CARBON STOCK ESTIMATION ALONG ALTITUDINAL GRADIENT IN WOODLAND VEGETATION IN ILU GELAN DISTRICT, WEST SHEWA ZONE OF OROMIA REGION, CENTRAL ETHIOPIA

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GRADUATE PROGRAMMES

This is to certify that the Thesis prepared by Deresa Abetu Gadisa, entitled: Carbon Stock Estimation along altitudinal gradient in Woodland vegetation, Ilu Gelan District, West Shewa Zone of Oromia Region, Ethiopia and Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science (Biology: Botanical Science) compiles with the regulations of the University and meets the accepted standards with respects to originality and quality.

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Abstract

Forests play a significant role in climate change mitigation by sequestering and storing carbon from the atmosphere which was released by anthropogenic factors. The overall objective of this study was to estimate Carbon stock of above and below ground biomass along altitudinal gradient in the woodland vegetation (Ilu Gelan District, Oromia Region). The study was used allometric models equation of Brown et al. (1989) for above ground and below ground biomass was calculated based on the ratio of below ground biomass to above ground biomass ratio of (MacDicken,1997) using systematic transects line sampling to estimate the above ground biomass data for different trees with diameter ≥5 cm found in the study area. Quadrants of 54 plots were established by dropping a distance of 25 m altitudinal gradient between each plot with square plots of 400 m^2 (20 m x 20 m). Parameters such as the diameter at breast height (DBH) and height were used. A total of 86 woody species of 39 families with stem number of 4188 was collected and analyzed. The results of this study showed that the total mean carbon biomass in 54 plots of the study was 87.77 C t /ha for above ground biomass (AGB) and 17.5 C t/ha for below-ground biomass (BGB). In this woodland ecosystem, the total mean carbon stock of AGC was more important compared to the total carbon stock of BGC which was 41.25 t C /ha against 8.25 t C/ha respectively. Similarly, the average carbon stock of lower altitude was larger than that of the higher altitudinal gradient with the same pattern of AGB and BGB (183.23, 60.49C t C/ha) respectively. This result showed that the species density is larger at higher altitude when compared to the lower altitude because of different anthropogenic disturbances and threats in the study area. This research indicates that, this woodland vegetation holds large stores of carbon, yet uncertainty remains regarding their quantitative contribution to global carbon cycle.

Key words: *Above ground biomass, Altitudinal gradient, below ground biomass, Carbon stock, Mountain Dirki woodland*.

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List of Acronyms/Abbreviations

AGB	Above ground biomass
AGC	Above ground Carbon
BGB	Below ground biomass
BGC	Below ground Carbon
C	Carbon
CDM	Clean Development Mechanism
CH4	Methane
Co_2	Carbon dioxide
COP	Conference of Parties
CSA	Central Statistical Agency of Ethiopia
DBH	Diameter at breast height
DOM	Dead organic matter/Dead organic wood
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
GHG	Green House Gas
GPP	Growth Primary Product
Gt	Giga tones

HWPs	Harvested wood products
IPCC	Intergovernmental Panel on Climate change of the United Nations
LC	Litter Carbon
LULUCF	Land Use, Land Use Change and Forestry
Mt	Mega tones
N2O	Nitrogen dioxide
NGOs	Non Governmental Organization
PFM	Participatory forest management
REDD	Reducing Emissions from Deforestation and Degradation
REDD+	"REDD+" goes beyond deforestation and forest degradation, and includes the roles of conservation, sustainable management of forests and enhancement of forest carbon stock.
RS	Root to Shoot
SOC	Soil organic Carbon
SOM	Soil organic matter
SSA	Sub Saharan Africa
TOC	Total organic Carbon
UNFCCC	United Nations Framework Convention on Climate Change
WBISPP	Woody Biomass Inventory and Strategic Plan Project

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the Study

Globally, forests cover 4.03 billion hectares approximately 30% of Earth's total land area and they account for 75% of terrestrial gross primary production (GPP) and 80% of Earth's total plant biomass that contain more carbon in biomass and soils than is stored in the atmosphere (Pan *et al.,* 2013). According to SCBD, (2010), forests also harbor the majority of species on Earth and provide valuable ecosystem goods and services to humanity, including food, fiber, timber, medicine, clean water, aesthetic and spiritual values, and climate moderation.

The potential to accurately and precisely measure the carbon stored and sequestered in forests is increasingly gaining global attention in recognition of the role forests in the global carbon cycle, particularly with respect to mitigating carbon dioxide emissions (Brown *et al.,* 1996; Kauppi and Sedjo, 2001). Forests are influenced by natural and human causes, including harvesting, over-harvesting and degradation, large-scale occurrence of wildfire, fire control, pest and disease outbreaks, and conversion to non-forest use, particularly agriculture and pastures. These disturbances generally cause forests to become sources of CO_2 because net primary productivity is exceeded by total respiration or oxidation of plants, soil, and dead organic matter. At the same time, however, some areas of harvested and degraded forests or agricultural and pasture lands are abandoned and revert naturally to forests or are converted to plantations, thus becoming carbon sinks, i.e. the rate of respiration from plants, soil and dead organic matter is exceeded by net primary productivity.

There are two key policy-related reasons for measuring carbon in forests: (1) commitments under The United Nations Framework Convention on Climate Change (UNFCCC), and (2) for potential implementation of the Kyoto Protocol. The UNFCCC, signed by more than 150 countries, requires that all Parties to the Convention commit themselves to develop, periodically update, publish, and make available to the Conference of Parties (COP) their national inventories of emissions by sources and removals by sinks of all GHGs using comparable methods (Houghton *et al.*, 1997).

Adugna Fayisa *et al.* (2013) noted that forests have a significant role in the natural global carbon cycle by sequestering and storing more carbon than any terrestrial ecosystem i.e. they store more than 80% of all terrestrial above ground carbon and more than 70% of all soil organic carbon. It was pointed out that, forest ecosystems are regarded as the largest terrestrial carbon pool that have an average biophysical mitigation potential of 5,380 Mt CO2/yr until 2050 (IPCC, 2007a)

According to Tesfeye Bekele (2002), in Ethiopia factors like deforestation, overharvesting and permanent conversion to other forms of land use are leading to shrinkage of forest resources. As a result, forest cover has been declining rapidly and only remnant forests are confined to some areas especially in the south and south-western parts of the country, which are less populated. Deforestation is one of the main causes of the prevailing land degradation in Ethiopia. Tree cutting is a common practice, which has been taking place for centuries. Some parts of northern Ethiopia that currently are bare and experience severe land degradation once had a good vegetation cover (FDRE, 1998). Even though the original forest cover of Ethiopia is not well documented, and estimates are not consistent, about 420,000 square kilometers (35% of Ethiopia‘s land) was covered by forests in the twentieth century. This forest cover has declined to 16% in 1952, 3.6% by 1980, 2.6% by 1987, and an estimated 2.4% in 1992 (FDRE, 1998).

Moreover, the presence of woodland vegetation in the dry lands of Ethiopia could provide as a sink for atmospheric CO_2 and have great roles to climate change mitigation and adaptation locally as well as globally. Carbon storage in forest ecosystems involves numerous components including above ground and below ground biomass, deadwood, and litter and soil carbon. Carbon stock is typically derived from above ground biomass by assuming that 50% of the biomass is made up by carbon. The most accurate method for the estimation of biomass is through cutting of trees and weighing of their parts. This destructive method is often used to validate others, less invasive and costly methods, such as the estimation of carbon stock using nondestructive in situ measurements and remote sensing (Clark *et al*., 2001; Wang *et al*., 2003).

Unlike in the developed countries, Ethiopia does not have enough carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. Different scholars like: Abel Girma *et al.* (2014); Biniyam Alemu (2014); Teshome Soromessa *et al.* (2004); Ensermu Kelbessa and Teshome Soromessa (2008); Teshome Soromessa *et al.,* (2011); Fekadu Gurmessa *et al*. (2011 and 2012); Adugna Feyissa *et al.* (2013); Teshome Soromessa (2013); Teshome Soromessa and Ensermu Kelbessa (2013a and 2013b); Teshome Soromessa and Ensermu Kelbessa (2014); Mohammed Gedefaw *et al*. (2014); Tullu Tola; Masfin Sahle; Beley Melese *et al*. (2014) agreed on the needs of studying and documenting the vegetation resources of Ethiopia.

Even though various scholars have studied the forest of Ethiopia, only small efforts have been made so far to quantify the forest carbon stock, biomass and soil carbon sequestration potential at small scale level with comparing the forest potential of Ethiopia particularly woodland vegetation. Because of this and to fill some of the gaps of area limitation and scarcity of data on woodland vegetation carbon stock of the Ethiopian woodland coverage, the study was important for management of forest to show the win-win strategies for the welfare of human society beside their aesthetic, spiritual, and recreational value.

However, no related study has been conducted in the Mountain Dirki woodland vegetation (Specially Ilu Gelan District) that aimed to investigating the carbon stock potential and associated dynamics of this woodland vegetation. Therefore, this study was undertaken to estimate the carbon stock of the Mountain Dirki woodland vegetation and to see the variations of the carbon stocks of different carbon pools under different altitudinal gradient.

1.2 Significance of the Study

Forests cover more than one third of the world’s land area and constitute the major terrestrial carbon pool (Roberntz and Sune, 1999). The amount of carbon sequestered and stored in forest varies greatly based on a large number of factors, including the type of forest, its net primary production, the age of the forest, and its overall composition (Millard, 2007). Carbon storage in forest ecosystems involves numerous components including biomass carbon and soil carbon. As more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissue above and below ground (Gorte, 2009; IPCC, 2003) resulting in growth of different parts (Chavan and Rasal, 2010). Biomass production in different forms plays an important role in carbon sequestration in trees (Chavan and Rasal, 2012). Above ground biomass, below ground biomass, Dead wood, Litter, and Soil organic matter are the major carbon pools in any ecosystem (FAO, 2005; IPCC, 2003; IPCC, 2006). Assessment of carbon stocks and stock changes in tree biomass are relevant to deal with the united nation Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol report (Green *et al*., 2007; Almgir and Al-Amin, 2007).

The global carbon (C) cycle has become an important topic in scientific research (Houghton *et al.*, 1992). This emphasis has emerged from two sources. First is the increased atmospheric concentrations of CO_2 since 1880 (from 280 ppmv to 356 ppmv), increased the concern about global warming. Second is the signing of the UN Framework Convention on Climate Change, pledging signatory nations to account to a stabilize their greenhouse gas emissions. Scientists have increasingly focused on the roles of changes in land cover, land use, and land management in regulating C flux, or movement of carbon, between the terrestrial biosphere and the atmosphere (Schimel, 1995).

According to Lyngbaek *et al*. (2001) the importance of forest ecosystems are considered in the context of climate change mitigation because they can act as the sinks of carbon dioxide. If the woodland is to be used in carbon sequestration schemes such as the CDM/REDD+, it is a better options in developing countries for the dual objective of reducing GHG emissions and contributing to sustainable woodland development and management (Biniyam Alemu, 2014). As a result, carbon determination may provide clear indications of the possibilities of promoting dry woodland development and management for climate change mitigation through soil and vegetation carbon sequestration and opportunities for economic benefit through carbon trading to farmers (Biniyam Alemu, 2014) and also woodlands have non-timber products (Gum and Resin) for local farmers benefit.

The study give direction for the rate of woodland vegetation changes, and related with the changes in carbon stocks, potential income generation from carbon trading that would assist in developing sustainable dry land forest management towards building climate resilient livelihoods in dry land areas of Ethiopia.

1.3 Statement of Problems

According to Demel Teketay (2001), the decline of forests in the tropics impairs significant atmospheric functions as carbon sinks, and the combustion of forest biomass releases atmospheric CO_2, contributing to the buildup of GHGs and global warming. Woodlands are under heavy pressure: they are cleared for fire wood, expansion of cash crops and new settlements and apparently are shrinking over time. Despite its potential for biodiversity conservation, water catchment and as carbon sink, high levels of forest degradation due to illegal lumbering and encroachment are threatening the future status of the forest. Deforestation and forest/ woodland degradation is closely linked with low levels of carbon stocks hence increasing green house gas (GHG) emissions and subsequent global warming.

In our country, it was also reported that, woodlands are covering huge areas and their carbon stock is much higher than high forests which are 1,263.13 million tons of carbon per 29.55 million hectare in woodland and 434.19 million tons of carbon per 4.07 million hectare in the high forest (Yitebitu Moges *et al*., 2010).

According to Yitebitu Moges *et al*. (2010), Ethiopian forests contain about 272 million metric tons of carbon, which is almost 83% of the country's global annual carbon emission (333 Mega tone of carbon per year). Today, forest management activities are increasingly taking into consideration the role of forests as carbon sinks and information on factors that determine the forest carbon stock is given concern (McEwan *et al*., 2011). The carbon storage in forest can be affected by different environmental factors such as altitude, slope and aspect by affecting the patterns of tree species distribution and this further affects carbon stored in forest ecosystem (McEwan *et al.,* 2011).

However, in Ethiopia, fully registered data on forests and carbon stocks is almost negligible, and this makes the country unable to develop sustainable forest management planning that attracts NGOs and govenments on the clean development mechanism through enhancing the environmental services of forests for the purpose of financing forest through forest carbon finance. It was stated that, in Ethiopia, people especially in the rural areas, are highly dependent on forest resources to fulfill their basic needs such as fuel wood for cooking, heat, foliage for livestock, and timber for shelter and non timber forest for medicine in the absence or unaffordable cost of alternative options. Deforestation, forest degradation, forest fire and burning of fossil fuel are playing a significant role in producing the green house gases (IPCC, 2000).

Therefore, this study was designed to estimate the carbon stock available in woodland vegetation in the study area along altitudinal gradient accompanied with ground survey of identified vegetation type measurement and quantifying the carbon stock in above ground biomass, below ground biomass and litter, which are the known pools for organic carbon.

1.4 Research question, Hypothesis and Objectives

1.4.1 Objectives

1.4.1.1 General objectives

The main objective of this study was to estimate the Carbon stock in the vegetation and its variation along altitudinal gradient in Mountain Dirqi woodland.

1.4.1.2 Specific objectives

- ✓ To estimate carbon stock in the above ground biomass;
- ✓ To estimate carbon stock below ground biomass;
- ✓ To estimate carbon stock in litter biomass;
- ✓ To compare the carbon content along different altitudinal gradient;
- ✓ To see variation of carbon with respect to the aspect of study area;
- ✓ T o list some of the species of specified DBH in the study area;
- ✓ To give some recommendation on proper forest management of the study area depending on visual observation.

1.4.2 Research Question

- How much C is stored in the woodlands vegetation of the study area?
- What is the diversity of plant species in the study area?
- What are the dominant plant species in the study area?
- What are the main disturbances and threats of woodland vegetation of study area?

