IMPACT OF CONVERSION OF MOIST AFROMONTANE FOREST TO RUBBER PLANTATION AND SEMI-FOREST COFFEE ON BIOMASS AND SOIL CARBON STOCKS: THE CASE OF GURAFERDA DISTRICT, SOUTH WESTERN ETHIOPIA

M. Sc THESIS

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A THESIS SUBMITTED TO

THE DEPARTMENT OF GENERAL FORESTRY, WONDOGENET COLLEGE OF FORESTRY AND NATURAL RESOURCES, SCHOOL OF NATURAL RESOURCES AND ENVIRONMENTAL STUDIES,

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST RESOURCE ASSESSMENT AND MONITORING

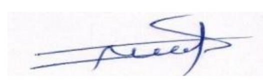
ADVISOR: MESELE NEGASH (PhD)

JUNE 2020

APPROVAL SHEET I

This is to certify that thesis entitled "Impacts of Conversion of Moist Afromontane Forest to Rubber Plantation and Semi-forest Coffee on Biomass and Soil Carbon Stocks: The Case of Guraferda District, Southwest Ethiopia" submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in forest resource assessment and monitoring of the graduate program under the department of general forestry, Wondogenet College of Forestry and Natural Resources and is recorded of original research carried out by Sewnet Enyew Ambaye Id. No. M.Sc/FRAM/R017/10, under my supervision, and no part of the research has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore I recommend that it has to be accepted as fulfilling of the thesis requirements.

Dr. Mesele Negash		27 JUNE 2020
Name of Advisor	Signature	Date

APPROVAL SHEET II

We, the undersigned, members of the Board of examiners of the final open defense by Sewnet Enyew Ambaye have read and evaluated his thesis entitled Impacts of conversion of moist Afromontane forest to rubber plantation and semi-forest coffee on biomass and soil carbon stocks: The case of Guraferda District, southwest Ethiopia and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science with specialization Forest Resource Assessment and Monitoring.

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DECLARATION

I, Sewnet Enyew, hereby declare to the school of graduate studies, Hawassa University that this is my original work not of any other person. All the source of materials used for the thesis have been explicitly acknowledged (including citation of published and unpublished sources). I also declare that the work has not previously been submitted in any form to any University or other institution for assessment of any other purpose.

Sewnet Enyew		29 JUNE 2020
Name		Date

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ABBREVATIONS AND ACRONYMS

AGB	Aboveground Biomass
ANOVA	Analysis of Variance
BAU	Busines as Usual
BD	Bulk Density
BGB	Belowground Biomass
Bt	Billion tone
C	Carbon
CIFOR	Center for International Forestry Research
CO_2e	Carbondioxide equivalent
CRGE	Climate Resielience Green Economy
CSA	Central Statistics Agency
DWB	Deadwood Biomass
EC	Ecosystem Carbon
EFCCC	Environment, Forest and Climate Change Commission
FAO	Food and Agriculture Organization of the United Nations
FC	Forest coffee
FRA	Forest Resources Assessment
FRL	Forest Reference Level
GC	Garden coffee
GDANRO	Guraferda District Agriculture and Natural Resource Office
GHG	Green House Gas
GPS	Global Positioning System

Gt	Gigatone (1Gt = 10^9 tones)
GTP	Growoth and Transformation Plan
ICRAF	International Centre for Research in Agroforestry
IPCC	Intergovernmental Panel on Climate Chang
LB	Litter Biomass
LSD	Least Significant Difference
m asl	Meter above sea level
MEFCC	Ministry of Environment, Forest and Climate Change
Mg	Mega gram (1Mg =1 ton)
Mt	Megaton (1Mt = 10^6 tones)
Mha	Million hectares
NF	Natural forest
PC	Plantation coffee
Pg	Petagram (1 Pg= 10^9 tones)
QGIS	Quantum Geographic Information System
REDD+	Reduce Emission from Deforestation and Forest Degradation
RP	Rubber plantation
SFC	Semi-forest coffee
SNNPR	South Nations Nationalities and Peoples Region State
SOC	Soil Organic Carbon
SS	Sub sample
UNFCCC	The United Nations Framework Convention on Climate Change
VCS	Voluntary Carbon Standard

WBISPP	Woody Biomass Inventory and Strategic Planning Project
WGCFNR	Wendo Genet College of Forestry and Natural Resources
WD	Wood Density
WFP	World Food Program

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Impacts of conversion of moist Afromontane forest to rubber plantation and semi-forest coffee on biomass and soil carbon stocks: The case of Guraferda District, southwest Ethiopia.

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ABSTRACT

Conversion of Natural Forest to other land uses negatively affect the biomass and soil carbon stocks. This study was carried out to investigate the impact of conversion of natural forest to rubber plantation and semi-forest coffee in terms of biomass and soil carbon stocks in Guraferda district, southern-western Ethiopia. For this study stratified systematic sampling technique was followed to establish plot sizes of 20m x 10m (200m2) across the three adjacent land uses, namely, natural forest, semi-forest coffee and rubber plantation. A total of nested 60 sample plots (20 plots for each land use) were used to conduct woody species inventory, soil sample collection to determine soil organic carbon (SOC) and bulk density (0-30 and 30-60 cm soil layer) and litter sampling. Total biomass carbon stocks (above plus belowground) in natural forest (302.59 t ha^{-1}) is greater than semi-forest coffee (79.96 t ha^{-1}) and rubber plantation (43.91 t ha^{-1}). The natural forest is significantly greater than rubber plantation and semi-forest coffee. And also, rubber plantation is significantly lower than semi-forest coffee. The mean deadwood biomass carbon of semi-forest coffee (2.64 t ha^{-1}) was significantly higher than natural forest (1.97 t ha^{-1}) ($p < 0.05$). Similarly, the mean litter biomass carbon of natural forest (2.56 t ha^{-1}) significantly higher than rubber plantation (1.85 t ha^{-1}) and semi-forest coffee (1.31 t ha^{-1}). The mean soil organic carbon stock was significantly highest in semi-forest coffee (112.01 t ha^{-1}) and lowest in rubber plantation (68.24 t ha^{-1}). It was lower in subsoil by 63.80%, 67.73% and 65.22% for natural forest, rubber plantation and semi-forest coffee respectively. The ecosystem carbon stocks (biomass and soil) were 391.49 t ha^{-1}, 112.15 t ha^{-1} and 191.97 t ha^{-1} in natural forest, rubber plantation and semi-forest coffee respectively. The present study reveled that conversion of natural forest to rubber plantation and semi-forest coffee significantly reduced the carbon stocks both in the biomass and soil. Therefore, it is very clear that there is a need for conservation of the existing forest through introduction of sustainable forest management approach to maintain climate mitigation potential while ensuring the economic benefits.

Key words: *Deadwood, Deforestation, Greenhouse gas removal, Litter carbon, Mitigation*

1. Introduction

1.1 Background of the study

Global forests resources of just over 4 billion hectares which cover some 30% of the world's land area (Macdicken *et al*., 2015) hold about 40% of the carbon in the atmosphere and represents over 50% of global greenhouse gas mitigation potential. (Yitebitu *et al*., 2010; IPCC, 2013). Carbon sequestration through forests has attracted much interest in climate change mitigation due to relatively inexpensive means of addressing climate change immediately (FAO, 2010a). Forests acting as carbon sinks, they absorb about 2 billion tons of carbon dioxide each year (FAO, 2018a). Forests sequester and store significant amount of carbon and are an important natural brake on climate change (Getaw Yilma, 2016). The world's forests store an estimated 296 Gt of carbon in both above- and below-ground biomass, which contains almost half of the total carbon stored in forests (FAO, 2015a).

Deforestation and forest degradation are global problems, significantly contributing to carbon emissions and affecting the regulation of global climate and terrestrial carbon storage (Munawar *et al*., 2015). In terms of carbon emission from the tropics, shifting cultivation is first largest emissions (432 Mt C yr^{-1}) and the conversion of forests to permanent croplands in the tropics was responsible for the second largest emissions of carbon (370 Mt C yr^{-1}) over the period 1990–2009 (Houghton, 2012). The harvest of industrial wood (e.g. timber, pulp) was responsible for a net loss of 141 Mt C yr^{-1} over the last two decades (Houghton, 2012). Most of the wood harvested in tropical countries is for fuel wood and the collection of traditional fuelwood (firewood and charcoal) for cooking and heating is common throughout the tropics and can lead to forest degradation where removals exceed re-growth (Pearson *et al*., 2017).

According to Friis and Sebsebe (2009) and Friis *et al*., (2010) the vegetation of Ethiopia has been classified into 12 vegetation types. Later on, the Forest and Landscape Inventory is not focused only on forest strata, during 2015 a new vegetation potential of Ethiopia was proposed to better represent the reliable carbon stock estimates into 4 major biomes Acacia-Commiphora, Combretum-Terminalia, Moist Afromontane Forest, and Dry Afromontane Forest (Ethiopia's FRL, 2017).

According to Behailu Assefa (2010), the annual deforestation rate of high forest of southwest Ethiopia was estimated about 0.92%–0.98% during the time period of 1987-2006. Ethiopia has been losing about 92,000 ha of forest (0.54% of total area of forest) annually between 2000 and 2013 (Ethiopia's FRL, 2017). Over the period 2000-2013 an annual forest gain was approximately 30,000 ha^{-yr} and installation of plantations are expected to reduce forest degradation and deforestation (Ethiopia's FRL, 2016). According to MEFCC, (2018) the country's plantation forest area consisting of 373,400 ha. It has historically lost most of its forest cover in the north and central areas from various drivers, and these areas now require large scale restoration (Ethiopia's FRL, 2016). Recently, deforestation occurs mainly in the remaining Moist Afromontane Forest in the southwest and southeast (REDD+ Ethiopia, 2015). A comprehensive study was published by Ethiopia's REDD+ secretariat (REDD+ Ethiopia, 2015) analyzing the causes of deforestation and degradation based on framework analysis were identified to be population growth, unsecure land tenure and poor law enforcement.

According to MEFCC and REDD+ Ethiopia, (2016) the drivers of deforestation and forest degradation has been identified as small and large-scale agricultural land conversion, increased wood extraction for fuel and construction, and pressure caused by increased free livestock grazing. The underlying causes of these deforestation and degradation were identified to be population growth, unsecure land tenure, poor law enforcement, inadequate legal and regulatory frameworks, historic institutional instability of the forest sector and poor capacity (Melaku *et al*., 2015). The large scale investment agricultural schemes both private ones and state owned have been significant drivers in Gambella, Benishangul Gumuz and Afar Regional States (MEFCC, 2018; MEFCC and REDD$^+$Ethiopia, 2016; REDD$^+$ Ethiopia, 2015).

Carbon sequestration via forests has attracted much interest in climate change mitigation approach due to their serve as a relatively inexpensive means of addressing climate change immediately (FAO, 2010a). Ethiopia is one of the tropical countries with significant forest cover (Admassu *et al*., 2019) and its overall forest cover is estimated to be around 13 million hectare covering 11.4% of the total area of the country (FAO, 2015a). But, the current statistics (MEFCC, 2018) show that Ethiopia has 17.78 million ha of forest resources, i.e. covering 15.5% of the country's total area.

