EFFECTS OF ELEVATIONS ON WOODY SPECIES DIVERSITY AND CARBON STOCKS OF KELLA NATURAL FORESTS IN KONSO ZONE, SOUTHERN ETHIOPIA

M.Sc. THESIS

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A THESIS SUBMITTED TO DEPARTEMENT OF GENERAL FORESTRY, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOUECES HAWASSA UNIVERSITY, WONDO GENET, ETHIOPIA

IN PARTIAL FULFILLMENET OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST RESOURCES ASSESMENT AND MONITORING

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APPROVAL SHEET- I

This is to certify that the thesis entitled "Effects of Elevation on Carbon Stocks and Woody Species Diversity of Kella Natural Forests in Konso Zone, Southern Ethiopia" submitted in partial fulfillment of the requirements for the degree of Master of science with specialization in Forest Resources Assessment and Monitoring of the graduate program of the department of General Forestry / Hawassa University, Wondo Genet College of Forestry and Natural Resources, and is a record of original research has been carried out by Biruk Lulseged ID No. M.Sc./FRAM/R004/09, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Dr Mesele Negash	________________	___________
Name of Advisor	Signature	Date

APPROVAL SHEET- II

We, the undersigned, members of the Board of Examiners of the final open defense by Biruk Lulseged have read and evaluated her thesis entitled "Effects of Elevation on Carbon Stocks and Woody Species Diversity of Kella Natural Forests in Konso Zone,Southern Ethiopia" 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 in Forest Resources Assessment and Monitoring.

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STATEMENT OF THE AUTHOR

I, Biruk Lulseged, hereby declare that this MSc thesis entitled “Effects of Elevation on Carbon Stocks and Woody Species Diversity of kella natural forests in konso zone, southern Ethiopia” 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.

Biruk Lulseged: __________________

Date: ______________

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DEDICATION

This work is dedicated to my beloved late Grandfather Gajabo Bacho

LIST OF ABBREVIATIONS AND ACRONYM

AGB	Aboveground biomass
BGB	Below ground biomass
C	Carbon
CO_2	Carbon dioxide
CRGE	Climate Resilient Green Economy
DBH	Diameter at breast height
DSH	Diameter at stump height
EMA	Ethiopian Meteorological Agency
GHG	Green house gases
H	Height
HE	High elevation
IPCC	Inter Governmental Panel on Climate Change
IVI	Importance value index
LE	Low elevation
ME	Middle elevation
MEFCC	Ministry of Environment, Forest and Climate Change
MRV	Measurement, Reporting, and Verification
REDD	Reducing Emission from Deforestation and Forest Degradation
SOC	Soil organic carbon
UNFCCC	United Nations Framework Convention on Climate Change

UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
WGCFNR	Wondo Genet College of Forestry and Natural Resources

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ABSTRACT

Tropical forests can make a significant contribution to both mitigation and adaptation strategies of climate change. An effective climate change response requires consideration of the role and potential impacts on, biodiversity and ecosystem services. Several studies indicate that, there is decline in species richness along altitude and it has influence on biomass and soil organic carbon. Thus, this study was conducted to evaluate the impact of Elevation on Woody species diversity and carbon stock potential in Kalla forest, Konso zone, Sothern Ethiopia. The study was conducted along three elevation gradients, namely, low elevation (1605-1690 m), middle (1691-1775m) and high (1776-1860m). A total of 60 sample plots (20mx20m) were systematically laid down at interval of 200m between transects and 50m between plots. In each main plot a 5 nested sub plots (four from corners and one at the center) with 4 m x 4 m were used to collect sapling and seedlings. Moreover, 1 m x 1 m subplots were used to collect litter and soil. A total of 120 soil samples for soil chemical analysis and 120 samples for bulk density determination were taken separately. A total of 22 woody species, belonging to 19 genera and 14 families were recorded. Of all woody species 10, 13 and 17 species were recorded in the high elevation (HE), middle elevation (ME)and low elevation (LE), respectively. Abundance, species richness, Shannon diversity index, Simpson diversity index, basal area and stem density were significantly higher in the LE than ME and HE. The average woody species stem density and basal area of LE were 76 ± 38stems ha^{-1} and 156.0 ± 90.9m^2 ha^{-1}, which is 1.5 and 1.7 ,1.2 and 1.4 times higher than that of the HE and ME respectively. The Shannon and Simpson diversity indices per plot were 1.62±0.2 and 0.76±0.06 in LE, 1.29±0.4 and 0.6±0.16 in ME whereas in HE 1.55±0.2and 0.73±0.11, respectively. Juniperes procera, Euphorbia tirucalli and Acacia Senegal were the most abundant woody species in the LE while Euphorbia tirucalli, Acokaathera schimpori and Juniperes procera were in the ME and Euclea racemosa, Juniperes procera and Acokaathera schimpori in HE .The total ecosystem carbon stocks (biomass plus soil, 0-30 cm) were significantly different ($p < 0.05$) between the LE, ME and HE. The LE showed higher ecosystem carbon stock (301.8 ± 171.6 t Cha^{-1}t Cha^{-1}) than ME (255.6±88.2) and HE (190.8± 58.2t C ha^{-1}). The SOC stock (0 - 60 cm depth), standing biomass and litter accounted 90.8 %, 6.6 % and 2.6% in the LE whereas 93.0 %, 5.1 % and 1.9 % in the ME and. 92.1%, 6.3% and 1.6% in the HE Juniperes procera and Euphorbia tirucalli in the LE contributed about 81 % of the total biomass carbon stocks. While in the ME and HE , Euphorbia tirucalli and Juniperes procera , Euclea racemosa and Juniperes procera were contributed 60 % and 48% of the total biomass carbon stock respectively. The total above ground biomass carbon stocks were significantly correlated with the species diversity. Finally, this study indicated that LE and ME have better contribution to improve woody species diversity and total carbon stock of biomass and soil in Kalla forest, Sothern Ethiopia.

Key words: *Elevation range, Biomass, carbon stock, woody species diversity*

1. INTRODUCTION

1.1 Back ground and Justification

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change. Understanding the determinants of forest carbon storage and allocation in different ecosystem components is important for predicting the response of carbon balance to climate change and forest management (Pregitzer and Euskirchen, 2004). On regional and continental scales, many studies based on forest biomass or soil survey have revealed broad geographical patterns of carbon density of forest biomass and soil organic carbon, and suggested the role of climate and vegetation type in shaping these spatial patterns (Dixon *et al.,* 1994). Generally, vegetation carbon density decreased but soil carbon density increased with increasing latitude (decreasing temperature). Many environmental factors such as temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity changes systematically with altitude. Therefore, altitudinal gradients are among the most powerful ''natural experiments'' for testing ecological and evolutionary responses of biota to environmental changes (Fang *et al.*, 2004). Although changes in species composition and distribution, biodiversity and community structure along altitudinal gradients have been well documented in the past few decades (Fang *et al.*, 2004), the altitudinal patters of carbon storage and partition among components (vegetation, detritus and soil) of forest ecosystems remain poorly studied(Fang *et al.*, 2004). As mountain regions cover about 24% of total global land area (UNEP-WCMC, 2002) and there have been rapid climate changes in mountain regions during the past few decades (IPCC, 2007), understanding the shifts in forest carbon storage and allocation along altitudinal gradients in mountain regions will help us better predict the response of regional and global carbon balance to future climate change. Ethiopia has a mean value 1.17 billion tons of carbon stock of which 434.19 million tons of carbon is constituted by the high forests of the country (Yitebitu Moges *et al.,* 2010). It was also noted that the figures indicated at national for carbon stock of the country by different authors is not consistent. For instance, 153 million tons Houghton (1999), 867 million tons Gibbs and Brown, (2007a) and 2.5 billion tons, and 2.5 billion tons by Sisay Nune *et al.,* (2009). In Ethiopia as one of the country in the tropics, little is known about inter site and temporal variability of forest biomass when compared to the large amount of information available in other continents (Chave *et al.,* 2001; Abel *et al.,* 2014). Periodic forest inventories and monitoring in the country are lacking even though they are most useful in order to evaluate the magnitude of carbon fluxes between AGB and the atmosphere (Abel Girma *et al.,* 2014 ; Adugna Feyissa *et al.,* 2013) reported that Ethiopia has limited information about carbon stocks of forest. Similarly, Belay Melese *et al.,* (2013) described that although carbon is varying from forest to forest and soil to soil, Ethiopia has only limited number of studies regarding carbon stock. In Konso wereda there are Kalla and Pamale forests, those are belong to Kalla and Pamale family respectively in Konso wereda. These forests are rich in woody species diversity and managed in cultural way by above mentioned family kings starting from a long time ago but, there was no information related with kalla forest woody species diversity and carbon stock.

1.2 Statement of the Problem

Ethiopia losses it's biologically diverse forest resource from time to time due to various human induced pressures such as: expansion of agricultural land, overgrazing, fire and settlements. The increasing pressures of the above mentioned factors has accelerated the decline of forest resources and led to further environmental degradation such as soil erosion, loss of biodiversity and deterioration of the ecosystem services. The ever increasing demands for forest products and forestland driven by human population increment are putting intolerable pressure on the remaining forest fragments of the country. Currently the demand of reliable information regarding forest carbon stock both at national and global levels is growing (Genene *et al.*, 2013). Reliable estimates of biomass, liter and soil carbon are needed to understand the contribution of forests on atmospheric carbon dioxide. This calls researchers to direct their interests to quantify forest carbon stocks following standardized carbon stock accounting method. Measuring and estimating carbon stocks and changes in carbon stocks in various pools are very important for carbon trading (Yitebitu *et al.*, 2010).

Several studies have been conducted in Ethiopia on ecosystem services of forest which indicate the empirical studies were lack the effects of elevation gradients on woody species diversity and carbon stocks (Feyera, 2006). Similarly, in Konso specifically in Kalla forests there were no studies that describe the effect of elevation gradient on woody species and carbon stock. This creates gap to manage the forest according to the elevation to increase the woody species diversity and carbon stocks so, this study was initiated to encourage knowledge related with effect of elevation gradient on woody species and carbon stock.

1.3 Objective

1.3.1 General objective

The general objective of this study is to investigate effects of elevation on woody species diversity and carbon stocks of Kella natural forest in Konso district, Southern Ethiopia

1.3.2 Specific objectives

- To determine woody species composition and diversity along altitudinal ranges
- To quantify biomass and soil organic carbon stocks along altitudinal ranges
- To evaluate the relationships of carbon stock and woody diversity following gradients

1.4 Research questions

- Do altitudinal differences have influence on woody species composition and diversity differ along altitudinal ranges?
- Do altitudinal differences have influence on biomass and soil organic carbon stocks?
- Is there relationships between carbon stock and woody diversity following gradients?

1.5 Significance of the Study

The reductions of emission from deforestation and degradation by managing the existing forests sustainably bring financial and technical incentives from industrialized nations to developing countries through REDD+. To tap this opportunity, accurate and consistent data that meet international standards while creating favorable policy environment are the most important requirements to derive benefits from climate funds. Therefore, carbon cycle in forests, periodic monitoring of changes in forest and carbon stocks and verifying the results and establishing empirical relationships are likely to be the issues of research and development undertakings. Studying the carbon stock of a given vegetation in order to know its status in carbon density or content thereby get credit from reduced emission (certified reduction emission can be sold in international carbon market).

For further contributing to scientific world, the investigation of the effect of elevation on woody species diversity and carbon stocks in Ethiopia particularly in Kella forest of Konso help to design the forest management plan according to the elevation effect on woody species and carbon stock. Moreover, it can benefit the country specifically the community of Kella forest in Konso district. This will creating away for carbon trade and enhances well-being of the community livelihood and sustainable natural resources management.

2. LITERATURE REVIEW

2.1 The Role of Woody Species Diversity

The relationship between biodiversity and carbon storage is being debated as one of the current ecological topics and some aspects of climate- related effects have been well investigated. Because biomass is an important component of forest stand productivity, the relationship between biomass, carbon and biodiversity can also be assimilated to the one of biodiversity and ecosystem function (Mutke and Barthlott, 2005). Basically, two well- debated mechanisms are commonly used to explain the role of plant diversity in ecosystem resource dynamics, ecosystem processes, and functions: niche complementarity effects and selection effects the niche complementary effects hypothesis assumes increasing diversity would promote greater variety of functional traits and provide opportunities to species to efficiently use the available resources, thereby increasing ecosystem function; the selection effects hypothesis suggests that in ecosystem with higher diversity, there would be a higher probability of occurrence of dominant species or traits that influence ecosystem functioning. Currently, great research efforts are made to elucidate how diversity components (taxonomic diversity, functional diversity, and functional dominance) drive biomass and carbon stocks, and the extent to which the findings support niche complementarity and selection effects hypotheses (Feyera , 2006).

