above ground, and 40% of terrestrial below ground biomass carbon storage (Kirschbaum, 1996).

Forest soils are also an important component of the global carbon cycle, which stocks a large amount of soil organic carbon (SOC) and are the largest reservoirs in the world. SOC plays important role in alleviating the effects of greenhouse gases and storing, enhancing soil quality, sustaining and improving food production, maintaining clean water and reducing CO_2 in the atmosphere (Sakin, 2012)

Forests provide a number of important local services that can reduce communities vulnerabilities to climate change such as water flow, reduce runoff, erosion, siltation, flooding as well as in the production of food and medicine. So sustainable management strategies are mandatory for forest conservation mechanism and manage soil organic matter (SOM). Therefore, it is necessary to make the forest carbon sinker rather than sources.

2.5. Global Climate Change

According to IPCC (2007) report most of the observed increase in global average temperatures since the mid-20th century is very likely due to observed increases in anthropogenic greenhouse gas concentrations. Average global temperatures have already registered an increase of 0.7°C, caused by the growing concentration of atmospheric greenhouse gases (IPCC, 2007).

Climate change may be limited to a specific region, or may occur across the whole earth (Houghton and Theodore, 2001). According to UNFCCC (1992) climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. The United Nations Framework Convention on Climate Change was created as a cooperative international effort to limit average global temperature increases and the resulting climate change, as well as to cope with whatever impact were, by that time, inevitable (UNFCCC, 1992). Ethiopia has long recognized the country's vulnerability to climate change impacts and the urgency for a national adaptive response to climate change effects. As a responsible member of the global community, Ethiopia has been an active participant in international climate negotiations, initiated and implemented a number of climate-related national policies.

Greenhouse gases including water vapor, carbon dioxide, methane, nitrous oxide, and ozone are believed to have played an important role in the global climate change (Patenaude *et al.*, 2005; UNFCCC, 1997). Sunlight reaches the earth as short wavelength and most are absorbed and warmed the earth. In turn, the earth emits long wave radiation back to the atmosphere. The greenhouse gases absorb a fraction of the energy and then emit long wave radiation both towards space and back to the earth. The downward emitted energy further warms the surface of the earth, which results in more warming of the earth‘s surface. This greenhouse effect process is increased by anthropogenic emission of greenhouse gases, a large portion of which is carbon dioxide (Junjie, 2008).

2.6. Forest Contribution to Climate Change Mitigation in Ethiopia

Climate change mitigation is the process of reducing greenhouse gas (GHG) emissions that come from forestry, agricultural and industrial activities. Ethiopia considers REDD+, which is an important component of the CRGE strategy, as an opportunity and viable source of sustainable finance for investment in forest management, forest conservation, and forest restoration to enhance multiple benefits of forests, including to biodiversity conservation, watershed management, and increased resilience to climate change, improved livelihoods and reduced poverty (REDD+, 2014 annual report).

Forests play an important role in keeping greenhouse effect and carbon cycle working naturally by reducing CO_2 emissions and increasing the CO_2 pulled out of the atmosphere and stored as carbon that helps for climate change mitigation. The world‘s greatest concern is on CO_2 (Patenaude *et al.,* 2005), hence an understanding of global carbon cycles is one of the fundamental steps in addressing greenhouse gases concerns. Forest plays an important role in the carbon cycle as they dominate the terrestrial vegetation, which exchanges CO_2 with the atmosphere through photosynthesis and respiration (Dixon *et al.,* 1994; Patenaude *et al.,* 2005).

Forest ecosystems are deemed to be an important factor in climate change because they can be both sources and sinks of atmospheric CO_2 which means forests are capable of mitigating the effect by absorbing and storing carbon. Furthermore, the carbon accumulation potential in forests is large enough that forests offer the possibility of sequestering significant amounts of additional carbon in relatively short periods. However, forest carbon also can be released fairly quickly; such as in forest burning (Sedjo *et al*., 1998).

2.7. Measuring Carbon Pools

Carbon pool is a reservoir which has the capacity to accumulate or release carbon. According to Brown (1997) carbon pool a reservoir or system which has the capacity to accumulate or release carbon, forest is composed of pools of carbon stored in the living trees and below ground, in dead matter, including standing dead trees, down woody debris and litter, in non-tree understory vegetation and in the soil organic matter.

2.7.1. Above Ground Biomass (AGB)

Aboveground plant biomass comprise all woody stems, branches and leaves of living trees, creepers, climbers and epiphytes as well as understory plants and herbaceous growth (Hairiah, 2010). It is mainly the largest carbon pool and it is directly affected by deforestation and forest degradation. The vegetation of tropical forest is a large and globally significant storage of carbon because tropical forest contains more carbon per unit area than any other land cover. About 50% of plant biomass consists of carbon.

The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation. Studies on aboveground living biomass and carbon stock in tropical forests have been carried outby several researchers, either measured directly based on destructive sampling in experimentalplots (Ludang and Jaya, 2007; Miyamoto *et al.,* 2007) or estimated based on volume data offorest inventories (Brown *et al.*, 1989) Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release up to 80% of the stored carbon back to the atmosphere (McHale *et al.,* 2007).

2.7.2. Below Ground Biomass (BGB)

Below ground biomass carbon pool consists of the biomass contained within live roots. The measurement of belowground biomass is more difficult due to the mass of soil that needs to be excavated and the difficulty in separating fine roots from soil particles and measuring root biomass is time consuming and expensive due to the way that roots are distributed in the soil (Pearson *et al.,* 2005). As with AGB, although less data exist, regression equations from root biomass data have been formulated which predict root biomass based on aboveground biomass carbon (Brown, 2002).

Roots play an important role in the carbon cycle as they transfer considerable amounts of carbon to the ground, where it may be stored for a relatively long period of ti The plant uses part of the carbon in the roots to increase the total tree biomass through photosynthesis, even though C is lost through the respiration, exudation and decomposition of the roots. Ponce-Hernandez (2004) described that some roots can extend to great depths, but the greatest proportion of the total root mass is within the first 30 cm of the soil surface.

2.7.3. Deadwood Biomass (DWB)

The dead wood organic matter carbon pool includes all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10cm Pearson *et al.,* (2005). The dead wood is then classified into one of several decomposition classes such as fallen dead wood, standing dead wood with branch and no branch and stump stand dead wood. According to Condit (2008), in tropical forests, there is less fallen wood because trunks decay much faster, so the importance of sampling is reduced, but it is still 10-15% of the living AGB. On the other hand, dead wood or litter carbon stocks (down trees, standing dead, broken branches, leaves) are generally assumed to be equivalent to around 10-20% of the AG forest carbon estimate in mature forests (Zhu *et al*., 2010).

2.7.4. Litter Biomass/ Dead Organic Matter (DOM)

Litter is defined as dead surface plant material that is still recognizable and is not decomposed to the point that identification is impossible to define. The DOM litter carbon pool includes all non-living biomass with a size greater than the limit for soil organic matter (SOM), commonly 2mm, and smaller than that of dead organic matter wood, 10cm diameter (Zhu *et al*., 2010). The accumulation of litter is a function of the annual amount of litter fall, which includes all leaves, twigs and small branches, fruits, flowers, and bark, minus the annual rate of decomposition.

2.7.5. Soil Organic Matter (SOM)

Soil organic carbon is the result of input of plant debris, decomposition, and transport of C between soil layers representing a dynamic equilibrium of gains and losses (Lal, 2004). The quality and composition of the plant litter falling to the soil surface have a tremendous impact on the composition of the soil carbon (Barth and Klemmedson, 1978). More recently, soils have gained attention within the global change debate as largest terrestrial C pool (Perruchoud *et al.*, 2000), storing more carbon (C) than is contained in plants and the atmosphere combined storing 1.5 to 3 times more carbon than vegetation (Wang *et al*., 2004).

The distribution of soils and their characteristics, among others, forming factors, is affected by topography (Jenny, 1980). Topography influences soil properties through its effects on geomorphological, hydrological and biogeochemical processes (Webster *et al.*, 2011). And also SOM is influenced through land use and management activities that affect the litter input, for example, how much harvested biomass is left as residue, and SOM output rates, for example tillage intensity affecting microbial survival. SOM includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal and Bruce, 1999). Inorganic forms of carbon are also found in soil: however, forest management has greater impact on organic carbon and so inorganic carbon impact is largely unaccounted.

The bulk density of the soil is influenced by several factors such as compaction, consolidation and amount of SOC present in the soil, but it is highly correlated to the soil organic carbon (SOC) content and soil organic matter (SOM).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in Kura-Chalte moist afromontane natural forest lies between 08° 22' "22 N – 063° 57' 28" E and 08° 23 '55" N – 036° 58' 33" E of Limmu Seka woreda, Jimma zone, Oromia regional state, South West Ethiopia. The administrative center of the district is Atinago town, which is located at about 454 km Southwest of Addis Ababa, and 109 km from Jimma town. The woreda is bordered by Yanfa woreda in the West, Limmu Kossa in the North, Nono Benja woreda in the South and Chora Botor woreda in the East.

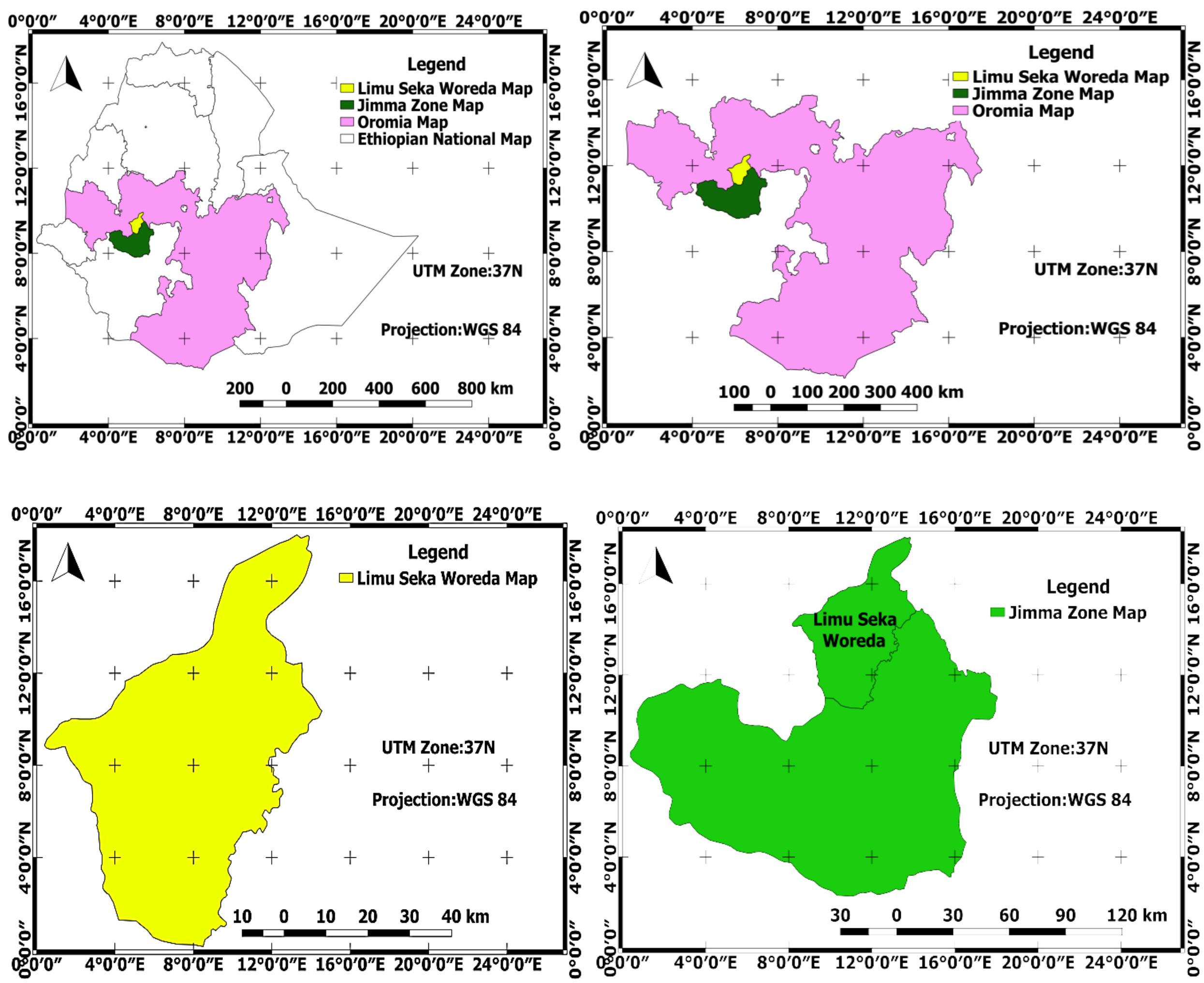

Figure 1: Map of the study area

3.1.2. Climate

There are two distinct seasons in Limmu Seka: the rainy season starting in late March and ending in October, and the dry season occurring during November to early March. The mean annual rainfall of the area ranges from 1800 mm to 2300 mm (Kitessa Hundera and Tsegaye Gadissa, 2008). The agro-ecology is characterized by 13% highland and 55% mid-highland and 32% lowland (WANRO, 2019). The mean and the maximum temperature of the woreda are about 12 ^{o}C and 30^{o}C respectively (NMA, 2019 Jimma).

3.1.3. Land use and human population

In the woreda, about 10,241 hectares (ha) land is currently covered by forest and bush, while 38,874 ha are under crop production (Cascape working paper, 2014). The woreda's potential for agriculture is estimated to be around 42,704 ha, from which sorghum covers 21,538 ha and maize covers 1,266 ha. The woreda has a total population 189,463, out of this 96,144 Males and 93,794 females respectively (Woreda Economic development and Finance office, 2019). Moreover, 80% of the population in the woreda is Muslim followed by 18% Orthodox Christians and 2% Protestant Christians. The total area of Kura-Chalte forest area is 2,196.12 ha according to Limmu Seka Environment, forest and climate change office (WEFCC, 2019).

