Jimma University

College of Natural Sciences

Department of Biology

Woody species diversity and above ground live carbon storage in Hunase natural forest, Gibe Woreda, Hadiya Zone, Southern Ethiopia

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Advisor: Dereje Denu (PhD)

Co-Advisor: Desalegn Rega (MSc)

A thesis Submitted to the Department of Biology, College Of Natural Sciences, Jimma University, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Botanical sciences.

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List of acronyms and Abbrevations

AGB	Above ground biomass
AGC	Above ground carbon
BA	Basal area
BGB	Below ground biomass
DAFF	Department of Agriculture, Forestry and Fisher
DBH	Diameter at Breast Height
GHG	Green House Gas
GPS	Geographical Positioning System
Ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
Mha	Million hectares
$REDD^+$	Reducing Emissions from Deforestation and Degradation
SNNPR	Southern Nation Natonality and Peoples of Republic
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
WBG	World Bank Group

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Abstract

This study was conducted on woody species diversity and above ground live carbon storage in different categories of Hunase natural forest of Gibbe Woreda, Hadiya Zone, Southern Ethiopia. The objectives of this study were: (1) to assess woody species richness and diversity; (2) to determine carbon storage and sequestration potential from a woody species biomass; (3) determine the variation of different categories of natural forest in carbon storage. Three transects were laid at a distance of 200m from each other. The transects encompass disturbed, semi-disturbed and undisturbed categories of the forest based on the degree of human disturbance and species composition respectively. Twelve plots of size 100m × 100m were systematical laid at 25m elevation interval along each transect lines (total = 36 plots). For all woody species diversity and carbon storage the DBH≥10cm were measured and recorded for all data analysis. Overall, 38 species of woody species belong to 36 genera and 27 families were collected and documented. Each sample specimen were identified using botanical keys of published Flora of Ethiopia and Eritrea. The Shannon-Weiner index and Sorensen Similarity index were used to measure species diversity and to compare species composition of each categories respectively and 2.75, 2.388, 2.14 diversity index value was calculated for undisturbed, semi-disurbed and disturbed categories respectively. The basal area of individual woody species was obtained by multiplying π with $(DBH/2)^2$ and aboveground live biomass of each species was determined by using the revised non-destructive allometric equation, carbon storage of each woody species was obtained as 50% of AGB and sequestration potential were also obtained from a stored carbon in the biomass.. In this study, 0.17t AGC/ha, 0.19t AGC/ha and 1.95t AGC/ha were obtained from disturbed, semi-disturbed and undisturbed categories respectively.

Key Words/phrases

Woody species diversity, richness, aboveground live biomass, carbon storage and categories of forest.

1. Introduction

Ethiopia is a country of natural and cultural biodiversities and the occurrence of these assets must be valued, conserved and developed in order to bring benefit to all (Girma Balcha, 2005). Biodiversity also referred to as the biological diversity which is the total number of all living organisms including the microbes and ecosystems with all variabilities among living organisms from all sources including, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part (Witamyna, 2016). Plant biodiversity is one of the biological diversity that constitutes all plant species with in the natural forests, tree outside the forests and from this the natural forests have taken a greater percentage of plant diversity with a higher carbon storage and carbon dioxide sequestration potential in their biomass and reduce the amount of carbon dioxide from the atmosphere. The major causes of woody species in natural forest declined by human-induced factors and natural factors from this human induced factors have high percentage like edge effects, habitat destruction and fragmentation, an invasive species, population expansion, deforestation, over exploitation, and climate change (Teklu Gebretsadik, 2016).

According to Teklu Gebretsadik (2016), the destruction of natural forests from the natural environments leads to increases of the level of GHG especially, carbon dioxide level in the atmosphere and which also leads to global warming to the environments. To reduce those GHG from the atmosphere, the main solution is properly conserving and managing forests, which is described with many researchers, non-governmental organization, and governmental organization in proper manner. So, natural forests could be taken as a good reservoir of carbon dioxide and hence help the global effort to mitigate climate change. Previous studies had not given due attention to carbon storage and sequestration potential of woody species in natural forests of the study area. Due to absence of sufficient studies, there was no enough information on woody species richness, diversity and carbon storage in different categories of Hunase natural forest. Therefore, studying the diversity of woody species, estimating and documenting the amount of carbon stored in different categories of natural forest is important in climate change mitigation.

A natural forest is generally multilayered vegetation unit dominated by trees (largely evergreen or semi-deciduous), whose combined strata have overlapping crowns (i.e. the crown cover is

75% or more), and where grasses in the herbaceous stratum are generally rare (DAFF, 2018). Forests play a great role of economic, ecological, environmental, socio-cultural, and have a great biomass that store excessive carbon in such a way that they reduce greenhouse gas (GHG) accumulation in the atmosphere but those woody species removed by human-induced factors, the stored carbon in their biomass is released back into the atmosphere (Vashum and Jayakumar, 2012).

The carbon storage of woody species in natural forests can be accumulated in the above ground biomass and below ground biomass and the highest carbon storage is obtained from above ground biomass (stems, leaves, and branches) and it assumed to be 50% of AGB and 20% of BGB. The above ground biomass estimation depends up on height, diameter at breast height, in the woody specific gravity for each woody species and calculated by using non-destructive allometric equation developed by (Chave *et al*., 2014). Also it is possible to get CO_2 sequestering level by woody species in a natural forests by multiplying carbon storage of each woody species with 3.67 (which is the ratio of the atomic mass of CO_2 to the atomic mass of carbon) in the natural forests.

1.1. Statement of problem

Agricultural expansion, infra-structure development, commercial timber harvesting, charcoal production, and fire wood collection have affected the natural forest of the study area. If the woody species in natural forests become declined, the carbon storage level and sequestration potential lowered. Which also leads to GHG emission in the atmosphere and as a result of this global warming happened in the natural envirnoments. Previous studies had not given due attention to carbon storage and sequestration potential of woody species in natural forest of the study area. Due to absence of sufficient studies, there was no enough information on woody species richness, diversity and carbon storage in different categories of Hunase natural forest. Therefore, this study was conducted to assess and document the diversity of woody species and carbon storage in different categories of Hunase natural forest.

The study was designed to address the following research questions.

i. Is there any variation in woody species richness and diversity among the three categories (disturbed, semi-disturbed and undisturbed) of Hunase natural forest?

ii. How much carbon is stored in the living above ground biomass of woody species in different categories (disturbed, semi-disturbed and undisturbed) of the study forest?

iii. Which category (disturbed, semi-disturbed or undisturbed) of natural forest stores more carbon in aboveground live biomass?

1.2. Objectives of the study

1.2.1. General objective

The general objective of this study is to assess the woody species richness, diversity and determine the above ground live carbon storage in disturbed, semi-disturbed and undisturbed categories of Hunase natural forest of Gibe Woreda, Hadiya Zone, SNNPR.

1.2.2. Specific objectives

1. To assess woody species richness and diversity in three categories (disturbed, semi-disturbed and undisturbed) of Hunase natural forest.
2. To determine carbon storage and sequestration potential in the three categories (disturbed, semi-disturbed and undisturbed) of the study forest.
3. To determine ecological importance of woody species in the study area.

1.3. Significance of the study

The study was provide basic information on woody species richness, diversity and carbon storage potential of Hunase natural forest. It gives information for the future management and conservation of woody species with respect to agricultural expansion, charcoal production, fire wood collection, animal grazing and infrastructural development (which leads to edge effect influences on natural forests), and it could be used as a baseline information for anyone interested to carryout on other aspects of the forest.

2. Literature review

2.1. Woody species diversity management role in natural forest

Woody species diversity is the major components of ecological diversity that provides the main information on species endemism, dominant, rarity, and commonness in natural forests. Some major general characteristics of the woody species dominated natural forest are food productivity, vegetation composition and structure that make woody vegetation a framework and basis for very rich and diverse life (Thomsen, 2016).

The decline of woody species diversity in natural forest leads to climate change, nutrient loss in ecosystem and those factors also affect biological diversity in the ecosystem indirectly (Yi-Chung *et al*., 2015). The species diversity in natural forests mainly measured by constructing mathematical indices commonly diversity indices approach.