1.4.3 Research hypothesis

Ho: There is low carbon stock density in the higher altitudinal gradient than lower altitudinal gradient.

Hi: There is high carbon stock density in the higher altitudinal gradient than lower altitudinal gradient.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 The need for ecosystem carbon management

The earth's climate is critically dependent on the composition of the atmosphere, and in particular on the concentration in it of greenhouse gases that increase the amount of the sun's heat that is retained. The two most important of these are carbon dioxide (CO_2) and methane (CH_4). Both gases are naturally present in the atmosphere as part of the carbon cycle but their concentration has been greatly increased by human activities, particularly since industrial revolution. There is more carbon dioxide in the atmosphere now than at any time in the past 650,000 years. In 2006 the global average atmospheric concentration of CO_2 was 381 parts per million (ppm), compared with 280 ppm at the start of the industrial revolution in about 1750. The rate at which the concentration is increasing is the highest since the beginning of continuous monitoring in 1959 (Canadell *et al*., 2007).

The Intergovernmental Panel on Climate Change (IPCC) has stated that limiting global temperature increase to 2 – 2.4°C and thereby the worst effects of climate change requires greenhouse gas concentrations in the atmosphere to be stabilized at 445–490 ppm CO_2 equivalent (IPCC, 2007b). Historically, it is estimated that since 1850 just under 500 Gt of carbon may have been released into the atmosphere in total as a result of human actions, around three quarters through fossil fuel use and most of the remainder because of land-use change, with around 5% attributed to cement production. Of the total around 150 Gt is believed to have been absorbed by the oceans, between 120 and 130 Gt by terrestrial systems and the remainder to have stayed in the atmosphere (Houghton, 2007).

The most recent estimates indicate that human activities are currently responsible for annual global carbon emissions of around 10 Gt, of which around 1.5 Gt is a result of land use change and the remainder comes from fossil fuel use and cement production (Canadell *et al.*, 2007). This has led to an average annual rate of increase of carbon dioxide concentrations in the atmosphere of just under 2 ppm for the years 1995–2005 compared with around 1.25 ppm for the years 1960–1995 (IPCC, 2007b).

2.2 The Role of Forest Carbon Stock on Climate Change Mitigation

Forests present a significant global carbon stock. Global forest vegetation stores 283 Gt of carbon in its biomass, 38 Gt in dead wood and 317 Gt in soils (top 30 cm) and litter. The total carbon content of forest ecosystems has been estimated at 638 Gt for 2005, which is more than the amount of carbon in the entire atmosphere (Houghton, 2005). This standing carbon is combined with a gross terrestrial uptake of carbon, which was estimated at 2.4 Gt a year, a good deal of which is sequestration by forests.

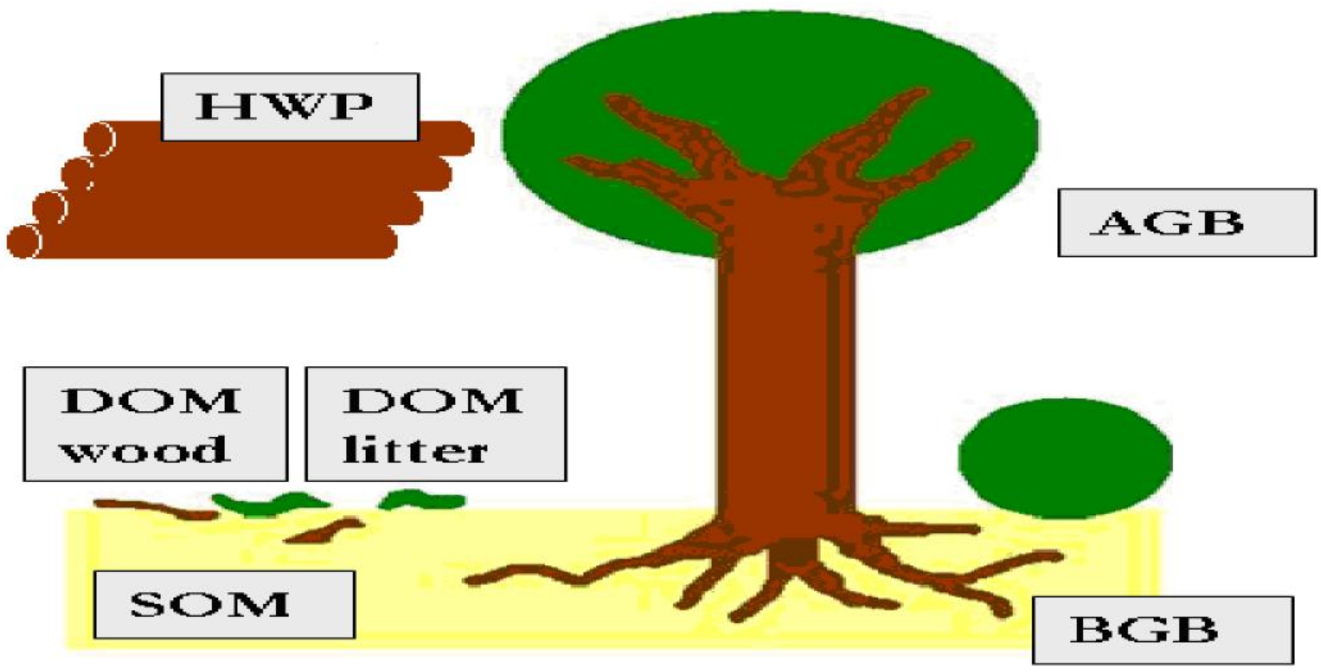
Forests also have a potentially significant role to play in climate change adaptation planning through maintaining ecosystem services and providing livelihood options. According to the Intergovernmental Panel on Climate Change (2000), the conservation and restoration of forests can considerably reduce emissions at a low cost and with potential co benefits for adaptation and sustainable development.

Forests play an important role in regional and global carbon cycles because they store huge quantities of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration, are sources of atmospheric carbon when they are disturbed by human or natural causes, become atmospheric sinks during regrowth, and can be managed to sequester or conserve significant quantities of carbon on the land. Forest biomass is a function of its successional state; direct human activities such as silviculture, and harvesting; natural disturbances caused by wildfire or pest outbreaks; and changes in climate and atmospheric pollutants. Biomass is also, a useful measure for assessing changes in forest structure and for comparing the status and trends of forest ecosystems across a wide range of environmental conditions (Brown, 1999).

2.3 Biomass, Carbon pools and Stock accounting

Forest biomass is organic matter resulting from primary production through photosynthesis minus consumption through respiration and harvest. 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 biomass assessments also illustrate the amount of carbon that may lost or sequestered under different forest management regimes. Carbon is lost to the atmosphere as CO_2. To convert carbon in biomass to CO_2, the tones of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12). Estimating the biomass density of forest components is, therefore, the first step in forest carbon accounting.

Carbon pools are components of the ecosystem that can either accumulate or release carbon and have classically been split into five main categories: living above-ground biomass (AGB), living below-ground biomass (BGB), dead organic matter (DOM) in wood, DOM in litter and soil organic matter (SOM) (Figure.1). The classification of carbon pools is not strict and it is not the number of categories that is important but their completeness; pools must not be double-counted and significant pools should not be excluded (Table 1). With harvested wood products (HWPs) increasingly recognized as an additional and potentially substantial carbon pool which exists outside of traditional forest boundaries (Lui & Han, 2009), many carbon pool classifications are being adapted to also include harvested wood products (HWPs).



Source: Genene Asefa *et al*. (2013).

Figure 1 Diagrammatic Representation of Carbon Pools. (AGB above-ground biomass; BGB below-ground biomass; SOM soil organic matter; DOM dead organic matter; HWPs harvested wood products)

A carbon source is a carbon pool from which more carbon flows out than flows in: forests can often represent a net source (rather than sink) of carbon due to the processes of decay, combustion and respiration. A carbon sink is a carbon pool from which more carbon flows in than out: forests can act as sink through the process of tree growth and resultant biological carbon sequestration (Brown, 2002). Forests can switch between being a source and a sink of carbon over time, with the stock of the forest referring to the absolute quantity of carbon held within a forest component at a specified time.

Stock accounting sums carbon pools at a single point in time. Decisions on which carbon pools should be included are largely dependent on the availability of existing data, costs of measurement and the level of conservativeness required (MacDicken, 1997). Trees often represent the greatest fraction of total biomass of a forested area, with other carbon pools only a fraction of the total tree biomass.

The understory is estimated to be equivalent to 3% of above-ground tree biomass, dead wood 5-40%, and fine litter only 5% of that in the above-ground tree biomass. BGB is more variable, ranging between 4 - 230%, and can be more than two times greater than that in the above-ground tree biomass (Brown, 1997). AGB in trees also responds more rapidly and significantly as a result of land-use change than other carbon pools. As a consequence, the majority of carbon accounting efforts is focused on tree AGB, for which there is a considerable forest science research base.

2.4 A review of global climate change

Global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide, and on measuring carbon absorbed by and stored in forests, soils, and oceans. In light of the continuing high rates of deforestation in developing countries and the resulting emissions of greenhouse gases (IPCC, 2007 and FAO, 2010), addressing these problems gained new momentum in 2005 when the negotiations on a post-Kyoto regime began at the 11th Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC).)

According to VanderWerf *et al*. (2009), in the tropical forests deforestation and degradation was estimated to contribute up to 17% of the global CO_2 emissions responsible for global warming, leading to climate change. Climate change has direct consequences on the economy, ecosystems, water resources and sea level rise (IPCC, 2001). In recognition of the impacts caused by deforestation in developing countries, in the Conference of Parties (COP 13) in Bali it was agreed that reducing emissions from deforestation and degradation (REDD) should be included in a post Kyoto mechanism (UNFCC, 2007). Recently UN also introduced REDD+ from the original concept of REDD to include emissions from deforestation and degradation of carbon rich ecosystems (Burgess *et al.*, 2010).

The Intergovernmental Panel on Climate Change (2001) estimates that carbon dioxide is responsible for about 60 percent of the current warming. Mean global temperature is projected to rise between 3 and 10 degrees Fahrenheit by end of the century, a rate of up to one degree Fahrenheit per decade (IPCC, 2001). Land use change, mainly deforestation, accounts for about a quarter of annual carbon dioxide releases from human activities, while the rest comes from fossil fuels emissions i.e., using gas, oil and coal to power cars and factories and produce electricity.

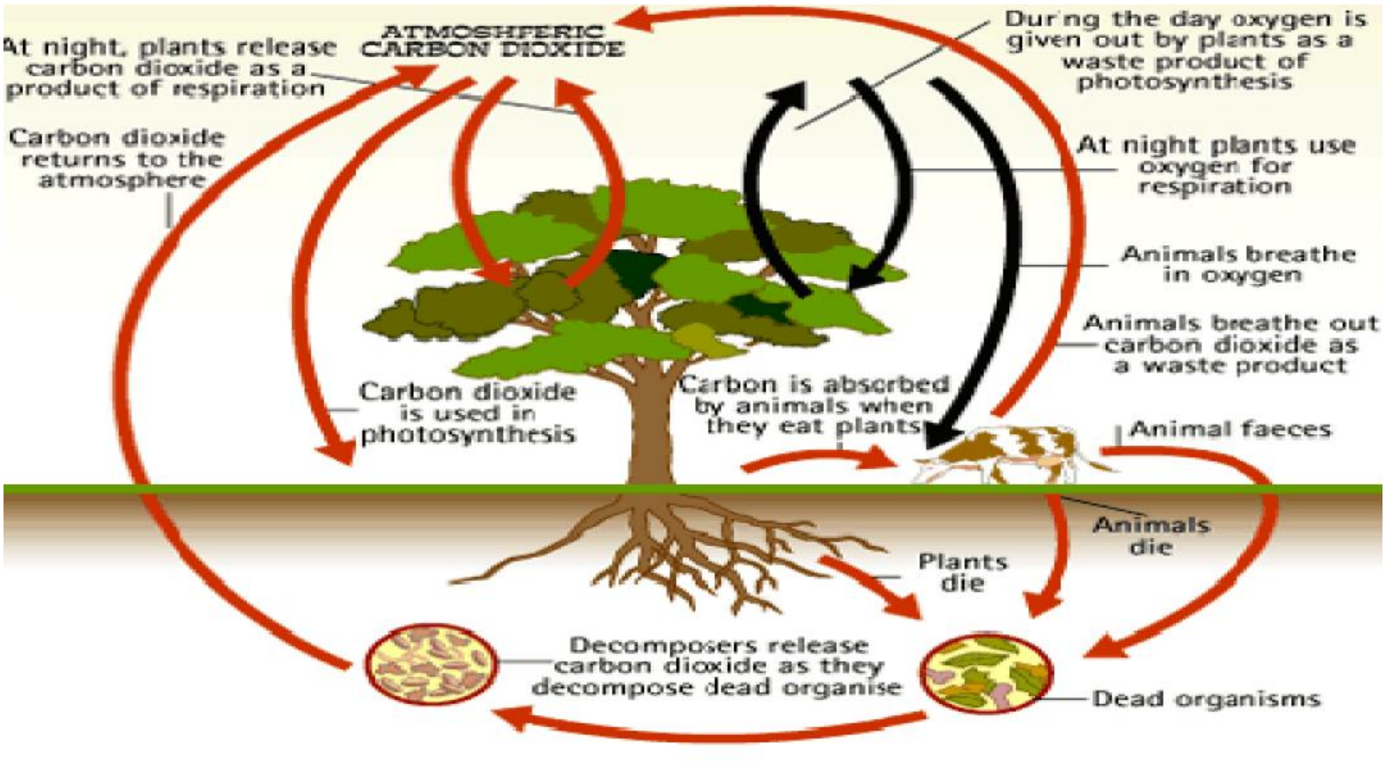
2.5 Carbon sequestration and storage

Globally there is a general positive relationship between biodiversity and carbon stocks (Midgley *et al*., 2010a) tropical moist forests, unaffected by direct anthropogenic disturbances like logging and fire, are rich in both i.e. to have good carbon content in plant biodiversity, the plant must be conserved very well. Within tropical forests there is less correlation between spatial patterns of carbon stocks and biodiversity in undisturbed areas and the patterns are complex (Talbot, 2010). At the macro-level, there is considerable variation from one tropical forest region to another in the number of species supported per unit area, but there is as of yet no compelling evidence that the most diverse tropical forests are also the most carbon rich.