3.2. Methods of Data Collection

3.2.1. Data Collection

3.2.1.1.Reconnaissance Survey

A reconnaissance survey was carried out in August 24 - 28, 2018 in order to obtain information and general impression of Kura-Chalte natural forest of Limmu Seka. This survey was aimed to have a better familiarization with the study site.

3.2.1.2. Delineation and Stratification of the Study Area

Stratification was done based on the physiognomy (physical structure) of the forest and attitude that make clear boundaries between in the forest in order to take accurate data from the field as well as to maintain the homogeneity of the area using Google Earth and QGIS. Forest zones are selected within altitudinal ranges above mean sea level as vegetation types differ according to altitudinal variation (Bhishma P. *et al.*, 2010). Based on physiognomy and altitude variation, the study site was classify into three vegetation zone: Lower altitude (1740m - 1970m) that were characterized by vegetation like *Acacia etbaica, Acacia abyssinica, Combretum adenogonium, Entada abyssinica, Gardenia ternifolia, Myrsine africana, Ozora insigns, Stereospermum kunthianum, Syzygium guineense subsp.guineensis* and *Terminalia macroptera,* Middle altitude (1971m - 2175m), this zone is dominated by species like *Albizia gummifera, Bersema abyssinica, Celtis africana, Millettia ferruginea, Croton macrostachyus, Spathoda campanulata, Podocarpus falcatus, Polyscias fulva, Schefflera abyssinica, Syzygium guineense. subsp.afromontanum* and *Vepris dainellii* and higher altitude (>2176m) is characterized by *Pouteria adolfi-friederici, Prunus africana, Olea welwitschii, Olea europea, Olea capensis,* *Warburgia ugandensis, Euphorbia abyssinica, Apodytes dimidiata* and *Ochna holstii.*

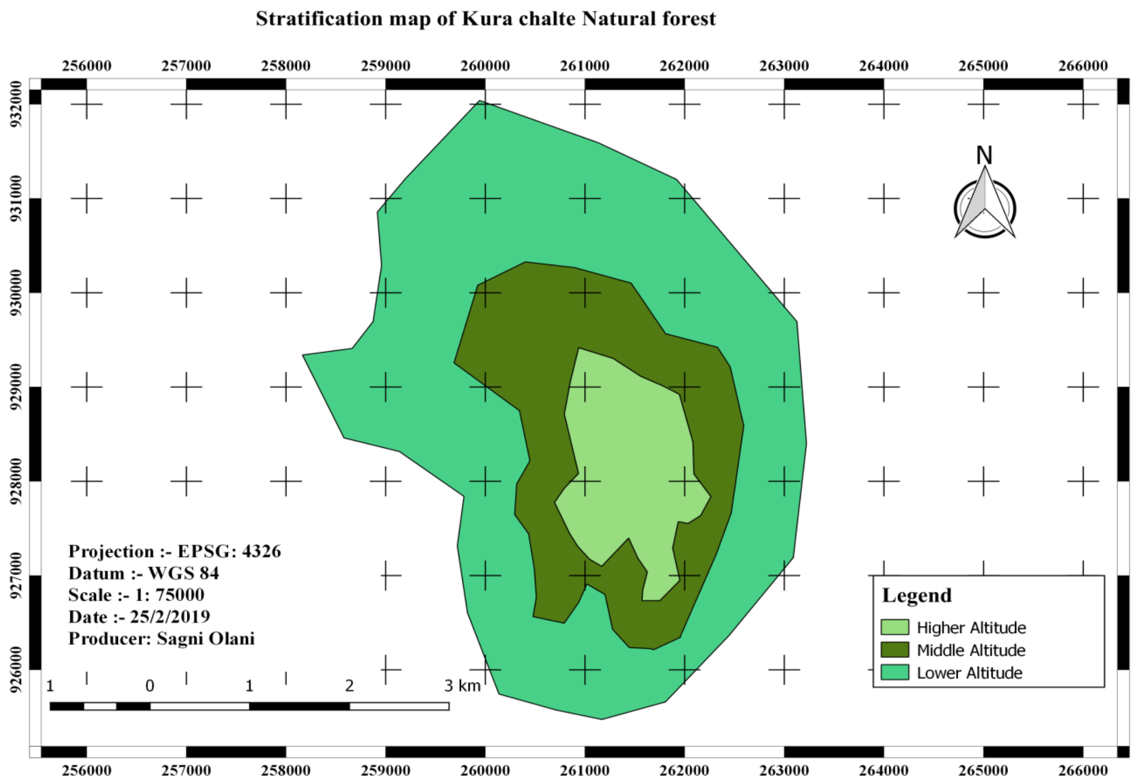

Figure 2: Map of the stratified Kurachalte natural forest

3.2.1.3.Sampling Design and Field Measurement

The vegetation was divided into three main vegetation zones based on the previous researchers by Friis (1986) and Bussmann (1997). At the stratified forest in four aspects, six samples at lower altitude, five samples at middle and four samples at higher altitude for biomass data in each direction and three samples at lower and middle elevation and two samples at higher altitude in each direction for soil data collection in each topographic direction in zigzag way (60 and 32 plots for biomass and soil respectively). Plots of 20m x 20m (0.04ha) were placed in forest zones across the forest physiognomy systematically to address each physiognomic variation and to get homogeneous samples in the study area accordingly. In all the three vegetation zone forest and soil data collection was carried out when the external appearance of vegetation, its vertical structure, and the growth forms of the forest make difference. The number of sample size required for each strata in the present study of both study sites was determined by the following Pearson *et al*., (2005) formula:

$$n=\frac{1}{\left(\frac{A}{tCV}\right)^2+\frac{1}{N}}$$

where, n = required sample size, A = allowable error percent (allowable error or the desired half-width of the confidence interval) which was alculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock x 0.1, for 10 per cent precision, t = t- value (the sample statistic from the t-distribution for the 95 per cent confidence level which is usually set at 2 as sample size is unknown at this stage, CV = coefficient of variation, and N = population size of each stratum.

The number of sample plots allocated for lower strata n=23.67**~ (24),** for middle n= 20.15~**(20)** and for higher n=15.75 ~ **(16)** and **60** total plots.

Trees/shrubs with multiple stems with DBH branched below 1.3m were counted as single individuals and bole circumference was measured separately. The latitude and longitude of the study plots were recorded by using Garmin 60 GPS. The materials used in data collections were diameter tape, Meter (50m), notebook, pen and pencil, caliper, core sampler, sensitive balance, knife, hammer, plastics, compass and hypsometer for field measurement. To avoid boarder edge effect the plots were laid 20 - 50 meters from the boarder of the forest and between the two vegetation zones in the forest.

3.2.1.4. Wood density

Wood specific densities of the collected woody plant species were collected as secondary information from ICRAF wood density database (www.worldagroforestry.org) and Global wood density database (Zanne *et al*., 2009). In this study, total numbers of sixty-seven (67) woody plant species were recorded. Of which the basic wood density of fifty-nine (88.06 %) woody plant species were collected as species specific basic wood density from Global Tree Wood Density data base website. The basic wood densities of eight woody plant species (11.94 %) were not available so an average wood density value of the woody species can be used (Ponce-Hernandez R, 2004).

3.2.1.5. Vegetation Data Collection and Identification

All woody species in each large plot (20m x 20m) with DBH ≥ 5cm were recorded. The plots were placed systematically in the forest across the altitudinal gradients and forest physical structure forming a zigzag line. This is to reveal the composition and biomass of all living trees and shrubs with a diameter ≥ 5 cm following (Pearson *et al.*, 2005, IPCC, 2007). The cover abundance of all the woody species was estimated and rated according to modified Braun Blanquet approach (Van der Maarel, 1979).

Identification of woody species well known to the researcher was done right in the field but for those that could not be identified in the field, herbarium specimens were collected, dried and used for identification with the help of Flora of Ethiopia and Eritrea (Vol. I, II, III, IV, V and VI) and also using authenticated specimens in Jimma Botanic garden herbarium. The identified herbarium specimens were placed at the herbarium of Wondo Genet College of Forestry and Natural Resources, Hawassa University.

3.2.1.6. Soil data collection

Soil samples were collected from each of the main plots (20m x20m) laid down in each of the altitudinal gradients: low (1740 – 1970 mas), middle (1971 – 2175 mas) and high (above 2176 mas) for vegetation data collection described above. Two types of soil samples were collected at each plot: disturbed and undisturbed soil samples. Composite/disturbed soil sample was considered the representative sample of the plot and used for analysis of carbon content of the soil. Undisturbed soils were collected to estimate bulk density of the soil using core sampler. Three subplots of 1m x 1m ($1m^2$) were laid down along a diagonal line drawn through the center of the main plot. The two subplots at the placed at the opposite ends of the diagonal line were used for soil sampling to determine soil organic carbon and litters, while the third sub plot placed at the center of the main plot (in the middle of the diagonal line was used to coolect soil samples for bulk density determination (Fig 2). Soil bulk density samples were collected using metallic auger of 6.5 cm diameter and 20 cm height from the three soil depths (0–20 cm, 20–40 cm, and 40–60 cm). Accordingly, a total of 288 soil samples (32 plots x 1 pit x 3 soil depth = 96 samples for soil bulk density) and (32 plots x 2 pits x 3 soil depth = 192 samples for soil composite) were designed for the study area. The number of soil samples designed and allocated for each stratum was based on the size of the area within each altitudinal range. Accordingly, 144 soil samples were collected from the low (72) and middle (72) altitudinal ranges, while only 48 soil samples were collected from the high altitudinal range for SOC determination. Similarly, 72 soil samples were collected from the low (36) and middle (36) altitudinal range and only 24 were collected from the high altitudinal range for BD determination. (For bulk density determination, the collected soil samples were first measured the fresh weight and then oven dried at 105^0C for 48 hours (Pearson *et al*., 2005).

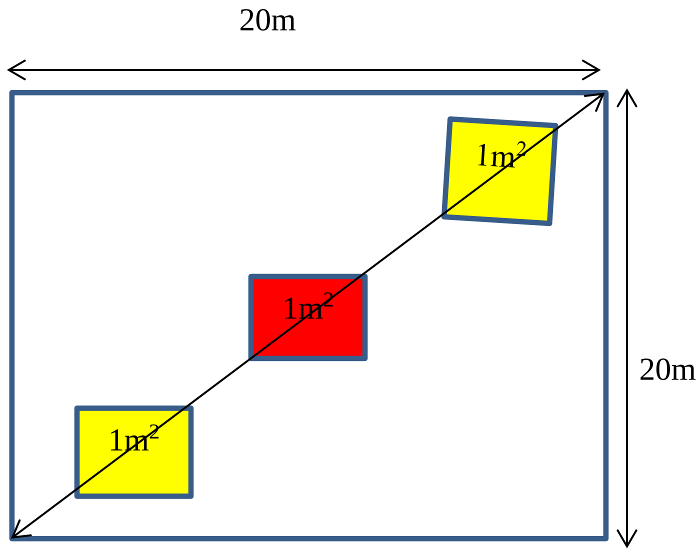

Figure 3: Plot layout of the study site in the forest

3.3. Method of Data Analysis

3.3.1. Plant community's determination

Plant community classification was carried out based on the cover abundance values of the canopy trees. Cluster analysis helps to group a set of observations (vegetation samples) together based on their attributes or floristic similarities (Kent and Coker 1992; McCune and Grace 2002). The PAST software version 2.17c (Oyvind Hammer and D.A.T, Harper, 2013) was used to determine vegetation community types. The community name was derived from the tree and/or shrub species with high synoptic value. Therefore, the percent cover-abundance value was estimated visually for each species within the sample plot and recorded. These were later used for the estimation of cover/abundance values and converted to the Braun-Blanquet 1-9 scale as modified by Van der Maarel (1979) as follows:

1 = rare, generally one individual,

2 = occasional or sporadic with less than 5% cover of the total area,

3 = abundant, with less than 5% cover of total area,

4 = very abundant, with less than 5% cover of the total area,

5 = 5-12% cover of the total area,

6 = 12-25% cover of total area,

7 = 25-50% cover of the total area,

8 = 50-75% cover of the total area, and

9 = 75-100% cover of the total area

3.3.2. Diversity indices analysis

Biological diversity can be quantified in different ways. To compare the woody species composition among elevation contours and physiognomic structure, Shannon diversity index, and evenness index was determined. Changes in temperature and water availability along elevation gradients are thought to be the main underlying drivers of spatial variation in plant species richness (Pausas and Austin, 2001), evenness (Hegazy *et al.,* 2007), and species composition (Semenova and Maarel, 2000).

3.3.2.1. Shannon - Wiener diversity Index

Species diversity has been identified as one of the key indices of sustainable land use practices and considerable resources are expended to identify and implement strategies that will reverse the current decline in biodiversity at local, regional and international scales (Schackelton, 2000). Understanding the variation in plant diversity patterns of different scales is an important topic and crucial for both ecological explanations and for effective conservation design (Devris *et al.*, 1997).

The Shannon diversity index was calculated from the equation:

$$\boxed{H' = -\sum_{i=1}^{S} p_i \ln p_i}$$

Where, H'= Shannon diversity index

Σ = Summation symbol,

S = number of species,

Pi = the proportion of individuals or the abundance of the ith species expressed as a proportion of the total cover; and ln = natural logarithm.

3.3.2.2. Shannon's Equitability (E)

Equitability is used to quantify the unique representation of a given species against a given hypothetical community in which all species are equally common, such that when all species have equal abundance in the community and hence evenness is maximal (Krebs, 1999). Equitability index is calculated using the formula:

E= H'/ Hmax, or E = H'/ lnS,

Equitability assumes a value between 0 and 1, with 1 being complete evenness. The higher the value of evenness index, the more even the species is in their distribution within the given area.

3.3.3. Analysis of vegetation structure

The structural analysis of the vegetation was described by using the following components: frequency, DBH and height class distribution, Importance Value Index (IVI), basal area, and relative density.