According to Yi-Chung, *et al*. (2015), woody species diversity management and maintenance are relatively critical to maximizing the health benefits of natural forests. Those management practice also importanant for the natural forests as carbon stocks, economic, ecological, environmental, socio-cultural, as a climate change mitigation and it gives a basic information about factors that determine carbon storage potential in forests (Belay Wolde, 2015).

2.2. Concepts of Natural Forest

Natural forest is one of the richest ecosystems in woody species diversity and other herbaceous plants and used as a home for a lot of diversified plant species. Ethiopia is one of the richest countries in having plant species diversity and covers a wide agro-climatic zones and important center of biological diversity in natural forest.

A natural forest is generally multilayered vegetation unit dominated by trees (largely evergreen or semi-deciduous), whose combined strata have overlapping crowns (i.e. the crown cover is 75% or more), and where grasses in the herbaceous stratum are generally rare (DAFF, 2018).

FAO estimated the global forest cover at just over 4 billion hectares, which is 31% of total land area of the world and it contain most of the world's terrestrial biodiversity and contained a carbon pool of 40% in the atmosphere. The counties with high forest cover in the world include USA (3040 mha), Russia (809 mha), Brazil (520 mha), Canada (310 mha), China (207 mha), DRC (154 mha), Australia (149 mha), Indonesia (94 mha), Sudan (70 mha), India (68 mha), wOthers (1,347 mha) (FAO, 2010).

Africa's forest cover is estimated to be 650 million ha, constituting 17% of the world's forests including a number of global biodiversity hotspots. Ethiopia is one of the most important countries in Africa with respect to biological resources and in 2000, Ethiopian natural forest cover was estimated at 4,344,000 ha, which is 4% of its total land area (Amanuel Ayanaw and Gemedo Dalle, 2018). So, protected natural forests play a great role in the conservation of native woody species and other biological diversity in the ecosystem and provide livelihoods for more than a billion people. The vital role of forests are ecological, economic, environmental, socio cultural, carbon storage and climate change mitigation. The woody species in natural forests is influenced by edge effect, deforestation, over exploitation, rise in human population, an invasive species and climate change.

2.2.1. Forest Services

2.2.1.1. Ecological Services

Forests provide a wide range of ecological services in the environmental system including: regulation of water regimes by intercepting rainfall, its flow across the hydrological system, improvement of soil quality and provision of organic materials through leaf and branch fall, reduction of soil erosion and conserving of soil from the direct impact of rainfall, controlling climate change and being major components of biodiversity within themselves and as a habitat for other species (Sousson *et al.,* 1995).

2.2.1.2. Economic services

According to Sousson, *et al.* (1995), forests form the basis of a variety of industral products including timber, processed wood and paper, rubber, fruits and they also contain products that are needed to the existence of rural agricultural communities like fuel, fodder, building materials, and medicines. Additionally, grazing occurs with in natural forests, and local woodlands are used to fulfil basic needs and the rural people cultivate crops on temporary plots of natural forest (FAO, 2010).

2.2.1.3. Environmental services

The world's forest coverage is about one third of the earth's surface and are the main contributors to the health of our natural environment. Especially, woody species absorb and store much of the carbon dioxide from the atmosphere during photosynthetic period and store in their biomass to mitigate climate change, regulate water cycles, maintain soil quality, minimize the effect of natural disasters (floods), home to about 80% of terrestrial biodiversity (WBG, 2018).

Forests and soils drive the global carbon cycle by sequestering carbon dioxide through photosynthesis and releasing it through respiration and consequently, the uptake of carbon dioxide is higher than the loss via respiration (Schuck *et al.*, 2002).

2.2.1.4. Sociocultural services

Forests are needed for the protective function of culture with in a comparative attitude with in a local people recognization how to conserve, how to use forest resources and they argued that woody species currently are being destroyed in forest, in part, they understand the lack of awareness about how best to exploit the vast diversity of medicines, foods, natural fertilizers and pesticides that forests contain (Sousson *et al.,* 1995). The positive attitudes and advantages of forests on human health and well-being forests are a unique place for leisure activities, restoration, recovery from stress and further social interventions and especially, in Hindu Spirituality life it gives a great position in nature and its orders of life based on woody species with including religious values and the indigenous belief have a major protective role in a culture's relationships with the natural world (Masaryka, 2017).

2.2.1.5. Increased carbon stocks

The carbon stock is the amount of carbon that has been sequestered from the atmosphere and is now stored with in the forest ecosystem, mainly with in living biomass and soil. Forest plays important role in the global carbon cycle by sequestering a substantial amount of carbon dioxide from the atmosphere and mainly the storage takes place on biomass of terrestrial ecosystem such as AGB and BGB (Jocelyn and Jennifer, 2016). The AGB of a woody species constitutes the major portion of these carbon pools (Vashum and Jayakumar, 2012).

The accumulation of carbon is high in trees and shrubs which is stored in mostly above ground biomass (AGB) and 50% of the whole biomass is taken as carbon stock (Chave *et al*., 2014).
The natural storage of carbon by above ground biomass (trees) is one of the effective techniques for mitigating the atmospheric CO_2 levels (Jina *et al*., 2009). Therefore, if they were enough woody species (tree and shrub) they enhances carbon storage mostly in above ground biomass.

Biomass, in ecology refers to the mass of living biological organisms or ecosystem in a particular area at a given time. It also indicates biomass of one or more species, or community including microorganisms, plants, and animals (Free, 2010) .

Biomass could be above ground (AGB) and below ground biomass (BGB). In the study of plants, above ground biomass includes all living biomass above the soil including stems, leaves, branches, bark, seeds, and below ground biomass includes all living biomass of living roots thicker than 2 millimeters in diameter in the soil (USEPA, 2018).

Estimation of the accumulated biomass in the forest ecosystem is important for assessing the productivity and sustainability of the forest. It also gives us an idea of the potential amount of carbon that can be emitted in the form of carbon dioxide when forests are being cleared or burned, enables us to estimate the amount of CO_2 that can be sequestered from the atmosphere and storage level of carbon (Vashum and Jayakumar, 2012).

2.2.1.5.1.Carbon stocks of forests in Ethiopia

According to Yitebitu, *et al*. (2010), the Ethiopian forest status and future management options in the cases of access to carbon finances reported 2,763.70 million tons of carbon in 61.62 million hectares covered in Ethiopian land without including agroforestry system. From total 2,763.70 million tons, high forests contain 434.19 (4.07ha) million tons, woodland contain 1,263.13 (29.55ha) million tons, plantation 61.52(0.50) million ha, lowland bamboo 50.80 (1.07) million ha, highland bamboo 2.53 (0.03ha) million ha, shrub land 951.54 (26.40ha) million tons.

2.2.1.6. Climate change mitigation

Climate change mitigation are actions to limit the magnitude or rate of long-term climate change(Fisher, 2007). Forests play a specific and important role in absorbing carbon dioxide during photosynthesis and storing carbon in their biomass, and producing oxygen as a byproduct. Due to this absorbance, the level of CO_2 in the atmosphere decreased and climate change become mitigated in the natural environments (Pavlis, 2012).

Effective climate change mitigation will not be achieved the goal if ever one (individual, institution or non-governmental organization) acts independently in its own selfish interest (IPCC, 2014).The were the main international treaty on climate change in the United Nations Framework Convention on Climate Change (UNFCCC) and the UNFCCC agreed at the Earth Summit in Rio de Janeiro in 1992, was the first major attempt to mitigate global climate change. Whilst it did not set targets for the reduction of GHG emissions, member parties (including Ireland) are required to develop, publish, update and make available national inventories of GHG emission by sources and removals by sinks (FAQS, 2018).

According to FAQS (2018), the 1997 the Kyoto Protocol (KP) was signed and ratified in 2004. Its main features are as follows: 1990 is the base year against which all emission reductions are calculated. Developed countries committed agreed to reduce annual GHG emissions to 5.2% below 1990 levels by the first commitment period of 2008-2012. The European Union committed itself to a reduction on 8%. This burden is shared between member states and under this agreement Ireland is committed to limiting its GHG emissions to 13% above 1990 levels by 2008-2012. Thirteen Countries have to (Article 3.3 KP) or may (Article 3.4 KP) based on forest. Article 3.3 refers to net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced afforestation, reforestation and deforestation which have taken place since 1990; Article 3.4 refers to additional human-induced activities in the agriculture, land-use change and forestry sectors. Under Article 3.4; for Ireland limits set at 50,000 t C yr-1 during the first commitment period i.e. 2008-2012 (Streck, C. and Scholz, S. 2006). In 2010, Parties to the UNFCCC agreed that future global warming should be limited to below 2.0 °C (3.6 °F) relative to the pre-industrial level (Keskitalo, 2011).