A great deal of uncertainty still surrounds biomass distributions and their causes, and different research groups and different approaches (including remote-sensing and ground-based measurements) have found different ideas. Overall, few studies yet exist that address whether the variation in biodiversity coincides empirically with large variation in biomass and soil carbon stocks. Whether and to what degree biodiversity influences carbon stocks in tropical forests is still uncertain, although experimental work in other ecosystems has shown that biodiversity often promotes stability and primary productivity, and therefore carbon stocks (Miles *et al.*, 2010a).

2.6 Means of carbon sequestration

Carbon sequestration means that carbon dioxide is captured from the atmosphere by photosynthesis that trees or plants to store it as cellulose in its trunk, branches, twigs, leaves and fruit and oxygen is released to the air in return. Also the roots of the trees and plants take up carbon dioxide. Decomposing organic materials increase the amount of carbon stored in the soil, which is higher than the total amount in the vegetation and the atmosphere. Animals breathe in oxygen and breathe out CO_2 and through their faeces carbon and N_2O is released to the soil (Fig.2).



Source: Trumbore (1997)

Figure 2 Shows means of carbon sequestration in plant.

2.7 Global carbon cycles and Forest

Forests form a significant part of the global carbon cycle. Plants use sunlight to convert CO_2, water, and nutrients into sugars and carbohydrates, which accumulate in leaves, twigs, stems, and roots. Plants also respire, releasing CO_2. Plants eventually die, releasing their stored carbon to the atmosphere quickly or to the soil where it decomposes slowly and increases soil carbon levels.

The carbon cycle has a large effect on the function and well being of our planet. Globally, the carbon cycle plays a key role in regulating the Earth's climate by controlling the concentration of carbon dioxide in the atmosphere. Carbon dioxide (CO_2) is important because it contributes to the greenhouse effect, in which heat generated from sunlight at the Earth's surface is trapped by certain gasses and prevented from escaping through the atmosphere. The greenhouse effect itself is a perfectly natural phenomenon and, without it, the Earth would be a much colder place.

The current discussion about global change, including land-use change and greenhouse gas emissions, has increased interest in the global carbon cycle (Clark, 2004). Tropical forests play a critical role with respect to global carbon pools and fluxes as these forests store about half of the world's biomass (Brown and Lugo, 1982) and 20% of the global soil carbon (Jobbagy and Jackson, 2000). The global carbon cycle is being altered in response to human interference; for instance land-use changes in the tropics are estimated to contribute about 23%tohuman-induced CO_2 emissions (Houghton, 2003a).

Humans are forcing the global carbon cycle into disequilibrium by increasing the atmospheric pool of greenhouse gases at a faster rate than it can be reduced by removal of CO_2 through natural processes. About 70% of the additional CO_2 in the atmosphere is the result of burning fossil fuel while 30% is from land conversion. Currently, emissions from deforestation are estimated to contribute ~17% of annual anthropogenic emissions (IPCC, 2007).

2.8 An Overview of Carbon Market

According to Mesfin Sahle (2014), carbon trading is a market mechanism allowing those most efficient at reducing emissions to do so and trade their carbon credits with those who cannot reduce emissions as cost effectively. It is a market mechanism to mitigate climate change. In carbon trading one Party pays for another Party in return for greenhouse gas emission reduction or for the right to emit (Rinaududo *et al*., 2008). The Kyoto mechanisms allow the countries with Kyoto commitments to meet their target of reducing greenhouse gas emissions in a cost effective way and motivate developing countries to join global emission reduction (UNFCCC, 2009).

It was stated that, developed countries have mainly caused climate change, but developing countries bear a disproportionate share of the impacts. Impacts are expected to be most severe in low-latitude and less developed areas. In this respect Sub-Saharan Africa (SSA) is considered to be one of the most vulnerable regions for climate change, because of the high exposure and the low adaptive capacity of agriculture, which is the most important livelihood of this people in this region (IPCC, 2007). Thus, carbon trading offers an opportunity to increase climate equity. Treaties include potential to finance mitigation and adaptation to climate change and enhance sustainable development.

According to Hamilton *et al.* (2009), there were two types of carbon market exist; the regulatory compliance and the voluntary markets. The compliance market is used by companies and governments that by law have to account for their GHG emissions. It is regulated by mandatory national, regional or international carbon reduction regimes. On the voluntary market the trade of carbon credits is on a voluntarily basis.

2.9 Kyoto protocol and forest carbon stock

The potential of enhancement of forest carbon stocks in particular has led to severe concerns by many scientists and NGOs. Assuming that the current forest definition remains unchanged, they criticize the present REDD+ design for considering forest biomass merely from the quantitative perspective of carbon storage; qualitative aspects referring to forest biodiversity are left unconsidered despite their significance for the resilience of forest ecosystems and the permanence of forest carbon stocks (Loumann *et al*., 2009; Thompson *et al.*, 2009). REDD+ focusing only on biomass production would pose severe risks to biodiversity if it provides incentives for a conversion of primary forests and degraded forests into commercial tree plantations.

The Kyoto Protocol allows for only afforestation and reforestation under its Clean Development Mechanism (CDM). The rules and modalities established under the Marrakech Accords allow developing countries to sell CDM certified emission reduction to developed countries up to a limit of 230 million metric tons of carbon dioxide (CO_2) during the period 2008-2012 (about 45 million metric tons of CO_2 per year on average). At the same time the Intergovernmental Panel on Climate Change (IPCC) estimates that 1.7 billion metric tons of CO2 are released annually to the atmosphere because of land use change and largely from tropical deforestation, dwarfing the possible impact of possible forest CDM projects. The magnitude of the emissions from deforestation not included in the Kyoto Protocol triggered the Conference of Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) to initiate a two-year process to address issues relating to reducing emissions from deforestation in developing countries. This process peaked during the COP13 in Bali in December 2007 with the Decision 2/CP.13 "Reducing emissions from deforestation in developing countries: approaches to stimulate action."

REDD (Reducing Emissions from Deforestation and Degradation) has been receiving a considerable attention as a post 2012 Kyoto mechanism to compensate developing countries to reduce CO_2 emissions from deforestation and forest degradation (Ebeling and Yasue, 2008). The important role played by Van Panchayat forests in sequestering CO_2 from the atmosphere, and the livelihoods and environmental benefits that will be accruing to the local communities enable community forests to meet the objectives of sustainable development and emissions reduction (Rawat, 2012). Active forest management can certainly increase carbon sequestration, especially in community forests by improving growing conditions, controlling stand density, protection of fire, appointment of forest guard, rotational grazing, imposing fine on illegal felling and grazing etc. The faster a tree grows the more effective it is at removing carbon from the air. Therefore, conservation of forests, including those under the control of local communities in developing countries, is an important component of overall climate strategy.

2.10 Forest Biomass and carbon sequestration assessment

According to Hua *et al*. (1996), biomass is the total mass of all living organisms; most of it on the Earth is produced by green plants through photosynthesis. It is of fundamental significance in ecosystems, it provides the entire basis of energy flow and food chain. Biomass is also vital for human being the largest portion of our food supply is from plants**.** It is also defined as; biomass is the total amounts of above ground living organic matter in trees expressed as oven dry tons per unit area. Biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity, carbon budgets, etc (Parresol, 1999; Pandey et al. 2010).

Even though the subject of biomass assessment has received considerable attention for quite sometimes, especially after pulpwood demand in 1960s and oil crisis in 1970s (de Gier, 2003), the amount of carbon stored in the biomass has gained special attention as a result of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Under these agreements, countries are required to estimate and report CO_2 emissions and removals by forests. The developing global carbon markets, particularly because of the incorporation of a Clean Development Mechanism (CDM) in the Kyoto protocol, require accurate and reliable methods to quantify the sources and sinks of carbon in forest. Estimation of biomass of forests is a usual practice to quantify fuel and wood stock and allocate harvestable amount (Dias *et al*., 2006).

Biomass analysis is an important element in the carbon cycle especially, carbon sequestration. Recently biomass is being increasingly used to help quantify pools and fluxes of green house gases (GHG) from terrestrial biosphere associated with land use and land cover changes (Cairns *et al*., 2003). The importance of terrestrial vegetation and soil as significant sinks of atmospheric CO_2 and its other derivatives is highlighted under Kyoto Protocol (Wani *et al.,* 2010). Vegetation especially, forest ecosystems store carbon in the biomass through photosynthetic process, thereby sequestering carbon dioxide that would otherwise be present in the atmosphere. Undisturbed forest ecosystems are generally highly productive and accumulate more biomass and carbon per unit area compared to other land use systems like agriculture. It is estimated that the carbon stored globally in the forest biomass amounts to 2,40,439 Mt with an average carbon density of 71.5 t ha-1and and a recent estimate indicates that tropical forests account for 247 Gt vegetation carbon, of which 193 Gt is stored above ground (Saatchi *et al.,* 2011)

2.11 Forest Carbon Pools

When viewing the Earth as a system, these components can be referred to as carbon pools (sometimes also called stocks or reservoirs) because they act as storage houses for large amounts of carbon. Any movement of carbon between these reservoirs is called a flux.

The carbon stock in a forest ecosystem can be broadly categorized as biotic (vegetation carbon) and pedologic (soil carbon) components. These stocks are dynamic, depending upon various factors and processes operating in the systems, the most significant being land use, land use changes, soil erosion and deforestation (IPCC, 2000). The carbon stock in forest vegetation varies according to geographical location, plant species and age of the stand (VanNoordwijk *et al.,* 1997). Estimates of the biomass contained within forests are critical aspects in the determination of carbon loss associated with a wide range of land use and land-cover changes. The above ground biomass and below ground root biomass both need to be measured to enable better calculations of the total amount of forest carbon (Hamburg, 2000).

Trees play an important role in the reduction of carbon dioxide from the atmosphere by carbon sequestration. Active absorption of CO_2 from the atmosphere through the process of photosynthesis and its subsequent storage in different plant parts in the form of biomass in growing trees are the essence of carbon storage (Baes *et al*., 1977). Tree, shrub, soil and seawater play a crucial role in absorbing atmospheric CO_2. The trees 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. As more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissues (above and below ground (Gorte, 2009; IPCC, 2003), resulting in growth of their different parts (Chavan and Rasal, 2010).

2.12 The Terrestrial Carbon Cycle: Managing Forest Ecosystems

Forests are important in the global carbon cycle because they store more than 55% of the global carbon stored in vegetation and more than 45% of that stored in soils, exchange carbon with the atmosphere through photosynthesis and respiration, are sources of atmospheric carbon when they are disturbed by human or natural causes and become atmospheric carbon sinks during regrowth after disturbance Forests can influence climate change by affecting the level of CO_2 in the atmosphere; through the production of other greenhouse gases such as carbon monoxide, ozone, and nitrous oxide; and through changes in albedo of land as forests are converted to other land cover types.

Globally, forest vegetation and soils contain approximately 359 and 787 Pg of C (Table 1), respectively (Pg= 1,000 million tones). Earlier projections ranged from 953 to 1400 Pg of global C. The allocation of carbon between vegetation and soils differs by latitude, with a large part of the vegetation (25%) and soil (59%) carbon pools located in the high latitude forests. Mid-latitude forests account for a small portion of the global carbon pool (16 and 13%

of the vegetation and soil, respectively). Low latitude tropical forests are relatively heterogeneous and contain 59 and 27% of global forest vegetation and soil C, respectively (Dixon *et al.,* 1994a).

Table 1 The estimated carbon pools and area weighted carbon densities in forest vegetation (above- and below-ground living and dead mass) and soils (O horizon, mineral soil to a depth of l m, and co-located peatlands) in forests of the world.

Latitudinal belt	**Country**	**Carbon pools**	
		Vegetation	**Soils**
High	Russia	17	249
	Canada	12	211
	Alaska	2	11
Subtotal	-	88	471
Medium	Count'I US	15	26
	European	9	25
	China	17	16
	Australia	18	33
Subtotal	-	59	100
Low	Asia	41-54	43
	Africa	52	63
	Americas	119	110
Subtotal		212	216
Total		359	787
1Pg= 10^{15}g or 1 gigatonne			

Source: Dixon *et al.* (1999).

2.13 Carbon Stock Biomass

2.13.1 Above ground biomass Carbon Stock

The above-ground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous undergrowth. For agricultural lands, this includes crop and weed biomass. For biomass estimation of woody vegetation any live plant greater than or equal to 2 cm DBH will be treated as above ground woody plant. Experience to date with the development of generic regression equations has shown that measurements of DBH explains more than 95% of the variation in tree biomass even in highly species rich tropical forests (Genene Asefa *et al.*, 2013)

The main carbon pools in tropical forest ecosystems are the living biomass of trees and understory vegetation and the dead mass of litter, woody debris and soil organic matter. The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation (Gibbs *et al.*, 2007). Knowledge of the aboveground living biomass density is useful in determining the amount of carbon stored through photosynthesis in the forest stands. The aboveground living biomass is also an excellent indicator of plant growth, condition and yield potential. Thus, estimating aboveground living biomass is the most important step in quantifying forest Carbon stocks and monitoring the changes.

Studies on aboveground living biomass and C-stock in tropical forests have been carried out by several researchers, either measured directly based on destructive sampling in experimental plots (Ludang and Jaya, 2007, Miyamoto *et al.*, 2007) or estimated based on volume data of forest inventories (Brown and Lugo 1984, Brown *et al.*, 1989). However, most of the studies focused on the estimation of forest biomass and C-stock at one occasion. Forest biomass and C-stock may be dynamic and changes occur continuously at individual tree and stand levels throughout time due to loss of carbon during deforestation and degradation caused by human activities and accumulation of carbon during regrowth of forests.

2.13.2 Below ground biomass (BGB)

The BGB carbon pool consists of the biomass contained within live roots. As with AGB, although less data exists, regression equations from root biomass data have been formulated which predict root biomass based on above-ground biomass carbon (Cairns *et al*., 1997; Brown, 2002). Cairns *et al.* (1997) review 160 studies covering tropical, temperate and boreal forests and find a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30. Although roots are believed to depend on climate and soil characteristics (Brown and Lugo, 1982), Cairns *et al*. (1997) found that root to shoot ratios were constant between latitude (tropical, temperate and boreal), soil texture (fine, medium and coarse), and the tree-type (angiosperm and gymnosperm).

2.13.3 Dead organic matter (litter) carbon stock

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 DOM wood, 10cm diameter. Carbon is stored in trees (stem, branches, leaves and root), understory, and forest litter and forest soils. The decay of litter is one of the main sources of SOC and the quality of litter is significant in this view (Lemma *et al.,* 2007). Biniyam Alemu (2014) also stated that, for the systems with high plant diversity, it is likely that they would have litters with different degrees of chemical resistance, creating the possibility of longer residence of C through slower decomposition of litters from some species. Lignin in litter is highly resistant to decomposition and therefore, litter with high lignin content would have slower decomposition rate (Mafongoya *et al*., 1998). In contrast, litter with low lignin, phenols, and high N content would have faster rate of decomposition.