Forests create opportunities for the mitigation of climate change. They stored a considerable amount of carbon stocks if appropriate conservation and management systems existed in the forest sector (Getaneh *et al*., 2018). The forestry sector in Ethiopia is the second largest contributor of GHG emissions accounted 53 Mt CO_2e (Ethiopia's CRGE, 2010) in the country after agriculture (MEFCC, 2018). It stores an estimated 2.76 billion tons of carbon, playing a significant role in the global carbon balance (Yitebitu *et al*., 2010). Reducing carbon emissions from deforestation and forest degradation (REDD) is expected to play key role in mitigating climate change (Thumaty *et al*., 2016).

1.2 Statement of the problem

In Ethiopia the moist Afromontane forests are located in the southern and south western part of the country (Badege Bishaw, 2001). This accounts for 18% of the country's forest cover, has seen significant deforestation over the last two decades (Gole *et al.*, 2001). Ethiopia's Southwestern forested area consists of most of the forest remaining in the country (BES, 2018). Similar to other parts of the country, in Guraferda District deforestation and forest degradation occurred due to large-scale agricultural investments and the allocation of farm land to investors. They are two major causes of deforestation and forest degradation. The first consist of growing cereal food crops. The second ones are more engaged in cash crops and fruit production like, coffee, mango, spices and rubber plantation. According to Guraferda District investment office, above 25,760 hectares of communal forest land transferred to private and domestic large-scale agricultural investors for varieties of agricultural investment (Addisu Guta, 2016). Farmers in Guraferda District have used forest resources for fuel wood as sources of energy, non-timber forest products such as coffee, honey, cardamom (*Aframomum corrorima*), wild pepper, long pepper (*Piper capense*), and turmeric (*Curcuma longa*) (Chilalo and Wiersum, 2011), for construction, for house construction and farming tools (Belay Haile, 2018).

Underlying drivers of deforestation and forest degradation in Guraferda District are: Inflow of resettlers from different parts of the country, population growth, both resettlement types (government-sponsored and spontaneous) impose adverse effects on the vital livelihood resources of land, forest and pasture (Abeje Menberu, 2010). Security of land tenure over land occupied by a household significantly increased the competition of expanding unplanned farms towards the neighboring natural forests, shrub and/or bush lands, and grass land (Addisu Guta, 2016). The Southwest part of Ethiopia is a region in the country that contains one of the counties remaining moist Afromontane forest. Particularly, Sheka, Kafa and Bench-Maji Zones are known for their natural forests with 60, 20 and 15% of forest cover, respectively (Chilalo and Wiersum, 2011). The forest covers in the region at the current situation are declining both in quality and quantity at a faster rate in this decade than ever before (Tessema and Awoke, 2014). Guraferda is one of Benchi Maji districts which falls under a high rate of land use/land cover change due to resettlement, agricultural land expansion, and large scale plantation of coffee (*Coffee arabica*) at the expense of the natural forest (Belay Haile, 2018).

But, studies are limited about impacts of conversion of moist Afromontane forest to rubber plantation and semi-forest coffee on biomass and soil carbon stocks. Therefore, this study is aimed to investigate impact of conversion of moist Afromontane forest to rubber plantation and semi-forest coffee in terms of carbon stocks in Guraferda district, southwestern Ethiopia.

1.3 Objectives

1.3.1 General objective

To investigate impact of conversion of moist Afromontane forest to rubber plantation and semi-forest coffee in terms of carbon stocks in Guraferda district, south western Ethiopia.

1.3.2 Specific objectives

a) To determine and compare biomass C stocks of forest in reference to adjacent rubber plantation and semi-forest coffee

b) To estimate and compare SOC stocks in forest reference to adjacent rubber tree and semi-forest coffee

c) To evaluate ecosystem carbon stocks (biomass and soil) across the three studied adjacent land uses

1.4 Research questions

- How do above and belowground carbon stocks vary among natural forest, rubber and semi-forest coffee lands?
- What carbon pools impacted by conversion of natural forest to rubber and semi-forest coffee?
- How do biomass carbon related to soil organic carbon in the three studied land uses?

1.5 1.5. Hypothesis

- Conversion of natural forest to rubber plantation and semi-forest coffee would impact above and belowground carbon stocks in moist Afromontane forest of southwestern Ethiopia

1.6 Significance of the study

Reliable estimates of C stock is essential for development of management plans related to climate change mitigation. In the study area, the biomass and soil organic carbon stock of the three land uses (forest, rubber and semi-forest coffee) are not assessed; since it is very important to evaluate the carbon stocks both in the biomass and soil due to conversion of natural forest to rubber tree and semi-forest coffee. Hence, this study develop the baseline data information of the relationship between biomass carbon stocks and SOC among the three adjacent land uses for Ministry of Environment, Forest and Climate change (MEFCC), REDD^{+} Ethiopiaand others forth coming researchers as a piece kind of background literature. This study will also usefull to scientific communities and academic students (researchers) can serve as a reference for creating and developing their projects that can give them ideas to make their work easier. The District of Agriculture and Natural Resource Office as well as investment office will be benefited from this study for conservation of the forest through introduction of sustainable forest management interventions in the area. It also gives relevant information for policy makers regarding managing the ecosystem function for carbon financing scheme.

2 LITERATURE REVIEW

2.1 Forest resources in Ethiopia

Ethiopia is one of the tropical countries with significant forest cover which can sequester a greater amount of carbon to mitigate climate change (Admassu *et al*., 2019). According to the Woody Biomass Inventory and Strategic Planning Project (WBISPP), Ethiopia owns a total of 59.7 million ha of land covered by woody vegetation. Of this total woody vegetation, 6.8% is high forests, 49% is woodland, 44.2% is scrubland or bush land, and plantations cover less than 1% (0.2%) (MEFCC, 2018). The forest resource of the country is classified into natural high forest, Plantation forest, woodland, and shrub land (WBISPP, 2004). The high forests in Ethiopia cover about 4 million hectares (3.56%), woodlands cover 29 million hectares (about 25%), the shrub lands 26 million hectares **(**23%) of the area of the country. The total area of planted forest is estimated at 216,000 ha. FAO, (2010) estimated the overall forest cover is to be around 13 billion hectare covering 11.4% of the total area of the country.

But, the current statistics show that Ethiopia has 17.78 million ha of forest resources, i.e. covering 15.5% of the country's total area (MEFCC, 2018). In 2015 Ethiopia adopted a new aggregation map to better represent the reliable carbon stock estimates. (Ethiopia's FRL, 2017; FAO, 2018b). Using 12 vegetation types as input, these have been aggregated into four Forest Resource Assessment (FRA) categories (biomes). This new stratification has been implemented to estimate the carbon content for the Forest Reference Level of Ethiopia. The vegetation biomes of Ethiopia are *Acacia*-Commiphora, *Combretum-Terminalia*, *Dry Afromontane* and *Moist Afromontane* forest (MEFCC, 2018; REDD+Ethiopia, 2018).

Ethiopia adopted a new forest definition in February 2015. Land spanning at least 0.5 ha covered by trees (including bamboo) (with a minimum width of 20 m or not more than two-thirds of its length) attaining a height of at least 2 m and a canopy cover of at least 20% or trees with the potential to reach these thresholds (Ethiopia's FRL, 2017).

Forests create opportunities for the mitigation of climate change. They stored a considerable amount of carbon stocks if appropriate conservation and management systems existed in the forest sector (Getaneh *et al*., 2018). The forestry sector in Ethiopia is the second largest contributor of GHG emissions accounted 53 Mt CO_2e (Ethiopia's CRGE, 2010) in the country after agriculture (MEFCC, 2018). It stores an estimated 2.76 billion tons of carbon, playing a significant role in the global carbon balance (Yitebitu *et al*., 2010). Reducing carbon emissions from deforestation and forest degradation (REDD) is expected to play key role in mitigating climate change (Thumaty *et al*., 2016).

Yet, the forests in the country are under direct and indirect threats (Melaku Bekele *et al*., 2015). Direct threats include small and large-scale agricultural land conversion, increased wood extraction for fuel and construction, and pressure caused by increased livestock grazing (Bishaw Badege, 2014; Getaneh *et al.*, 2019). The indirect threats comprise gaps in the application of forest policy and regulations; tenure/unclear forest user rights; lack of private investment in forestry development; population growth; and inadequate land use planning and participatory forest management (PFM) MEFCC, 2018; REDD+ Ethiopia, 2015; Yitebitu *et al*., 2010).

2.2 Tropical forest and climate change mitigation

Tropical forests are one of the most carbon (C) rich ecosystems in the world that accounts about 40% of the total carbon (C) storage as terrestrial biomass (Lewis *et al*., 2009) and, playing a fundamental role in the global C cycle (Pan *et al*., 2011). According to FAO, (2015) estimates, forests continue to be a net carbon sink globally, having stored on average some 2.1 Gt of CO_2 annually, during the period 2011–2015. Other recent study showed the potential of the world's tropical forests are a net carbon source of 425.2 (±92.0) Tg C yr^{-1} and net release of carbon consists of losses of 861.7 (±80.2) Tg C yr–1 and gains of 436.5 ± 31.0 Tg C yr–1(Baccini *et al*., 2019). Tropical forests store a large part of the terrestrial carbon and play a key role in the global carbon (C) cycle (Gibbs *et al*., 2007). In 2015 the forest covers were 3,999 Mha globally. This is equivalent to 31% of the global land area, or 0.6 ha for every person on the planet (Keenan *et al.*, 2015). The total tropical forest area(1,949 Mha) accounts for ~50% of global forest biomes (Pan *et al.*, 2011). Carbon storage and fluxes in forests have been the focus of research in recent years because of the role of CO2 in global climate change and hold 70–90% of terrestrial aboveground and belowground biomass (Houghton *et al*., 2009).

2.3 Deforestation and forest degradation in tropics

Global forest in the tropics has decreased much during the last century (Hansen *et al*., 2010). Forest degradation occurs when there is a direct, human-induced decrease in carbon stocks in forests resulting from a loss of canopy cover that is insufficient to be classed as deforestation (Pearson *et al*., 2017). The collection of traditional fuelwood (firewood and charcoal) for cooking and heating is common throughout the tropics and can lead to forest degradation where removals exceed re-growth (Alm *et al*., 2018).

Deforestation accounts for an estimated 12–15% of global greenhouse gas emissions through the annual loss of nearly 20 Mha of the forest, a third of which is in the tropics (Hansen, 2013). Deforestation and forest degradation in the tropics have been estimated to contribute 12–15% of the global anthropogenic CO_2 emissions (Blécourt *et al*., 2013) and mainly caused by the conversion of forest land to agriculture and livestock areas (FAO, 2018b). According to the study published by Pearson *et al*., (2017), the total emissions from tropical deforestation and forest degradation were 6.22 Bt CO_2e and 2.1Bt CO_2e respectively.

2.4 Deforestation and forest degradation in Ethiopia

Deforestation and forest degradation are major problems facing the forestry sector in Ethiopia (Habtemariam *et al.*, 2015). Destruction of the natural forests results directly in the loss of countless plant and animal species and depletion of forest resources that contributes significantly to the climatic changes of the environment (Amisalu Milkias and Tessema Toru, 2018). These is because of agricultural land expansion, increased wood extraction for fuel and construction and overgrazing (Getaneh *et al*., 2019) that result in major loss of forest biodiversity and ecosystem services (Mulugeta *et al*., 2005; Tefera *et al*., 2005). Similarly, gaps in the application of forest policy and regulations; unclear forest user rights; lack of private investment in forestry development; population growth (Amisalu Milkias and Tessema Toru, 2018); and inadequate land use planning and participatory forest management (PFM) (Badege Bishaw, 2001; Demel Teketay, 2001; Getaneh *et al*., 2019; Melaku *et al*., 2015; REDD+ Ethiopia, 2015; Yitebitu *et al*., 2010).