2.3. Factors influencing woody species diversity in natural forest

2.3.1. Edge Effect

Edge” is the boundary (interface) between two biological communities or between a different landscape elements and the creation of edge effects depends on numerous factors, either inherent or induced. An inherent edge is a natural, usually long-lasting feature of the biosphere which may be closely related to topographic differences, and an induced edge is human causes for the different development activities like for roads, agriculture (Teklu Gebretsadik, 2016). However, the responses of species to ecotones and correspondingly to edge effects occur on both sides of an edge. Due to this causes it decreases habitat quality with in the remaining natural forests, reduction in habitat amount, increase in number of habitat patches, decrease in sizes of habitat patches, the capacity of native species become diclined from the natural forests and those also leads to reduction of carbon storage level and cut the functional connectivity as whole (Gustavo *et al*., 2012).

2.3.2. Habitat Destruction and Fragmentation

According to Teklu Gebretsadik (2016), habitat destruction is the process in which natural habitat is rendered functionally unable to Support the species present and it can be result in habitat fragmentation, habitat isolation, habitat degradation and habitat loss, which is recently the first ranked as cause of species extinction (about 70 % of species are threatened by the destruction of habitat & up to 25% of animal species face risk) due to this problems in the worlds, where as habitat fragmentationis often defined as a process during which" a greater expanse of habitats transformed to a number of smaller patches of area and isolated from each other by a matrix of habitats unlike the original"(Lenore, 2009).

2.3.3. An invasive species

An invasive species that is not native to a specific location and has a tendency to spread, which is believed to cause damage to the woody species diversity and some times it refers to non-native or introduced species that has become widespread (Teklu Gebretsadik, 2016). The spread and impact of invasive species takes a process rather than immediate phenomenon and it passes step by step (transportation and introduced to new area, establishment, spreading and causes impact) before they causes economic and ecological impact (Julie *et al*., 2007).

Invasive/ alien species seriously affect many sectors of the economy, especially they are noted for being an important cause of global biodiversity loss and due to this Ethiopia has great challenge with *Lantana camarain* Nile river millennium park of Bahir Dar (Taye Birhanu and Ashenafi Ayenew, 2017). Not only this but also invasive plant species reduced the effectiveness of development investments by controlling irrigation canals, fouling industrial pipelines and threatening hydroelectric (Mohammed *et al*., 2018).

2.3.4. Population Expansion

Population expansion refers to the increases in the number of individuals in a population and this increasing level of population has a greater influences on the woody species diversity. Because for the purpose of basic needs people, especially, for agricultural expansion: they degrade the natural forest land, deforest woody species, over grazing, increased exploitation of fuel wood and construction material (Dereje Denu, 2007). So, the growing human population and demand for agricultural products and the consequent expansion of both commercial and subsistence farming play a great role in causing woody species loss (Kissinger *et al*., 2012)**.**

2.3.5. Over Exploitation

Overexploitation, also called overharvesting, which refers to harvesting a renewable resource to the point of diminishing return (Teklu Gebretsadik, 2016). Due to this many individuals are removed with including a single species from the ecosystem and this process also change the composition of other species with in a given habitat, including a shift in species dominance or greately decrease in the survival ability of the remaining species (Nicole, 2015).

2.3.6. Deforestation

Deforestation refers to the cutting, clearing, and removal of rainforest or related ecosystems into less bio-diverse ecosystems such as pasture, cropland, which leads to biodiversity loses such as microbes, plants, insects, animals, and which results habitat fragmentation, soil erosion, desertification, edge effects, and climate change (Kricher, 1997). Humans have been clearing forests for the aim to meet a diverse range of industrial and agricultural needs especially developing countries for agriculture, firewood, mining, timber and developed countries for industrial purpose (WBG, 2003). Those factors lead to global climate change and it accounts approximately 15-20% of the world's carbon emissions in the atmosphere (FAO, 2010).

Deforestation affects an estimated 13 million hectares per year between 2000- 2010 and compared to other East African countries Ethiopia's deforestation rate is about average, however, the deforestation rates of Ethiopia in East Africa are second highest of the Africa level and as compared with Northern Africa, East African countries show the second highest decline rates of conservation forests in the continent (FAO, 2018).

2.3.7. Climate change

Climate change is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time or it may refer to a change in average weather conditions, or in the time variation of weather within the context of longer-term average conditions. It is caused by factors such as biotic processes, variations in solar radiation received by Earth, and volcanic eruptions. Certain human activities like the rise of CO_2 concentration in the atmosphere is mainly attributed to human activities and have been identified as primary causes of on going climate change, often referred to as global warming (IPCC, 1970).

Global climate change leads to rising temperatures, sea-level rise, changing weather patterns, more unpredictable weather events and it affects environmental norms, human populations, and causing serious negative impact to the global economy (Telemos and Sebsebe, 2014).

The global climate changes leads to the global warming and global warming itself is very likely due to the observed increase in atmospheric greenhouse gas concentrations as a result of emissions from human and natural activities. So, to solve those problems, we must reduce or prevent emissions from such activities (EEA, 2018).

3. Materials and Methods

3.1. Description of Study Area

This study was conducted in Hunase forest, Amboro kebele, Gibe Woreda, Hadiya Zone, SNNPR, Southern Ethiopia. Hunase forest is one of the natural forest in Hadiya Zone, Gibe Woreda and found in Amboro Kebele with a coverage area of 134 ha from total land area of 41,039 ha (GWAO, 2018). Gibe Woreda is 260 km south of Addis Ababa and 30 km from Hosanna town. Hunase natural forest is located at the boarder of Gomboro Woreda of the Zone. The total area of Gibe Woreda is 41,039 ha. Geographically, the Woreda is located between 7^0 37’53” – 7^0 42’ 43” N latitude and 37^0 37’ 07”- 37^0 44’ 25” E Longitude. The elevation of Gibe Woreda ranges between 1001m-2500m.

