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Carbon Stock of Banja Forest in Banja District, Amhara Region, Ethiopia: An Implication for Climate Change Mitigation

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By

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Abstract

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Fentahun Abere Tamene

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Forests play enormous role in combating climate change, the most pressing global issue currently, by sequestering and storing carbon from the atmosphere through photosynthesis. This study was conducted to estimate of carbon stock in dry Afromontane forest type of Banja Forest with elevation that ranges between 1870 and 2570 m a. s. l. in Amhara Region, Ethiopia. The study was aimed to explore the potential of climate change mitigation from carbon stock of Banja Forest. A systematic sampling method was used to identify each sampling point through Global Positioning System (GPS). Loss on ignition and Walkley Black method were used to estimate biomass and soil carbon stock, respectively. Results revealed that the total carbon stock of the forest was 639.87 t/ha whereas trees store 406.47t/ha, litter, herbs and grasses (LHGs) 2.58 t/ha and soil 230.82 t/ha (up to 30cm depth). The carbon pools' carbon stock variation with altitude, slope and aspect gradients were not significant at ($p>0.05$). The forest in the study area is a reservoir of high carbon, as it has a good capacity to sink carbon from the atmosphere. To enhance the carbon stock of Banja Forest, it should be integrated with Clean Development Mechanism (CDM), carbon trading system of the Kyoto Protocol.

Keywords: Banja Forest, Carbon sequestration, Climate change, carbon stock, Mitigation

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AGB	Aboveground biomass
AGC	Aboveground carbon
ARARI	Amhara Region Agriculture Research Institute
BGB	Belowground biomass
BGC	Belowground carbon
CDM	Clean Development Mechanism
CRGE	Climate-Resilient Green Economy
DBH	Diameter at breast height
DMU	Debre Markos University
GHGs	Greenhouse gases
GPS	Global positioning system
IPCC	Intergovernmental Panel on Climate Change
LHGs	Litter, herbs and grasses
LOI	Loss on ignition
NOAA	National Oceanic and Atmospheric Administration
REDD+	Reducing emissions from deforestation and forest degradation + Conservation of forests + Sustainable forest management + Enhancing forest carbon stock
SOC	Soil organic Carbon
TAGB	Total above-ground biomass
TAGC	Total above-ground carbon
TBGB	Total below-ground biomass
TBGC	Total below-ground carbon
TC	Total carbon
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER ONE

INTRODUCTION

1.1. Background

Forests play an important role in global climate change regulation. The potential of forests in naturally sequestering carbon out of the atmosphere which is important for climate change mitigation was recognized by international climate agreements (IPCC, 2007a). Currently, there is great interest in assessing forest carbon stock (Djomo *et al*., 2016; Gibbs *et al*., 2007); since forests are cleared the carbon is converted to carbon dioxide in the atmosphere (Condit, 2008) which is the cause of global climate change at one hand and reduction of forest cover on the other hand. Forests cover just over four billion hectares, 31% of the world‟s total land area and world‟s forests store 289 gigatone of carbon in their biomass alone (FAO, 2011 in UNEP, 2012). According to FAO (2015), the forest cover of Ethiopia declines from 13.78 to 11.40% in 1990 and 2015 respectively of having widespread deforestation. The average annual deforestation rate is about one percent which is high compared to other Sub-Saharan African countries (0.8%) (FAO, 2010). African forest constitute 21% of global total of carbon stock in forest biomass and have the ability to sequester up to 630kg of carbon per hectare per year, thereby providing critical shock absorber against global climate change (Katerere *et al.,* 2009). The aboveground carbon pools of tropical forests in their natural condition contain more carbon per unit area than any other land cover type. 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, but aboveground carbon storage in natural forest is higher than that in any other vegetation (Genene Assefa *et al.,* 2013).

The 1997 Kyoto Protocol, the first major international agreement on climate change, recognized forests playing an important role in mitigating climate change by naturally taking carbon out of the atmosphere, thereby reducing the impact of CO_2 emissions (IPCC, 2007a; Perschel *et al.,* 2007). The response of forests to the rising atmospheric CO_2 concentrations is crucial for the global carbon cycle, and sequester and store more carbon than any terrestrial ecosystem; they store more than 80% of all terrestrial above ground carbon and more than 70% of all soil organic carbon (Jandl *et al*., 2006; Perschel *et al.,* 2007; Sundquist *et al.,* 2008). As indicated by UNFCCC (2015), forests are habitats that conserve biodiversity, reduce soil erosion, protect watersheds and sustain indigenous ways of life. They are also natural capital that enables economic growth, and they are carbon sinks that mitigate the greenhouse gas emissions that drive climate change. But, the increment of carbon in the atmosphere is one of today‟s major worry, which was addressed in the Kyoto protocol (Ravindanath *et al.,* 1997) because it is the most important causal factor for global warming (Lal, 2001). The concentration of Greenhouse gases (GHGs) in the atmosphere including CO_2 has increased considerably. Over the last century carbon is accumulating in the atmosphere at a rate of 3.5 pentagram (is 10^{15} gram or billion tones) per annum, mainly resulting from the burning of fossil fuel and conversion of forests to agricultural land (Paustain *et al*., 2000). For this reason, the recent assessment shows the world as a whole carbon stocks in forest biomass decreased by an estimated 0.5 gigatone annually during period 2005-2010, mainly because of a reduction in the global forest area (FAO, 2010). Loss of forest biomass through deforestation and forest degradation make up 12 to 20% of annual greenhouse gas emission, which is more than all forms of transport combined (Saatchi *et al.,* 2011). The ultimate result would be climate change; which is the real current problem that can impact environmental norms and populations, causing serious negative impacts internationally. To lessen the problem, IPCC (2007a) emphasized on its Fourth Assessment Report to reduce deforestation and enhance forest carbon stock as the mitigation option to store and sink the carbon emitted from clearing of forests which is taken as cost effective measure.

Climate change‟s impacts on Ethiopia are bringing many challenges due to its low adaptive capacity. The reason behind is because of its geographic exposure and complexity, low income, and great reliance on climate sensitive economic sectors particularly agriculture and pastoralism (Davies, J. and Nori M., 2008; FAO, 2016a). Rainfall is becoming increasingly erratic that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture (Edame *et al*., 2011) and droughts followed often by floods are more frequent (Edwards, 2010) which is due to rapid deforestation and degradation of land resources. Population increment has resulted in extensive forest clearing for Agricultural use, over grazing, and exploitation of existing forest for fuel wood, fodder and construction materials. Due to such reasons forest area of Ethiopia has been reduced from 40% a century ago to an estimated of 11.40% today (FAO, 2015) with significant environmental degradation. As Ethiopia is experiencing the effects of climate change such as an increase in average temperature and rainfall patterns, the Government of the Federal Democratic

Republic of Ethiopia has therefore initiated the Climate-Resilient Green Economy (CRGE) by means of protecting and re-establishing forests for their economic, ecosystem services and carbon storage in 2011. As a responsible member of the global community, Ethiopia has recognized important role that it can play in global climate change mitigation. As one of the four pillars of the Climate Resilient Green Economy (CRGE) Strategy of Ethiopia, Reducing Emissions from Deforestation and forest Degradation (REDD+) is envisaged to avoid emissions from the forest sector, while absorbing greenhouse gases from other sectors contributing to be a carbon neutral economy by 2030 (Yitebitu Moges and Eyob Tenkir, 2014). Since reducing emissions through REDD+ have the highest mitigation potential for a tropical developing countries (FAO, 2016b). Therefore, managing natural forests and enhance carbon stock is essential for absorbing large quantity of carbon enabling to generate carbon credit to meet the CRGE strategy by increasing carbon sequestration potential and conservation of biodiversity in line with improving the livelihoods of local communities.

The Banja Forest (BF) which is natural state forest and dry Afromontane forest type found in Banja district of Awi Zone, Amhara Regional State can be used to involve in the Non Timber Forest Products (NTFP) activities by the local communities, even though the forest is at the critical stage. This is due to large extent of people living close to the forest and cultivating inside it. So with the local communities incorporating the existing forest management strategies with climate change through the sequestration of carbon is more than anything in building awareness to overcome the problem. However, few researches have been conducted to measure the potentiality of forests of Ethiopia in carbon storage. Therefore, the study was aimed to measure the carbon stock potential of BF while to contribute and give some relevant information for local and regional administration, policy makers and other conservation organization on the status of the forest.

1.2. Statement of the Problem and Significance of the Study

The roles of forests nowadays is impaired by human-induced actions like deforestation and forest degradation which results loss of forest cover, loss of soil productivity, rise in global temperature, erratic rainfall, sea level rise and landslides and more frequent sever environmental disturbance more than ever before (FAO, 2010a; IPCC, 2002). The challenge of environmental degradation is primarily resulted from the day to day increment of atmospheric CO_2. Fossil fuel combustion, industrial processes, and unprecedented land use conversion have led to rising levels of CO_2 and other GHGs in the atmosphere (Perschel *et al.,* 2007). Therefore, it is considered as the global issue that large scale CO_2 emission reductions are required with strict limits on each country to what level carbon is absorbed to mitigate climate change. According to IPCC (2000) report, forests are a current focus for action since they play an important role in mitigating climate change by naturally taking carbon out of the atmosphere through photosynthesis.

As Ethiopia is also the most climate change vulnerable country, the government of Ethiopia has ratified CRGE in 2011 to achieve sustainable development by means of reconciling the environment, economic and social aspects. Keeping emissions constant by applying abatement measures in sectors such as forestry, agriculture and industry, becoming green economy frontrunner by investing into low carbon economy and reducing climate change vulnerabilities is the CRGE strategic framework to achieve the middle income status by 2025. Event though, strategic framework focuses on carbon emission management; Ethiopia does not have carbon accumulation records and databank to monitor and enhance carbon sequestration potential of different forests. Only small efforts have been done so far to assess forest carbon sequestration (Alefu Chinasho *et al.,* 2013). The deficient in scientific quantitative data produces lack of responsiveness for sound management of forests in local communities. Due to this fact, extensive clearing of existing state and community managed forests for agricultural use, over grazing, urbanization and exploitation for fuel wood, fodder and construction materials is still continued. As many of Ethiopian people living close to forests, the relationship of these people to trees and forests has not longer been emphasized as an opportunity for spreading community managed forest to improve carbon sequestration. Unless early encouragement for protection of environment has to be done, the CRGE Strategy will not be achieved as a result future will not be bright.

To lessen and prevent the problem, this study was proposed to quantify carbon storage potential of BF through examining the forest above and belowground carbon, LHGs carbon, and soil organic carbon; so as to disclose the gap present in carbon sequestration potential of the forest, and provide some relevant information for local and regional administration, policy makers and other conservation organization on the status of BF.

1.3. Objectives of the Study

The general objective of this study was to examine the existing above and belowground carbon stock and its variation along environmental variables of Banja Forest as a possibility for climate change mitigation.

The specific objectives of the study were:

- To estimate stored carbon in above and below ground of trees, LHGs, and organic soil,
- To examine the correlation of carbon stocks of different carbon pools along slope and altitudinal gradient,
- To investigate the correlation and distribution of carbon stocks of different carbon pools within aspect of Banja Forest, and
- To explore the climate change mitigation capacity of the Banja Forest.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1. Global Climate Change Overview

Global climate change is a change in either the mean state of the climate or in its variability, persisting for several decades or longer which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere; being unequivocal and representing one of the greatest environmental, social and economic challenges that lives on Earth are currently facing (IPCC, 2013). At this time, the concept of human induced climate change is accepted as reality and put at the top of the list burning issue for instance global warming, having attentions from the local pub to the stages of international higher level government fora. The current uncharted global climate change is observed due to anthropogenic greenhouse gas (GHG) emissions, principally CO_2 concentration which is rising in the atmosphere by reckless activities of fossil fuel combustion and deforestation. As a result, the natural balance of CO_2 sequestration and release that takes place between sinks and sources has been disturbed by which global net annual emission exceeds annual sequestration that is beyond acceptable level of greenhouse gases accumulation in the atmosphere and consequently, causes global climate change (IPCC, 2014a). According to IPCC report (2007a), the amount of CO_2 in the atmosphere has increased from 280 ppm in the pre-industrial era (1750) to 379 ppm in 2005, and is increasing by 1.5 ppm per year. As reported by NOAA (2016) on climate change, the level of CO_2 has reached 404.36 ppm in July 2016 record which was above historic levels (Figure 1), where the dotted red line represents the monthly mean values, centered on the middle of each month and the other line represents the same, after correction for the average seasonal cycle.

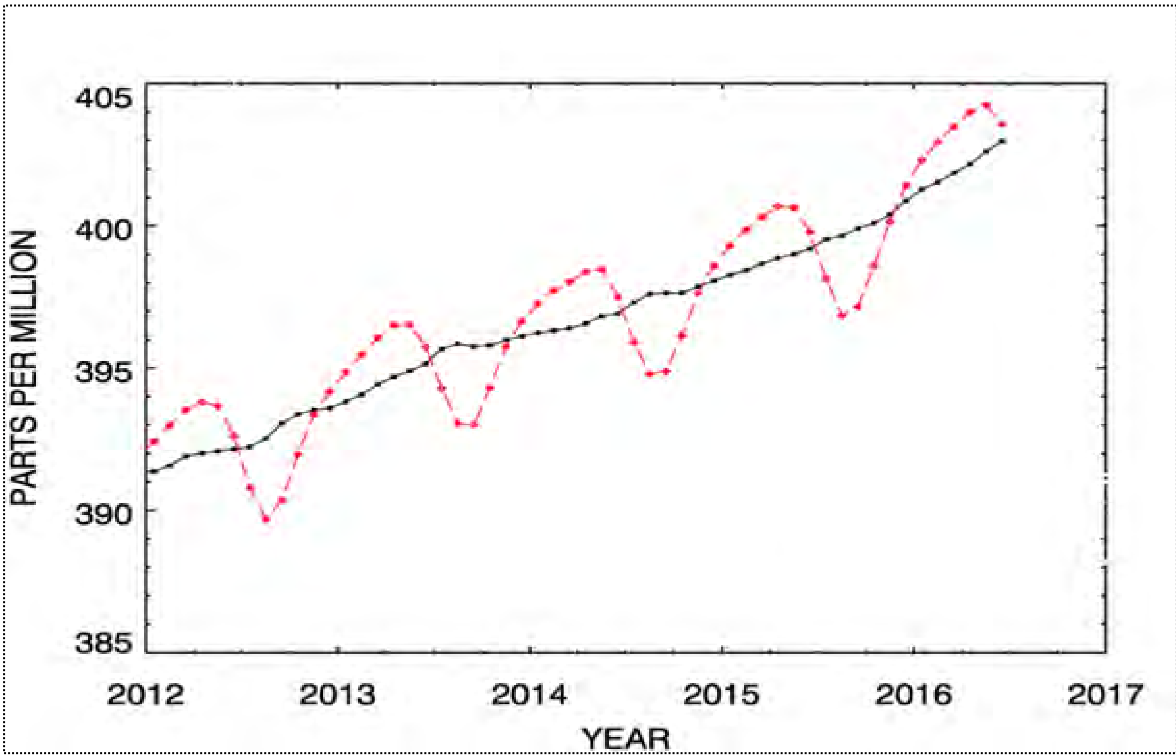


Figure 1. Recent global trends of atmospheric CO_2 (ppm)   Source: NOAA (2016)

According to IPCC (2007a) there is a discernible human influence on global climate witnessed by the global average land-ocean surface temperature (Hansen *et al*., 2016) that the increment from 1985-2015 of 31 years (Figure 2). Accordingly, there has been a clear variation of global temperature that shows global climate is changing. According to Hansen *et al*. (2016), the global surface temperature in 2015 was 0.87°C which made it the warmest year and 2006-2015 was the warmest decade on record since thermometer-based observations began.

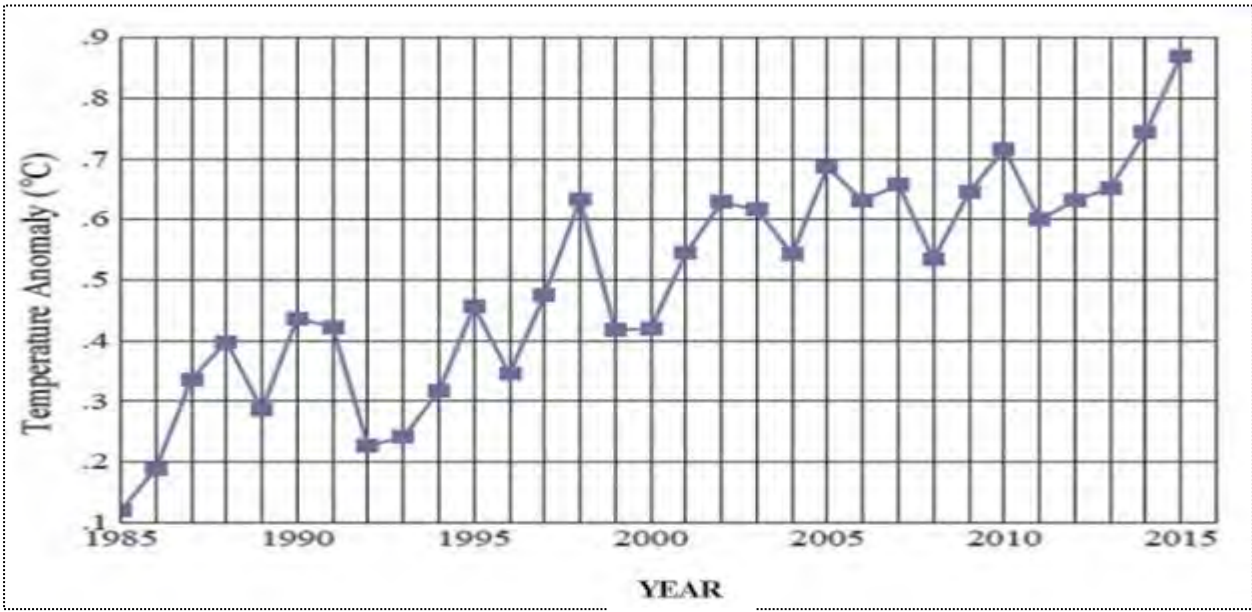


Figure 2. Global mean annual surface temperature anomaly (°C) from 1985 to 2015 of 31 years to clarify year-to-year changes. Source: (Hansen *et al*., 2016) of NOAA.

2.2. Greenhouse Gases (GHGs) and Contributions to Global Warming

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wave-lengths within the spectrum of thermal infrared radiation emitted by the Earth"s surface, the atmosphere itself, and by clouds (IPCC, 2007a) which causes the greenhouse effect that helps to maintain the Earth as a habitable planet. But at this time, greenhouse gas levels are rising and being at their highest atmospheric concentrations. Human-driven emissions of carbon dioxide and other GHGs, as well as land-use change, are the processes primarily responsible for the increase. As reported by UNFCCC, global leaders have started negotiations aiming at „stabilization of GHGs concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (IPCC, 2007a). As far as GHGs concentration have been concerned, human induced activities like fossil fuel burning for power generation, industrial manufacturing and transportation, agricultural activities like synthetic fertiliser use, livestock rearing, and change in land use patterns such as deforestation as well as waste disposal have contributed to the increased atmospheric concentration of greenhouse gases. This increase is an important contributor to climate change leading to increased global temperature and other stresses of global warming which is caused by enhanced greenhouse effect (IPCC, 2007a) of global warming. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth‟s atmosphere. In addition to these, sulphur hexafluoride (SF6) hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are human made GHGs in which the Kyoto Protocol deals with (UNEP, 2007b). Some of GHGs with their sources and contributions to global warming (IPCC, 2007a) is shown in Table 1.

GHGs	Main GHG sources	Sources (%)	Contribution to global warming (%)	Share of Annex 1 country (%)
CO_2	Fossil fuel	95	60-70	82
	Industrial processes	5		
CH_4	Fossil fuel	33	21-22	12
	Agriculture	33		
	Waste	33		
N_2O	Agriculture	40	6-7	4
	Fossil fuel	25		
	Industrial processes	35		
HFCs PFCs SF_6	Industrial processes	*	<1	2%

* Not available

Table 1. Some of greenhouse gases‟ sources and their contribution to global warming adopted from IPCC (2007a).

2.3. Impacts of Climate Change

Climate change has posed challenges discerned from local, national to international levels. The climate change impacts are most observed in developing countries where agriculture is the primary source of food like Ethiopia. The impact impedes the socio-economic and environmental developments, relaying on rain-fed agricultural systems, sensitive to climate change (FAO, 2016). It is highly affecting the development of Africa due to erratic weather patterns and climate extremes threaten agricultural production and food security, health, water and energy security. Specifically, Ethiopia in 2015 faced one of the worst droughts in thirty years caused by the El Niño climate conditions, leading to failed harvests and shortages of livestock forage (Admit Wondifraw *et al*., 2016). So such catastrophe, threaten human security and that triggers competition in basic need resources, results instabilities among nations.

2.4. International Conventions and Commitments on Climate Change Mitigation

The international community created the United Nations Framework Convention on Climate Change (UNFCCC) from the Earth Summit in Rio de Janeiro in June, 1992 to prevent dangerous climate change. Under the Convention, 194 nations agreed to protect the climate system for present and future generations according to their “common but differentiated responsibilities and respective capabilities” of climate change mitigation actions.

Climate change Mitigation refers to human intervention to reduce the sources or enhance the sinks of GHGs or any activities that reduce the overall concentration of GHGs in the atmosphere (IPCC, 2014). To reduce the impacts of global climate change, numbers of international conventions and commitments from the Kyoto Protocol in 1997 to the Paris agreement in 2015 have been done so far. The first major attempt to curb or at least stabilize GHGs emissions was made with the Kyoto Protocol in 1997, the first commitment period (2008-2012). The other recent agreement done by 196 countries was the Paris agreement**,** a new universal climate agreement negotiated by the member countries of UNFCCC in which the parties took their own non legally binding commitments of nationally determined contributions (NDC) that serve and support as road map to report their levels of GHGs emissions and sinks potential by implementing climate change mitigation actions through REDD+, especially for parties of developing countries (UNFCCC, 2015).

The Paris climate agreement held in 2015 was a milestone that recognized and incorporated different climate issues and assignments by the conference of the parties (COP21). For instance, the need to respect the rights of Indigenous Peoples and gender equality was recognized (UNSD, 1992).

The Paris agreement brought rapid entry into force in which the world‟s top two GHGs emitters that China and USA ratified the landmark climate change agreement at G20 Summit (Hangzhou, China) in September, 2016. According to Climate Scorecard (2016), France and Ukraine were the first two countries that have already ratified the agreement with high commitment ratings.

According to the global assessment done by Germanwatch and Climate Action Network Europe on the climate change performance index (CCPI), Denmark leads the ranking in 4th place while Moroco takes ranking of 10th with good and moderate ratings respectively by taking effective commitment of climate protection policies for energy efficiency and promotion of renewable energies made them role model in climate protection (Burck *et al.,* 2016).

In order to tackle or delay impacts of climate change, different mitigation measures that aim to reduce GHGs emissions have to be done (IPCC, 2000; GreenFacts, 2014). These includes efforts to switch from fossil fuels to renewable energy sources such as wind and solar, or to improve energy efficiency, plant trees and protect forests (afforestation and reforestation through REDD+), or to farm land in ways that prevent GHGs from entering the atmosphere (UNESCO, 2013).

There are also existing actions taken by the international agreements on forests with clear targets and timeframes already set out in the sustainable development goals (Goal 15) that reduces GHGs emissions. For instance, the New York Declaration on forests to restore 150 million hectares by 2020, and 200 million hectares by 2030 to reduce deforestation and enhance forest carbon stock from reforestation (Langley, 2015). To be effective in such interventions, impartial involvement has to be given for gender, governmental and non-governmental sectors and Indigenous Peoples that collectively enable to achieve the sustainable development goals as stipulated by UNSD (1992) of Agenda 21.

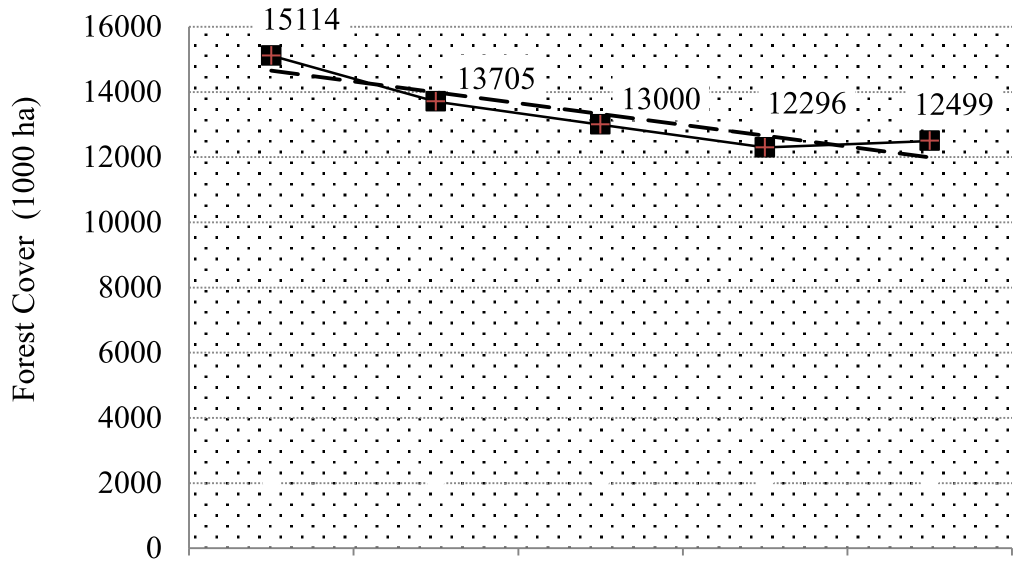
2.5. Forest Resources and associated challenges in Ethiopia

Forest in Ethiopia is defined in different ways that could be used for the National Forest Inventory purpose or for international reporting to the Global Forest Resources Assessment (FAO). Accordingly, in 2015 Ethiopia adopted a new forest definition as follows: „Land spanning at least 0.5 ha covered by trees and bamboo, attaining a height of at least 2m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course" (MEFCC, 2016).The reason to use this definition is to better capture dry and lowland-moist vegetation resources.

The forest cover of Ethiopia since 1990-2015 ranges 13.78-11.40% of having widespread deforestation trend (FAO, 2015) with reduction trend of deforestation that could be due to improvement in forest resource conservation activities of afforestation and reforestation works in the country since 2015 (Table 2 and Figure 3). The average annual deforestation rate is one percent which is higher compared to other Sub-Saharan African countries (0.8%) (FAO, 2010b). Whereas the global rate of annual net loss of forest has slowed from 0.18 % in the 1990s to 0.08 % in the period 2010−2015 (FAO, 2016b). Generally, the black broken line shows that the forest cover of Ethiopia has a declined trend (Figure 3).

Table 2. Forest cover and its trend from 1990–2015 which is adopted in (FAO, 2015) forest resource assessment report.

S.No.	Year	Forest cover		Remark
		1000 ha	% (land)	
1	1990	15114	13.78	No activity data
2	2000	13705	12.50	No activity data
3	2005	13000	11.86	Afforestation and reforestation
4	2010	12296	11.21	Natural expansion
5	2015	12499	11.40	Natural regeneration



Year	1990	2000	2005	2010	2015
Forest cover (1000 ha)	15114	13705	13000	12296	12499
Foret cover	13.78%	12.50%	11.86%	11.21%	11.40%

Figure 3. Forest coverage and its trend from 1990–2015 of Ethiopia

2.5.1. Deforestation and Forest Degradation

Deforestation and forest degradation in the forest ecosystem are the global sources of GHGs emissions mostly through land conversion accounted about 15% of global emissions (Yitebtu Moges *et al*., 2014); specifically CO_2 that constitutes 70% of GHGs (IPCC, 2007a) has resulted global climate change. The FAO (2016b) report pointed out that Africa‟s rate of deforestation is about twice the world rate, and the continent is losing more than four million hectares of forest cover every year. Deforestation and poor agricultural practices account for about 65% of Africa‟s emissions. As pointed out by MEFCC (2016), the main drivers of deforestation and forest degradation in Ethiopia are free livestock grazing, fodder use and fuel wood collection with charcoal production followed by farmland expansion, land fires and construction wood harvesting in line with the underlying causes of population growth, unsecure land tenure and poor law enforcement. As a result, there is an increasing of farmland expansion due to population growth that forest land is replaced by other land uses (Figure 4). For instance, more than 25% of the forest land is changed into agricultural land.

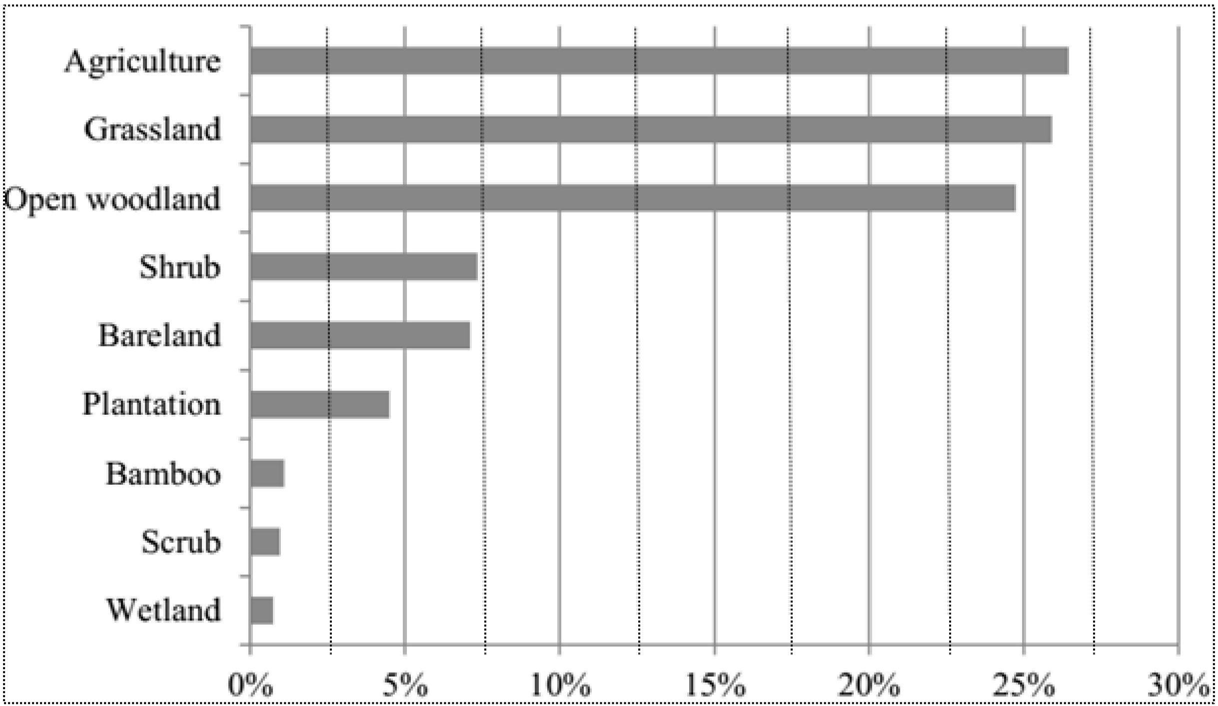


Figure 4. Land-uses replacing forest over the period 2000-2013 of Ethiopia (as % of the total forest loss over this period). Source: MEFCC (2016).

2.5.2. Reducing Emissions from Deforestation and Forest Degradation (REDD+)

To counter GHGs emissions from deforestation and forest degradation, REDD+ concept was created in Montreal in 2005 during the COP11 session of UNFCCC as a proposal by the Coalition of Rainforest Nations (UNEP, 2014). Then in the COP19 in Warsaw (2013), all member states adopted the rulebook for REDD+ implementation which included Measurement, Reporting and Verification with financing mechanisms. The Plus (+) indicates the expanded and included role of forest conservation, sustainable forest management, and enhancement of forest carbon stocks in forests by afforestation, reforestation, agroforestry, forest rehabilitation actions.

REDD+ is an incentive mechanism through which rewards are provided to parties which take action to reduce emissions from forest lands (Harris, 2016). According to Yitebtu Moges and Eyob Tenkir, 2014), the forest sector in Ethiopia is responsible for the emission of 65 million tons of CO_2 equivalents, about 40% of the national GHG emissions. To take the responsibility, Ethiopia has recognized important role that it can play in global climate change mitigation. As one of the four pillars of the Climate Resilient Green Economy (CRGE) Strategy of Ethiopia, REDD+ is envisaged to avoid emissions from the forest sector, while absorbing greenhouse gases from other sectors and helps in achieving a carbon neutral economy by 2030. Accordingly, Ethiopia had given opportunity by UNFCC to submit its forest reference emission level (FREL) intended for accessing the results-based payments under the global REDD+ mechanism (MEFCC, 2016). Therefore, to apply forest conservation through afforestation and reforestation actions that enhance carbon stock is essential for absorbing large quantity of carbon; so as to generate carbon credit (FAO, 2016b) that enables Ethiopia to meet its CRGE strategy.

The REDD+ mechanism is an avenue for supporting developing countries in their contribution to mitigation through the forest sector as reported by FAO (2016b). The mechanism is ensured by the payments for carbon emission in terms of per tonne CO_2eq. However, the price for carbon emission payment is not fixed which varies significantly from less than US$1 per t$CO_2$eq to US$130 per tCO_2eq (Ecofys and World Bank, 2015) with majority of emissions (85 percent) are priced at less than US$10 per t$CO_2$eq. Another report by Linacre (2014) indicated that most of REDD+ carbon projects had an offset values between US$3-$6/tCO2e, while the average value was US$4.2/ t$CO_2$eq which could be used for carbon price calculation.

2.6. The Role of Forest Carbon Stock on Climate Change Mitigation

It is widely recognized that forests have paramount role in climate change mitigation because they store a large amount of carbon in vegetation biomass and soil (Falkowski *et al*., 2000) and they are also a critical component of the global carbon cycle, storing over 80% of global terrestrial aboveground carbon (FAO, 2014a). Hence, forest ecosystem is known to be cost-effective ways of reducing global CO_2 emissions which is the major GHG causing climate change (Anup *et al*., 2013) so forests serve as long term sink if forest fire and forest degradation is strictly controlled. They have also tremendous potential to contribute to sustainable development and to a greener economy (FAO, 2014b). This is why international governments specifically, the current government of Ethiopia is relaying on enhancing forest carbon stock for the CRGED strategy for reducing GHGs emissions enables to sell its abatement services to developed countries by which forest carbon credit is generated (Busch and Engelmann, 2015).

Forest ecosystems store carbon through the photosynthetic assimilation of atmospheric CO_2 and the subsequent storage in the form of biomass (trunks, branches, foliage, roots, etc.)

(Malhi *et al*., 2002; Houghton, 2005), litter, woody debris, soil organic matter and forest products (Malhi *et al*., 2002), and organic carbon in the soil (Houghton, 2005). As Yitebitu Moges *et al*. (2010) pointed out that the forest resources of Ethiopia can store about 2.76 billion tons of carbon, playing a significant role in the global carbon balance provided that the nightmare scenario on forests is critically managed. In such away, forests being protected and more carbon in the atmosphere sequestered and enhanced carbon stock in the biomass of forests, consequently climate change mitigation through forests can be achieved and enabled to generate forest carbon credit, positive impact to the economy and environment (FAO, 2010b; Milimo, 2014; Busch and Engelmann, 2015).