In Ethiopia large areas, which were once under vegetation cover are now changed to farmland and revealed to soil erosion resulting into environmental degradation and serious danger to the land (Amare Bantider, 2007). The demand for agricultural land, would be the predominant driver of deforestation and about 1.24 million ha of natural high forest cleared for agricultural expansion between 1990 and 2014 (Melaku *et al*., 2015). According to Behailu Assefa (2010), the annual deforestation rate of high forest of south west Ethiopia was estimated about 0.92%–0.98% during the time period of 1987-2006.

According to MEFCC and REDD+ Ethiopia, (2016) the drivers of deforestation and forest degradation has been identified as small and large-scale agricultural land conversion, increased wood extraction for fuel and construction, and pressure caused by increased free livestock grazing. The underlying causes of these deforestation and degradation were identified to be population growth, unsecure land tenure, poor law enforcement, inadequate legal and regulatory frameworks, historic institutional instability of the forest sector and poor capacity (Melaku *et al*., 2015). The large scale investment agricultural schemes both private ones and state owned have been significant drivers in Gambella, Benishangul Gumuz and Afar Regional States (MEFCC, 2018; MEFCC and REDD$^+$Ethiopia, 2016; REDD$^+$ Ethiopia, 2015).

Emissions from the Forestry sector are mainly caused by human beings, and are driven by deforestation for agriculture and forest degradation from fuel wood consumption and logging. Under the BAU scenario, emissions from forestry will increase from 53 Mt CO_2e in 2010 to 88 Mt CO_2e in 2030 (Ethiopia's CRGE, 2010). Ethiopia has been losing about 92,000 ha (0.54%) of forest annually between 2000 and 2013 as indicated in the countries forest emission baseline (Ethiopia's FRL, 2016). It has historically lost most of its forest cover in the north and central areas from various forces, and these areas now require large scale restoration (Ethiopia's FRL, 2017). Recent deforestation occurs mainly in the remaining moist Afromontane forest in the southwest and south east, and the dry forest areas in western lowlands (Combretum-Terminalia woodlands) and must be priority areas for intervention (MEFCC, 2018).

2.4.1 Rubber tree plantation

Natural rubber (*Hevea brasiliensis*), native to the Amazon basin in South America and then introduced and distributed to Southeast Asia Countries during the late 19th century (Fong *et al*., 2018). Thailand, Indonesia, Vietnam, India, China, and Malaysia are the main rubber producing countries and 83% of the world's natural rubber supply today comes from this region. The first two countries produce more than 58%, and the next four each one produces around 8% of world rubber production (Li and Fox, 2012). The worldwide consumption of natural has been increasing steadily for many decades (Fox, 2014). Worldwide consumption of natural rubber is increasing from 9.6 million tons in 2008 to 13.8 million tons by 2018 a growth of 3.7% per year (Prachaya, 2009). It is cultivated for latex production in all tropical zones on a total land area of about 9,675,000 ha and the economic lifetime of a rubber tree is 25–30 years (Hytönen *et al*., 2018).

The expansion of agro-industrial rubber plantations in the tropics has been considered as a major factor negatively affecting biodiversity and ecosystem services (Abood *et al*., 2015). Oil palm and rubber expansion is the main driver of the widespread deforestation of tropical rainforests taking place (Meijide *et al*., 2018) and rainforests have been logged since the mid-20th century, usually followed by tree cash crops such as oil palm (Elaeis *guineensis*) and rubber (*Hevea brasiliensis*) monocultures (Abood *et al*., 2015) in Southeast Asia. Little research has been done on currently forest-to-rubber plantation conversion in the tropical region, for which the impacts on soil carbon stocks have hardly been studied (Blécourt *et al., 2013)*. IPCC, (2006), showed the fact that perennial crops, like rubber, can play a role in sequestering carbon, but (Petsri *et al*., 2013) data on carbon stocks and the sequestration potential of rubber tree plantations are rarely available.

The rubber plantations (*Hevea brasiliensis*) carried out in the southwestern part of Ethiopia, where this region is considered the most suitable for rubber cultivation (Dejene *et al*., 2018). According to Guraferda district Agriculture and Natural Resource Office, (2015) 3,800 ha of land is covered by rubber plantation. The Ethiopian Investment Agency, (2012) reported that in the year 2010, Bebeka area (around study site) has a potential of 78,000 ha for rubber plantation out of which 1,652.04 ha, 975 ha and 4,500 ha of lands are cultivated in Addis Berhan, Bebeka and Toli kobo area respectively by National Nucleus Project for Rubber Plantation and Processing of Ethiopia.

2.4.2 Coffee plantation

Coffee is grown widely throughout the tropics on about 5 million farms from 85 countries (Toledo and Moguel, 2012). Arabica coffee (*Coffea arabica*) has its centre of origin in Southwestern Ethiopia and, where it still occurs naturally in the undergrowth of the unique forest ecosystems (Tessema and Awoke, 2014). They Ethiopia is the main coffee producing country in Africa and the fifth worldwide and increases in production from 1.2% to 7.55 million bags in 2019 (ICO, 2019). Coffee production systems in Ethiopia are categorized into four: forest coffee 10% semi-forest coffee 35 %, garden coffee 50% and coffee plantations 5%

of the total production, and mainly found in southwestern and southern Ethiopia (De Beenhouwer *et al*., 2016). The forest coffee system (FC) is the practice of coffee harvesting in natural forests with no or very little anthropogenic disturbance (Schmitt-Harsh *et al*., 2012) whereas, In the semi-forest coffee system (SFC), there is a high anthropogenic disturbance resulting in poor canopy consisting of tree species. Mulching is common practice and organic fertilizers are used (Mitiku *et al*., 2018). Garden coffee production system (GC) owned by smallholder coffee growers which are produced in plots of varying sizes around dwellings (De Beenhouwer *et al*., 2016), but in the plantation coffee system (PC), there is a high anthropogenic disturbance resulting in a poor canopy consisting and shade plantations with only a few, large canopy trees. Herbicides and chemical fertilizers are applied regularly and mulching is common practice (De Beenhouwer *et al*., 2014).

Carbon storage is affected by land-use changes and fragmentation (Getachew *et al*., 2014). The conversion of forest to coffee plantations is expected to cause a carbon loss (Magrach and Ghazoul, 2015). Among these four coffee management systems, FC and SFC hold the greatest degree of canopy cover and thus have the greatest potential in terms of carbon storage (Getachew *et al*., 2014). The specific thinning regime applied by farmers in the semi-forest coffee system to maximize productivity results in low species diversity and simplified forest structure (reduced number of stems, the lower canopy of SW Ethiopia (Aerts *et al.*, 2011). The stem component of coffee accounted for 56 % of aboveground total plant biomass on average, branch 39 % and twigs plus foliage 5 % (Mesele *et al*., 2013). Coffee in southwest Ethiopia plays a vital role in biomass carbon storage and climate regulation (Getachew *et al*., 2014). Ethiopia's SFC maintains 75% of the carbon stored in natural forests, but it maintains more long-term carbon stocks than alternative forms of agricultural land use (Dereje *et al*., 2016).

2.5 Biomass carbon pools

A carbon pool is a reservoir of carbon that has the potential to accumulate or release carbon (VCS, 2008) whereas biomass refers to the vegetation biomass density, which is mass per unit area of live or dead plant material (Solomon *et al*., 2013). Carbon pools in the forest ecosystem are categorized mainly into five major pools and they are aboveground, belowground, deadwood, litter and soil organic carbon (IPCC, 2006).

2.5.1 Aboveground carbon pool

Reliable and accurate estimates of tropical forest aboveground biomass (AGB) are important to reduce uncertainties in carbon budgeting (Thumaty *et al*., 2016). All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage (IPCC, 2006). The above-ground biomass of a tree is mainly the largest carbon pool and it is directly affected by deforestation and forest degradation (Gibbs *et al*., 2007). Tropical forests account for 247 Gt vegetation carbon, of which 193 Gt is stored above ground (Saatchi *et al*., 2011). During forest inventory, the diameter at breast height (DBH at 1.3m) for all woody species having DBH ≥ 5 cm should be recorded (Pearson *et al*., 2005). For forked trees, measuring the diameter of trees those forked below DBH (below 1.3m) independently and then taking the equivalent diameter (Snowdon., *et al* 2002). Additionally, for the trees those forked above 1.3m, their DBH should be measured as a single tree (UNFCC, 2015). The most common methods for the field measurements of DBH are calipers or diameter tapes (Luoma *et al*., 2017). The AGB estimates have been calculated by using the allometric equations of Chave *et al*., (2014). A carbon fraction of 0.47 can be applied, which is the default value for wood in the tropical and subtropical domain (IPCC, 2006).

2.5.2 Belowground carbon pool

The BGB is the biomass of the living roots of trees under soil profile. It does not include fine roots with < 2 mm diameter because these often cannot be distinguished empirically from soil organic matter (Fonseca and Alice, 2012; IPCC, 2006). The below-ground biomass value is calculated from the above-ground biomass values (Tolunay, 2011) which means the below ground (root biomass) was derived from AGB by using R:S; BGB = 0.27*AGB and the estimated dry biomass carbon was converted to carbon by using biomass conversion factor 47% (IPCC, 2006).

2.5.3 Deadwood carbon pool

Deadwood plays a significant role in carbon storage in the forest ecosystems (Paletto and Tosi, 2010) and need to be quantified (Alexander and Ducey, 2010). During the decomposition of deadwood, C is partly emitted to the atmosphere and partly stored as C resources in the soil (Błońska *et al*., 2019). Dead plants or trees are those either fallen dead trees and the remains of large branches on the ground in forests or a standing, partly or completely dead trees with branches, leaves and other pieces of naturally occurring wood in the forest ecosystem (Rondeux and Sanchez, 2010). Coarse woody debris (deadwood with ≥10 cm diameter) can contain significant portions of a forest's carbon stock (Pearson *et al*., 2015). Standing deadwood is usually inventoried with the same methodology as living trees (Rondeux and Sanchez, 2010).

2.5.4 Litter carbon pool

The IPCC, (2006) recognizes litter carbon (C) as one of the five C pools in forest ecosystems. Litter carbon in forests is a relatively small but important part of carbon budgets (Domke *et al*., 2016). Litter accounts for an estimated 5% of all forest ecosystem carbon stocks worldwide (Domke *et al*., 2016) and which includes all leaves, twigs, small branches fruits, flowers, roots, and bark (IPCC, 2006). The deadwood with a diameter of less than 10 cm and greater than 2mm is also considered as part of the litter layer carbon pool (Pearson *et al*., 2005).