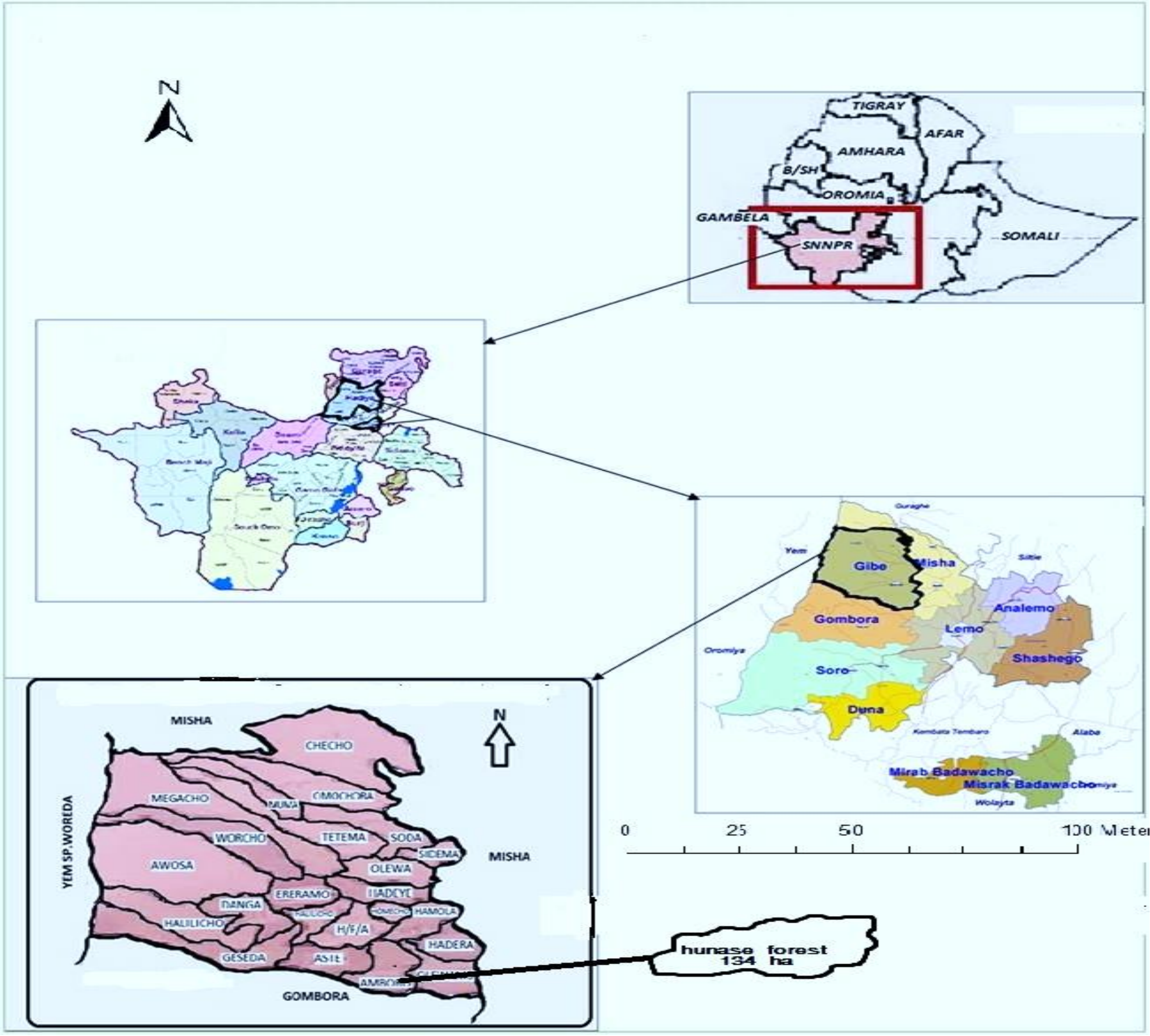

Figure 1:The map of study area showing Ethiopia, southern Nations Nationalities and People Region, Gibe Woreda and the study site. (source: Gibe woreda agricultural sector office, 2013).

3.1.1. Climate

Based on agro-climatic condition, the Woreda has three agroclimatic Zones: Kola (24%), Woynedega (63%) and Dega (13%). The mean annual rainfall of Gibe Woreda is between 600 mm-1200 mm. The Woreda gets rainfall twice in a year. Summer season (June-August) receives heavy rainfall and belge season (April-May) moderate rainfall. The mean annual temperature of Gibe Wored ranges from$17.6^{0}{}_{C}$ to $25^{0}{}_{C}$. Temperature becomes high in the months of January, February, March and low in June, July, August.

3.1.2. Soil types

The Woreda has clay, sandy soil and litosol types. Litosol is more dominant soil type. They are generally considered as fertile soils and stable soils with favorable physical properties. The deep porous and stable soil structure permits deep rooting and make the soil quite resistant to erosion. Thus, they are the most productive soils to produce the commonly grown food and plantation crops (FAO, 2001).

3.1.3. Economic Activity and population

The major economic activity of the study area is agriculture, particularly mixed farming system including animal rearing. The dominant cereal crops include maize (*Zea mays* L.), teff (*Eragrostis teff* L.), sorghum (*Sorghum bicolor* L.), barley (*Hordeum vulgares* L.), and with a rarely pulse crops like beans (*Phaseolus vulgaris* L.), peas (*Pisum sativum* L.). A commonly found wild animals in the study area include hyena, ape, monkey, wild cat, and others.

The total population of Gibe Woreda is 141,312. The majority of the population lives in the rural area and depends on agriculture. The major ethnic group is hadiya, rarely Gurage, and major spoken language is Hadiyigna and rarely Guragigna. The protestantants are most common (Agago *et al.*, 2015).

3.2.1. Materials

Materials used during the study include GPS, glove, measuring tape, digital camera, scientific calculator, plant press, plastic bag, plant cutter, clinometer and paint.

3.2.2. Reconnaissance survey

A reconnaissance survey was conducted before data collection on September 2019 to obtain general information about the study area or environmental condition, to select sampling site from whole natural forest.

3.2.3. Data Sources

The data were collected from both primary and secondary data sources. Primary data were obtained through field work and the secondary data (wood specific gravity for each tree species) was taken from global wood density data base, developed by Chave *et al*. (2009).

3.2.4. Sampling Design

Three transects were laid at a distance of 200m from each other.These transects encompasses different categories of the natural forest (disturbed, semi-disturbed and undisturbed) based on degree of human disturbance/modification and species composition respectively. Twelve plots of size 100m×100m were systematically laid at 25m elevation interval along each transect line (total = 36 plots).

3.3. Data collection

The data collection was conducted from 11/03/-11/04/ 2019. Data on tree DBH (at 1.3m above the ground) and height above 1.3m of those with DBH≥10cm were collected from 100m × 100m (1ha) plots. The local name of each woody species was recoreded in the field.The circumfrance (later changed to DBH) of each woody species was measured with measuring tape. All individual woody species with DBH≥10cm in each plot were counted and recorded.The height of each tree species was measured using clinometer. Wood specific gravity (g/cm^3) for each tree species was taken from global wood density data base (Chave *et al*., 2009). This was used to calculate aboveground woody species biomass and carbon storage. For stem abnormalities, I followed Rainfor protocol (Phillips *et al*., 2009). For trees and shrubs that were branched around the breast height, the circumference was measured separately and averaged. To know the plot location and elevation, each plot were recorded by using GPS. Local names of each woody species was taken (consulting the local community). The collected species were identified by using botanical keys from Flora of Ethiopia and Eritrea. Identified specimens were properly pressed, dried and deposited in botanical herbarium of Jimma University for further identification.

3.4. Data analysis

3.4.1. Woody species diversity analysis

Shannon-Wiener (1949) diversity index was used to measure species diversity.The Shannon index assumes that all species are represented in a sample and that the sample was obtained systematically:

$H' = -\sum p_i \ln p_i$ where, H' = Shannon diversity index,

Pi =relative aboundance of the i^{th} species.

ln = natural logarithm to the base e.

Shannon's Equitability (E), Evenness

The actual diversity value was compared with to the maximum possible diversity by using a measure called evenness.

The evenness of the sample was obtained from the formula:

- $E = H'/H_{max} = H'/\ln S$

Where, H\` = Shannon diversity index

S = total number of species in the sample

ln = natural logarithm

The value of evenness index falls between 0 and 1. The higher the value of evenness index, the more even the species in their distribution with in the studied area.

3.4.2. Sorensen similarity Index (Ss)

Sorensen similarity index was used to compare woody species composition and it was calculated as:-

$$Ss = \frac{2a}{(2a+b+c)}$$,where:

Ss= Sorensen similarity coefficient

a= number of species common to both sites

b= number of species unique to the first site

c= number of species unique to the second site

3.4.3. Woody species structural analysis

All collected and recorded woody species from the study forest was used in the structural analysis. Like basal area, relative dominancy, frequency, relative frequency, density, relative density, and importance value index (IVI).

Diameter at Breast Height (DBH)

Circumference (C) of the woody species was taken and converted to diameter(D) using: D = C/π, where D is diameter at breast height.

Basal Area

It is the cross-sectional area of all stems in a stand at breast height. Basal area of all woody species with DBH ≥ 10 cm was calculated using the following formula. $BA = \pi*(DBH/2)^2$
Where: BA = Basal area, DBH = Diameter at breast heat, π = 3.14

It also used to calculate the dominance of species and expressed in square meter/hectare.

Relative Dominance (RDM)

Relative dominance is measured using the following formula.

$$\text{Relative dominance (RDM)} = \frac{\text{Basal area of a species}}{\text{Total basal area of all species}} \times 100$$

Frequency (F)

It is the number of times a plant species occurs in a given study area. The more frequent the species, the wider its distribution in the study area.