2.7. Biomass and Carbon Stock Estimation in Ethiopia

Biomass is defined as the total amount of live organic matter and inert organic matter aboveground and belowground expressed in tonnes of dry matter per unit area (FAO, 1997 cited in Muluken Nega, 2014); calculated in terms of dry biomass with allometric equation. Forest biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system and is a larger global store of carbon than the atmosphere, and changes in the amount of vegetation biomass already affect the global atmosphere by being a net source of carbon, and having the potential either to sequester carbon in the future or to become an even larger source (FAO, 2009). The calculation of carbon stock consists of multiplying the total biomass by a conversion factor that represents the average carbon content in biomass. A generic conversion factor of 0.47 adopted by IPCC (2006) is widely used internationally.

Soil is also an important pool for carbon storage and plays an important role in the carbon cycle. The carbon in the soil is intense and concentrated in the top layer of soil profiles which is up to 30 cm soil depth considered and sampled (IPCC, 2006).

Event though, the Ethiopia‟s National Forest Inventory (NFI) data started to be collected (MEFCC, 2016); Ethiopia does not have carbon monitoring databank. As a result, the actual biomass carbon stock has been little known. But some efforts have been done to assess the forest biomass carbon of Ethiopia in different forests indicated as good reservoir of carbon. Some of the efforts witnessed this were study in carbon stock capacity of Adaba-Dodola Community Forest, Tara Gedam Forest, Woody Plants of Mount Zequalla Monastery Forest, Egdu Forest, Menagesha Suba State Forest and Woody Plants of Arba Minch Ground Water Forest can be raised as exemplary as Ethiopia had good reservoir of carbon. The biomass estimation is done using a generalist method due to the absence of country specific allometric model developed based on distinguished forest type. So the model selection based on climatic condition of the forest area to be found is recommended and most studies conducted in Ethiopia have confirmed (Muluken Nega *et al*., 2014; Mohammed Gedefaw *et al*., 2014; Abel Girma *et al*., 2014; Belay Melese *et al*., 2014).

2.8. Forest Carbon Stock Measurement

Forest inventories provide vital and up-to-date information for well informed decision making on the management and conservation of forest resources for policy makers, governments, ecologists and environmentalists. To facilitate the works on forest carbon stock measurement, forest carbon is identified in three major pools that is, above and below ground living vegetation, dead organic matter and soil organic carbon (IPCC, 2006). To use reliable allometric models for forest biomass carbon estimation is important for the successful implementation of climate change mitigation policies (Chaeve *et al*., 2014). Hence, different allometric equations have been developed by many researchers to estimate the aboveground biomass. These equations are different depending on type of species, geographical locations, forest stand types, climate and others (Baker *et al.*, 2004; Brown *et al.*, 1989). By considering these factors, different authors provided different carbon estimation models according to the ecological Zone of the forest to be found (Table 3).

Table 3. Different Allometric Equations for Estimation of Biomass adopted (Mesfn Sahlie, 2011; Muluken Nega, 2014).

Allometric Equation	Ecological Zone to be Applied	Author	Remark
$Y = 0.0673 \times (\rho * D^2 * H)^{0.976}$	Tropical dry forest	Chave *et al.*, 2014	D:5-212 cm
$Y = \exp.\{-2.187 + 0.916 \ln(\rho * D^{2*} H)\}$	Tropical dry forest	Chave *et al.*, 2005	D: ≥ 5 cm
$Y = \exp.\{-2.977 + \ln(\rho * D^2 * H)\}$	Tropical rainforest	Chave *et al.*, 2005	D: ≥ 5 cm
$Y = \exp.\{-2.4090 + 0.9522 \ln(\rho D^2 H)\}$	Tropical rainforest	Brown *et al.*, 1989	D: >5cm
$Y = 34.4703 - 8.0671 * D + 0.6589 * D^2$	Tropical shrubland	Brown *et al.*, 1989	D: ≥ 5 cm
$Y = \exp.\{-3.1268 + 0.9885 \ln(D^2 * H)\}$	Tropical moist	Djomo *et al.*, 2010	D:5–138 cm
$Y = \exp.\{-1.996 + 2.32 \ln(D)\}$	Dry to moist (R.f >900mm)	FAO, 1997	D:5–40 cm
$Y = 10.0899((D^2)^{0.9522}) * (S^{0.9522}) * (H^{0.9522})$	General	Luckman *et al.*, 1997	D: General

Y- above-ground biomass (kg), D- diameter (cm) at breast height (1.3 m), H- height (m) and ρ-wood density (t/m^3), R.f- rainfall.

2.9. Factors Affecting Forest Carbon Stock

Forest carbon stock could be affected by different environmental factors such as topographical factors like altitude, slope and aspect gradients. It is also known carbon stock varies due to the presence of different tree species, soil nutrient availability, climate, disturbance and management regime (Clark *et al.*, 2000; Houghton, 2005; Suwal *et al.*, 2014). In Ethiopia, different studies also showed that forest carbon stock had affected by such factors by Belay Melese *et al*. (2014); Mohammed Gedefaw *et a*l. (2014); Muluken Nega *et al*. (2014); Tibebu Yelemfrhat *et al*. (2014).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographical Location

The study area is found in Banja District, Awi Administrative Zone, Amhara National Regional State, Ethiopia. The District is located at latitude of 11° 10' north and longitude of 36° 15' east and 122km far from the regional city Bahir Dar to south and 447km north to Addis Ababa (Figure 5). The area of BF is 4,966.54 ha which is under state forest and it has an elevation ranges between 1870 and 2570 m a. s. l.

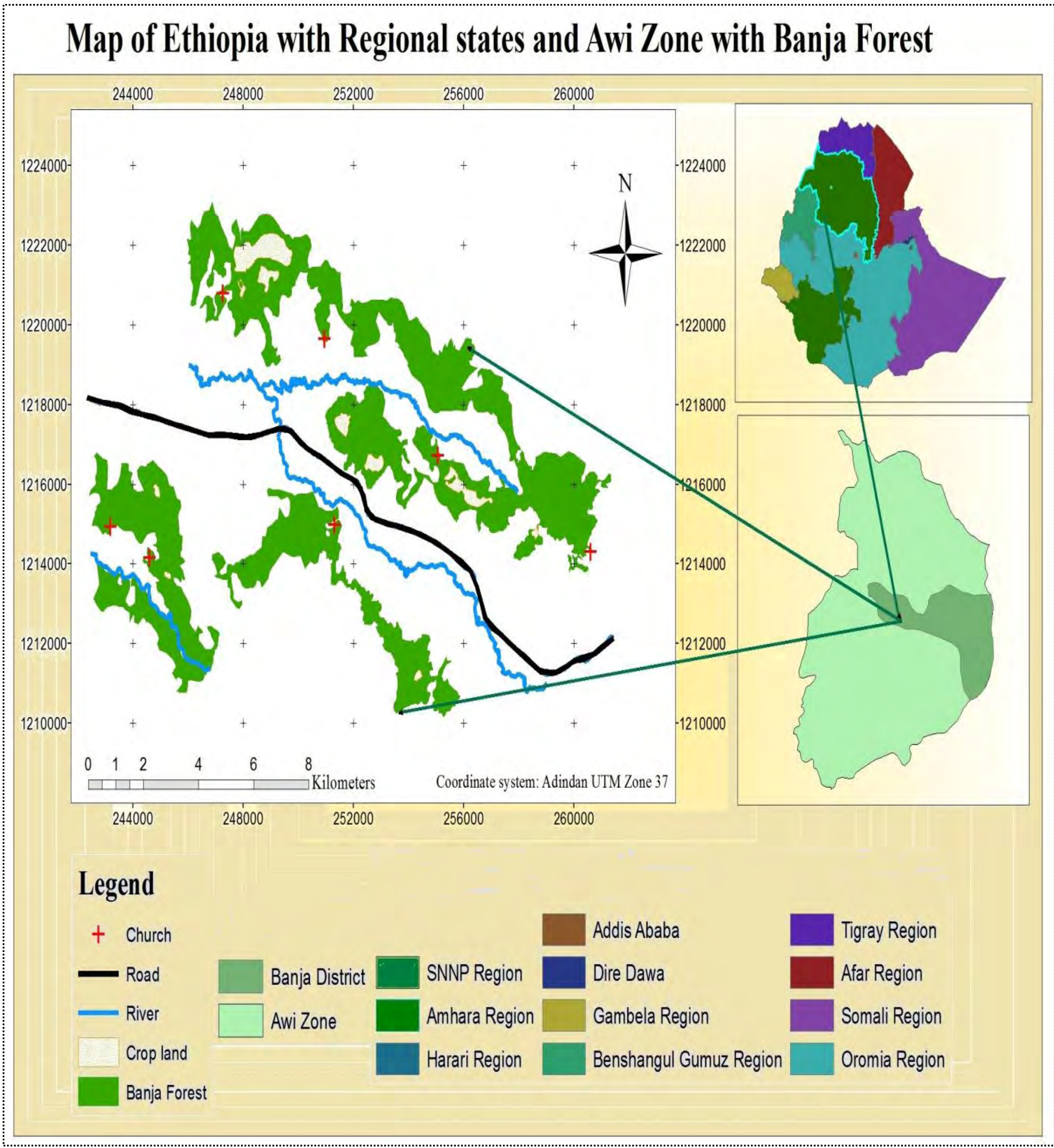


Figure 5. Map of Ethiopia and the study site (Banja Forest)

3.1.2. Climate

According to National Meteorology Agency weather data from 1984–2015, the mean minimum and maximum temperature of the study area was 9.4°C and 26°C, respectively. The mean annual rainfall was 1215.3 mm with main wet season from June to September usually continued with a less pronounced wet period up to November (Figure 6).

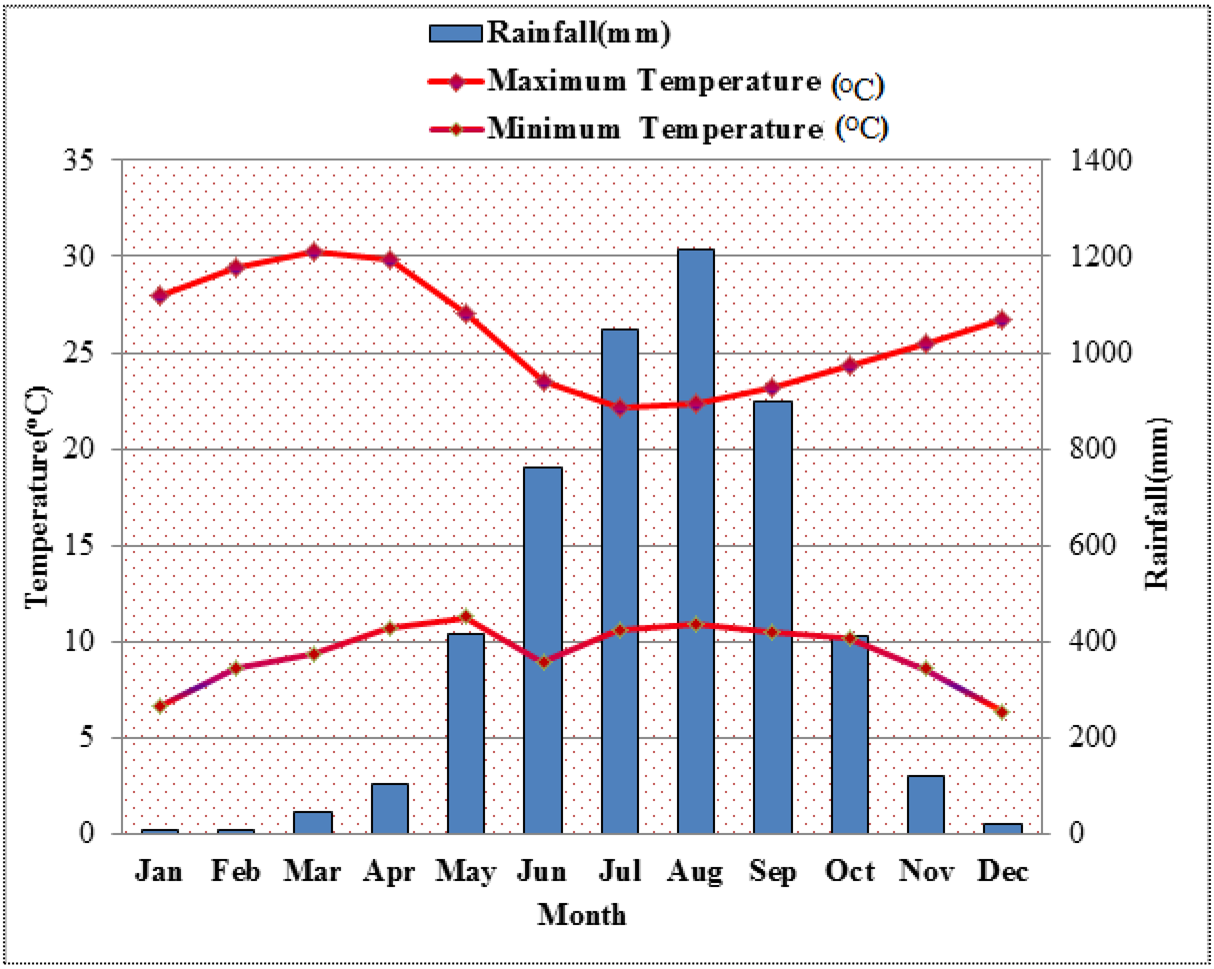


Figure 6. Climate of Banja District (Kidamaja Station)

3.1.3. Geology and Soil

The parent material is made up of the volcanic rock and quaternary basalts. The major soil types include Andisols, Nitosols, and Cambisols. Generally, the soil types of the study area are characterized with shallow, moderate to deep and very deep in depth and sandy clay to clay texture types (Bireda Alemayehu, 2015).

3.1.4. Vegetation Cover

The Vegetation type of Banja Forest falls under dry Afro-montane forest (Sebsebe Demissew *et al*., 2010). The study area was dominated by *Albizia gummifera, Croton macrostachyus, Prunus africana and Apodytes dimidiata.* Lower altitude class (1850-2100m) revealed strong dominance of *Albizia gummifera* followed by *Croton macrostachyus.* In the Middle altitude class (2100-2350m) *Prunus africana and Apodytes dimidiata* species were found while *Juniperus procera* and *Ekebergia capensis* were found sparsely with undergrowth shrub species in the higher altitude.

3.2. Methodology

The methodology and procedures used to estimate carbon stocks for this study were simple allometric procedures using standard carbon inventory principles and techniques. That was based on data collection and analysis of carbon accumulating in the above-ground biomass, below-ground biomass, leaf litter and soil carbon of forests using verifiable modern methods (Pearson *et al.,* 2005 and Walker *et al.,* 2012).

3.2.1. Delineation and Stratification of the Study Area

The boundaries of the study forest area were delineated to facilitate accurate measurement and accounting of the forest carbon stock. GPS points were used for delineation of boundary of the study area. In order to form relatively homogenous units and obtain accurate data from the field work, the stratified sampling by elevation segments was used since the area under the study has an altitudinal variation that help to determine the elevation variations as predictor variable to relate with forest carbon stocks. At the end, the study site classified into three strata: Lower altitude (1850 - 2100); Middle altitude (2100 - 2350m) and upper altitude (2350 - 2600m).

3.2.2. Data type and sources

The primary and secondary data were used in order to collect the important data to meet the objectives of this study. Primary data were obtained through field measurements in the study area and the secondary data were collected from different resources like published and unpublished materials, books, journals, articles, reports, and electronic web sites.

3.2.3. Sampling Techniques and Field Measurement

The field work for forest inventory was conducted from January 12 to February 21, 2016. A systematic sampling method was used for identification of each intersection point in the field at regular interval. The geo-position of the study area was mapped out, and then 888 m intervals were inserted in the map and finally, a total of 63 intersection points were located on the map (Figure 7). Each point was identified using GPS and Compass in the field.

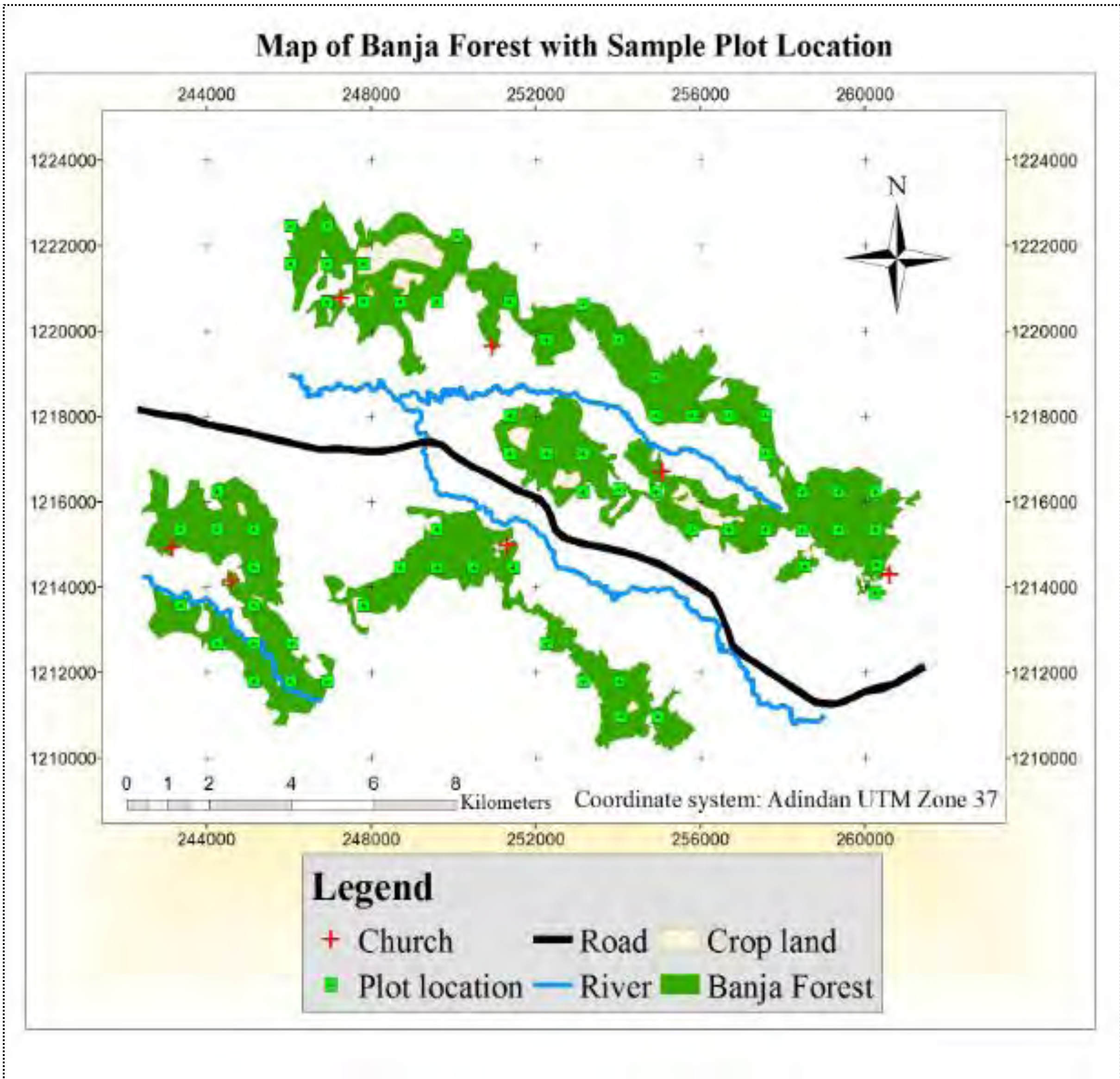


Figure 7. Map of BF depicting recorded locations of sample plots

3.2.4. Woody Plant Species Sampling

A main plot of 20m x 20m (400 m^2 equivalent to 0.04 ha) was systematically set at each intersection points of the grids for biomass inventory. Trees ≥5 cm in DBH and height were measured using diameter tape and Suunto Hypsometer, respectively. Five smaller sub-plots of one square meter in size were established, at the middle and corner of each plot to collect leaf litter, herb and grasses (LHGs) and soil (Figure 8).

Both diameter at breast height (DBH) at 1.3m above the ground and height of the individual of all woody plant species having diameter ≥5cm were measured. Woody plants which have multiple stems at 1.3m height were considered as a single individual and DBH of the largest stem was taken. Branched woody plants at 1.3m were measured at the smallest point below 1.3m, where the stem assumes near cylindrical shape. A woody plant with multiple stems or fork below 1.3m height was treated as a single individual. Those trees on the border were included when ≥50% of their basal area fell within the plot and excluded if <50% of their basal area fell outside the plot. Trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included (Bhishma *et al*., 2010).

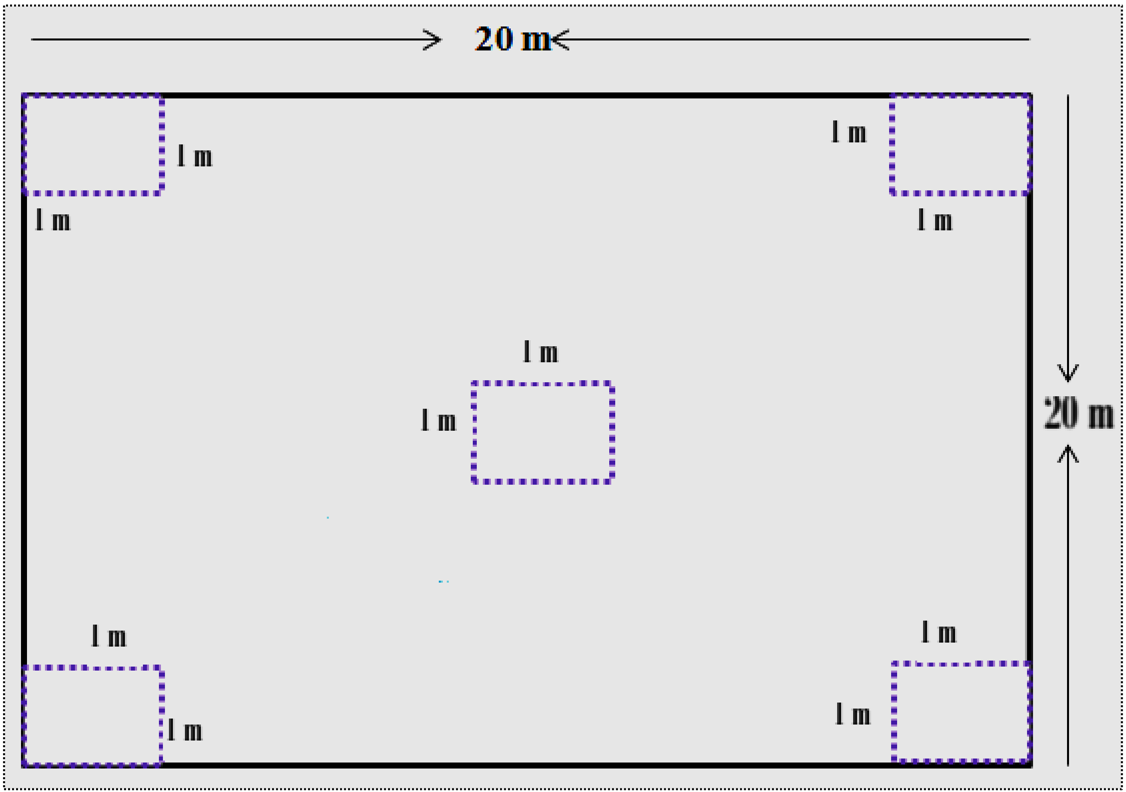
Plant identification was done at the field using their local name and Useful Trees and Shrubs for Ethiopia (Azene Bekele, 1993 and; Mark *et al*., 2002). Each woody plant which was listed at field again cross checked its Botanic name using volumes of Flora of Ethiopia and Eritrea.

3.2.5. Litter, Herbs and Grasses (LHGs) Sampling

The LHGs samples were collect from 1m × 1m quadrat sub-plots in each plot (Figure 8). LHGs within five 1m^2 quadrat sub-plots of each main plot were collected, weighed and recorded as field wet weight on the field, and 100g of evenly mixed sub-samples for each plot were taken to laboratory to determine dry biomass and percentage of carbon. Determination of percentage of carbon in LHGs was conducted in the laboratory of Center for Environmental Science laboratory at Addis Ababa University (AAU). According to Bhishma *et al.* (2010), dead wood was not considered in this study due to the absence of deadwood in the study site that local communities obtained their sources of fuel wood in the form of biding of dead wood collected regularly by the forest guards.

3.2.6. Soil Sampling

For sampling of soil the 1m × 1m quadrat sub-plots at all corner and middle positions of each main plot were used. For SOC determination, soil samples were collected within five $1m^2$ sub-plots in which LHGs samples were taken (Figure 8). In each sub-plot one soil sample was taken using soil auger at depth of 30cm from the four corners and middle of each plot. A composite sample was obtained by mixing soil from five sub-plots of each main plot in order to determine bulk density and organic carbon. About 200g of composite samples were collected from each main plot. All samples were labelled to which plot they belong and brought to the laboratory for analysis. Determination of percentage of carbon in soil was conducted in the laboratory of Center for Environmental Science at AAU.



Key

20 × 20m is main plot that was used for sampling of trees with DBH >5cm

1m × 1m quadrat sub-plots that were used for sampling of LHGs and soil

Figure 8. Design of main plot and sub-plots for sampling of carbon pools

3.2.7. Data Analysis

Above Ground Biomass Estimation: To develop and use of locally developed allometric equations used to generate a reliable estimate of forest carbon stocks for AGB. But to develop allometric relationships a large number of trees needs to be harvested, this makes it time-consuming and expensive (Gibbs *et al.,* 2007). Although, many allometric equations had been developed globally, no African site had been included in previous efforts (Chave *et al*., 2005) except the pantropical AGB model developed by Chave *et al*. (2014), included sites from Africa by considering 58 study sites of woody vegetation, excluding plantations and agroforestry systems with a total of 4004 trees and DBH ranging from 5 to 212cm, spanning a wide range of climatic conditions and dry tropical forest types. The model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors (Chave *et al*., 2014; Victor, 2015). According to Henry *et al*. (2010), equations that integrate more than one tree dimension improve the reliability of forest biomass estimation. Therefore, the model of Chave *et al*. (2014) was used by many studies and has been the best model for carbon stock assessment in Africa (MEFCC, 2016; Victor, 2015) on the basis of climatic condition, DBH of trees and forest type of the study area to determine biomass of tree species having ≥ 5 cm DBH. The model:

$AGBest = 0.0673 \times (\rho D^2 H)^{0.976}$ ……………………………………………………..eq. (1)

Where, $AGBest$– Estimation of the aboveground biomass (kg),

H– Height of tree (m),

D– Diameter (cm) at breast height (1.3m), and

ρ– Wood density (t/m^3)

The DBH and tree height were directly measured, wood density of species was obtained from other studies and databases (IPCC, 2003; Reyes *et al*., 1992). Average wood density value of the known species was used for species which wood density was not found which was 0.6g/cm^3 that was equivalent to average value reported for wood density of trees in Africa ranges between 0.58 and 0.67g/cm^3 (Henry *et al*., 2010).

According to IPCC (2006), the biomass stock density of a sampling plot is converted to carbon stock densities by default carbon fraction of 0.47, as the dry biomass contains 47% organic carbon in the tropical and sub-tropical region.

Below Ground Biomass Estimation: BGB was calculated by considering 20 % of the AGB (Macdicken, 1997). The biomass of stock density was converted to carbon stock density by multiplying 0.47 fraction of IPCC (2006) default value.

BGB= AGB*0.2……………………………………………………………………eq. (2)

Litter, Herbs and Grasses (LHGs) Biomass (LB) Estimation: For biomass and percentage of carbon estimation, the loss on ignition (LOI) method was used. In this method; initially fresh weight of samples were taken on the field, and then dried at 65°C in the oven for 48 hours to take dry weight. Oven dried grind samples were taken (5.00g) in pre-weighted crucibles, after that put in the furnace at 550ºC for one hour to ignite. The crucibles were cooled slowly inside the furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated according to Allen *et al*. (1986).

$$Ash\% = \frac{(W3 - W1)}{(W2 - W1)} * 100 \quad \text{……………………………………………………..eq. (3)}$$

C (%) = (100 – % Ash) × 0.58…………………………………………………….. eq. (4)

By considering 58% carbon in ash-free litter material.

Where; C – Biomass carbon stock,

W1 – Weight of crucible,

W2 – Weight of the oven-dried grind sample and crucible, and

W3 – Weight of ash and crucible.

The LB was calculated according to Pearson *et al*. (2005), the subsamples were used to determine an oven-dry-to-wet mass ratio that was used to convert the total wet mass to oven dry mass. The amount of biomass per unit area was calculated as:

$$LB = \frac{Wfield}{A} * \frac{Wsubsample, dry}{Wsubsample, wet} * \frac{1}{10{,}000} \quad \text{………………………………………... eq. (5)}$$

Where; LB – Biomass of leaf litter, herbs, and grasses (t/ha),

Wfield – weight of wet field sample of LHGs sampled within an area of size 1m^2 (g);

A – Size of the area in which leaf LHGs were collected (ha), Wsubsample, dry – Weight of the oven-dry sub-sample of leaf LHGs taken to the laboratory to determine moisture content (g), and

Wsubsample, wet – Weight of the fresh sub-sample of leaf LHGs taken to the laboratory to determine moisture content (g).

Carbon stocks in Litter Biomass:

$CL=LB\times\%C$……………………………………………………………………..eq. (6)

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

Soil Organic Carbon Estimation: To determine SOC, field"s moist soil were dried in an oven at 105°C for 12 hours in laboratory, and re-weighted to determine moisture content and dry bulk density. To estimate the percentage of organic carbon, samples were analysed by the Walkley Black method. The carbon stock density of soil organic carbon was calculated as Pearson *et al*. (2007) from the volume and bulk density of the soil.

$V = h \times \pi r^2$…………………...………..eq. (7)

Where, V is volume of the soil in the core sampler in cm^3, h is the height of core sampler in cm which is four, and r is the radius of core sampler in cm that is 2.5. Moreover, the bulk density of a soil sample can be calculated as follows:

$$BD = \frac{Wav, dry}{V}$$ ……………………………………………………………………….eq. (8)

Where, BD is bulk density of the soil sample per plot,
Wav, dry is average air dry weight of soil sample per the quadrate,

V is volume of the soil sample in the core sampler in cm^3.

Then, the carbon stock in soil was calculated as follows:
SOC = BD * d * % C ……………………………………………………………. eq.(9)
Where, SOC- Soil Organic Carbon stock per unit area ($t\ ha^{-1}$), BD soil bulk density (g/cm^3), D- the total depth at which the sample was taken (30cm), and

%C- Carbon concentration (%) determined in the laboratory.

Total Carbon Stock Density of BF in 2016: Total carbon stock density was calculated by summing the biomass carbon stock densities of the individual carbon pools using the Pearson *et al*. (2005) formula and in agreement to Bhishma *et al*.(2010), had recommended that carbon pool could be ignored if it did not contribute significantly to the total carbon stock.

TC = TAGC + TBGC + C (LHGs) + SOC …………………………………………… eq. (10)

Where; TC – Total carbon stock for all carbon pools (t/ha),

TAGC – Total aboveground carbon of tree species (t/ha),

TBGC – Total belowground carbon of tree species (t/ha),

C (LHGs) – Carbon in litter, herbs and grasses (t/ha), and

SOC – Soil organic carbon (t/ha).

The total carbon stock is then converted to tons of CO_2 equivalent by multiplying it by 44/12 or 3.67 of molecular weight ratio of CO_2 to O_2 (Pearson *et al*., 2007) in order to understand climate change mitigation potential of the study area.

Data of trees both aboveground and belowground, LHGs and soil carbon were processed using MS Excel spreadsheet and R Software Version 3.2.2 for one-way analyses of variance (ANOVA) were used.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Results

4.1.1. Floristic Composition of Banja Forest

In total, 24 common families with 29 tree species were found in the Banja Forest (BF). Among families, Fabaceae was the most diverse having four species and both Rubiaceae and Rutaceae were also diverse having two species while the remaining families had only one species. *Albizia gummifera* (157 stems/ha), *Croton macrostachyus* (123 stems/ha) and *Prunus africana* (88 stems/ha) were the most dominant species with their relative density of 23, 18 and 13% respectively whereas the least dominant tree species were *Cordia africana, Juniperus procera, Dracaena steudneri* and *Pittosporum virdiflorum* with relative density of 0.46, 0.35 and 0.06% (the latter two) respectively (Table 4, Figure 9 and 10). Generally, individual trees having DBH ≥5cm with total 1,728 of trees were recorded with number of tree species ranged from 1 to 395.