2.6 Soil organic carbon pool

Soil is the largest carbon pool in the terrestrial ecosystem (Takahashi *et al*., 2010). Worldwide, soils are estimated to hold 3,150 Pg of carbon (C) which is more than four times the amount of carbon stored in terrestrial plant biomass (650 Pg C) or the atmosphere (750 Pg C) (Fan *et al.*, 2016). As the result, Soils are a potentially viable sink for atmospheric carbon (Lal et al., 2012). Small proportional changes in the SOC stock can strongly influence greenhouse gas concentrations in the atmosphere and have a high impact on global climate change *(*Amanuel *et al*., 2018; Breuning-Madsen *et al*., 2013). Although there is considerable variation, most studies report the global SOC estimated roughly 1,500 billion tons of carbon (Scharlemann *et al*., 2014).

Worldwide, forest soils contain double as much carbon as forest vegetation (Gimmi *et al*., 2013). The 59 % of the carbon stock originally accumulated in the top surface layers of soil under native forest and SOC stock under natural forests is higher than other land use types and also significantly varied with soil depth and showed a decreasing trend (Amanuel *et al*., 2018). Sadly, the role of the tropical forests soils of Africa in the global C cycle is poorly understood, mainly with respect to SOC (Henry *et al*., 2009), but estimates of tropical wet and moist forest ecosystems indicate that soils contain approximately 50% of the ecosystems' C stock (Scharlemann *et al*., 2014).

There is a marked variability of the SOC stocks for different depth intervals (Kirsten *et al*., 2016) and considering the soil depth within land uses, SOC stock was declined (Amanuel *et al*., 2018). Conversion of the native forest ecosystem to cropland has considerably degraded the soil nutrient levels (Fantaw *et al*., 2008). The SOC concentration showed significant difference with land use types and the overall mean SOC concentration was higher under natural and mixed forest, but, lower under cultivated land (Amanuel *et al*., 2018). The study by Taylor and Lai, (2008) indicated that deforestation and the conversion of natural to agricultural ecosystems deplete the C pool. Another study by Fantaw *et al*., (2007) agrees with the above study that the conversion of a forest ecosystem into cropland has significantly reduced the soil organic carbon and SOC stock of soils significantly lower in cropland compared to the contents in the native forest.

Better estimates of SOC stocks are needed for a better understanding of the carbon balance and potential for climate change mitigation (Scharlemann *et al*., 2014). The contribution of soil carbon sequestration to the total ecosystem carbon sink had been roughly 10% in global forests (Pan *et al*., 2011). In tropics, the mean SOC pool (kg/m^2) for 0-100 cm depths, has been reported 11.3 for Oxisols, 6.4 for Alfisols, and 6.4 for Ultisols (Taylor and Lai, 2008). Land management that exert the least soil disturbance contributes to increase SOC accumulation, while severe disturbance results in lower SOC and consequent soil degradation

(Post and Kwon, 2000). As the result it can be a source or a sink of atmospheric carbon depending upon land use and soil management (Ghimire *et al*., 2019).

3 MATERIAL AND METHODS

3.1 Site description

3.1.1 Location

Gurafarda is one of the ten districts of Bench-Maji Zone in South Nation Nationalities and Peoples Regional State (SNNPR). It is located 602 Km southwest of Addis Ababa and 42 Km from Mizan Teferi (the principal town of the zone). Geographically, it is positioned between 34°55'59" to 35°26'13" E (Latitude) and 6°29'5" to 7°13'20" N (Longitude) (Belay Haile, 2018) and altitudinal range of 500 to 2,500 m asl. It is bordered by Sheko district in the north, Me'enit Shasha district in the south, South Bench district in the west, Surma district in the southwest and the Gambella region in the northwest. The district has an estimated area of 2,565.42 km^2 (256,542 ha). It has 27 kebeles and one administrative town known as Biftu (Addisu Guta, 2016).

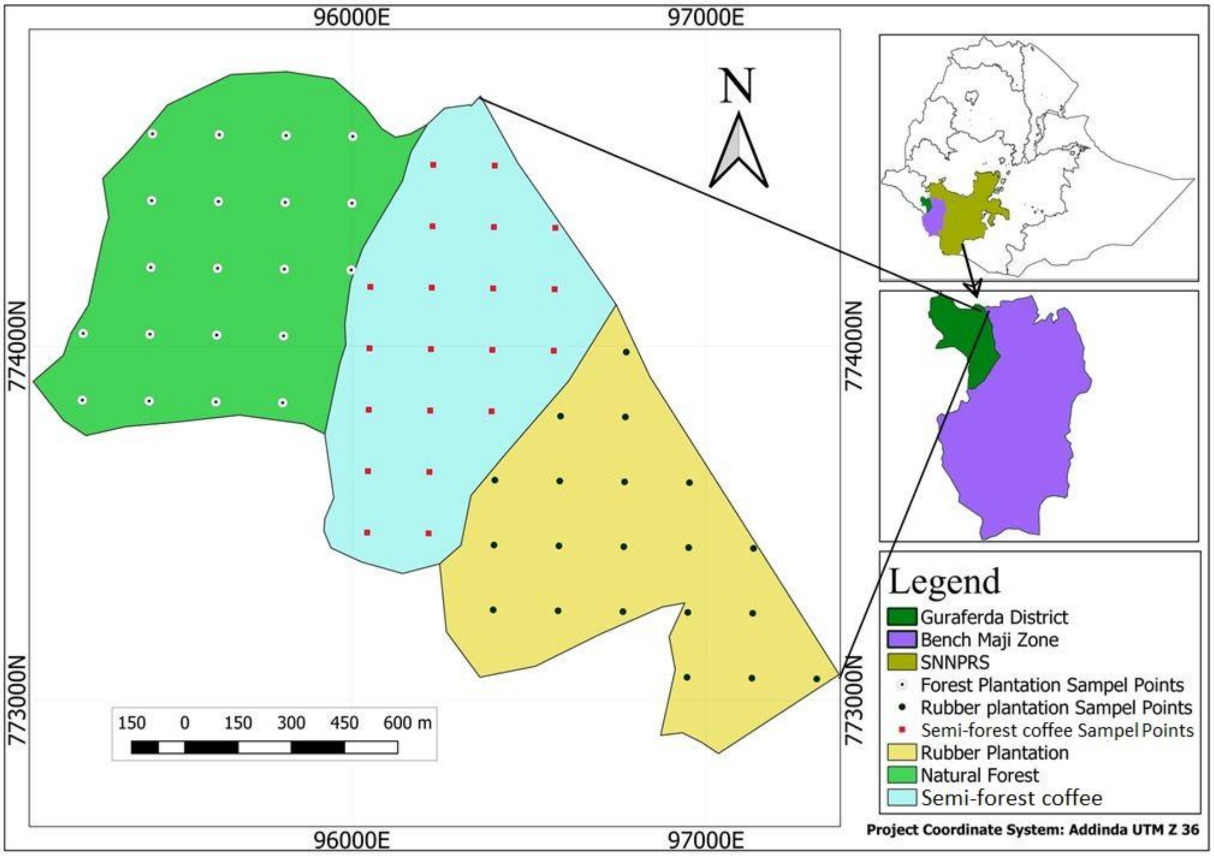

Figure 1: Location map of the study area

3.1.2 Climate

The Agro-ecologies of Guraferda district are 78% lowland (wet qolla) and 22% midland (Woynadaga). The mean annual minimum and maximum temperature of the area ranges between 20°C and 29°C, respectively (Abeje Menberu, 2010) and the annual rainfall ranges from 1,600-2,000 mm with an average of 1,332 mm (Belay Haile, 2018). Agricultural seasons of the district are two-Meher and Belg. Meher is a rainy season which ranges from June–September and Belg from February–April. The main rainy season, Meher, is considered as important for rain-fed agriculture in the area (Abeje Menberu, 2010).

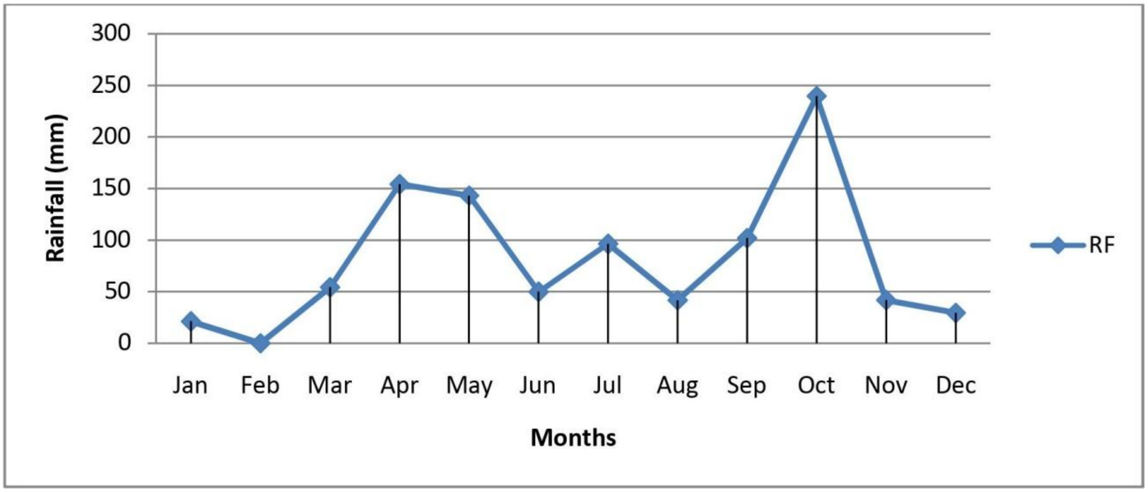

Figure 2: Ten years (2000- 2009) average monthly rainfall of the study area

Source: Dejenie Abere, (2011)

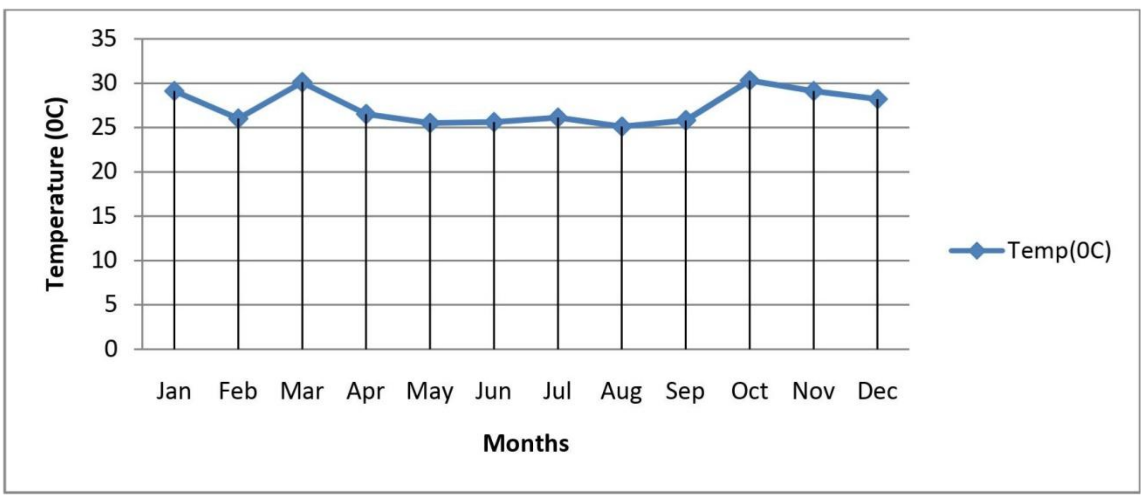

Figure 3: Ten years (2000- 2009) average monthly temperature of the study area

Source: Dejenie Abere, (2011)

3.1.3 Soil characteristics

The soil of Guraferda District is mostly characterized as fertile or nitisol (a deep, red, well-drained tropical soil with a clay content of more than 30% and a blocky structure) and the massif above 2000 m has stony and rocky surfaces while between 1500 and 2000 m, somewhat stony and the soil textural class is loam to clay (Hildebrand, 2003). The plains are characterized by silt and loam soils whereas, the steep lands of escarpments and along ridges, are thin and young (Derege Denu, 2006). According to Hildebrand (2003), some of the high, flat areas of Guraferda are poorly drained.