Relative Frequency (RF)

It was refers to the percentage or proportion of times that species occurs with in a set of total numbers species in study area.

$$\text{RF} = \frac{\text{The frequency of individual species}}{\text{The frequency of all species}} \times 100$$

Density

Density is defined as the number of individuals of a species with in the plots or it is the number of stem count in the study area (Kent and Coker, 1992). It also closely related to abundance but more useful in estimating the importance of a species. It was calculated by summing up all stems across all area per hectare.

$$\text{Density} = \frac{\text{Total number of individuals}}{\text{Sampled area in hectare}}$$

Relative Density (RD)

Relative density is the density of a species as a percent of total plant density (Matthew *et al.*,1993). It was calculated as follows :

$$\text{RD} = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100$$

Importance Value Index (IVI)

It is a combination of relative frequency (RF), relative density (RD) and relative dominance (RDO) (Kent and Coker, 1992). A species with the highest IVI value, it was relatively dominant in that ecosystem and ecologically more important. It was calculated as follows:

$$\text{Importance value index (IVI)} = \text{Relative Density} + \text{Relative dominance} + \text{Relative frequency}$$

3.4.4. Estimation of above ground Biomass

Non-destructive allometric Equation was used for biomass estimation in the study area (Chave, *et al*., 2014). The aboveground biomass estimation depends up on height, diameter at breast height, woody specific gravity of each woody species.

$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$ Where: AGB = Above ground biomass, ρ = Wood specific gravity, D = Diameter at breast height, H = Height

3.4.5. Estimation of above ground carbon storage

Aboveground live carbon storage (AGC) was calculated as 50% of the AGB of each woody species with DBH $\geq$10 cm (Chave *et al*., 2014).

3.4.6. Estimation of carbon sequestration

The carbon sequestration ($AGCO_2$) estimated from above ground carbon storage. $AGCO_2$ = 3.67xAGC, Where 3.67 means the ratio of molecular weight of carbon to carbon dioxide. One ton of carbon stored in a tree represents removal of 3.67 ton of CO_2 from the atmosphere, and the release of 2.67 tons of oxygen back into the atmosphere (Ugle *et al*., 2010).

3.4.7. Comparison of different categories of natural forest in terms of carbon storage

The variation in species diversity and AGC among different categories of the study area was analyzed using one way ANOVA.

4. Results and Discussion

4.1. Results

4.1.1. Woody species composition

In the study area, a total of 38 woody species (29 trees and 9 shrubs), belonging to 36 genera and 27 families were recorded from the three categories of natural forest (disturbed, semi-disturbed and undisturbed) (Appendix.1). Fabaceae was the most dominant family with four genera (11.11%), and five species (13.15%) in studied area, followed by Anacardiaceae, Boraginaceae, Celastraceae, Cupressaceae, Euphorbiaceae, Myrtaceae, and Ulmaceae each with two genera (5.56%) and two species (5.26%). Salicaceae has one genera (2.78%) and two species (5.26%). Acanthaceae, Araliaceae, Arecaceae, Asteraceae, Celastraceae, Dichapetalaceae, Moraceae, Myrsinaceae, Oleaceae, Podocarpaceae, Proteaceae, Rhamnaceae, Rosaceae Rutaceae, Sapindaceae, Rubiaceae and others each with one genera (2.85%) and one species (2.63%).

Table 1: Families with ≥2 species in the study area in 2019

Family	Number of species	Percentage (%)
Fabaceae	5	13.15
Anacardiaceae	2	5.26
Boraginaceae	2	5.26
Celastraceae	2	5.26
Cupressaceae	2	5.26
Euphorbiaceae	2	5.26
Myrtaceae	2	5.26
Ulmaceae	2	5.26
Salicacea	2	5.26
Total	21	55.23

All the collected and recorded woody species distributed throughout disturbed, semi-disturbed and undisturbed categories of the Hunase natural forest. From a total of 38 species of the study area, 31 (81.6%) were recorded from undisturbed, 19 (50%) from semi-disturbed and 17 (44.8%) from disturbed categories of the forest. Twelve species (31.6%) were common for the three categories, 14 species (36.8%) common to undisturbed and semi-disturbed categories, 14 species (36.8%) common to undisturbed and disturbed categories, 13 species (34.2%) common to semi-disturbed and disturbed categories, 16 species (42.1%) unique for undisturbed category, 5 species (13.15%) unique for semi-disturbed category and 2 species (5.26%) were unique to disturbed category.

Table 2: Distribution of tree and shrubs species in three categories of natural forest as follows:

	Habit		
Categories of natural forest	Tree	Shrubs	Total
Undisturbed	25	6	31
Semi-disturbed	18	1	19
Disturbed	15	2	17

4.1.2. Woody species diversity, richness and evenness

Table 2 indicates that, undisturbed forest category has the highest richness of the woody species as compared to the semi-disturbed and disturbed forest categories of study area. Each species richness represented graphically in figure 2.

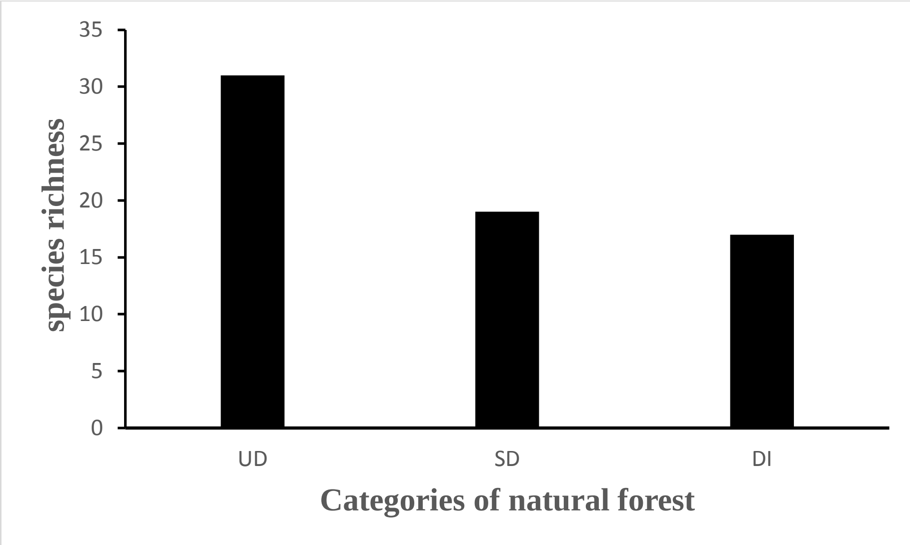

Figure 2: Woody species richness of the three categories of natural forest in the study forest (UD = undisturbed, SD = semi-disturbed, DI =disturbed).

The highest Shannon's diversity index was calculated for undisturbed category of the forest while the disturbed category was with the least (Table 3). Undisturbed category has the highest species diversity, richness, second in species evenness. Semi-disturbed category is second in species richness, species diversity and first in species eveness. Disturbed category ranked 3rd in diversity, species richness and eveness.

Undisturbed category relatively has the highest woody species richness compared to the remaining two categories. The more value of species richness has a great importance in keeping ecological diversity of the ecosystem. On the other hand, disturbed category was the least in terms of its species richness and had less ecological importance compared to the rest two categories.

Table 3: The value of Shannon–Wiener Diversity Index

Forest categories	Richness (S)	Diversity index (H')	(LnS)	Equatibility/eveness(J) (H'/lnS)
Undisturbed	31	2.75	3.433	0.801
Semi-disturbed	19	2.388	2.944	0.811
Disturbed	17	2.14	2.833	0.755

4.1.3. Similarity among the three forest categories

Sorenson similarity calculation gives the similarity between three categories of natural forest. Semi-disturbed and disturbed categories showed high similarity in woody species composition where as the least similarity was observed between undisturbed and semi-disturbed categories.

Table 4: Sorensen's similarity between different categories in woody species

Categories of forest	Undisturbed	Semi-disturbed	Disturbed
Undisturbed	1.00	0.57	0.60
Semi-disturbed		1.00	0.79
Disturbed			1.00

The percentage similarity of undisturbed and semi-disturbed categories were (57%), undisturbed and disturbed categories (60%), semi-disturbed and disturbed categories (79%).

4.1.4. Woody species structures

4.1.4.1. Basal Area

The total basal area of woody species in this study was 4.975m^2/ha. The highest basal area was calculated for undisturbed forest category (3.505 m^2/ha) and the least for disturbed forest category (0.66 m^2/ha). Of the species encountered in the study area *Syzygium guineense* contributed the highest basal area in both undisturbed and disturbed forest categories. In semi-disturbed forest category *Podocarpus falcatus* has contributed the highest BA/ha. The basal area, basal area per hectars, and relative basal area of all woody species in the study area (three categories) (Appendix- 3, 4, 5) and the largest basal area of a species in each category were calculated and given in Table: 5, 6 and 7.