3.3.3.1. Importance Value Index (IVI)

Importance Value Index (IVI) is useful to compare the ecological significance of the species (Dereje Denu, 2007). High value of IVI indicates that the species sociological structure in the community is high. The IVI for each tree species was calculated by summing up relative frequency (RF), relative density (RD) and relative dominance (RDO) or Relative basal area values (Kent and Coker, 2002).

IVI= RF+ RD+ RBA.

Frequency (F): - is the chance of finding a species in a particular area in a particular trial sample. It is frequency of quadrats occupied by a given species. It is calculated with this formula:

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of tree species}}{\text{Frequency of all species}} * 100$$

Density: - Tree density was computed by converting the count from the total quadrats into hectare basis or count of individual per unit area.

$$\text{Relative Density (RD)} = \frac{\text{Number of above ground stems of species } counted}{\text{Total number of above ground stems in the sample area}} \boldsymbol{x}100$$

Basal area: - The basal area for the woody species was determined from the DBH measurement. Basal area is calculated from the following formula.

Basal area (BA) = $\pi \left(\frac{d}{2}\right)^2$ = where d is the diameter of the tree (cm) $\pi = 3.14$

$$\text{Relative dominance (relative basal area)} = \frac{\text{Basal area of species}}{\text{Total basal area of the sample}} \text{x}100$$

3.3.4. Carbon Stock estimation and analysis

3.3.4.1. Estimation of Aboveground Carbon Stock (AGC)

The above ground biomass consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The DBH (at 1.3m) and height of individual trees ≥ 5cm and DBH were measured in each sampling plot (IPCC, 2006). DBH biomass and soil carbon stock were estimated using appropriate allometric equations (Chave *et al.*, 2014) and (Perason *et al.*, 2005). For moist forest, the aboveground biomass were estimated by using general allometric equation which includes wood density, DBH and H recommended by (Chave *et al.*, 2014) for which is given below:

AGB (kg) = $0.0673*(WD*D^2*H)$ ^0.976……………………………………..…………… (1)

Where, AGB is aboveground tree biomass (kg/tree), D is diameter at breast height (cm), WD is wood density (g/cm^3) and, H is total height (m) of the tree with carbon fraction of 0.47 (IPCC, 2006) and also for forest coffee plantation managed by the local community of the area AGB will be calculated according to Negash, *et al.*, (2013) which is:

Coffee AGB (kg) = $0.147*d40^2$ ………………………………………………………….…. (2)

Where, d is diameter of forest coffee at 40 cm measurement. The above ground biomass carbon stock for coffee was estimated by multiplying AGB with 0.49 (Negash *et al.*, 2013).

3.3.4.2. Estimation of Belowground Carbon Stock (BGC)

Measuring aboveground biomass is relatively established and simple. But measuring of belowground biomass (coarse and fine roots) is time consuming (Pearson *et al.*, 2005), so it is more efficient to apply a regression model to estimate belowground biomass (living and dead) as a function of aboveground biomass.

BGB = AGB × 0.26 ……………………………………………………………………… (3)

Where, BGB is belowground biomass, AGB is aboveground biomass. The biomass was converted to units of carbon stock by multiplying by a carbon fraction of 0.47 (IPCC 2006).

The belowground biomass for coffee (DBH>2cm) were estimated using an allometric equation developed for agroforestry systems by Kuyah *et al.*, (2012b) in western Kenya and cited by Mesele Negash (2013). Besides, the study site was having similar environmental conditions (climate or altitude, temperature and rainfall) to the study site.

BGB=0.490AGB^0.923………………………………………………………………………(3)

where, BGB is the belowground biomass (kg dry matter/ plant) and AGB is aboveground biomass (kg dry matter/plant) for agroforestry coffee.

3.3.4.3. Litter Biomass/Dead Organic Matter

The forest litter includes dead leaves, twigs, dead grasses and small branches which are all dead organic surface material on top of the mineral soil. The loss on ignition (LOI) method was used to estimate the % carbon content in litter biomass. In this method, fresh weight of samples collected from field were oven dried at 65^0c for 48 hours to get dry weight Allen *et al*., (1986).

Approximately 100 g of evenly mixed sub-samples were brought to the laboratory to determine moisture content, from which total dry mass could then be calculated. According to Pearson *et al.,* (2005), estimation of biomass in the litter was carried out as:

$$\mathrm{LB} = \frac{\mathrm{Wfield}}{\mathrm{A}} * \frac{\mathrm{Wsub\ sample\ (dry)}}{\mathrm{Wsub\ sample\ (fresh)}} * \frac{1}{10{,}000} \quad \text{...} (4)$$

Where: LB = Litter biomass ($ha^{-}1$); W field = Weight of wet field sample of litter sampled within an area of size 1 m^2 (g); A = Size of the area in which litter were collected (ha); W sub-sample dry = Weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and W sub-sample, fresh = Weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

CL = LB * % C ……………………………………..…………………………………… (5)

Where, CL is total carbon stocks in the dead litter in t/ha, % C is carbon determined in the laboratory **(**Pearson *et al.,* 2005).

3.3.4.4. Estimation of Carbon in dead wood pool

The dead wood carbon pool can be classified as standing and downed or fallen dead wood. The amounts of biomass found in dead wood were measured according to the types of dead wood.

i. For standing dead woods which have branches, their biomass were calculated by using the allometric equation of above ground biomass of live trees of similar species **(A).** The standing individual dead trees with DBH greater equal to 5cm of its height and DBH (at 1.3m) was measured and recorded within main plot. According to Pearson *et al.,* (2005) for standing dead wood which have no leave needs to subtract 5-6% for soft wood (conifer species) and 2-3% for hard wood (broadleaved) species from obtained from dead wood biomass using allometric equation of AGB of live trees.

ii. Biomass in standing dead wood/non branched: The allometric equation stated in REDD+ methodology (2009) was used in this study to estimate the amount of biomass in standing stump dead wood/non branched as**:**

$$\text{BSDW} = \sum_{i=0}^{n} \frac{1}{3}\left(\frac{D}{200}\right)^2 * h * s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(B)},$$

Where BSDW1= Biomass of stand stump dead wood (kg), h = length (m), D = tree diameter (cm) and s = specific gravity (g/cm^3) of wood.

The specific density is estimated at 0.5 g/cm^3 as default value, but can be around 0.8 for dense hard woods and around 0.3 for very light species in tropical regions (IPCC, 2006).

iii. The downed lying dead wood: Volume of lying dead wood per unit area was estimated using the equation where diameter of the downed tree is greater than 10cm according to Pearson *et al.,* (2005).

$$V = \frac{\pi 2[d1^2 + d2^2]}{8L}$$

Where, V is the volume in m^3/ha; d is diameter of the dead wood tree and L is the length of the downed dead wood.

There were two decomposition classes recorded for deadwood particles: sound and rotten. If the decomposition class was missing in the data, it was assumed that deadwood piece was sound. Because a rotten wood contains less biomass than a sound wood, the wood density of dead wood is scaled down using lower wood densities than for standing trees, as follows:

$$\left.\begin{array}{l} \text{➢ Sound deadwood biomass: Volume * 90\% * Default WD} \\ \text{➢ Rotten deadwood biomass: Volume * 50\% * Default WD} \end{array}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\text{(C)}$$

The default wood density of the species is 0.612 g/cm^3, similarly as for trees. Then the carbon content in dead wood was calculated by multiplying total biomass of dead wood with the default carbon fraction of 0.47 (IPCC, 2006).

So, **TBDW= A+B+C**, Where TBDW=Total biomass of dead wood in a given plot; A= standing dead wood which has branches; B= Biomass in standing stump dead wood and C= Biomass down lying dead wood.

3.3.4.5. Soil Organic Carbon (SOC)

The carbon stock of soil was calculated by using the following formula which is recommended by Pearson *et al*., (2005) from the total depth, carbon fraction and bulk density of the soil. Volume of the soil was determined by the radius and height of core sampler.

$$\mathbf{V = h \times \Pi\, r^2}$$

Where, V is volume of the soil in the core sampler in cm^3; h is the height of core sampler in cm, (20cm) and r is the radius of core sampler in cm (3.25cm). The soil analysis was done at Jimma University College of Agriculture and veterinary medicine laboratory following standard laboratory procedures and methods. Soil carbon was determined by Walkley-Black (1934) loss on ignition (LOI) method. The samples to determine bulk density were oven dried for 48 hours at 105^{o}C and the dry mass was determined and subsequently the dry bulk density (BD) was calculated by Pearson *et al.*, (2005) method:

$$\mathrm{BD} = \frac{\text{Oven dry mass (g/m3)}}{\text{Core volume (m3)} - [\frac{\text{Mass of course fragment (g)}}{\text{Density of rock fragments } \left(\frac{\mathrm{g}}{\mathrm{cm3}}\right)}]}$$

Similarly, the composite sample was collected per soils layers were analysed for soil carbon concentration and stocks determine the soil organic carbonstock usingas described by (Pearson *et al.*, 2005):

$$SOC\ (t\ C\ ha^{-1}) = BD * D * \%C$$

Where, SOC = Soil Organic Carbon stock per unit area (t/ha), BD = Soil bulk density (g/ cm^3), D = the total Depth at which the sample was taken (cm) and % C = Carbon concentration (%).

- **CT = AGC + BGC + LC +SOC**

Where, CT = Total Carbon stock for all pools (ton/ha), AGC=Above Ground Carbon stock (ton/ha), BGC= Below Ground Carbon stock (ton/ha), LC=litter carbon stock (ton/ha) and SOC= soil organic carbon (ton/ha) for all sampled area.

4. RESULTS AND DISCUSSIONS

4.1. Woody species composition

A total of 67 woody plant species (shrubs and trees) belonging to 35 families and 56 genera were recorded and identified from Kura-Chalte natural forest. Out of these, the most dominant family was Fabaceae which accounted for 11.94% of the species followed by Moraceae (8.96%) (Table 1) and described in annex 2. The top seven families were represented by three to eight species were indicated in Table 1 below, while nine families were represented by two species each and nineteen families were represented only by one species (Annex 2). Among the species encountered in the forest, two species, *Millettia ferruginea* and *Erythrina brucei* were endemic to Ethiopia. The geographical location of Ethiopia covers wide agro-climatic zones and important center of biological diversity. This wide ecological condition of Ethiopia has created diverse and conducive environments for the development of a variety of flora (FAO, 2001).

Table 1: The most dominant families with respective species diversity

Family	No. of species	Percent (%)	Rank	Genera	Percent (%)
Fabaceae	8	11.94	1	7	12.50
Moraceae	6	8.96	2	1	1.79
Oleaceae	4	5.97	3	2	3.57
Rubiaceae	3	4.48	4	3	5.36
Rutaceae	3	4.48	5	3	5.36
Sterculiaceae	3	4.48	6	2	3.57
Euphorbiaceae	3	4.48	7	3	5.36

4.2. Plant Community in Kura-Chalte natural forest

Three plant communities types were derived from the hierarchical cluster analysis (Figure 3). The name for each community type was given based on high synoptic values of tree and/or shrub species which may be estimated from cover percentage as the whole forest area. Cluster analysis was not matched with the fixed altitudinal zonation because of boundary mixed tree species. Plots are located along the zigzag based on their floristic similarity to each other i.e. species were located based on the similarity of their occurrence within the plots in the forest. The validation method for this dendrogram was measured paired group algorithm and corrected by similarity measure of simpson in PAST software at 95 % confidence interval.

Accordingly, in the other forests of moist afromontane forests pant community types were different based on the similarity or dissimilatity of tree species. For instance, Komto forest has four community types (Fekadu Gurmessa *et. al.,* 2013), six community types were recorded in Gendo forest of moist montane forest of Eat wollega (Teshome Gemechu *et al.,* 2015) and nine community types in afromontane and transitional rainforest vegetation of southwestern Ethiopia (Kumelachew Yeshitela and Tamrat Bekele, 2002). So Kura-chalte natural forest was near similar with Komto forest and dissimilar by community types with the other listed in above examples of Ethipian forest.

1. ***Podocarpus falcatus - Pouteria adolfi-friederici-* Community type One (C1)**

This community type is distributed between the altitudinal ranges of 1979 m and 2450 m a.s.l. in the forest. The dominant species (mainly based on cover abundance value) in this type were *Podocarpus falcatus* and *Pouteria adolfi-friederici.* This community consisted of 28 sample plots and 49 species. This community was experienced a low level of anthropogenic disturbance in middle to high altitude area, fire burning for hunting of wild honey collection and withdrawing trees for coffee plantation. This community was also dominated with tree/shrub species of *Olea capensis*, *Olea europea*, *Olea welwitschii*, *Podocarpus falcatus*, *Syzygium guineense. subsp.afromontanum*, *Teclea nobilis*, *Vepris dainellii*, *Pouteria adolfi-friederici*, *Prunus africana*, *Acacia abyssinica. Albizia gummifera*, *Allophylus abyssinicus*, *Apodytes dimidiate*, *Clausena anisata*, *Coffea arabica* species were appeared. Compared to the other community it has more number of species and more of this community was found in middle to high altitude in the study area.

2. ***Syzygium guineense. subsp.afromontanum - Albizia gummifera* – Community Two (C2)**

Syzygium guineense. subsp.afromontanum and *Albizia gummifera* has high synoptic values and the second most dominant species in this community type. This community constituted that 22 plots and 44 woody species. This community was found between the altitudes of 1740 m to 2275 m.a.s.l. The associated trees and shrubs of this plant community are *Acacia abyssinica*, *Syzygium guineensesubsp.guineense*, *Terminalia macroptera*, *Coffea arabica*, *Combretum adenogonium*, *Cordia africana*, *Croton macrostachyus*, *Dombeya torrida*, *Ehretia cymosa*, *Acacia etbaica*, and *Albizia gummifera* were some of dominant species.