Table 1: Soil texture percentage of the study area

Soil depth (cm)	**Natural forest**				**Rubber plantation**				**Semi-forest Coffee**			
	Sand %	Clay %	Silt %	Textural class	Sand %	Clay %	Silt %	Textural class	Sand %	Clay %	Silt %	Textural class
0-30	28	51	21	Clay	31	51	18	Clay	25	54	21	Clay
30-60	21	58	21	Clay	18	63	19	Clay	22	53	25	Clay

Source: From laboratory analysis of sample soil

3.1.4 Demographic characteristics

According to the CSA, (2017) projection the Guraferda district total population is 44,287 and detail was shown in (Table 2). Guraferda is home for a multitude and diverse population (Amhara, Bench, Gedeo, Guragie, Hadiya, Kambata, Majang, Me'enit Oromo, Sheko, Sidama, Wolayta, and others) (Abeje Menberu, 2010). Major languages spoken in the District (Amharic, Sheko, Majang). Accordingly, the Me'enits resides around the northeastern part of the District ranging from Biftu (the capital) to Kuja (Megen'teya). On the northwestern portion alongside the Sheko District, Shekos inhabitants. At the side of the south on the boundaries of Gambella the Majang inhabitants occupy. Now, the District became the place of multiple ethnic and linguistic groups (Addisu Guta, 2016).

Table 2: Projection human population of Guraferda district in the years 2014-2017

Total population			**Urban population**			**Rural population**		
Male	Female	Total	Male	Female	Total	Male	Female	Total
24,082	20,205	44,287	4,773	4,754	16,587	19,309	15,451	34,760

Source: CSA, (2017).

3.1.5 Land use

According to the data obtained from the Guraferda district Agricultural and Rural Development Office, the total area of the district is 228, 281 hectares. As shown in table 2 119,000 ha (52%) of the district was used for forest land. The rests are used for cropland, coffee plantation, rubber tree plantation, pastureland and others (GDANRO, 2015).

Table 3: Land use land cover of Guraferda district

Land use type	**Area (ha)**	**Area (%)**
Forest land	119,000	52
Agriculture land	31,827	13.9
Coffee plantation include SFC*	28,642	12.5
Rubber plantation	3,800	1.66
Pastureland	497	0.22
Others	44,515	19.72
Total	228,281	100

Source: GDANRO, (2015)

*SFC: Semi-forest coffee

Table 4: Characteristics of the three studied land uses

Characteristics	Natural forest	Rubber plantation	Semi-forest coffee
Altitude (m asl)	968-1022	942-1024	936-971
Annual rainfall (mm)	1600 to 2000		
Annual temperature (°C)	20-29		
Major trees	*Cordia africana, Celtis africana, Croton macrostaches, Albiza gumifera, Antiaris toxicaria*		
Year of conversion		2005	2004
Management practice			Tree pruning, lopping, thinning
Major food and cash crops	Rice,maize,sorghum, fruit production, coffee, spices and rubber plantation		

3.1.6 Vegetation

The main crops in the area are rice, maize and sorghum while *Cordia african*a (wanza), Celtis *africana* (qewet, yezihon enchet.), *Croton macrostaches* (bisana), *Albiza gumifera* (sesa), *Antiaris toxicaria* (tenge) are the dominant tree species (GDANRO, 2015). The broad-leaved deciduous woodlands are found in the northwestern, western parts and the southwest along the Ethio-sudan boundary between 500-1900 m asl The vegetation is characterized by *Combretum* spp., *Oxytenanthera abyssinica*, *Boswellia papyrifera*, *Lannea schimperi*, *Anogeisus* *leiocarpus*, and *Stereospermim kunthianumcham,* where the under story constitute a combination of herbs and grasses (Belay Haile, 2018).

3.1.7 Livelihoods

Like other parts of our country, Gurafarda district is predominantly based on rain fed agriculture. Major crops produced in this district are: cash crops like coffee, sesame and rice. Cereal crops sorghum, maiz and millet. Perennial cash crops such as coffee and fruits being intensified in both resettlement schemes and enset (a banana like plant whose stem and root is used as source of food in SNNPR) is planted in the state-organized resettlement sites. Besides crop production, the farmers of the district raise livestock for their farm and for their milk consumption (Abeje Menberu, 2010). The livelihood of the local population (Sheko and Majang) based on gathering and production of honey and cattle production.

3.2 Study site selection and sampling design

3.2.1 Site selection

In order to achieve the objectives of this study, Guraferda district was subjectively selected because there is rubber tree and coffee plantation investment in this district. In the selected area, there is high deforestation and forest degradation due to rubber and semi-forest coffe activities. Studeis Abeje Menberu, (2010); Dejenie Abere, (2011); Addisu Guta, (2016); and Belay Haile, (2018) showed that the existence of severe deforestation with a significant expansion of agricultural land, settlement, rubber and coffee plantation while decreasing trends of shrub, bush land, grass land, and natural forest. Accordingly, Berhan kebele is selected from the district where the three adjacent land uses (natural forest, rubber plantation and semi-forest coffe) are available. The natural forest adjacent to the rubber tree and semi-forest coffee was used as control treatment by assuming both land uses (rubber tree and semi-forest coffee) were natural forest prior to land use conversion.

3.2.2 Preliminary survey

Preliminary survey was conducted to determine distribution and location of specific sites. The three adjacent land uses (natural forest, rubber plantation and semi-forest coffe) were selected purposively. The natural forest adjacent to the rubber tree and semi-forest coffee was used as control treatment by assuming both land uses (rubber plantation and semi-forest coffe) were natural forest prior to land use conversion.

3.2.3 Stratification of the study area

The boundaries of the study area were delineated using handheld GPS. Then it was stratified into three stratums (natural forest, rubber tree and semi-forest coffee) to get representative sample and make homogenize by using ground control points that have taken during preliminary survey. Stratum one consists natural forest that is land with relatively continuous cover of trees, which are moist ever green Afromontane. The stratum two consists of rubber plantation and the third one is semi-forest-coffee plantation.

3.2.4 Sampling techniques and intensity

For this study stratified systematic sampling method was used to layout the sample plots across three land uses. Nested rectangular plot with the size of 10m*20m (200 m^2) was used to conduct woody species inventory and soil data. Three subplots size of 1m*1m one at the middle and two at opposite corners were assigned in each main plot to collect litter and soil samples. Rectangular shape of the main plot was selected due to its easy of application and tally trees in the plot once the plot boundary has been established on the ground plots can be efficient in strata with high stocking density (UNFCCC, 2015).

Accordingly, 20 plots per stratum or land uses (natural forest, rubber plantation and semi-forest coffe) and the total of 60 plots were decided and pragmatic approach was followed based on the available resources (budget, time, etc.). For litter sampling 60 plots and 30 plots for soil sampling (10 plots for stratum) were sellected. 60 subsamples for BD from (0-30 and 30-60 cm) depth class by using soil core sampler have the size of 6 cm diameter and 30 cm height (588.75 cm^{-3}) then, 60 composited sub samples for SOC from two depth class by using augur and also 60 sub samples for litter biomass carbon were measured. The shapes of the sample plots were square with nested smaller for soil and litter sub samples. The determined sample plots intensities were systematically distributed for each land uses by using computer based QGIS $GRASS_{123}$ version software vector menu.

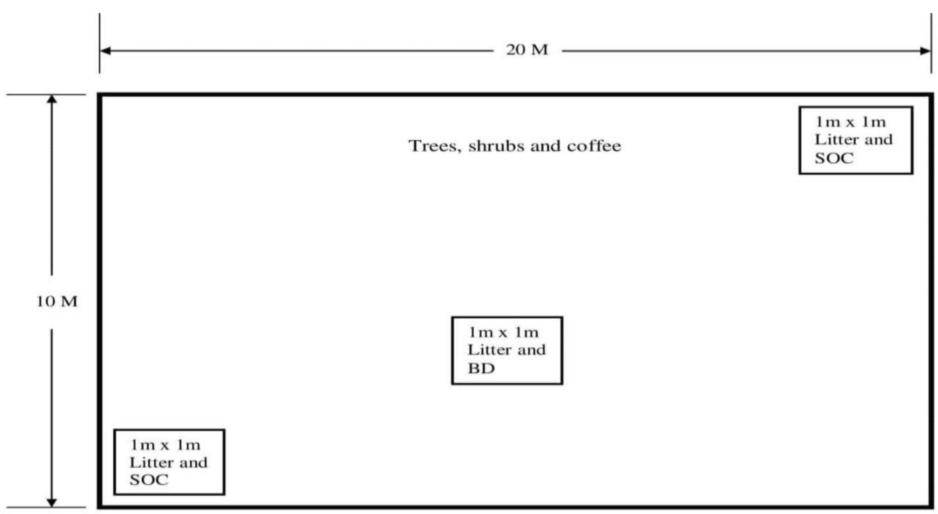

Figure 4: Layout of sample plots

3.3 Data collection methods

3.3.1 Woody species inventory

In the major sample plots (20m*10m) the diameter at breast height (DBH at 1.3m) for all live trees having DBH $\geq$ 5 cm were recorded (Pearson *et al*., 2005). Height and DBH of trees were measured by hypsometer and graduated caliper respectively. The species identification was done in the field and when the identification become difficult in the field, local names were recorded and identified by using identification manual (REDD+ Ethiopia, 2015). Similarly, rubber trees DBH (at 1.3 m aboveground) and tree height (H) were measured. For coffee plants stem diameter at stump height (40cm, d_{40}) with DBH $\geq$ 2.5 cm and height $\geq$ 1.5 m within the sample plot were measured and recorded. All stem diameter measurements (d and d_{40}) were taken in two perpendicular directions and the average value used in subsequent calculations. In the case of multi-stemmed plants, each stem was measured and the equivalent diameter of the plant was calculated as the square root of the sum of diameters of all stems per plant (Snowdon *et al.*, 2002):

$$de = \sqrt{\sum_{i=1}^{n} di} \qquad \text{Equation} \qquad (1)$$

where d_e is diameter equivalent (at breast or stump height), di is diameter of the i^{th} stem at breast or stump height.

3.3.2 Deadwood sampling

Dead wood lying on the ground was measured using the line-intersect method and wood with a diameter > 10 cm is measured. within the plot along the length of lines intersecting point of the transect and crossing the transect line through at least half of its diameter down dead wood diameter was measured (NFI, 2014; Pearson *et al*., 2005). Two decomposition classes (sound and rotten) were recorded for deadwood particles (Ethiopia's FRL, 2017).

3.3.3 Litter sampling

All fresh litters per plot were weighed on the site by digital balance. Then all collected litters from 3 sub plots per main plot were composited and 100g of fresh weight was taken for laboratory analysis to determine dry weight to fresh weight. Samples should be oven-dried to constant weight at 70°C for 24 hours (Mesele Negash and Mike Starr, 2015) and reweighed to estimate the dry matter.