Table 4 : Basal area, BA/ha, RBA of four most important species in disturbed category. (BA/ha = Basal area per hectare, RBA = Relative basal area).

Species name	BA/ha	RBA
Syzygium guineense	0.384683	58.2927
Tapura fischeri	0.1665	25.2304
Eucalyptus globulus	0.037083	5.61939
Croton macrostachyus	0.02483	3.755

Table 6 : Basal area, BA/ha, RBA of three most important species in semi- disturbed category. (BA/ha = Basal area per hectare, RBA = Relative basal area).

Species name	BA/ha	RBA
Podocarpus falcatus	0.2388	29.58
Tapura fischeri	0.2097	25.97
Syzygium guineense	0.1301	16.11

Table 7 : Basal area, BA/ha, RBA of six most important species in undisturbed forest category. (BA/ha = Basal area per hectare, RBA = Relative basal area).

Species name	BA/ha	RBA
Syzygium guineense	1.723341667	49.1680932
Trema orientalis	0.60515	17.26533524
Apodytes dimidiate	0.2011	5.73
Polyscias fulva	0.178	5.093
Prunus Africana	0.178	5.083
Macaranga capensis	0.176	5.03

4.1.4.2. Frequency

Three most frequent species in disturbed category were: *Croton macrostachyus* (17.1%) *Syzygium guineense* (14.06%) and *Albizia gummifera* (12.5%). *Syzygium guineense* (15.1%), *Albizia gummifera* (13.6%), *Trema orientalis* (12.12%) for semi-disturbed category and *Syzygium guineense* (9.3%), *Trema orientalis* (9.3%) and *Ficus sycomorus* (7.6%) have the highest frequency value for undisturbed category. The frequency and relative frequency of all woody species in the study area were calculated and recorded for disturbed, semi-disturbed and undisturbed categories (Table 11,12,13).

4.1.4.3. Density

It was calculated by summing up all woody species stems across in a sample per hectare those DBH≥ 10 cm. Thirty eight woody species comprising 770 individuals with DBH ≥ 10cm and height ≥1.3 m above the ground were recorded. From these, 728 (94.54%) individuals were trees and 42 (5.45%) individuals were shrubs. Out of 770 total stem count, 412 (34.33 stems/ha) were collected from undisturbed category, 185 (15.4 stems/ha) from semi-disturbed category and 173 (14.4 stems/ha) from disturbed category. The above result indicated that undisturbed forest category has the highest woody species density and richness from the rest categories in the study area (Figure 3).

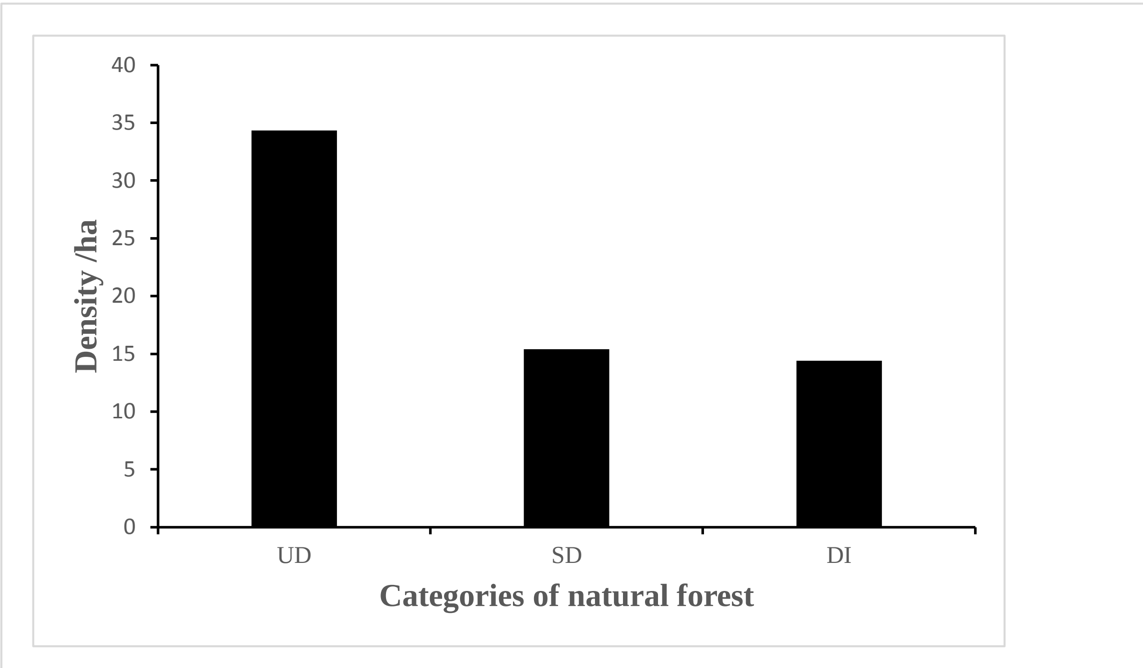

Figure 3: Woody species density of the three categories of the study forest (UD=undisturbed, SD=semi-disturbed, DI=disturbed).

Table 5: Stem count and percentage of woody species recorded from three categories of natural forest.

	Tree		Shrubs		Total	%
Categories of forest	Stem count/ha	%	Stem count/ha	%	Stem count/ha	%
Undisturbed	386	50.39	26	3.39	412	53.71
Semi-disturbed	175	22.72	10	1.29	185	23.59
Disturbed	167	21.80	6	0.78	173	22.68
Total	728	94.51	42	5.47	770	100

Table 6 : Mean value ± standard error of three categories of Hunase natural forest.

Categories of forest	Mean and standard error
Undisturbed	13.29 ±2.38
Semi-disturbed	9.62 ±1.55
Disturbed	10.23±2.31

From three categories of species collected, *Syzygium guineense* (78 stems/ha), *Trema orientalis* (69 stems/ha) *Croton macrostachyus* (50 stems/ha), *Eucalyptus globulus* (38 stems/ha), *Macaranga capensis* (26 stems/ha) and *Albizia gummifera* (23 stems/ha) were the top six dominant tree species in the study area, while *Grevillea robusta*, *Casuarina equisetifolia*, *Juniperus procera*, *Azadirachta indica* each has 1 stem/ha from tree habit and *Justicia schimperiana* 1stem/ha from shrub habits.

Table 7: Dominant and rare woody species density in the three categories of study area

Habit	Dominant species		Rare species	
	Scientific name	No of individuals	Scientific name	No
Tree	*Syzygium guineense*	78	*Oleaeuropaea*	3
	Trema orientalis	69	*Celtis africana*	3
	Croton macrostachyus	50	*Acacia seyal*	2
	Eucalyptus globulus	38	*Ehretia cymosa*	2
	Macaranga capensis	26	*Grevillea robusta*	1
	Albizia gummifera	23	*Casuarina equisetifolia*	1
	Catha edulis	20	*Juniperus procera*	1
Shrub	*Clausena anisata*	10	*Justicia schimperiana*	1
	Rhamnus prinoides	4		

The highest stem count/ha was recorded from undisturbed category (34.33), followed by semi-disturbed category (15.08) and the least from disturbed category (14.41).

The frequency, Relative frequency, Density, and Relative density of the highest stem count in all category were given in (Table 11,12 and 13).

Table 11: Frequeny (F), Relative frequency (RF), Density (D), and Relative density (RD) of top species from disturbed forest category.

Species	F	RF	D	D/ha	RD
Croton macrostachyus	11	17.18	32	2.67	1.53
Syzygium guineense	9	14.06	38	3.17	1.82
Albizia gummifera	8	12.5	20	1.67	0.96
Eucalyptus globulus	7	10.93	38	3.17	1.82
Catha edulis	7	10.93	20	1.67	0.96
Maesa lanceolata	4	6.25	4	0.33	0.919
Ficus sycomorus	3	4.68	3	0.25	0.14

Table 12: Frequency (F), Relative frequency (RF), Density (D), and Relative density (RD) of top species from semi-disturbed forest category.