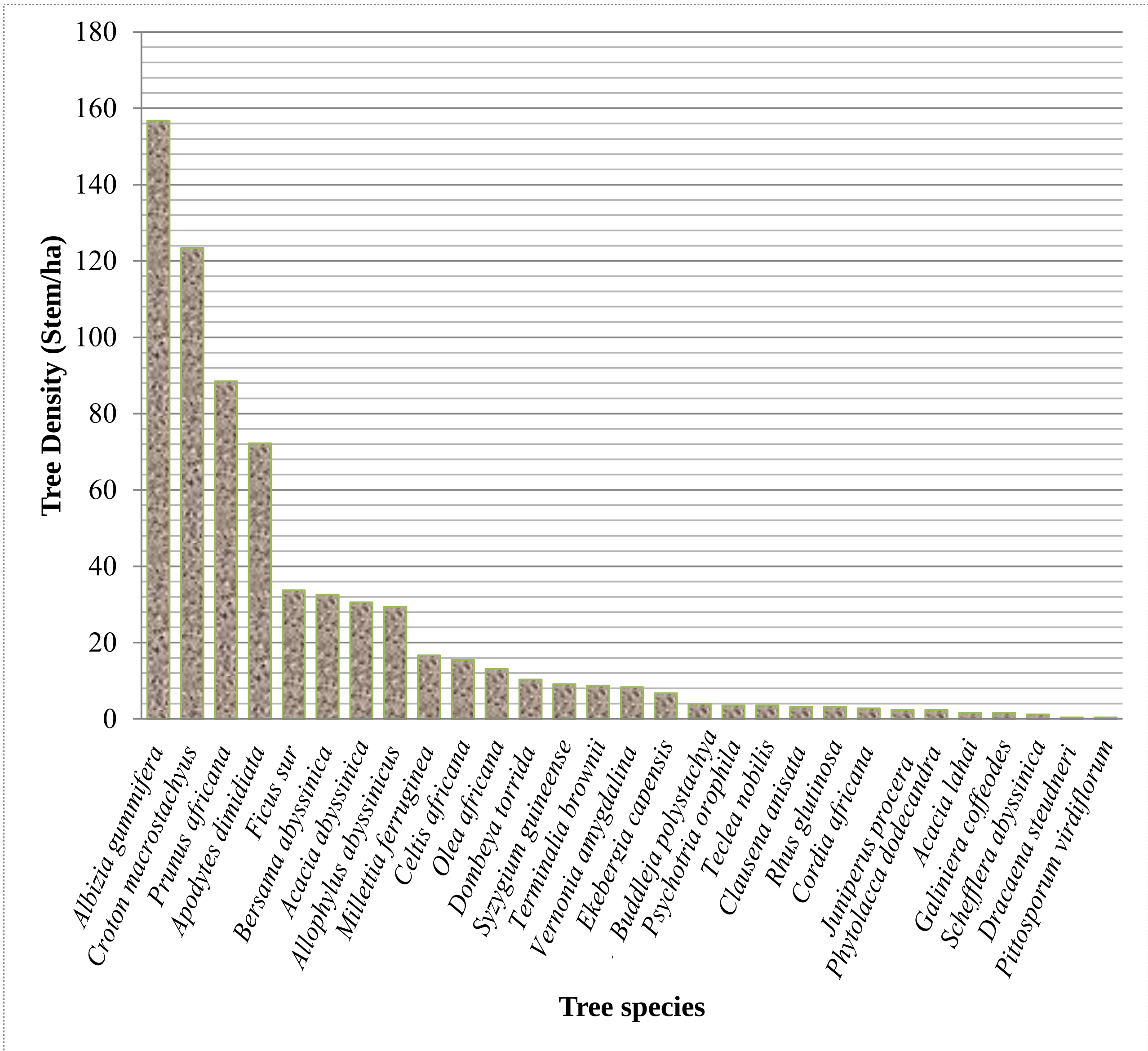


Figure 9. Number (Density) of sampled tree species (stems/ha)

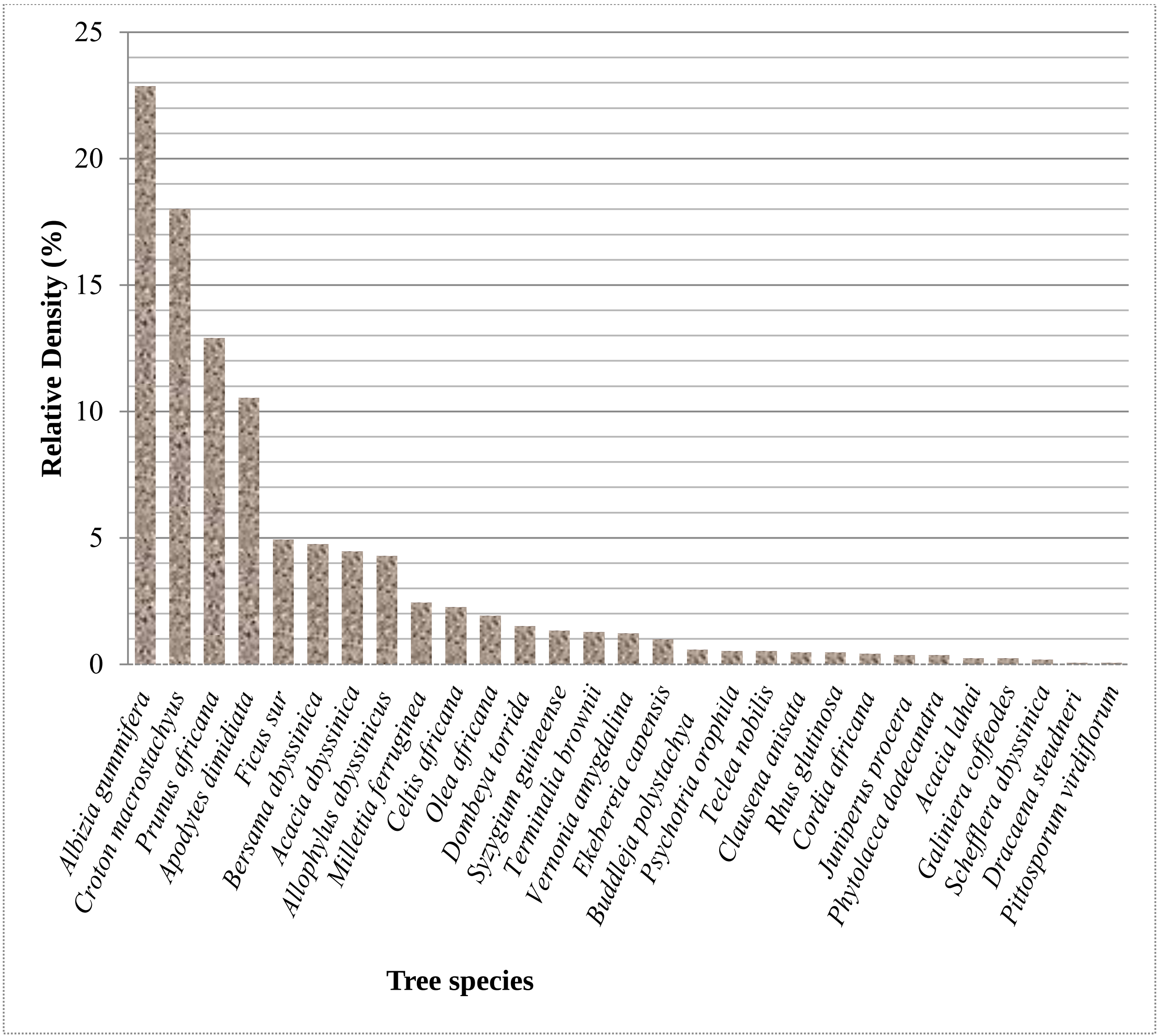


Figure 10. Relative Density of sampled tree species (%)

Albizia gummifera and *Croton macrostachyus* were the most frequently occurred species with frequency of 75 and 70% respectively while *Dracaena steudneri, Pittosporum virdiflorum* and *Schefflera abyssinica* were the least that each had frequency of 2% (Figure 11).

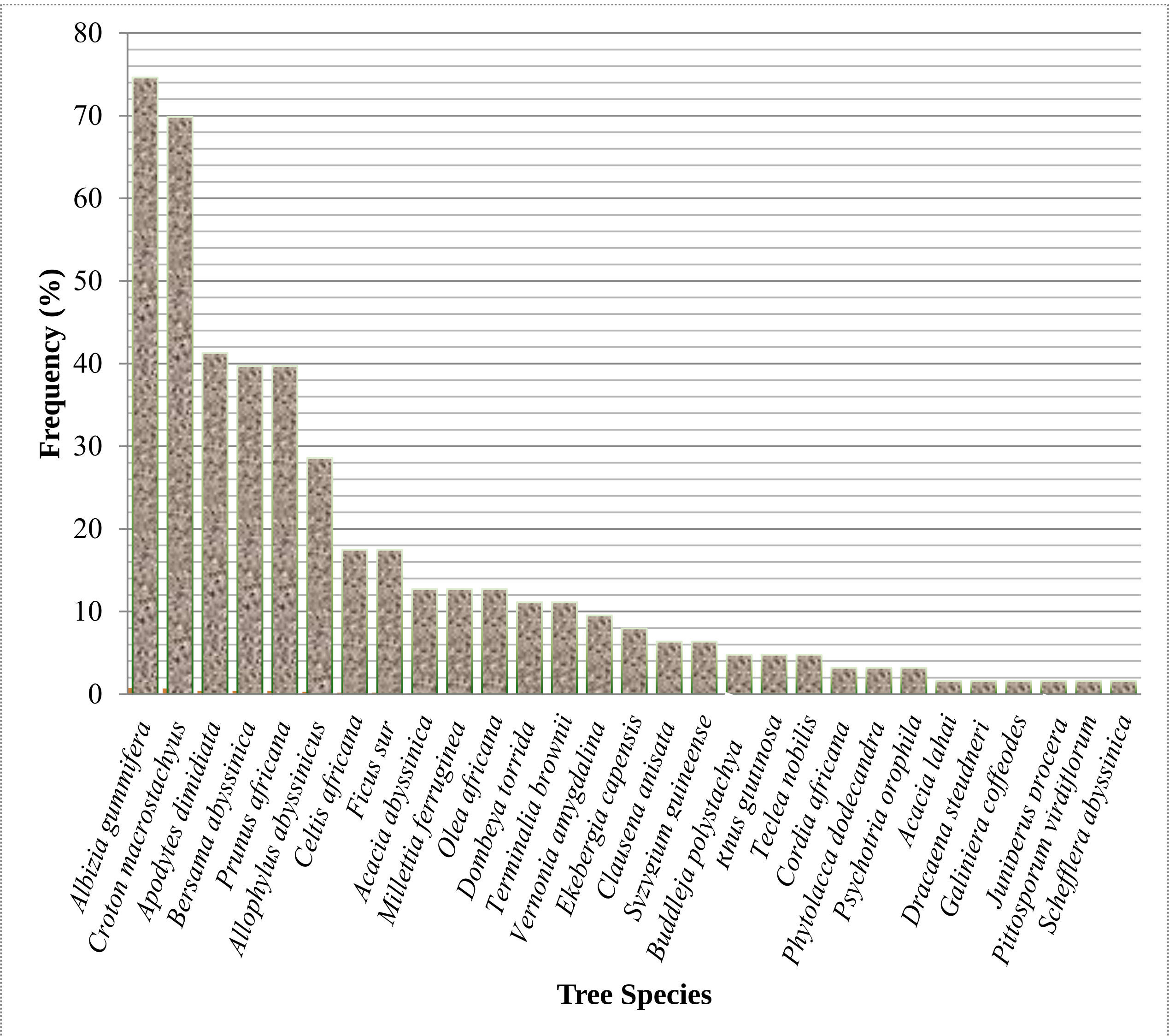


Figure 11. Frequent occurrence of sampled tree species (%)

Table 4. The names of tree species with their density and frequency of BF

S.No.	Scientific name	Local name (Awigni)	Family name	No. Spp. sampled	No. of Plots Spp. Occurred	Density		Frequency(F)	
						(Stem /ha)	R.D (%)	Occurred in plot (%)	R.F (%)
1	*Acacia abyssinica* Hochst.ex Benth	Tsatsi	Fabaceae	77	8	31	4.46	13	2.81
2	*Acacia lahai* Steud. and Hochst. ex Benth	Tsivi	Fabaceae	4	1	2	0.23	2	0.35
3	*Albizia gummifera* J.F.Gmel. C.A.Sm.	Kansini	Fabaceae	395	47	157	22.86	75	16.51
4	*Allophylus abyssinicus* (Hochest) Radlkofer	Entahtahi	Sapindaceae	74	18	29	4.28	29	6.32
5	*Apodytes dimidiata* E. Mey. ex Benth.O.	Zindi	Icacinaceae	182	26	72	10.53	41	9.13
6	*Bersama abyssinica* Fresen	Dinkifi	Melianthaceae	82	25	33	4.75	40	8.78
7	*Buddleja polystachya* Fresen	Ashkuari	Loganiaceae	10	3	4	0.58	5	1.05
8	*Celtis africana* Burm. f.	Saringi	Ulmaceae	39	11	15	2.26	17	3.86
9	*Clausena anisata* Hook. f. ex Benth.	Luntsi	Rutaceae	8	4	3	0.46	6	1.40
10	*Cordia africana* Lam.	Bugitsi	Boraginaceae	7	2	3	0.41	3	0.70

11	*Croton macrostachyus* Del.	Asisi	Euphorbiaceae	311	44	123	18.00	70	15.45
12	*Dombeya torrida* (G.F.Gmel.) P. Bamps	Tsari	Sterculiaceae	26	7	10	1.50	11	2.46
13	*Dracaena steudneri* Engler	Zagri Emparpari	Dracaenaceae	1	1	0.4	0.06	2	0.35
14	*Ekebergia capensis* Sparrm.	Churi	Meliaceae	17	5	7	0.98	8	1.76
15	*Ficus sur* Forsk.	Emuy	Moraceae	85	11	34	4.92	17	3.86
16	*Galiniera coffeodes* (Hochst.) Bridson	Dengay Seber	Rubiaceae	4	1	2	0.23	2	0.35
17	*Juniperus procera* Hochst. Ex Endel.	Tsdi	Cupressaceae	6	1	2	0.35	2	0.35
18	*Millettia ferruginea* Bak.	Chihui	Fabaceae	42	8	17	2.43	2	2.81
19	*Olea africana* L.	Wiri	Oleaceae	33	8	13	1.91	2	2.81
20	*Phytolacca dodecandra* L'Herit.	Sibti	Phytolaccaceae	6	2	2	0.35	3	0.70
21	*Pittosporum virdiflorum* Sims	Zhinkuti	Pittosporaceae	1	1	0.4	0.06	2	0.35
22	*Prunus africana* (Hook. f.) Kalkm.	Damtsi	Rosaceae	223	25	88	12.91	40	8.78
23	*Psychotria orophila* Petit.	Zemahay	Rubiaceae	9	2	4	0.52	3	0.70
24	*Rhus glutinosa* A.Rich.	Kumini	Anacardiaceae	8	3	3	0.46	5	1.05
25	*Schefflera abyssinica* (Hochst). ex A.	Pimepini	Araliaceae	3	1	1	0.17	2	0.35

26	*Syzygium guineense* (Willd.) DC.	Bagootsi	Myrtaceae	23	4	9	1.33	6	1.40
27	*Teclea nobilis Del.*	Sila	Rutaceae	9	3	4	0.52	5	1.05
28	*Terminalia brownie* Fresen.	Kawnabala	Combretaceae	22	7	9	1.27	11	2.46
29	*Vernonia amygdalina* Del.	Kukitsi	Asteraceae	21	6	8	1.22	10	2.11

4.1.2. Diameter Distribution of Tree Species

According to IPCC (2003), each tree species DBH was measured starting from minimum value of greater than or equal to five cm and categorized in twelve classes of DBH (4.5≤5; 5–35; >35–50; >50–65; >65–80; >80–95; >95–110; >110–125; >125–140; >140–155 and >155 cm), DBH class of (>20-35) had the highest density with 204 trees/ha or 29.46% while trees with DBH classes greater than 125 cm were the least dominant in the study site and consisting of one tree/ha or 0.12% (Figure 12). As depicted in Figure 12, the distribution indicated that it decreased towards the higher DBH class distribution.

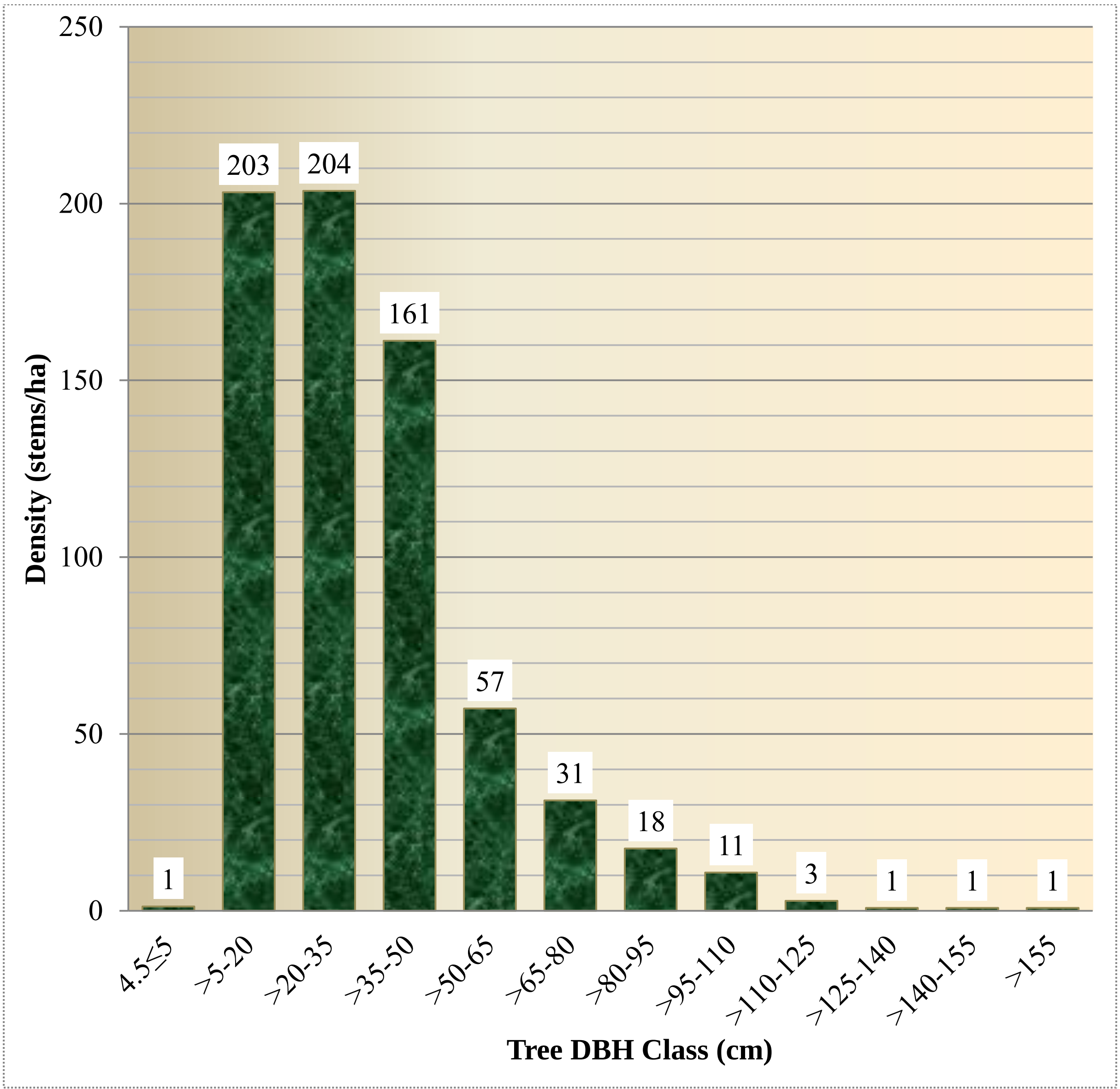


Figure 12. DBH class distribution of existed trees in Banja Forest

There was a strong difference among tree species in their DBH sizes (Figure 13). *Juniperus procera*, *Ekebergia capensis* and *Prunus africana* were the first three species having highest mean DBH of 93.42±13.31, 66.82±29.61 and 52.36±21.60 cm respectively while *Galiniera coffeodes* was the least having mean DBH of 5.49±0.48 cm (Figure 13).

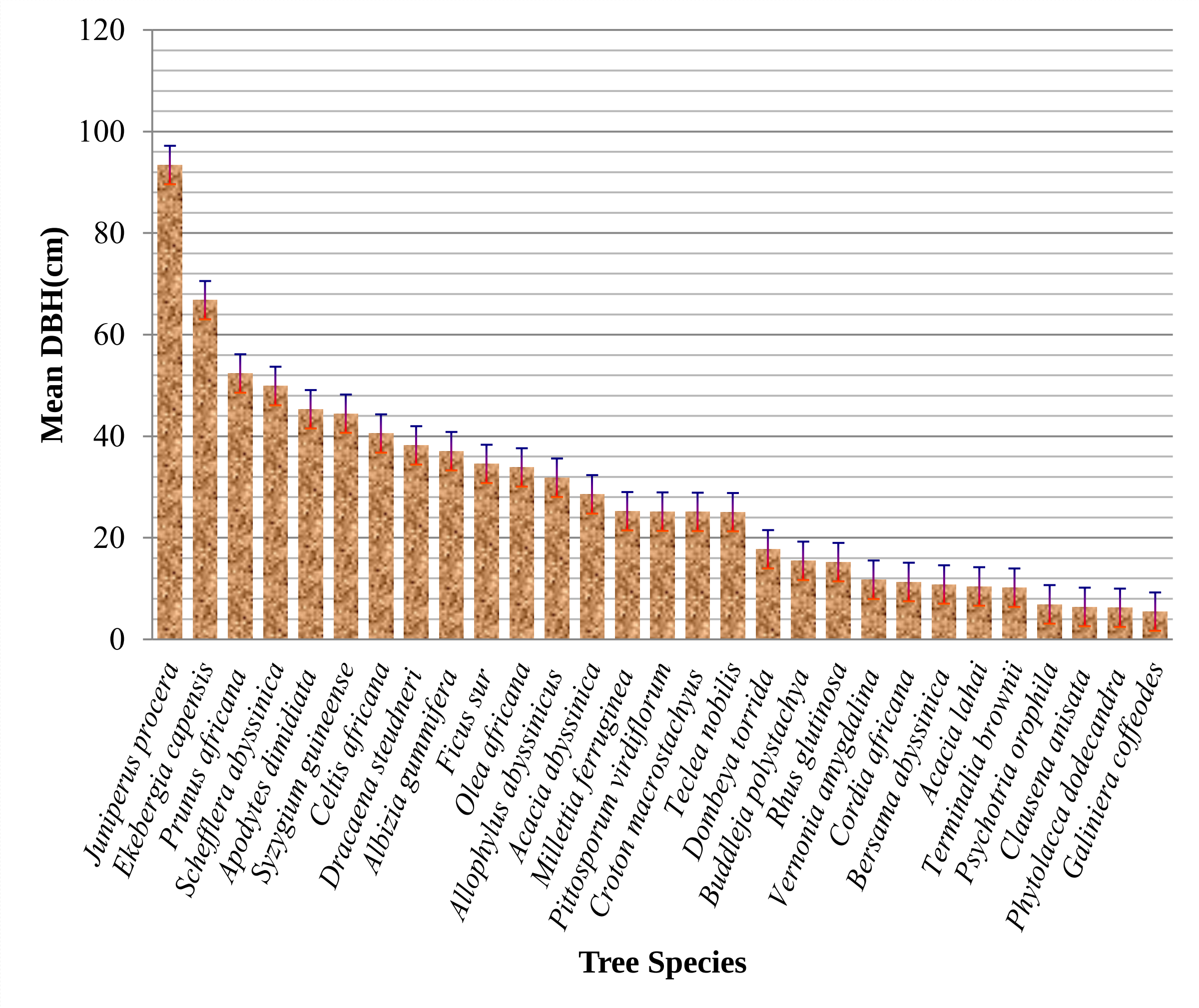


Figure 13. Mean DBH class distribution of each tree species existed in Banja Forest

4.1.3. Height Distribution of Tree Species

Likewise trees DBH; each tree height was measured and categorized in eight classes (3.5≤5; >5-10; >10-15; >15-20; >20-25; >25-30; >30-35 and >35), of which more number of individual trees were found in the height class (>10-15) with 368 trees/ha or 53.24% and the second class with more number of individuals were found in the DBH class (>15-20) with 195 trees/ha or 28.18%. The least number of individuals were found in both classes (3.5≤5) and (>35) with 2 and 4 trees/ha or 0.29 and 0.52% respectively (Figure 14).

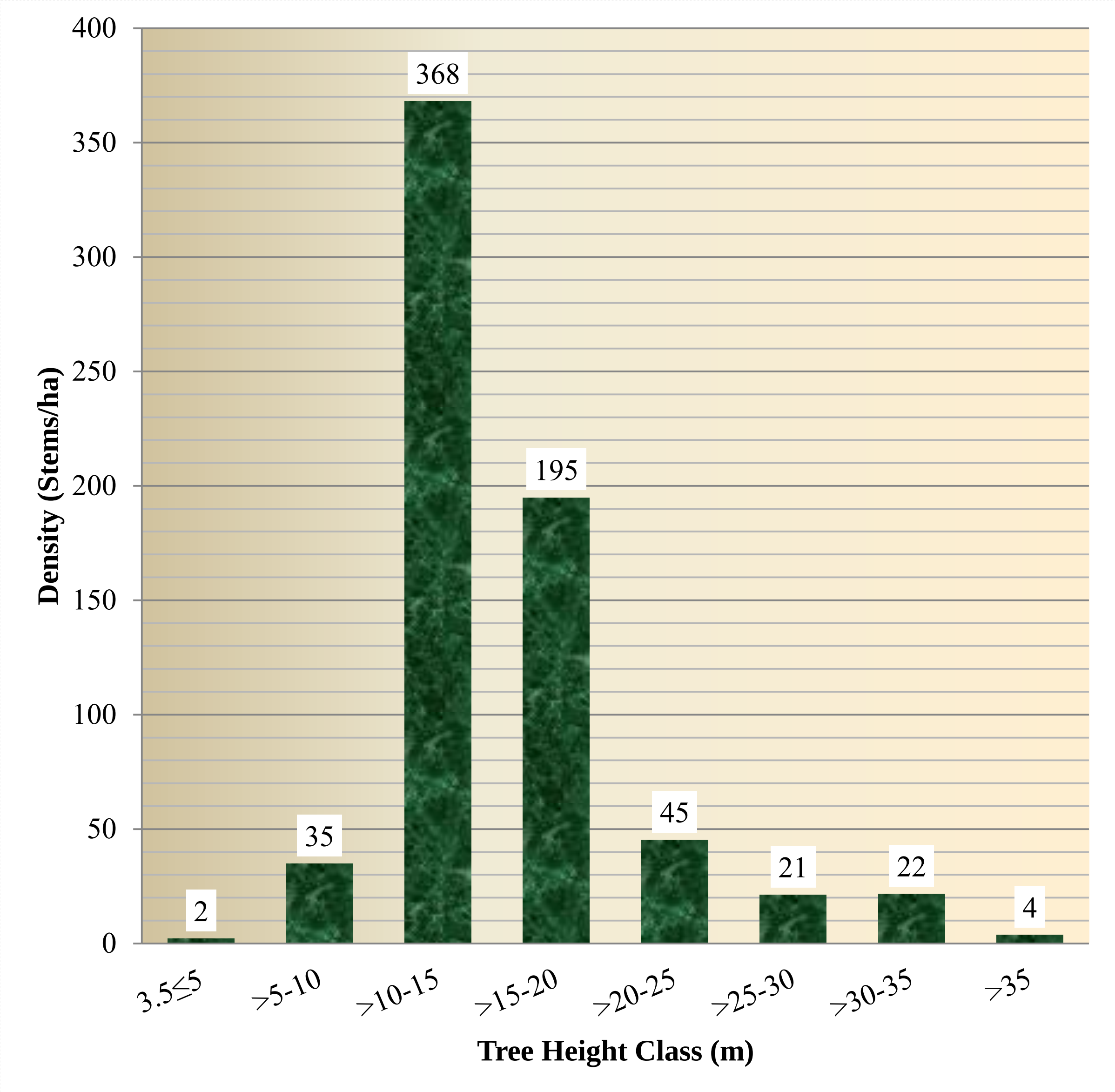


Figure 14. Height class distribution of existed trees in Banja Forest

Likewise the DBH; there was a strong difference among tree species in their height sizes. *Juniperus procera*, *Ekebergia capensis* and *Prunus africana* were the first three species having highest mean height of 34±1.79, 21.67±4.82 and 19.76±5.21 m respectively while *Galiniera coffeodes* was the least having mean height of 6.63±3.59 m (Figure 15).

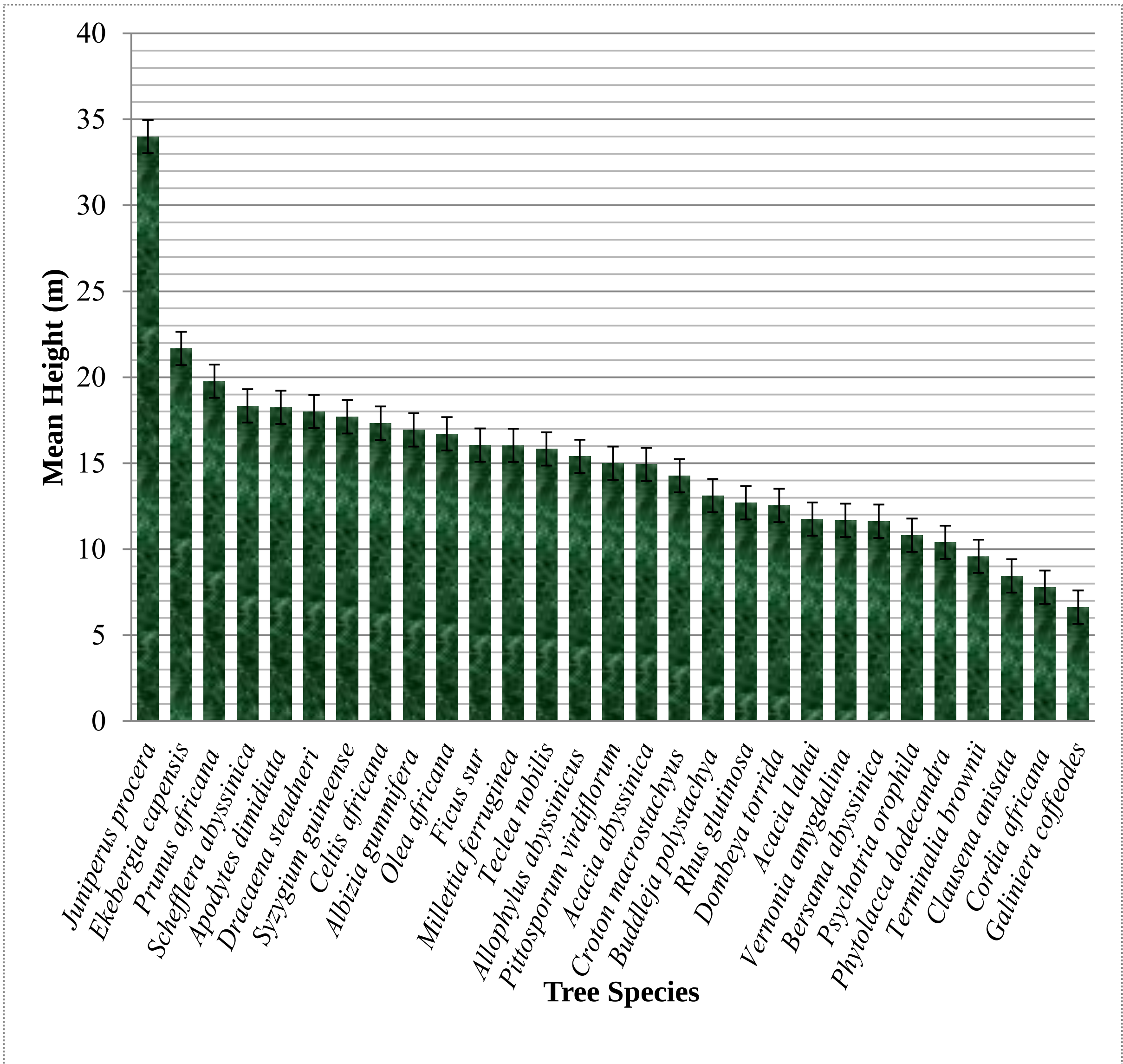


Figure 15. Mean Height class distribution of each tree species existed in Banja Forest

4.1.4. Biomass and Carbon Stock in Different Carbon Pools of BF

4.1.4.1. Estimation of Above Ground Biomass and Carbon Stock

The result revealed that mean above ground biomass and carbon stock stored in tree species were 720.69±503 and 338.72±236.41 t/ha respectively. The minimum and maximum carbon density with 12.61 and 1187.04 t/ha was estimated in the region of plots one and sixteen respectively (Figure 16). Accordingly, minimum and maximum of 46.28 and 4356.43 t/ha corresponding plots of CO_2 equivalents were sequestrated in above ground biomass. Details are provided in Appendix 1.

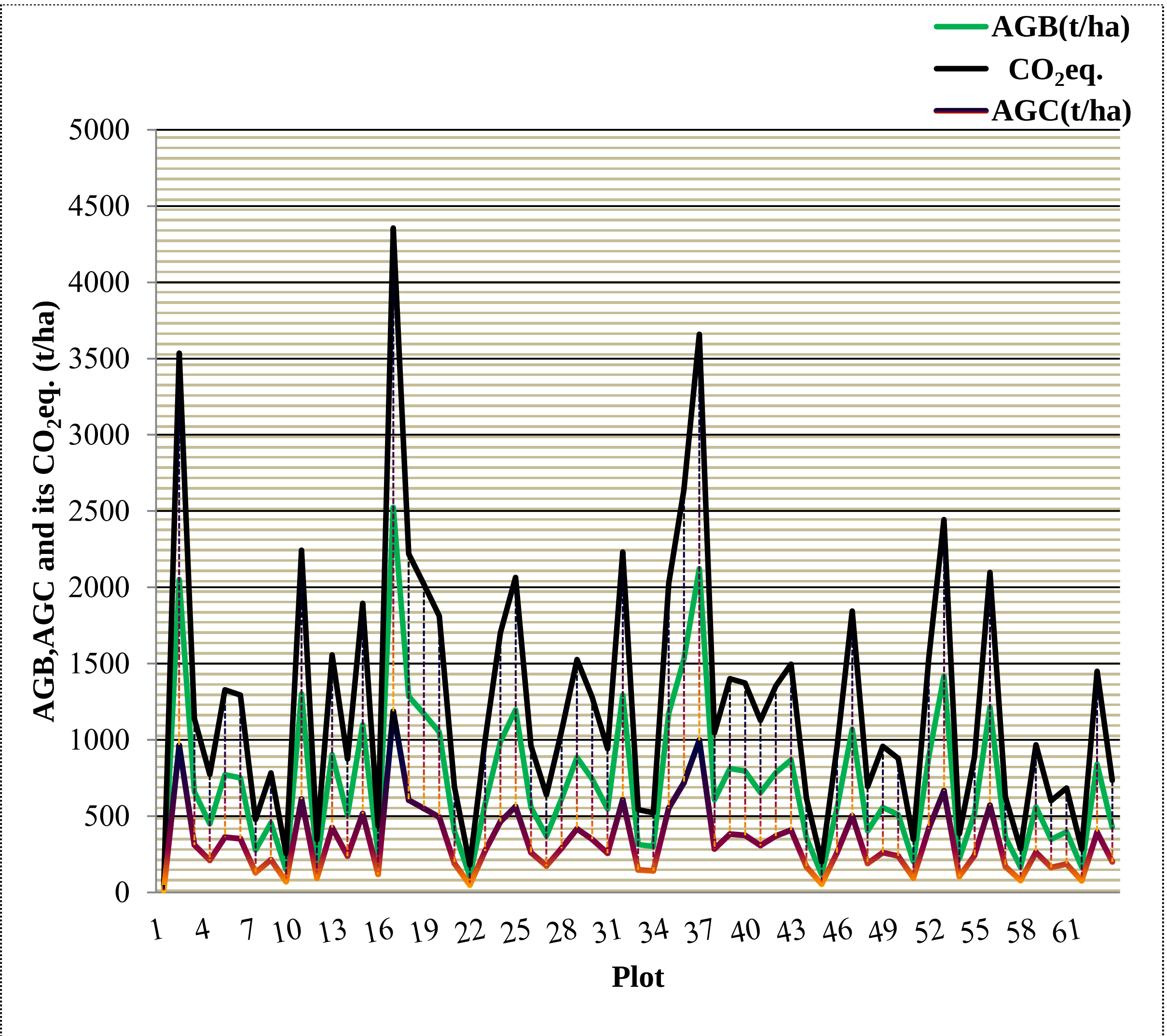


Figure 16. Mean Total AGB, AGC and its CO_2eq. of tree species within the plot

4.1.4.2. Estimation of Below Ground Biomass and Carbon Stock

The result revealed that mean below ground biomass and carbon stock stored in tree species were 144.14±100.60 and 67.74± 47.28 t/ha respectively. The minimum and maximum below ground carbon density with 2.52 and 237.41 t/ha were estimated in the region of plots one and sixteen respectively (Figure 17). Accordingly, minimum and maximum of 9.26 and 871.29 t/ha corresponding plots of CO_2 equivalents were sequestrated in below ground biomass. Details are provided in Appendix 1.