3. ***Celtis africana – Croton macrostachyus* – Community Three (C3)**

This community is distributed between the altitudinal ranges of 2174 m to 2210 m.a.s.l. The most dominant woody species in this category are Celtis africana and Croton macrostachyus and followed by *Acacia abyssinica*, *Acacia etbaica*, *Albizia gummifera*, *Celtis africana*, *Clausena anisata*, *Coffea arabica*, *Cordia africana*, *Croton macrostachyus*, *Millettia ferruginea*, *Vepris dainellii*, *Vernonia amygdalina* and *Vernonia auriclifera*. The community occupied 10 sample plots and 39 woody tree/shrub species. This community is highly disturbed by different anthropogenic activities (such as agriculture, coffee plantation, and livestock ranching).

4.2.1. Woody species diversity across the community types

Of the three community types, community type one (C1) had the highest woody species diversity (3.459) and evenness (0.649) and followed by community type two (C2) which has 3.357 and 0.736 diversity and evenness, and ommunity three (C3) recorded the least speciesdiversity and evenness respectively as shown below (Table 2).

Table 2: Woody species diversity across the community types

Community	Abundance (Individual)	Dominance (D)	Simpson (1-D)	Shannon (H')	Evenness (H'/ lnS)	Equitability (J)
1	436	0.041	0.959	3.459	0.649	0.889
2	193	0.043	0.957	3.357	0.736	0.916
3	244	0.049	0.951	3.327	0.633	0.879

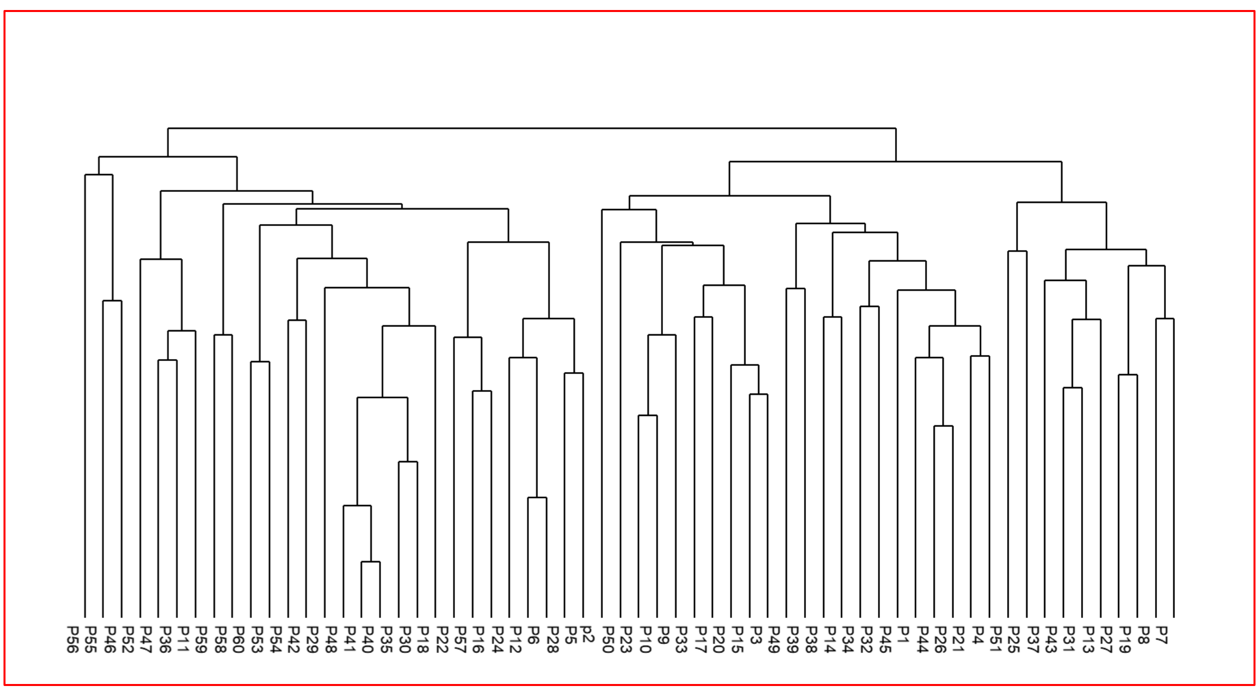

Figure 4: Dendrogram showing plant community types of Kura-Chalte Natural Forest

(Similarity measure of community by Simpson, CI=95%)

Table 3: Synoptic table value of Kura-Chalte community types

No.	List of species	Synoptic 1 (C1)	Synoptic 2 (C2)	Synoptic 3 (C3)
1	*Acacia abyssinica*	8.20	5.72	7.33
2	*Acacia etbaica ssp. Etbaica*	0.00	5.00	5.60
3	*Albizia gummifera*	8.71	**9.12**	8.00
4	*Allophylus abyssinicus*	7.29	7.00	6.00
5	*Apodytes dimidiata*	9.17	7.71	0.00
6	*Bersema abyssinica*	8.20	0.00	6.89
7	*Brucea antidysenterica*	0.00	5.00	5.00
8	*Byttneria catalpitiolata*	6.25	0.00	0.00
9	*Calpurina aurea*	4.96	5.00	5.00
10	*Celtis africana*	9.13	8.33	**9.06**
11	*Chionanthus mildbraedii*	6.59	0.00	0.00
12	*Clausenia anisata*	4.90	0.00	5.15
13	*Coffea arabica L.*	5.00	4.83	5.00
14	*Combretum adenogonium*	0.00	5.00	0.00
15	*Cordia africana*	7.25	6.67	7.00
16	*Croton macrostachyus*	9.17	7.86	**9.13**
17	*Diosporyus abysssinica*	6.22	0.00	5.00
18	*Dombeya quinqueseta*	0.00	0.00	5.25
19	*Dombeya torrida*	0.00	6.40	5.75
20	*Dracaena steudneri*	4.88	0.00	5.00
21	*Ehretia cymosa*	0.00	5.00	5.00
22	*Ekebergia capensis*	0.00	8.00	8.00
23	*Entada abyssinica*	5.00	5.33	7.00
24	*Erythrina brucei*	7.00	9.00	0.00
25	*Euphorbia abyssinica*	7.83	0.00	0.00
26	*Ficus vallis*	8.50	0.00	8.33
27	*Ficus ovata*	0.00	8.00	8.68
28	*Ficus sur*	0.00	0.00	7.33

No.	List of species	Synoptic 1 (C1)	Synoptic 2 (C2)	Synoptic 3 (C3)
29	*Ficus sycomorus L*	0.00	8.00	8.00
30	*Ficus thonningii*	7.00	0.00	8.45
31	*Ficus vasta*	0.00	9.00	0.00
32	*Flacourtia indica*	6.00	6.33	8.00
33	*Gardenia ternifolia*	0.00	4.80	5.00
34	*Grewia ferruginea*	5.50	5.00	5.00
35	*Indigofera macrantha*	5.50	0.00	5.50
36	*Lannea barteri*	5.00	5.00	5.00
37	*Maesa lanceolata*	5.00	5.00	6.50
38	*Millettia ferruginea*	8.33	7.67	6.70
39	*Mimusops kummel*	7.75	0.00	0.00
40	*Myrsine africana L.*	0.00	4.71	0.00
41	*Nuxia congesta*	6.00	6.00	0.00
42	*Ochna holstii Engl.*	5.50	0.00	6.00
43	*Olea capensis L.*	5.89	0.00	5.33
44	*Olea europea L.*	5.40	0.00	0.00
45	*Olea welwitschii*	8.06	0.00	0.00
46	*Olinia rochetiana*	5.50	3.67	0.00
47	*Ozora insigns*	0.00	5.17	0.00
48	*Phoenix reclinata*	5.20	0.00	5.00
49	*Pittosporum viridiflorum*	7.33	7.00	6.00
50	*Podocarpus falcatus*	**9.31**	0.00	0.00
51	*Polyscias fulva*	8.50	0.00	0.00
52	*Pouteria adolfi-friederici*	**9.46**	0.00	0.00
53	*Premna schimperi*	0.00	5.00	0.00
54	*Prunus africana*	8.53	0.00	0.00
55	*Rothmannia urcelliformis*	5.33	0.00	4.44
56	*Sapium ellipticum*	6.00	0.00	6.50
57	*Schefflera abyssinica*	8.33	9.00	8.50

No.	List of species	Synoptic 1 (C1)	Synoptic 2 (C2)	Synoptic 3 (C3)
58	*Spathoda campanulata*	7.50	9.00	0.00
59	*Stereospermum kunthianum*	0.00	5.00	0.00
60	*Syzygium guineense. subsp.afromontanum*	8.28	**9.40**	8.60
61	*Syzygium guineense subsp.guineensis.*	0.00	8.88	0.00
62	*Teclea nobilis Del.*	5.71	0.00	5.80
63	*Terminalia macroptera*	0.00	6.33	5.50
64	*Vepris dainelli*	5.33	0.00	5.57
65	*Vernonia amygdalina*	5.00	5.50	4.83
66	*Vernonia auriculifera*	5.00	0.00	5.20
67	*Warburgia ugandensis*	7.69	0.00	0.00

4.2.2. Woody species diversity along altitudinal gradients and topographic aspects

The highest species richness was recorded in the middle altitudinal gradients while the lowest was recorded in the high altitudinal gradients. The relationship of forest structure, composition, and species diversity with elevation gradient and other environmental variables have emerged as a key issue in ecological and environmental sciences (F. Ojeda, T. Maranon, and J. Arroyo, 2000 and G. Austrheim, 2002). Number of species found in the lower altitude was low as compared to middle altitude, this is may be due to anthropogenic activities like illegal tree felling for timber production, illegal settlements along low altitude areas, withdrawing trees for coffee plantation and reducing coffee shades as shown in the figure 4. The middle altitude of the forest was high number of species and evenness. This is may be because of low anthropogenic activities and natural cases of the topography of the area. Concerning the mechanisms explaining altitudinal gradients of diversity, there were a numberof factors considered to be important for elevation

(Lomolino, 2001). Some of these may include climatic factors, mainly rainfall and temperature, area effect, and increased isolation with elevation. The higher altitude has more low number of species than the lower and middle altitude, may be due to climatic factors, mainly temperature and rainfall, temperature decrease with increasing altitude and hence produce a double complex gradient and affect the abundance and diversity of species along the mid altitudinal gradient. The other factor, which was thought to affect the pattern of species diversity along altitudinal gradient, is the effect of area. As altitude increases the total area decreases towards the top of a mountain (Körner, 2000).

The overall Shannon wiener diversity and evenness of woody species in the forest was 3.855 and 0.705 respectively. Shannon wiener diversity along lower, middle and higher elevation zone was 2.755, 2.765 and 2.761 respectively (Table. 4).

Table 4: Woody plant diversity along altitudinal gradients of the study area

Altitude	**Number of species**	**Dominance (D)**	**Simpson (1-D)**	**Shannon (H')**	**Evenness (H'/ lnS)**	**Equitability (J)**
Lower	271	0.06466	0.9353	2.755	0.9830	0.9938
Middle	359	0.06349	0.9365	2.765	0.9921	0.9971
Higher	243	0.06390	0.9361	2.761	0.9887	0.9959

The result was similar with (Lomolino, 2001; Sanders and Rahbek, 2012). The Shannon wiener diversity and species richness has a positive relationship as shown in the table (as species increase, shannon wiener also increase). The speciese richness of the forest have different patterns due to differences in temperature, moisture (rain fall) and anthropogenic activities such as deforestation and degradation for agriculture expansion and animal feeding along the elevation gradient. Based on one way ANOVA analysis, altitude has significant effect on woody plant diversity (F-Value =27.97, P-value =0.000). The higher the value of evenness index, the more even the species is in their distribution within the study area. The mean diversity of Kura-Chalte natural forest was 17, 23 and 15 plants per plot starting from low, middle and higher altitude respectively.

Table 5: Descriptive Statistics of plant diversity along altitude in the forest per plot

Altitude	**Mean**	**SE Mean**	**(St.Dev.)**	**Minimum**	**Maximum**
Lower	17.000	0.819	3.276	12.000	23.000
Middle	23.000	0.730	2.921	18.000	27.000
Higher	15.000	0.586	2.344	11.000	19.000

The other factor that affect plant diversity was topographic aspect of the area. Number of individuals in West and South direction were equal (225) per plot and in North (218) and East (207) woody species per plot in the study area. This similarity was may be due to more or less same anthropogenic and natural pressures in the study area. The Shannon wiener and simpson diversity, and evenness value of this natural forest was more or less near to similar in their values. The result depicts that there was no significant diffences at (F-value=0.490, P-value=0.688) along topographic aspects.

Table 6: Woody plant diversity along topographic aspect in the forest.

Aspect	**Individuals (Abundence)**	**Dominance (D)**	**Simpson (1-D)**	**Shannon (H')**	**Evenness (H'/ lnS)**	**Equitability (J)**
West	225	0.08543	0.9146	2.471	0.9864	0.9945
South	225	0.08650	0.91350	2.467	0.9825	0.9929
North	218	0.08640	0.9136	2.467	0.9824	0.9929
East	207	0.08623	0.9138	2.467	0.9818	0.9926

Table 7: Mean descriptive Statistics of plant diversity along topograpcic aspects (per plot)

Aspect	Mean	SE Mean	(St.Dev.)	Minimum	Maximum
West	19.00	0.90	3.12	11	23
South	19.00	1.10	3.82	15	28
North	18.00	1.05	3.64	14	26
East	17.00	0.97	3.36	11	21

The mean plant diversity in Kura-Chalte forest was nearly the same in all topographic direction. This may be due to more or less same temperature and rainfall (climatic condition) and anthropogenic activities (grazing, firing, human interferences) and also the culture of forest management.