Taxonomic diversity, expressed by species richness and alpha- diversity indices, has been commonly used as a simple measure of biodiversity (Vormisto *et al.*, 2006) and has been shown to correlate positively with carbon stocks. However, because a new species with different functional traits added to an ecosystem would likely contribute to the physiological processes, the effects of taxonomic diversity on carbon storage could be treated as different effects of functional diversity (accounting for niche complementarity) or/and functional dominance (comprising selection effects). The functional diversity is known as "the value and range of functional traits of the organisms present in a given ecosystem" and therefore might be the starting point of elucidating the mechanisms underlying the relation between biodiversity and carbon. Yet, some recent reviews showed controversy in the relationship between taxonomic and functional diversity. On the one hand, functional diversity was positively correlated with species richness, and in this case, taxonomic diversity can simply be used to replace functional diversity. On the other hand, it was pointed out that land use, the local species pool, etc. could also influence the relationship between functional and taxonomic diversity (Cadotte *et al.*, 2011; Mayfield *et al.*, 2010). Consequently, whether diversity (species richness) effects on ecosystem function are fully mediated by functional diversity or codetermined by selection effects (dominance patterns) is still well debated. In tropical natural forests, where several species cohabit and fulfill the major ecosystem functions, it is common to observe the abundance and dominance of highly productive tree species, thus increasing the chances that diversity–carbon relationships are mediated by selection effects. This was partly confirmed by them previous observations in South African mistbelt forests, especially the greater influence of the most dominant species on biomass stocks. More and more, research tends to show how functional diversity and/or functional dominance play a major role in ecosystem functioning (Baraloto *et al.*, 2012). Understanding whether diversity effects on ecosystem function are more likely mediated through functional diversity than functional dominance, or vice versa, will bring substantial insights into which mechanism is more relevant.

Very few studies have addressed the relationships between diversity and ecosystem function in natural multispecies tropical forests. Using aboveground tree carbon data in a northern mist-belt forest in South Africa, they examined the relationship between diversity and carbon stocks through the effects of functional diversity and functional dominance. We hypothesized that (1) diversity influences tree carbon storage through both functional diversity and functional dominance effects. However, there are insights that diversity and carbon relationships can be caused by covarying environmental factors (Mutke and Barthlott, 2005). Therefore, we considered altitude and slope as the most physical gradients in these forests, and tested their effects on tree carbon storage. In addition, while accounting for significant environmental gradient effects, we also hypothesized that (2) effects of diversity on carbon storage would be greater for functional dominance than for functional diversity.

2.2 The Importance of Studying Carbon stocks in a Forest

Estimating the amount of forest biomass is very crucial for monitoring and estimating the amount of carbon that is lost or emitted during deforestation, and it also provides information about the forest's potential to sequester and store carbon in the forest ecosystem. Estimations of forest carbon stocks are based upon the estimation of forest biomass, because forest carbon stocks are generally assumed to be half of its biomass (Vashum and Jayakumar, 2012). According to these authors, any sort of forest management practices affect the flux of carbon between the terrestrial forest ecosystem and the atmosphere. Hence, estimating the forest carbon stocks is mainly important to assess the magnitude of carbon exchange between the forest ecosystem and the atmosphere.

On the other hand, as described by Vashum and Jayakumar (2012) the reason why carbon cycle drew much attention at global level is that (1) it is the chief among other GHGs (2) its potentials to influence the global climate pattern and (3) relatively its long residence time in the atmosphere. Likewise, there are two key policy related reasons for measuring carbon in forests: (1) commitments under UNFCCC, and (2) for potential implementation of the Kyoto Protocol (Brown, 2002).

Therefore, assessment of the amount of carbon sequestered by a forest gives us an estimate of the amount of carbon emitted into the atmosphere when this particular forest area is deforested or degraded. Furthermore, it can help us to quantify the carbon stocks which will enable us to understand the current status of carbon stocks and also derive the near future changes in the carbon stocks. Estimation of AGB is an important step in identifying the amount of carbon in terrestrial vegetation pools and is central to global carbon cycle because much of the flux takes place in above the ground of forest structure.

In addition, UNFCCC requires that all Parties to the Convention commit themselves to develop, periodically update, publish, and make information available to the Conference of Parties (COP) their national inventories of emissions by sources and removals by sinks of all GHGs using comparable methods. Forestry is one sector for which a national inventory of sources and sinks of GHGs must be developed. If carbon stocks can be measured accurately and precisely at some intervals using the same approaches, it provides the necessary information to determine the changes in carbon stocks as required by the UNFCCC and forestry projects for mitigating carbon emissions.

2.3 Carbon Pools

Carbon pools are components of the ecosystem that can either accumulate or release carbon. Different authors classified them in to different pools; this may be related to the type of forest and the objectives of the project. According to Vashum and Jayakumar (2012), there are six carbon pools applicable to aforestation/reforestation LULUCF project activities: AGB, BGB, litter, non-tree vegetation (NTV), dead wood and soil organic matter (SOC). But, not all six pools will be significantly impacted in a given project. The most important pools measured in any projects are

AGB and BGB, because trees are simple to measure and contain the major portion of the carbon pool.

There are five carbon reservoirs in a forest ecosystem: soil, plant debris (dead wood, dead roots, and leaf litter), AGB, BGB, and herbaceous plants (Ekoungoulou *et al*., 2014). Forest inventory data can provide high quality information for a particular region. Biomes likely represent the most important variation of forest carbon stocks because they account for major bioclimatic gradients such as temperature, precipitation and geologic substrate. However, forest carbon stocks vary further within each biome according to slope, elevation, drainage class, and soil type and land use history.

However, classically IPCC (2006) carbon pools have been grouped into five main categories: living AGB, living BGB, DOM in wood, litter and soil. In a tropical forest ecosystem, the living biomass of trees, the understory vegetation and the deadwood, woody debris and soil organic matters constitute the main carbon pool.

2.3.1 Components of tree biomass

The biomass of trees is often subdivided into above- and below-ground components with further subdivisions of each. For example, above-ground biomass includes foliage, branches, stem, and bark. Various researchers may define components somewhat differently (Hairiah *et al.*, 2001). About 83% of the biomass of this tree is aboveground and 17% is below-ground. The stem, including bark, is about 72% of the total biomass. Care must be exercised in interpreting biomass data. Some researchers report only the aboveground portions; the stem (with bark) of the 16 inch Douglas-fir represents 87% of its above-ground biomass. Some may consider the stump as part of the stem, while others include it with the roots. The stem biomass may be the entire stem to the tip of the tree or it may be measured to a minimum top diameter with their minder considered part of the crown. The original researchers' report must be examined to be certain that definitions of components are clearly understood.

2.3.2 Collection and calculation of biomass reference data based on field measurements

Detailed spatial biomass reference data are a prerequisite for biomass estimation (Avitabile *et al.*, 2011). The roles of biomass reference data can be grouped into five aspects: (1) identifying suitable variables from remote sensing data by establishing relationships between biomass reference data and potential variables; (2) developing biomass estimation models by relating biomass reference data and selected variables; (3)evaluating model estimates or comparing estimates among different models; (4)conducting uncertainty analysis to identify factors influencing the accuracy of biomass estimation; and (5) providing not only a statistical population estimate but also the standard error. Therefore, collecting high-quality and representative biomass reference data is critical for a successful biomass estimation study. In general, biomass reference data can be obtained using destructive sampling, allometric models, and conversion from volume to biomass (Lu, 2006).

Direct collection of field measurements is the most accurate method to obtain biomass reference data and is generally used to develop species-specific allometric models based on measured attributes such as diameter at breast height (DBH), tree height, and/or wood density (Overman *et al.*, 1994; Chave *et al.*, 2014). This method involves destroying tree sand is only used to collect sample data in small areas due to prohibitive time and labor required for fieldwork (Klinge *et al.*, 1975). In general, AGB for a specific tree can be expressed as a function of DBH, tree height (H), and/or wood density (S): AGB = f(DBH, H, S). Once allometric models are available for tree species, they can be used quickly and nondestructively for stand biomass inventories. Many models have been developed based on various combinations of the aforementioned three parameters through linear or nonlinear regression models (Chave, 2006). When allometric models are used for obtaining biomass reference data, caution should be taken because soil conditions, tree densities, land-use history, and climate.

2.4. The Role of Forest in Mitigating Atmospheric CO2

Forest plays an important role in the global carbon cycle as carbon sinks of the terrestrial ecosystem. Generally, carbon stock in a forest is broadly divided in to two: biotic (vegetation carbon) and pedologic (soil carbon) components (Bhat *et al.*, 2013). The carbon sequestered or stored on the forest trees are mostly referred as the biomass of the forest. It is estimated that about 86% of the terrestrial above ground carbon and 73% of the earth's soil carbon are stored in the forests (Vashum and Jayakumar, 2012). Of which, 46% of the world's terrestrial carbon pool and about 11.55% of the world soil carbon pool stored in tropical forests.

Trees in the forest act as major CO_2 sink that captures carbon from the atmosphere and stores it in the form of fixed biomass during the growth process (Bhat *et al.*, 2013). In this natural process, it removes the carbon dioxide from the atmosphere and stores the carbon in the plant tissues, forest litter and soils. Thus, forest ecosystem plays a very important role in the global carbon cycle by sequestering a substantial amount of carbon dioxide from the atmosphere.

When trees in a forest grow or attain large biomass, the amount of CO_2 taken by the trees is increased thereby the concentration of CO_2 in the atmosphere can be reduced. The roles of forest take major parts in activities to minimize and adapt the impact of climate change. So that knowing their roles in efforts to minimize the concentration of CO_2 in the atmosphere.

It is good to identify and control the factors (land use change, soil erosion and deforestation) for the proper management of the forests sustainably. Therefore, the amount of carbon in a forest and the rate of sequestering carbon from the atmosphere could be increased if deforestation will be altered and sustainable forest management is practiced.

2.4.1. Above ground biomass (AGB)

The total standing AGB of woody vegetation is often one of the largest carbon pools. It comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous under growth. It is mainly the largest carbon pool and it is directly affected by deforestation and forest degradation. The most direct way of quantifying the carbon stored in AGB is to harvest all trees in a known area, dry them and weigh the biomass. While this method is accurate for a particular location, it is prohibitively time consuming, expensive, destructive and impractical for country level analyses. All plant materials normally contain 50% carbon from their dry weight (Clark and Kellner, 2012; Basuki *et al.*, 2009; Gibbs *et al.*, 2007; Pearson *et al.*, 2005 and Hairiah *et al.*, 2001).

The other way of estimating carbon in AGB is grouping all species together and using generalized allometric relationships, stratified by broad forest types or ecological zones, is highly effective for the tropics because DBH alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions (Gibbs *et al.*, 2007). It is often assumed in inventories that small trees ≤ 10cm diameter contribute little to the total biomass carbon of a forest and thus they often tend not to be measured (Brown, 2002). However, their contribution depends on the succession stage of the stand.

2.4.2. Below ground biomass (BGB)

The measurement of AGB is relatively established and simple. But, measuring BGB is time consuming methods. Thus, it may be more efficient and effective to apply a regression model to estimate BGB. It is derived from the measurement of the AGB. The majority of the BGB of the forest is contained in the heavy roots, generally defined as those greater than 2mm in diameter. However, it is recognized that most of the annual plant growth is dependent on fine or thin roots. Roots play an important role in the carbon cycle as they transfer considerable amounts of C to the ground, where it may be stored for a relatively long period of time. Root biomass is often estimated from root: shoot ratios (R/S). According to Brown (2002), the R/S did not vary significantly with latitudinal zone (tropical, temperate, and boreal), soil texture (fine, medium and coarse), or tree type (angiosperm and gymnosperm).

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 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. This author described that carbon loss in the ground is intense in the top layer of soil profiles (0 - 20cm). Therefore, sampling should concentrate on this section of the soil profile accumulation. Gibbs *et al.* (2007) and Ponce (2004) stated that root biomass is typically estimated to be 20% of the aboveground forest carbon stocks.