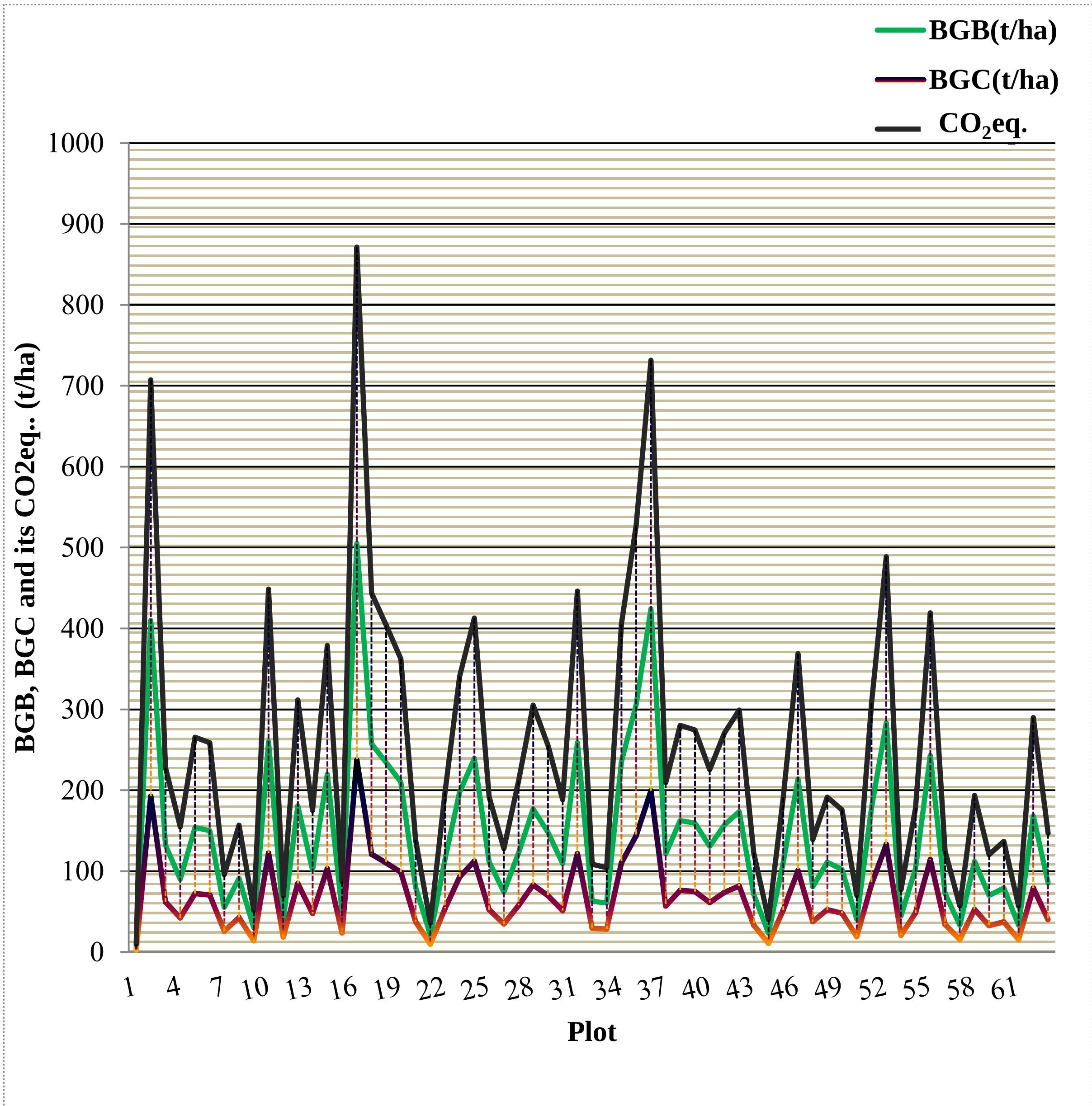


Figure 17. Mean TBGB, TBGC and its CO_2eq. of tree species within the plot

4.1.4.3. Trees Species Biomass Carbon Stock Contribution in BF

The biomass carbon stock contained in each tree species of BF varied from one tree species to the other. The result showed that tree species of *Juniperus procera* (28.09%) and *Ekebergia capensis* (19.42%) had sequestered the largest portion of the forest carbon with 95.13 and 65.79 t/ha respectively of AGC whereas *Phytolacca dodecandra* (0.04%) and *Galiniera coffeodes* (0.03%) were accounted as the least biomass carbon stock reserves (Figure 18 and Table 5).

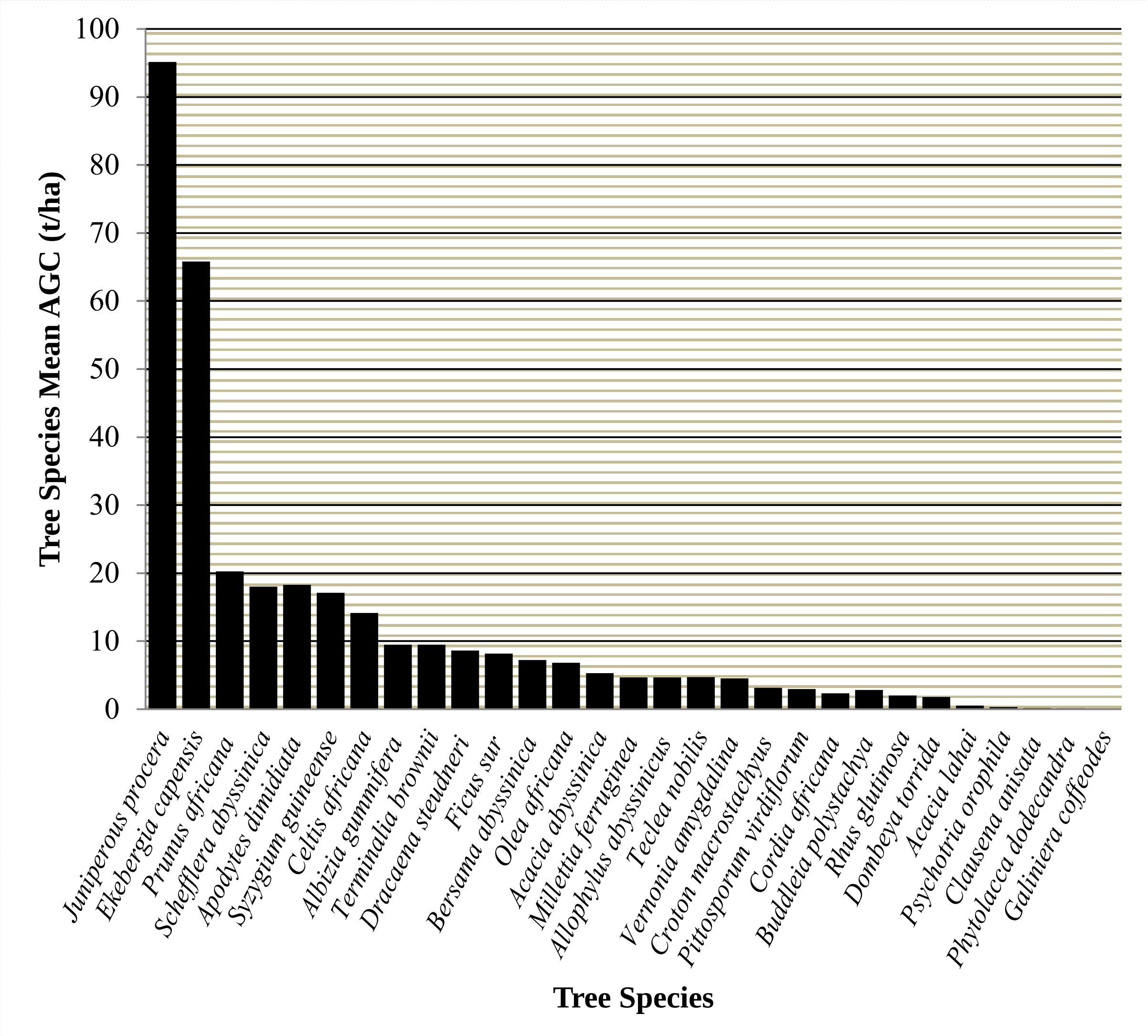


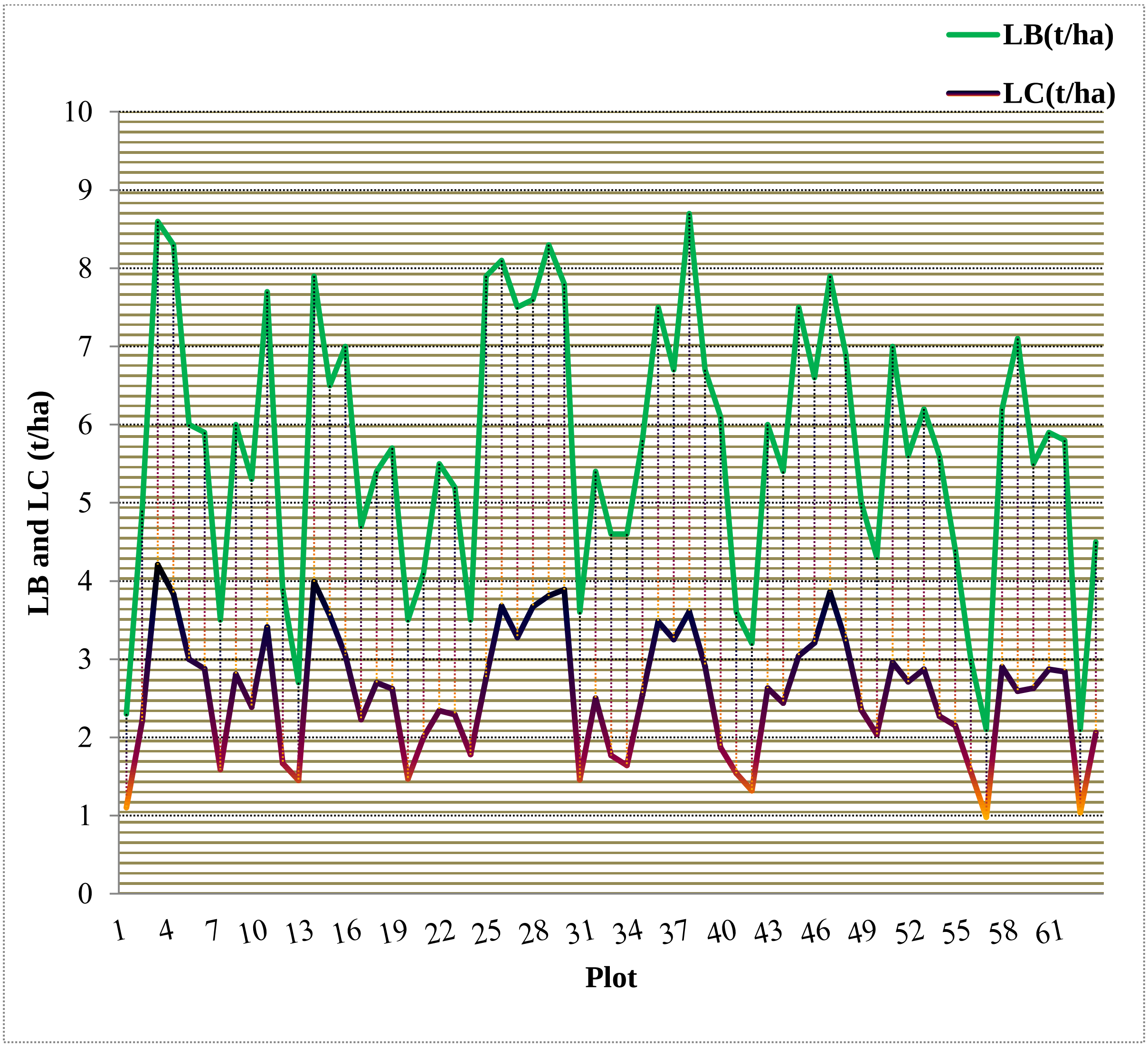
Figure 18. The biomass carbon stock contained within tree species

Table 5. Share of biomass carbon stock in each tree species

Tree Species	Tree species mean biomass carbon stock (t/ha) and each Species contribution (%)							
	TAGB	TBGB	TB	TAGC	TBGC	TC	CO_2eq.	(%)
Juniperus procera	202.41	40.48	242.89	95.13	19.03	114.16	418.97	28.09
Ekebergia capensis	139.98	28.00	167.98	65.79	13.16	78.95	289.75	19.42
Prunus africana	43.13	8.63	51.76	20.27	4.05	24.33	89.28	5.98
Schefflera abyssinica	38.36	7.67	46.03	18.03	3.61	21.64	79.41	5.32
Apodytes dimidiata	38.93	7.79	46.72	18.30	3.66	21.96	80.58	5.40
Syzygium guineense	36.36	7.27	43.64	17.09	3.42	20.51	75.27	5.05
Celtis africana	30.13	6.03	36.15	14.16	2.83	16.99	62.36	4.18
Albizia gummifera	20.15	4.03	24.18	9.47	1.89	11.36	41.71	2.80
Terminalia brownii	20.13	4.03	24.15	9.46	1.89	11.35	41.66	2.79
Dracaena steudneri	18.32	3.66	21.98	8.61	1.72	10.33	37.92	2.54
Ficus sur	17.43	3.49	20.91	8.19	1.64	9.83	36.07	2.42
Bersama abyssinica	15.35	3.07	18.42	7.21	1.44	8.66	31.77	2.13
Olea africana	14.56	2.91	17.47	6.84	1.37	8.21	30.14	2.02
Acacia abyssinica	11.29	2.26	13.55	5.31	1.06	6.37	23.37	1.57
Millettia ferruginea	9.88	1.98	11.86	4.64	0.93	5.57	20.45	1.37
Allophylus abyssinicus	9.88	1.98	11.86	4.65	0.93	5.58	20.46	1.37
Teclea nobilis	10.07	2.01	12.08	4.73	0.95	5.68	20.84	1.40
Vernonia amygdalina	9.69	1.94	11.62	4.55	0.91	5.46	20.05	1.34
Croton macrostachyus	6.70	1.34	8.04	3.15	0.63	3.78	13.88	0.93
Pittosporum virdiflorum	6.30	1.26	7.56	2.96	0.59	3.55	13.04	0.87
Cordia africana	4.93	0.99	5.91	2.32	0.46	2.78	10.20	0.68
Buddleja polystachya	6.00	1.20	7.20	2.82	0.56	3.38	12.41	0.83
Rhus glutinosa	4.31	0.86	5.18	2.03	0.41	2.43	8.93	0.60
Dombeya torrida	3.78	0.76	4.53	1.78	0.36	2.13	7.82	0.52
Acacia lahai	1.17	0.23	1.41	0.55	0.11	0.66	2.43	0.16
Psychotria orophila	0.61	0.12	0.73	0.29	0.06	0.34	1.26	0.08
Clausena anisata	0.33	0.07	0.39	0.15	0.03	0.19	0.68	0.05
Phytolacca dodecandra	0.30	0.06	0.36	0.14	0.03	0.17	0.63	0.04
Galiniera coffeodes	0.19	0.04	0.23	0.09	0.02	0.11	0.39	0.03

4.1.4.4. Estimation of Carbon Stock in Litter, Herb, and Grass (LHG)

The result showed that mean LHGs biomass and carbon stock contained were 5.69± 1.72 and 2.58±0.81 t/ha respectively. The minimum and maximum LHGs carbon density with 0.98 and 4.21 t/ha were estimated in the region of plots fifty six and two respectively (Figure 19). Accordingly, minimum and maximum of 3.59 and 15.45 t/ha corresponding plots CO_2 equivalents were sequestrated in LHGs biomass. Details are provided in Appendix 2.



Where, LB- Litter Biomass and, LC- Litter Carbon

Figure 19. Mean Litter Biomass (LHGs) and Litter Carbon within the plot

4.1.4.5. Estimation of Soil Organic Carbon

Likewise other carbon pools, the result showed that mean soil organic carbon stock contained in it was 230.82±68.88 t/ha. The minimum and maximum soil organic carbon density with 88.47 and 358.07 t/ha were estimated in the region of plots one and twenty nine respectively (Figure 20). Accordingly, minimum and maximum of 324.69 and 1314.10 t/ha corresponding plots CO_2 equivalents were sequestrated in the soil. Details are provided in Appendix 3.

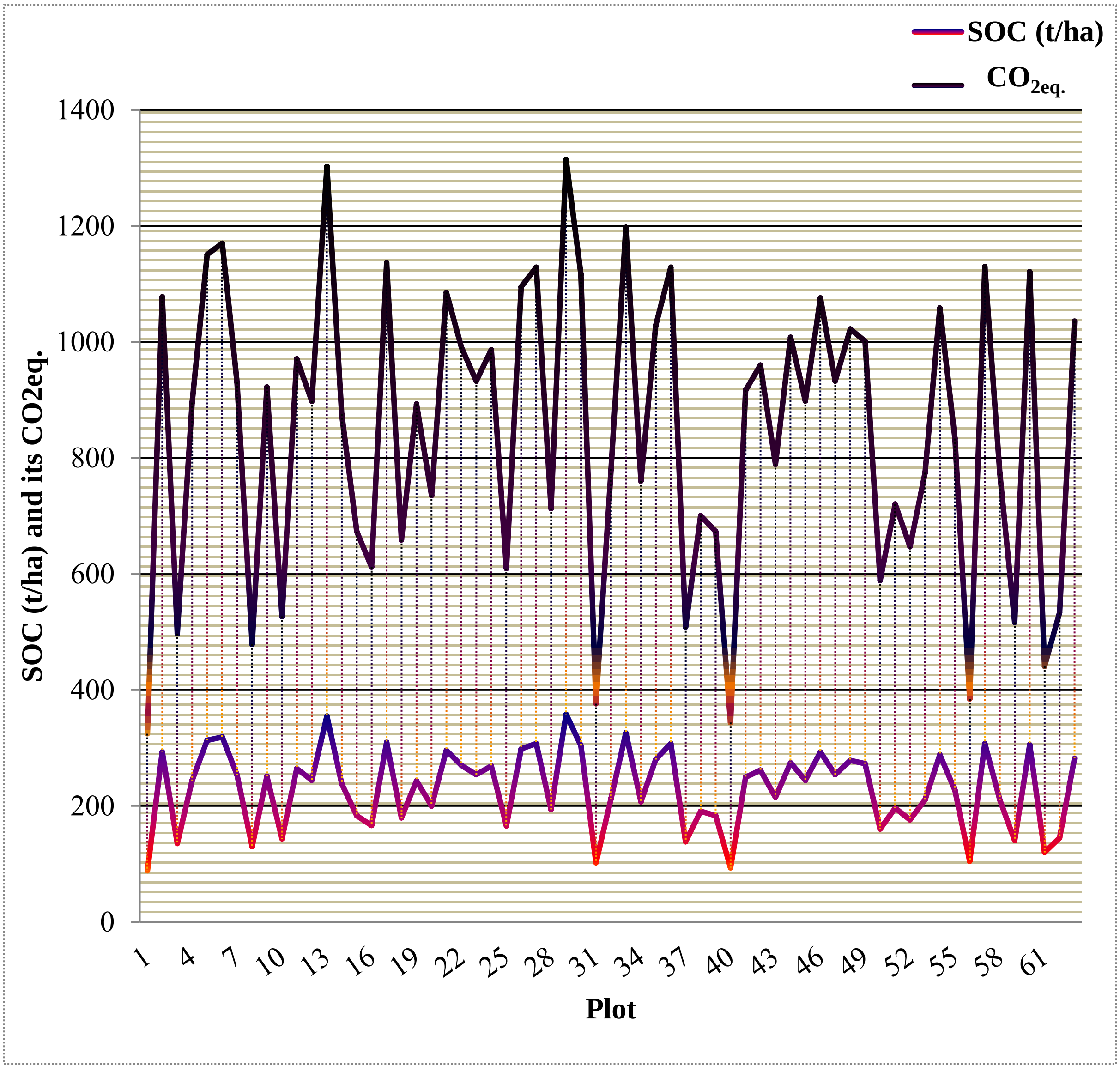


Figure 20. Mean SOC and its CO_2eq. within the plot

4.1.4.6. Total Carbon Stock of BF

The carbon stock in the plots was ranged in the minimum value of 104.7 t/ha in the region of plot one and maximum value of 1593.43 t/ha in the region of plot sixteen with corresponding minimum value of 384.25 and maximum value 5847.89 CO_2 equivalents (Figure 21).

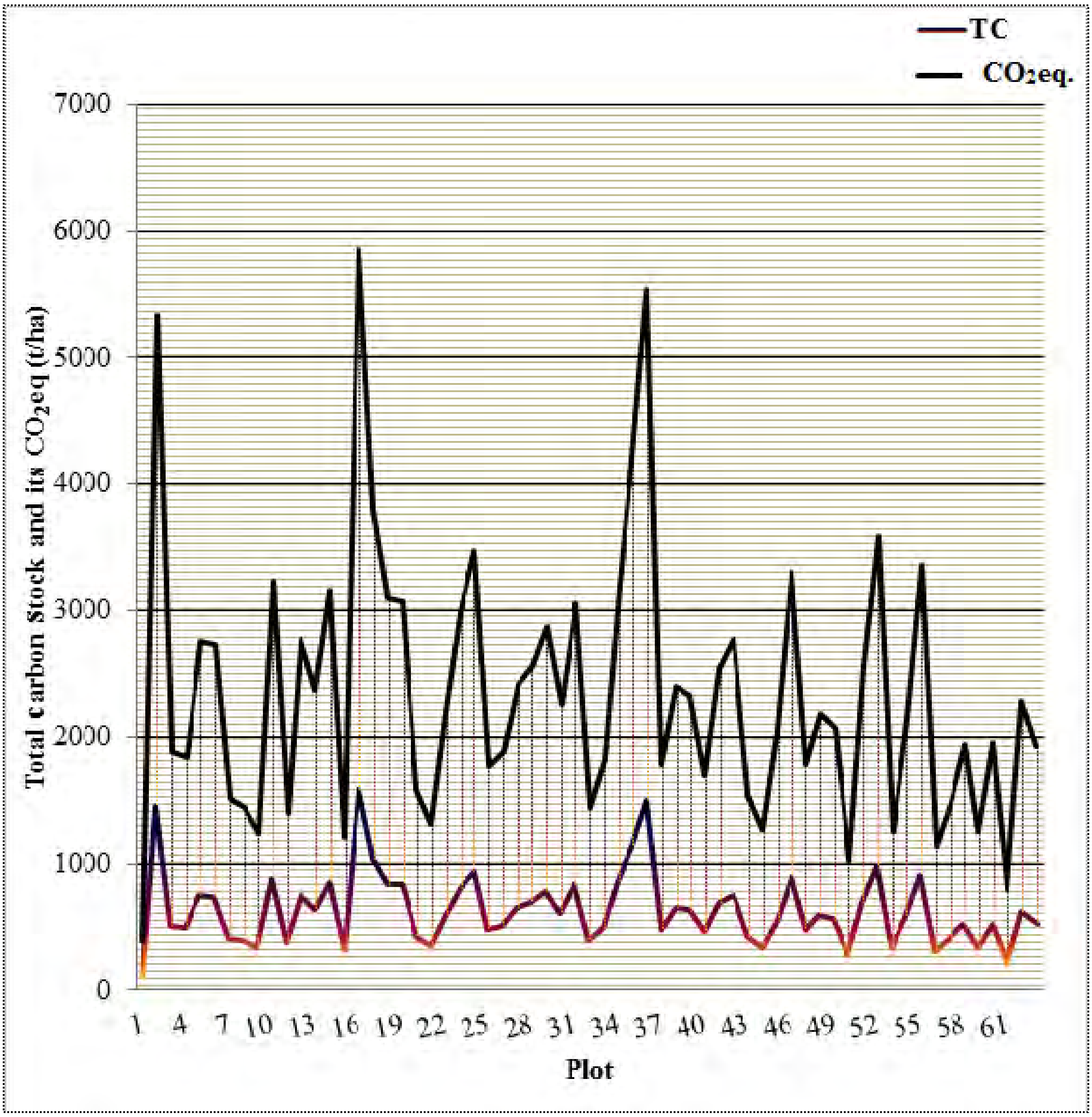


Figure 21. Total carbon stock of the plots

The total mean carbon stock of BF was obtained by summing up the carbon stock found in each carbon pool namely, aboveground carbon stock (AGC), belowground carbon stock (BGC), carbon in LHGs (LC) and carbon in organic soil (SOC) with 338.72, 67.74, 2.58 and 230.82 t/ha respectively. Therefore, the total carbon stock of BF in 2016 was to be 639.87±293.69 t/ha with 2348.32±1077.84 CO_2 equivalents (Table 6) which could generate carbon credit of US$ 9,862.94.

Carbon Pools	TAGB	TBGB	TB	TAGC	TBGC	TCt.	LC	SOC	TCp	CO_2 eq.
Trees	720.69	144.14	864.82	338.72	67.74	406.47				
LHGs							2.58			
Soil								230.82		
Total	720.69	144.14	864.82	338.72	67.74	406.47	2.58	230.82	639.87	2348.32

Table 6. Carbon pools with total biomass carbon stock and its CO_2eq. of BF in 2016 in (t/ha)

Hereafter and before, TAGB and TBGB – Total above- and belowground biomass respectively, TB – Total biomass, TCt and TCp – Total carbon for trees and pools respectively, LC – Litter carbon for LHGs (litter, herbs and grasses), SOC – Soil organic carbon, and CO_2eq. – Carbon dioxide equivalent.

Accordingly, the carbon stock distribution and the percent share of each carbon pool was examined to be maximum carbon reservoir in the trees accounted 64% (53% of AGC with 11% of BGC) and the soil was the second carbon reservoir with 36% while minimum carbon stock was contained in the litter, herbs and grasses (Figure 22).

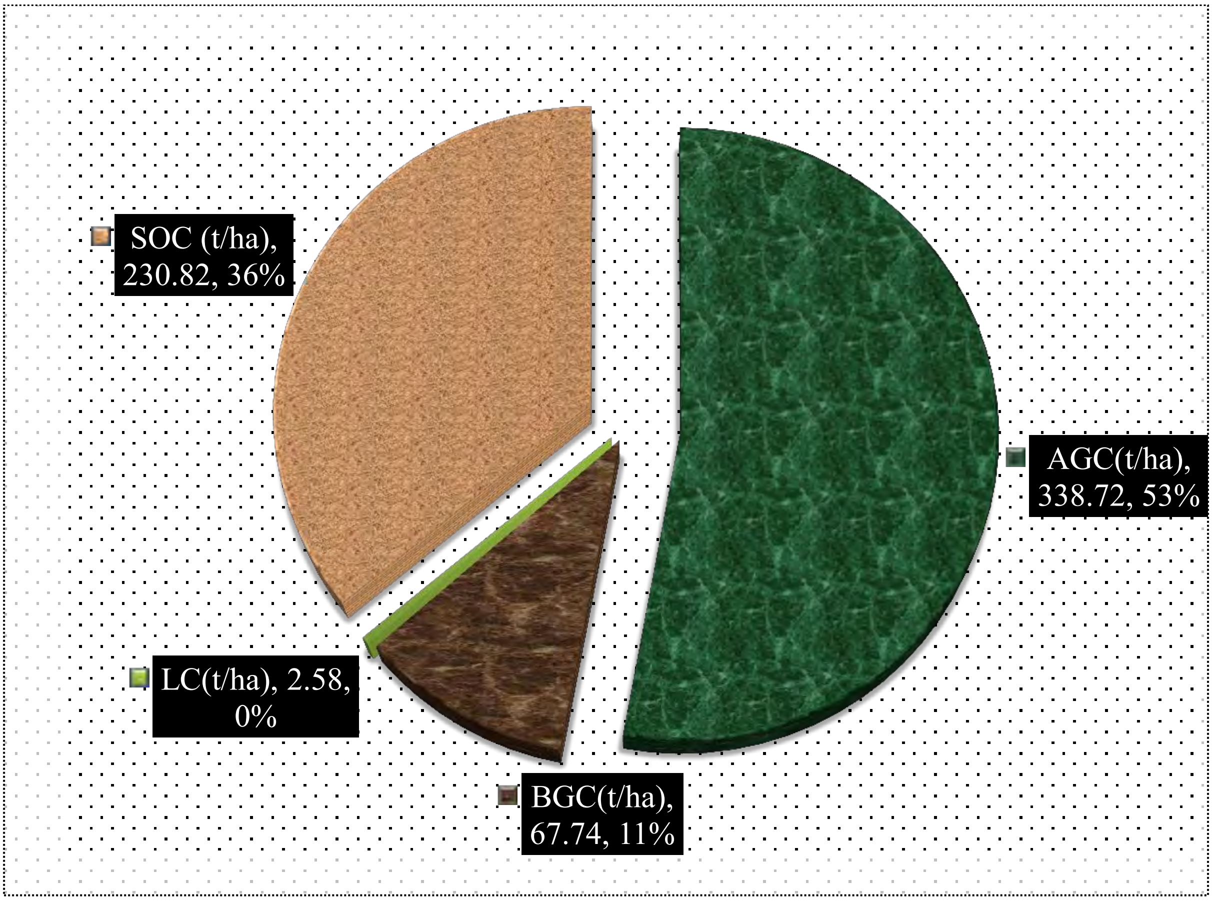


Figure 22. The BF carbon pools‟ percentage distribution of carbon reservoirs

4.1.4.7. Factors Affecting Carbon Stocks of BF

In this study, from the environmental factors which affect forest carbon stock of altitude, slope and aspect were investigated and observed that their effect had week correlation on the carbon pools.

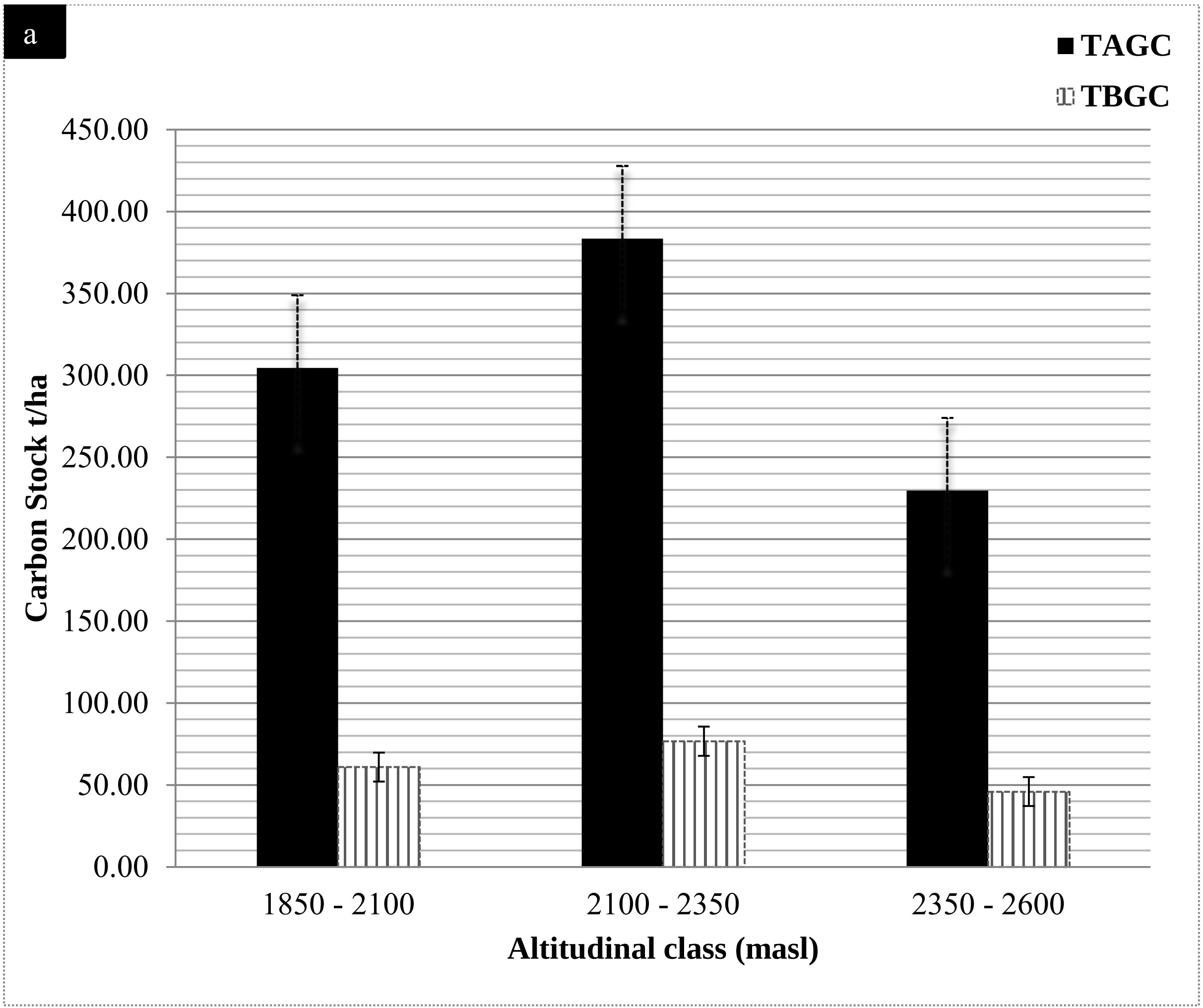
4.1.4.8. Carbon Stock along Altitudinal Gradient

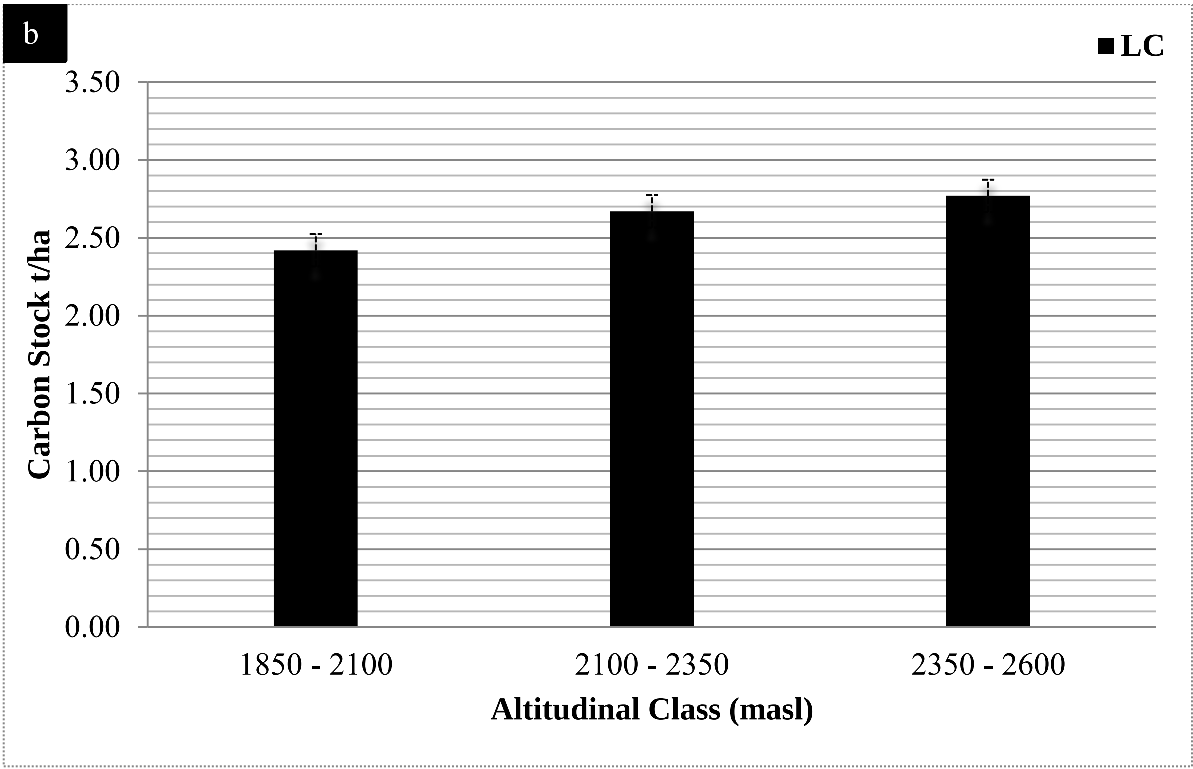
The different carbon pools such as carbon stock in above and belowground of trees, LHGs and carbon in soil were distributed along the altitudinal gradient and the carbon stored was varied among carbon pools as shown in Figure 22.