Local estimation of the DOM litter pool again relies on the establishment of the wet-to-dry mass ratio. Where this is not possible default values are available by forest type and climate regime from IPCC ranging from 2.1 tones of carbon per hectare in tropical forests to 39 tones of carbon per hectare in moist boreal broadleaf forest (IPCC, 2006).

2.13.4 Dead wood organic matter

The DOM wood carbon pool includes all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10 cm. Often ignored, or assumed in equilibrium, this carbon pool can contain 10-20% of that in the AGB pool in mature forest (Delaney *et al.,* 1998). However, in immature forests and plantations both standing and fallen dead wood are likely to be insignificant in the first 30-60 years of establishment.

The primary method for assessing the carbon stock in the DOM wood pool is to sample and assess the wet-to-dry weight ratio, with large pieces of DOM measured volumetrically as cylinders and converted to biomass on the basis of wood density, and standing trees measured as live trees but adjusted for losses in branches (less 20%) and leaves (less 2-3%) (MacDicken, 1997). Methods to establish the ratio of living to dead biomass are under investigation, but data is limited on the decline of wood density as a result of decay (Brown, 2002).

2.13.5 Soil organic matter (SOM)

SOM includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal & 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. 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. In SOM accounting, factors affecting the estimates include the depth to which carbon is accounted, commonly 30 cm, and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years. The mechanism of species driven C sequestration in soil is influenced by two major activities, aboveground litter decomposition and belowground root activity (Binyam Alemu, 2014). Soil organic carbon is affected by different factor (Table 2) and environmental influences (Canadell *et al.*, 2009).

Table 2 Factors affecting forest carbon stocks.

Factors affecting forest carbon stocks		
Natural Impacts	**Indirect Human-Impacts**	**Direct Human-Impacts**
Climate variability (e.g. El Nino, Pacific Decadal Oscillation, heat waves)	CO_2 fertilization Nitrogen deposition Air pollutant effects	Afforestation and reforestation
Natural disturbances (e.g. fire, insect attacks)	Long-term climate and variability trends due to GHG forcing (e.g. length of growing season)	Deforestation Forest management (including rotation, thinning, fire management
	Disturbances associated with long-term climate and variability trends due to GHG forcing (e.g. fire, insect attacks	Cropland management Grazing land management Revegetation

Source: Canadell *et al.* (2009).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was carried out in Ilu Gelan District, West Shewa Zone of Oromia Regional State, in central Ethiopia (Fig. 3). The District is located on the Addis Ababa - Nekemte main road about 200 km from Addis Ababa to the west. IJaji is the central town of the District and is located on geographical coordinates of 08^{o} 59’ 51’’N and 037^{o} 19’ 49’’E with the altitude of 1812 m a.s.l. The District is bordered on the north and the east by Cheliya, on the west by Bako Tibe, on the south by Dano districts. It is bordered also on the southwest by Nono Benja of Jimma Zone and Boneya Boshe of West Wollega Zone districts. Gibe River demarcates the boundary of the District on the southwest while Fato River separates it from Dano District on the south. According to the information obtained from the District, the area of Ilu Gelan is 332.04 km^2.

This study was conducted in two nearby sites known as Dirki and Jato woodland that are found south of the main road when we drive from Gedo, the central town of Cheliya District, to Ijaji about 195 km from Addis Ababa to the west. The vegetation of Dirki lies on a steep mountain between the range of latitudes 08^{o}59’16.1’’ to 08^{o}59’50.8’’ N and longitudes 037^{o}23’15.8’’ to 037^{o}22’45.50’’ E while that of Jato extends on north and northwest facing plateau escarpment (Fig 3).

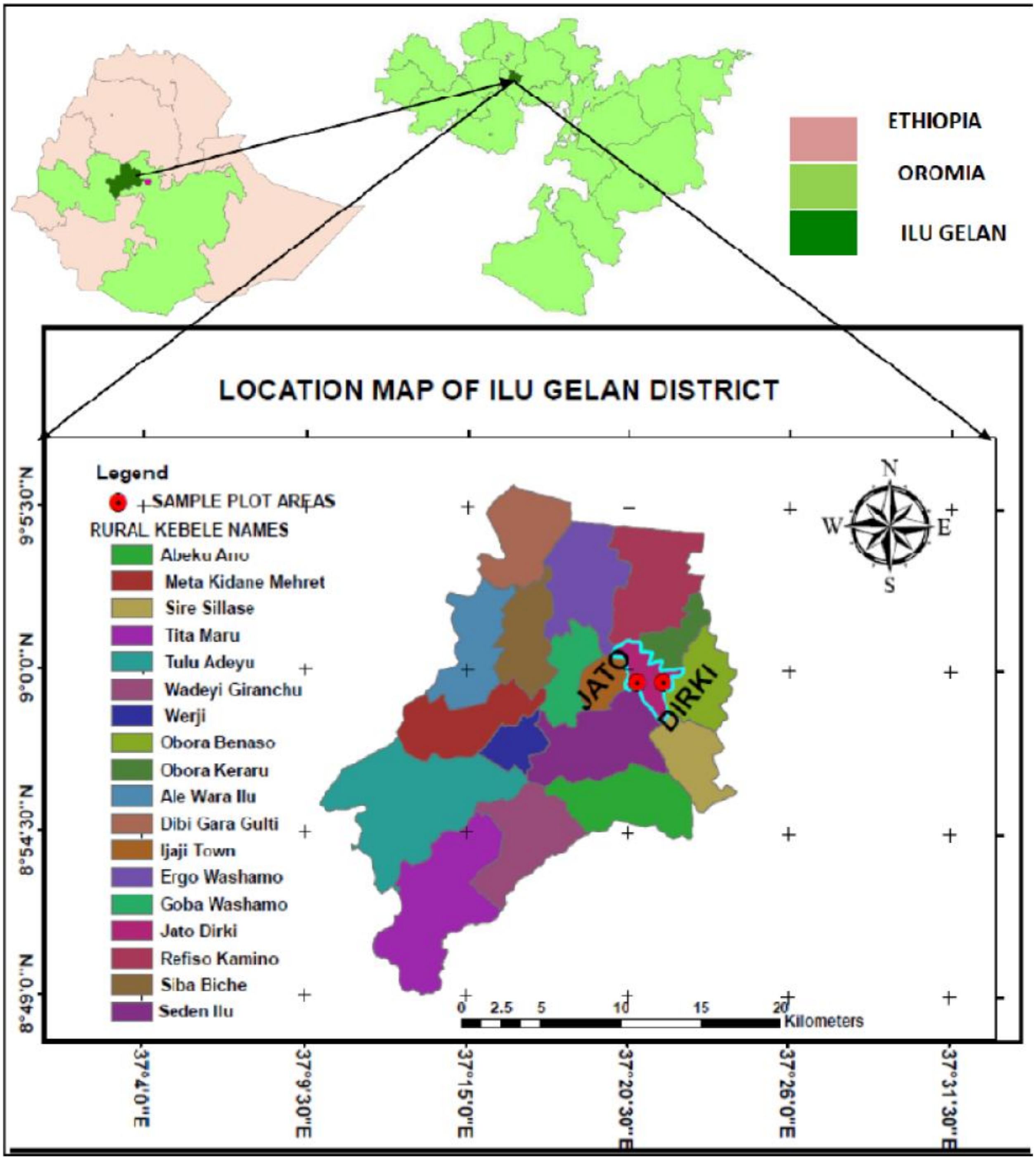


Figure 3 Map of Ethiopia showing Regional states and the study area (Mountain Dirki and Jato woodland)

3.1.2 Topography

Ilu Gelan District is generally characterized by rough topographic features. It has gorges, escarpments, mountains and plateaus. Tullu Dirki, Tullu Niti and Gara Habib are mountains well known with medium altitude in the District. Tullu Niti was believed traditionally as the place where the local female leader named 'Akkoo Manooyee/ Haadha Sonkooruu'' was living in the past. Gara Habib mountain is least covered with vegetation but almost with rocks. The altitudinal range of the District falls within 1500- 2200 m a.s.l. Mountain Dirki is found between altitudinal ranges of 1795 to 2078 m a.s.l. while that of Jato is from 1905 to 2136 m a.s.l. The vegetation of Dirki is found on a steady mountainous slope whereas that of Jato is located on a slopppy escarpment of land face. The vegetation is found on the north and northwest facing parts of the escarpment.

Perennial rivers such as Alanga, Washamo, Bisil and Karsa rivers are flowing from the highlands into Gibe River by crossing the District in north to south direction. The water from these rivers gives services for drinking, washing and irrigation. Three mineral water places, namely, Hora Ambo and Hora Dirki where the local people use the water to drink their livestock, are found in the District. In addition to these, Ilu Gelan District hosts ''Oda Bisil'', the historical place where the Oromo people celebrate every new year through praying to Waqa.

3.1.3 Climate

The climate of Ilu Gelan District is considered to Weina Dega and Kolla agro-ecological Zone of Ethiopia. As most part of the District is found in lowland, the mean annual temperature of the area is relatively high (Endale Amenu, 2007). Meteorological data obtained from National Meteorology Service Agency (Addis Ababa) indicates that Ilu Gelan area obtains high rainfall between May and September and low rainfall from December to February (Fig. 4). The mean annual rainfall of the study area was 1351mm and recorded in July. The lowest mean annual rainfall was 11.2 mm recorded in February. The mean maximum temperature over twenty years was 28.1 C^o while that of minimum temperature was 13.8 C^o. The highest temperature, 31.7 C^o, was recorded in February whereas the lowest temperature, 11.2 C^o, was recorded in November.

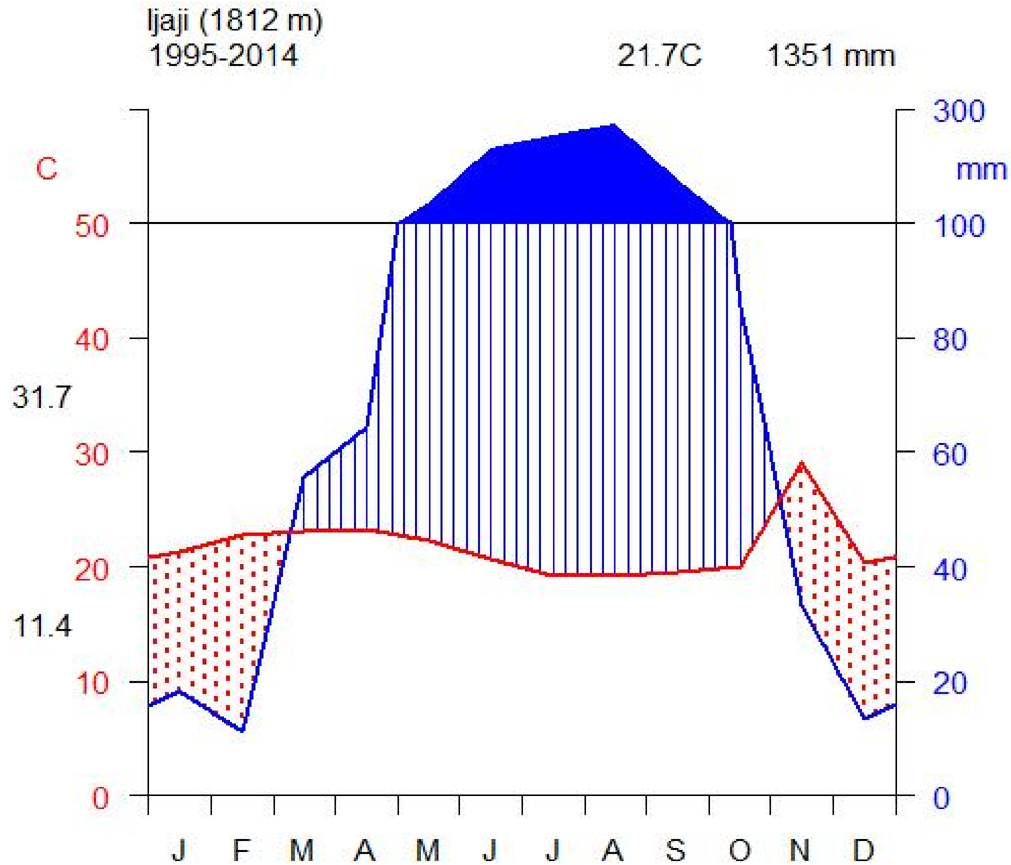


Figure 4 Climadiagram showing rainfall distribution and temperature variation around Ijaji Town.

Source: Data (raw) obtained from National Meteorological Service Agency.

3.1.4 Soil

According to Endale Amenu (2007), the type of soil found in the District can be classified into four categories. These are clay soil, black soil, sand soil, and the soil type from a mixture of all the three soil types mentioned above. However, the data obtained from the office of the

Natural Resource Conservation and Management of the District reveals that large proportion of the soil of the District is considered clay soil.

3.1.5 Vegetation

The information obtained from Ilu Gelan District indicates that most parts of the lands currently observed as free in the District were covered with vegetation in the past. Today, few remnants of big trees are observed in the farm lands and road sides. For example, plant species like *Ficus vast*, *Albizia schimperiana*, *Cordia africana*, *Ficus sycomorus, Prunus africana, Croton macrostachyus, Podocarpus falcatus, Olea europaea* and *Ficus sur* are observed in the farm lands and on road sides. It can also be deduced from this respect that the vegetation cover of the District was larger in the past than what is really observed at the present.

Currently, there are some vegetation areas of woodlands and forests found the District. These vegetation areas are known by the names: Dirki, Jato, Irgo Washemo, Ale Wara Ilu, Obora Benaso, Obora Keraru, Rafiso Kamino, Dibi Gara Gulti and Sire Sillase. They are separated by settlements and almost restricted to mountainous areas and slopes of escarpments. This indicates as most proportions of the vegetation of the woodlands and forests have been removed from areas that are suitable for expansion agriculture (i.e, bases of mountains and flat lands).

3.2 MATERIALS

3.2.1 Tools

Different instruments and materials were used to carry out forest carbon measurement. Garmin map 62s GPS was used for locating plots with the help of base map. Linear tape (steel long 50 mt) and diameter tape (fiber 10 mt were used for locating plot boundary and for distance measurement and for measuring the diameter of the trees at breast height and plastic bags were used to collect samples and leaf of litter and weighted in weighing machine. The heights of trees were measured using Haga hypsometer.

3.3 Data Type

Both primary and secondary data were used in order to collect the relevant data to achieve the objectives of the study. Primary data were obtained through field measurement on necessary parameters that was used to estimate carbon stock of the study area whereas secondary data that were important to this study were collected from secondary sources.