2.4.3. Dead standing and downed dead wood

The biomass of the dead tree can be calculated by using its DBH and subtracting 10-20% of the AGB, which is due to the absence of leaves and branches as well (Kauffman and Donato, 2012). 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. Brown *et al.* (1997) reported that dead tree constitute 5-40% of 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). The dead wood carbon pool is grouped in to two; dead standing and dead downed wood.

I. Standing dead wood

Standing dead trees can be measured in the same plots that are delineated for live trees. The parameters recorded for live trees are also recorded for dead standing trees. In addition to that of the parameters recorded for live trees, relative state of the wood for dead tree is needed. According to Brown *et al.* (2004), relative states for standing dead tree are described as follows:

1. Tree with branches and twigs and resembles a live tree (except for leaves)
2. Tree with no twigs but with persistent small and large branches
3. Tree with large branches only
4. Bole only, no branches

For state 1, biomass is estimated from DBH using the same function as that of live trees, but subtracting out the biomass of leaves, which is about 2 -3% of AGB for hardwoods and 5 -6% for softwoods. Where only a bole is remaining (class 4), volume is estimated using DBH and height measurements and an estimate of the top diameter. Volume is then estimated as the volume of a truncated cone, and converted to dry biomass using an appropriate dead wood density class (sound or intermediate). For classes 2 and 3 estimates of the proportion of the tree that is missing need to be made. The principle of conservatism should be applied. An estimated value of the proportion of biomass in the stem, branches, and foliage for living hardwoods and softwoods in the United States, which could be used to deduct the portion of AGB that is missing.

II. Downed/lying Dead Wood

Lying dead wood can be measured by complete inventory in one of the nested plot or by the line-intersect method. According to Brown *et al.* (2004), if the line is long enough (at least 100 m), the line-intersect is a time-efficient method. Two lines of 50 m in length are established that intersect at right angles through the plot center. Along the length of the lines, the diameter at the intersection point of any course (> 10 cm diameter) dead wood that intersects the line is measured. For smaller-stature forests, coarse wood could be > 5 cm diameter the method will be the same. There are several criteria that should be observed when deciding if a piece of dead wood should be measured. A piece should only.

Wood type Tree parts be measured if: (a) more than 50% of the log is aboveground, and (b) the sampling line crosses through at least 50% of the diameter of the piece.

If the log is hollow at the intersection point, this should be noted in the data recording system and the total diameter measured; the hollow portion in the volume estimates is deleted. Each measured piece is assigned to one of three density states: sound, intermediate, or rotten. A simple and practical method for determining the density class a piece of dead wood is to strike each piece with a saw. If the saw does not sink into the piece (bounces off), it is classified as sound. If it sinks partly into the piece, and there has been some wood loss, it is classified as intermediate. And, if it sticks into the piece, there is more extensive wood loss, and the piece is crumbly, it is classified as rotten.

For each density class separately, the volume is calculated as follows: Volume (m3/ha) = π2) (Brown *et al.*, 2004)

Where d1, d2 … dn = diameters of intersecting pieces of dead wood and L = length of line.

Representative dead wood samples of the three density classes, representing the range of species present, should be collected for density (dry weight per green volume) determination. Using a chainsaw or a handsaw, a complete disc from the selected piece of dead wood is cut. The average diameter and thickness of the disc is measured to estimate volume. Volume can also be estimated by the water displacement method.

III. Litter and Duff

The forest litter layer is defined as all dead organic surface material that includes dead leaves, twigs, dead grasses and small branches and unidentifiable decomposed fragments of organic material on top of the mineral soil. Dead wood with a diameter of < 10 cm and length < 0.5 m is included in the litter layer (Brown *et al.*, 2004; Zhu *et al.*, 2010). 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. Similarly Brown *et al.* (2004) defines the duff layer as decomposing organic material, decomposed to the point at which there are no identifiable organic materials such as pine straw, leaves, twigs, or fruits. It is the organic material layer between the uppermost soil mineral horizon and the litter layer. Both of these layers could be combined as one pool and sampled together using small subplots.

It also includes live fine roots less than 2mm in diameter as these cannot be distinguished empirically from the litter and dead wood (Zhu *et al.*, 2010). Litter layer can be collected from 1 m^2 four at the corners and one at the center of each main plot and weigh and take 100g from the collected sample to laboratory analysis for moisture content determination.

2.4.4. Non-tree vegetation (NTV)

Non-tree vegetation includes all plant species with less than specific maximum DBH (diameter at breast height =1.3 above the ground) in the forest floor. The maximum DBH mainly given for NTV is < 2 cm in diameter (MacDicken, 1997; Swai *et al.*, 2014). It is measured simply by harvesting techniques. According to Brown (2004), aboveground NTV may need to be measured if it is a significant component, such as where trees are only present at low densities. But, NTV is generally not a significant biomass component in mature forest. A small subplot (dependent on the size of the vegetation) is established and all the vegetation is harvested and weighed. An alternative approach, if the shrubs are large and common, is to develop local shrub biomass regression equations based on variables such as crown area and height or diameter at base of plant or some other relevant variable (e.g., number of stems in multi-stemmed shrubs) (Brown *et al.*, 2004). The equations would then be based on regressions of biomass of the shrub versus some logical combination of the independent variables.

2.5. Soil

Soil plays an important role in the global carbon cycle. Globally, the soil carbon stock is nearly three times the amount in the AGB and about twice as large as the carbon stock of the atmosphere (Mäkipää *et al.*, 2012). Soil organic matter is the main source of soil organic carbon while vegetation is the main source of SOM. Therefore, any factor that influences SOM has impact on soil organic carbon (SOC). SOM is influenced by a number of factors, mainly climate, vegetation types, soil types and human activities. According to Mäkipää *et al.* (2012), in broad geographic areas, the role of climate and natural vegetation on the levels of SOM is very important.

Generally, in similar moisture conditions and comparable soils and vegetation, the SOM is higher in cooler climates than in warmer ones. Moreover, high rainfall promotes vegetation growth and hence production and accumulation of SOM. Since plants (particularly natural vegetation) are the major source of soil organic matter, vegetation types and their density influence the SOC stock.

To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample. The 2006 IPCC guidelines recommend using a default 0-30 cm layer is sufficient. Within this layer, the influence of management practices is more pronounced than in the deeper soil layers.

2.6 Carbon stocks along altitudinal gradient

The relationship between species richness, aboveground biomass and carbon stock at different altitudes can have crucial implications for the management and conservation of carbon sinks. The result of some study revealed the carbon stocks in AG and BG carbon pools were greater in lower altitude than the higher altitude (Abel Girma *et al.*, 2014). Woody plant species with higher DBH class were recorded at lower altitude. This was one of the reasons that greater AGC and BGC at lower forest stratum were estimated. In other side the highest total carbon stock was recorded in the higher altitudinal range whereas smaller carbon stock was recorded in lower altitudinal range, the reason for this may be due to, disturbance level and species composition and density occurred in the altitudinal ranges (Asersie and Motuma, 2019). The study done by (Adugna Feyissa *et al.*, 2013) at Egdu forest resulted that the AGC, BGC and carbon in the soil revealed a direct relationship with altitude, but carbon stock in the litter showed an irregular pattern with altitude.

A similar research work done by Belay Melese et al. (2013) at Arba Minch riverine forest also revealed that the mean carbon stock density was considered to be large (i.e. 583.27 t ha-1). The mean carbon is high in the lower and low in the middle altitude. On the other hand, the amount of carbon stock in all carbon pools except litter pool was higher on the southern aspect as compared to other aspects. Other study done by Mesfin Sahle (2011) at Menagesha Suba State Forest based on Remote Sensing, GIS and Ground Survey the total estimated forest carbon sequestration potential of the forest in year between 1984 and 2005 were 35 tons per ha. During 1984 – 2005, plantation in Menagesha Suba State Forest has resulted in increase in forest carbon stocks of about 113,766 tons.

SOC globally increases with precipitation and clay content, even though it is mainly determined by carbon output (decomposition) and decreased with increase in temperature. As altitude increase the net primary productivity (NPP) and the carbon input (litter fall) to the soil decreases (Zhu *et al.,* 2010) so, SOC decreased with increasing altitude (Abel Girma *et al.,* 2014).

3. METHODS AND MATERIALS

3.1 Description of Study Area

3.1.1 Location

Kalla natural forest is located in Konso zone in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia. Konso district is found 356 km far away from Hawassa town to South, and 562 km far from Addis Ababa, Capital city of Ethiopia. It is located at 5°19'60" N and 37°19'60" E in the Great Rift Valley. Konso is also bordered on the south by the Oromia Region, on the west by the Weito River which separates it from the Debub Omo Zone, on the north by the Dirashe special woreda, on the northeast by Amaro special woreda, and on the east by Burji special woreda. The Sagan River, which flows south then west to join the Weito, defines part of the woreda's boundary with Burji and the entire length of the boundary with the Oromia Region.

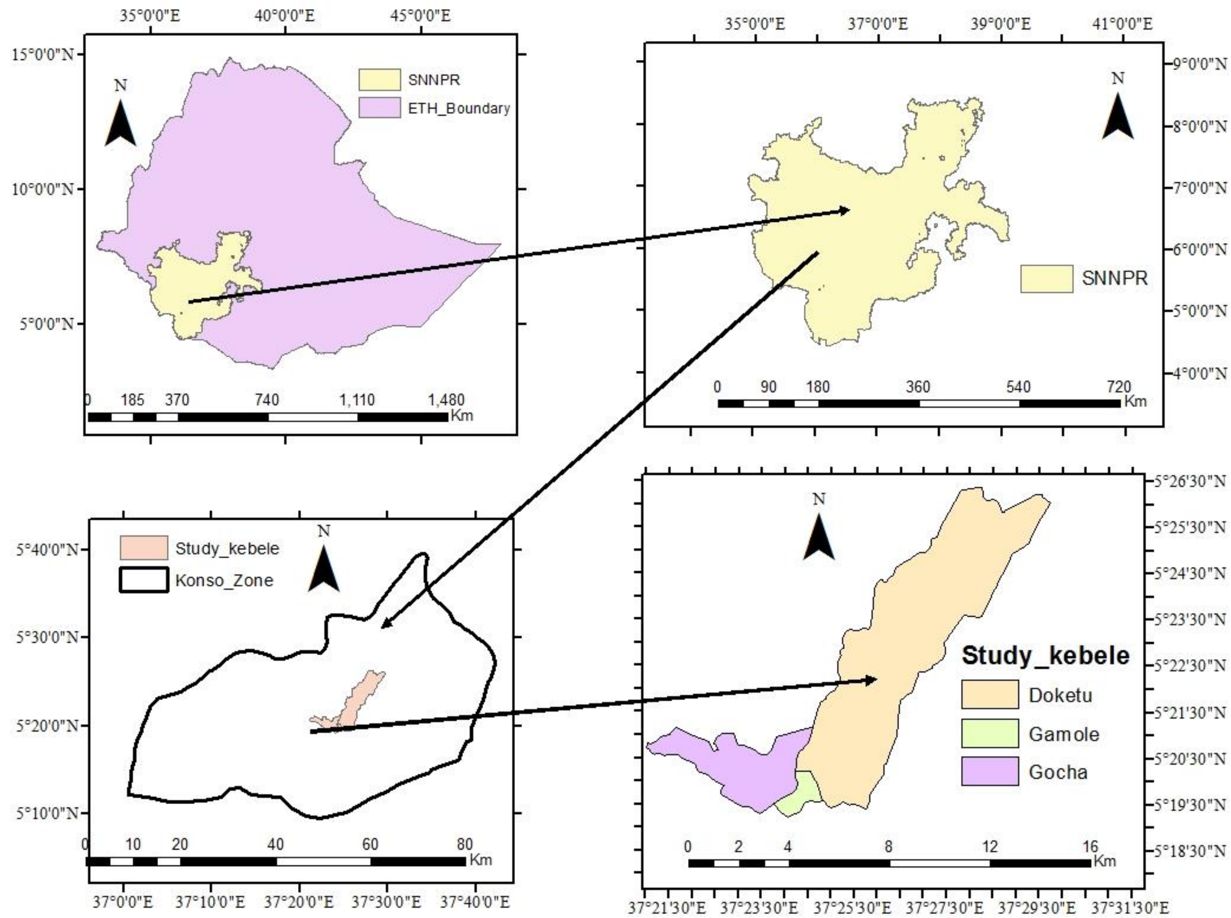


Figure 1: Study area map

3.1.2. Climate

In Konso wereda, the mean annual temperature is about 18.7°C with a mean maximum of 28.7°C and a mean minimum of 11.0°C. Mean monthly temperatures are from 10.6 - 21.6°C (EMA, 2016). The area has mainly semiarid climate with bimodal rainfall type locally called “Kiremt” from June to September and follows the pre monsoon rainy season, February to May, (locally called Belg) that adds a small amount of rain to the area.