Hence, the distribution of mean total aboveground biomass carbon stock density was varied in altitudinal class and the amount found in each lower, middle and higher altitudinal class of the forest were 304.53±186.98, 383.41±273.82 and 229.71±138.94 t/ha (Figure 23a and Table 10a). Since the mean total belowground biomass carbon stock was derived from the above ground biomass; the trend showed similar fashion in each altitudinal class. The mean total belowground biomass carbon stock density found in each lower, middle and higher altitudinal class of the forest were 60.91±37.396, 76.68±54.76 and 45.94±27.79 t/ha. Thus, the maximum aboveground biomass carbon stock of BF was recorded in middle altitudinal class, followed by lower and then upper altitudinal classes. Despite the presence of mean biomass carbon stock density variation in altitudinal classes, there was no statistical significant differences ($p>0.05$) in above and belowground carbon stocks along altitudinal gradient (Table 7).

In the same way, the mean total carbon stock density of LHGs was varied in altitudinal class. The mean total carbon density of LHGs found in each lower, middle and higher altitudinal class of the forest were 2.42 ±0.78, 2.67±0.76 and 2.77±1.22 t/ha (Figure 23b and Table 10a). Hence, the mean total maximum carbon stock density of LHGs was stored in the higher altitudinal class, followed by middle and lower altitudinal classes that carbon stock density was increased from lower to higher altitudinal classes with no statistical significant differences along altitudinal gradient (Table 7).

Similarly, the mean total soil carbon stock density was varied in classes of lower, middle and higher altitude with carbon stock density of 216.78±72.12, 241.97±61.51 , and 225.65±94.31 t/ha respectively (Figure 23c and Table 10a). Therefore, the mean total maximum soil carbon stock was stored in the middle altitudinal class, followed by higher and lower altitudinal classes with no statistical significant differences along altitudinal gradient (Table 7).





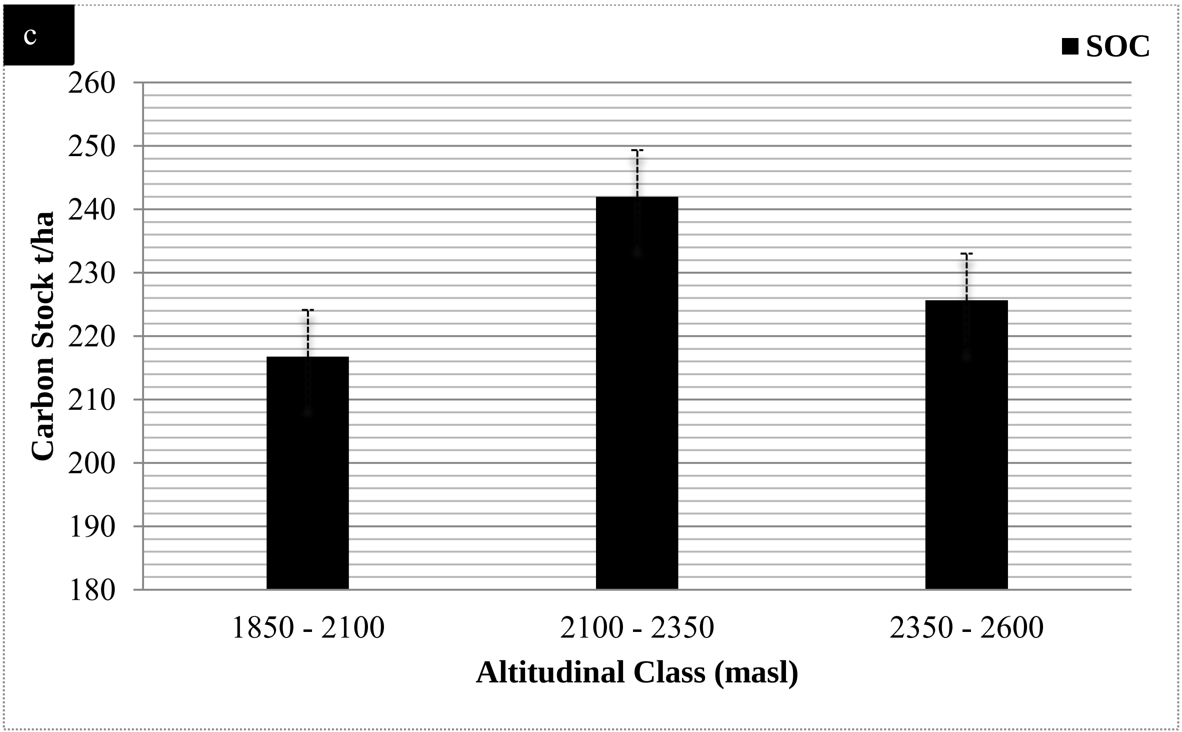


Figure 23. Mean Carbon stocks (t/ha) in different carbon pools (a)-Trees-TAGC and TBGC, (b)-C(LHGs) and (c)-SOC with altitudinal classes

Table 7. Summarized results of one way ANOVA of correlation between different carbon stocks with altitude

Gradient	Carbon Stock			
Altitude	AGC	BGC	C(LHGs)	SOC
F	0.3765	0.3765	0.3950	0.3906
P	0.7935	0.7935	0.7338	0.7478

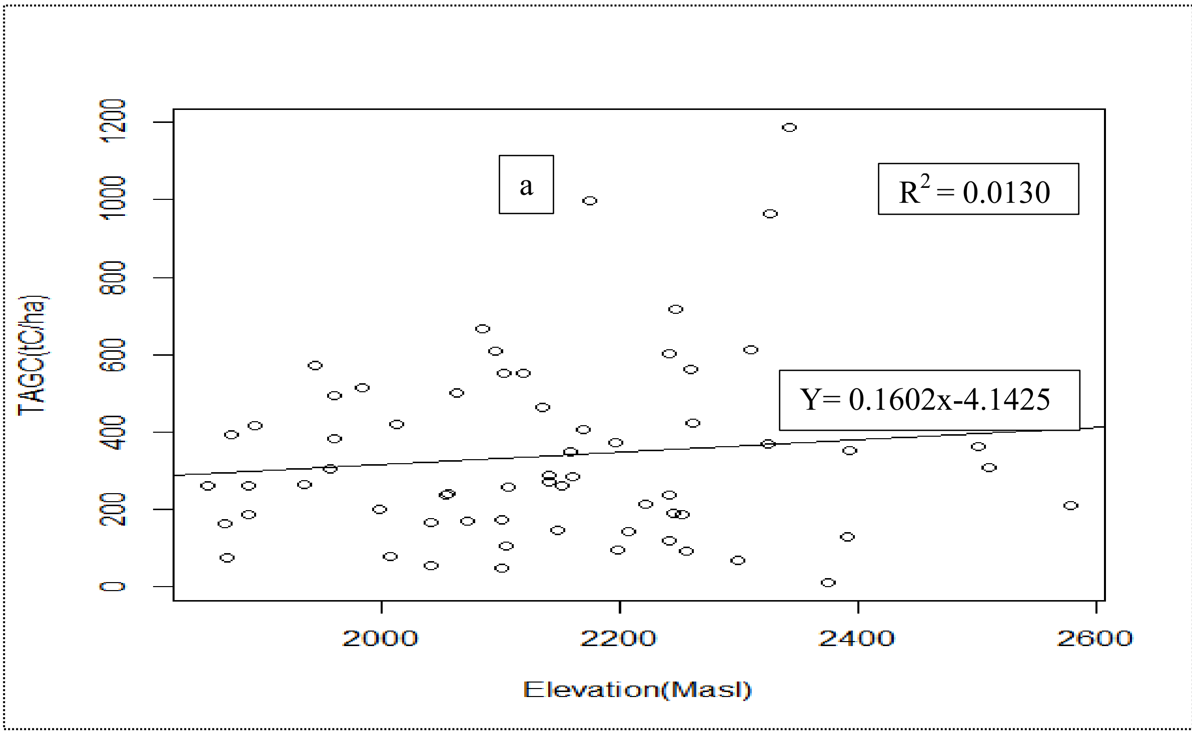
AGC, BGC - above- and belowground carbon respectively; C(LHGs) - litter, herbs and grasses carbon, and SOC-soil organic carbon

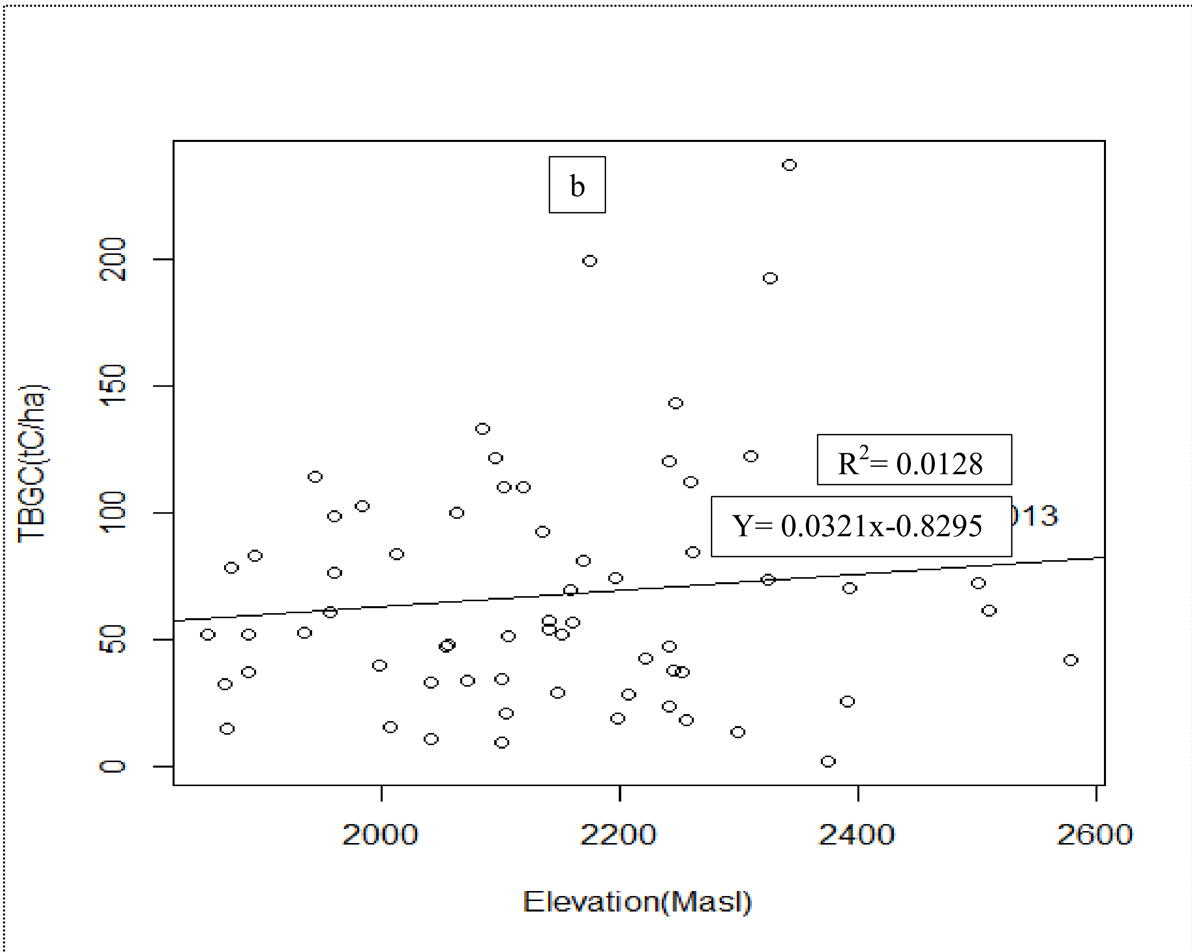
4.1.4.9. Correlation between Carbon Stock and Altitude

In order to analyse the correlation between carbon stock and altitude, sixty three plots of biomass carbon stock were regressed against corresponding altitudinal gradient. Consequently, the total aboveground carbon stock of trees in line with altitude showed that the maximum aboveground biomass carbon stock was found in middle altitudinal class, followed by lower and then upper altitudinal classes. The relationships were linearly regressed and ultimately resulted that aboveground biomass carbon stock and altitude had weak positive correlation (R^2= 0.0130, Figure 24a). Total belowground biomass carbon stock has also showed similar trend as it was derived from aboveground biomass (R^2= 0.0128, Figure 24b).

Similarly, the relationship between LHGs biomass carbon stock and altitude was conducted. The ultimate result showed that weak correlation (R^2= 0.0119, Figure 24c).

The soil organic carbons of all plots with corresponding altitude were regressed linearly. The result showed that weak correlation (R^2= 0.0121, Figure 24d).


a
$R^2 = 0.0130$
Y= 0.1602x-4.1425
TAGC(tC/ha)
0
200
400
600
800
1000
1200
2000
2200
2400
2600
Elevation(Masl)


b
R^2= 0.0128
Y= 0.0321x-0.8295
)13
TBGC(tC/ha)
0
50
100
150
200
2000
2200
2400
2600
Elevation(Masl)

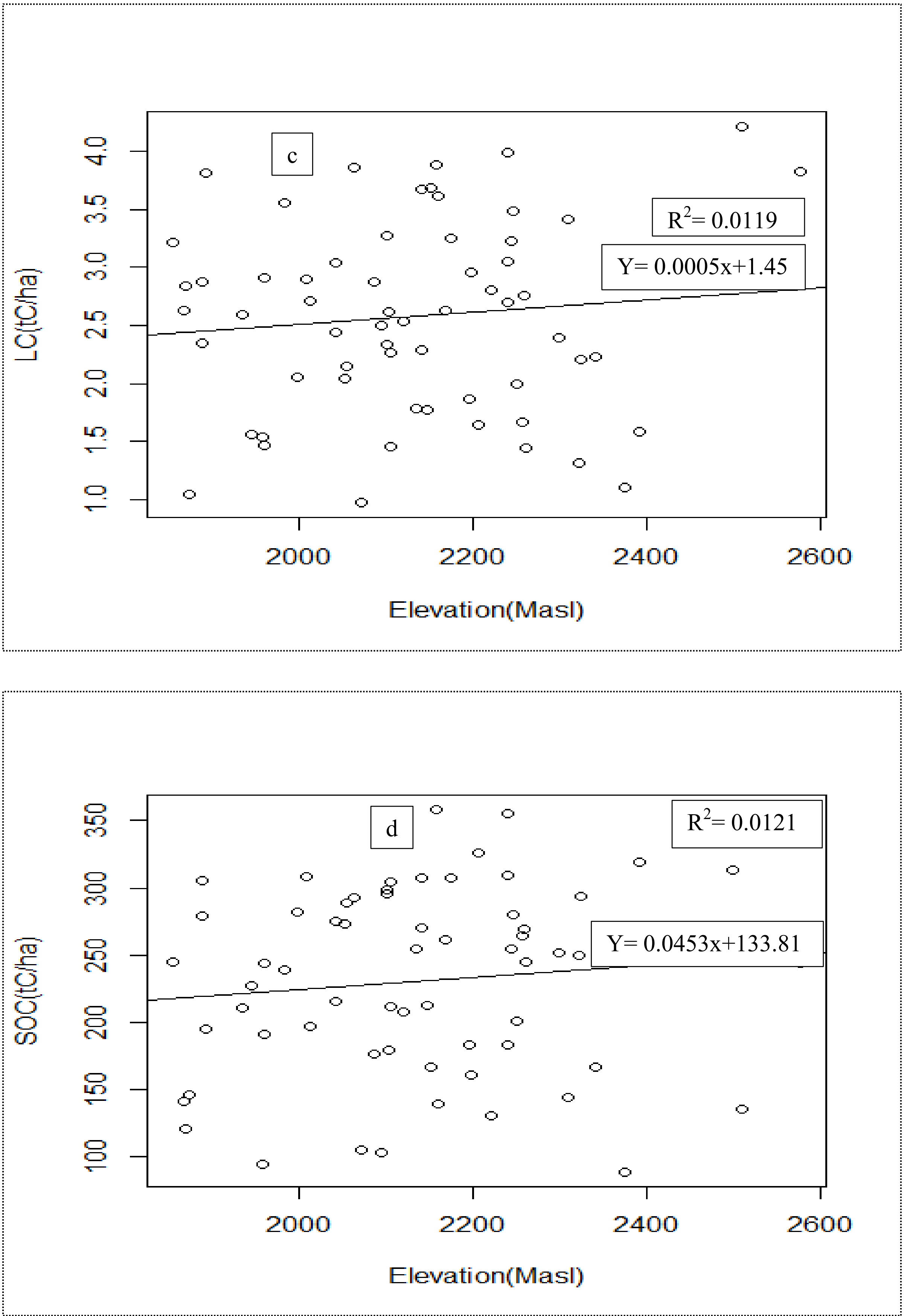


Figure 24. The correlation of carbon stock of different carbon pools (a) - TAGC, (b)- TBGC of trees, (c)-C(LHGs) and (d)-SOC with altitudinal gradient

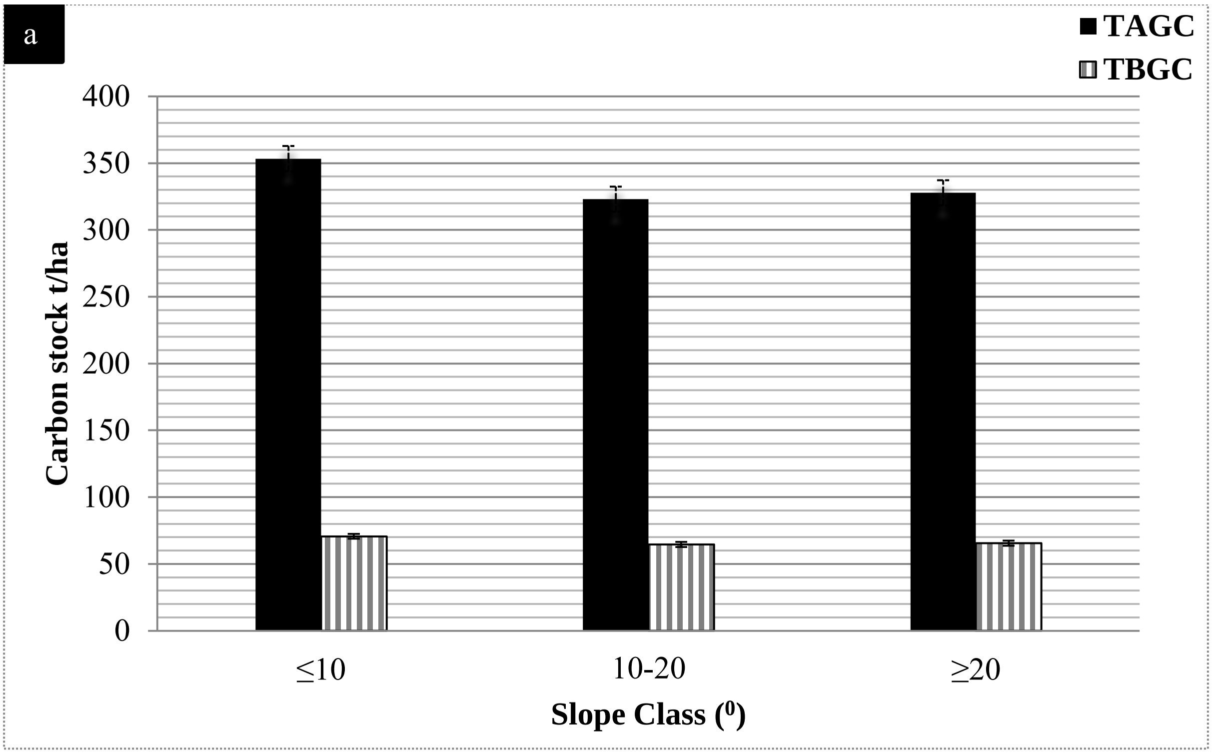
4.1.4.10. Carbon Stock along Slope Gradient

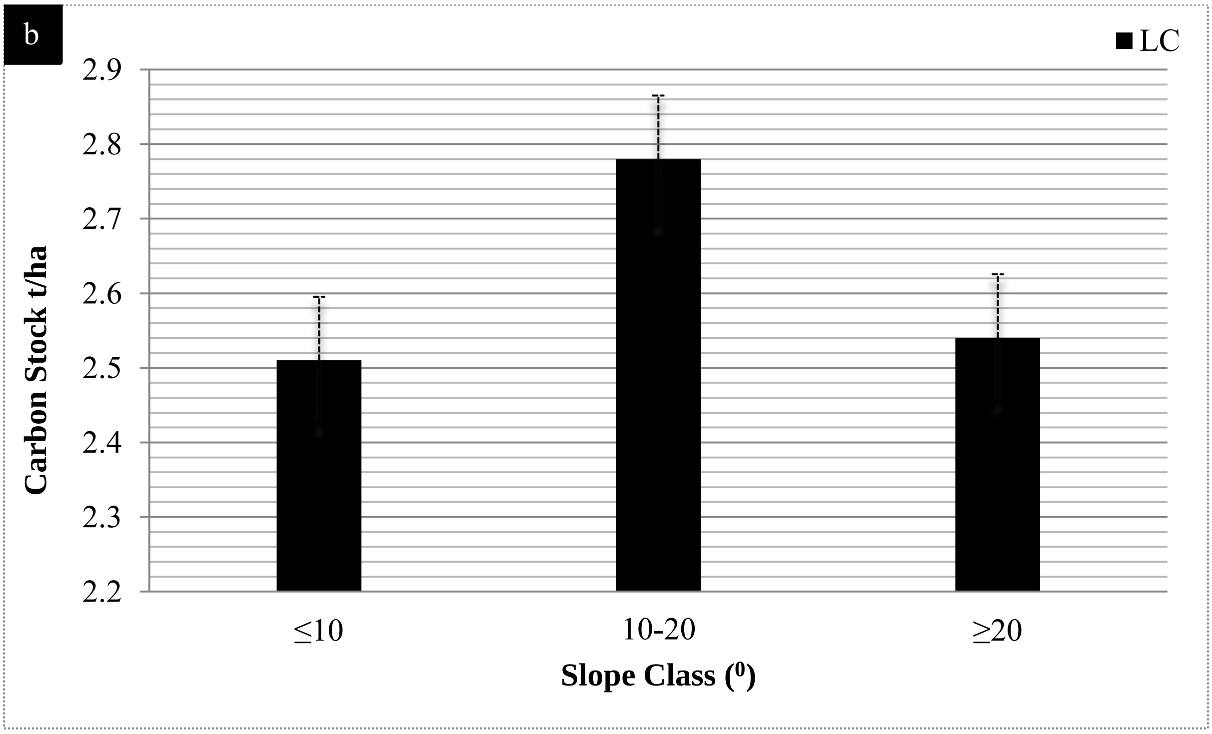
The effect of slope on carbon pools such as carbon stock in above and belowground of trees, LHGs and carbon in soil was also investigated in each lower, middle and higher slope classes.

Accordingly, the mean total aboveground biomass carbon stock density was varied in slope class and the recorded amount in each lower, middle and higher slope class of the forest were 353.30±212.01, 323.01±218.41 and 327.78±299.35 t/ha (Figure 25a and Table 10b) while mean total belowground biomass carbon stock density recorded in each respective slope class were 70.66±42.40, 64.60±43.68 and 65.56±59.87 t/ha. Hence, the maximum aboveground biomass carbon stock was recorded in lower slope class, followed by upper and then middle slope class. Except the presence of mean biomass carbon stock density variation in slope class, there was no statistical significant differences ($p>0.05$) in above and belowground carbon stocks along slope gradient (Table 8).

Similarly, the mean total carbon stock density of LHGs was varied in slope classes. The mean total carbon density of LHGs found in each lower, middle and higher slope class of the forest were 2.51±0.80, 2.78±0.81 and 2.54±0.86 t/ha (Figure 25b and Table 10b). Hence, the mean total maximum carbon stock density of LHGs was stored in the middle slope class, followed by higher and lower slope class with no significant differences ($p>0.05$) along slope gradient (Table 8).

In the same way, the mean total soil carbon stock density was varied in classes of lower, middle and higher altitude with carbon stock density of 219.90±71.91, 240.45±56.77, and 241.02±74.59 t/ha respectively (Figure 25c and Table 10b). Therefore, the mean total maximum soil carbon stock was stored in the higher slope class, followed by middle and lower slope class with no statistical significant differences along slope gradient (Table 8).


a
TAGC
TBGC
400
350
300
250
200
150
100
50
0
Carbon stock t/ha
≤10
10-20
≥20
Slope Class (0)


b
LC
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
Carbon Stock t/ha
≤10
10-20
≥20
Slope Class (0)

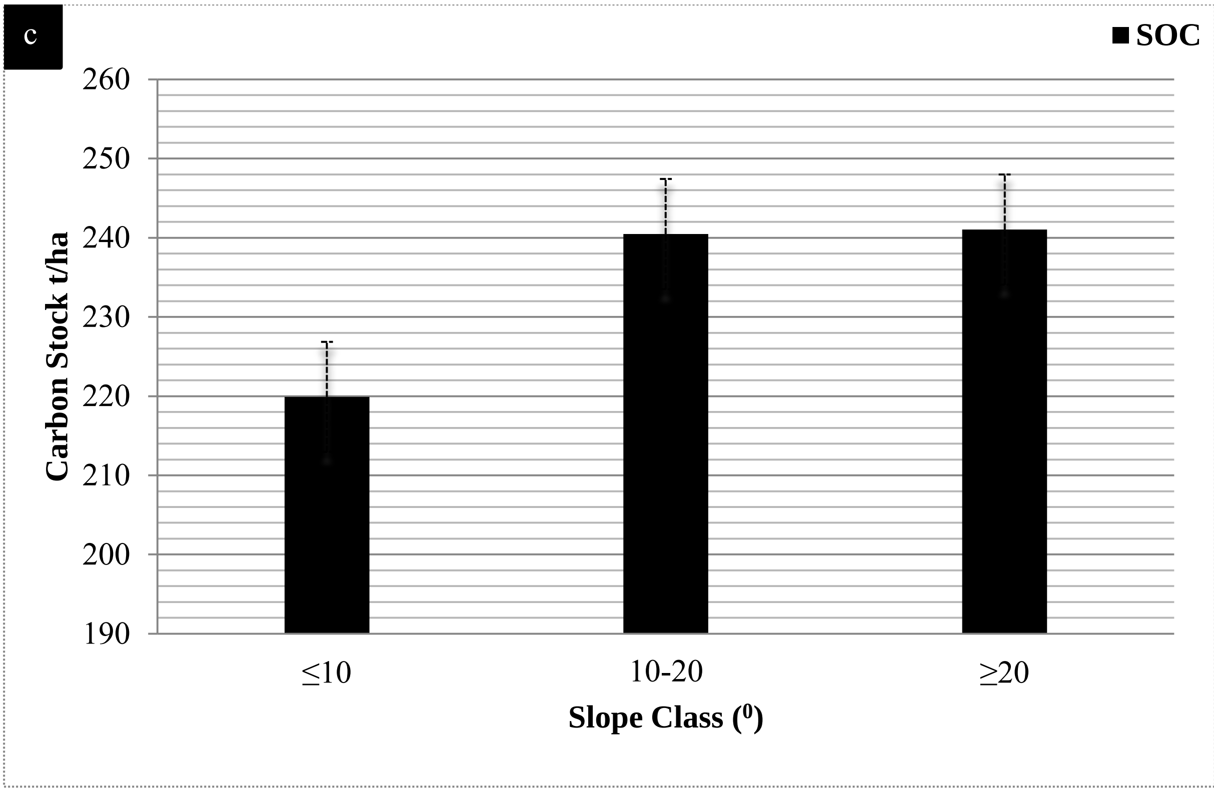


Figure 25. Mean Carbon stocks (t/ha) in different carbon pools (a) - trees-TAGC and TBGC, (b) - C (LHGs) and (c) - SOC with slope classes

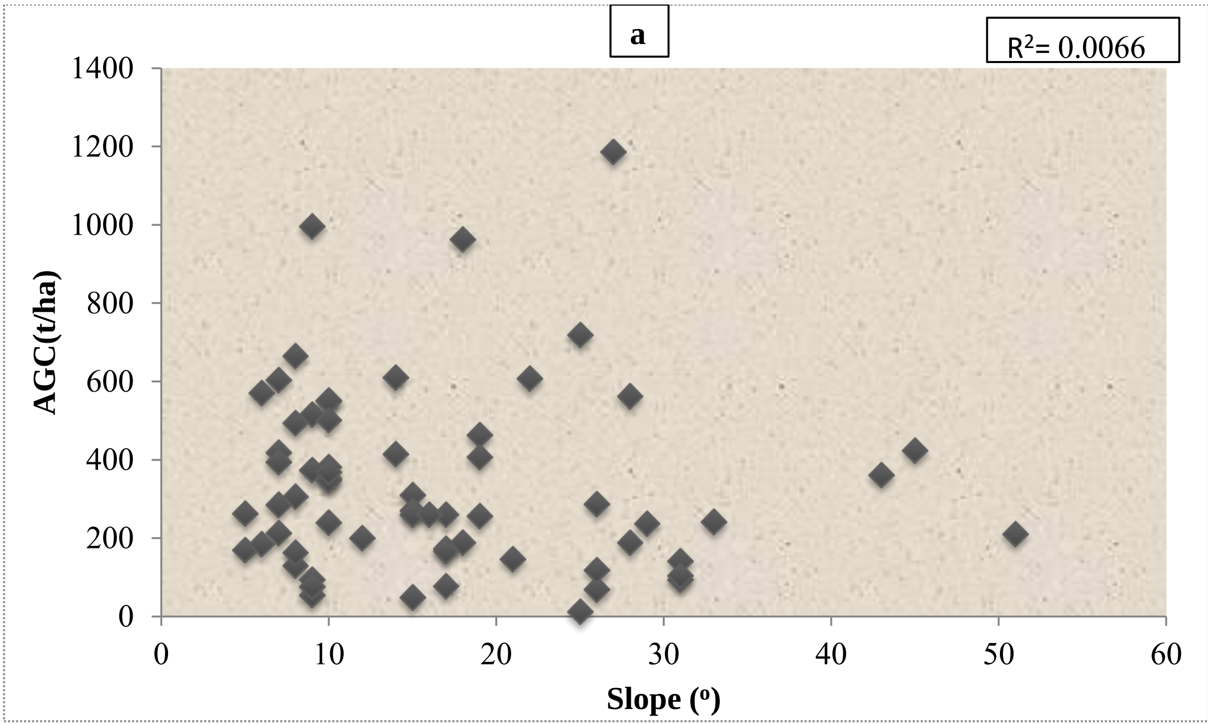
Gradient	Carbon Stocks			
Slope	AGC	BGC	LC	SOC
F	0.5271	0.5271	0.8470	3.7611
P	0.4047	0.4047	0.0565	0.0571

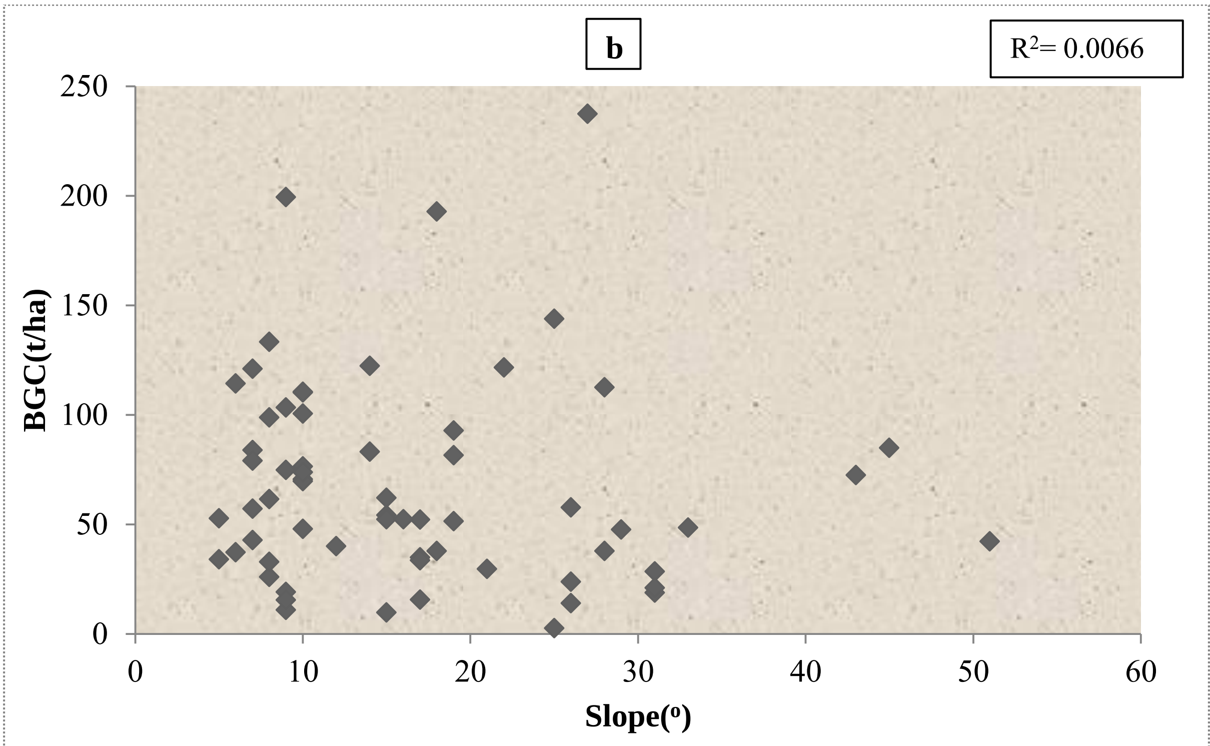
AGC, BGC - above- and belowground carbon respectively; C(LHGs) - litter, herbs and grasses carbon, and SOC-soil organic carbon

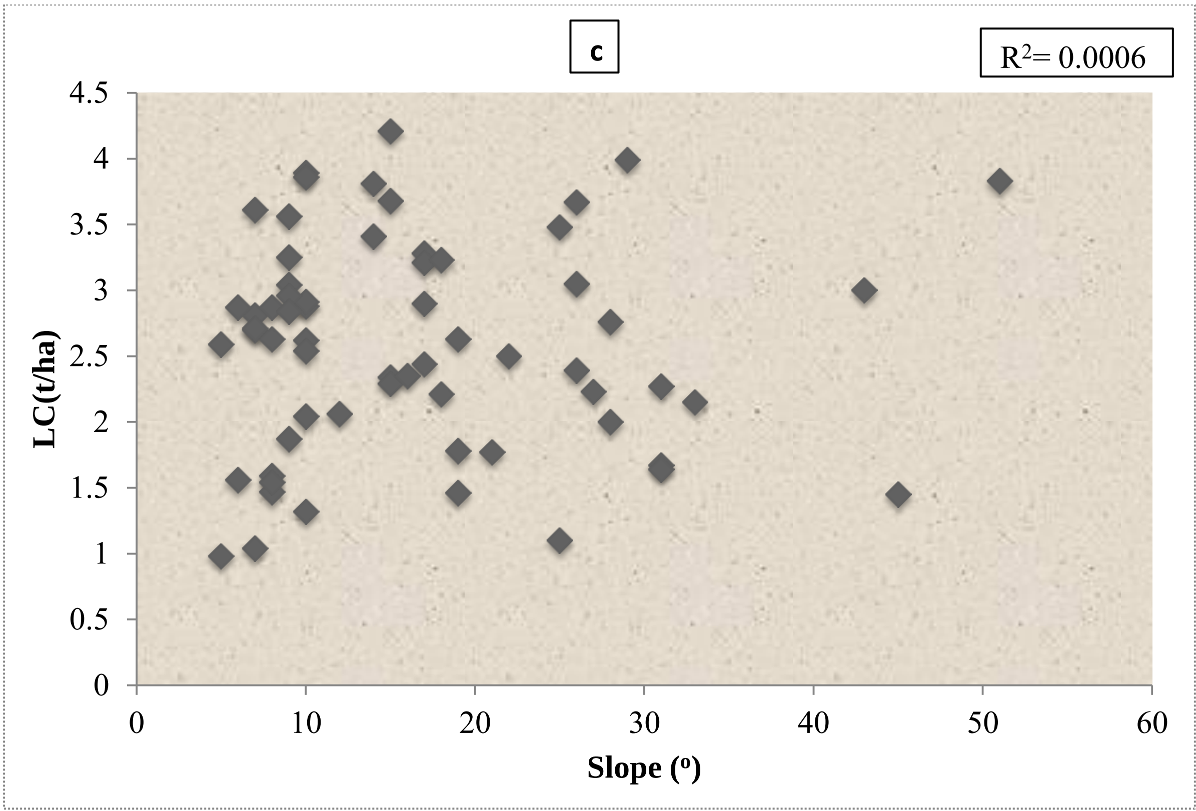
Table 8. Summarized results of one way ANOVA of correlation between different carbon stocks with slope

4.1.4.11. Correlation between Carbon Stock and Slope

The carbon pools of all plots with slope gradient were regressed linearly. As the result revealed that the correlation between all carbon pools distribution and slope gradient did not show clear pattern in linear regression (Figure 26 a, b, c, d). Therefore, slope gradient did not influence the carbon pools considerably.