3.3.4 Soil Sampling

Soil samples for organic carbon determination from nested sub plots of diagonally from the two corner per plot were collected by using augur within two (0-30 and 30-60cm) depths (Wang *et al*., 2015). A total of 60 samples (30 plots * 2 depths) composite of 250g for a single soil samples were placed into a plastic bag, tagged and coded per depth class and taken to WGCFNR soil laboratory to analyze SOC and texture analysis. The reason of composite those by layer are to take representative samples. From the centre of the plot, the same number of samples (60 samples from 30 plots within two depth difference) were taken for bulk density determination using soil core sampler. The collected individual samples will be then inserted to individual plastic bags coded and brought to Wondo Genet College of Forestry and Natural Resources (WGCFNR) soil laboratory and oven-dried at 105^0c for 48 hours.

3.4 Data analysis

3.4.1 Biomass carbon stock estimation

3.4.1.1 Aboveground and belowground biomass

Different allometeric equations were preformed to calculate AGB carbon. The general equation for tropical forests by Chave *et al*., (2014) was applied in this study for trees of natural forest with DBH ≥5cm, the following formula. The reason for using the above equation is that in the absence of applicable biomass models for every Ethiopian ecosystem or biome consistent with international requirements, the choice between the models has been restricted to the pan tropical model and it gave values that are closer to the average biomass estimates for the different forest types (MEFCC, 2018).

Specific wood densities for woody species were acquired from Basic Wood Density of Indigenous and Exotic Tree Species in Ethiopia (Ethiopia's FRL, 2017, 2016) and World Agroforestry Centre (ICRAF) Wood Density Database.

$$AGB=0.0673*(WD *D^2 *H)^{0.976} \tag{2}$$

Coffee plants dry biomass was calculated using the equation developed by Mesele *et al.*, *(*2013):

$$AGB = 0.147 * d^2_{40} \tag{3}$$

where d_{40} is stem diameter (cm) of the coffee plant at 40 cm height. For the aboveground biomass of the trees in semi-forest coffee the allometric equation developed by Kuyah *et al*., (2012) was used:

$$AGB=0.225 * d^{2.341} * WD^{0.73} \quad (4)$$

Belowground biomass of the tree and coffee plants were calculated using the generic equation developed by Kuyah *et al*., (2012b)

$$BGB = 0.490 * AGB^{0.923} \quad (5)$$

The reason for using the above equation is that it had the highest R^2 and lowest error of prediction values, and developed for trees grown in agroforestry systems.

The rubber tree (*Hevea brasiliensis*) above and belowground biomass was calculated by using the equation Yang *et al*., (2017):

$$AGB=0.0419*DBH^{2.316}*H^{0.478} \text{ and } BGB = 0.207*DBH^{1.668} \quad (6)$$

Prediction of AGB by the model calibrated with the harvested rubber tree biomass and wood density was more accurate and that why this model was used in this study.

The root biomass (belowground) was derived from AGB by using R:S (IPCC, 2006).

$$BGB = 0.27*AGB \quad (7)$$

According to IPCC, (2006) the estimated dry biomass was converted to carbon by using biomass conversion factor 47%.

$$AGBC_{trees}=AGB * 0.47 \quad (8)$$

Whereas, biomass conversion factor for coffee is 49% (Mesele Negash *et al*., 2013):

$$AGBC_{coffee}=AGB * 0.49 \quad (9)$$

Where: AGB=Aboveground biomass (kg/tree), BGB=Belowground biomass, DBH=Diameter at Breast height, H=Tree height, WD=is species wood density (g/cm^3).

3.4.1.2 Deadwood biomass

For fallen deadwood, the De Vries' formula (De Vries, 1986) was applied, estimating log volume in m^3 ha^{-1}. This formula requires the length of the transect (L) and the log diameter (d) at the point of intersection.

$$V = \frac{\pi^2 \sum d^2}{8L} \qquad (10)$$

where:

V= volume in m^3 ha^{-1}, L=length of the transect (L) and the log diameter (d) at the point of intersection. Two decomposition classes were recorded for deadwood particles: sound and rotten. A rotten wood contains less biomass than a sound wood, the wood density of dead wood was scaled down using lower wood densities than for standing trees, as follows:

Sound deadwood biomass = Volume* 90% * Default WD (11)

Rotten deadwood biomass = Volume * 50%*Default WD (12)

The default wood density for the species is 0.612 g cm^3, similarly as for trees.

3.4.1.3 Litter biomass estimation

According to Pearson *et al*., (2005) the dry biomass of the collected sample under this parameters was calculated by the following formula:

$$LB = \frac{\text{W field}}{\text{A}} \times \frac{\text{W sub sample dry}}{\text{W sub sample wet}} \times 10{,}000 \qquad \text{Equation (13)}$$

Where:

Where: LB = Litter biomass (ha^{-1}), W field = weight of wet field sample of litter sampled within an area of size $1m^2$ (g), A = size of the area in which litter were collected (ha), Sub-sample dry = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), W sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g). Litter biomass was converted to carbon by following biomass conversion factor(IPCC, 2006):

$$LC = LB \times 0.37 \tag{14}$$

Where, LC: Toal carbon stocks in the dead litter in t ha^{-1}, 0.37, carbon fraction (IPCC, 2006). Determined the dry biomass and carbon stocks per plot and extrapolate on ha basis (t ha^{-1}) (Expansion factor = 10,000 m^2 /Area of plot (m^2).

3.4.2 Soil organic carbon

To determine soil organiccarbon the bulk density of the mineral soil core was calculateed by Pearson *et al*., (2007):

$$Bulk\ density\ (g/cm^3) = \frac{Oven\ dry\ mass\ (g)}{Core\ volume\,(cm^3) - \left[\frac{Mass\ of\ coarse\ fragments\,(g)}{Density\ of\ coarse\ fragments\,(g/cm^3)}\right]} \tag{15}$$

SOC stocks (t ha^{-1}) were calculated using the equation developed by (Norris, 2014):

$$SOC = C\% * BD * SD \tag{16}$$

Where:

SOC, Soil organic Carbon (t ha^{-1}), C: Carbon concentration in (%), BD: Bulk density in (g/cm^{-3}), Soil depth: (cm). The dry biomass and carbon stocks per plot and extrapolate on hectare basis (t ha^{-1}) and the expansion factor is = 10,000 m^2 / area of plot (m^2).

3.4.3 Ecosystem carbon stock density

The ecosystem biomass carbon and SOC stocks were summarized by:

$$ECS = \sum AGBC + BGBC + DWBC + LBC + SOC \quad (17)$$

Where: ECS= Ecosystem carbon stock density for all pools (t ha^{-1}), AGBC= aboveground biomass C stocks (t ha^{-1}), BGBC = Belowground biomass C stocks (t ha^{-1}), DWBC = Deadwood biomass C stocks (t ha^{-1}), LBC = Litter biomass C stocks (t ha^{-1}), SOC = Soil organic C stocks (t ha^{-1}).

3.5 Statistical analysis

The data were organized and analyzed using Microsoft Office Excel 2007 and the 2019 version of Minitab Statistical and Data Analysis Software respectively. Two-way analysis of variance (ANOVA) was performed to compare the average carbon stock of the five different pools (i.e., above and belowground, dead wood, litter biomass, and soil) among the natural forest, rubber plantation and semi-forest coffee. The statistical significant difference between each land use were tested by least significant difference at $p < 0.05$.

4 RESULTS

4.1 Stand characteristics

Guraferda forest is characterized by moist Afromontane forest type vegetation and its stand characteristics of the studied natural forest was shown in (Table 3). From twenty plots a total of 29 species and 148 stems were recorded. The stem density in natural forest was by 64.32% higher than trees in semi-forest coffee. The total basal area of the NF was by 66.73% and 91.86% higher than rubber plantation and coffee shrubs, respectively.

Table 5: mean (± SD) of stand characteristics of the three land use types

LULC	**DBH (cm)**	**Height (m)**	**Stem density (ha^{-1})**	**Basal area (m^2 ha^{-1})**
NF	26.67± 2.74^{a}	20.32 ± 0.99^{a}	370.00 ± 19.10^{b}	39.07 ± 3.35^{a}
RP	19.87 ± 0.34^{b}	18.85 ± 0.21^{a}	407.00 ± 78.70^{b}	13.00 ± 0.39^{b}
CS	4.46 ± 0.31^{c}	2.43 ± 0.17^{b}	1,777.00 ± 566^{a}	3.18 ± 1.20^{b}
TSFC	28.00 ± 3.20^{a}	17.53 ± 1.55^{a}	132.00 ± 11.30^{c}	13.89 ± 1.34^{b}
P-value	0.000	0.000	0.000	0.000

Note: NR: Natural forest; RP: Rubber plantation (10-year-old), CS; Coffee shrub; TSFC: Trees in semi-forest coffee.

Different letters shows significant difference between land use types, and similar letters not significance differences at LSD ($p < 0.05$).

4.2 Biomass carbon stocks

The mean aboveground biomass carbon stock of natural forest (NF), rubber plantation (RP) and semi-forest coffee (SFC) were summarized and shown in (Table 6). Results showed that the mean aboveground biomass carbon stock of NF was significantly higher than that of RP and SFC ($p<0.05$). Similarly, mean below ground biomass carbon stock of NF was significantly higher than the RP and SFC as larger diameter and tall tree were available in NF. In the same way, there was also a significant difference in mean above and below ground carbon stock of SFC and RP ($p<0.05$). In this study conversion of natural forest to RP and SFC resulted in decline of biomass carbon stocks by an average of 258.68 t ha^{-1} and 222.63 t ha^{-1} , which was equal to 85.49% and 73.57% of the initial biomass C stocks in the NF for RP and SFC respectively.

The mean litter carbon stock was significantly higher in NF than RP and SFC ($p<0.05$).Yet, there was a significant variation of C stock in deadwood of NF and SFC ($p<0.05$). Because site clearing for tapping of latex there was no deadwood in RP.

Table 6: Mean (±SD, t ha^{-1}) of biomass carbon stocks in the three land uses

Carbon Pools	Land Use Types			F-value	P-value
	NF	RP	SFC		
AGBC	234.70 ± 28.10^{a}	36.10 ± 3.46^{c}	56.70 ± 18.50^{b}	31.24	0.000
BGBC	63.36 ± 7.59^{a}	5.96 ± 0.537^{c}	19.31 ± 5.84^{b}	9.43	0.000
DWC	1.97 ± 0.712^{a}	—	2.64 ± 0.762^{b}	4.17	0.020
LC	2.56 ± 0.262^{a}	1.85 ± 0.111^{b}	1.31 ± 0.174^{c}	10.63	0.000
Total BC	**302.59 ± 35.70^{a}**	**43.91 ± 3.97^{c}**	**79.96 ± 24.90^{b}**	**25.98**	**0.000**

Different letters shows significant difference between land use types, and similar letters not significance differences at LSD (p < 0.05).

4.3 Soil organic carbon stocks

The total (0-60 cm depth) SOC shows that SFC maintain higher SOC in relation to adjacent RP and NF. The average topsoil SOC (30 cm) and subsoil (30-60 cm) significantly differed among the three land uses ($p < 0.05$) and also significant difference recorded for 0-60 cm depth between the land uses ($p < 0.05$). The contribution of topsoil to the total SOC were 63.80%, 67.73% and 65.21% for NF, RP and SFC respectively.