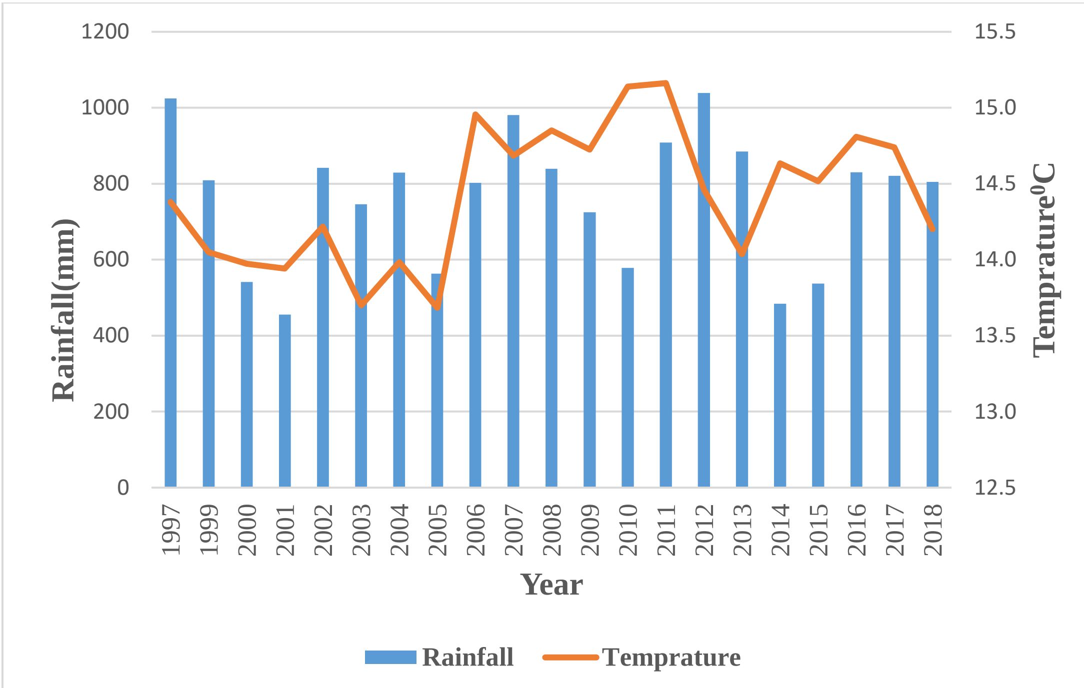


Figure 2 Average climate diagram of konso district from 1997-2018 E.C (Source: National Meteorological Agency SNNPR branch, Konso, 2018)

3.1.3. Soils

Due to information limitation on the soil of the study site soil sample was taken from Kalla forest to describe some basic soil physicochemical characteristics (Table 1).

Table 1: Soil properties (mean ± SD) of specific study sites

	Depth	Elevation Range		
		LE	ME	HE
%Silt	0-30	21.76(8.58)	22.76(8.59)	24.01(9.52)
	30-60	20.52(5.02)	20.55(5.02)	23.52(6.01)
%Clay	0-30	30.50(10.74)	29.30(10.74)	27.04(8.04)
	30-60	36.46(11.62)	34.45(10.02)	34.06(11.62)
%sand	0-30	37.50(25.09)	36.50(24.11)	36.25(24.02)
	30-60	44.69(13.85)	42.69(11.05)	43.69(12.35)
%C	0-30	3.91(2.03)	3.01(1.92)	2.07(1.43)
	30-60	2.46(1.23)	1.86(0.83)	1.66(0.72)

Textural Class	0-30	sandy loam		sandy loam
	30-60	sandy loam		sandy loam
BD(g/cm^3)	0-30	1.17(0.28)	1.54(0.28)	1.97(0.28)
	30-60	1.20(0.24)	1.92(0.24)	2.01(0.24)
Soil pH (**1:25,H2O**)	0-30	6.93(0.16)	6.95(0.25)	6.95(0.25)
	30-60	6.96(0.11)	6.96(0.11)	6.97(0.13)

3.1.4 Population and land use type

The District has 18 kebeles with a total population of 103,521 (57,201 males and 46,320 females). Total land cover of the District is estimated to be 62,185 ha, of which 29 % are arable land, 29 % forests land, 23 % grazing land and 19 % are ‘others’ (Abera *et al.*, 2014) . Crop production is the mainstay of the District economy According to EBOARD (2009), livestock population are estimated to be about 77,921 (local cattle), 783 (cross cattle), 59,333 (sheep), 4,844 (goat), 305 (horse), 423 (mule), 13,053 (donkey), 110,493 (poultry), 31 (camel), 2,196 (modern hive), 7,716 (local hive).

3.1.5. Vegetation

According to zone agricultural office and personal observation, in Konso zone there are vegetation covers managed by government and clan king. Availability of natural vegetation is more in clan kings managing forest those are Pamale and Kalla forest. konso people internationally known by tracing and written on UNESCO as world heritage to control soil erosion and production of crop and vegetable .In crop production areas of the farmer currently, the dominant woody species is *Moring stenopetal* (Haleko) by using cultural agroforestry system (konso zone agricultural office, 2017) and over all natural forests is *Juniperes procera*.

3.2 Sampling Techniques and Layout

A systematic sampling technique was employed to collect data from the Kalla forest vegetation and soil data. In each of the land use, transects lines were laid at center of each elevation ranges to address the whole forest by equal interval, 30 m away from the edge to avoid border effect. Then temporary sampling plots 20 m x 20 m were laid down at 50 m interval distance between plots. A total of 60 quadrants (240000m^2) from total 960000m^2; 20 samples from each elevation ranges. The elevation range is not wide but, because of topographic nature of the place under low elevation it nears to flat but, by contrast without going long the elevation picks up until facing difficult to walk so, by using vegetation variation and topographic nature the elevation was divided; 1605-1690 (low elevation), 1691-1775 (middle elevation) and 1776 - 1860 (high elevation) were laid down along the transect lines using wooden pegs and plastic rope. The first quadrant was assigned randomly at the beginning of the transect line. Inside each major plot, five subplots (4m x 4m) four at the corners, and one at the center were established to measure sapling and seedlings. In each five 4m x 4m sub-plots, plot with size of 1m x 1m were also established to collect soil samples and litter (Figure 2).

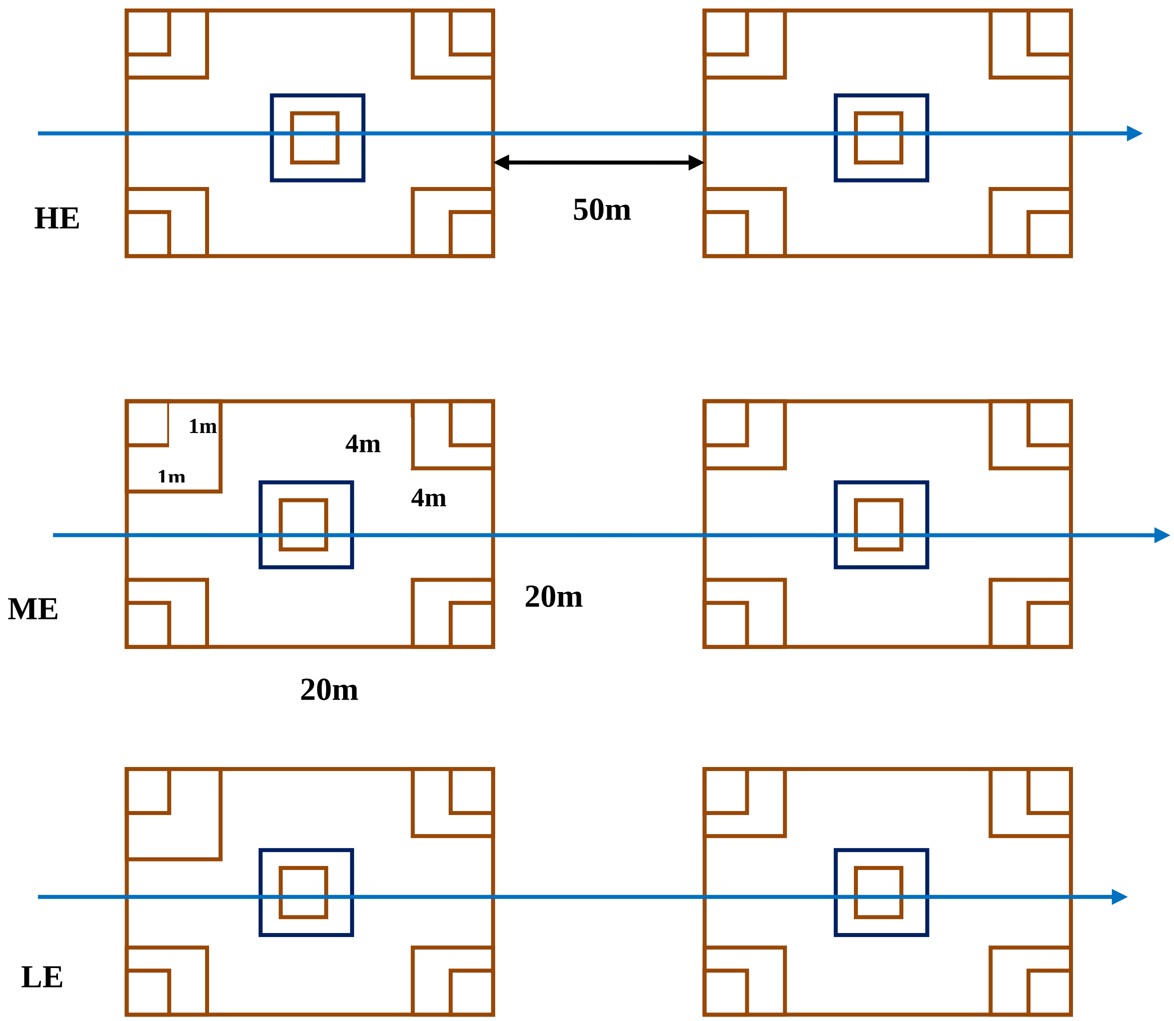


Figure 3: Sampling lay out of vegetation, litter and soil

3.3. Data Collection Methods

3.3.1. Inventory of woody species

The tallying of woody plants in sample plots included the measurement of stem diameter at breast height (DBH), and total height (H). The field survey was conducted during the dry season of December and January, 2017. Hand held Global Positioning System (GPS) device, measuring tape, colored measuring rope, compass, and pegs were used to set-up sample plots. In each plot, DBH and H of all individual trees with DBH ≥ 5 cm were marked, measured, and identified. DBH and DSH were measured from a conventional height of 1.3m and 30cm respectively (Alamgir and Al-Amin , 2008) from the ground level using tree caliper and diameter tape. Individual tree height in each plot was systematically measured using a clinometer and a graduated pole for low trees. When used correctly, the Suunto Clinometer has an accuracy of ± 0.5m for a 20m tall tree, i.e., about 2.5% (Bekele and Tessema, 2007). In case of multi-stemmed woody species, each stem were measured separately and the equivalent diameter of plant was calculated as the square root of the sum of diameters of all stems per plant (Snowdon et al., 2002). Woody vegetation identification was done in the field using key informants and each vernacular name was translated to their botanical names using flora of Ethiopia and Eritrea (Hedberg et al., 1995; Edwards et al., 1997; Edwards et al., 2000); useful trees and shrubs for Ethiopia (Bekele, 2007) and (Woldemichael et al., 2010)

3.3.1.1 Woody species composition Woody Species Composition

The species area accumulation curve of woody plants for low elevation, medium elevation and high elevation of kalla forest was flattened before the total number of samples was exhausted (Figure 4). Low elevation showed a sharper increase initially and then tended to maintain steady after plot 18 while medium elevation and high elevation was flattened after plot 10 and 16 respectively. This showed that sufficient number of sample was taken to determine woody species diversity in three elevation ranges of kalla forest.