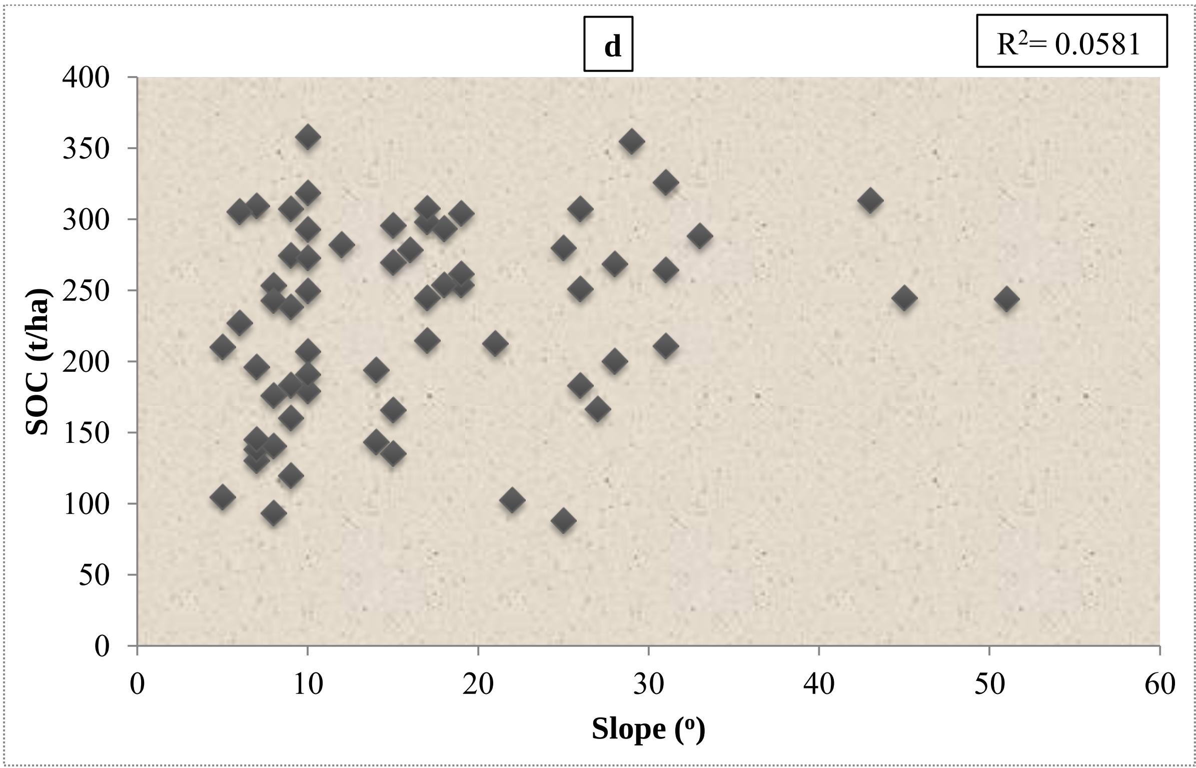


Figure 26. The correlation of carbon stock of different carbon pools (a) - TAGC, (b)- TBGC of trees, (c)-C(LHGs) and (d)-SOC along slope gradient

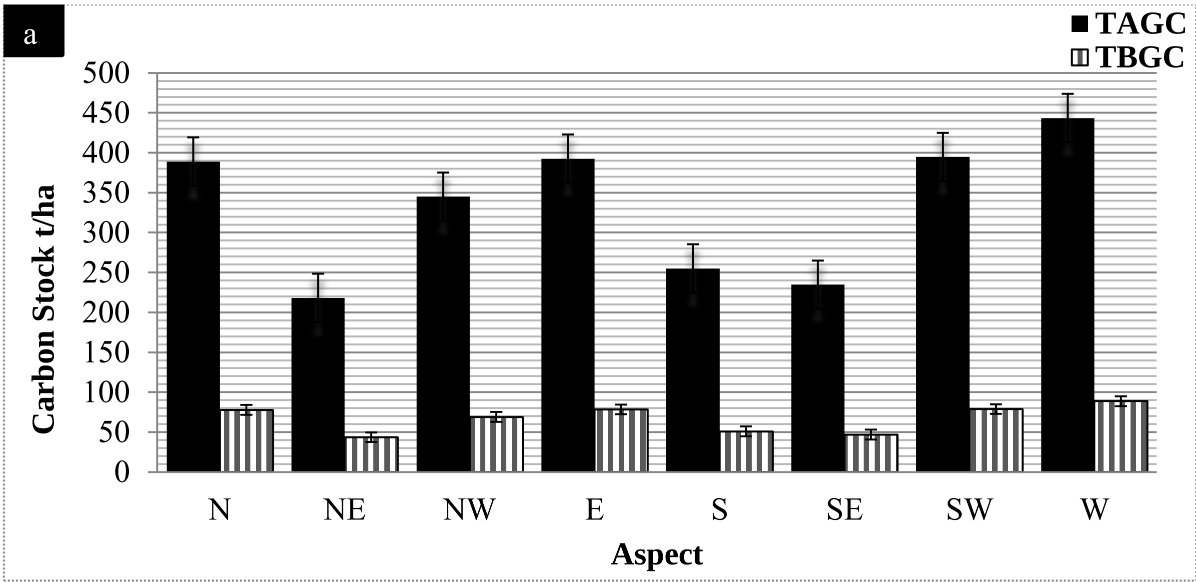
4.1.4.12. Aspect on Carbon Stock

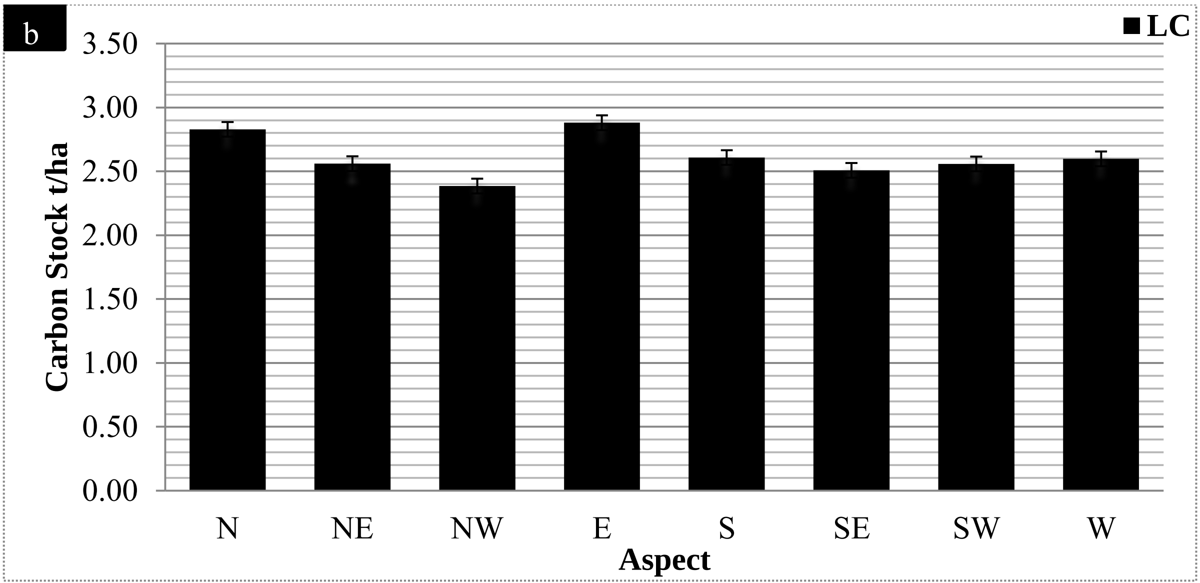
Likewise, the effect of aspect on carbon pools such as carbon stock in above and belowground of trees, LHGs and carbon in soil were investigated in different directions of the forest.

Accordingly, the mean total aboveground biomass carbon stock density was varied in aspect and the recorded amount in each North (N), Northeast (NE), Northwest (NW), East (E), South (S), Southeast (SE), Southwest (SW) and West (W) aspect of the forest were 388.96 ±197.03 , 218.01±153.57, 344.97±282.13, 392.40±171.15, 254.93±171.45, 234.70±161.09, 394.65±301.91 and 443.44±296.16 t/ha (Figure 27a and Table 10c) while mean total belowground biomass carbon stock density recorded on each respective aspect was 77.79±39.41, 43.60±30.71, 68.99±56.43, 78.48±34.23, 50.99±34.29, 46.94±32.22, 78.93±60.38 and 88.69±59.23 t/ha. Hence, the maximum aboveground biomass carbon stock was recorded on W part, followed by SW part of the forest whereas the lowest carbon stock density was recorded on the NE aspect followed by the SE aspect. Except the presence of mean biomass carbon stock density variation on aspect facings, there was no statistical significant differences ($p>0.05$) in above and belowground carbon stocks along aspect gradient (Table 9).

Similarly, the mean total carbon stock density of LHGs was varied in slope classes. The mean total carbon density of LHGs found in each N, NE, NW, E, S, SE, SW and W aspect of the forest were 2.83±0.96, 2.56±1.23, 2.39±0.79, 2.88±0.58, 2.61±0.82, 2.51±0.85, 2.56±1.01, and 2.60±0.75 t/ha (Figure 27b and Table 10c). Hence, the mean total maximum carbon stock density of LHGs was stored on E part, followed by N aspect of the forest whereas the lowest carbon stock was stored on NW part, followed by SW aspect of the forest with insignificant differences ($p>0.05$) (Table 9).

In the same way, the mean total soil carbon stock density was varied in aspect of N, NE, NW, E, S, SE, SW and W with carbon stock density of 203.82±46.67, 319.36±33.78, 219.37±66.60, 289.71±19.81, 232.19±81.21, 202.24±96.20, 230.42±79.08 and 226.16±38.72 t/ha respectively (Figure 27c and Table 10c). Therefore, the mean total maximum soil carbon stock was stored on NE part, followed by E part of the forest whereas the lowest carbon stock was stored on SE part, followed by N part of the forest with no statistical significant differences (Table 9).


a
TAGC
TBGC
Carbon Stock t/ha
500
450
400
350
300
250
200
150
100
50
0
N
NE
NW
E
S
SE
SW
W
Aspect


b
LC
Carbon Stock t/ha
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
N
NE
NW
E
S
SE
SW
W
Aspect

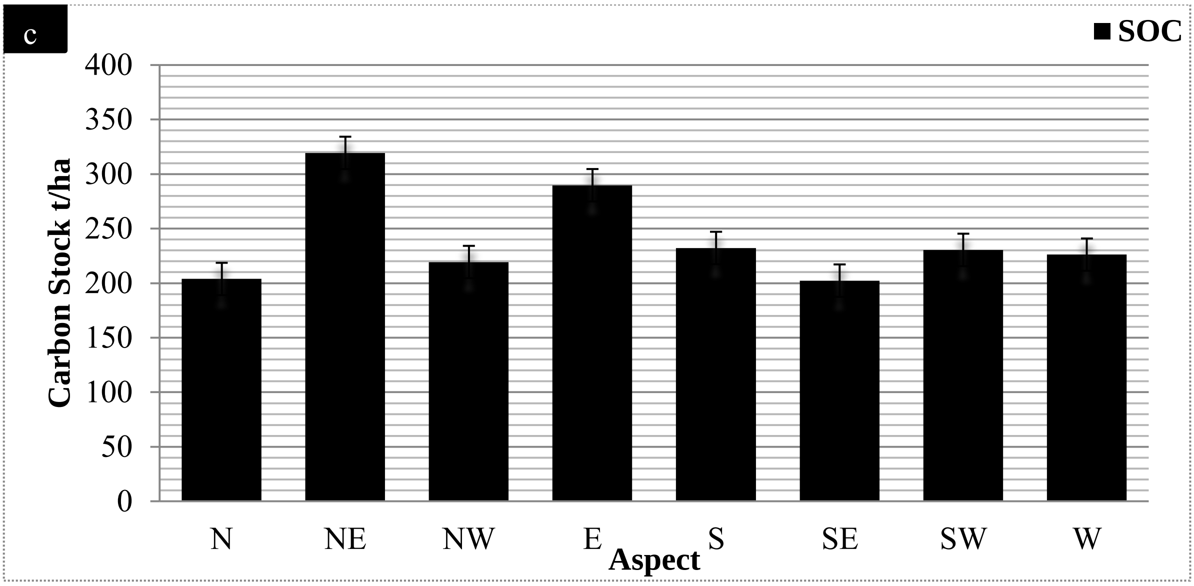


Figure 27. Mean Carbon stocks (t/ha) in different carbon pools (a) - trees-TAGC and TBGC, (b) - C (LHGs) and (c) – SOC within Aspect

Table 9. Summarized results of one way ANOVA of correlation between different carbon stocks with aspect

Gradient	Carbon Stock			
Aspect	AGC	BGC	LC	SOC
F	0.2566	0.2566	0.8548	0.8088
P	0.6143	0.6143	0.0538	0.0591

Insignificant at α=0.05 (95%)

AGC, BGC - above- and belowground carbon respectively; C(LHGs) - litter, herbs and grasses carbon, and SOC-soil organic carbon

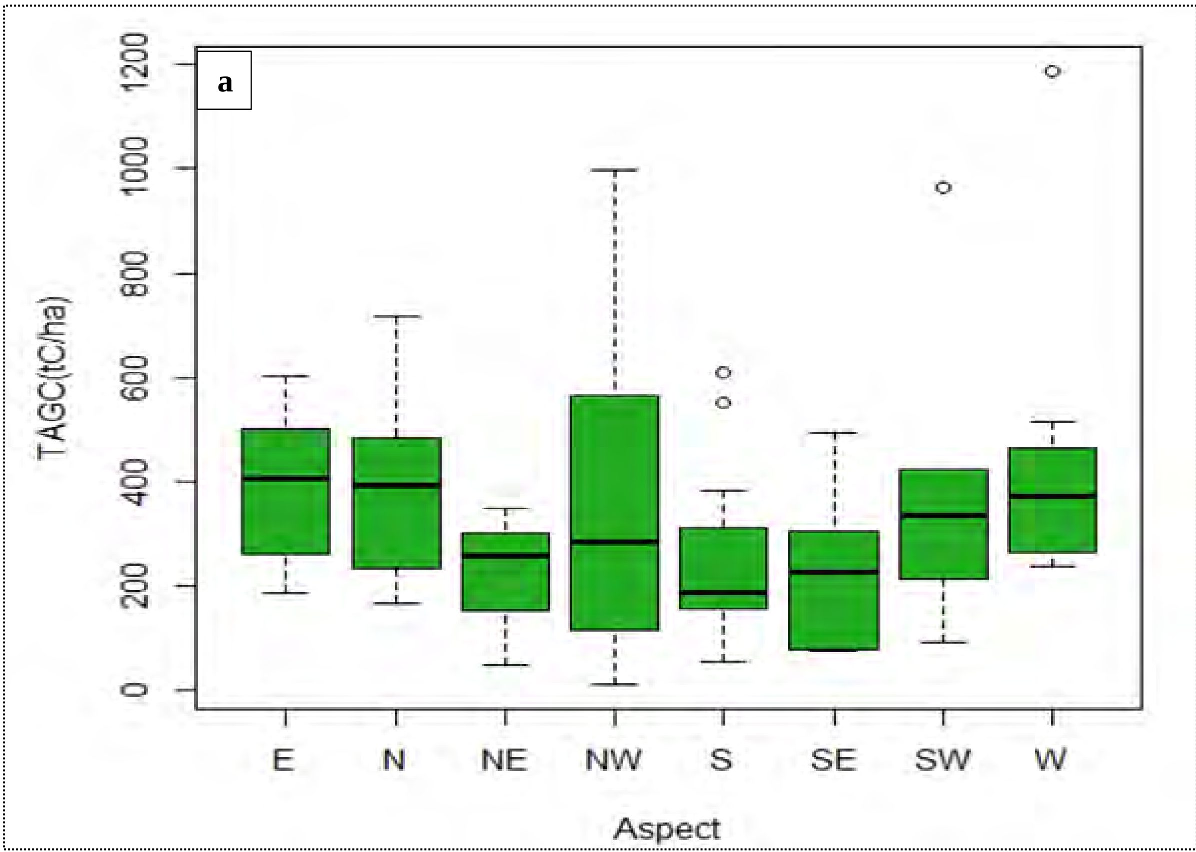
4.1.4.13. Correlation between Carbon Stock and Aspect

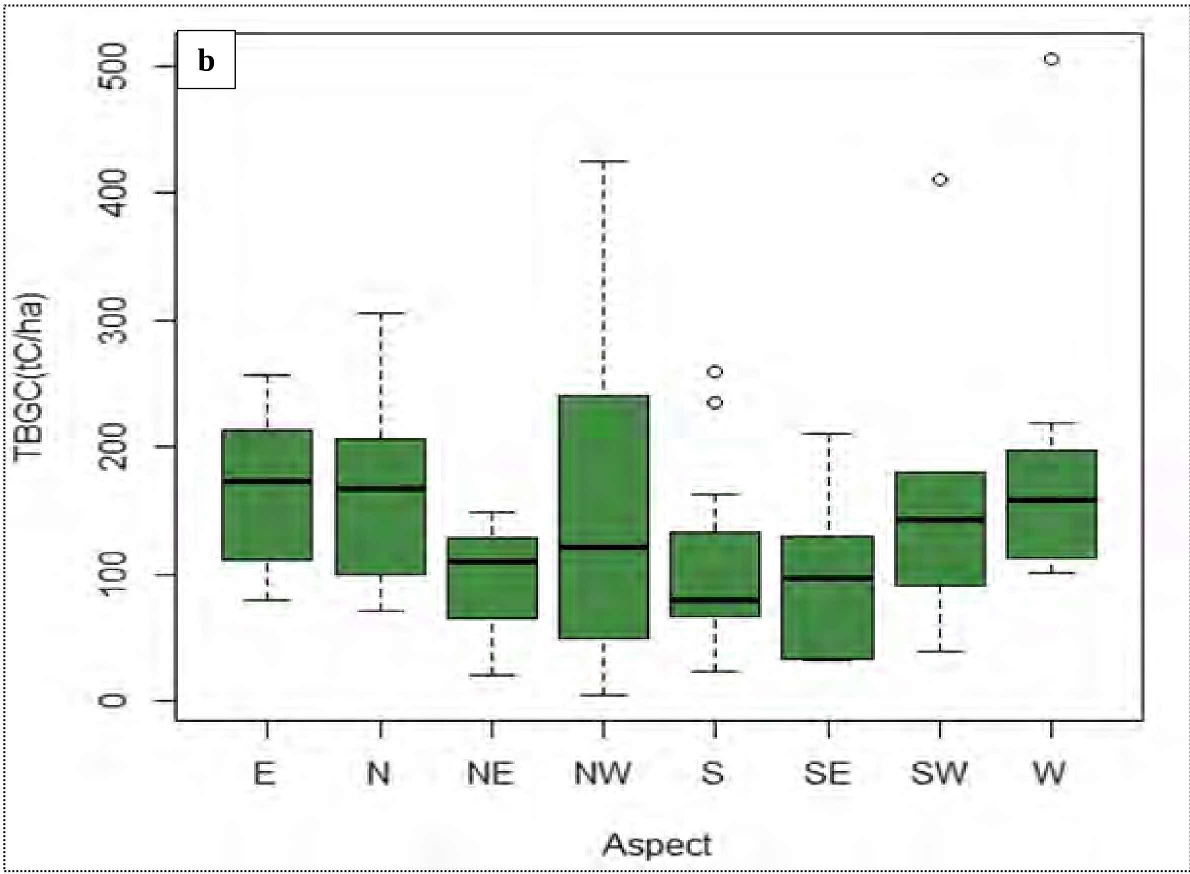
Aspect was analysed to recognize its correlation with all carbon pools. Hence, the total aboveground carbon stock of trees in line with aspect showed that the mean maximum and mean minimum aboveground biomass carbon stock was found in West and Northeast aspects respectively. The relationships were linearly regressed and ultimately resulted that aboveground biomass carbon stock and aspect had weak positive correlation (R^2= 0.0042,

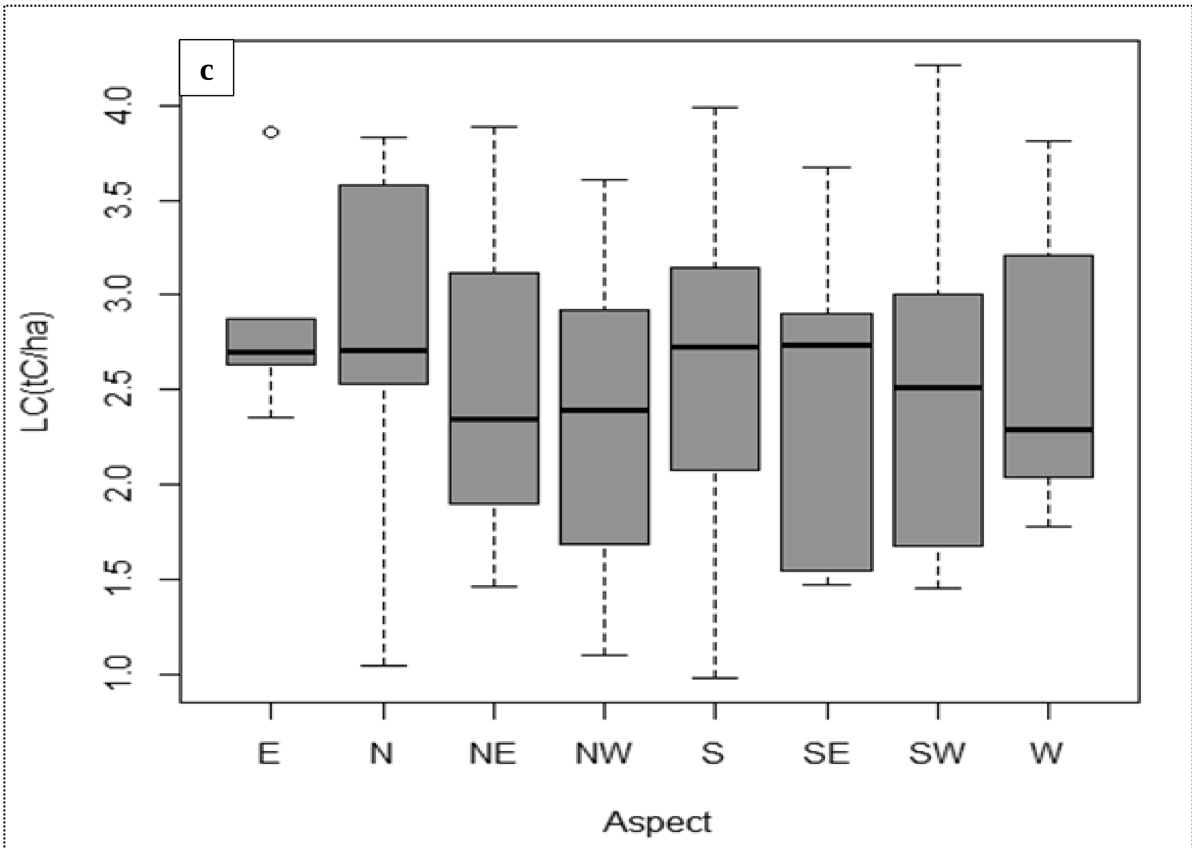
Figure 28a). Mean total belowground biomass carbon stock has also showed similar trend as it was derived from aboveground biomass (R^2= 0.0042, Figure 28b).

Similarly, the relationship between LHGs biomass carbon stock and aspect was also conducted. The ultimate result showed that weak positive correlation (R^2= 0.0006, Figure 28c).

In the same way, the relationship between soil organic carbons of all plots and corresponding aspects were conducted. The result has showed that weak correlation (R^2= 0.001, Figure 28d).




b
TBGC(tC/ha)
0
100
200
300
400
500
E
N
NE
NW
S
SE
SW
W
Aspect


c
LC(tC/ha)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
E
N
NE
NW
S
SE
SW
W
Aspect

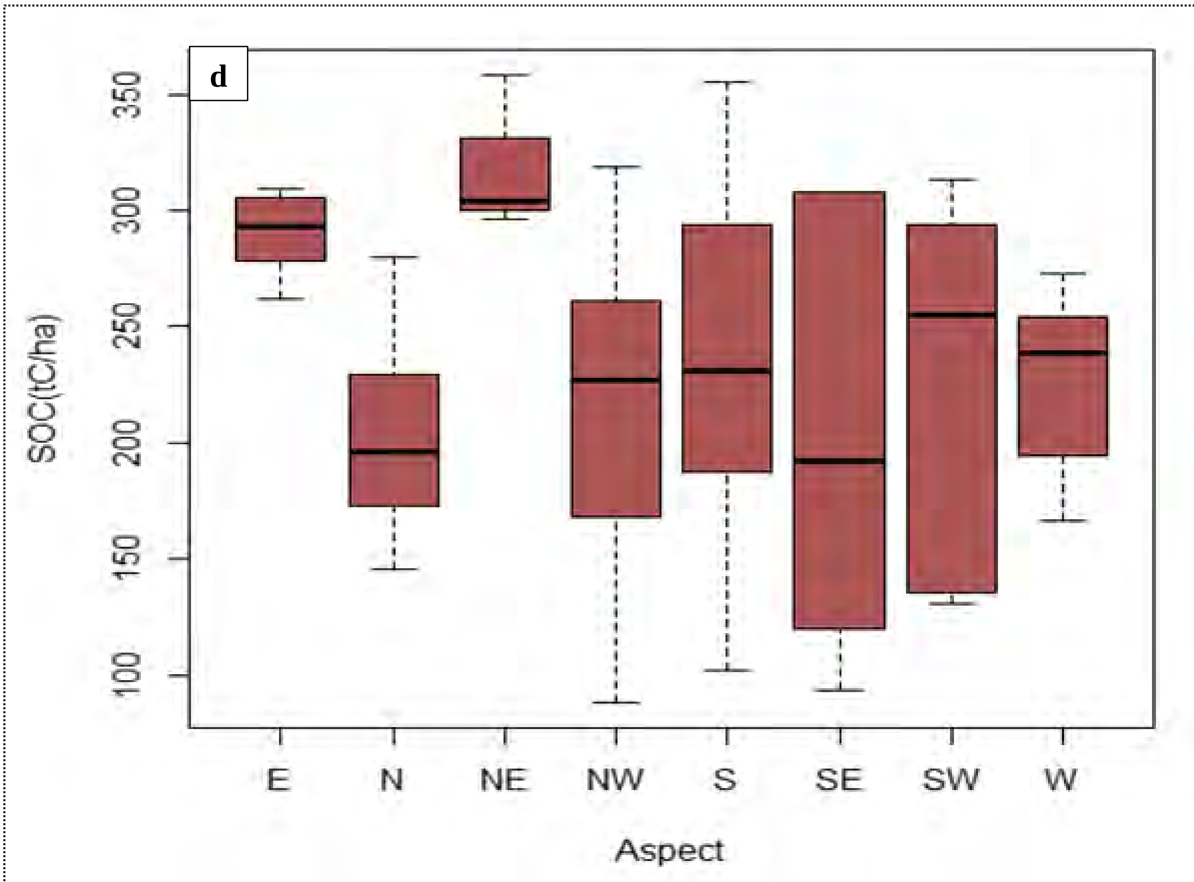


Figure 28. The distribution of carbon stock of different carbon pools (a) - TAGC, (b)- TBGC of trees, (c)-C(LHGs) and (d)-SOC in vertical box plots of different aspects

Keys on above boxplots:

- The box contains the middle 50% of the data,
- The upper edge of the box indicates 75th percentile of the data, and
- The lower edge indicates 25th percentile of the data.
- The black line inside the box is the median and
- The ends of the horizontal lines, the whiskers, represent minimum and maximum values.
- The black round circles in the figure indicate an outliers.

Table 10. The three environmental factors (a) – altitude class, (b) – slope class and (c) – aspect facing with biomass and carbon stock density (t/ha)

a

Altitudinal Class	Altitudinal Range (masl)	No. Plots	TAGB	TBGB	TB	TAGC	TBGC	LB	LC	SOC	TC
Lower	1850 - 2100	24	647.94	129.59	777.52	304.53	60.91	5.3	2.42	216.78	584.64
Meddle	2100 - 2350	33	815.77	163.15	978.92	383.41	76.68	5.93	2.67	241.97	704.73
Higher	2350 - 2600	6	488.75	97.75	586.5	229.71	45.94	5.77	2.77	225.65	504.07

b

Slope class	Slope Range (^{o})	No. Plots	TAGB	TBGB	TB	TAGC	TBGC	LB	LC	SOC	TC
Lower	≤10	30	751.71	150.34	902.05	353.30	70.66	5.53	2.51	219.90	646.38
Meddle	>10-20	16	687.25	137.45	824.70	323.01	64.60	6.09	2.78	240.45	630.83
Higher	≥20	17	697.40	139.48	836.89	327.78	65.56	5.56	2.54	241.02	636.89

c

Aspect (Facings)	No. Plots	TAGB	TBGB	TB	TAGC	TBGC	LB	LC	SOC	TC
N	7	827.58	165.52	993.09	388.96	77.79	6.1	2.83	203.82	673.40
NE	3	463.85	92.77	556.62	218.01	43.60	5.63	2.56	319.36	583.53
NW	15	733.97	146.79	880.76	344.97	68.99	5.47	2.39	219.37	635.71
E	5	834.89	166.98	1001.87	392.40	78.48	6.04	2.88	289.71	763.47
S	12	542.41	108.48	650.90	254.93	50.99	5.83	2.61	232.19	540.72
SE	6	499.37	99.87	599.25	234.70	46.94	5.37	2.51	202.24	486.39
SW	6	839.68	167.94	1007.62	394.65	78.93	5.35	2.56	230.42	706.56
W	9	943.49	188.70	1132.19	443.44	88.69	5.81	2.60	226.16	760.89

4.2. DISCUSSION

4.2.1. Floristic composition of Banja Forest

For the characterization of vegetation structure of Banja Forest, different parameters were used such as number of individuals of a species, density, frequency, DBH and height distribution (Tables 4 and 5; Figures 9, 10, 11, 12,13, 14 and 15). The Banja Forest was dominated mainly by *Albizia gummifera*, *Croton macrostachyus* and *Prunus africana* trees (Table 4), in agreement with the study done by Alemu Ayen (2015). This might be due to the geographical locations of both study sites, north-western part of Ethiopia.

According to Getachew Tesfaye (2007), the vegetation structure of a forest could help to understand the status of the forest stand. Hence, the vegetation structure of present study was almost inverse J-shaped distribution which indicates greater potential of regeneration capacity of young (low DBH) trees, grow much faster and have higher capacity in accumulating large carbon than older trees (Getachew Tesfaye 2007). Such vegetation distribution was seen in many studies done in Ethiopia (Muluken Nega, 2014; Biniam Alemu, 2012; Alemu Ayen, 2015; Getachew Tesfaye, 2007) in agreement with the present study.

The number of species found in Banja Forest (29) was lower than the number of species found in Munessa-Shashemene State Forest (36) and Guangua Ellala Forest (48) by Getachew Tesfaye (2007); Alemu Ayen (2015) respectively and higher than Danaba Community Forest (16) and Forest of north-western lowlands of Ethiopia (24) by Muluken Nega (2014); Biniam Alemu (2012) respectively. This could be due to the variation of agroecological zone among those study sites; the diameter of sampled trees considered and may be due to human disturbances of forests.

The density of trees/ha (Table 4), in present study was almost in agreement with Guangua Ellala Forest which was 29 trees/ha (Alemu Ayen, 2015).

Moreover, the tree species of the study area were also categorized into twelve DBH and eight height classes (Figures 12 and 14, respectively). From total 1,728 individuals of 29 different tree species recorded, less than 24% of the trees were found in <35 cm DBH class and more than 76% of the trees were found in >35cm DBH class (Figure 12). Hence, old trees were found largely in the Banja Forest. So, the study showed the forest was dominated by old trees without recent plantation and natural regenerations. Therefore, this indicates that currently the forest is high biomass carbon reserve, but the carbon sequestering potential of the forest is impaired unless forest management interventions that could improve carbon sequestration and enhance carbon stock (Bravo *et al*., 2008) are done in the future.

4.2.2. Biomass Carbon Stock in the Carbon Pools

According to IPCC (2006), a generic conversion factor of 0.47 has been used to estimate the carbon stocks in trees biomass for most tropical forests as it is widely accepted and used by (Bhishma *et al*., 2010; Adugna Feyissa *et al*., 2013; Mohammed Gedefaw *et al*., 2014; Muluken Nega *et a*l., 2014).

The report of Brown (1997) and Achard *et al*. (2004) as cited in Muluken Nega, 2014, on Biome-average tropical forest biomass carbon stock estimates and implications for global carbon cycle, the average carbon stock of Sub-Saharan Africa, Tropical Asia and Brazilian Amazon forests are 143, 151, 186 t/ha, respectively. Hence, the current study was higher than those continental assessments.

However, the result of mean aboveground and belowground trees carbon stock was almost similar to the previous Ethiopian studies of tree biomass carbon of Tara Gedam Forest, Woody Plants of Arba Minch Ground Water Forest and Egdu Forest while greater than Danaba Community Forest, Menagasha Suba State Forest, Woody Plants of Mount Zequalla Monastery and Guangua Ellala Forest aboveground carbon (Table 11). The differences might be due to variations in age of the trees, management of the forests, the allometric model used (Lasco *et al*., 2000), regional variability in soil, topography, existing species height and DBH range of trees that few large individuals can account for large proportion of the plots above and below ground carbon (Brown and Lugo, 1982).

On the other hand, mean biomass carbon stock in LHGs for tropical dry forests was 2.1 t/ha as reported by IPCC (2006) and almost similar result was found by the present study which was 2.58t/ha. Slightly similar result was found in Yeka Forest which was 2.01t/ha (Getnet Abate, 2015) and almost twice of other results done in Ethiopia (Muluken Nega *et al*., 2014; Belay Melese *et al*., 2014; Mohammed Gedefaw *et al*., 2014). Hence, litter biomass could be considered good reservoir of carbon as compared to other study sites in Ethiopia with the present study that could be due to the presence of old and big trees that had tendency of leaving their leaves and barks which contribute to litter carbon.