4.3. Analysis of Vegetation Structure

4.3.1. Stem density

A total of 67 woody species with DBH ≥5cm and height ≥3m was recorded in the study area. A total of 873 individuals was counted with the DBH ≥ 5cm within sampled plots. The mean total density of all woody species with height ≥3 m and DBH ≥5cm in the study area was 455/ha. The total density was 215 stems per ha for DBH 5 - 10cm and 130 individuals per ha for DBH 10 - 20 cm and others with DBH 20 – 30 cm were 169/ha (table 4). The ratio of the density of individuals with DBH >10 cm (a) to those greater than 20 cm (b) showed the distribution of size classes (Grubb *et al*., 1963). The ratio described as a/b, is taken as the measure of size class distribution. So, the ratio of individuals with DBH > 10 cm (a) to DBH> 20cm (b), a/b was 1.65.

Table 8: Tree density ratio comparison with other 5 afromontane forest studied area

Forest	**DBH Class (cm)**		**Ratio (A/B)**	**Sources/References**
	DBH5 - 20 (a)	DBH>20 (b)		
Gura-ferda	560	263	2.13	Dereje Denu (2006)
Komto	330	215	1.53	Fekadu Gurmessa (2002)
Alata-Bolale	365	219	1.67	W/yohannes Enkossa (2008)
Masha-Andaracha	386	160	2.41	Kumlachew Yeshtela and Taye Bekele (2003)
Jimma	335	184	1.82	Fufa Kenea (2008)
Kura-Chalte	215	130	1.65	Present study (2020)

As you have seen in the above table the present study has a similar distribution of size classes (density) with Alata-Bolale, and nearly close similarity with Jimma, but Kura-Chalte natural forest has less tree density than Gura-ferda and Masha-andaracha and greater than Komto forest. This may be because of altitude difference, agroecology of the area and anthropogenic disturbances for agricultural expansion and animal ranching.

4.3.2. DBH Distribution

Density at various DBH classes was used to determine the population structure of 67 woody species. The number of stems in DBH class less than 10 cm is 215/ha (24.63%). The distribution of tree species in different DBH classes of 10-20 cm is 130/ha (14.89 %), 159/ha (24.5%) in 20-30 cm and 91/ha (10.42 %) in 30–40 cm, 69/ha (1.7%) in 40-50 cm, 47/ha (5.38%) and DBH with >60 cm was found to be 163/ha (18.67%) of the total in the DBH class as shown in (figure 4).

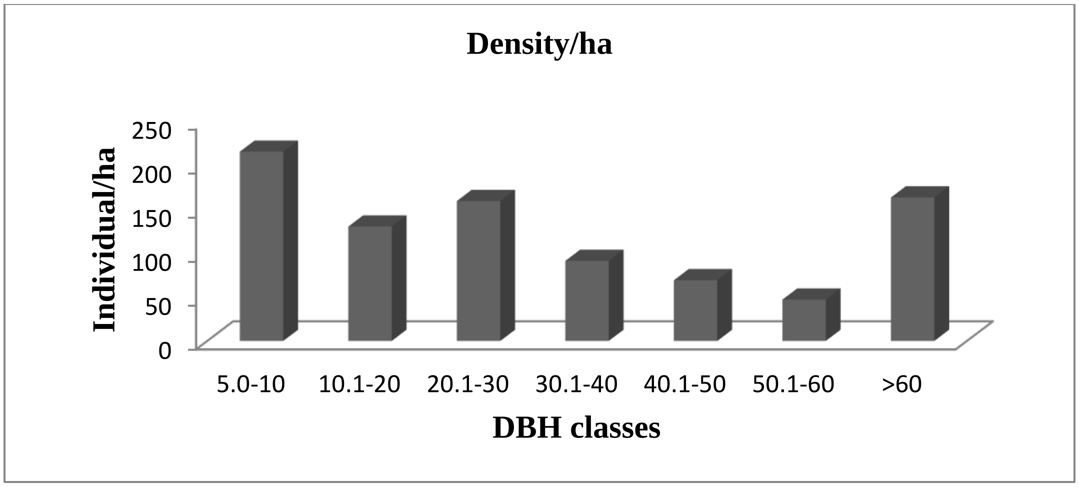

Figure 5: DBH Classes and Density of woody species

4.3.3 Height Structure

The woody species in the study area conveniently classified into 6 height classes (figure 5). : **I** = 3-8m, **II** = 8.1-13m, **III** = 13.1-18m, **IV** = 18.1-23m, **V** = 23.1-28m, **VI** = >28m. Density of woody species decreased with increasing height classes, showing reversed J-shape (Figure.7). This means the forest had high density in lower DBH class and lower density at higher DBH class. The decreasing in density of each height class towards the highest height classes reveals the dominance of small sized individuals in the forest.

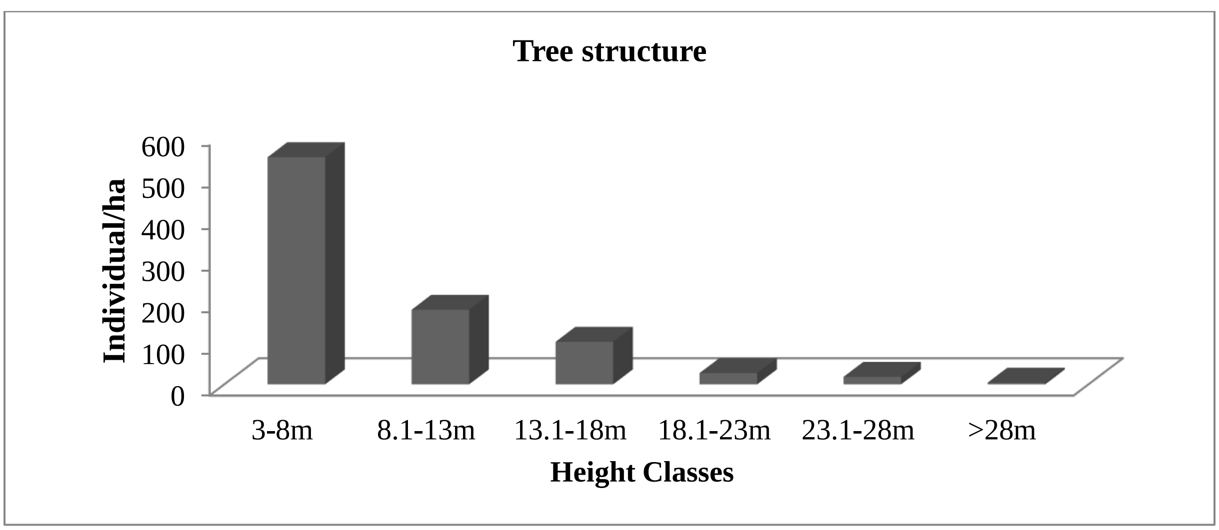

Figure 6: Height Classes and Density of woody species

Such reversed J-shaped distribution pattern depicts that the forest is on the status of favorable regeneration and recruitment potential. Similar results were reported by Feyera Senbeta (2006) and Teshome Gemechu (2009).

4.3.3. Basal Area

The basal area of woody species in Kura-Chalte forest was 48.17m^2/ha which is extrapolated from DBH. *Albizia gummifera, Syzygium guineense. subsp.afromontanum, Croton macrostachyus, Pouteria adolfi-friedericii, Acacia abyssinica, Podocarpus falcatus, Millettia ferruginea, Celtis Africana, Olea capensis* and *Olea welwitschii* constitute large basal area of the site. Kura-Chalte natural forest had low basal area as compared to Belete moist evergreen forest 103.5 m^2/ha (Kitessa Hundera and Kiflay Gebrehiwot, 2006), Masha Anderacha 81.90 m^2/ha (Kumilachew Yeshitila and Taye Bekele, 2003) and Gura-ferda (Bibita) 69.90 m^2/ha Dereje Denu (2007), and also a greater basal area of Gura-lopho and Bonga natural forest with 29.63 and 45.20 m^2/ha respectively.

4.3.4. Importance Value Index (IVI)

Importance Value Index combines data from three parameters which include relative frequency (RFr), relative density (RD) and relative basal area (RBA/relative dominance/RDO) (Kent and Coker, 1992). The importance value index of ten woody species in Kura-Chalte was shown in (Table 5) and the whole IVI were in (annex.1). The total IVI of all woody species in the study area was 300.01; of these ten species contribute high IVI such as *Albizia gummifera (6.9 %), Acacia abyssinica (6.46%), Croton macrostachyus (5%), Syzygium guineense. subsp.afromontanum (4.17 %), Bersema abyssinica (3.86 %), Pouteria adolfi-friedericii (3.73*

%), Acacia etbaica (3.2 %), Byttneria catalpitiolata (3.16), Allophylus abyssinicus (3.08 %) and *Celtis africana (2.52 %)* respectively.

Table 9: Ten tree species which were having high IVI and most ecologically important

List of Species	**RFr**	**RD**	**RBA**	**IVI**	**%**	**Rank**
Albizia gummifera (J.F.Gumel.)	3.66	3.89	13.14	20.70	6.90	1
Acacia abyssinica Hochst ex Benth.	4.76	4.93	9.69	19.37	6.46	2
Croton macrostachyus A.Rich	2.75	2.18	10.07	14.99	5.00	3
Syzygium guineense subsp.afromontanum	0.37	0.46	11.69	12.52	4.17	4
Bersema abyssinica Fresen	3.30	5.50	2.79	11.58	3.86	5
Pouteria adolfi-friederici (Eng.) Baehni	0.73	0.46	10.00	11.19	3.73	6
Acacia etbaica ssp. etbaica Schweinf.	4.58	4.70	0.31	9.59	3.20	7
Byttneria catalpitiolata Jacq.	4.58	3.67	1.24	9.48	3.16	8
Allophylus abyssinicus (Hochst) *Radlkofer*	4.21	4.70	0.34	9.25	3.08	9
Celtis africana Burm.f.	1.83	1.83	3.90	7.57	2.52	10

4.3.5. Carbon Stock estimation

4.3.5.1. Aboveground Biomass carbon

The presence of variation in altitudinal gradient affects the carbon stock of different pools in the forest. The total mean of aboveground biomass (t/ha) and mean carbon of the study area is 478.54 and 224.91 tC/ha respectively along altitudinal gradient. The result shows that as altitude increase the biomass and Carbon increase in the independent factor, this may be because of anthropogenic disturbances at lower and middle for coffee plantation and livestock grazing in this forest. For instance, at lower and higher elevation carbon stored in woody species between these strata is 132.3 and 291.2 t/ha respectively (Table 6). This may be due to gazing and tree thinning for coffee shade and low DBH at lower altitude and vice versa for higher altitude and species composition/richness, for example, 413/ha, 486/ha and 470/ha in lower, middle and higher elevation respectively. Using the Tukey Method and 95% Confidence interval the mean variation of carbon along altitudinal gradients was highly significant at (F=5.51 and P=0.007).

The present result is similar to Yikunoamlak Gebrewahid *et al.,* (2018), Nesru Hassen (2005), Tibebu Yelemfrhat and Teshome Soromessa (2015), and Abel Girma *et al.,* (2014) which is the increasing biomass carbon with altitude in higher altitude is may be due to low disturbance and high diameter class distribution. But this result is opposite to Hamere Yohannes *et al.,* (2015) and Belay Melese Wolde *et al.,* (2014) may be due to altitude variation and microclimate. Elevation influences climatic factors, such as temperature, incoming solar radiation, humidity and the presence and frequency of clouds and fog, which are in its turn responsible for a lot of botanical characteristics of the forest and this may make changes in carbon storage along aspect gradients (Körner *et al.,* 2005).

Table 10: Mean aboveground biomass and its Carbon along altitude in the study area (ton/ha)

Altitude	**Biomass**	**Mean**	**SE Mean**	**(St.Dev.)**	**Minimum**	**Maximum**
Lower	281.41	132.3	17.3	69.1	45.4	250.2
Middle	534.64	251.3	44.0	175.9	54.0	749.6
Higher	619.56	291.2	38.6	154.5	94.0	600.1

Aspect is the second factor that may affect the total carbon stock in the studied forest. As shown in Table 11 below, higher carbon is sequestered in the South and West which was 255.4 and 252.9 tC/ha in both directions. This may be due to high DBH trees classes in both and low disturbance in South. On the other hand carbon stored in the North and East were 191.1 and

200.4 tC/ha respectively, and this result shows some reduction from other aspects. The aspect factor has no significant impact on aboveground carbon of the forest at 95% confidence interval at (F=0.57 and P= 0.639).

Table 11: Mean aboveground biomass and its Carbon along aspect in the study area (ton/ha)

Aspect	**Biomass**	**Mean**	**SE Mean**	**(StDev.)**	**Minimum**	**Maximum**
West	538.03	252.9	25.6	88.6	83.5	416.5
South	543.33	255.4	64.4	223.0	69.9	749.6
North	406.49	191.1	26.5	91.7	45.4	363.7
East	426.29	200.4	51.1	177.0	54.0	575.8

4.3.5.2. Belowground carbon

The total mean of the BGB and BGC stored in the study area were 228.58 and 107.43 t/ha respectively. Below ground biomass and carbon stock shows a similar pattern with that of the above ground, showing an increasing trend with increasing elevation. For instance, BGC in lower, middle and higher altitude classes were increasing from lower to higher altitude gradients (37.96, 67.83 and 78.62 t/ha) separately (Figure. 8). The variation of means in relation altitude gradients was not statistically significant (P-value = 0.05) from low to middle elevation, but it was significantly different between lower and higher altitude at (P-value = 0.014). Aspect is also the other factor affect carbon stock in this study area. Since BGC was derived from AGC it had the same increasing or decreasing pattern with AGC against all the independent factors. For example, the mean BGC stored in West, South, North and East were 71.27, 68.90, 51.58 and 54.10 t/ha respectively, and there was not statistically significant in relation to the aspect (P-value= 0.569).