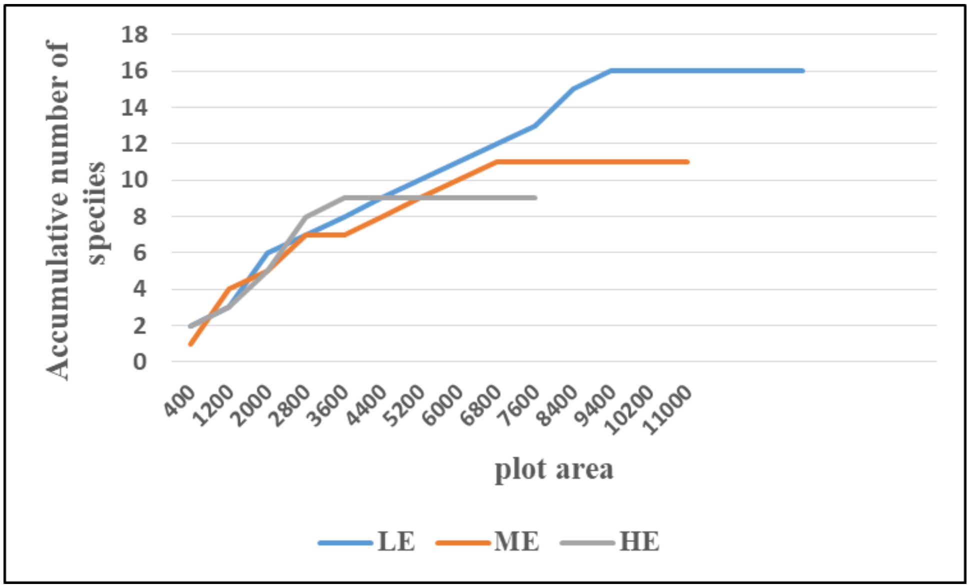


Figure 4: Species accumulation curve of woody plants in the LE, ME and HE

3.3.2 Litter sampling

Litter plant sampling was done in the interior sub sample of five 1 m x 1 m. The collected samples were mixed to make a composite sample. Fresh weight of sample was recorded in the field using string balance. Then a 100 g sub-sample was taken and transported to Hawassa University WGCFNR, soil laboratory

3.3.3. Soil sampling

Soil samples were collected from five pits arranged within four corners and from central point established well inside each site. The pits were dug to 60 cm depth and soil samples taken from 0 - 30 and 30 - 60 cm increments from each pit with hand trowel uniformly along each sample depth. Total 60 samples was taken from each depth that means from each elevation ranges 20 samples was taken (LE,ME and HE). The soil samples were air dry, mix well and pass through a 2mm sieve for chemical analysis. Other sets of soil core samples from each pit and sample depth had taken for bulk density determination. A sharp edged steel cylinder corer (height 15cm and diameter 7.2cm) had been forced manually into the soil for drawing the samples for bulk density (Mulugeta and Fesseha, 2004).

3.4. Laboratory work for litter and soil samples

I. Determination of litter dry biomass and carbon content analysis

The collected litter samples were air-dried and oven-dried for 24 hours at 65 ºC to constant weight. Then the samples were weighed, ground using mortar and pesto then sieve with 2 mm mash. The loss on ignition (LOI) method was used to estimate percentage of carbon in the litter. From the oven dried grinded sample 3.00 g of each litter sub sample were taken in pre-weighted crucibles, and then put in the furnace at 550 ºC for two hours to ignite (Negash & Starr, 2013). Then, the crucibles were cooled slowly for two hours inside the furnace. After cooling, the crucibles with ash were weighed and LOM fraction was calculated according to Allen *et al.,* (1986).

II. Soil analysis

The collected soil samples were air-dried, ground, homogenized and then sieved with a 2 mm mesh size sieve. Bulk density was estimated using oven dried samples at 105 ^{0}C for 48 hours. Soil organic carbon was determined using Walkley & Black Method (Walkley & Black, 1934), soil particle sizes for < 2 mm fractions by Boycouos hydrometric method (Bouyoucos, 1962), bulk density using core method (Blake & Hartge, 1986) and soil pH using digital pH (Carter, 1993).

3.5. Data Analysis

3.4.1 Woody species diversity analysis

Species diversity is the combination of species richness and evenness. Shannon-Wiener' index and Simpson’s index are the two most commonly used diversity measure indices.

a) **Shannon-Weiner Index (H’)**

Shannon-Weiner Index used to characterize species diversity in a community. The Shannon-Weiner Index (H) and Shannon evenness (E) indices are calculated as a measure to incorporate both species richness and species evenness (Magurran, 2004). A rich ecosystem with be high species diversity has a large value for the Shannon Diversity Index (H’), while an ecosystem with little diversity has a low H’. The Shannon-Weiner index (H') was calculated from the equation:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \text{ ....} \textit{Equation} 1$$

Where, H' = the Shannon Diversity Index

Pi = is the proportion of individuals found in the ith species:-number of individual ith species /total number of individual species in all species

S = total number of species (1, 2, 3…..n)

b) **Shannon evenness (E)**

Evenness compares the observed distribution with the maximum possible even distribution of the number of species in the studied forest (Pielou, 1975) or it is the distribution of individuals among the species in a studied forest. Evenness is maximum when all the species have same or nearly equal number of individuals. The Shannon evenness index (E) was calculated from the ratio of observed diversity to maximum diversity using the equation.

$$E = \frac{H'}{H'_{max.}} = \frac{\sum_{i=1}^{s} p_i \ln p_i}{\ln s} \text{...} Equation 2$$

Where, E= Equitability (evenness) index which has values between 0 (a situation in which the abundance of all species are completely disproportional) and 1 (all species are equally abundant).

H' = the Shannon Diversity Index

$H'_{max=}$ is the maximum level of diversity possible within a given population

Pi = is the proportion of individuals found in the i^{th} species

S = total number of species (1, 2, 3…..s)

c) Simpson's Index (D)

Another group of diversity indices are weighted by abundances of evenness of the commonest species and are usually referred to as either dominance of evenness measures (evenness and dominance are two sides of the same coin) (Magurran, 2004). Simpson's index reflects the dominance because it is more sensitive to the most abundant species than the rare species.

Simpson's index was calculated as:

$$D = \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)} \text{.........................} Equation 3$$

Where n_i = the number of individuals in the i^{th} species; and N= the total number of individuals. D ranges between 0 (represents infinite diversity) and 1(no diversity) i.e as D increase diversity decreases. This is neither intuitive nor logical, so Simpson's index is therefore usually expressed as 1- D or 1/D (Magurran, 2004). Therefore, Simpson's index was calculated as follow:

$$D = 1 - \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation 4$$

Here high D value suggests a stable and ancient site, while a low D value could suggest a polluted site, resent colonization agricultural management (*http://wwww.countrysideinfo.co.uk/simpsons.htm)* or a forest with low diversity.

d), **Important Value Index (IVI)**

Important of value index (IVI) shows the importance of species in the system, and calculated using three components as follow (Kent & Coker, 1992)

$$\text{Relative density} = \frac{\text{Density of each species (ha}^{-1})}{\text{Density of all speies (ha}^{-1})} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 5}$$

$$\text{Basal area } (m^2) = \frac{\Pi D^2}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 6}$$

$$\text{Relative Dominance} = \frac{\text{Basal area of individual woody plants}}{\text{Total basal area of all species}} \text{ x } 100 \ldots\ldots\ldots \textbf{Equation 7}$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{frequency of all species}} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation8}$$

Important value of each woody species is the sum of the above three components (Relative density, relative dominancy and relative frequency).

3.4.2. Carbon stock estimation

3.4.2.1 Above and below ground biomass estimation

The above ground biomass of each elevation range with dbh ≥ 5 cm was analyzed using the general allometric equation developed by Chave *et al*. (2014). This model was selected, because this model was developed for wide range of climatic conditions and vegetation types. Moreover, this model uses the most important biomass predictor variables such as diameter at breast height, wood density and total height. This model also, currently being proposed for inclusion in the IPCC Emission Factor Database and used by $REDD^+$ protocols.

AGB (kg) =0.0673*(WD*DBH^2*Ht)^0.976……………………………Equation 9

AGB carbon stock = AGB *0.5………………………………………..Equation 10

Where: AGB = Aboveground biomass (kg/tree), WD = Wood density, g/cm^3, DBH = Diameter at breast (DBH in ranging from 5-158 cm); H = Height (m).

Since direct measurement of BGB is expensive and time consuming task, it is derived from AGB (root shoot ratio). The BGB is 20% of AGB (Gibbs *et al*., 2007; and Ponce-Hernandez, 2004):

BGB = 0.2 X AGB ………………………………………………………………Equation 11

Where BGB – belowground biomass, AGB – aboveground biomass

Extrapolating carbon stocks from a per plot basis into a per hectare basis requires the use of expansion factors. This standardization is required so that results can be easily interpreted and also compared to other studies. According to Pearson *et al*. (2005), the expansion factor is calculated as the area of a hectare in square meters divided by the area of the sample in square meters, that is:

$$\textbf{Biomass Expansion Factor} = \frac{10000\,m^2}{\text{Area of plot, frame or soil core } m^2} \quad \ldots\ldots\ldots\ldots\ldots \textbf{Equation 12}$$

3.4.3 Litter dry biomass and their carbon estimation

The dry biomass of herb was calculated using the equation below (Pearson et al., 2005)

$$LDM = \frac{\text{Sub sample dry mass}}{\text{Sub sample fresh mass}} * \text{Fresh mass of the whole sample} \quad \textbf{Equation 13}$$

Where, LDM (Litter dry biomass)

The expansion factor to hectare was converted using expansion factor = 10,000m^2/Area of plot (m^2).

The percentage of organic carbon was calculated as

$$Ash = \frac{(W_3 - W_1)}{(W_2 - W_1)} * 100 \quad \textbf{Equation 14}$$

$$C\% = (100 - \% Ash) * 0.5 \quad \textbf{Equation 15}$$

Percentage carbon content was estimated as 50% of OM (Berhe et al., 2013)

Where

C– Biomass carbon stock
W1–Weight of crucible
W2–Weight of the oven-dried grind sample and crucible, and W3–
Weight of ash and crucible

The carbon density of herbaceous plant was then calculated by multiplying biomass of herbs per unit area with the percentage of carbon determined for each sample.

$$CSL = LDM * \%C \quad \textbf{Equation 16}$$

Where, CSL is the total carbon stock in dead litter in t ha^{-1}, % C is the carbon fractions determine in the laboratory (Pearson et al., 2005).

3.4.4 Soil analysis

To determine the SOC, firstly determine the bulk density using the formula

$$\text{Bulk density} = \frac{ODW}{CV - (RF/PD)}$$ (Pearson *et al.*, 2007)……………………………..**Equation 17**

CV = Core volume (cm3)

ODW = Oven-dry mass of fine fraction (<2 mm) in g

RF = Mass of coarse fragments (>2 mm) in g

PD = Density of rock fragments (g/cm^3). This often is given as 2.65 g/cm^3,

SOS was calculated using (Pearson *et al.*, 2007)

SOS (tha^{-1}) = [(soil bulk density, (g/cm^3) * soil depth (cm) * %C)] 100……..**Equation 18**

In this equation % C was expressed as a decimal fraction;

3.4.5. Statistical analysis

A normality (Kolmogorov- Smirnov test) and equality of variance (Levene's test) was done to check the data prior to further statistical analysis. Elevation ranges(low elevation, middle elevation and high elevation) were independent variables while species richness, species diversities, density, basal area, DBH, height, soil organic carbon, biomass carbon stock, ecosystem carbon stock were dependent variables. The size and variation in species richness, diversity and C stocks for each elevation were described by the mean and standard deviation. To test for differences in woody species richness, diversity, soil carbon stock (0 - 60 cm) and ecosystem carbon stock between the elevation ranges(LE,ME and HE) one-way ANOVA were performed ($\alpha = 0.05$). While, to find out the effect of elevation ranges (LE,ME and HE) and soil depths on soil organic carbon stock two way Analysis of Variance (ANOVA) was used.

Kruskal - Wallis ANOVA was conducted to evaluate differences between LE,ME and HE in terms of woody species stand structure and Biomass carbon stock. Spearman correlations test were conducted to examine the relation between biomass and soil carbon stocks with woody species diversity. IBM SPSS Statistics software (version 21) was used for the statistical analysis (IBM Corp. Released 2012).