Table 7: Mean (± SD, t ha^{-1}) of SOC in the three land uses

Depth (cm)	**NF**	**RP**	**SFC**	**F-value**	**P-value**
0-30	56.72 ± 7.07^{b}	46.22 ± 4.17^{c}	73.05 ± 5.54^{a}	5.59	0.009
30-60	32.18 ± 5.17^{b}	22.02 ± 1.20^{c}	38.96 ± 4.49^{a}	4.51	0.020
Total (0-60)	88.90 ± 11.40^{b}	68.24 ± 4.44^{c}	112.01 ± 8.89^{a}	6.29	0.006

Different letters shows significant difference between land use types, and similar letters not significant differences at LSD (p < 0.05).

4.4 Ecosystem carbon stocks

The total C stocks were significantly different (F-value=28.06, P-value=0.000) between the three studied land uses as shown in figure 3. In the NF, the estimated total C stock density was 391.49 ± 35.70^{a}, which was found the biggest C amount than in SFC (191.97 ± 24.00^{b}) and lowest C stored in RP (112.15 ± 4.27^{c}). The relative contribution of biomass C to the total C stock in NF was significant, valuing approximately 77.3%, but SOC stocks were significantly greater than biomass C stocks averaging 60.84% and 58.34% for the RP and SFC respectively.

The least C found in the deadwood pool which accounts 0.5% in NF but, it is higher in SFC which accounts 1.37%. In contrary to this, C stock from litter were lower in RP and SFC than C found in NF as shown in (Table 6).

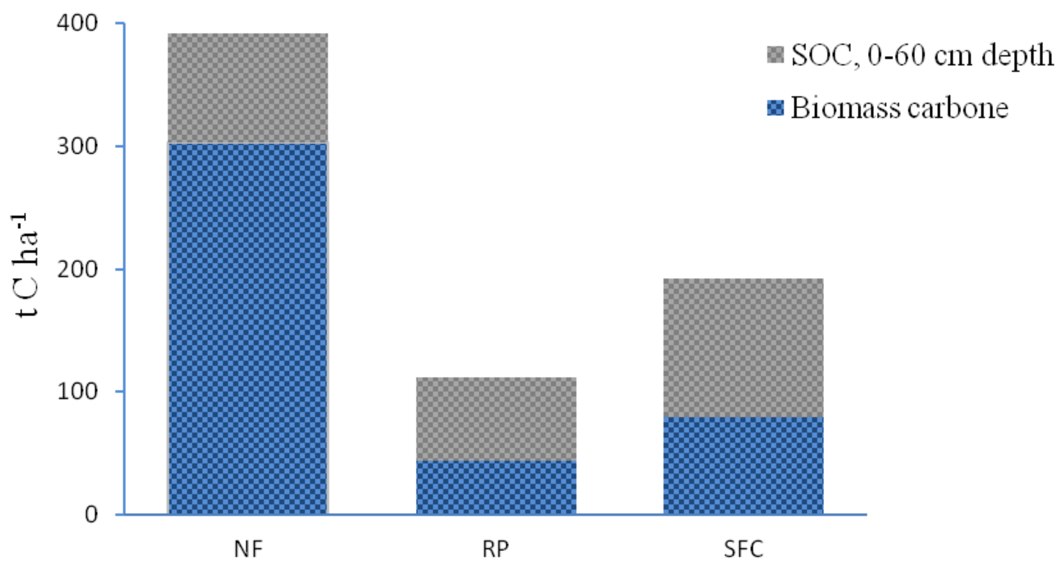

Figure 5: Total ecosystem carbon stocks (biomass plus SOC) of the studied land uses

5 DISCUSSION

5.1 Stand characteristics

The total basal area of the natural forest of the present study was about (39.07 m^2 ha^{-1}). It is comparable with other dry Afromontane forests such as Menagesha Forest (about 36 m^2 ha^{-1}), Denkoro Forest (45 m^2 ha^{-1}) (Abate Ayalew, 2003). On the other hand, it was lower than to the moist Afromontane forest of Gesha and Sayilem (115 m^2 ha^{-1}) (Admassu Addi, 2018) and Mana Angetu moist montane forest (94 m^2 ha^{-1}) (Lulekal *et al*., 2008). The might be due to various factors such as species and size of trees. For instance, the moist Afromontane forest of Gesha and Sayilem in southwest Ethiopia (Admassu *et al*., 2019), large sized-tree species like *Pouteria adolfi-friederici* and *Croton macrostachyus* are dominant and contributed a considerable amounts to the total basal area of the forest.

5.2 Biomass carbon stocks

Aboveground biomass C in natural forest (NF) showed significantly higher than that of semi-forest coffee (SFC) but, SFC stores significantly higher than rubber plantation (RP). The higher mean carbon stock in SFC could be related to the availability of higher tree DBH and basal area. Furthermore, the age of trees in RP of the current study was 10 years and C stocks were mostly affected by stand age (Yang *et al*., 2017). The average carbon in AGB of NF was more than that of Gera forest in southwestern Ethiopia 134.34 t ha^{-1} (Mohammed and Bekele, (2014); open dry Afromontane forest (153 t ha^{-1}) (Tadesse *et al*., 2014) (104.83 t ha^{-1}); dense dry Afromontane forest (181.78 t ha^{-1}) in northern Ethiopia (Negasi *et al*., 2018) and Afromontane forests of northwest Ethiopia (Gebeyehu *et al*., (2019) (191.6 t ha^{-1}).

However, AGB C stocks in NF was highly lower than findings of (Hamere *et al*., 2015) who reported Gedo forest (281 t ha^{-1}); forest of Semen Mountains National Park (Tibebu *et al*., 2014) (270.89 t ha^{-1}); Chato Afromontane forest of western Ethiopia (Birhanu Iticha, 2017) (301.86 t ha^{-1}) and tropical evergreen forests of south western, India (Devagiri *et al*., 2013) (287.05 t ha^{-1}). The difference in biomass C stocks might be due to various factors such as kind of forest, tree size, density and species composition. For instance, in the Chato moist Afromontane forest studied by Birhanu Iticha, (2017), the forest consisting high diversity of tree species and good understory cover. While in this study, the NF mean diameter and species composition of trees are lower.

The present study was comparable with the C stocks of Gerba-Dima Afromontane forest (Abyot *et al*., 2019) (243.86 t ha^{-1}); forest of Semen Mountains National Park (Tibebu *et al*., 2014) (240.63 t ha^{-1}); Mount Zequalla forest (Abel *et al*., 2014) (237.20 t ha^{-1}); the protected dry Afromontane forests of Ethiopia (107 to 285 Mg C ha$^{-1)}$ (Simegn *et al*., 2014; Yitebitu *et al*., 2010 and Hamere, 2015) and Afromontane forest in Kenya (Pellikka *et al*., 2018) (231 t ha^{-1}). The above and belowground biomass C of RP in this study was in agreement of other studies (Munasinghe *et al*., 2014) Sri Lanka, intermediate zone, (Tang *et al*., 2009) Xishuangbanna, China and (Sone *et al*., 2014) Sumatra, Indonesia and the AGB carbon was within the range of reported by Li *et al*., (2008) (15– 61 t ha^{-1}) in Southeast Asia.

The AGB carbon stock in SFC was comparable with coffee based agroforestry southwest, Ethiopia (Mohammed and Bekele, 2014) (58.27 t ha^{-1}); indigenous agroforestry (fruit-coffee) systems on the southeastern Rift Valley escarpment, Ethiopia (Mesele Negash and Mike Starr, 2015) (58.30 t ha^{-1}) and semi-forest coffee in the Jimma highlands, Ethiopia (Dereje *et al*.,

2016) (61.50 t ha^{-1}). But, lower than coffee agroforests in Guatemala (Schmitt-Harsh *et al*., 2012) (73.18 t ha^{-1}) and Coffee plantation in south western, India (Devagiri *et al*., 2013) (81.10 t ha^{-1}). The difference in AGB carbon stocks might be due to the adopted allometric equation. For example, in the coffee agroforests studied by Schmitt-Harsh *et al*., (2012), the diameter of coffee plant was measured at 15 cm above ground while in this study, the diameter was measured at 40 cm aboveground.

The mean belowground biomass C stock in NF was 10.63 and 3.28 times higher than RP and SFC respectively. The reason for this difference was due to the existence of larger trees in NF than RP and SFC. This was because, largest trees have much more potential to produce larger quantities of belowground biomass compared to smallest trees. The present study was supported by the findings of (Mohammed and Bekele, 2014).

Litter carbon concentration in NF was comparable to those reported for Chato Afromontane forest in Welega (Birhanu Iticha, 2017), Banja dry Afromontane forest northwest, Ethiopia (Fentahun *et al*., 2017) and the (IPCC, 2006) default value for tropics (1-5 t ha^{-1}). However, the mean C stock in litter was less compared to values recorded for evergreen forests in Northwestern Ethiopia (Kendie *et al*., 2019); Mount Zequalla Monastery forest (Abel *et al.*, 2014) and moist tropical forest of Bangladesh (Ullah and Al-Amin, 2012). The low C stock in litter can probably be attributed to the high decomposition rate and with less amount of litter fall. The Agro-ecologies of Guraferda District (the study area) is characterized by 78% lowland (wet qolla) and high mean annual temperature. Hence, the lowest C stock in litter pool might be due to the high rate of litter decomposition.

The carbon stock in deadwood of NF was comparable with the Gedo dry evergreen montane forest forests (Hamere *et al.*, 2015) (2.37t ha-1). However, C stock in SFC was higher than the NF. This indicated that high rate of trees cutting for shade reduction which affects carbon stock contributed from above and belowground biomass. Values in the two land uses were lower than findings in Lemlem Terara (2.89 t ha^{-1}) but higher than Adi Goshu (Binyam Alemu, 2012) (0.48 t ha^{-1}). Saki *et al*., (2008) suggested that the warm and humid climate induces quick decomposition of deadwood. This may result in low accumulation of deadwood carbon in the lowland of Ethiopia. In contrary to this there was no deadwood in RP. Since the rubber tree is monoculture commercial plantation for latex production common intensive management practices like cleaning and weeding of biomass might influence availability of deadwood.

5.3 Soil organic carbon stocks

The SOC stock in this study significantly ($p< 0.05$) varied with soil depths in the three land uses. SOC stock was significantly higher in the upper layer than in the lower layer and decreasing SOC concentration with increasing soil depth. Comparatively higher SOC stock in top layer could be due to high organic matter content, (Ghimire *et al.*, 2019). This finding is in agreement with the findings of (Mulugeta *et al*., 2020) coffee based agroforestry system and (Fantaw *et al*., 2015) ex-closure and open grazing land use types in the Central Rift Valley of Ethiopia. The overall mean (0–60 cm depth) of SOC was higher in soil under SFC than NF and RP. The higher SOC stock in the SFC might be attributed to the lower organic C turnover rate as a result of minimum soil disturbance in the system, and more litter fall inputs from trees and coffee plants (Mulugeta *et al.*, 2020). The differences in the soil C may be attributed to topographic aspect induced microclimatic differences, which are causing differences in the biotic soil component. Differences in microclimate are often linked to varying soil moisture and erosion potential and, in turn, could be used to explain distribution of plant communities (Tesfay *et al*., 2017).