Species	F	RF	D	D/ha	RD
Syzygium guineense	10	5.15	49	4.08	26.5
Albizia gummifera	9	13.63	20	1.67	10.8
Trema orientalis	8	12.12	15	1.25	8.10
Croton macrostachyus	7	10.6	21	1.75	11.35
Apodytes dimidiata	6	9.09	7	0.58	3.78
Macaranga capensis	4	6.06	9	0.75	4.86
Acacia abyssinica	4	6.06	12	1	6.48

Table 13: Frequency (F), Relative frequency (RF), Density (D), and Relative density (RD) of top species from undisturbed forest category.

Species	F	RF	D	D/ha	RD
Syzygium guineense	11	9.32	78	6.5	18.93
Trema orientalis	11	9.32	69	5.75	16.74
Ficus sycomorus	9	7.62	18	1.5	4.37
Croton macrostachyus	8	6.77	50	4.16	12.13
Macaranga capensis	7	5.93	26	2.16	6.31
Apodytes dimidiate	7	5.93	12	1	2.91
Albizia gummifera	7	5.93	23	1.91	5.58
Millettia ferruginea	5	4.23	14	1.17	3.39
Cordia africana	4	3.38	10	0.83	2.43

4.1.4.4. Importance Value Index (IVI)

Importance value index (IVI) is essential to compare the ecological importance of species in ecosystem and a key structural parameter in vegetation study. *Syzygium guineense* (74.1%), *Tapura fischeri* (28.4%), *Croton macrostachyus* (22.4%) were highest IVI value in disturbed category. *Syzygium guineense* (56.12%), *Podocarpus falcatus* (31.6%), *Tapura fischeri* (28.04%) and *Syzygium guineense* (77.4%), *Trema orientalis* (43.3%), *Croton macrostachyus* (21.16%) were the highest IVI value for semi-disturbed and undisturbed categories.

Table 14: Relative frequency (RF), Relative density (RD), Relative dominance (RDM) and IVI of species from disturbed forest category.

Species	RF	RD	RDM	IVI
Dovyalis caffra	1.56	0.14	0.3699	2.0699
Croton macrostachyus	17.19	1.53	3.755	22.475
Eucalyptus globulus	10.94	1.82	5.61939	18.3793
Albizia gummifera	12.5	0.96	2.1467	15.6067
Syzygium guineense	14.06	1.82	58.2927	74.1727
Catha edulis	10.94	0.96	2.16946	14.069
Podocarpus falcatus	3.13	0.096	0.2248	3.4508
Apodytes dimidiate	1.56	0.048	0.09976	1.7077
Maesa lanceolata	6.25	0.19	0.33186	6.772
Macaranga capensis	4.69	0.14	0.345750	5.1758
Ficus sycomorus	4.69	0.14	0.572041	5.4020
Tapura fischeri	3.13	0.096	25.2304	28.4564
Dodonaea angustifolia	3.13	0.14	0.308877	3.5788
Ehretia cymosa	1.56	0.048	0.09976	1.7078
Polyscias fulva	1.56	0.096	0.214673	1.8706
Trema orientalis	1.56	0.048	0.12249	1.73049
Dovyalis abyssinica	1.56	0.048	0.09976	1.7078
Total 17	100	100	100	300

Table 15: Relative frequency (RF), Relative density (RD), Relative dominance (RDM) and IVI of species from sem-disturbed forest category

Species	RF	RD	RDM	IVI
Dovyalis caffra	1.51	1.10	0.165119	2.785243
Croton macrostachyus	10.60	11.60	3.104231	25.3125
Eucalyptus globulus	3.03	5.53	1.898865	10.45403
Albizia gummifera	13.64	11.05	2.890041	27.57613
Syzygium guineense	15.15	24.86	16.11352	56.12691
Catha edulis	4.55	6.63	1.237647	12.41294
Apodytes dimidiate	1.52	0.55	0.596491	2.664129
Macaranga capensis	9.09	3.87	1.101135	14.05945
Ficus sycomorus	6.06	4.97	0.131465	11.16445
Tapura fischeri	1.52	0.55	25.9742	28.04184
Cupressus lusitanica	3.03	1.66	5.194014	9.881776
Juniperus procera	4.55	9.95	0.081527	14.57173
Acacia abyssinica	1.52	0.55	1.872033	3.939671
Grevillea robusta	6.06	6.63	0.081527	12.77197
Polyscias fulva	1.52	0.55	4.34644	6.414077
Trema orientalis	1.52	0.55	2.260062	4.3277
Casuarina equisetifolia	12.12	8.29	3.285862	23.69437
Phoenix reclinata	1.52	0.55	0.089474	2.157111
Podocarpus falcatus	1.52	0.55	29.57688	31.64452
Total 19	100	100	100	300

Table 16: Relative frequency (RF), Relative density (RD), Relative dominance (RDM) and IVI of species from undisturbed forest category

Species	RF	RD	RDM	IVI
Croton macrostachyus	6.78	12.13	2.25583	21.16583
Syzygium guineense	9.32	18.93	49.1681	77.4181
Trema orientalis	9.32	16.75	17.2653	43.3353
Millettia ferruginea	4.24	3.39	0.29672	7.92672
Macaranga capensis	5.93	6.31	5.03386	17.27386
Podocarpus falcatus	2.54	1.46	0.14672	4.14672
Ficus sycomorus	7.63	4.37	3.15977	15.15977
Apodytes dimidiate	5.93	2.91	5.73776	14.57776
Prunus Africana	2.54	0.72	5.08321	8.34321
Ehretia cymosa	1.69	0.49	0.03875	2.21875
Cordia Africana	3.39	2.42	0.21778	6.02778
Albizia gummifera	5.93	5.58	0.62387	12.13387
Polyscias fulva	3.39	2.91	5.09368	11.39368
Olea europaea subsp. Cuspidata	1.69	0.73	0.06003	2.48003
Coffea arabica	0.85	0.73	0.05801	1.63801
Tapura fischeri	3.38	2.43	4.00856	9.81856
Vernonia amygdalina	2.54	0.97	0.07815	3.58815
Eucalyptus globulus	0.85	1.21	0.09748	2.15748
Celtis africana	2.54	0.73	0.05937	3.32937
Justicia schimperiana	0.85	0.24	0.01878	1.10878
Catha edulis	1.69	0.49	0.03804	2.21804
Acacia abyssinica	1.69	0.49	0.03804	2.21804
Salacia congolensis	3.39	2.43	0.30801	6.12801
Acacia seyal	1.69	0.49	0.03804	2.21804
Phoenix reclinata	0.85	1.21	0.20685	2.26685
Dovyalis abyssinica	0.85	2.43	0.31859	3.59859

Azadirachta indica	0.85	0.24	0.03019	1.12019
Rhamnus prinoides	0.85	0.97	0.07751	1.89751
Clausena anisata	1.69	2.43	0.19448	4.31448
Rhus vulgaris	3.39	2.43	0.19496	6.01496
Calpurnia aurea	1.69	0.97	0.07608	2.73608
Total 31	100	100	100	300

4.1.5. Comparison of undisturbed forest category with the remaining two categories.

Analysis of variance (ANOVA) showed that there is significant variation (F = 26.166, P <0.05) in woody species density among the three categories of forest (Table 17). Tukey's multiple comparison also showed the variation between each pair of categories (Table 18).

Table 17: Summary of values of significance for one -way ANNOVA between the three categories for density

Density/ha	Sum of Squares	Df	Mean Square	F	P
Between Groups	8972.523	2	815.684	26.166	0.00
Within Groups	218.214	33	31.173		
Total	9190.737	35			

Table 88: Summary of ANNOVA for variation of density between each categories.(S.E = standard error, L.B = Lower boundery, U.B = upper boundery).

(I) Forest category	(J)Forest category	Mean difference (I-J)	S.E	P	95% C.I	
					L.B	U.B
Undisurbed	Disturbed	3.06	2.3	0.000	6.37	20.20
Disturbed	Semi-disturbed	0.71	2.3	0.022	4.16	14.88
Semi-disurbed	Undisturbed	-3.77	1.5	0. 021	3.19	17.27

4.1.6. Above ground live carbon storage and sequestration in Hunase forest

4.1.6.1. Above ground live carbon storage and carbon dioxide sequestered potentials in disturbed forest category.

The aboveground live carbon storage in disturbed forest category was 0.17 ton/ha. The amount of carbon dioxide sequestered by this forest category was 0.65 ton/ha. The plant species with relatively highest aboveground carbon storage was *Syzygium guineense*, while the least contributor was *Ehretia cymosa*.