3.4 Methodology

3.4.1 Delineation of Study Area

Delineation is the first activity of the forest carbon measurement area boundaries (Bhishma *et al.*, 2010). Unless the spatial boundaries of the study site were not separated and properly recognized it is difficult to get accurate measurement and effective work. On the first step activities like observing the study site area (reconnaissance survey) of the general area in order to get the ways and to record GPS points for boundary delineation of this study site were done.

3.4.2 Sampling method on the field

Reconnaissance survey was made through the study site in order to obtain general idea of the site conditions of the study area (environment), situation and the vegetation, to collect information on the accessibility of the study area before transect was laid. A systematic transect sampling technique was used in this study by following the aspects of the mountain/hills that found at two sites Dirqi and Jato. From the site Dirqi four transect was laid from top to down and three transect was from Jato by following the transect method with different aspect and with different amount of plots were sampled. Following a reconnaissance survey the aspect (North, South, West and East), the altitudinal range including both sites Lower (1803-1902) and Higher (1903-2100) of the Woodland vegetation was identified from GPS reading that include both sites based on their size and DBH increment and the transects were laid from the peak of the mountain to down by dropping 25 m difference between plots at two sites. The range of altitude for Dirqi was from (1795-2078) whereas the Jato was from 1905 to 2100 and the data were collected from these two ranges of altitudes found at different sites which was approximately 1.5 km far from each other. There were differences in plot number because some aspects has long in phase and less in disturbances due to surrounded by river round the hills/ mountain whereas some aspects disturbed due to agricultural expansion.

In some aspects where there was human intervention and animal disturbance the plot was laid 100 m away from the border in order to avoid the disturbance of the plot before the line transect was laid. In order to see the carbon content difference of the woodland vegetation one plot was laid on the top of the mountain. Totally, seven transects were laid to the different aspects by using the GPS reading system and 54 sample plots were sampled with the ratio of 32 plots with range of (1803-2078) with four aspect from Dirqi mountain and 22 plots (1905-2136) with three aspects were from jato sites.

3.4.2.1 Shape and Size of the Plots

Forest carbon measurement can be carried out in rectangular, circular and square plots. Even though, both rectangular and circular plots are applied in most of the forest carbon measurements, square plot is recommended for the study area (Pearson *et al.,* 2005). This is because a square plot is similar with rectangular that tends to include more of within plot homogeneity and since the area has more or less uniform slope, and thus be more representative than the circular plots of the same area (Brown, 1997; Hairiah *et al.,* 2001). In this study, sample plots of size 20 m x 20 m (400 m^2) were used for vegetation sampling (Pearson *et al.,* 2005). In each plot, trees with a DBH of ≥ 5cm were measured for DBH and height because of the life zone, the shrub plant couldn't withstand with high temperature and type of woodland under which grouped was similar with the current study.

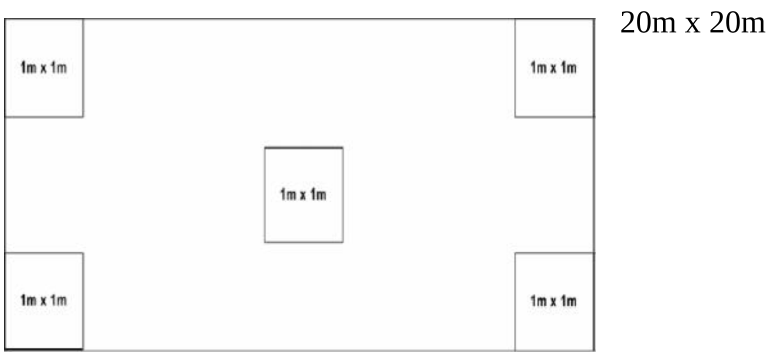


Figure 5 Shape of the sample plot**.**

3.5 Field Measurements

3.5.1 Plant Specimen Collection and Identification

The Vegetation data were collected by recording the scientific and/or vernacular names of the woody plant species in the sampling plot and the local name was identified in the field by local botanist and the entire specimen were taken to the National Herbarium (ETH) for identification. For each sample plot, altitude and aspect was measured using Garmin map 62 GPS with precision ±7 m and the areas of the woodland of each sample plots was determined by tape meter (steel long 50 m) measurement. Plant specimens was collected for every plant species of specified DBH, pressed and dried. Finally all of the plant specimens were identified and checked at ETH, Addis Ababa University.

3.5.2 Above Ground Biomass (Diameter and Height measurement)

The above ground biomass consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The DBH (diameter at breast height) and height (H) of all plant species with diameter ≥ 5 cm in the study area were measured as follows: The diameter of tree at (1.3 m above the ground) of all woody plants were measured using an instrument called diameter tape (faber 10 mt). Kent and Coker (1992) stated that, the trees with multiple stems at 1.3 m height were treated as a single individual and DBH of the largest stem was taken as the sample for the measurement. It was also emphasized that, the trees with multiple stems or fork below 1.3 m height were measured as a single individual tree, and trees on a slope area were measured on the uphill side. For the trees near the plot side that have > 50% of their basal area falls within the plot was included and, trees overhanging into the plot are excluded, but trees with their trunks inside the sampling plot and branches outside were included (Karky and Banskota, 2007) and MacDicken, 1997). In order to categorize tree and shrub species with DBH ≥ 5 cm a complete list of each plot was done.

3.5.3 Below ground biomass

MacDicken (1997), stated that, the appropriate method used for estimation of below ground biomass (BGB) can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 is used.

3.5.4 Dead Litter

The litter carbon pool includes all non-living biomass with a size greater than the limit for soil organic matter (SOM), commonly 2 mm, and smaller than that of DOM wood, 10 cm diameter. The samples of litter (leaves, twinges, fruits or flowers, and barks) were collected in five square subplots of 1 meter square in size inside the main sample plot 20 m x 20 m (400 m^2), which was established at the four corners and one at the center of each plot. The all five samples of fine litter, including litter within the 1 m^2 subplot were collected and placed in a weighing bag. A composite sample of 100 g of evenly mixed sub-samples were brought to the laboratory for analysis placing in a plastic bag and oven dried at 70^{O}C for 24 hours and weighed for analysis of total carbon concentrations to determine oven dry mass from which total dry mass and carbon fraction were calculated (Pearson *et al*., 2005). Dead wood was not measured in the woodland due to the nonexistence of dead wood within the sample plots because of uncontrolled production of charcoal.

Figure 6 Photo showing the researcher collecting litter from the study area plots.

3.6 Data Analysis

The data which were collected from the field inventory were organized and recorded in micro soft excel 2007 data sheet. The frequencies of each tree species in all 54 sample plots were analyzed. Biomass of each tree species in all sample area was made using data from diameter class distribution, referred to as above ground biomass. The data obtained from DBH, diameter, height of each species, field weight (Ww), fresh weight-(FW) and dry weight (Wdry) of dead litter were organized by excel 2007 and analyzed using MINITAB software version 16. DBH data was arranged in classes applying appropriate model of biomass estimation equation. The relationship between each parameter was tested by descriptive statistics. One way ANOVA test was done to observe the effect of factors (altitude, disturbance and aspect) on woodland carbon stock.

3.6.1 Estimation of carbon in different pools

3.6.1.1 Estimation of Carbon in the above ground biomass

The above ground biomass (AGB) of all the tree species with the specified diameter in the sample plot was estimated. For above ground biomass estimation different mathematical equation has been developed and used by many researchers (Brown *et al*., 1989; Negi *et al*., 1988). The model developed by Brown *et al*. (1989) to estimate above ground biomass has been used in present investigation due to accuracy and life zone of the study is fitted with the life zone recommended for the equation. The allometric equation is suitable for rain fall less than 1500 mm and the DBH $\geq$ 5 cm. It is also stated that this method is nondestructive method and the most appropriate method (Alves *et al*., 1997; Brown, 1997; Schroeder *et al*., 1997 and FAO, 1997).

The general equation that was used to calculate the aboveground biomass is given below:

$$Y = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \text{ ………. (eq.1)}$$

$$Y = \exp\{-1.996 + 2.32 \times \ln(D)\} \text{ ………………………… (eq.2)}$$

Where, Y is above ground biomass, DBH is diameter at breast height.

The biomass density (Mega gram per hectare) was calculated by multiplying the dry mass by an expansion factor calculated from the plot size. The expansion factor was calculated as the area of a hectare in square meters divided by the area of the sample in square meters, that is:

$$\text{Expansion factor} = \frac{10{,}000 \text{ m2}}{\text{Area of the plot (20 m x 20 m (m2)}} \ldots\ldots\ldots\ldots\ldots \text{(eq.3)}$$

The carbon content in litter biomass was also calculated by multiplying herbaceous/litter biomass by 0.47% (IPCC, 2006).

3.6.1.2 Estimation of Carbon in below ground biomass

Measuring below ground tree biomass (roots) is not as easy as the above ground biomass. It is more complex, time consuming, destructive and almost never measured, but instead it is included through a relationship to above ground biomass (usually a root-to-shoot ratio) (Geider *et al*., 2001). MacDicken (1997), stated that, the appropriate method used for estimation of below ground biomass (BGB) can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 is used. At the same time, Pearson *et al*. (2005) defined this method as it is more efficient and effective to apply a regression model to calculate below ground biomass from the calculated data of biomass in above ground. Thus, the equation developed by MacDicken (1997) to estimate below ground biomass was used.

$$BGB = AGB \times 0.2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(eq. 4)}$$

Where, BGB is below ground biomass,

AGB is above ground biomass, 0.2 is conversion factor (or 20% of AGB). And the carbon content of the biomass is about 47% by dry weight (IPCC, 2006), the carbon stock in the biomass was estimated using the formula:

$$\text{Biomass C stock} = \text{Biomass} \times 0.47 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(eq.5)}$$

Biomass carbon stock was then converted in to CO_2 equivalent as follows:

$$CO2\ eq = biomass\ C \times 3.67 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (eq\ 6).$$

3.6.1.3 Estimation of Carbon in the Litter Biomass

According to Pearson *et al.* (2005), estimation of the amount of biomass in the leaf litter can be calculated by:

$$LB = Weight\ field \times \frac{W_{sub-sample\ dry}}{W_{sub-sample\ fresh}} \times BEF \ldots\ldots\ldots (eq. 7)$$

Where: LB = Litter (biomass of litter t ha-1)

Wfield = weight of wet field sample of litter sampled within an area of size $1m^2$ (g);

A = size of the area in which litter was 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).

3.6.1.4 Carbon Stocks in Dead Litter biomass

$$CL = LB \times 0.47\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (Eq. 8)$$

Where, CL is total carbon stocks in the dead litter in t ha-1.

LB is litter biomass

3.6.1.5 Total Carbon Stock Density

The total carbon stock density was calculated by adding the carbon stock densities of the individual carbon pools using the formula (Pearson *et al.,* 2005). Carbon stock density of the study area:

C density = CAGB + CBGB + C Lit…….…… (eq .9)

Where: C density = Carbon stock density for all pools (t ha-1)

C AGTB = Carbon in above ground tree biomass (t ha-1)

CBGB = Carbon in below ground biomass (t ha-1)

C Lit = Carbon in dead litter (t ha-1). The total carbon stock was then converted to tons of CO2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al.*, 2007).

CHAPTER FOUR

4 RESULTS

4.1 Diameter at Breast Height (DBH)

From this study it has been found that the woodland vegetation contains various diverse woody plant species with their DBH was ≥ 5 cm. A total of 86 woody species of 39 families with stem number of 4175 plants were collected, of which *Clausena anisata* family Rutaceae was the dominant and *Podocarpus falcatus* family Podocarpaceae was the least dominant in the study site (Appendix 1**)**. Additionally, species like *Calpurnia aurea, Acacia abyssinica, Syzgium guineense* where dominant at lower altitude whereas *Bersama abyssinica, Olinia rochetiana, Maesa lanceolata, Euclea divinorum, Premna schimperi* where some of the dominant for higher altitude of the study area identified based on their vegetation strucure.

According to the raw data collected from the field, the DBH of trees were classified into three classes: 5-10 cm, 11-15 cm and ≥16 cm. The DBH ≥16 cm was added together because of there was only few number of high DBH plants were found with different DBH. The majority of woodland plants were distributed in the first class (5 -10 cm) followed by the 3rd class (≥16 cm) and the least woodland vegetations plants were recorded in the 2nd (11-15 cm). This showed that the first classes were occupied by dense and short plants species of woodland vegetations (figure 7)

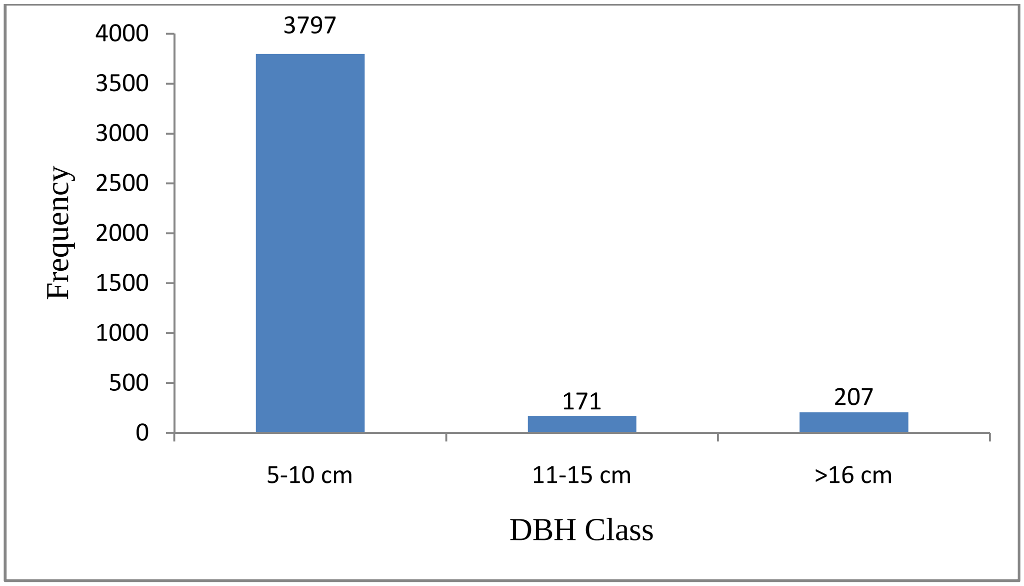


Figure 7 DBH classes of woody plant species of study area.

4.2 Woodland Vegetation Carbon Stock in different Pools

4.2.1 Carbon Stock across the three Carbon Pools

This studies indicates that, the largest carbon stock was covered by above ground biomass with average of 56.7% with comparison to the others pools. The minimum amount of carbon was stored in litter carbon pool (0.006%) followed by below ground pool (5.33%). Therefore, the carbon stock value of the study site in different carbon pool showed different storage capacity. Table 3 shows the amount of carbon stocks in terms of percentage for above ground and below ground biomass, litter biomass and their mean carbon stocks.