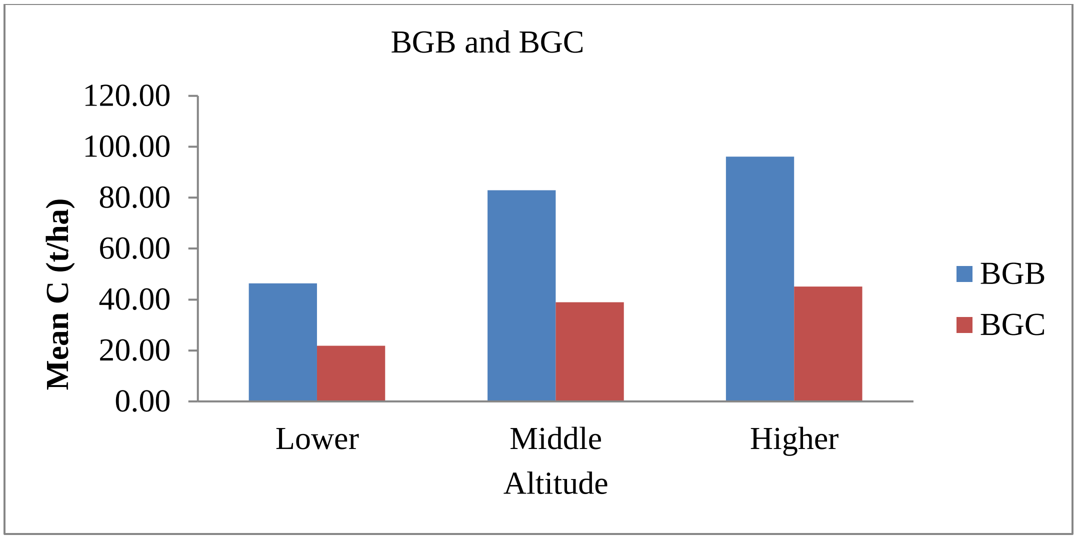

Figure 7: The mean of BGB and BGC in the study area along altitudinal gradients

4.3.5.3. Litter Carbon along altitude and aspect

To determine the biomass of litter biomass (leaf, herbs and grass), samples were collected within 1 m^2 area. The total mean of biomass and carbon stock in the litter carbon pool of the Forest was 9.62 and 3.57 t/ha respectively. The mean carbon stocks of the forest in the litter carbon pool at lower, middle and higher altitudes were 1.12, 0.94, and 1.41 t/ha separately. The result shows that high accumulation of litter at higher and lower altitude. This result showed a similar pattern with research reports of (Tibebu Yelemfrhat and Teshome Soromessa, 2015; Nesru Hassen (2015). The biomass and its carbon stock of litter in a given forest are determined by the condition of a forest (species, stand age and density) and climate (Fisher and Binkly, 2000). Therefore, the carbon stock variation in the litter carbon pool with respect to altitude and in this forest may be the result of these factors.

Table 12: Mean litter biomass and carbon stock along attitude range in the forest (ton/ha)

Altitude	Biomass	Mean	SE Mean	(St.Dev.)	Minimum	Maximum
Lower	3.02	1.12	0.13	0.44	0.44	1.95
Middle	2.53	0.94	0.13	0.46	0.42	1.70
Higher	4.07	1.51	0.16	0.56	0.59	2.08

East, North and West aspect has been highest carbon mean, respectively, while the South direction has been low carbon in the forest. The results obtained in four aspects of litter carbon were 1.39, 1.33, 1.13 and 0.78 t/ha in the direction of east, north, west and south respectively. This may be due to tree composition, tree leaf maturity and species leaf shade time. Using the Tukey Method and 95% Confidence there no significance difference (P-value=0.078) along an altitude in litters carbon pools in the forest. But, along aspect it had significant difference at (0.039).

Table 13: Mean biomass of litter and its carbon along aspect in the forest (ton/ha)

Aspect	Biomass	Mean	SE Mean	(St.Dev).	Minimum	Maximum
West	3.54	1.13	0.174	0.521	0.444	2.078
South	2.11	0.78	0.0797	0.2392	0.4192	1.1898
North	3.59	1.33	0.203	0.609	0.478	2.050
East	3.76	1.39	0.150	0.450	0.712	2.017

4.3.5.4. Carbon in dead wood along altitude and aspect

Deadwood biomass were recorded in the in the all altitudes (strata) and aspect, but in different amount in the study area. The mean biomass and carbon stock in the deadwood carbon pool along altitude was 7.30 and 3.43 t/ha respectively. The highest carbon was recorded in the middle (1.64), higher (0.96) and lower (0.83) t/ha in altitude respectively. This is due to the deadwood in lower altitude was used for fuel wood and charcoal production. High biomass of deadwood recorded in middle altitude because coffee plantation is increasing from lower to middle layer of the forest and burning the stem of the tree to decrease coffee shade (figure 4). This could cause forest degradation and reduce carbon stock in all carbon pools of terrestrial ecosystem. The mean carbon of dead wood along altitude was not statistically significant at $\alpha = 0.05$ ($F= 1.38$, $P= 0.271$).

Figure 4. Forest/stem burning to reduce coffee shade in the study area

Table 14: Biomass Mean and carbon stock in Deadwood along attitude in the forest (ton/ha)

Altitude	**Biomass**	**Mean**	**SE Mean**	**(StDev)**	**Minimum**	**Maximum**
Lower	1.77	0.83	0.31	0.92	0.02	2.88
Middle	3.48	1.64	0.60	1.33	0.15	3.14
Higher	2.04	0.96	0.19	0.65	0.02	2.48

Forest biomass and carbon stock could not only affected by altitude, but also influenced by aspect. For instance, carbon stored in deadwood across the west, south, north and east directions were 1.33, 0.61, 1.05 and 1.13 t/ha respectively in Kura-Chalte natural forest. Carbon in dead wood along aspect increased due to people's encroachment in and around, especially in West (Ganda Kuraflebu) and East direction (Ganda Bontu) in some parts of the forest (Table.11). This may be due to human disturbances in the forest (tree cutting for charcoal, fuel wood, timber production and coffee plantation). The mean variations in the deadwood along the aspect at 95% confidence interval was highly insignificant (F=0.58, P=0.634).

Table 15: Mean Biomass and carbon stock in Deadwood along aspect in the forest (ton/ha)

Aspect	**Biomass**	**Mean**	**SE Mean**	**(St.Dev.)**	**Minimum**	**Maximum**
West	2.54	1.33	0.42	1.25	0.05	3.07
South	0.92	0.44	0.20	0.33	0.15	0.81
North	2.23	1.05	0.28	0.68	0.04	2.15
East	2.67	1.13	0.43	1.05	0.02	3.14

4.3.5.5. Soil Bulk density and carbon stock (SOC stock)

A. Bulk Density

Bulk density typically increases with soil depth since subsurface layers are more compacted as seen from this study, and have less organic matter, less aggregation, and less root penetration compared to surface layers. It is indicated that bulk density values were obtained in laboratory analyses; bulk density of the soil increases from top to subsoil surface and decreases in soil organic carbon and organic matter (Table 17). But the condition is insignificant at 95% confidence interval except 0-20 cm ($F=4.56$, $P=0.009$) for instance in the case of 20-40 cm ($F=2.12$, $P=0.117$) and 40-60 cm ($F=0.80$, $P=0.501$) incase of altitudinal gradients. This is may be due to low soil porocity (pore space), aeration, low microorganism in subsoils and resulted low root penetration in the soil, but the upper gradients have low bulk density than the middle and lower gradients (Cavigelli, M, 1998). This variation is may be due to litter, leaf, tree branches (tree biomass decomposition) eroded to the middle one. It was higher mean SE (mean value ±0.022) in the upper altitude as compared with the rests; and in the eastern and southern (mean value ±0.0262 and 0.0203) than in the rest topographic aspects respectively (Table. 16). The lower bulk density in the upper and middle altitude was a result of high soil carbon than than lower altitude (Table. 17). Bulk density affects infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity (Cavigelli, M, 1998). So the result depicts low organic carbon in lower altitude may be due to human activities like overgrazing, tree cutting for coffee plantation, and erosion in the area.

Table 16: Mean values of SE and StDv along aspects and altitude

Bulk density along Aspects					
Aspecst	Mean SE	StDv	Bulk density along Altitude		
West	0.0167	0.0501	Altitude	Mean SE	StDv
South	0.0203 *	0.0609	Lower	0.019	0.066
North	0.0184	0.0552	Middle	0.019	0.064
East	0.0262 *	0.0785	Higher	0.022 *	0.077

Note * shows higher value of Mean SE

Generally, the soils in tropical regions are characterized by low bulk density (Bernoux *et al.*, 1998). The result also shows low bulk density at higher altitude may be due to high accumulation of litters and aboveground biomass as seen in the above ground and litter estimation. The higher bulk densities were found in lower altitude may be due to human being interferences (cutting trees for charcoal, fuelwood and coffee shade reduction), animal grazing, firing (litters, grasses, branches and other deadwoods) and agricultural expansion to be compacted in this forest. Bulk density along aspects also increases as deph increase in all direction by different amount. Bulk density was significantly different between soil depths in natural forest from low values in the top soil layer and higher values in the subsoil layer (Mehari Alebachew, 2015).

Table 17: Mean values of bulk density along altitude and aspects (cm)

Bulk density along aspects				Bulk density along altitudinal gradients			
Depth	0-20	20-40	40-60	Depth	0-20	20-40	40-60
W	0.79	0.85	0.87	Lower	0.78	0.84	0.88
S	0.76	0.83	0.90	Middle	0.76	0.80	0.87
N	0.77	0.80	0.86	Higher	0.74	0.79	0.85
E	0.70	0.80	0.85				

B. Soil Carbon stock along altitude

The total carbon stock and mean carbon along the altitude in the study area was 569.51 and 189.84 tC/ha respectively. The average carbon stock result along altitude were 162.02, 216.77 and 190.72 tC/ha which shows an increasing or decreasing pattern due to disturbance reduction (human and animal/ overgrazing), litter decomposition and high deadwood in middle altitude and vice versa with lower case (Figure. 9). This shows that plant physiognomy/structures and altitude has its own impact on soil variation. SOC variation may be due to micoclimate, rain fall and temperature, microbial activities and vegetation corer of the forest. The stability and distribution of SOC in the soil profile is influenced by biotic controls such as the abundance and vigor of faunal, microbial and plant species as well as environmental controls like temperature, moisture and soil texture (Lorenz K. and Lal, R. 2005). As altitude increases the net primary productivity (NPP) and the carbon input (litter fall) to the soil decreases (Zhu *et al.*, 2010), but in present study there was relatively an increasing and decreasing trend in the mean SOC with increasing altitude. This may be related to the decomposition of dead organic matter and litters in wood debris was recorded on the ground of middle altitude. This finding is similar with (Nesru Hassen, 2015; Asersie Mekonnen and Motuma Tolera, 2019).

Table 18: Soil organic carbon along Soil depth and altitude in the study forest

SOC in different layer (ton/ha) mean values				
Altitude	Depth (cm)			
	0-20	20-40	40-60	Total
Lower	63.96 ± 12.44	42.72 ± 9.38	26.08 ± 11.39	132.76 ± 33.21
Middle	81.88 ± 19.34	55.97 ± 16.47	42.79 ± 20.26	180.64 ± 56.07
Higher	80.63 ± 14.13	48.26 ± 10.82	29.02 ± 13.48	157.91 ± 38.43
F-value	4.95	3.35	3.97	-
P-value	0.013	0.048	0.028	-

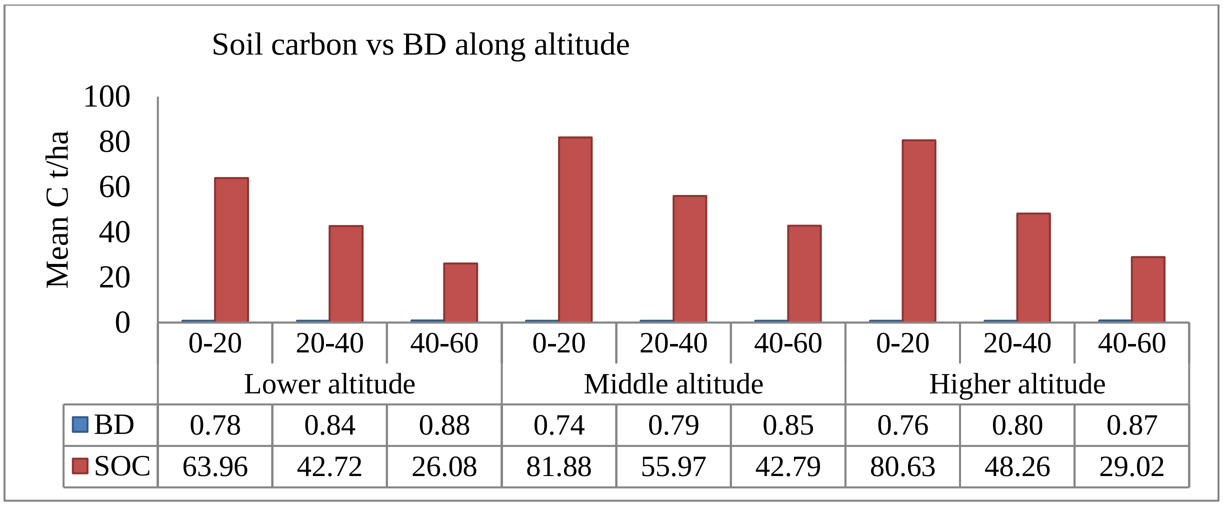

Figure 8: Soil carbon and bulk density along altitude of the study area

(BD= Soil bulk density (g/ cm^3), SOC= Soil organic carbon (t/ha))

C. Soil Carbon stock along topographic aspects

The total soil carbon and mean carbon along sunlight direction (aspect) was 628.42 and 157.11 t/ha respectively, while individually soil carbon were 133.53, 172.61, 152.67 and 169.61 t/ha along topographic aspects in W, S, N and E respectively. Carbons sequestered in west and north were moderately low as compared to south and east direction (Table. 14). Carbon accumulation along topographic aspect of the study site shows some variation because of the microclimate, sunlight direction (solar radiation), evapotranspiration, moisture and temperature, subsequent rate of plant biomass and its decomposition and human anthropogenic activities as shown in (table 18 and figure 10).