4. RESULTS

4.1. Woody Species Composition and Diversity along altitudinal ranges

4.1.1. Woody species composition

A total of 20 woody species categorized under 19 genera and 14 families were recorded, all are naturally grew wood species. In the whole area of forest, highest number of species (22.5 %) was recorded in *Fabaceae*, followed by *Euphorbiaceae* (17.5 %) family. A total common species in three elevations (LE, ME and HE) were five (5) recorded with in twenty woody species. In HE ten woody species belonging to eight family were recorded and thirteen woody species under eight families, seventeen woody species under thirteen families in ME and LE respectively. Sorensen's coefficient of similarity for the LE, ME and HE was 30 % this shows low woody species similarity between three elevations. Within identified wood species 3, 3 and 2 shrub and 10, 7 and 6 tree, 3,1 and 1 shrub/tree form of species for LE,ME and HE respectively.

Table 2: Woody species frequency, relative abundance and life forms

No	*Spcies Name*	LE		ME		HE		LF
		RA %	RF %	RA %	RF %	RA %	RF %	
1	*Acacia mearnsii*			3.8	0.1			T/S
2	*Acacia senegal*	25.0	0.1	1.4	0.4	4.2	0.2	T/S
3	*Acalypha fruticosa*					5.2	0.1	T
4	*Acokaathera schimpori*	9.0	0.1	0.3	25.7	5.0	16.3	T
5	*Balanites aegyptiaca*	3.5	8.1	16.4	0.1			T
6	*calpernia aurea*	1.4	8	1.6	10	1.2	9	
7	*Dodonaea viscosa*	4.8	7.2	3.7	3.4	4.0	3.8	T/S
8	*Euclea racemosa*					4.2	25.5	T/S
9	*Euphorbia candelabrum*			11.3	12.8	7.4	11.4	T
10	*Euphorbia tirucalli*	9.3	23.7	6.7	30.4	3.1	2.6	T
11	*Ficus carica*			30.1	0.1			T/S
12	*ficus sur*			4.3	20.9			T
13	*Gardenia volkensii*			0.4	0.6			T
14	*Juniperes procera*	19.3	40.7	8.0	20.9	10.3	19.1	T

15	*Maytenus arbutifolia*					1.6	0.1	T/S
16	*Olea Africana*	1.6	9			21.2	3.5	T
17	*Pavetta qardennifolia*	8.3	5	11.5	4.6	3.9	12.9	T
18	*Strychnos spinosa*					3.7	0.1	T
19	*Terminalia brownii*					7.2	0.2	T
20	*Vernonia amygdalina*					4.4	0.7	S

LE = Low elevation, ME = Middle elevation, HE = High elevation = Relative frequency, RE = Relative abundance, LF = Life form, T = tree, S = shrub, T/S = tree/shrub

4.1.2 Woody Species Diversity

A total of 900, 1206 and 1426 individuals in the high, middle and low elevations respectively, were counted. The number of individuals, species number, Shannon and Simpson diversity indices per plot were significant between low, middle and high elevations ($P<0.05$) but insignificant in evenness ($P>0.05$). However, evenness in the middle elevation was slightly higher than low elevation and high elevation (Table 3). The average abundance and species richness in the high elevation was almost two third (2/3) of the middle elevation.

Table 3: Woody Species Diversity mean and SD along Elevation within 20mx20m Plot

Elevation	Abundance	Richness	Shannon SDI[1]	Simpson SDI	Evenness
HE	45(21.8)[a]	9[a]	1.29(0.4)[a]	0.6(0.16)[a]	0.71(0.22)[a]
ME	76(38.5)[b]	11[b]	1.55(0.2)[b]	0.73(0.11)[b]	0.70(0.15)[a]
LE	61(36.9)[b]	16[b]	1.62(0.2)[b]	0.76(0.06)[b]	0.81(0.11)[a]
P – Value	<0.05	<0.05	<0.05	<0.05	0.87

4.1.2.1 Important Value Index (IVI) of woody species

Juniperes procera, Euphorbia tirucalli and Acacia Senegal were the top three most important woody species in the LE, all together accounted for 79 % of the total IVI values. The remaining tree accounted for 21% of the IVI. *Euphorbia tirucalli, Acokaathera schimpori and Juniperes*

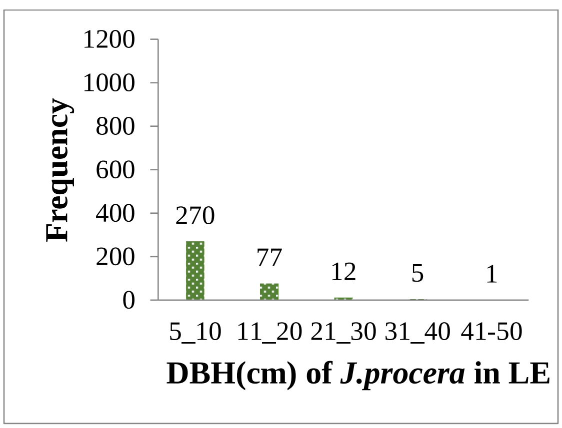
[1]SDI: Species Diversity Index

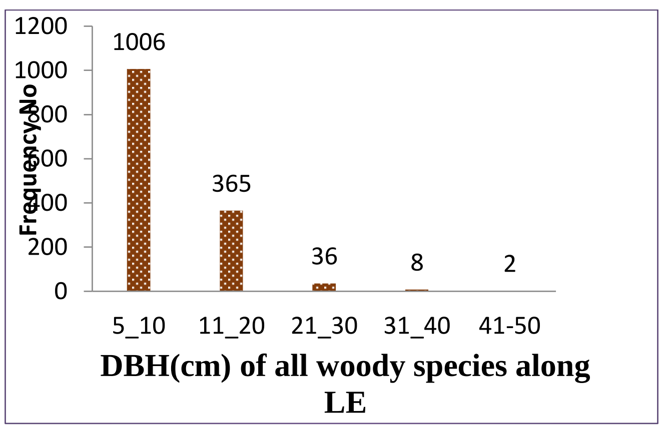
procera were important woody species recorded in the ME (Table 4) and *Euclea racemosa, Juniperes procera and Acokaathera schimpori* were important woody species recorded in the HE each accounts 61%, 49% and the remaining tree 39% and 51% respectively. In LE *Juniperus procera* is the most frequent woody species accounted 69 % and in ME and LE *Euphorbia tirucalli* is the most frequent accounted 76% and 65% respectively.

Table 4: Important Value Index (IVI) of Kalla forest along elevations

No	Species name	LE	ME	HE
1	*Acacia mearnsii*		3.9	
2	*Acacia Senegal*	25.3	2.1	4.7
3	*Acalypha fructose*			5.3
4	*Acokaathera schimpori*	9.2	51.7	37.6
5	*Balanites aegyptiaca*	19.7	16.5	
6	*calpernia aurea*	4.8	2.3	5.0
7	*Dodonaea viscosa*	19.2	10.6	11.7
8	*Euclea racemosa*			55.1
9	*Euphorbia candelabrum*		36.9	30.2
10	*Euphorbia tirucalli*	56.7	67.4	8.3
11	*Ficus carica*		30.4	
12	*ficus sur*		46.1	
13	*Gardenia volkensii*		1.6	
14	*Juniperes procera*	100.7	49.8	48.6
15	*Maytenus arbutifolia*			1.8
16	*Olea Africana*	19.6		28.1
17	*Pavetta qardennifolia*	18.3	20.7	29.7
18	*Strychnos spinosa*			3.8
19	*Terminalia brownie*			7.5
20	*Vernonia amygdalina*			5.7

Analysis of variance showed there was significant difference in DBH between LE and HE but not with in LE and ME,ME and HE.





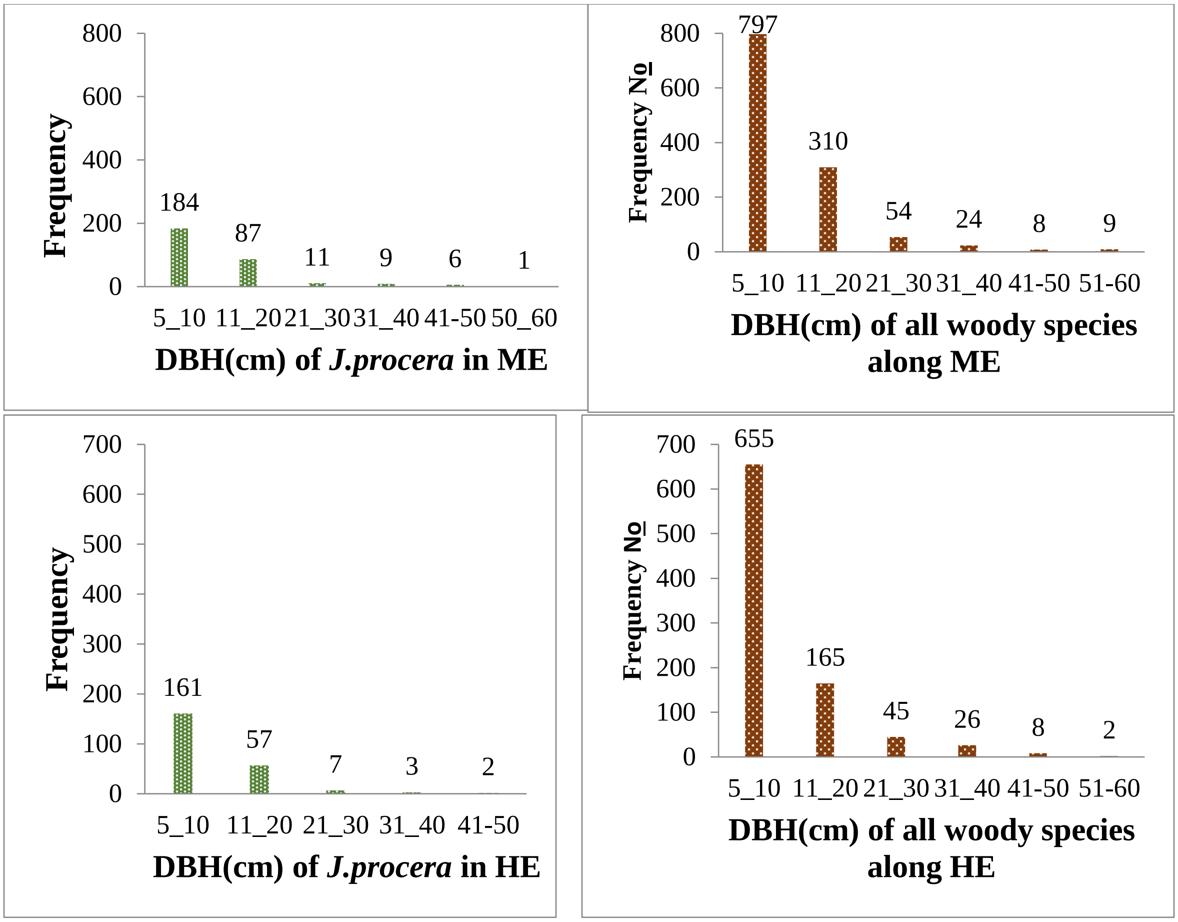


Figure 5: Comparison of diameter class frequency distribution of all woody species with dominant tree *J. procera* species of LE ,ME and HE

4.2 Biomass and soil organic carbon stocks along elevations

4.2.1 Biomass

4.2.1.1 Above and Belowground Biomass Carbon Stocks

Above and belowground woody trees and shrubs carbon stocks were significantly differed between LE, ME and HE ($P<0.05$) (Table 5). The above ground biomass carbon stocks accounted for 80 % of the total biomass of LE, ME and HE. The total biomass carbon stock recorded in LE was nearly 50% higher than two elevation classes (ME and HE) total biomass carbon stock.

Table 5: AGBC and BGBC stock mean (± SD, t ha^{-1}) along elevation

Biomass component	AGBC	BGBC	TBC	P – Value
HE(n = 20)	96(48) [a]	19.2(9.6) [a]	115.5(57.6)[a]	<0.05
ME(n = 20)	108(72) [b]	21.6(14.4) [b]	129.6(86.4)[b]	<0.05
LE(n = 20)	162(108) [b]	32.4(21.6) [b]	194.4(129.6)[b]	<0.05

Also as depicted in figure 5 below, *J. procera* and *E. tirucalli* in the LE contributed high amount to the total biomass carbon stocks. While in the ME and HE, *E. tirucalli* and *J. procera*, *E racemosa* and *J. procera* were contributed high amount to the total biomass carbon stock respectively.