Table 3 Carbon pools in the different biomass, mean, carbon stocks and its percentage.

Carbon Pools	54 plots	
	Percentage (%)	**Mean (t/ha)**
Above ground biomass	56.700	87.77
Below ground biomass	11.304	17.50
Litter biomass	0.015	0.02
Above ground carbon	26.650	41.25
Below ground carbon	5.330	8.25
Litter carbon	0.006	0.01

4.2.2 Carbon Stock and Elevation

4.2.2.1 Above and Below Ground Carbon Stock along Altitudinal Gradient

According to this result there were different results for different carbon pools of study area because of some impacts on different carbon pools (above ground, below ground and litter biomass). Based on the result calculated from the mean above ground biomass the lower altitude was 183.23 ton per hectare and 60.49 ton per hectare higher altitude and the result for the mean carbon stock was 86.12 ton per hectare in the lower altitude while 28.43 ton per hectare in higher altitude which was indicated below at (Table 4).

The calculated mean for both below ground biomass and below ground carbon stock was show the same result with above ground biomass and above ground carbon stock. The mean below ground biomass for the lower class was 36.65 ton per hectare and 12.10 ton per hectare upper classes and the mean carbon stock was 17.22 ton per hectare and 5.69 ton per hectare for the lower and higher altitudinal class respectively. Totally the result shows the lower altitude was larger than higher altitude with the carbon content of the woodland vegetation. (Table 4), with a significant variation in both above and below ground carbon stock within the altitude classes (F= 6.63, P = 0.013).

Table 4 The mean biomass and carbon stock t/ha in different carbon pools along altitudinal gradient.

Carbon Pools (t/ha)	Altitudinal classes	
	1803-1902	**1903-2136**
	Lower altitude	**Higher altitude**
Above ground biomass	183.23	60.49
Above ground carbon	86.12	28.43
Below ground biomass	36.50	12.10
Below ground carbon	17.22	5.69
Litter biomass	0.04	0.05
Litter carbon	0.02	0.02
Total carbon stock	323.13	106.78

4.2.2.2 Litter Carbon Stock along Altitudinal Gradient

The litter biomass and carbon stock in a different altitudinal gradient was different from that of above and below ground carbon stocks. As shown below (Table 5), the litter biomass for lower altitude was 0.04 ton per hectare with 0.02 ton per hectare of litter carbon while the litter biomass for higher altitude was 0.05 ton per hectare and 0.02 ton per hectare of litter carbon. The result indicates that the litter carbon was the same for lower and higher altitude classes and totally higher altitude (0.07 t/ha) was larger than lower altitude (0.06) (Table 5), the difference was statically insignificant (F= 1.11, *P*= 0.297).

Table 5 Mean litter biomass and carbon stock (t ha-1) along the altitudinal gradient.

Carbon Pools (t/ha)	Altitudinal classes	
	1803-1902	**1903-2136**
	Lower altitude	**Higher altitude**
Litter biomass (t/ha)	0.04	0.05
Litter carbon (t/ha)	0.02	0.02
Total carbon stock (t/ha)	0.06	0.07

4.2.2.3 Total Carbon Density along Altitudinal Gradient

The hypothesis of this study was to check whether there is low carbon stock density in the higher altitudinal gradient than lower altitudinal gradient. The result of this study showed that the maximum total carbon density was recorded in the lower altitude class (103.36 t ha-1) whereas the higher altitude class had the lowest value (34.14 t ha-1) by summing up the result of specified altitude for lower and higher altitude depending on their DBH size. So, the total carbon density of the study area showed there were lower carbon stock densities at higher altitudinal gradient than lower altitudinal gradient (Table 6). The total carbon stock density of each carbon pools in different altitude classes of the study area were completed by summing up all the mean values of each pool within specified altitude classes.

Table 6 Total carbon stocks (t/ha) along the altitudinal gradient.

Carbon Pools (t/ha)	**Altitudinal classes**	
	1803-1902	**1903-2136**
	Lower altitude	**Higher altitude**
Above ground carbon (ton/ha)	86.12	28.43
Below ground carbon (ton/ha)	17.22	5.69
Litter carbon (ton/ha)	0.02	0.02
Total carbon stock (ton/ha)	103.36	34.14

4.2.2.4 Above ground carbon per Altitude

The result shows that at lower altitude large amount of carbon was stored at altitude with elevation of (1870 m a.s.l) which contain high DBH plant species most of them were greater than16 cm in the third class and the lower carbon shows the result of first class with 5-10 cm DBH (figure 8). Generally from this figure the carbon content of different plot shows different result and the result shows not clear pattern.

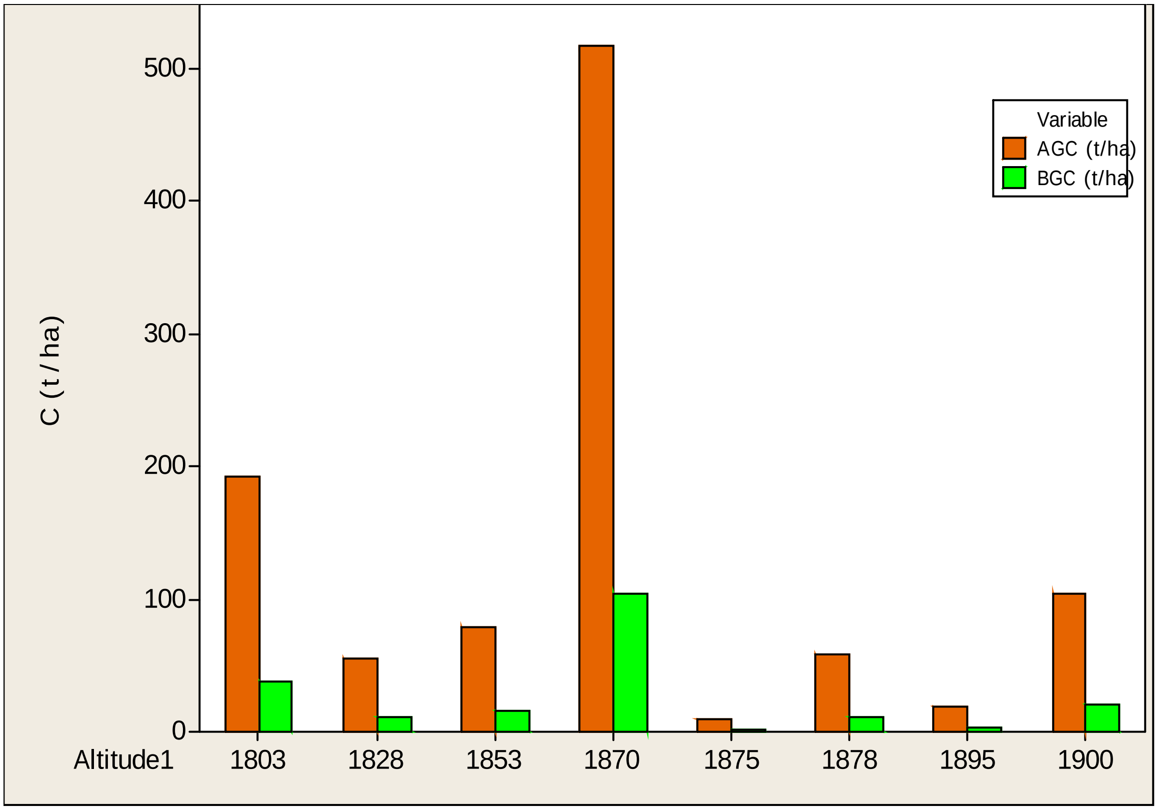


Figure 8 Mean carbon stock at lower altitudinal gradient (1803-1902) study area

The result from the higher altitude of (1903-2136) study area also shows unpattern variation between plots.

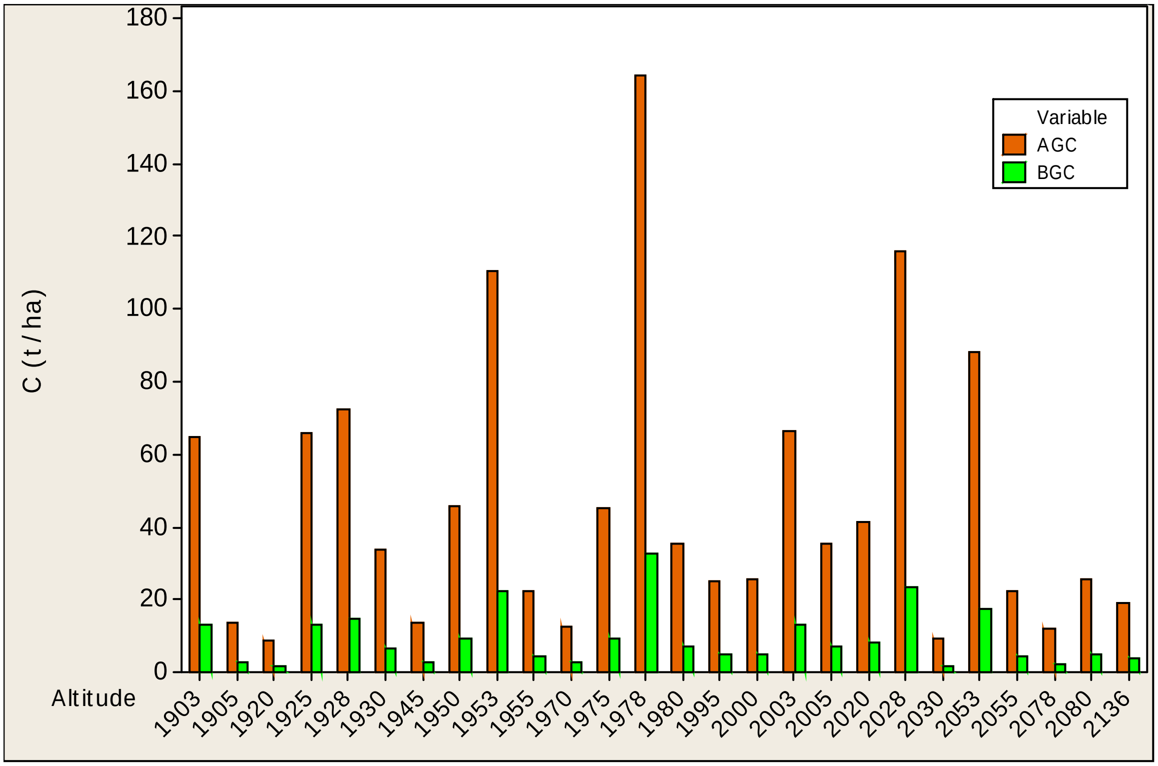


Figure 9 Mean carbon stock of higher altitudinal gradient (1903-2136) study area

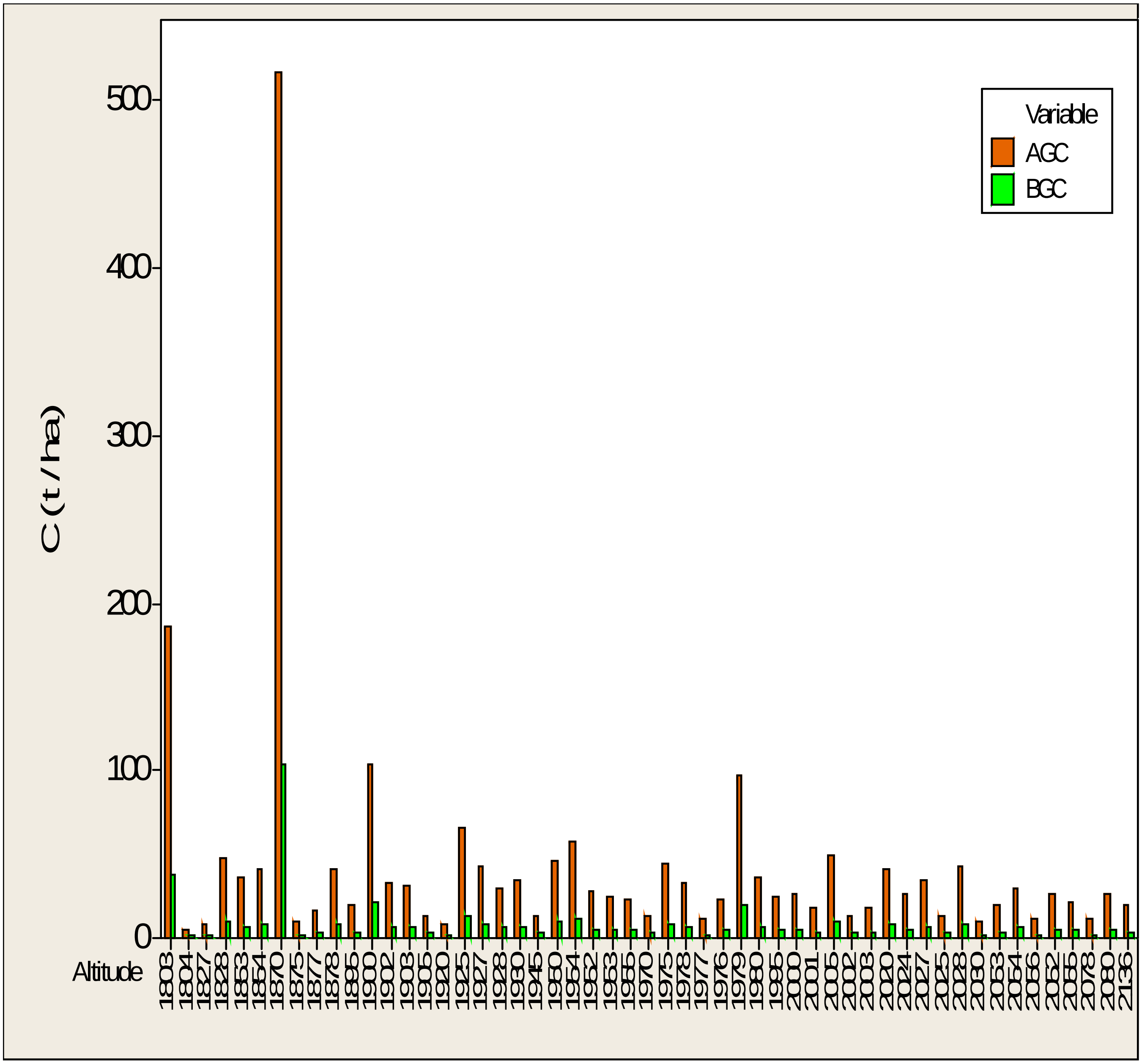


Figure 10 The Mean total carbon stock distribution based on elevation (1803-2136) of study area.