Table 19: Soil organic carbon along Soil depth and aspects of the study area

SOC in different direction (ton/ha)				
Aspect	Depth (cm)			
	0-20	20-40	40-60	Total
West	69.48 ± 12.74	42.10 ± 12.17	21.95 ± 12.89	133.53 ± 37.89
South	82.49 ± 13.56	52.86 ± 7.43	37.26 ±20.60	172.61 ± 41.59
North	71.96 ± 22.05	43.57 ± 10.63	37.14 ± 12.83	152.67 ± 45.51
East	78.02 ± 18.79	57.41 ± 16.99	34.18 ± 17.26	161.18 ± 53.04
F-value	1.05	3.23	1.80	-
P-value	**0.382	*0.035	**0.166	-

* is significant and ** shows statistically not significant.

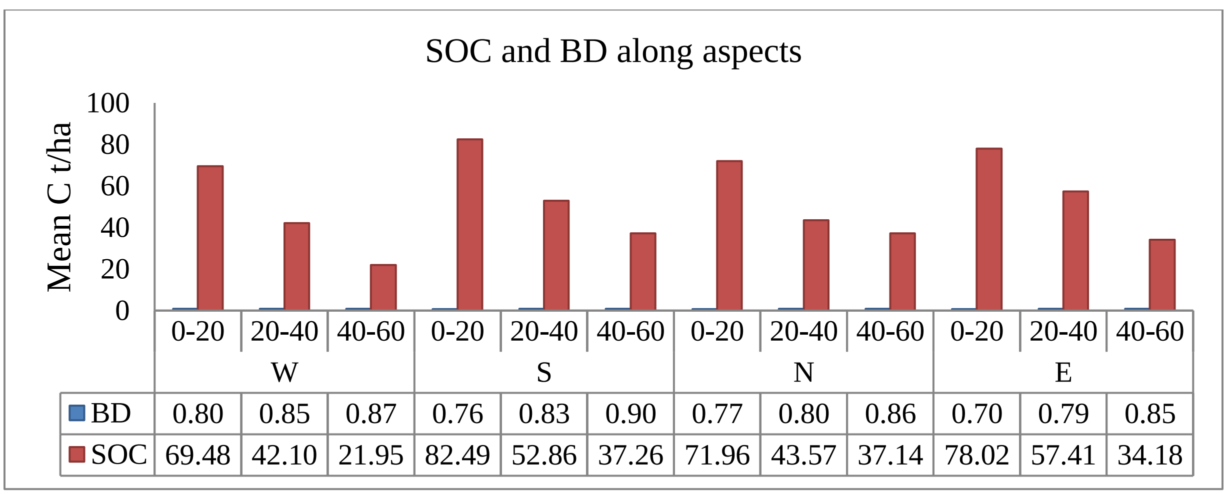

Figure 9: Soil Carbon and Bulk density along aspect of the study area

(BD= Soil bulk density (g/ cm^3), SOC= Soil organic carbon (tC/ha) in W=West, S=South, N=North and E= East direction)

4.3.5.6. Total carbon density of the forest along altitude and topographic aspect

The total carbon stock density was the summation of all carbon pools in the forest. As shown in the (Table.15), the AGC component shares the highest carbon stock (674.74 tC/ha) and followed by soil carbon (569.51 tC/ha) of the total forest carbon stock, whereas the below ground carbon contribute low (107.43 tC/ha), deadwood carbon (25.65 tC/ha) and litter (3.60 tC/ha) contributed the lowest carbon stock in the study forest. This is due to high DBH trees, especially in the middle and higher altitude and low human interference at middle and high elevation of the study site in relation to aboveground carbon and soil carbon. The rest carbon pools (deadwood carbon and litter carbon were low. Similar finding was reported from Abel Girma *et al.,* (2014); Nesru Hassen (2015). Below ground biomass had similar patterns with that of the above ground biomass due to the fraction of 0.26 (26%) of above ground biomass. Belowground carbon in lower altitude was low as compared to middle and higher elevation of the forest. This may be due to low DBH, tree degradation for coffee plantation and cuttings for different household use (Abel Girma *et al.,* 2014; Alefu Chinasho *et al.,* 2015).

Table 20: Total mean carbon of the Kura-Chalte natural forest

	Total carbon pools					
	AGC	BGC	DWC	LC	SOC	Total carbon
Mean C (ton/ha)	674.74	107.43	25.65	3.60	569.51	1380.93
Percentage (%)	48.85	7.80	1.85	0.26	41.24	100

The total carbon stock densities of the forest were depicted as follows (AGC, BGC, DWC, LC and SOC) along altitudinal gradients. High carbon storage obtained in higher elevation both in aboveground and soil because of low anthropogenic impacts upper elevation and low carbons were recovered at lower altitude due to human interference for coffee plantation, over grazing, tree cutting for fuel wood, charcoal and sometimes forest fires for animal forage and wild bee hunting (Table.16).

The mean carbon of dead wood in the forest was also determined, but it has some variation along with altitude. For instance, low deadwood in low elevation and high dead wood in middle altitude were recorded. Comparatively, this is may be a lower elevation area was near to settlements and used for fuel wood, charcoal, and construction purposes. Deadwood in the study site shows an increasing and/ or decreasing pattern because of coffee plantation and hand over the land to have their own land. The carbon in the litter carbon pool of the study area was greater in higher altitude (1.54 t/ha) than the lower altitude (1.41 t ha-1) and middle. This is related to tree biomass, free of fire and low anthropogenic disturbance in the high altitude because the area is inaccessible to road, but litter carbon in the middle and lower elevation was vice versa with higher elevation. The result of litter along altitude in the this forest is similar with Tibebu Yelemfrhat Simegn and Teshome Soromessa (2015), however, the result was not satisfying the other researcher like Belay Miles *et al.*, (2014); Yohannes Hamare *et al.*, (2015).

The other larger carbon pool is soil organic carbon (SOC), which was affected by altitude and aspect in the study forest. Soil carbon mean shows an increasing and/ or decreasing pattern along altitude due to anthropogenic factors such as forest degradation and erosion in low altitude and increased in middle altitude may be due to high decomposition of litter and dead woods. This finding was similar with Asersie Mekonnen and Motuma Tolera (2019); Tibebu Yelemfrhat and

Teshome Soromessa (2015) and opposite to the others researcher Belay Melese *et al.*, (2014); Zelalem Teshager *et al.*, (2018).

Table 21: The total carbon stock density in the forest along altitudinal gradients (ton/ha)

Altitude	AGB	AGC	BGB	BGC	DWB	DWC	LB	LC	SOC	Total B	Total C
Lower	281.41	132.26	80.76	37.96	9.00	4.22	3.02	1.12	162.02	374.19	337.58
Middle	534.64	251.28	144.33	67.83	28.83	13.57	2.53	0.94	216.77	710.33	510.77
Higher	619.56	291.19	167.27	78.62	16.52	7.86	4.17	1.54	190.72	807.52	595.98

The second type of environmental factor which affect the carbon stock of the forest is an aspect. The result of the study showed that, the higher mean value of above and below ground carbon stock has been recorded on the south (S) and west (W) direction, and low amount from the east (E) and north (N) direction. But high soil carbon mean was recorded in the south (175.62) and east (170.98 t/ha) and shows small reduction in north (152.67) and west (133.52 t/ha) respectively. Litter carbon in west, north and east respectively obtained high carbon amount, while low carbon in south direction. This is may be due to low disturbances in those three aspects and high decomposition and burning in south direction.

The deadwood carbon in the west and north were almost high as compared to east and south direction. The reason for these is anthropogenic disturbances (cuttings for construction purpose, human settlements, fuel wood and charcoal production). The other carbon stock pool is soil organic carbon. The mean carbon soil of the study are low in the west may be due to erosion and soil degradation, and on the other aspects of the forest was more or less high in south and east. This is may be due to high canopy and less disturbed from the other aspects.

Table 22: Total carbon stock density along aspect in Kura-Chalte natural forest (ton/ha)

Aspect	AGC	BGC	LC	DWC	SOC	Total C
West	269.02	72.63	1.06	5.16	133.52	481.39
South	271.66	73.34	0.72	2.77	175.62	524.11
North	203.24	54.88	1.25	4.21	152.67	416.25
East	213.15	57.54	1.31	3.94	170.98	446.92

5. Conclusion and Recommendation

5.1. Conclusion.

Ethiopia presents a great geographical diversity with high and rugged mountains, flat-topped plateaus, deep gorges, river valleys and plains. Its diverse topography has given rise to a wide range of diversities of flora and fauna and in rich endemic species. However, these rich biological resources of Ethiopia are vanishing at an alarming rate due to extensive anthropogenic activities. Tropical forest lands contain the largest carbon pools and have a significant function in the global carbon cycle and the result of the study confirms this important function of the forest. In the study site, a total of 67 woody plant species (shrubs and trees) were collected from Kura-Chalte natural forest and identified into 35 families and 56 genera. Out of these, the most dominant family was Fabaceae (11.94%) followed by Moraceae (8.96%), Oleaceae (5.97%).

The forest was distinguished in three plant community types based on hierarchical cluster analysis by using PAST version 2.17c (Oyvind Hammer and D.A.T, Harper, 2013) based on their similarity. From these community types, C1 had highest woody species diversity (3.459) and evenness (0.649) and followed by C2 which has 3.357 and 0.736 diversity and evenness, respectively. Woody species with DBH ≥5cm and height ≥3m, 67 species were recorded in the study area. The mean total density of all woody species with height ≥3 m and DBH ≥5cm in the study area is 455/ha. The forest was classified into seven DBH classes and six height classes.

The basal area of woody species in forest was 48.17m2/ha which is extrapolated from DBH. *Albizia gummifera, Syzygium guineense. subsp.afromontanum, Croton macrostachyus, Pouteria adolfi-friedericii, Acacia abyssinica, Podocarpus falcatus, Millettia ferruginea,* *Celtis africana, Olea capensis* and *Olea welwitschii* constitute large basal area in site. The total IVI of all woody species in the study area was 300.01.

Of these some species contribute high IVI such as *Albizia gummifera, Acacia abyssinica, Croton macrostachyus, Syzygium guineense. subsp.afromontanum, Bersema abyssinica* and *Pouteria adolfi-friedericii.*

The presence of variation in altitude and aspect can affect the carbon stock of different pools in the forest. The total mean of aboveground carbon of the study area was 224.91 t/ha along altitudinal gradient. The result shows an increasing pattern with increasing altitude in above ground carbon, below ground carbon, and in the other carbon pools it depicts an increasing or decreasing pattern dead wood, litters and soil organic carbon along altitudinal gradients in the anthropogenic effects and some natural activities. The other factor that affects carbon pools of terrestrial ecosystem was aspect or sunlight direction. In all four aspects forest carbon means shows different results due to the effects of sunlight direction, microclimate (temperature and rainfall variation or offshore and onshore), wind direction along aspect, etc. For instance, above ground carbon stored in the West and South were 252.9 and 255.4 t/ha, and in east and north were 200.4 and 191.1 t/ha respectively.

In the soil carbon pools there were no more differences in carbon amount. i.e. individually soil carbon were 133.53, 172.61, 152.67 and 169.61 t/ha along aspect in W, S, N and E independently. The total carbon stock density in AGC and BGC increases as altitude increases, while the other carbon pools like litters, dead wood and soil carbon in the forest depicts that an increasing or decreasing pattern. Carbon stock density along aspect also shows some variation in carbon storage due to the variation sunlight direction, rugged mountains, flat-topped plateau and deep gorges, river valleys and rolling plains in the study site.

5.2. Recommendation

Kura-Chalte natural forests have the potential stock for future genetic resources, sources of life for almost all animals and environmental function, biological diversity, and socioeconomic importance and carbon stock potential in global climate change mitigation. So the resources that have such values from local levels to global level in development have been under danger conditions. The following are recommended as a solution.

- Creating community awareness, through extension programs and different agents, offices and individuals on the multiple uses of forest resources and ecosystems is essential to safeguard the biological diversity of the forest,
- Participatory forest management programs should be introduced and implemented so that local communities and responsible government offices assume responsibility for the management and conservation of the forest and became beneficiaries of the economic payback derived from this forest,
- Introducing projects, governmental and nongovernmental organization, private investor who take care on forest conservation and management, and benefits local community without devastating this forest for coffee plantation and agriculture expansion into the forest.