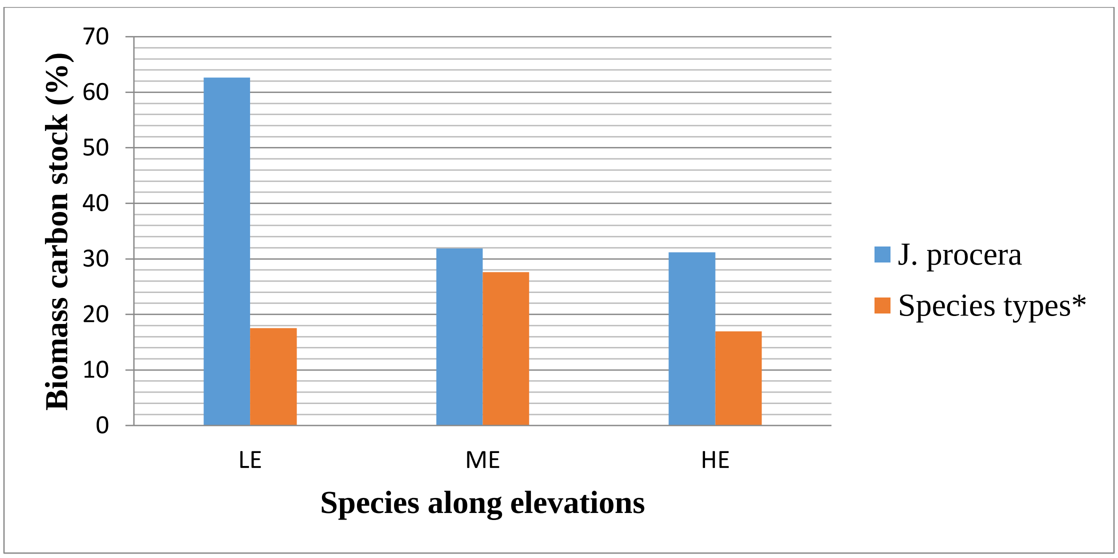


Figure 6: Biomass carbon stock (%) values of the dominant tree species

Species types* represents for LE, ME and HE is *Euphorbia tirucalli,*, *Euphorbia tirucalli* and *Euclea racemosa* respectively

4.2.2 Litter carbon stocks

There was no significant variation (p > 0.05) in the litter carbon stock between the LE, ME and HE. The average litter carbon stock estimated to be 4.74 ± 0.42 t ha-1 for HE, 4.86 ± 0.48 for ME and 5.04 ± 0.18 t ha- 1 for LE.

4.2.3 Soil organic carbon stocks

The SOC stocks (t C ha^{-1}) within 0 - 30 cm depth showed significant difference between the LE, ME and HE ($P < 0.05$) (Table 6). The surface layer (0 - 30 cm) contributed 58.5%, 61.3 % and 62.9% of the total SOC stock for the LE, ME and HE respectively. LE enhanced the soil organic carbon stock over the other.

Table 6: Soil carbon stock mean (±SD, t C ha^{-1}) of LE, ME and HE

Depth	N	Elevation			P – Value
		HE	ME	LE	
0 – 30	20	177.6(58.8)	242.4(87)	282(171.6)	0.013
30 – 60	20	126.6(60.6)	148.2(71.4)	166.2(85.2)	0.03
Total	40	153(64.8)	195(91.8)	224.4(145.8)	0.009

Within each soil layer, in all elevations (LE, ME and HE) means ± SD are significantly different ($\alpha \leq 0.05$) .Variation with mean SOC stock was significant within elevations ($P < 0.05$) and soil depth ($P<0.05$) whereas the interaction effect was significant ($P< 0.001$)(Table 7).

Table 7: General linear model of SOC stocks in relation to elevation ranges and soil depths

Source	Df	MS	p-value
Elevation	2	948.068	0.03
Soil depth	1	508.573	0.017
Elevation * soil depth	5	3701.504	0.000
Error	114	262.591	

MS: mean square, df: degree of freedom

4.2.4 Ecosystem carbon stock

The total ecosystem carbon stocks (biomass plus soil, 0 - 60cm) were significantly differ ($P< 0.05$) between the LE, ME and HE. The LE showed higher ecosystem carbon stock (301.8 ± 171.6 t Cha^{-1}) than ME (255.6±88.2) and HE (190.8± 58.2 t C ha^{-1}). The SOC stock (0 - 60 cm depth), live biomass and litter accounted 90.8 %, 6.6 % and 2.6% in the LE whereas 93.0 %, 5.1 % and 1.9 % in the ME and.92.1%, 6.3% and 1.6% in the HE (Figure 6).

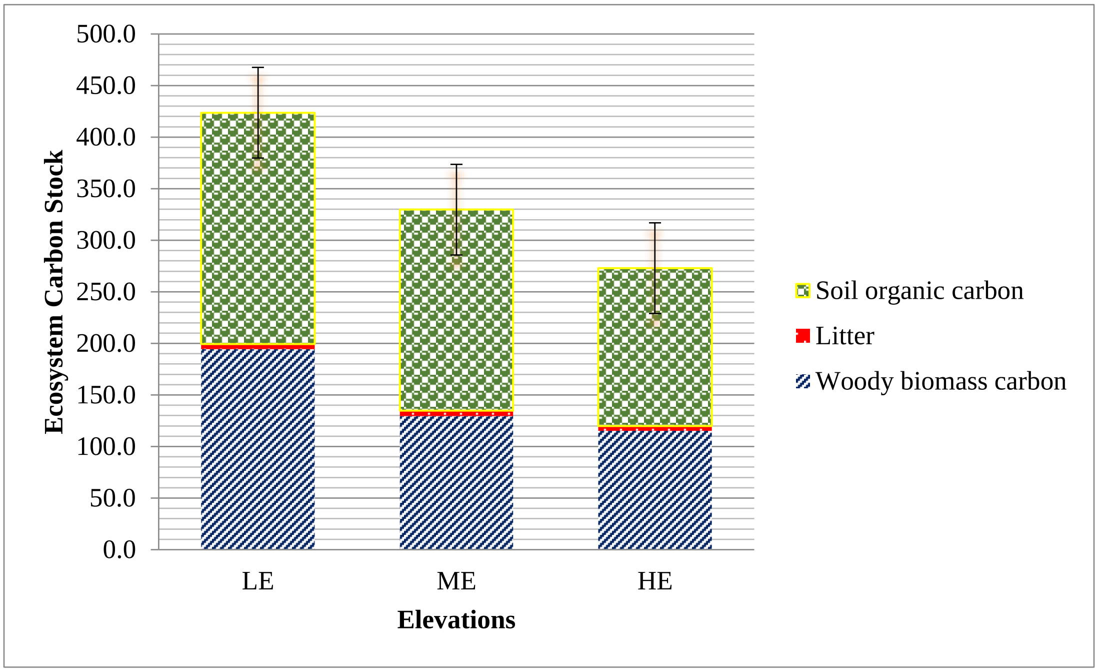


Figure 7: LE(low elevation), ME(middle elevation) and HE(high elevation) total carbon stocks of woody biomass, litter, and soil organic carbon stock)

4.3 Relationships of Carbon Stock and Woody Diversity along Elevations

The total above and belowground biomass C stocks were significantly correlated to woody species abundance ($P<0.001$) species richness, Shannon and Simpson diversity index (Spearman r = 0.28, $P< 0.05$). SOC stock was significantly correlated with species richness, Shannon and Simpson diversity index (Spearman r = 0.27, *P<0.05*) and significantly correlated with abundance (*P<0.001*) Ecosystem carbon stock significantly correlated (Spearman r = 0.26, *P<0.05*) with species abundance, species richness, Shannon and Simpson diversity index (Table 8).

Table 8: Spearman correlations between biomass, soil carbon stocks and woody species Composition

	Abundance	Species Richness	Simpson	Shannon
Total AG-BGBC	0.389**	0.279*	0.251*	0.216*
SOC	0.421**	0 .265*	0.253*	0.226*
Ecosystem C stock	0.372*	0.261*	0.210*	0.202*

***. Correlation is significant at the 0.01 level; *. Correlation is significant at the 0.05 level*
Total AG-BGBC = Total above and below ground biomass carbon (=above + belowground biomass C)

5. DISCUSSION

5.1. Woody Species Composition and Diversity

5.1.1 Woody species composition

The Kalla clan forest management system has great contribution to keep and improve the forest woody species composition because every one cannot inter without permission of the kalla clan king. The study indicate that the woody species composition of the forest is in enhancing progress, as indicated in the result, continuous time protection from free grazing and human interface allows regeneration of tree and shrubs (Wassie *et al.*, 2005; Zegeye *et al.*, 2011; Mekuria and Yami, 2013). Even if the status of woody species composition of kalla forest is enhancing, there is variation between elevations. In this study low elevation has more species composition followed by meddle elevation and high elevation. This result is in line with other findings in other parts of world (Shazmeen , 2015). Other literatures were also reported Fabaceae family as dominant and but not Euphorbiaceae family (Zelalem *et al.*, 2018).The number of species found in the study Low elevation was almost cover 75% from all number of species that of adjacent High elevation in line with the finding of (Vanessa *et al.*, 2015). LE, ME and HE showed low species similarity in line with other studies conducted in Ethiopia (Alefu *et al.*, 2015). This might be due existence of different elevation range. Moreover, this also indicate that elevation was a reason for vegetation variation, but it contradict research in humboo district (Alefu *et al.*, 2015).

5.1.2. Woody species diversity

The evidence from this study suggests that low elevation and middle elevation were more comfortable for different woody species abundances, richness and diversity even if this forest is conserved forest. The higher woody species abundance indicates the intensive coverage of Kalla forest. The Shannon and Simpson diversity indices showed higher value in ME as compared to the LE and ME. This was probably due to high species richness and evenness value of woody species in the ME. Similar results have been reported from studies conducted in elevation ranges (Vanessa *et al.*, 2015).

5.2. Carbon Stock Potential

5.2.1. Above and belowground biomass carbon stock

The higher biomass carbon stock in LE indicates that there is good comfort zone for woody species than ME and HE. This was mainly due to higher number of stem density, diameter and height growth whereas low biomass carbon stock in the HE forest is likely due to low number of species, diameter and height. Several studies in part of Ethiopia reported similar findings (Hamere *et al.*, 2015) and in opposite this study result contradict with Thokchom and Yadava, 2017. This finding was also in agreement with a study elsewhere in the Tropics (Shazmeen, 2016).

Moreover, the difference between HE and LE in above ground biomass carbon stock was comparable with (Alefu *et al.*, 2015) which is (117.91 and 138.89 t C ha^{-1}). In contrast the total biomass carbon stock of this study also somewhat lower as compared with study conducted in highlands of Oromia (Adugna and Teshome , 2016) and higher than the mid highlands by Hailu *et al.*, 2014.This could be due to the diameter class they used, species type, management system of the site and other physical factors. Besides, variation in tree dendrological parameters measured, allometric equations applied, carbon fraction used and root shoot ratio used to estimate below ground biomass may also have resulted in the discrepancy of estimation of aboveground and belowground biomass and carbon stock because of that the different types of models used for biomass estimation have impact on the value of carbon estimated in a given forest. Outside from Ethiopia, this study is also in line with similar studies conducted in other countries (Shazmeen, 2015).

5.2.2. Litter biomass carbon stock

Higher litter biomass carbon stock might be due to high abundance of species in low elevation. The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density), climate and relatively fast decomposition rate in the tropics. The reason for smaller litter carbon may be due to fast decomposition rate and less amount of litter fall in the study area. In this study result indicates there was no significant difference between HE and ME in litter biomass carbon stock. This result is consistence with (Hamere *et al.*, 2015) and contradict with (Alefu *et al.*, 2015) result.