4.2.2.5 Carbon stocks of different pools and aspect

Depending on the result showed in table 7 below the mean AGC stock was lowest in Gentle (without aspect) (5.13 ton/ha) and highest in North (58.80 ton/ha). But other values was observed for carbon stocks in below ground carbon pool with the highest value in Gentle direction (12.05 ton/ha) and lower value South direction (3.56 ton/ha). On the other hand, the highest carbon stocks in litter biomass was recorded in the North, South and West (0.02 ton/ha) and the minimum carbon stock was recorded in East and Gentle (0.01 ton/ha) direction (Table 7). Totally, for all pools the highest carbon stock was recorded in North aspect (70.62 ton/ha) and the minimum carbon stock recorded was in the Gentle (17.21 ton/ha) aspect. Finally, the carbon stock value of each aspect from highest to lowest was put as follow: North > West > East > South > Gentle (no aspect**).**

Table 7 The Mean carbon stock t/ha of different pools in different Plots and aspects

Aspect	**Plot number**	**Above ground carbon**	**Below ground carbon**	**Litter biomass**	**Litter carbon**	**Total carbon stock**
S	5	17.19	3.56	0.03	0.02	20.80
E	4	22.90	4.58	0.02	0.01	27.51
N	24	58.80	11.76	0.04	0.02	70.62
W	20	31.19	6.24	0.05	0.02	37.50
Gentle (without aspect)	1	5.13	12.05	0.02	0.01	17.21

4.2.2.6 Disturbance effect on Carbon stock with Aspect

Based on the result from observation of study area (Table 8) indicated that there were different kinds of disturbances which affected the carbon storage of the woodland vegetation. Charcoal production, Cutting, Grazing, and agricultural expansion were one of the most disturbances found in all plot and in all aspects. Gentle (without aspect) part was one of the most speciously disturbed and South, West and North were more or less disturbed. Even though, cutting and grazing were the serious problem it was low in East and West.

Table 8 The level of disturbances in different aspect (South (S), East (E), North (N), West (W), Gentle (without aspect)).

Level of disturbances	**No of plot**	**Disturbance type**	**Aspect**				
			Gentle	**S**	**E**	**W**	**N**
			Plot	Plot	Plot	Plot	Plot
Very high	11	Cutting, Grazing, Charcoal production,	1	3	1	3	3
High	15	Cutting, Grazing, Charcoal production, Agricultural expansion			2	7	6
Medium	23	Cutting, Grazing, Charcoal production and		1	2	11	9
Low	5	Grazing, Small cutting, Charcoal		1			4

Table 9 Values of significance for one-way ANOVA between the altitudinal gradients for above ground carbon, below ground carbon and litter carbon stock. The variation of a mean carbon stock in relation to altitude, aspect and disturbances where not statistically significant at (P›0.005).

Carbon Pools	**F- value**	**P-value**	**Gradient**
Above ground carbon	6.630	0.013	Altitude
Below ground carbon	6.630	0.013	
Litter carbon	1.110	0.297	
Above ground carbon	0.680	0.612	Aspect
Below ground carbon	0.680	0.612	
Litter carbon	1.200	0.299	
Above ground carbon	0.940	0.428	Disturbances
Below ground carbon	0.940	0.428	
Litter carbon	1.960	0.132	

Bold values are significant at α=0.005 (95%)

CHAPTER FIVE

5 DISCUSSION, CONCLUSION, RECOMMENDATIONS

5.1 Discussion

5.1.1 Previous studies on Woodland Carbon sequestration

Mountain Dirki woodland vegetation, like other vegetation types, has spatial carbon storage variability because of variations in growth conditions and possibly species composition. However, differences in approaches to data collection like the use of larger (1 ha) plot, i.e. small or larger, analysis techniques such as the use of several allometric models and different micro climates at different sites could be the cause of this variation (Shirima *et al*., 2011). According to Brown (2003), equations used in carbon estimates can result in different outputs depending on input variables, vegetation type and geographical location from which the model was originally developed.

When it was compared with other studies, the mean carbon stock in above and below ground biomass of Mountain Dirqi woodland vegetation was higher than those reported from Miombo woodland in Tanzania (Saw *et al.*, 2014), Miombo woodland in Zambia (Shirima *et al.*, 2011) and Miombo woodland in Mozambique (Ribeiro *et al.*, 2013). But the result which were reported from Miombo woodland in Zambia (Shirima *et al.*, 2011), were similar with the present study result. However, this result is comparable to those reported for the global above ground carbon stock in tropical dry and wet forests that range between 13.5-122.85 t ha-1 and 95-527.85 t ha-1, respectively (Murphy and Lugo, 1986); cited in Belay Melese *et al.* (2014). But while it was comparing with Ethiopian forest it was much less than Arba Minch Ground Water Forest (Belay Melese *et al.*, 2014), Selected Church Forest (Tulu Tolla, 2011). The reason for having higher carbon stock density than other African woodland were that of the study area woodland was mixed with tree species of dry afromontane forest like *Olea europaea, Carissa spinarium* and there was some remnant trees like *Ficus vasta*, *Podocarpus falcatus, Syzgiume guiensee* and *Prunus africana* with high DBH range and the altitude of the study area was higher (1800-2100 m) than that of the Africa study woodlands (300-1700 m) but lower than that of other studied woodland in Ethiopia (> 2200 m) that may be made variation of result by affecting the nature of species (Table 10).

Brown and Lugo (1982), stated that, litter fall in dry tropical forests range between 2.52- 3.69 t ha-1/year. Compared with other studies, the mean carbon stock in litter biomass in the studied woodland vegetation was much less than those reported from Miombo woodland in Mozambique (Ribeiro *et al*., 2013) and Menagasha Suba State Forest dry afromontane forest (Masfin Sahile, 2014). Due to different factors like the rate of decomposition which is governed by climatic factor like temperature and moisture there were variations of carbon stock content. Also the amount of litter fall and its carbon stock of the woodland can be influenced by the woodland vegetation (species, age and density) and climate (Fisher and Binkly, 2000). Since the study area is composed of shrubby plants, litter fall intensity also decreased in the area in addition at some season the part of the woodland vegetation area is dry and it may have lost its leaf due to high temperature and also dominant plant species like, *Bersama abyssinica, Clausena anisata, Maytenus arbutifolia, Premna schimprei, Acacia abyssinica, Calpurnia aurea, Syzygium guineense* subsp. *guineese, Rhus natalensis, Carissa spinarum, Albizia schimperiana, Grewia ferruginea, Rhus vulgaris, Osyris quadripartita, Olinia rochetiana, Rytigynia neglecta* and *Millettia ferruginea* to control their moisture content which contributed less litter for the study area. The comparatively low quantities of Carbon stored in litter carbon stock in the studied forest may be due to the high decomposition rate as reported in a 10-year study by Tang *et al.* (2010). Because of disturbances from grazing, sparsely populated plant species and charcoal production the lower part of altitude litter carbon stock was lower than higher altitudinal gradient.

Table 10 Comparison of carbon stock (t ha-1) of the present result with other previous studies (Above ground carbon, Below ground carbon and Litter carbon).

Study area	Above ground carbon t/ha	Below ground carbon	Litter carbon	Total carbon t/ha
Mountain Dirki woodland (present study)	41.25	8.25	0.01	49.51
Miombo woodland in Tanzania (Nyanganje) (Saw *et al*., 2014)	30.70	-	-	30.70
Miombo woodland in Zambia (Shirima *et al*., 2011)	39.60	-	-	39.60
Miombo woodland in Mozambique (Ribeiro *et al*., 2013)	29.88	-	0.03	29.91
Arba Minch Ground Water Forest (Belay Melese, 2014)	414.70	83.48	1.28	499.46
Selected Church Forest (Tulu Tolla, 2011)	122.85	25.97	4.95	153.77

5.1.2 Comparison of DBH with carbon stock estimation

Comparison of the ranges of tree diameters with respect to the above ground biomass accumulation revealed that tree species with lower range of diameter possess more density but accumulated less biomass. On the other hand, trees having bigger diameters were few in number but accumulated more biomass. Therefore, an inverse relationship was seen between tree density and DBH whereas a direct relationship was observed between the above ground biomass and DBH. In this regard, the findings from Terakunpisut *et al*. (2007); Juwarkar *et al*. (2011); cited in Binyam Alemu (2014), indicate similar results with the current study. Trees during their initial stages of growth i.e. when their DBH is smaller could sequester less carbon but gradually increases in DBH and would accumulate more carbon. Moreover, it has been observed the younger trees grow much faster as compared to older ones. Thomas (1996) suggested that fast growing tree species are expected to have higher growth rates, and may accumulate large amounts of carbon in the first stage of their lifespan while the high specific gravity of slower-growing species allows them to accumulate more carbon in the long-term.

5.1.3 Environmental factors affecting the carbon stocks of different pools

From different environmental factors which affected the carbon storage of different pools in the study area altitudinal gradient, slope, disturbance and aspects were some of major ones. Many environmental factors (e.g. temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity) change systematically with altitude. Therefore, altitudinal gradients are among the most powerful "natural experiments" for testing ecological and evolutionary responses of biota to environmental changes (Cui *et al.,* 2005; Fang *et al.,* 2004; Korner, 2007).The carbon stocks of the study woodland vegetation were highest at the lower altitudinal range decreasing of the elevation and lowest at higher altitudinal gradient with increasing of elevation. This may be due to the absence of matured large trees at higher altitude and lower altitudinal gradient was surrounded by a river and there were some big trees at the end of the woodland vegetation site and possibly also due to the favorable conditions for tree growth in the lower part. The upper part of the woodland was dominated by shrubs and secondary vegetation, and there were a low number of mature trees.

The highest carbon stock was found in the northern aspect and the least in the gentle part of the woodland vegetation which was perhaps due to the availability of moisture, and seeing protected by the river that surrounded it, matured vegetation (dense) and fertile soil in the northern part and less moisture, scattered tree, shrub dominance, rocky habitat and infertility of soil in gentle part. According to different previous works (Luo *et al*., 2005; Alves *et al.*, 2010), it also reported that, altitude has been known to have a major impact on the diversity, biomass and carbon stock in the forest ecosystems. In different studies, in other parts of the world, it has been reported that the result of above and below ground tree biomass and its carbon stock decline with an increase in altitude (Luo *et al*., 2005; Zhu *et al.*, 2011), which were agree with the present findings from Mountain Dirqi Woodland vegetation.

5.1.4 Disturbance and carbon stock estimation

Disturbances are the main drivers altering forest structure, creating landscape mosaics, and setting the initial conditions for successional dynamics and structural development (Swanson *et al.,* 2011). Human modified woodlands are increasingly prevalent in the tropics (Broadbent *et al.,* 2008; Melo *et al.,* 2013), hence understanding the effects of human disturbances on woodland carbon stocks is crucial for better practices of woodland management and conservation measures. In this study, there were human disturbances like cutting, charcoal production, grazing and agricultural practices that affected the above ground carbon stock of the woodland which was similar with previous study. So, the disturbances of the study area were insignificant. The spatial pattern of woody biomass described above is subject to frequent and widespread disturbances (Frost, 1996) that reduce biomass: primarily clearance for agriculture (Williams *et al*., 2008), charcoal production (Brouwer & Falcao, 2004, Falcao, 2008) and fire (Ryan & Williams, 2010) and the interactions of all these effects. In this study disturbances has direct relation with the result of carbon with all carbon pools (Above ground carbon, below ground carbon and, litter carbon), i.e. for all the study area where there were disturbances there was low carbon and this true for different aspect studied for present study.

Various natural or human induced disturbances exert profound impacts on global woodland. According to a recent global assessment, more than 60% of the world's 4 billion ha of forest are recovering from a past disturbance and 3% of the world's forests are disturbed annually by logging, fire, pests, or weather (FAO, 2006). Agricultural expansion has been the most important proximate cause of recent woodland loss, accounting for 80% of deforestation worldwide, primarily during the 1980s and 1990s through conversion of tropical forests (Gibbs *et al*., 2007; Houghton, 2007). In this study the impact of agricultural expansion were significant for woodland degradation and Climate change, induced by anthropogenic GHG emissions (IPCC, 2007), is becoming another important factor that shapes woodlands globally (Walther, 2010) which were similar with the present study.

According to (Brown, 1997; Achard *et al*., 2004) Ethiopia have a potential of forest carbon stock about 168 Mt C. Gibbs and Brown (2007) also estimates the potential of Ethiopia forest carbon stock at national level 867 Mt C. There is high carbon stock in the woodlands than other forest categories; this is because there is higher area coverage i.e. 29.55 Mha in the woodlands of Ethiopia (Yitebitu Moges *et al*., 2010). So, the recent study agrees with the result cited in Yitebitu Moges *et al*. (2010) that has higher result than the woodland studied in other African country.

5.2 Conclusion

From this study, it has been found that woodland vegetation contains various diverse woody plant species. A total of 86 woody species of 39 families with stem number of 4188 plants were collected, of which *Clausena anisata* family Rutaceae was the dominant and *Podocarpus falcatus* family Podocarpaceae was the least dominant in the study site. The densities of tree species decreases as the DBH and height classes increased in the woodland vegetation. This implies that, the predominance of small sized tree species in the higher classes than in the lower classes. The analysis of these two parameters in the study woodland indicated that higher percentage of number of tree species in the lower than in the upper frequency classes. The carbon stocks of the study area showed a variation among the plots due to the presence of high biomass plants in some plots and low biomass in other plots due to some remnant primary vegetation.

The average carbon stocks of the different carbon pools of this study was lower than most research done in Ethiopia, most of which was related to dry afromontane forest carbon sequestration potentials of forests while the carbon stock was higher than the result of similar woodlands in report by other researchers in other African countries even if the nature of the woodlands were different. The presence of high carbon stocks in the study forest indicates its potentials in the mitigation of climate change. The lower parts of altitude was high in above ground and below ground carbon stocks while the upper parts of altitude had low carbon stock in carbon pools due to the fact that there were species with high DBH and high biomass vegetation cover in the lower altitudinal range like *Ficus vasta* and *Syzgiume guiensee*. On the contrary, the litter carbon stock was similar in the upper and lower parts of gradient, due to the uniformity of vegetation coverage through the whole vegetation and the decomposition ability of litter due to high temperature.