The total SOC stocks for NF in this study was within the range of IPCC, (2006) global forest soils to default value (20-300 t ha^{-1}) to 1m depth. In the present study, soil organic carbon was found highest in the top layer of soil, and this may be due to the rapid decomposition of forest litter in the favorable environment and this finding is in agreement with the findings of (Ullah and Al-Amin, 2012). The mean of SOC (0–30 cm depth) was higher than Yerer Mountain forest (Aregu Balleh, 2015) (41.78 tha^{-1}) but, substantially lower than different forest types (dry and moist Afromontane forests) in Ethiopia: Awi Zone, (Getaneh *et al.*, 2019), Gerba-Dima forest (Abyot et al., 2019), Gesha and Sayilem forest (Admassu *et al*., 2019) and moist tropical forest of Bangladesh (Ullah and Al-Amin, 2012). The variation in SOC could be due to tree species, moisture, soil nutrient availability, topography and disturbance regime (Houghton *et al.*, 2005). Forest stand with dense canopy and higher input of litter can results in maximum storage of carbon and less vegetation coverage resulted soil erosion (Kidanemariam, 2015) and organic matter has been lost from the topsoil layer which makes soil more likely to erode by water (Li *et al*., 2014).

In this study forest-to-rubber plantation conversion resulted in losses of soil carbon stocks by an average of 20.66 t $ha\text{-}^{1}$ in the entire (0-60cm depth), which was equal to 23.24% of the initial soil carbon stocks in the forest. This finding is in agreement with the findings of (Chakarn and Advisor, 2011) loss of soil organic matter can occur in all plantations through soil erosion in surface runoff and a leaching process. Furthermore, comparatively lower SOC stock in RP might be due to greater soil disturbance (Alm *et al*., 2018) during land preparation for rubber tree planting (Tumwebaze and Byakagaba, 2016).

The SOC stocks of the RP in this study was comparable with the 7-year-old rubber plantation in Yunnan province, China (Blécourt *et al*., 2013) but, higher than the same age stands of rubber plantations in northeastern, Thailand (Chakarn and Advisor, 2011) and rubber plantations in Mountainous southeast Asia (Fox, 2014).

On the contrary, the current study of SOC was lower than the rubber tree plantation in Rio de Janeiro and Parana, Brazil and (Wauters *et al*., 2008; Maggiotto *et al*., 2014). This variation may be due to intra specific variation (genotype), age, type of soil, climate conditions, and management practices are important factors driving soil and tree biomass C accumulation in rubber tree plantations (Diniz *et al*., 2015; Egbe *et al*., 2012). For instance, in the above two sites (Rio de Janeiro and Parana, Brazil) the rubber tree plantations were 14-year-old whereas, in the current study the RP were 10-year-old. This revealed that soil carbon stocks were determined together with carbon stocks in the plant biomass of rubber plantations (Cheng *et al*., 2007; Wauters *et al*., 2008).

The SFC soil organic C stocks in this study was within the range reported for the indigenous agroforestry systems on the south-eastern Rift Valley escarpment, Ethiopia (109-253 t ha^{-1}) by Negash and Starr, (2015). The mean of SOC (0–30 cm depth) was similar with the same depths SOC stocks reported for coffee based agroforestry systems in southwestern Ethiopia, (Mulugeta *et al*., 2020) but, substantially lower than (0-60cm) depth. Similarly, the SOC stocks of the topsoil layer (0–30 cm depth) under SFC in this study is lower than the same layer of SOC stocks (92.48 t ha^{-1}) of coffee agroforests in Southwest Ethiopia (Mohammed and Bekele, 2014). The variation in SOC might be the result of differences such as elevation and climate (Soto-Pinto *et al*., 2010) soil type (Lal, 2004), planting density (Nair *et al*., 2009), type of coffee and the type of trees present on farm, lack of cover provided by the coffee shrubs that protect the soil surface (Tumwebaze and Byakagaba, 2016). In the this study relatively the planting density of coffee shrubs were lower and few tree species are recorded.

5.4 Ecosystem carbon stocks

The total C stocks (biomass plus soil) in SFC (191.62 t ha^{-1}) which is significantly higher than RP (112.15 t ha^{-1}) and lower than NF (391.45 t ha^{-1}) ($p<0.05$). This result is in line with (Getaneh *et al*., 2019) who reported Apini (385.7 t ha^{-1}) and Dabkuli (387.9 t ha^{-1}) dry Afromontane forests of northwest, Ethiopia. The NF total C stock was the highest followed by SFC and RP. The reason was due to NF had more AGB and BGB as well as litter biomass C stock compared to the adjacent RP and SFC. One reason why there was more C stock in NF might be due to the ability of plants to capture CO_2 through the process of photosynthesis and this was due to the presence of individual tree species in NF with relatively higher DBH than compared to the other forests mentioned (Lulekal *et al*., 2008). The RP total C stock was (112.15 t ha^{-1}) is in agreement with (Ziegler *et al*., 2012) reported rubber plantations in southeast Asia have a total ecosystem carbon stock density in the range (93–376 t ha^{-1}). Similarly, the SFC ecosystem C stock comparable with other findings (Mulugeta *et al.*, 2020) (194.96 t ha^{-1}) who reported coffee based agroforestry systems, (Vanderhaegen *et al*., 2015) the semi-forest coffee production in southwest, Ethiopia and (Schmitt-Harsh *et al*., 2012) the coffee agroforests of Guatemala.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this study, land use conversion from natural forest to rubber plantation and semi-forest coffee significantly reduced biomass and soil C stocks. It significantly decline, if converted from NF to RP resulted in losses of C stocks by an average of (279.34 t ha^{-1}) and from NF to SFC (199.52 t ha^{-1}). In addition, land use and land cover change could affect the amount and composition of soil organic matter through their influence on decomposition and humification process. The present study finding suggest that where the NF conversion to RP and SFC decreased C stocks and the reverse process usually increased it.

The studied three land uses and their respective soil and biomass contributed for climate change mitigation by sequestration of GHGs in addition to social service they provide. This study showed that NF had high carbon sequestration potential and provides significant mitigation option by managing them for increased storage of carbon pool. As the result of this, NF become the focus of global climate change policy and is given a key position in international climate treaties. While sustainable management, planting and rehabilitation forests can conserve or increase forest carbon stock. On the contrary, deforestation, degradation and poor forest management will decrease forest carbon stock. The highest carbon content in NF implied the highest potential to reduce GHGs. Even though, the RP and SFC contained lower C stock compared to NF have the potential to reduce GHGs and mitigate climate change.

6.2 Recommendations

Based on the findings, the following are recommended:

- Conservation of the forest through introduction of sustainable forest management interventions including REDD+ that focuses on maintaining and improving carbon sequestration.
- Rubber in mixed agroforestry systems increase soil organic carbon better than rubber planted alone and planting leguminous cover crops between rubber trees can also substantially increase carbon accumulation. Yet, additional field studies are needed to develop recommendations adapted to local contexts.
- It is thus important that rubber tree plantation be considered by managers for reforestation of deforested land.
- To make good condition for coffee production which results lower species diversity and carbon reduction. Thus, number and woody species retained for shade in semi-forest coffee should be identified by concerning body in the study site.
- There should be integration among different sectors and empowering local communities towards sustainable managements of the natural forest around the study area.

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APPENDIXES

Appendix 1:Woody species inventory format

Kebele ____________

Land use type: ____________

Sample taken by: ____________

Date: ____________

Location: N___________E_____

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

Soil type: ___________________

Sample area: 10 * 20 m

Scientific Name	Local Name	DSH (cm)	Average DBH (cm)	Tree height (m)	Remark

Additional information
Slope aspect _____________: gradient_______________________________

Evidence on natural or anthropogenic disturbances____________________

Other related may have effect on biomass stock______________________

Appendix 2:Litter sample format

Kebele ____________

Land use type: ____________

Sample taken by: ____________

Date: ____________

Location: N___________E_____

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

Soil type: ___________________

Sample area: 10 * 20 m

plot no	Fresh weight (g/m^2)	Sample fresh weight (g)	Sample Oven-dried weight (g)	Sample moisture content

Appendix 3: Deadwood data collection format

Kebele ____________

Location: N___________E_____

Land use type: ____________

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

Sample taken by: ____________

Soil type: ___________________

Date: ____________

Sample area: 10 * 20 m

No	Standing deadwood		Logged tree		Fallen deadwood		Remark
	DBH (cm)	Height (m)	Mid Diameter (cm)	Length (m)	Mid Diameter (cm)	Length (m)	

Appendix 4: Soil sample format

Location: N__________E_____

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

Kebele ___________

Land use type: ___________

Soil type: _________________

Sample area: 10 * 20 m

Sample taken by: ___________

Date:___________

plot no	Sampling depths (cm)	Soil by Auger sampling	Bulk soil for BD		
			Field weight	Oven dried weight	Moisture content
	0-30				
	30-60				
	0-30				
	30-60				

Appendix 5: Tree species and there wood density of the studied area

S.No	Scientific name	WD ($g^{-}cm^{3}$)	References
1	Albizia *grandibracteata*	0.534	Ethiopia's FRL, 2016
2	Albizia *gummifera*	0.580	Getachew Desalegn *et al*., 2012
3	Alchornea *laxiflora*	0.427	http://db.worldagroforestry.org
4	Alstonia *macrophylla*	0.695	http://db.worldagroforestry.org
5	Baphia *abyssinica*	0.559	Zanne et al., 2009
6	Bersama *abyssinica*	0.671	http://db.worldagroforestry.org
7	Blighia *unijugata*	0.700	Getachew Desalegn et al., 2012
8	Celtis *africana*	0.770	http://db.worldagroforestry.org
9	Coffee *arabica*	0.620	http://db.worldagroforestry.org
10	Cordia *africana*	0.482	http://db.worldagroforestry.org
11	Croton *macrostachyus*	0.518	http://db.worldagroforestry.org
12	Diospyros *abyssinica*	0.790	Getachew Desalegn *et al*., 2012
13	Ehretia *cymosa*	0.484	http://db.worldagroforestry.org
14	Ekebergia *capensis*	0.580	Getachew Desalegn *et al*., 2012
15	Ficus *sur*	0.335	http://db.worldagroforestry.org
16	Ficus *sycomorus*	0.482	Vreugdenhil et al., 2012
17	Hevea *brasiliensis*	0.487	http://db.worldagroforestry.org
18	Lepisanthes *senegalensis*	0.700	http://db.worldagroforestry.org
19	Macaranga *capensis*	0.452	http://db.worldagroforestry.org
20	Milicia *excelsa*	0.570	Getachew Desalegn *et al*., 2012
21	Millettia f*erruginea*	0.738	Ethiopia's FRL, 2016
22	Pouteria *adolfi-friderici*	0.711	http://db.worldagroforestry.org
23	Spathodea *nilotica*	0.330	http://db.worldagroforestry.org
27	Trichilia *dregeana*	0.482	http://db.worldagroforestry.org
24	Trilepisium *madagascariense*	0.560	Getachew Desalegn et al., 2012
25	Vepris *dainellii*	0.678	http://db.worldagroforestry.org
26	Vernonia *amygdalina*	0.413	Ethiopia's FRL, 2016