Table 11. Comparisons of carbon stocks of Banja Forest with other studies in Ethiopia

Study sites	Carbon stocks (t/ha)					Source
	TAGC	TBGC	C(LHGs)	SOC	TC (t/ha)	
Danaba Community Forest	277.78	41.65	1.06	186.40	506.89	Muluken Nega *et al.*, 2014
Woody Plants of Arba Minch Ground Water Forest	414.70	83.48	1.28	83.80	583.26	Belay Melese *et al.*, 2014
Egdu Forest	278.08	55.62	3.47	277.56	614.73	Adugna Feyissa *et al.*, 2013
Tara Gedam Forest	306.37	61.52	0.90	274.32	643.11	Mohammed Gedefaw *et al.*, 2014
Woody Plants of Mount Zequalla Monastery	237.20	47.60	6.49	57.62	348.91	Abel Girma *et al.*, 2014
Menagasha Suba State Forest	133.00	26.99	5.26	121.28	286.53	Mesfin Sahile, 2011
Guangua Ellala Forest	291.78	*	*	*	*	Alemu Ayen, 2015
Banja Forest	338.72	67.74	2.58	230.82	639.86	Present Study

*BGC, C (LHGS) and SOC were not studied

4.2.3. Influences of Environmental Factors on Carbon Stock

4.2.3.1. Variation of Carbon Stock along Altitudinal Gradient

Forests have a large potential for temporary and long term carbon storage (Houghton, 2001) and the forest biomass and carbon stock is influenced by altitudinal variations (Alves *et al*., 2010; Asner *et al*., 2014). Murphy and Lugo (1986) pointed out that the global pattern aboveground biomass in tropical dry and wet forests ranged between 30-275 ton/ha and 213-1173 ton/ha respectively. The results of the present study showed that the mean carbon stock is more than the mean global carbon stock (Figure 16) and varied in altitude class (Figure 23). Accordingly, maximum trees biomass carbon stock was stored in the middle altitude class followed by lower and upper altitude, respectively (Figure 23a). The reason of high carbon stock in the middle altitude might be its climatic conditions that allow many species to coexist (Hemp, 2006). It might be also due to the topographical nature where middle altitude is almost steep slope made itself away from human disturbance. On the other hand, upper altitude is more prone to arable land due to gentle slope nature made to store less carbon. This study had found out that a middle altitude peak for tree species carbon stock density along the elevation gradient, is in agreement with other studies in Ethiopia (Mohammed Gedefaw *et al*., 2014; Muluken Nega *et al*., 2014) while it showed dissimilarity with the study of Adugna Feyissa *et al*.(2013).

On the other hand, mean biomass carbon stock of LHGs distribution showed that maximum carbon was stored in the higher followed by middle and lower altitudinal class (Figure 23b). Similar result was reported in Woody Plants of Arba Minch Ground Water Forest (Belay Melese *et al*., 2014). Open canopy in higher altitudinal class might favor the growth of annual herbs and grasses. The reasons might be due to the decline in litter fall amount and decomposition with increasing altitude (Zhang *et al*., 2008) and the mean annual temperature decreased linearly with increasing altitude and mean annual precipitation showed an overall increasing trend (Chi *et al*., 1981) as cited in Muluken Nega, (2014).

The result of SOC showed that slight variation along altitudinal classes (Figure 23c). SOC density increased with precipitation and decreased with temperature (Jobbagy and Jackson, 2000). In the present study, relatively, an overall increasing trend in mean SOC density with increasing altitude was observed (Figure 24b) concurred with result found by Belay Melese *et* *al*. (2014). The mean SOC of Banja Forest was more or less comparable with studies of altitudinal variation effect on SOC in Egdu Forest (Adugna Feyissa *et al*., 2013) and Tara Gedam Forest (Mohammed Gedefaw *et al*., 2014) of Ethiopia.

In the present study, the distribution of carbon stocks with each sample plot in all carbon pools was found to be positively correlated and had insignificant differences with altitude (Figure 24d) concurred with other studies done in Ethiopia (Muluken Nega *et al*., 2014; Adugna Feyissa *et al*., 2013; Alefu Chaniso *et al*., 2015) and other study in Apennine Beech Forest by Bayat (2011) in Italy.

4.2.3.2. Variation of Carbon Stock along Slope Gradient

Slope is one of the environmental factors that influence the distribution of carbon density (Clark *et al*., 2000). Mohammed Gedefaw *et al*. (2014) found that slope significantly influences litter carbon and SOC of Tara Gedam Afromontane Forest of Ethiopia. On the contrary, the effects of slope on Banja Forest carbon stocks were very small and the relations were insignificant for all carbon pools (Table 8), and non-linear correlation was identified (Figure 26), which is similar with other studies of Apennine Beech Forest in Italy (Bayat, 2011) and Danaba Community Forest in Ethiopia (Muluken Nega, 2014) with a slightly small variations among slope classes.

4.2.3.3. Variation of Carbon Stock in the Aspects (Slope Facings)

Aspect has significant relationship with biomass carbon in forest areas due to the interaction between solar radiation and soil properties (Hicks *et al*., 1984). Hence, aspect could be used as a useful variable to predict the forest carbon stock in different carbon pools. But other study pointed out that aspect had insignificant relation with biomass carbon (Bayat, 2011). Present study result showed that highest mean value of aboveground biomass carbon stocks on western aspect and lowest mean value on the north-eastern aspect were recorded with a weak positive relation (Figure 28 a and b). Similarly, in the carbon stock study of Apennine Beech Forest by Bayat (2011) higher mean values of aboveground biomass carbon stocks on western aspect was found and aspect can affect 20% of the variation in aboveground biomass. In addition, the highest carbon stock was found in the western aspect in Tara Gedam Forest of Ethiopia (Mohammed Gedefaw *et al*., 2014) and the lowest carbon stock found on north-eastern aspect in Woody Plants of Arba Minch Ground Water Forest of Ethiopia (Belay Melese *et al*., 2014) were in excellent agreement to the present study. This is possibly due to the availability of moisture and fertile soil in the western part and less moisture and fertility in north-eastern part of Banja Forest as pointed out by Hicks *et al*. (1984) that soil properties are influenced by aspect.

Moreover, maximum biomass carbon stock of litter was stored on eastern part, and the lowest carbon stock was stored on north-eastern aspect, with weak positive relations and insignificant differences (Table 9, Figure 28c) which was in agreement with result found by Belay Melese *et al*.(2014). The reason might be the absence of high decomposition rate of litter on north-eastern aspects may contribute for the presence of high litter biomass and carbon than the eastern aspect.

In addition, the maximum soil carbon stock was stored on north-eastern part and the lowest carbon stock was stored on south-eastern part of the forest with a weak positive relation and insignificant differences (Table 9, Figure 28d). The maximum values of soil organic carbon on the north-eastern aspect of the present study which might be due to the presence of cooler and moist climate on this aspect. This may also be the probable cause for high decomposition rate of a litter which further enhanced large carbon stocks on the north-eastern aspect compared to the other aspects.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Banja Forest which is found in Amhara Region had a high carbon stock capacity as compared to other previous similar studies in Ethiopia. The characterization of vegetation structure of the Banja Forest indicates in total of 24 common families with 29 tree species were recorded, of which *Albizia gummifera, Croton macrostachyus* and *Prunus africana* were the most dominant species. *Juniperus procera* and *Ekebergia capensis* recorded as the highest DBH tree species and reserved the highest biomass carbon stock that tree species stored the highest carbon stock of all carbon pools. Forest soil was also found to have a good reservoir of carbon stock in the Banja Forest. The other important carbon pool was the LHGs that contributed for carbon sink in this forest with comparable carbon density as compared to other Ethiopian and tropical forests. Currently, the Banja Forest had the capacity to store 639.87t/ha of carbon. Consequently, this forest could sequester 2348.32t/ha of CO_2eq. and generate carbon credit of US$ 9,862.94 which indicates the potential of the forest that will enhance climate change mitigation of the area. Factors of carbon pools which were altitude, slope and aspect had weak positive correlation in each carbon pool concurred with other studies done in Ethiopia. Enhancing the capacity of climate change mitigation actions could be done using forests as recognized by the international negotiations in the UNFCCC that confirmed carbon sequestration by forests is the low-cost method enables to reduce global greenhouse gas emissions through which receiving funds for carbon sequestration in the REDD+ mechanism, compensation provided to developing countries. Therefore, carbon stock estimation is crucial that researchers, administrators and policy makers to be involved to analyse and generate global carbon credit that can be helpful to achieve sustainable development of Ethiopia and to be middle income country by 2025.

5.2. Recommendations

In line to combating climate change, the most pressing issues in the world today, forests play enormous role as serving potential carbon sinks. Thus, the Banja Forest was potentially high in its carbon storage capacity as compared to other studies in Ethiopia and in the tropical countries. However, other cumbersome human activities such as arable land expansions and settlements open grazing, cutting of big trees for charcoal and local timber productions will hinder the forest not to generate its role in a sustainable way unless effective measures have to be enforced.

According to the study held in Banja Forest, the following recommendations have been forwarded.

- ❖ The research result of existing trees of the Banja Forest was dominated by large sized trees and sequestered high carbon stock. Therefore, to sustain the present carbon stored in the forest and increase its biomass in the future, it will be necessary to involve in planting new seedlings, promote natural regeneration and conserving degraded areas with local community participation.

- ❖ There was a challenge on the boundary of Banja Forest with the local communities that continuously encroached for arable land and settlements. Therefore, an attempt should be given on the forest boundary demarcation and buffer zone development with local communities and stakeholders participation that simplified implementation of appropriate conservation activities and reduction of anthropogenic activities in the forest.
- ❖ Further research should focus on developing and applying the country specific (species specific) allometric equations. This will increase the reliability and acceptance of the existing data on forest carbon stocks.
- ❖ Currently, the Banja Forest is playing its role in mitigating climate change by sequestering 2348.32t/ha of CO_2eq. that could account US$ 9,862.94. Hence, carbon sequestration should be integrated with Reduced Emission from Deforestation and forest Degradation (REDD+) and Clean Development Mechanism (CDM) carbon trading system of the Kyoto Protocol to get monetary benefits of carbon dioxide mitigation that can help to improve livelihoods of the communities and carbon stock enhancement of the Banja Forest.

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Appendices

Appendix 1: Biomass and carbon stock of tree species recorded in each sample plot

Plot	Scientific Name	No. Stems	DBH(cm) Class			Height (m)			Biomass and carbon stock of each species (t/plot)							TC (t/ha)	CO_2eq.
			Class	Mean	± Std.dev	Class	Mean	± Std.dev	TAGB	TBGB	TB	TAGC	TBGC	TC spp.	TC /plot		
1	*Albizia gummifera*	9	4.5-35	11.07	7.17	3.5-20	12.44	2.88	0.61	0.12	0.73	0.29	0.06	0.35	0.97	24.19	88.77
	Buddleja polystachya	1	5 to 20	5.73	0	10-15	14	0	0.02	0.003	0.02	0.01	0.002	0.01			
	Clausena anisata	2	4.5-20	5.01	0.01	3.5-5	4.25	0.35	0.007	0.002	0.01	0.003	0.001	0.004			
	Bersama abyssinica	3	4.5-20	6.67	1.51	10-15	12.67	2.08	0.06	0.01	0.07	0.028	0.005	0.03			
	Apodytes dimidiata	3	>5-35	23.24	10.21	10-20	16.33	2.08	0.99	0.20	1.19	0.47	0.09	0.56			
	Galiniera coffeodes	4	>5-20	5.49	0.48	3.5-15	6.63	3.59	0.03	0.01	0.04	0.014	0.003	0.02			
2	*Allophylus abyssinicus*	4	>5-35	18.07	8.03	10-20	14	1.83	0.75	0.15	0.89	0.35	0.070	0.42	46.25	1156.19	4243.23
	Bersama abyssinica	4	>5-20	7.80	2.4	5-15	10.5	1	0.10	0.02	0.12	0.05	0.01	0.06			
	Dombeya torrida	2	>5-20	12.74	2.25	10-15	11.5	0.71	0.13	0.03	0.16	0.06	0.01	0.07			
	Juniperus procera	6	>65-125	93.42	13.31	30-35	34	1.79	55.22	11.04	66.26	25.95	5.19	31.14			
	Olea africana	3	>20-65	35.03	19.57	10-25	19	4	3.03	0.61	3.63	1.42	0.28	1.71			
	Teclea nobilis	4	>5-65	34.63	16.87	10-20	17	2.16	3.27	0.65	3.92	1.54	0.31	1.84			

	Terminalia brownii	2	5 - 20	5.73	0.90	5-10	8	1.41	19.51	3.90	23.41	9.17	1.83	11.01			
	Allophylus abyssinicus	1	>20-35	22.29	0	10-15	14	0	0.23	0.05	0.28	0.11	0.02	0.13			
	Apodytes dimidiata	7	>20-110	56.55	26.67	15-35	25.86	8.30	25.92	5.18	31.11	12.18	2.44	14.62			
3	*Bersama abyssinica*	3	>5-20	5.81	0.60	>10-15	11.5	0.58	0.06	0.01	0.07	0.03	0.01	0.03	14.90	372.45	1366.90
	Dombeya torrida	5	>5-20	6.86	2.39	>5-15	11.22	0.83	0.19	0.04	0.23	0.09	0.02	0.11			
	Phytolacca dodecandra	1	>5-20	6.69	0	>10-15	12	0	0.02	0.004	0.02	0.01	0.002	0.01			
	Apodytes dimidiata	3	>80-95	88.11	4.86	>20-30	24.67	2.08	17.66	3.533	21.20	8.30	1.660	9.96			
4	*Bersama abyssinica*	3	>5-20	11.68	2.43	>10-15	12	1	0.17	0.03	0.20	0.08	0.02	0.10	10.12	252.92	928.20
	Clausena anisata	2	>5-20	6.05	0.45	>5-15	10.5	0.71	0.03	0.01	0.03	0.01	0.003	0.02			
	Dombeya torrida	1	>5-20	14.33	0	>10-15	11	0	0.08	0.02	0.09	0.04	0.01	0.04			
	Allophylus abyssinicus	2	>20-35	33.44	9.01	>15-20	16.5	3.54	0.98	0.20	1.18	0.46	0.09	0.55			
5	*Apodytes dimidiata*	5	>35-110	70.61	18.06	>15-35	24.43	5.29	29.78	5.96	35.73	14.00	2.80	16.79	17.37	434.29	1593.83
	Bersama abyssinica	1	>5-20	5.41	0	>10-15	12	0	0.01	0.002	0.01	0.01	0.001	0.01			
	Vernonia amygdalina	2	>5-20	6.05	1.41	>10-15	12	1.41	0.03	0.006	0.04	0.01	0.003	0.02			
	Albizia gummifera	1	>65-80	76.43	0	>25-30	27	0	4.84	0.97	5.81	2.27	0.45	2.73			
	Allophylus abyssinicus	1	>35-50	38.22	0	>20-25	22	0	0.77	0.15	0.93	0.36	0.07	0.44			
6	*Apodytes dimidiata*	8	>5-80	43.03	20.04	>5-35	21.25	4.17	12.88	2.58	15.45	6.05	1.21	7.26	16.93	423.14	1552.92
	Bersama abyssinica	1	>5-20	5.73	0	>10-15	12	0	0.01	0.003	0.02	0.01	0.001	0.01			
	Olea europaea	1	>20-35	27.07	0	>15-20	19	0	0.45	0.09	0.54	0.21	0.04	0.26			
	Prunus africana	2	>35-80	48.60	29.19	>15-35	22.00	7.45	11.05	2.21	13.26	5.20	1.04	6.23			
	Acacia abyssinica	12	>5-50	30.16	10.39	>10-20	15	3.31	7.66	1.53	9.19	3.60	0.72	4.32			
	Albizia gummifera	1	>50-65	55.73	0	>20-25	25	0	2.42	0.48	2.91	1.14	0.23	1.37			
7	*Croton macrostachyus*	1	>20-35	34.71	0	>15-20	17	0	0.66	0.13	0.79	0.31	0.06	0.37	6.24	156.01	572.57
	Pittosporum	1	>20-35	25.16	0	>10-15	15	0	0.31	0.06	0.37	0.15	0.03	0.18			

	virdiflorum																
	Rhus glutinosa	1	>5-20	6.05	0	>10-15	12	0	0.02	0.003	0.02	0.01	0.001	0.01			
8	*Albizia gummifera*	1	>80-95	93.95	0	>25-30	27	0	6.18	1.24	7.41	2.90	0.58	3.48	10.25	256.37	940.88
	Bersama abyssinica	2	>5-35	33.03	28.16	>10-20	17.29	4.75	0.43	0.09	0.52	0.20	0.04	0.24			
	Croton macrostachyus	6	>5-50	23.35	21.34	>10-20	15.27	4.06	0.87	0.17	1.04	0.41	0.08	0.49			
	Dombeya torrida	1	>5-20	30.00	9.55	>10-15	12	0	0.04	0.01	0.05	0.02	0.004	0.02			
	Ficus sur	3	>20-50	34.71	23.39	>15-20	17.67	3.48	1.97	0.39	2.36	0.93	0.185	1.11			
	Vernonia amygdalina	6	>5-35	20.72	21.25	>5-20	14.44	4.16	8.70	1.74	10.44	4.09	0.818	4.91			
9	*Albizia gummifera*	1	>35-50	38.2	0	>10-20	15	0	0.60	0.12	0.72	0.28	0.057	0.34	3.34	83.49	306.42
	Buddleja polystachya	6	>5-50	27.34	7.50	>10-20	13.67	1.63	2.15	0.43	2.58	1.01	0.20	1.21			
	Croton macrostachyus	8	>5-35	26.95	3.86	>10-20	13.625	1.19	2.24	0.448	2.69	1.05	0.21	1.26			
	Terminalia brownii	3	>5-20	9.02	3.93	>5-15	9.67	1.53	0.08	0.02	0.10	0.04	0.01	0.05			
	Vernonia amygdalina	3	>5-35	22.93	8.16	>10-20	14	2.65	0.84	0.17	1.01	0.40	0.08	0.48			
10	*Albizia gummifera*	2	>50-65	57.01	4.05	>25-35	32.50	3.54	5.64	1.13	6.76	2.65	0.53	3.18	29.35	733.64	2692.46
	Apodytes dimidiata	6	>50-95	67.36	14.36	>25-35	30.17	5.60	27.64	5.53	33.17	12.99	2.60	15.59			
	Croton macrostachyus	2	>5-20	15.76	4.28	>10-20	14.00	1.41	0.21	0.04	0.25	0.10	0.02	0.12			
	Ficus sur (F. capensis)	22	>5-95	27.95	17.13	>(10-35)	20.55	5.57	18.55	3.71	22.26	8.72	1.74	10.46			
11	*Albizia gummifera*	15	>5-50	20.13	8.95	>10-20	14.47	2.56	3.26	0.65	3.92	1.53	0.31	1.84	4.52	112.88	414.27
	Apodytes dimidiata	1	>35-50	40.45	0.00	>15-20	18.00	0.00	0.94	0.19	1.13	0.44	0.09	0.53			
	Cordia africana	3	>5-50	29.62	17.69	>10-25	18.67	4.04	1.44	0.29	1.73	0.68	0.14	0.81			
	Croton macrostachyus	6	>5-50	20.59	12.10	>5-20	14.50	3.02	1.52	0.30	1.82	0.71	0.14	0.86			
	Dracaena steudneri	1	>35-50	38.22	0.00	>15-20	18.00	0.00	0.84	0.17	1.01	0.40	0.08	0.47			
12	*Albizia gummifera*	10	>20-65	43.85	7.60	>15-20	17.20	1.03	9.32	1.86	11.19	4.38	0.88	5.26	20.37	509.30	1869.14

	Croton macrostachyus	5	>5-35	22.29	5.96	>10-20	14.20	1.30	1.06	0.21	1.27	0.50	0.10	0.60			
	Prunus africana	10	>5-95	52.96	29.30	>10-35	24.30	6.90	25.73	5.15	30.88	12.09	2.42	14.51			
13	*Albizia gummifera*	8	>5-65	23.89	11.95	>10-20	15.75	1.98	2.66	0.53	3.19	1.25	0.25	1.50	11.43	285.81	1048.94
	Apodytes dimidiata	12	>5-65	42.99	11.54	>10-25	18.00	1.95	13.95	2.79	16.74	6.56	1.31	7.87			
	Croton macrostachyus	7	>5-50	32.53	10.64	>10-20	16.43	0.98	3.66	0.73	4.40	1.72	0.34	2.07			
14	*Albizia gummifera*	7	>35-110	54.85	16.47	>15-35	20.44	4.64	17.90	3.58	21.49	8.42	1.68	10.10	24.78	619.57	2273.83
	Apodytes dimidiata	4	>20-65	46.58	11.87	>5-20	15.75	1.71	4.71	0.94	5.66	2.22	0.44	2.66			
	Bersama abyssinica	1	>5-20	17.52	0	>10-15	12	0	0.12	0.02	0.15	0.06	0.01	0.07			
	Croton macrostachyus	6	>5-35	22.93	4.37	>10-20	13.83	1.47	1.27	0.25	1.52	0.59	0.12	0.71			
	Prunus africana	9	>35-110	57.86	22.16	>10-35	18.89	6.41	19.93	3.99	23.92	9.37	1.87	11.24			
15	*Albizia gummifera*	12	>5-65	30.94	13.35	>10-25	16.33	3.85	6.72	1.34	8.06	3.16	0.63	3.79	5.70	142.41	522.64
	Allophylus abyssinicus	1	>35-50	35.03	0.00	>15-20	19.00	0.00	0.57	0.11	0.68	0.27	0.05	0.32			
	Apodytes dimidiata	3	>20-50	35.46	2.57	>10-20	16.00	1.00	1.95	0.39	2.34	0.92	0.18	1.10			
	Croton macrostachyus	3	>5-35	21.02	8.09	>10-20	13.25	3.20	0.82	0.16	0.98	0.38	0.08	0.46			
	Terminalia brownii	5	>5-20	6.18	1.12	>5-15	9.40	1.14	0.05	0.01	0.06	0.02	0.005	0.03			
16	*Albizia gummifera*	2	>5-35	24.68	7.88	>10-20	14.50	0.71	0.51	0.10	0.61	0.24	0.048	0.29	56.98	1424.45	5227.72
	Bersama abyssinica	2	>5-20	9.08	4.95	>5-15	11.50	0.71	0.07	0.01	0.08	0.03	0.006	0.04			
	Croton macrostachyus	3	>20-50	40.21	7.73	>10-20	15.75	2.75	2.92	0.58	3.51	1.37	0.275	1.65			
	Ekebergia capensis	4	>(65-155)	118.23	53.64	>(20-35)	32.00	6.00	67.40	13.48	80.88	31.68	6.336	38.01			
	Ficus sur (F. capensis)	3	>35-65	52.44	11.08	>15-25	21.67	3.21	5.98	1.20	7.17	2.81	0.562	3.37			
	Prunus africana	6	>35-95	68.52	17.18	>(20-35)	30.17	5.38	23.95	4.79	28.74	11.26	2.251	13.51			
	Teclea nobilis	1	>5-20	19.11	0.00	>15-20	16.00	0.00	0.19	0.04	0.23	0.09	0.018	0.11			

17	*Apodytes dimidiata*	10	>20-95	48.19	19.20	>10-35	18.32	4.97	36.39	7.28	43.67	17.10	3.420	20.52	29.02	725.44	2662.36
	Croton macrostachyus	3	>5-35	19.11	4.21	>5-15	10.67	0.58	0.34	0.07	0.41	0.16	0.032	0.19			
	Prunus africana	12	>5-80	40.23	17.87	>10-30	16.92	4.47	11.66	2.33	14.00	5.48	1.096	6.58			
	Syzygium guineense	4	>20-65	39.81	11.11	>10-20	13.50	1.73	3.06	0.61	3.67	1.44	0.287	1.72			
18	*Acacia abyssinica*	4	>5-35	18.31	4.21	>10-20	13.75	0.96	0.65	0.13	0.78	0.31	0.061	0.37	26.43	660.87	2425.38
	Apodytes dimidiata	8	>5-80	40.80	21.19	>10-35	19.88	5.77	12.66	2.53	15.19	5.95	1.190	7.14			
	Bersama abyssinica	5	>5-20	5.99	0.82	>5-15	11.00	0.71	0.07	0.01	0.09	0.03	0.01	0.04			
	Ficus sur (F. capensis)	8	>5-65	32.64	15.95	>10-25	17.25	3.69	6.61	1.32	7.93	3.11	0.62	3.73			
	Prunus africana	9	>20-95	59.84	19.51	>(15-35)	26.56	6.78	26.87	5.37	32.25	12.63	2.53	15.16			
19	*Ficus sur (F. capensis)*	14	>20-65	36.40	12.22	>10-20	15.64	2.44	10.90	2.18	13.08	5.12	1.02	6.15	23.71	592.73	2175.33
	Prunus africana	11	>35-95	61.12	15.33	>(15-35)	25.45	6.85	31.14	6.23	37.37	14.64	2.93	17.56			
20	*Bersama abyssinica*	3	>5-20	6.69	1.15	>5-15	11.00	1.00	0.05	0.01	0.06	0.03	0.01	0.03	9.06	226.55	831.43
	Croton macrostachyus	6	>5-35	20.06	4.55	>10-20	15.17	1.47	1.09	0.22	1.31	0.51	0.10	0.62			
	Prunus africana	11	>20-80	46.79	17.54	>15-30	19.45	3.05	14.92	2.98	17.91	7.01	1.40	8.42			
21	*Albizia gummifera*	16	>5-35	19.71	6.15	>10-20	13.06	1.98	2.69	0.54	3.23	1.27	0.25	1.52	2.34	58.57	214.94
	Croton macrostachyus	14	>5-35	16.26	4.15	>5-20	12.71	1.73	1.46	0.29	1.75	0.69	0.14	0.82			
22	*Albizia gummifera*	12	>5-65	28.37	13.05	>10-20	15.17	2.17	5.25	1.05	6.30	2.47	0.49	2.96	12.99	324.65	1191.45
	Allophylus abyssinicus	2	>20-50	32.17	6.31	>10-15	13.50	0.71	0.70	0.14	0.85	0.33	0.07	0.40			
	Apodytes dimidiata	3	>35-110	66.14	29.23	>(10-35)	23.00	10.58	13.14	2.63	15.77	6.17	1.23	7.41			
	Syzygium guineense	3	>20-65	46.18	15.68	>10-20	16.33	1.53	3.68	0.74	4.41	1.73	0.35	2.07			
	Terminalia brownii	3	>5-20	14.54	4.46	>5-15	10.33	2.08	0.25	0.05	0.30	0.12	0.02	0.14			
23	*Albizia gummifera*	11	>20-95	54.49	19.98	>(10-35)	20.27	6.56	23.78	4.76	28.54	11.18	2.24	13.41	22.28	556.91	2043.84
	Allophylus abyssinicus	7	>20-50	32.26	6.19	>10-15	11.86	0.90	2.22	0.44	2.67	1.05	0.21	1.25			

	Bersama abyssinica	6	>5-35	13.80	4.69	>5-15	11.00	1.26	0.47	0.09	0.57	0.22	0.04	0.27			
	Ficus sur (F. capensis)	8	>20-95	43.75	20.58	>10-35	15.63	7.46	13.02	2.60	15.62	6.12	1.22	7.34			
24	*Croton macrostachyus*	16	>20-50	35.69	9.90	>10-20	13.38	1.63	8.17	1.63	9.80	3.84	0.77	4.61	27.00	674.94	2477.04
	Prunus africana	15	>(80-155)	53.78	35.30	>10-35	17.53	6.05	39.70	7.94	47.64	18.66	3.73	22.39			
25	*Acacia abyssinica*	5	>5-50	30.57	9.45	>10-20	14.40	2.30	2.45	0.49	2.94	1.15	0.23	1.38	12.54	313.54	1150.70
	Albizia gummifera	5	>5-35	17.83	6.10	>5-15	11.60	1.34	0.61	0.12	0.73	0.29	0.06	0.34			
	Apodytes dimidiata	5	>20-125	54.78	32.45	>15-35	19.40	6.50	15.12	3.02	18.15	7.11	1.42	8.53			
	Bersama abyssinica	3	>5-20	13.38	4.90	>5-15	11.00	1.00	0.22	0.04	0.27	0.10	0.02	0.13			
	Croton macrostachyus	8	>5-35	18.11	6.53	>5-15	11.13	1.13	0.96	0.19	1.15	0.45	0.09	0.54			
	Ficus sur (F. capensis)	4	>20-35	24.84	2.82	>5-15	12.00	0.82	0.99	0.20	1.19	0.47	0.09	0.56			
	Prunus africana	3	>35-50	38.43	3.51	>10-20	16.00	1.00	1.88	0.38	2.26	0.89	0.18	1.06			
26	*Acacia lahai*	4	>5-20	10.43	2.64	>10-20	11.75	0.96	0.19	0.04	0.23	0.09	0.02	0.11	8.36	209.01	767.06
	Albizia gummifera	6	>20-65	36.78	12.39	>5-15	14.17	2.14	3.69	0.74	4.42	1.73	0.35	2.08			
	Croton macrostachyus	7	>20-65	34.99	12.02	>10-20	14.57	2.23	3.98	0.80	4.78	1.87	0.37	2.25			
	Ficus sur (F. capensis)	5	>5-35	16.69	5.12	>10-15	12.20	0.84	0.63	0.13	0.75	0.30	0.06	0.35			
	Prunus africana	6	>35-80	48.78	14.26	>10-20	14.83	2.14	6.26	1.25	7.51	2.94	0.59	3.53			
	Vernonia amygdalina	3	>5-20	8.60	1.39	>5-15	10.33	0.58	0.08	0.02	0.10	0.04	0.01	0.05			
27	*Albizia gummifera*	10	>20-80	45.38	16.38	>10-30	16.20	4.64	11.49	2.30	13.79	5.40	1.08	6.48	13.84	346.06	1270.03
	Apodytes dimidiata	10	>5-80	44.78	20.08	>5-25	14.60	4.01	12.87	2.57	15.45	6.05	1.21	7.26			
	Bersama abyssinica	4	>5-20	10.75	2.72	>5-15	10.50	0.58	0.17	0.03	0.21	0.08	0.02	0.10			
28	*Albizia gummifera*	18	>5-125	46.96	27.93	>(10-35)	18.50	5.36	34.12	6.82	40.95	16.04	3.21	19.24	19.95	498.87	1830.84
	Bersama abyssinica	4	>5-20	6.53	0.76	>5-15	11.00	0.82	0.07	0.01	0.08	0.03	0.01	0.04			
	Croton	4	>5-30	24.36	6.12	>10-20	17.00	1.63	1.19	0.24	1.43	0.56	0.11	0.67			

	macrostachyus																
	Albizia gummifera	5	>5-35	21.02	2.08	>10-15	13.40	0.55	0.81	0.16	0.97	0.38	0.08	0.46			
	Bersama abyssinica	4	>5-20	10.75	2.72	>5-15	10.75	0.96	0.18	0.04	0.22	0.09	0.02	0.10			
29	*Croton macrostachyus*	9	>5-35	22.82	5.52	>10-15	12.78	1.09	1.78	0.36	2.14	0.84	0.17	1.01	16.73	418.29	1535.13
	Ekebergia capensis	4	>20-50	34.63	9.04	>10-20	16.00	0.82	2.64	0.53	3.16	1.24	0.25	1.49			
	Prunus africana	8	>35-110	66.68	22.67	>10-30	21.13	5.96	24.25	4.85	29.10	11.40	2.28	13.68			
	Albizia gummifera	5	>5-50	17.20	12.12	>10-20	13.80	0.84	2.71	0.54	3.25	1.27	0.25	1.53			
	Bersama abyssinica	4	>5-20	11.31	3.51	>10-15	12.00	0.82	0.23	0.05	0.27	0.11	0.02	0.13			
	Croton macrostachyus	5	>5-35	17.64	6.41	>10-15	12.20	1.30	0.62	0.12	0.74	0.29	0.06	0.35			
	Dombeya torrida	4	>5-30	21.10	4.84	>10-20	14.00	0.82	0.86	0.17	1.04	0.41	0.08	0.49			
30	*Ficus sur (F. capensis)*	4	>20-50	32.96	9.28	>10-20	14.00	0.82	2.12	0.42	2.54	0.99	0.20	1.19	16.03	400.78	1470.87
	Millettia ferruginea	4	>20-65	39.89	13.12	>10-20	14.50	1.73	4.00	0.80	4.80	1.88	0.38	2.26			
	Prunus africana	3	>15-125	55.20	49.98	>(10-35)	20.33	12.74	11.31	2.26	13.57	5.31	1.06	6.38			
	Rhus glutinosa	3	>15-50	26.01	8.17	>10-20	14.33	1.53	1.05	0.21	1.27	0.50	0.10	0.59			
	Schefflera abyssinica	3	>35-80	49.89	23.04	>10-30	18.33	4.16	5.53	1.11	6.63	2.60	0.52	3.12			
31	*Albizia gummifera*	6	>25-80	40.29	15.93	>10-30	14.50	5.17	5.35	1.07	6.43	2.52	0.50	3.02			
	Celtis africana	4	>20-110	54.14	29.76	>10-35	21.25	7.68	9.99	2.00	11.99	4.70	0.94	5.64			
	Croton macrostachyus	5	>5-35	26.50	5.17	>10-15	12.40	1.14	1.24	0.25	1.49	0.58	0.12	0.70			
	Ekebergia capensis	3	>35-50	39.28	1.84	>10-15	13.33	0.58	1.99	0.40	2.39	0.93	0.19	1.12	29.18	729.55	2677.46
	Millettia ferruginea	3	>5-35	16.99	3.31	>10-15	12.67	0.58	0.45	0.09	0.54	0.21	0.04	0.26			
	Prunus africana	14	>20-155	49.54	34.77	>(10-35)	16.50	7.14	32.71	6.54	39.25	15.37	3.07	18.45			
	Acacia abyssinica	12	>5-35	24.81	6.01	>10-20	13.92	1.51	3.66	0.73	4.39	1.72	0.34	2.06			
32	*Apodytes dimidiata*	7	>20-65	42.04	9.37	>10-30	16.71	3.82	7.44	1.49	8.93	3.50	0.70	4.20	7.09	177.14	650.09
	Bersama abyssinica	5	>5-20	11.34	2.24	>5-15	10.00	1.22	0.23	0.05	0.28	0.11	0.02	0.13			