5.2.3. Soil organic carbon stock

Soil organic carbon plays a vital role in the global carbon cycle and C pools (Sundarapandian *et al.*, 2015). The rate of soil organic carbon stock was significantly affected by changing in elevation (Girmay *et al.*, 2008; Zhang *et al.*, 2009; Sundarapandian *et al.*, 2015). The soil organic carbon in this study LE was higher than the adjacent ME and HE, this is may be due to the accumulation of soil organic carbon depends on the quantity of litter and root activity such as rhizo - deposition and decomposition. This result was consistent with other studies in Ethiopia (Hamere *et al*., 2015) and in China (Biao *et al*., 2016). In contrast, (Alefu *et al.*, 2015) reported that elevation did not influence soil organic carbon. This study showed that SOC stock increased by 48 % through the low elevation to high elevation. This might be due to increased vegetation composition, reduced erosion loss and the subsequent production and decomposition of litter fall from vegetations.

In LE, there was higher dry litter biomass accumulation than middle elevation and high elevation. Litter fall contributes a major role for the return of organic matter to the soil (Liang *et al.*, 2011). The higher soil organic matter accumulation in the study low elevation might be also due to the presence of *J. procera* and other dominant woody species. In addition, low elevation had higher woody species abundance than middle and high elevation land which is positively correlated with the SOC stock of this study.

In contrast the mean SOC stock in the high elevation land is minimal because woody species abundance. Soil organic carbon content decreases with soil depth. This might be due to the presence of lower accumulation of organic matter resulting from lower below-ground root biomass in the sub-surface layer; which is similar with the justification of Yimer *et al.* (2015). The result is consistent with other studies (Shazmeen, 2015).

The total SOC stock (0-30 cm) of the study LE was comparable with reports from tropical dry forest that ranged between 33.36 and 48.82 t C ha^{-1} (Sundarapandian *et al.*, 2013). In African savannahs and woodlands ranged between 30 - 140 t C ha^{-1} (Williams *et al.*, 2008) but higher than the central Mozambique woodlands reported by Woollen *et al.*, (2012) (40.1 ± 2.5 Mg C ha^{-1}) and study conducted by Tesfaye *et al.*, (2016) at the crop lands of central highland Ethiopia (43.60 ± 4.97 t ha^{-1}) for the 0–30 cm layer. Maintaining of higher SOC levels ensures the productivity of degraded land as well as regulating the climate system.

5.2.4. Ecosystem carbon stock

The contribution of SOC stock was higher than the total biomass contribution. Similar results were reported in other studies (Mekuria *et al.*, 2009 and 2013). The total ecosystem carbon stock in the low elevation was higher than the reports of Alefu , (2015) and lower than other studies in Sothern Ethiopia (Mekuria *et al.*, 2009 and 2013). The ecosystem carbon stock variation, in this result was lower or higher because of difference in the model to estimate the biomass carbon, variation in soil type, management of forest and topography. Moreover, establishing LE forest in this site improves the carbon sequestration potential.

In the present study woody species diversity, abundance and species richness positively correlated with above and below ground biomass carbon stock and soil organic carbon. In addition these findings are consistent with study conducted by Lange *et al.*, 2015 showed that positive plant diversity effects on soil carbon storage, Dayamba *et al.*, 2016) showed positive relationships between diversity and biomass C pools, Negash, (2013) reports biomass C pools were significantly correlated to species abundance and richness and Mekuria *et al.*, (2009) positive correlation between naturally regenerated plant species diversity and soil carbon concentration. However, the results of this study on woody species diversity and biomasss carbon in contrary with Zhang *et al.*, 2011 found a negative relation in subalpine coniferous forest. This might be due to the effect of species diversity on biomass storage depends on management practices, species, age and site factors.

5.2.5 Relationships of carbon stock and woody species diversity along elevations

The correlation between carbon stock and woody species diversity is significant. That mean in this study both total above ground and below ground biomass and SOC increase when woody species abundance, species richness, Shannon and Simpson diversity index increases and also ecosystem carbon stock, this finding is in line with (Sundarapandian *et al.*, 2013) and contradict with (Alefu *et al., 2015*).

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The result of the study indicates that LE had better woody species diversity, composition, and structure followed by ME and HE. These forests were suitable provenance for some indigenous woody species that were previously listed as threatened species in Ethiopia. In general Kalla forest is suitable for *Juniperus procera*, even if LE in Kalla forest is the most suitable for the growth and development of *Juniperus procera* followed by ME and HE. It had a total of 20 species, belonging to 19 genera and 14 families. Total biomass carbon stock and soil organic carbon were significantly increased from HE to LE. This implies LE had high potential woody species diversity, composition, and structure, biomass carbon stock and soil organic carbon in Kalla forest.

6.2 Recommendations

Based on this study, the following points have been forwarded as recommendation

- Site and species specific biomass equations should be developed for accurate estimation of biomass of indigenous and dominant species such as *Juniperus procera, Euphorbia tirucalli, Acokaathera schimpori* and *Euclea racemosa.*

- As indicate in the result part *Juniperus procera, Euphorbia tirucalli, Acokaathera schimpori* and *Euclea racemosa* were indigenous and dominant species in this forest so,if plantation forest will done by considering those species ,it will have high survival present.

- Kalla forest is healthy forest so, if study will done on cultural sustainable forest management system of this forest ,it will be an example for other.
- If Kalla forest will consider for carbon trading ,it will get good result

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APPENDICES

Table 1: Data sheet for woody species inventory (dbh ≥ 5)

Data collector: ________________ Date: _________________ Site: _________

Land use type: ________________ Transect No: ________ Plot no: _______

Location: N ___________ E ________ Altitude (m a.s.l.):___________

Tree No	**Stem No**	**Scientific Name**	**Local Name**	**DSH (cm)**	**DBH (cm)**	**Total H (m)**	**Crown D(cm)**	**Remark**

Table 2: Data sheet for seedling and sapling assessment (dbh < 5)

Site	Trans	Plot No	Scientific Name	Local Name	Number of		Ave.RCD Sapling (cm)	Ave. H sapling (m)
					Seedling	Sapling		

Table 3: Data sheet for litter sampling

Site; ____________ land use type: ________________

Transect	Plot	Sample type	Fresh weight (g/m^2)	Sub sample fresh weight (g)
		Litter		
		Litter		

Table 4: Data sheet for soil sampling format

Soil organic carbon

Site name: _____________ Elevation range: ___________

Plot No: _______________ Transect number: __________ Depth: __________________

Soil bulk density

Site name: _____________ Elevation range: ___________

Plot No: _______________ Transect number: __________

Depth: ____________

Table 5: List of woody species in the study area

Elevation	species.name	Local name	genera	family
High elevation	Acacia senegal	Yawochaya	Acacia mill	Fabaceae
High elevation	Balanites aegyptiaca	Hakayta	Balanites	Balanitaceae
High elevation	Acokanthera schimperi	Lawa	Acokanthera	Apocynaceae
High elevation	Euphorbia candelabrum	Holayta	Cerberiopsis	Euphorbiaceae
High elevation	Caporinia aurea	Orakelta	Calpurnia	Fabaceae
High elevation	Dodonaea viscosa (D. angustifolia)	Ditata	Dodonaea	Sapindaceae
High elevation	Euphorbia tirucalli	Hartayta	Euphorbia	Euphorbiaceae
High elevation	Juniperus procera	Birbrta	Juniperus	Cupressaceae
High elevation	Olea Africana	Akerta	Oliea	Olacaceae
High elevation	Pavetta oliveriana	Puni karayo	Pavetta	Rubiaceae
				total
Middle elevation	Acacia mearnsii	Asata	Acacia	Fabaceae
Middle elevation	Acacia senegal	sabanta	Acacia mill	Fabaceae
Middle elevation	Acokaathera schimpori	Lawa	Acokanthera	Apocynaceae
Middle elevation	Balanites aegyptiaca	Hankalta	Balanites	Balanitaceae
Middle elevation	calpernia aurea	Orakelta	Calpurnia	Fabaceae
Middle elevation	Euphorbia candelabrum	Holayta	Euphorbia	Euphorbiaceae
Middle elevation	Dononia augustifolia	Ditata	Dodonaea	Sapindaceae
Middle elevation	Euphorbia tirucalli	Hatayta	Euphorbia	Euphorbiaceae
Middle elevation	Ficus carica	kukaleta	Ficus	Moraceae
Middle elevation	ficus sur	Arata	Ficus	Moraceae
Middle elevation	Juniperes procera	Birbrta	Juniperus	Cupressaceae
Middle elevation	Pavetta qardennifolia	Puni karayo	Pavetta	Rubiaceae
Middle elevation	Gardenia volkensii	Masaaganta	Gardenia	Rubiaceae

Elevation	species.name	Local name	Genera	family
Low elevation	Acacia mimosa	Kaputayta	Mimosa	Fabaceae
Low elevation	Acacia senegal	Sabanta	Acacia	Fabaceae
Low elevation	Acalypha fruticosa	sehayta	Arcaiypha	Euphorbiaceae
Low elevation	Acokaathera schimpori	Lawa	Acokantherd	Apocynaceae
Low elevation	Calpernia aurea	Orakelta	Calpurnia	Fabaceae
Low elevation	Euphorbia candelabrum	Holayta	Euphorbia	Euphorbiaceae
Low elevation	Dononia augustifolia	Ditata	Dodonaea	Sapindaceae
Low elevation	Euclea racemosa subsp. Schimperi	Makayta	Euclea	Ebenaceae
Low elevation	Euphorbia tirucalli	Hakayta	Euphorbia	Euphorbiaceae
Low elevation	Juniperes procera	Birbrta	Juniperus	Cupressaceae
Low elevation	Maytenus arbutifolia	Dakkayta	Maytenus	Celastraceae
Low elevation	Olia Africana	Akerta	Olia	Olacaceae
Low elevation	Pavetta qardennifolia	Puni karayo	Pavetta	Rubiaceae
Low elevation	Strychnos spinosa	Porporisa	Strychnos	Loganiaceae
Low elevation	Terminalia brownii	Oybata	Terminalia	Combretaceae
Low elevation	Vernonia amygdalina	Mudukanta	Vernonia	Asteraceae

Table 6: Relative Density (RDE), Relative basal area (RBA)

NO		LE			ME			HE		
1	Species_name	RA	RD	W/P	RA	RD	W/P	RA	RD	W/P
2	Acacia mearnsii			W	1.5	25.7	W			W
3	Acacia mellizera			W			W	1.5	25.7	W
4	Acacia mimosa			W			W	7.9	85.5	W
5	Acacia Senegal	25.0	0.1	W			W	6.6	115.6	W
6	Acalypha fruticosa			W			W	1.8	19.5	W
7	Acokaathera schimpori	115.6	8.1	W	3.3	56.8	W		0.0	W
8	Balanites aegyptiaca	9.0	0.1	W	1.9	33.4	W			W
9	calpernia aurea			W	2.9	50.1	W	2.3	24.9	W
10	Dodonaea viscosa	4.8	7.2	W			W			W
11	Euclea racemosa			W			W	0.7	8.1	W
12	Euphorbia candelabrum	15.2	5.7	W			W	10.9	117.7	W
13	Euphorbia tirucalli	9.3	23.7	W	8.1	141.3	W	13.2	142.5	W
14	Ficus carica			W	1.1	18.5	W			W
15	ficus sur			W	2.7	46.3	W			W
16	Gardenia volkensii			W	3.1	53.4	W			W
17	Juniperes procera	19.3	40.7	W	4.8	83.6	W	4.5	48.6	W
18	Maytenus arbutifolia			W			W	2.0	21.2	W
19	Olea Africana	1.6	9.0	W			W	6.6	71.6	W
20	Pavetta qardennifolia			W	21.6	377.3	W	19.0		W
21	Strychnos spinosa			W			W	3.6	39.0	W
22	Terminalia brownie			W			W	3.8	40.8	W
23	Vernonia amygdalina			W			W	2.8	30.3	W

Side view of the forest

soil sample labeling

Lunch time

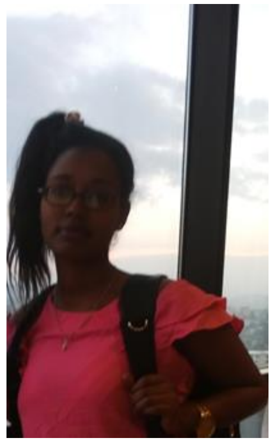
After field

During DBH and Height measurement

During local name translation

BIOGRAPHICAL SKETCH

Email - biruklul874@gmail.com

Biruk Lulseged Tilahun was born in 

Dirashe district, SNNPR Region, Ethiopia on January 20, 1990.

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