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Appendixes

S. No	Scientific Name	Family Name	Vernacular Name (A/O)	Habit
1	*Acacia abyssinica* Hochst ex Benth.	Fabaceae	Laaftoo/sondii	T
2	*Acacia etbaica ssp. etbaica* Schweinf.	Fabaceae	Doddota	T
3	*Albizia gummifera* (J.F.Gumel.) C.A.Sm	Fabaceae	Hambabbeessa	T
4	*Allophylus abyssinicus* Hochst.) Radlkofer	Sapindaceae	Xaaxessaa	T
5	*Apodytes dimidiata* E.Mey.ex Am.	Icacinaceae	Wandabiyoo	T
6	*Bersema abyssinica* Fresen	Melianthaceae	Lolchiisaa	T
7	*Brucea antidysenterica* J.F. Mill.	Simaroubaceae	Qomonyoo	T
8	*Byttneria catalpifolia* Jacq.	Sterculiaceae	Halalee/Wallaaggoo	T
9	Calpurina aurea (Ait.) Benth	Fabaceae	Ceekaa	S
10	*Celtis africana* Burm.f.	Ulmaceae	Qayii/Cayii	T
11	*Chionanthus mildbraedii* (Gilg and Schel/enb.)	Oleaceae	Digaja	T
12	*Clausena anisata* (Wild.) Hook. F.ex. Benth	Rutaceae	Ulumaayii	S
13	*Coffea arabica* L.	Rubiaceae	Buna	S
14	*Combretum adenogonium* Steud. Ex.A. Rich.	Combretaceae	Adda jaboo	T
15	*Cordia africana* Lam.	Boraginaceae	Waddeessa	T
16	*Croton macrostachyus* A.Rich	Euphorbiaceae	Bakkaannisa	T
17	*Diospyros abyssinica* (Hiern.) F.White	Ebenaceae	Lookoo	T
18	*Dombeya quinqueseta* (Del.) Exel	Sterculiaceae	Daannisa gammoojjii	T
19	*Dombeya torrida* (J.F.Gmel.) P. Bamps	Sterculiaceae	Daannisa diimaa	T
20	*Dracaena steudneri* Engl.	Dracaenaceae	Merqoo/yuuddoo	T
21	*Ehretia cymosa* Thonn.	Boraginaceae	Ulaagaa	T
22	*Ekebergia capensis* Sparm.	Meliaceae	Somboo	T
23	*Entada abyssinica* Steud. Ex A. Rich.	Fabaceae	Ambaltaa	T
24	*Erythrina brucei* Schweinf	Fabaceae	Waleensuu	T
25	*Euphorbia abyssinica* Gmel.	Euphorbiaceae	Adaamii	T

S. No	Scientific Name	Family Name	Vernacular Name (A/O)	Habit
26	*Ficus vallis choudae* Del.	Moraceae	Madaallee	T
27	*Ficus ovata* Vahl	Moraceae	Qiliinxoo	T
28	*Ficus sur* Forssk.	Moraceae	Harbuu	T
29	*Ficus sycomorous* Forssk	Moraceae	Odaa	T
30	*Ficus thonningii* Blume	Moraceae	Dambii	T
31	*Ficus vasta* Forssk	Moraceae	Qilxuu	T
32	*Flacourtia indica* (Brm.f.) Merr	Flacourtiaceae	Akuukkuu	T
33	*Gardenia ternifolia* Schumach. and Thonn.	Rubiaceae	Gambeelloo	T
34	*Grewia ferruginea* Hochst. ex A. Rich.	Tilliaceaee	Dhoqonuu	S
35	*Indigofera macrantha* Harms	Fabaceae	Midhaan/lootii qamalee	T
36	*Lannea barteri* (Oliv.) Engl.	Anacardiaceae	Duuloo	T
37	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayyii	T
38	*Millettia ferruginea* (Hochst.) Bak	Fabaceae	Askiraa/Sootalloo	T
39	*Mimusops kummel* A. DC.	Sapotaceae	Qolaatii	T
40	*Myrsine africana* L.	Myrsinaceae	Dhandhansa	T
41	*Nuxia oppositifolia* (Hochst.) Benth.	Loginaceae	Nanfuroo/Qana'ee	T
42	*Ochna holstii* Engl.	Ochnaceae	Lookoo gurraacha	T
43	*Olea capensis L. subsp. macrocarpa* (C.H.Wright)	Oleaceae	Gagamaa	T
44	*Olea europea L. ssp. cuspidata* (Wall. ex G. Don).	Oleaceae	Ejersa	T
45	*Olea welwitschii* (Knobl.) Gilg. and Schellenb	Oleaceae	Bayaa	T
46	*Olinia rochetiana* A. Juss.	Oliniaceae	Soolee	T
47	*Ozora insigns* Del.	Anacardaceae	Gaarrii	T
48	*Phoenix reclinata* Jacq.	Arecaceae	Meexxii	T
49	*Pittosporum viridiflorum* Sims	Pittosporaceae	Qarsammee	T

S. N<u>o</u>	Scientific Name	Family Name	Vernacular Name (Afaan Oromoo)	Habit
50	*Podocarpus falcatus* (Thunb.) R. B. ex Mirb.	Podocarpaceae	Birbirsa	T
51	*Polyscias fulva* (Hiern) Harms	Araliaceae	Kaariyoo/Gurra fardaa	T
52	*Pouteria adolfi-friederici* (Eng.) Baehni	Sapotaceae	Qararoo	T
53	*Premna schimperi* Engl.	Lamiaceae	Urgeessaa	S
54	*Prunus africana* (Hook.f.) Kalkam.	Rosaceae	Hoomii	T
55	*Rothmannia urcelliformis* (Hiern.) Robyns	Rubiaceae	Buruurii	T
56	*Sapium ellipticum* (Krauss) Pax	Euphorbiaceae	Bosoqa	T
57	*Schefflera abyssinica (*Hochst.ex. A.Rich.)	Araliaceae	Bottoo/Gatamaa	T
58	*Spathoda campanulata* P.Beauv	Bignoniaceae	Anuunuu	T
59	*Stereospermum kunthianum* Cham.	Bignoniaceae	Botoroo	T
60	Syzygium guineense (Willd.) subsp. Afromontanum DC.	Myrtaceae	Baddeessaa	T
61	*Syzygium guineense subsp.guineensis (*Willd.)	Myrtaceae	Goosuu	T
62	*Teclea nobilis* Del.	Rutaceae	Hadheessa kormaa	T
63	*Terminalia macroptera* Giull and Perr.	Combretaceae	Dabaqqaa	T
64	*Vepris dainellii* (Pichi-serm.) Kokwaro.	Rutaceae	Hadheessa dhalaa	T
65	*Vernonia amygdalina* Del.	Asteraceae	Eebicha	T
66	*Vernonia auriculifera* Hiern.	Asteraceae	Reejjii	S
67	*Warburgia ugandensis* Sprague	Canellaceae	Biiftii	T

Annex 1. Importance Value index of species in the area

List of Species	RFr	RD	RBA	IVI	%	Rank
Albizia gummifera (J.F.Gumel.) C.A.Sm	3.66	3.89	13.14	20.70	6.90	1
Acacia abyssinica Hochst ex Benth.	4.76	4.93	9.69	19.37	6.46	2
Croton macrostachyus A.Rich	2.75	2.18	10.07	14.99	5.00	3
Syzygium guineense (Willd.) DC. *subsp.afromontanum* F. White.	0.37	0.46	11.69	12.52	4.17	4
Bersema abyssinica Fresen	3.30	5.50	2.79	11.58	3.86	5
Pouteria adolfi-friederici (Eng.) Baehni	0.73	0.46	10.00	11.19	3.73	6
Acacia etbaica ssp. etbaica Schweinf.	4.58	4.70	0.31	9.59	3.20	7
Byttneria catalpitiolata Jacq.	4.58	3.67	1.24	9.48	3.16	8
Allophylus abyssinicus (Hochst.) Radlkofer	4.21	4.70	0.34	9.25	3.08	9
Celtis africana Burm.f.	1.83	1.83	3.90	7.57	2.52	10
Brucea antidysenterica J.F. Mill.	3.48	3.89	0.01	7.38	2.46	11
Cordia africana Lam.	1.65	2.06	2.73	6.44	2.15	12
Podocarpus falcatus (Thunb.) R. B. ex Mirb.	0.73	0.46	4.98	6.17	2.06	13
Diosporyus abysssinica (Hiern.) F.White	1.10	4.81	0.24	6.15	2.05	14
Millettia ferruginea (Hochst.) Bak	0.92	0.69	4.31	5.91	1.97	15
Dombeya torrida (J.F.Gmel.) P. Bamps	2.38	3.32	0.15	5.86	1.95	16
Euphorbia abyssinica Gmel.	1.83	1.26	2.59	5.69	1.90	17
Olea capensis L. subsp. macrocarpa (C.H.Wright) Verdc.	0.92	0.69	3.75	5.36	1.79	18
Dombeya quinqueseta (Del.) Exel	2.75	2.52	0.02	5.29	1.76	19

Combretum adenogonium Steud. exA.	2.56	2.52	0.01	5.09	1.70	20
Calpurina aurea (Ait.) Benth	2.75	2.18	0.09	5.02	1.67	21
Olea welwitschii (Knobl.)Gilg. and Schellenb	0.73	0.80	3.27	4.81	1.60	22
Chionanthus mildbraedii (Gilg. and Schel/enb.) Stearn	2.01	1.95	0.75	4.71	1.57	23
Entada abyssinica Steud. ex A. Rich.	1.83	2.63	0.10	4.57	1.52	24
Erythrina brucei Schweinf	2.38	1.95	0.10	4.42	1.47	25
Coffea arabica L.	2.20	1.95	0.21	4.35	1.45	26
Dracaena steudneri Engl. ???	1.47	2.75	0.07	4.28	1.43	27
Clausenia anisata (Wild.) Hook. F.ex. Benth	2.20	1.83	0.06	4.09	1.36	28
Prunus africana (Hook.f.) Kalkam.	0.55	0.57	2.92	4.04	1.35	29
Ekebergia capensis Sparm.	2.01	1.83	0.15	4.00	1.33	30
Ehretia cymosa Thonn.	2.01	1.83	0.03	3.87	1.29	31
Ficus vallis choudae *Del.*	1.65	1.37	0.66	3.68	1.23	32
Ficus ovata Vahl	1.28	1.72	0.20	3.20	1.07	33
Apodytes dimidiata E.Mey.ex Am.	1.10	1.49	0.33	2.92	0.97	34
Ficus sycomorus L	1.47	1.37	0.08	2.92	0.97	35
Ficus thonningii Blume	1.47	1.15	0.17	2.79	0.93	36
Flacourtia indica (Brm.f.) Merr	1.47	1.03	0.10	2.60	0.87	37
Ficus vasta Forssk	1.47	1.03	0.08	2.57	0.86	38
Gardenia ternifolia Schumach. & Thonn.	1.47	0.92	0.05	2.43	0.81	39
Grewia ferruginea Hochst. ex A. Rich.	1.47	0.92	0.00	2.38	0.79	40
Indigofera macrantha Harms	1.28	1.03	0.00	2.32	0.77	41
Vepris dainelli (Pichi-serm.) Kokwaro.	0.37	0.23	1.68	2.28	0.76	42
Schefflera abyssinica (Hochst.ex. A.Rich.) Harms	0.55	0.34	1.17	2.06	0.69	43
Maesa lanceolata Forssk.	1.10	0.92	0.02	2.04	0.68	44
Lannea barteri (Oliv.) Engl.	1.10	0.92	0.01	2.02	0.67	45
Teclea nobilis Del.	0.37	0.34	1.28	1.99	0.66	46

Nuxia congesta R.Br.ex Fresen	0.92	0.80	0.26	1.98	0.66	47
Ficus sur Forssk.	0.92	0.92	0.12	1.95	0.65	48
Pittosporum viridiflorum Sims	0.73	0.46	0.72	1.91	0.64	49
Myrsine africana L.	1.10	0.69	0.04	1.82	0.61	50
Ochna holstii Engl.	0.92	0.80	0.05	1.77	0.59	51
Warburgia ugandensis Sprague	0.18	0.11	1.29	1.59	0.53	52
Olea europea L. ssp. cuspidata (Wall. ex G. Don) Cif.	0.92	0.57	0.04	1.53	0.51	53
Olinia rochetiana A. Juss.	0.73	0.69	0.05	1.47	0.49	54
Sapium ellipticum (Krauss) Pax	0.55	0.57	0.28	1.40	0.47	55
Terminalia macroptera Giull & Perr.	0.37	0.34	0.68	1.39	0.46	56
Polyscias fulva (Hiern) Harms	0.73	0.46	0.18	1.37	0.46	57
Mimusops kummel A. DC.	0.73	0.46	0.14	1.33	0.44	58
Ozora insigns Del.	0.73	0.57	0.02	1.32	0.44	59
Phoenix reclinata Jacq.	0.73	0.46	0.02	1.22	0.41	60
Rothmannia urcelliformis (Hiern.) Robyns	0.55	0.57	0.07	1.19	0.40	61
Spathoda campanulata P.Beauv	0.55	0.34	0.20	1.10	0.37	62
Stereospermum kunthianum Cham.	0.55	0.46	0.04	1.05	0.35	63
Syzygium guineense subsp.guineensis (Willd.) DC.	0.37	0.46	0.12	0.95	0.32	64
Premna schimperi Engl.	0.55	0.34	0.00	0.89	0.30	65
Vernonia amygdalina Del.	0.18	0.23	0.11	0.52	0.17	66
Vernonia auriculifera Hiern.	0.18	0.11	0.01	0.31	0.10	67

Annex 2. List of species and their families in the study area

Family	No. of species	Percent (%)	Rank	Genera	Percent (%)
Fabaceae	8	11.94	1	7	12.50
Moraceae	6	8.96	2	1	1.79
Oleaceae	4	5.97	3	2	3.57
Rubiaceae	3	4.48	4	3	5.36
Rutaceae	3	4.48	5	3	5.36
Sterculiaceae	3	4.48	6	2	3.57
Euphorbiaceae	3	4.48	7	3	5.36
Combretaceae	2	2.99	8	2	3.57
Boraginaceae	2	2.99	9	2	3.57
Anacardaceae	2	2.99	10	2	3.57
Myrsinaceae	2	2.99	11	2	3.57
Sapotaceae	2	2.99	12	2	3.57
Bignoniceae	2	2.99	13	2	3.57
Myrtaceae	2	2.99	14	1	1.79
Asteraceae	2	2.99	15	1	1.79
Araliaceae	2	2.99	16	2	3.57
Sapindaceae	1	1.49	17	1	1.79
Icacinaceae	1	1.49	18	1	1.79
Melianthaceae	1	1.49	19	1	1.79
Ulmaceae	1	1.49	20	1	1.79
simaroubaceae	1	1.49	21	1	1.79

Family	No. of species	Percent (%)	Rank	Genera	Percent (%)
Ebenaceae	1	1.49	22	1	1.79
Dracaenaceae	1	1.49	23	1	1.79
Meliaceae	1	1.49	24	1	1.79
Flacourtiaceae	1	1.49	25	1	1.79
Tilliaceae	1	1.49	26	1	1.79
Loginaceae	1	1.49	27	1	1.79
Ochnaceae	1	1.49	28	1	1.79
Oliniaceae	1	1.49	29	1	1.79
Arecaceae	1	1.49	30	1	1.79
Podocarpaceae	1	1.49	32	1	1.79
Lamiaceae	1	1.49	33	1	1.79
Rosaceae	1	1.49	34	1	1.79
Canellaceae	1	1.49	35	1	1.79
Total	67	100.00		56	100.00