	Croton macrostachyus	9	>5-35	18.37	5.08	>5-20	13.11	1.90	1.23	0.25	1.48	0.58	0.12	0.69			
33	*Albizia gummifera*	10	>5-50	27.87	13.94	>10-15	13.00	0.94	3.54	0.71	4.25	1.67	0.33	2.00	6.81	170.32	625.07
	Clausena anisata	2	>5-20	9.24	1.35	>5-10	8.00	1.41	0.05	0.01	0.06	0.02	0.005	0.03			
	Croton macrostachyus	10	>5-35	21.97	4.85	>10-20	13.20	1.62	1.92	0.38	2.30	0.90	0.18	1.08			
	Ficus sur (F. capensis)	8	>5-80	34.99	17.65	>10-20	15.00	2.73	6.57	1.31	7.89	3.09	0.62	3.71			
34	*Albizia gummifera*	10	>5-65	34.0	14.7	>10-25	14.3	2.5	5.82	1.16	6.99	2.74	0.55	3.28	26.50	662.48	2431.29
	Apodytes dimidiata	8	>5-80	28.4	20.4	>5-25	14.5	3.7	5.76	1.15	6.91	2.71	0.54	3.25			
	Bersama abyssinica	3	>5-20	6.8	1.0	>5-15	8.3	1.5	0.04	0.01	0.05	0.02	0.00	0.02			
	Croton macrostachyus	8	>35-65	43.5	9.1	>10-30	15.8	3.8	7.08	1.42	8.50	3.33	0.67	3.99			
	Prunus africana	6	>50-125	86.0	15.5	>15-35	23.3	5.5	28.28	5.66	33.94	13.29	2.66	15.95			
35	*Apodytes dimidiata*	16	>20-155	46.3	20.8	>10-25	15.8	4.8	26.23	5.25	31.47	12.33	2.47	14.79	34.50	862.41	3165.05
	Ekebergia capensis	3	>35-140	78.6	47.3	>(15-35)	25.7	8.3	21.80	4.36	26.16	10.25	2.05	12.30			
	Prunus africana	13	>20-65	47.6	10.4	>10-20	16.1	1.5	13.13	2.63	15.76	6.17	1.23	7.41			
36	*Albizia gummifera*	11	>20-95	33.3	19.9	>10-30	14.6	3.6	8.30	1.66	9.96	3.90	0.78	4.68	47.85	1196.23	4390.16
	Apodytes dimidiata	7	>5-80	33.3	19.3	>10-20	15.1	2.0	5.39	1.08	6.46	2.53	0.51	3.04			
	Bersama abyssinica	3	>5-20	6.7	1.3	>5-15	11.0	1.0	54.31	10.86	65.17	25.52	5.10	30.63			
	Celtis africana	2	>65-95	79.6	18.0	>20-35	26.5	4.9	10.95	2.19	13.14	5.14	1.03	6.17			
	Croton macrostachyus	10	>20-65	34.0	10.1	>10-25	15.3	2.7	5.56	1.11	6.67	2.61	0.52	3.14			
	Rhus glutinosa	4	>5-20	13.6	3.3	>5-15	11.8	0.5	0.31	0.06	0.37	0.15	0.03	0.17			
	Terminalia brownii	3	>5-20	5.7	0.6	>5-15	8.3	1.5	0.03	0.01	0.04	0.01	0.00	0.02			
37	*Albizia gummifera*	11	>20-80	50.4	14.8	>10-25	16.8	3.3	14.79	2.96	17.75	6.95	1.39	8.34	13.69	342.26	1256.103
	Allophylus abyssinicus	5	>5-50	26.2	9.2	>5-15	11.8	1.5	1.17	0.23	1.41	0.55	0.11	0.66			
	Prunus africana	10	>35-80	44.4	8.8	>10-25	14.7	2.5	8.31	1.66	9.98	3.91	0.78	4.69			

38	*Albizia gummifera*	7	>20-95	52.7	32.4	>10-30	19.3	7.06	16.85	3.37	20.22	7.92	1.58	9.50	18.32	458.01	1680.89
	Allophylus abyssinicus	6	>5-65	36.4	14.0	>10-20	15.3	1.86	3.52	0.70	4.23	1.66	0.33	1.99			
	Croton macrostachyus	10	>5-95	40.9	21.7	>5-35	16.4	5.19	11.71	2.34	14.05	5.50	1.10	6.60			
	Olea africana	6	>5-20	12.4	3.6	>5-15	11.5	1.05	0.40	0.08	0.48	0.19	0.04	0.23			
39	*Albizia gummifera*	8	>5-35	20.94	5.82	>5-20	13.13	2.03	1.47	0.29	1.76	0.69	0.14	0.83	17.95	448.66	1646.59
	Apodytes dimidiata	9	>20-80	50.25	16.30	>10-20	15.67	2.12	13.11	2.62	15.73	6.16	1.23	7.39			
	Croton macrostachyus	8	>5-35	17.91	5.81	>5-15	12.13	1.25	0.98	0.20	1.18	0.46	0.09	0.55			
	Prunus africana	7	>35-110	61.24	21.23	>10-35	18.43	5.88	16.26	3.25	19.51	7.64	1.53	9.17			
40	*Albizia gummifera*	5	>5-20	15.35	3.20	>10-20	13.00	1.58	0.47	0.09	0.56	0.22	0.04	0.27	14.74	368.40	1352.03
	Croton macrostachyus	5	>5-35	19.11	4.36	>10-20	14.00	1.87	0.77	0.15	0.93	0.36	0.07	0.44			
	Syzygium guineense	11	>20-95	47.63	22.16	>10-35	22.18	6.08	24.83	4.97	29.79	11.67	2.33	14.00			
	Vernonia amygdalina	4	>5-10	6.45	1.08	>5-15	9.00	1.41	0.06	0.01	0.07	0.03	0.01	0.03			
41	*Albizia gummifera*	4	>5-65	40.60	15.76	>10-25	16.75	2.87	3.76	0.75	4.51	1.77	0.35	2.12	17.71	442.86	1625.29
	Allophylus abyssinicus	4	>20-65	45.78	13.60	>10-20	16.00	1.63	3.53	0.71	4.24	1.66	0.33	1.99			
	Apodytes dimidiata	8	>5-50	29.22	11.27	>10-20	13.50	1.60	3.60	0.72	4.32	1.69	0.34	2.03			
	Croton macrostachyus	6	>20-65	35.35	11.32	>10-20	14.83	1.33	3.39	0.68	4.07	1.59	0.32	1.91			
	Prunus africana	8	>35-110	58.52	21.20	>15-30	19.75	3.53	17.13	3.43	20.56	8.05	1.61	9.66			
42	*Allophylus abyssinicus*	4	>20-50	31.29	10.07	>10-20	14.75	1.71	1.73	0.35	2.07	0.81	0.16	0.97	19.57	489.28	1795.64
	Apodytes dimidiata	11	>20-110	49.10	25.55	>10-35	17.36	5.18	22.74	4.55	27.29	10.69	2.14	12.83			
	Bersama abyssinica	2	>5-20	6.21	0.68	>5-15	10.50	0.71	0.03	0.01	0.03	0.01	0.00	0.02			
	Clausena anisata	2	>5-20	5.25	0.23	>5-15	11.00	1.41	0.02	0.00	0.03	0.01	0.00	0.01			
	Olea africana	8	>20-80	44.23	17.37	>10-25	16.38	2.92	10.16	2.03	12.19	4.77	0.95	5.73			
	Psychotria orophila	2	>5-20	5.73	0.45	>5-15	10.50	0.71	0.02	0.00	0.03	0.01	0.00	0.01			

43	*Albizia gummifera*	11	>5-80	31.24	21.82	>10-25	15.45	3.59	8.08	1.62	9.70	3.80	0.76	4.56	8.04	200.99	737.62
	Allophylus abyssinicus	4	>5-50	25.08	10.19	>10-20	13.75	1.71	1.02	0.20	1.23	0.48	0.10	0.58			
	Celtis africana	3	>20-50	28.13	7.18	>10-20	14.67	3.06	1.07	0.21	1.29	0.50	0.10	0.61			
	Croton macrostachyus	11	>5-35	19.08	5.75	>5-20	13.09	1.70	1.67	0.33	2.00	0.78	0.16	0.94			
	Millettia ferruginea	6	>5-35	17.20	4.53	>10-20	25.50	31.61	2.41	0.48	2.89	1.13	0.23	1.36			
44	*Albizia gummifera*	12	>5-110	41.53	24.00	>10-35	16.17	5.36	2.47	0.49	2.97	1.16	0.23	1.39	2.62	65.46	240.24
	Allophylus abyssinicus	3	>20-65	35.77	21.59	>10-20	14.00	1.00	0.65	0.13	0.78	0.30	0.06	0.36			
	Apodytes dimidiata	8	>20-65	41.68	11.36	>10-20	14.13	1.36	0.52	0.10	0.63	0.24	0.05	0.29			
	Croton macrostachyus	4	>5-35	17.60	5.70	>5-15	10.75	0.96	0.07	0.01	0.08	0.03	0.01	0.04			
	Millettia ferruginea	4	>5-50	25.72	15.32	>10-20	13.75	2.22	0.65	0.13	0.78	0.31	0.06	0.37			
	Terminalia brownii	3	>5-50	24.42	9.73	>10-20	13.33	2.52	0.28	0.06	0.34	0.13	0.03	0.16			
45	*Albizia gummifera*	9	>5-95	39.28	47.77	>10-25	19.33	4.95	11.24	2.25	13.48	5.28	1.06	6.34	12.50	312.41	1146.56
	Croton macrostachyus	6	>5-65	30.41	13.44	>10-25	17.50	3.89	3.48	0.70	4.18	1.64	0.33	1.96			
	Millettia ferruginea	10	>5-65	28.34	14.30	>10-30	16.40	4.06	7.44	1.49	8.93	3.50	0.70	4.20			
46	*Allophylus abyssinicus*	9	>20-80	48.44	13.40	>10-30	17.44	3.61	10.22	2.04	12.27	4.80	0.96	5.77	24.12	603.08	2213.30
	Albizia gummifera	9	>5-35	20.17	6.06	>10-20	13.44	1.59	1.58	0.32	1.90	0.74	0.15	0.89			
	Prunus africana	6	>20-140	73.51	40.96	>(15-35)	24.33	7.94	30.77	6.15	36.92	14.46	2.89	17.35			
	Psychotria orophila	7	>5-20	8.05	2.87	>5-15	11.14	0.90	0.20	0.04	0.24	0.09	0.02	0.11			
47	*Albizia gummifera*	7	>5-35	23.20	5.82	>10-20	15.00	1.29	1.72	0.34	2.06	0.81	0.16	0.97	9.07	226.77	832.24
	Allophylus abyssinicus	5	>20-35	22.68	5.56	>10-20	13.60	1.14	0.92	0.18	1.11	0.43	0.09	0.52			
	Apodytes dimidiata	7	>20-80	41.45	16.53	>10-30	18.00	3.83	8.83	1.77	10.60	4.15	0.83	4.98			
	Bersama abyssinica	5	>5-20	5.35	0.27	>5-15	11.80	1.30	0.06	0.01	0.07	0.03	0.01	0.03			
	Celtis africana	3	>35-65	39.28	17.54	>15-20	16.67	2.31	2.95	0.59	3.54	1.39	0.28	1.66			

	Dombeya torrida	7	>5-35	20.93	6.86	>10-20	13.86	1.57	1.60	0.32	1.92	0.75	0.15	0.90			
48	*Albizia gummifera*	15	>20-65	40.00	13.19	>10-20	15.20	1.74	11.53	2.31	13.84	5.42	1.08	6.50	12.53	313.23	1149.54
	Allophylus abyssinicus	5	>20-65	39.81	13.13	>10-25	18.00	3.81	4.09	0.82	4.91	1.92	0.38	2.31			
	Cordia africana	4	>5-20	15.61	3.40	>10-15	12.50	1.29	0.29	0.06	0.35	0.14	0.03	0.17			
	Syzygium guineense	5	>35-65	44.27	7.67	>10-30	18.80	4.15	6.30	1.26	7.56	2.96	0.59	3.55			
49	*Albizia gummifera*	9	>5-95	36.52	28.73	>10-30	18.00	5.05	11.91	2.38	14.29	5.60	1.12	6.72	11.49	287.22	1054.11
	Celtis africana	6	>5-95	33.70	26.15	>10-25	14.67	4.18	6.45	1.29	7.75	3.03	0.61	3.64			
	Croton macrostachyus	10	>5-35	17.42	3.42	>10-20	13.90	1.37	1.26	0.25	1.51	0.59	0.12	0.71			
	Olea africana	3	>5-35	21.02	4.46	>15-20	15.67	1.53	0.72	0.14	0.87	0.34	0.07	0.41			
	Terminalia brownii	3	>5-20	5.63	0.49	>5-15	8.00	2.00	0.03	0.01	0.03	0.01	0.00	0.02			
50	*Albizia gummifera*	13	>5-65	39.69	26.60	>10-35	17.38	5.80	3.46	0.69	4.15	1.62	0.32	1.95	4.56	114.02	418.44
	Celtis africana	4	>20-50	27.87	6.69	>10-20	13.50	1.29	0.27	0.05	0.33	0.13	0.03	0.15			
	Croton macrostachyus	9	>5-50	26.86	12.18	>5-20	13.44	2.19	0.57	0.11	0.68	0.27	0.05	0.32			
	Ficus sur (F. capensis)	6	>20-65	42.99	7.74	>10-20	15.00	0.89	1.03	0.21	1.23	0.48	0.10	0.58			
	Olea europaea	4	>35-110	61.31	30.37	>10-35	22.00	8.04	2.76	0.55	3.32	1.30	0.26	1.56			
51	*Albizia gummifera*	10	>5-125	54.36	33.56	>10-35	18.70	6.46	26.19	5.24	31.43	12.31	2.46	14.77	20.11	502.66	1844.78
	Celtis africana	3	>5-35	20.70	2.76	>10-15	13.33	0.58	0.58	0.12	0.69	0.27	0.05	0.33			
	Croton macrostachyus	7	>5-65	34.76	16.44	>10-30	17.43	3.95	5.45	1.09	6.54	2.56	0.51	3.08			
	Dombeya torrida	6	>5-35	18.47	4.14	>10-20	14.17	1.17	1.03	0.21	1.24	0.49	0.10	0.58			
	Millettia ferruginea	4	>5-50	23.09	8.67	>10-20	15.00	2.16	1.47	0.29	1.76	0.69	0.14	0.83			
	Teclea nobilis	4	>5-35	21.50	4.01	>10-20	14.50	1.29	0.93	0.19	1.11	0.44	0.09	0.52			
52	*Apodytes dimidiata*	6	>5-50	27.65	8.00	>10-20	14.17	1.17	2.34	0.47	2.81	1.10	0.22	1.32	31.97	799.16	2932.92
	Bersama abyssinica	3	>20-35	27.07	2.76	>10-20	14.00	1.00	1.02	0.20	1.23	0.48	0.10	0.58			
	Celtis africana	3	>20-110	63.16	35.90	>(15-35)	22.33	11.15	13.04	2.61	15.64	6.13	1.23	7.35			

	Prunus africana	13	>20-110	54.73	25.14	>10-35	19.92	7.79	40.27	8.05	48.33	18.93	3.79	22.71			
53	*Acacia abyssinica*	9	>5-50	29.72	10.71	>10-20	16.56	2.51	5.07	1.01	6.09	2.39	0.48	2.86	5.03	125.67	461.21
	Albizia gummifera	4	>5-50	23.09	12.30	>10-20	15.00	3.65	1.24	0.25	1.49	0.58	0.12	0.70			
	Buddleja polystachya	3	>5-20	13.38	3.37	>5-15	11.67	1.53	0.23	0.05	0.28	0.11	0.02	0.13			
	Croton macrostachyus	9	>5-50	22.47	9.10	>10-20	14.89	2.42	2.33	0.47	2.80	1.10	0.22	1.32			
	Vernonia amygdalina	3	>5-20	5.73	0.64	>5-15	10.33	0.58	0.04	0.01	0.04	0.02	0.00	0.02			
54	*Albizia gummifera*	9	>5-35	20.98	6.84	>10-20	15.00	2.50	1.98	0.40	2.37	0.93	0.19	1.11	11.62	290.53	1066.26
	Bersama abyssinica	4	>5-35	19.67	6.03	>10-20	14.50	1.29	0.82	0.16	0.99	0.39	0.08	0.46			
	Celtis africana	5	>5-35	20.38	8.38	>10-20	13.40	2.41	0.97	0.19	1.17	0.46	0.09	0.55			
	Croton macrostachyus	4	>5-20	15.21	3.68	>10-15	12.50	1.29	0.35	0.07	0.42	0.17	0.03	0.20			
	Prunus africana	11	>5-95	45.11	21.60	>10-30	20.00	4.92	16.48	3.30	19.78	7.75	1.55	9.30			
55	*Acacia abyssinica*	6	>5-110	40.13	28.74	>10-30	15.50	5.47	9.26	1.85	11.12	4.35	0.87	5.23	27.42	685.56	2516.02
	Albizia gummifera	7	>5-110	59.37	37.75	>10-30	19.71	5.91	21.23	4.25	25.48	9.98	2.00	11.98			
	Croton macrostachyus	6	>5-65	26.06	15.59	>10-20	14.00	2.37	2.27	0.45	2.72	1.06	0.21	1.28			
	Ekebergia capensis	3	>35-110	63.38	36.23	>15-35	21.33	8.39	12.21	2.44	14.66	5.74	1.15	6.89			
	Olea africana	3	>35-65	46.71	12.06	>10-20	16.33	1.53	3.65	0.73	4.38	1.71	0.34	2.06			
56	*Albizia gummifera*	5	>20-80	36.88	23.10	>10-30	17.80	6.34	5.75	1.15	6.89	2.70	0.54	3.24	8.17	204.15	749.23
	Bersama abyssinica	4	>5-20	5.73	0.69	>5-15	11.00	0.82	0.05	0.01	0.06	0.02	0.00	0.03			
	Celtis africana	4	>5-35	21.89	3.28	>10-20	14.25	1.26	0.93	0.19	1.12	0.44	0.09	0.53			
	Croton macrostachyus	8	>5-50	19.47	8.49	>10-20	13.25	2.12	1.43	0.29	1.72	0.67	0.13	0.81			
	Olea africana	5	>5-50	23.25	10.15	>10-20	13.80	1.92	1.54	0.31	1.84	0.72	0.14	0.87			
	Prunus africana	8	>5-80	32.13	22.28	>10-20	14.63	2.07	4.78	0.96	5.73	2.25	0.45	2.70			
57	*Acacia abyssinica*	20	>5-35	22.07	6.45	>10-20	15.00	1.78	5.46	1.09	6.55	2.57	0.51	3.08	3.73	93.24	342.21
	Croton macrostachyus	7	>5-35	18.88	5.39	>10-20	15.00	1.53	1.15	0.23	1.38	0.54	0.11	0.65			

58	*Acacia abyssinica*	9	>5-35	32.77	24.33	>10-20	15.33	3.00	8.63	1.73	10.35	4.06	0.81	4.87	12.66	316.42	1161.25
	Albizia gummifera	11	>5-80	35.12	15.85	>10-25	16.09	2.66	7.86	1.57	9.44	3.70	0.74	4.44			
	Celtis africana	2	>35-80	57.32	27.02	>15-25	20.00	4.24	4.93	0.99	5.92	2.32	0.46	2.78			
	Croton macrostachyus	8	>5-35	17.56	4.44	>10-20	13.38	1.60	1.02	0.20	1.22	0.48	0.10	0.57			
59	*Prunus africana*	14	>5-80	33.19	17.97	>10-30	17.14	4.33	11.09	2.22	13.31	5.21	1.04	6.25	7.87	196.65	721.72
	Millettia ferruginea	6	>20-50	26.91	5.67	>10-20	15.83	1.72	2.86	0.57	3.43	1.34	0.27	1.61			
60	*Albizia gummifera*	10	>5-110	29.36	24.21	>10-35	15.40	5.62	9.23	1.85	11.07	4.34	0.87	5.20	8.94	223.38	819.81
	Apodytes dimidiata	7	>5-35	20.29	5.10	>10-20	13.86	1.35	1.44	0.29	1.72	0.68	0.14	0.81			
	Croton macrostachyus	6	>20-65	33.07	14.99	>10-20	15.50	2.43	3.50	0.70	4.20	1.64	0.33	1.97			
	Millettia ferruginea	5	>20-35	23.95	2.73	>10-20	14.60	1.14	1.68	0.34	2.02	0.79	0.16	0.95			
61	*Allophylus abyssinicus*	7	>5-50	25.16	6.72	>15-25	16.00	2.45	1.98	0.40	2.38	0.93	0.19	1.12	3.71	92.79	340.53
	Croton macrostachyus	6	>5-50	27.34	6.26	>15-25	17.50	2.88	2.35	0.47	2.82	1.11	0.22	1.33			
	Prunus africana	8	>5-50	24.40	6.42	>10-20	15.75	1.98	2.25	0.45	2.69	1.06	0.21	1.27			
62	*Albizia gummifera*	14	>5-110	48.20	28.80	>10-35	20.93	6.51	31.03	6.21	37.23	14.58	2.92	17.50	18.96	473.88	1739.15
	Allophylus abyssinicus	4	>5-50	24.92	9.58	>10-20	15.50	1.91	1.12	0.22	1.34	0.53	0.11	0.63			
	Croton macrostachyus	6	>5-50	23.09	7.17	>10-20	14.67	1.63	1.46	0.29	1.75	0.69	0.14	0.82			
63	*Albizia gummifera*	11	>5-80	29.62	21.18	>10-35	17.82	6.00	9.46	1.89	11.36	4.45	0.89	5.34	9.61	240.13	881.28
	Croton macrostachyus	14	>5-50	29.16	14.06	>10-25	16.79	3.75	7.51	1.50	9.01	3.53	0.71	4.24			
	Phytolacca dodecandra	5	>5-20	5.80	0.61	>5-15	8.80	1.30	0.05	0.01	0.06	0.03	0.01	0.03			

Appendix 2. Biomass and carbon stock of Litter, herbs and grasses (LHGs)

Plot	Weight (gram)							% Ash	%C	Biomass-carbon (t/ha)		CO_2 eq.
	Field	Sub-sample wet	Sub-sample dry	Oven dried grind sample wt.	W1	W2	W3			B (LHGs)	C (LHGs)	
1	255	100	90.4097	5	23.4482	28.4482	24.3456	17.948	47.59016	2.31	1.10	4.03
2	565	100	86.5735	5	27.6468	32.6468	28.7444	21.952	45.26784	4.89	2.21	8.13
3	950	100	90.7921	5	22.1428	27.1428	22.9345	15.834	48.81628	8.63	4.21	15.45
4	925	100	89.6549	5	23.4482	28.4482	24.4623	20.282	46.23644	8.29	3.83	14.07
5	675	100	88.6584	5	26.6719	31.6719	27.3548	13.658	50.07836	5.98	3.00	11.00
6	650	100	90.2571	5	55.8292	60.8292	56.6041	15.498	49.01116	5.87	2.88	10.55
7	450	100	78.6543	5	24.5675	29.5675	25.6845	22.34	45.0428	3.54	1.59	5.85
8	750	100	79.5346	5	25.7974	30.7974	26.7378	18.808	47.09136	5.97	2.81	10.31
9	650	100	80.8545	5	27.6468	32.6468	28.7341	21.746	45.38732	5.26	2.39	8.75
10	850	100	90.2351	5	26.1828	31.1828	27.3542	23.428	44.41176	7.67	3.41	12.50
11	475	100	82.0507	5	64.0724	69.0724	65.3779	26.11	42.8562	3.90	1.67	6.13
12	350	100	78.5524	5	26.9364	31.9364	27.3857	8.986	52.78812	2.75	1.45	5.33
13	855	100	92.7894	5	64.0724	69.0724	64.7395	13.342	50.26164	7.93	3.99	14.63
14	725	100	90.3187	5	26.6719	31.6719	26.9811	6.184	54.41328	6.55	3.56	13.08
15	775	100	90.6986	5	55.9228	60.9228	57.1782	25.108	43.43736	7.03	3.05	11.21
16	550	100	84.5634	5	61.7705	66.7705	62.6456	17.502	47.84884	4.65	2.23	8.17
17	550	100	98.6668	5	79.3846	84.3846	80.092	14.148	49.79416	5.43	2.70	9.92
18	650	100	87.8512	5	22.6873	27.6873	23.729	20.834	45.91628	5.71	2.62	9.62

19	400	100	87.7841	5	22.6873	27.6873	24.0818	27.89	41.8238	3.51	1.47	5.39
20	450	100	90.6666	5	61.7705	66.7705	62.552	15.63	48.9346	4.08	2.00	7.33
21	675	100	81.5546	5	24.0233	29.0233	25.3648	26.83	42.4386	5.50	2.34	8.57
22	650	100	80.4361	5	26.3216	31.3216	27.5468	24.504	43.78768	5.23	2.29	8.40
23	450	100	78.6875	5	25.7974	30.7974	26.4638	13.328	50.26976	3.54	1.78	6.53
24	875	100	90.7492	5	24.5675	29.5675	26.5765	40.18	34.6956	7.94	2.76	10.11
25	925	100	87.841	5	61.7705	66.7705	62.8703	21.996	45.24232	8.13	3.68	13.49
26	850	100	87.7672	5	64.073	69.073	65.2776	24.092	44.02664	7.46	3.28	12.05
27	850	100	88.8867	5	26.3216	31.3216	27.1359	16.286	48.55412	7.56	3.67	13.46
28	900	100	91.8538	5	24.0233	29.0233	25.0481	20.496	46.11232	8.27	3.81	13.99
29	875	100	89.6125	5	22.6873	27.6873	23.413	14.514	49.58188	7.84	3.89	14.27
30	400	100	89.4337	5	26.1828	31.1828	27.6728	29.8	40.716	3.58	1.46	5.35
31	650	100	83.3338	5	26.9364	31.9364	27.9648	20.568	46.07056	5.42	2.50	9.16
32	500	100	91.3847	5	22.1428	27.1428	23.801	33.164	38.76488	4.57	1.77	6.50
33	525	100	88.1918	5	25.7974	30.7974	27.7377	38.806	35.49252	4.63	1.64	6.03
34	725	100	79.5423	5	23.4482	28.4482	24.654	24.116	44.01272	5.77	2.54	9.31
35	825	100	91.3704	5	56.3232	61.3232	57.3435	20.406	46.16452	7.54	3.48	12.77
36	800	100	83.4594	5	32.6227	37.6227	33.4237	16.02	48.7084	6.68	3.25	11.94
37	950	100	91.6567	5	23.4482	28.4482	24.8772	28.58	41.4236	8.71	3.61	13.24
38	750	100	89.999	5	26.6719	31.6719	27.9508	25.578	43.16476	6.75	2.91	10.69
39	650	100	94.2242	5	24.5675	29.5675	26.93	47.25	30.595	6.12	1.87	6.88
40	450	100	79.3652	5	22.1428	27.1428	23.4238	25.62	43.1404	3.57	1.54	5.65
41	375	100	85.0907	5	64.073	69.073	65.52	28.94	41.2148	3.19	1.32	4.83
42	665	100	89.6588	5	27.6468	32.6468	28.8512	24.088	44.02896	5.96	2.63	9.63
43	650	100	82.4737	5	55.9228	60.9228	56.9942	21.428	45.57176	5.36	2.44	8.97
44	850	100	87.9645	5	64.073	69.073	65.5685	29.91	40.6522	7.48	3.04	11.16
45	775	100	84.7638	5	25.7974	30.7974	26.5845	15.742	48.86964	6.57	3.21	11.78

46	875	100	89.7892	5	55.8292	60.8292	56.597	15.356	49.09352	7.86	3.86	14.16
47	800	100	86.2648	5	55.9228	60.9228	56.8912	19.368	46.76656	6.90	3.23	11.84
48	600	100	83.5115	5	26.1828	31.1828	27.1408	19.16	46.8872	5.01	2.35	8.62
49	450	100	95.3729	5	64.0724	69.0724	64.9714	17.98	47.5716	4.29	2.04	7.49
50	900	100	78.2259	5	24.0233	29.0233	25.3941	27.416	42.09872	7.04	2.96	10.88
51	710	100	78.1802	5	24.5675	29.5675	25.3557	15.764	48.85688	5.55	2.71	9.95
52	750	100	82.2891	5	26.6719	31.6719	27.6633	19.828	46.49976	6.17	2.87	10.53
53	700	100	79.8787	5	26.3216	31.3216	27.8256	30.08	40.5536	5.59	2.27	8.32
54	550	100	79.5676	5	27.6468	32.6468	28.4128	15.32	49.1144	4.38	2.15	7.89
55	334	100	91.1113	5	55.8292	60.8292	56.4124	11.664	51.23488	3.04	1.56	5.72
56	225	100	91.4571	5	64.073	69.073	64.9713	17.966	47.57972	2.06	0.98	3.59
57	850	100	72.3793	5	22.1428	27.1428	23.0817	18.778	47.10876	6.15	2.90	10.64
58	800	100	88.9875	5	26.9364	31.9364	28.802	37.312	36.35904	7.12	2.59	9.50
59	650	100	85.2306	5	32.6227	37.6227	33.5248	18.042	47.53564	5.54	2.63	9.66
60	600	100	97.6441	5	55.9228	60.9228	56.7015	15.574	48.96708	5.86	2.87	10.53
61	750	100	77.4578	5	23.4482	28.4482	24.2345	15.726	48.87892	5.81	2.84	10.42
62	255	100	82.742	5	22.6873	27.6873	23.4472	15.198	49.18516	2.11	1.04	3.81
63	550	100	82.4533	5	26.3216	31.3216	27.4055	21.678	45.42676	4.53	2.06	7.56

Plot	Soil depth (cm)	Volume (cm3)	Dry wt. (g)	Bulk Density (g/cm^3)	%OC	SOC(t/ha)	CO_2 eq.
1	30	78.5	0.873	3.379	0.034	88.47	324.69
2	30	78.5	0.888	11.025	0.110	293.65	1077.69
3	30	78.5	0.617	7.315	0.073	135.50	497.27
4	30	78.5	0.557	14.606	0.146	244.03	895.58
5	30	78.5	0.807	12.955	0.130	313.52	1150.63
6	30	78.5	0.693	15.344	0.153	318.85	1170.18
7	30	78.5	1.109	7.623	0.076	253.53	930.47
8	30	78.5	0.845	5.148	0.051	130.51	478.98
9	30	78.5	0.573	14.616	0.146	251.29	922.24
10	30	78.5	0.371	12.904	0.129	143.60	527.01
11	30	78.5	0.728	12.112	0.121	264.59	971.05
12	30	78.5	1.301	6.269	0.063	244.73	898.14
13	30	78.5	0.895	13.216	0.132	355.01	1302.90
14	30	78.5	0.761	10.449	0.104	238.59	875.62
15	30	78.5	0.703	8.691	0.087	183.38	673.00
16	30	78.5	0.867	6.408	0.064	166.76	612.01
17	30	78.5	1.030	10.024	0.100	309.65	1136.41
18	30	78.5	0.751	7.970	0.080	179.56	658.98
19	30	78.5	0.763	10.633	0.106	243.29	892.89
20	30	78.5	0.579	11.539	0.115	200.39	735.44
21	30	78.5	1.031	15.148	0.151	295.82	1085.64
22	30	78.5	0.859	10.474	0.105	269.96	990.74
23	30	78.5	0.843	15.723	0.157	254.08	932.48
24	30	78.5	0.768	11.672	0.117	268.88	986.80
25	30	78.5	0.993	5.574	0.056	166.04	609.37
26	30	78.5	0.752	13.231	0.132	298.49	1095.45
27	30	78.5	1.126	9.108	0.091	307.63	1129.01
28	30	78.5	0.738	8.773	0.088	194.30	713.09
29	30	78.5	0.762	15.654	0.157	358.07	1314.10
30	30	78.5	0.756	13.411	0.134	304.20	1116.43
31	30	78.5	0.617	5.537	0.055	102.57	376.42
32	30	78.5	1.014	6.996	0.070	212.71	780.65
33	30	78.5	0.845	12.873	0.129	326.33	1197.65
34	30	78.5	1.014	6.809	0.068	207.14	760.20
35	30	78.5	0.745	12.540	0.125	280.20	1028.34
36	30	78.5	0.990	15.717	0.157	307.54	1128.68
37	30	78.5	0.756	6.111	0.061	138.55	508.48

38	30	78.5	0.693	9.181	0.092	190.92	700.68
39	30	78.5	0.800	7.647	0.076	183.48	673.36
40	30	78.5	0.888	3.518	0.035	93.75	344.05
41	30	78.5	0.578	14.403	0.144	249.77	916.65
42	30	78.5	0.965	14.431	0.144	261.66	960.29
43	30	78.5	0.981	7.310	0.073	215.17	789.67
44	30	78.5	0.907	10.100	0.101	274.70	1008.14
45	30	78.5	0.796	10.245	0.102	244.78	898.35
46	30	78.5	1.027	14.607	0.146	293.14	1075.81
47	30	78.5	0.902	14.586	0.146	254.10	932.56
48	30	78.5	0.913	10.170	0.102	278.59	1022.44
49	30	78.5	0.837	10.871	0.109	272.91	1001.57
50	30	78.5	0.958	5.581	0.056	160.41	588.71
51	30	78.5	0.665	9.851	0.099	196.40	720.79
52	30	78.5	0.784	7.498	0.075	176.33	647.14
53	30	78.5	0.831	8.465	0.085	211.10	774.73
54	30	78.5	1.029	14.376	0.144	288.39	1058.41
55	30	78.5	0.639	11.844	0.118	227.13	833.57
56	30	78.5	0.573	6.093	0.061	104.82	384.70
57	30	78.5	1.175	8.738	0.087	307.95	1130.18
58	30	78.5	0.969	7.243	0.072	210.60	772.91
59	30	78.5	0.581	8.081	0.081	140.74	516.50
60	30	78.5	0.743	13.708	0.137	305.52	1121.26
61	30	78.5	0.698	5.731	0.057	120.08	440.71
62	30	78.5	0.763	6.348	0.063	145.35	533.42
63	30	78.5	1.209	7.786	0.078	282.32	1036.11

Appendix 3. Carbon stock of organic soil (SOC)

Appendix 4. Location of sample plots

Plot	Location (UTM)		Altitude (m.a.s.l)	Slope (Degree)	Aspect (Slope Facing)
	Easting	Northing			
1	259919	1214151	2374	25	NW
2	259956	1215048	2325	18	SW
3	260523	1215767	2510	15	SW
4	260782	1216298	2578	51	N
5	260025	1216659	2500	43	SW
6	259522	1215731	2392	10	NW
7	258223	1214680	2391	8	NW
8	258236	1215795	2221	7	SW
9	258241	1216204	2298	26	NW
10	257566	1215647	2309	14	NW
11	257274	1214903	2256	31	SW
12	257226	1217440	2260	45	SW
13	256065	1218015	2240	29	S
14	245610	1215398	1983	9	W
15	256065	1218015	2240	26	S
16	255796	1216285	2342	27	W
17	255433	1215677	2240	7	E
18	245593	1214829	2102	10	N
19	245385	1213035	1960	8	SE
20	255045	1218395	2251	28	S
21	254702	1217817	2101	15	NE
22	254742	1216743	2140	15	W
23	253577	1211796	2134	19	W
24	252362	1212441	2258	28	NW
25	252094	1213607	2151	15	N
26	253605	1216675	2101	17	S
27	253489	1219520	2140	26	SE
28	243960	1213404	1893	14	W
29	258254	1219793	2158	10	NE
30	252701	1212587	2105	19	NE
31	251780	1216580	2095	22	S
32	251331	1214015	2148	21	NW
33	252610	1216627	2206	31	S

34	251941	1219516	2119	10	S
35	251068	1220766	2246	25	N
36	250942	1220471	2175	9	NW
37	251021	1214914	2160	7	NW
38	244908	1214734	1960	10	S
39	249809	1214062	2195	9	W
40	245486	1213838	1957	8	SE
41	249091	1221277	2323	10	NW
42	249155	1220110	2168	19	E
43	249354	1219505	2041	17	N
44	248755	1214556	2041	9	S
45	242497	1213858	1854	17	W
46	247875	1219789	2062	10	E
47	248061	1221081	2244	18	S
48	244403	1213943	1887	16	E
49	247266	1221741	2053	10	W
50	247215	1221127	2197	9	NW
51	247232	1220288	2012	7	N
52	246667	1221818	2085	8	NW
53	246290	1220734	2104	31	NW
54	246000	1220395	2055	33	S
55	246616	1220158	1944	6	NW
56	244665	1215762	2072	5	S
57	251037	1217061	2007	17	SE
58	244594	1216366	1935	5	W
59	243630	1216540	1867	8	SE
60	244032	1214876	1888	6	E
61	243778	1215083	1869	9	SE
62	242896	1214783	1873	7	N
63	251280	1218066	1998	12	NW

Declaration

I, the undersigned hereby declare that, this Thesis is my original work and has not been presented nor is being currently submitted for a degree in other Universities or publication. All sources of materials used have been duly acknowledged. It is free for use as far as proper citation and acknowledgment is made.

Signature   Date

29/10/2016

Fentahun Abere Tamene

This Thesis has been submitted for examination with the approval of my University advisor.

	Signature	Date
Dr. Teshome Soromessa (Advisor)	-------------------	29/10/2016