The mean above ground carbon and below ground carbon stocks were lowest in gentle and southern part respectively but highest in northern and gentle parts respectively. In other cases, the highest carbon stocks in litter biomass were recorded in the northern, western and southern part equally and the minimum carbon stock was recorded in eastern and gentle aspects, due to the vegetation character and disturbances level of the aspect. Generally, the carbon stocks in the different pools were placed in this order northern, western, eastern, southern and gentle were ranked from highest to lowest respectively with their potential carbon content. The ANOVA result showed that at 95% confidence interval, the carbon stocks in the different carbon pools (Above ground carbon, below ground carbon and litter carbon) were different due to environmental factors (Aspect, Altitude and disturbances)

5.3 Recommendation

The Mountain Dirki woodlands are important for storage of carbon, soil protection/conservation and different ecological services. However, the Mountain Dirki woodlands are facing a variety of threats, including illegal tree harvesting, destructive fuel wood collection, uncontrolled (charcoal burning, cutting and free grazing), and agricultural practices with settlement around and near the woodland vegetation. In the long term, these threats, if not removed, will contribute to diminished quantities of Carbon stored in this woodland system.

Thus, improving the management of Mountain Dirki woodlands in ways that reduce or eliminate the mentioned threats could result in improvements in above ground carbon storage that would contribute to regional and global climate change regulation.

So, based on the findings of this study the following recommendations were made for mountain Dirki woodland vegetation.

1. Creating awareness at all levels of the society how to use the woodland resource properly with respect to environmental, socio and economic benefit.
2. Try to applying Participatory forest management (PFM), which would influence the growth of Mountain Dirki woodlands, reverses the deforestation and woodland degradation, and therefore has potential for carbon storage and sequestration. However, the existing socio economic and ecological potentials in Mountain Dirki woodlands need to be further examined for their sustainability.
3. Despite Mountain Dirki woodlands showing potential for carbon storage and sequestration, yet local communities' dependence on the resource is significant. The efforts should be on promoting PFM while optimizing trade-offs between multiple functions of Mountain Dirki woodland products for local livelihoods and climate change mitigation. Carbon credits resulting from the increased carbon stock and sequestration should contribute to sustainable development. This should also help to safe Dirki woodlands products and services upon which thousands of people depend.

4. The amount of carbon sequestered in this study site was significant. In Ethiopia, there are large woodlands conserved in different parts of the country so conducting similar research on those resources to would benefit the local people and the country.
5. The carbon stock sequestered in some carbon pools in the present study site is significant so considering all carbon pools (soil carbon) during carbon estimation is recommendable.
6. The potential role of woodland in sequestrating carbon to reduce the buildup of greenhouse gases in the atmosphere is now well recognized. Adequate understanding on climate change issues and more powerful methods to implement cost/benefit analyses of woodland based GHG mitigation and livelihood improvement to define incentives for wide scale adoption of the protection of the woodlands should be implemented.
7. Finally, promotion of collaboration among local communities and government, to encourage knowledge and understanding of woodland/forest conservation and to find methods for rehabilitation of the degraded forests will help increase the potentiality of the woodlands as a carbon sink to meet the challenge of global climate change and to get benefit from the preserved forests.
8. For highly threatened species the government should give due attention and plant and replace it in the woodland with awareness creation for the local community for their threatening.
9. Mountain Dirki woodlands are facing a variety of threats, including destructive fuel wood collection, uncontrolled (charcoal burning, cutting and free grazing), and agricultural practices with settlement around and near the woodland vegetation must be controlled and managed with the supply of energy save materials and preparation of biogass for the society around and near the woodland vegetation. Free grazing and extensive farming system should must be replaced by cut and carry system with the use of modern cattle and intensive farming system should must be adopted and applied for the surrounding community to save the woodland from degradation.

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APPENDIXES

Appendix 1 Tree Data Collection Form

Recorder: ______________________________ Date: ______________________

Stratum: ______________________________

Plot no: ____________________

Location: N _____________ E ______________

Altitude (m a.s.l.): ____________

Soil type: _______________________

Local Name	Scientific Name	DSH (cm)	DBH (cm)	Total height (m)	Remark

Appendix 2 Herb, Litter and Soil Sample Form

Stratum:____________________Plot no: ______________________________________

Location: N _____________ E ______________ Altitude (m a.s.l.):_________________

Stratum and plot no	Sample type	Fresh weight (g/m2)	Sample fresh weight gram(g)

Appendix 3 List of woody plant species ≥ 5 cm DBH identified from Study area (T= Tree, S= Shrub and L=Liana).

No	**Local name**	**Scientific name**	**Habit**	**Family name**
1	Arangamaa	*Pterolobium stellantum* (Forssk.) Brenan	L	Fabaceae
2	Bakkanniisa	*Croton macrostachyus* Del.	T	Euphorbiaceae
3	Ceekaa	*Calpurnia aurea* (Ait.) Benth.	*S*	Fabaceae
4	Daalachoo	*Olinia rochetiana* A.Juss.	*T*	Oliniaceae
5	Gambeela	*Gardenia ternifolia* Schumach. &Thonn.	*T*	Rubiaceae
6	Hidda hoomachoo	*Helinus mystacinus* (Ait.) E. Mey. ex Steud.	*L*	Rhamnaceae
7	Imalaa	*Albizia schimperiana* Oliv.	*T*	Fabaceae
8	Kombolcha	*Maytenus arbutifolia* (A.Rich.) Wilczek	*S*	Celastraceae
9	Koshommii	*Dovyalis abyssinica* (A. Rich.) Warb.	*T*	Flacourtiaceae
10	Lolchiisaa	*Bersama abyssinica* Fresen.	*T*	Melianthaceae
11	Mi'eessaa	*Euclea divinorum* Hiern	T	Ebenaceae
12	Rukeessa	*Combretum adenogonium* Steud. exA. Rich.	*T*	Combartaceae
13	Ulmaayii	*Clausena anisata* (Willd). Benth.	*T*	Rutaceae
14	Urgeessaa	*Premna schimperi*	*S*	Lamiaceae
15	Waatoo	*Osyris quadripartita* Decne	*T*	Santalaceae
16	Xaaxessaa	*Rhus natalensis* Krauss	*T*	Anacardiaceae
17	Abbayyii	*Maesa lanceolata* Forssk.	*T*	Myrsinaceae
18	Agamsa	*Carissa spinarum* L.	*T*	Apocynaceae
19	Dhoqonuu	*Grewia ferruginea* Hochst.ex A. Rich	*T*	Tiliaceae
20	Laaftoo qola adii	*Acacia abyssinica* Hochst. ex Benth	*T*	Fabaceae
21	Qana'ee	*Schrebera alata* (Hochst.) Welw.	*T*	Oleaceae
22	Baddeessaa	*Syzygium guineense* (Willd.) DC.	*T*	Myrtaceae
23	Botoroo	*Stereospermum kunthianum* Cham.	*T*	Bignoniaceae
24	Qawwisa	*Nuxia congesta* R.Br. ex Fresen.	*T*	Loganiaceae
25	Xaxessa fakkaata	*Rhus vulgaris* Meikle	*T*	Anacardiaceae
26	Ejersa	*Olea europaea* L. subsp. *Cuspidata* (Wall.ex G.Don) Cif.	*T*	Oleaceae
27	Ilkee	*Diospyros abyssinica* (Hiern) F. White	*T*	Ebenaceae
28	Somboo	*Ekebergia capensis* Sparrm.	*T*	Meliaceae
29	Akuukkuu	*Flacourtia indica* (Burm.f.) Merr	*T*	Flacourtaceae
30	Cayii	*Celtis africana* Buerm.f.	*S*	Ulmaceae
31	Gaafatoo	*Senna ptersiana (Bolle) Lock*	*S*	Fabaceae
32	Sarxee	*Dalbergia lactea* Vatke	*S*	Fabaceae

N<u>o</u>	Local name	Scientific name	Habit	Family name
33	Buruurii	*Vangueria apiculata* K. Schum.	*T*	Rubiaceae
34	Hidda Indirifaa	*Rhoicissus revoilii* Planch.	*C*	Rhamnaceae
35	Kombolcha adii	*Scutia myrtina* (Burm. f.) Kurz	*S*	Rhamnaceae
36	Waddeessa	*Cordia africana L.*	*T*	Boraginaceae
37	Dambii	*Ficus thonningii* Blume	*T*	Moraceae
38	Sarara	*Allophylus macrobotrys* Gilg	*T*	Sapindaceae
39	Meexxii	*Phoenix reclinata* jacq.	*H*	Arecaceae
40	Odaa	*Ficus sycomorus L.*	*T*	Moraceae
41	Sootalloo/Birbirra	*Millettia ferruginea* (Hochst.) Bak.	*T*	Fabaceae
42	Daannisaa	*Dombeya torrida* (G.F. Gmel.) P. Bamps	*T*	Sterculiaceae
43	Hidda baggii	*Combretum paniculatum* Vent.	*L*	Combretaceae
44	Arangamaa qamalee	*Capparis tomentosa Lam.*	*S*	Capparidaceae
45	Bosoqa	*Sapium ellipticum* (Krauss) Pax.	*T*	Euphorbiaceae
46	Gagamaa	*Olea capensis* L. subsp. *macrocarpa* (C.H. Wright) Verdc.	*T*	Oleaceae
47	Qacamoo	*Phyllanthus ovalifolius* Forssk.	*S*	Euphorbiaceae
48	Qolaatii	*Mimusops kummel* A. DC.	*T*	Sapotaceae
49	Qawwisa	*Buddleja polystachya* Fresen.	*S*	Loganiaceae
50	Qumbaala/Calalaqa	*Apodytes dimidiata* E. Mey. Ex Am.	*T*	Icacinaceae
51	Gaarrii	*Hymenodictyon floribundum (Hochst.* & *Steud.)*	*T*	Rubiaceae
52	Rukeessa	*Combertum molle* R. Br. Ex G.Don	*T*	Combertaceae
53	Birbirsa	*Podocarpus falcatus* (Thunb.) R.B. ex. Mirb.	*T*	Podocarpaceae
54	Hadheessa	*Teclea nobilis* Del.	*T*	Rutaceae
55	Qaqawwii	*Rosa abyssinica* Lindley	*S*	Rosaceae
56	Ibicha	*Vernonia amygdalina* Del.	*T*	Asteraceae
57	Hinnee	*Hypericum quartinianum* A. Rich.	*T*	Guttiferae
58	Agiraabaa	*Bridelia micrantha* (Hochst.) Baill.	*T*	Euphorbiaceae
59	Dabaqqaa	*Terminalia macroptera* Giull & Perr.	*T*	Combretaceae
60	Gaarrii	*Terminalia schimperiana* Hochst.	*T*	Combretaceae
61	Ittacha	*Dodonaea angustifolia L. f.*	S	Sapindaceae
62	Bunittii	*Galiniera saxifraga* (Hochst.) Bridson	*S*	Rubiaceae
63	Mixoo	*Rytigynia neglecta* (Hiern) Robyns	*S*	Rubiaceae
64	Qadiidaa	*Rhamnus staddo* A.Rich.	*T*	Rhamnaceae
65	Harbuu	*Ficus sur* Forssk.	*T*	Moraceae

No	Local name	Scientific name	Habit	Family name
66	Laanqisaa	*Urera hypselodendron* (A.Rich,) Wedd.	*L*	Urticaceae
67	Qilinxoo	*Ficus mucuso Ficalho.*	T	Moraceae
68	Sokorruu	*Achantus sennii* Chiov.	*S*	Acanthaceae
69	Bururii	*Vangueria apiculata* K. Schum.	*T*	Rubiaceae
70	Qacama	*Myrsine africana L.*	*S*	Myrsinaceae
71	Reejjii	*Vernonia myriantha* Hook.f.	*T*	Asteraceae
72	Karra waayyuu	*Chionanthus mildbraedii* (Gilg & Schellenb.)	*T*	Oleaceae
73	Laaftoo	*Acacia persiciflora Pax*	*T*	Fabaceae
74	Acaacii	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	*S*	Celastraceae
75	Qola-gurraa	*Rothmannia urcelIiformis* (Hiem) Robyns	*T*	Rubiaceae
76	Kombolcha	*Maytenus obscura* (A. Rich.) Cuf.	*T*	Celastraceae
77	Qaqaroo	*Gnidia involucrata* Steud. exA. Rich.	*S*	Thymelaeaceae
78	Ilkee	*Diospyros abyssinica* (Hiern) F. White	*T*	Ebenaceae
79	Qilxuu	*Ficus vasta* Forssk.	*T*	Moraceae
80	Ambaltaa	*Entada abyssinica* Steud. ex A. Rich.	*T*	Fabaceae
81	Doddota	*Acacia etbaica* Schweinf.	*T*	Fabaceae
82	Qarxammee	*Allophylus africanus* P. Beauv.	*S*	Sapindaceae
83	Ulaagaa	*Ehretia cymosa Thonn*	*T*	Boraginaceae
84	Gambeela	*Gardenia volkensii* K. Schum. subsp. *volkensii* var. *volkensii*	*T*	Rubiaceae
85		*Combretum nigrican* Lepr. ex Guill. & Perr.	*T*	Combretaceae
86		*Combretum collinum* Fresen.	*T*	Combretaceae

Appendix 4 Above ground biomass estimation models suggested by different literatures for tropical forests using regression equations of biomass as a function of DBH.

Author	**Equations**	**Restrictions: DBH and climate based on annual rainfall**
Winrock (from Brown, Gillespie and Lugo, 1989)	(Winrock -1) Y = 34.4703 - 8.0671 DBH + 0.6589 DBH^2 R2 = 0.67	DBH ≥ 5 cm Dry (rainfall < 1 500 mm)
FAO	(FAO-1) Y = exp{-1.996 + 2.32 × ln(DBH)} R^2 = 0.89	5 < DBH < 40 cm Dry transition to moist (rainfall > 900 mm)
FAO	(FAO -2) Y = 10 ^ (- 0.535 + log10 (p × r2)) R2 = 0.94	3 < DBH < 30 cm Dry (rainfall < 900 mm)
FAO	(FAO -3) Y = exp{-2.134 + 2.530 × ln (DBH)} R2 = 0.97	DBH < 80 cm Moist (1 500 < rainfall < 4 000 mm)
Winrock (from Brown, Gillespie and Lugo, 1989)	(Winrock-DH) Y = exp{-3.1141 + 0.9719 × ln[(DBH2)H]} R2 = 0.97	DBH > 5 cm Moist (1 500 < rainfall < 4 000 mm)
Winrock (from Brown Gillespie and Lugo, 1989)	(Winrock-DHS) Y = exp{-2.4090+ 0.9522 × ln[(DBH2)HS]} R2 = 0.99	DBH > 5 cm Moist (1 500 < rainfall < 4 000 mm)
Luckman	*Y* = (0.0899((DBH2)0.9522) × (H0.9522) × (S0.9522))	Not specified

Declaration

I, the undersigned declare that this Thesis is my original work and it has not been presented in other universities, colleges or institutes for a degree or other purpose. All sources of materials used have been duly acknowledged

Name: Deresa Abetu   Signature ___________________   Date____________________

This Work has been done under my/our supervision

Name: ____ Signature _________________________

Name: ____ Signature _________________________