4.1.6.2. Aboveground live carbon storage and carbon dioxide sequestered potentials in semi- disturbed forest category.

The aboveground live carbon storage in semi- disturbed forest category was 0.198 ton/ha. The amount of carbon dioxide sequestered by this forest category was 0.72 ton/ha. The plant species with relatively highest aboveground carbon storage was *Podocarpus falcatus*, while the least contributor was *Grevillea robusta*.

4.1.6.3. Aboveground live carbon storage and carbon dioxide sequestered potentials in undisturbed forest category.

The aboveground live carbon storage in undisturbed forest category was 1.95 ton/ha. The amount of carbon dioxide sequestered by this forest category was 7.16 ton/ha. The plant species with relatively highest aboveground carbon storage was *Syzygium guineense*, while the least contributor was *Justicia schimperiana*.

Overall, 2.32 ton AGC/ha and 8.56 ton/ha sequestered carbon was calculated from all categories of the study forest (Table 19).

Table 19: Summary of AGB , AGC and $AGCO_2$ in different category of forest.

Category of forest	AGB in ton	AGC in ton	AGB t/ha	AGC t/ha	$AGCO_2$ t/ha
Disturbed	4.23	2.11	0.35	0.17	0.65
Semi-disturbed	4.85	2.42	0.40	0.198	0.74
Undisturbed	46.9	23.45	3.90	1.95	7.17
Total	55.98	27.98	4.65	2.32	8.56

4.1.7. Differences in carbon storage among different woody species in each forest category

The amount of carbon stored varies from species to species in forest each category. The top six species in carbon storage in the disturbed category were: *Syzygium guineense* (0.007t/ha), *Tapura fischeri* (0.0055 t/ha), *Eucalyptus globulus* (0.00041 t/ha), *Croton macrostachyus* (0.0001 t/ha), *Catha edulis* (0.0000034t/ha) and *Albizia gummifera* (0.0000033t/ha).

The top six species with relatively higher AGC in semi-disturbed category were: *Podocarpus falcatus* (0.061t/ha), *Tapura fischeri* (0.05 t/ha), *Syzygium guineense* (0.02 t/ha), *Apodytes dimidiata* (0.011 t/ha), *Polyscias fulva* (0.0048t/ha) and *Cupressus lusitanica* (0.0021t/ha).

The top six species having relatively higher AGC in undisturbed forest category were: *Syzygium guineense* (1.26t/ha), *Trema orientalis* (0.18t/ha), *Apodytes dimidiata* (0.17t/ha), *Prunus africana* 0.16t/ha, *Polyscias fulva* (0.051t/ha) and *Macaranga capensis* (0.036t/ha).

Table 20: Mean value ± standard error of study area forest in AGC (ton/ha)

Category of forest	Mean and standard error
Undisturbed	0.164 ±0.07
Semi-disturbed	0.017 ±0.0095
Disturbed	0.0134±0.007

Analysis of variance (ANOVA) showed that there was no significant variation ($F = 1.22$, $P = 0.61$) in carbon storage among the three forest categories of Hunase forest

4.2. Discussion

Fabaceae was the species rich family compared to all other plant families identified in this study. Similar result has been reported from Beleta forest by Kfley Gebrehiwot and Kitessa Hundara (2011) and from Gra-Kahsu natural vegetation, Alamata District of the Tigray Regional State, Northern Ethiopia by Tesfay Atsbha *et al*. (2019). Similar result has been reported from this studied area by Zinabu abeba (2017). As compared toTesfay Atsbha *et al*. (2019), the woody species abundance in the study area was low, may be due to poor management strategy followed by the community and related government organization in forest conservation.

In the study area , the highest number of woody species was recorded in undisturbed category (31) as compared with semi-disturbed (19) and disturbed categories (17). This was because of human settlements far from it and a number of danger wild animals on it. The recent studied individual woody species (770) was less than the previous studies of Zinabu Abeba (2017) that of (825) from the three categories. This due to increasing levels of illegal disturbance of forest for different purpose. Out of the total 770 individual woody species recorded in the study area, 412 stems count were from undisturbed category. Out of this, the top five large number of stem count of woody species were: *Syzygium guineense* (Myrtaceae), *Trema orientalis* (Ulmaceae), *Croton macrostachyus* (Euphorbiaceae), *Albizia gummifera* (Fabaceae) and *Macaranga capensis* (Euphorbiaceae). Mostly these species have natural capacity for nitrogen fixation, due to symbiotic associations between their roots and rhizobia, improving soil fertility for other woody species in natural forest (Dereje Denu *et al.*, 2016). Compared to Tesfay Atsbha *et al*. (2019) the stem count/ha in the current study was much smaller. This was due to the unproper usage of natural forest for charcool production, fire wood collection, for infrastructural development (road) and timber harvesting.

The current study indicated that disturbed and semi-disturbed categories were lower in woody species richness than undisturbed category. This could be due to the protection provided to conserve the forest. The people afraid to move deep into the center of the forest for resource extraction such as charcoal production, fire wood collection, infrastructural development by the nearby community. Similar study conducted in Tigray region (Kidane Giday, 2002) showed that species richness in area near to the human settlement are exposed for resource extraction, while the undisturbed category which is far from human settlement are not easily exposed to human impact. In the study area *Syzygium guineense* has the highest abundance in three categories of natural forest due to less consumption of the species for different purposes as a result of its low wood quality.

The number of shrub species in the study area was very small compared to tree species because natural forest become dominated by tree species.

The recent studied Shannon diversity index value (H') for undisturbed categories (2.75) and disturbed categories (2.14) were lower than the previous studies of Zinabu Abebe (2.98) and (2.21) those species far from human settlement and near to human settlements respectively. This is due increasing level of woody species disturbance from year to year in un proper maner for charcoal production, fire wood collection, timber harvesting, agriculture. Shannon diversity index value (H'), Shannon equitability/evenness index (E) and species richness (S) (Table 3) above showed that undisturbed category has the highest species diversity, richness, second in species evenness. Semi-disturbed category is second in species richness, species diversity and first in species eveness. Where as disturbed category ranked 3rd in diversity, species richness and eveness. Similar study conducted by Lecointre and Guyader (2001) that an ecosystem where some species are represented by many individuals and other species are represented by very few individuals have high and low species evenness, respectively. The high Shannon diversity index value of undisturbed category indicated that the forest were relatively higher in average number of woody species as compared to other categories of the study forest. This indicated that the type of management practices influenced both species richness, diversity and especially reason for this species variability of each category in study area were arise from extent of disturbance (agriculture, infrastructural development, fire wood collection, timber and charcoal production activity).

Syzygium guineense was the most important woody species in the study area in having large basal area (1.72 m^2/ha) followed by *Trema orientalis* (0.6 m^2 /ha) and *Podocarpus falcatus* (0.23m^2/ha) due to higher density and DBH value. *Podocarpus falcatus* has a low density but there were higher DBH value and it was a higher BA/ha in the study area. A species with the highest basal area do not necessarily have the highest density, indicating size difference between species (Dereje Denu, 2006). The result indicated that woody species in undisturbed category were the highest basal area followed by semi-disturbed category, while the basal area in disturbed category was the least. Due to this woody species in undisturbed category relatively has more basal area than other categories. This is because of the age of trees (usually they are maintained for many years) and relatively higher number of stems (density/ha) with high DBH value.

The total basal area of woody species in this study 4.975 m^2/ha was much lower than what was reported by Getahun Yakob and Anteneh Fekadu (2016) that the total basal area of woody species in Keja Araba (2611m^2/ha) and Tula forests (3761 m^2/ha) and from Kitessa Hundera and Tsegaye Gadissa (2008) that the total basal area of woody species (90.6m^2/ha) of the Belete Forest, Jimma Zone, South Western Ethioipia. The main reason for such a greater variation is that Hunase natural forest highly disturbed than the above study area due to its accessibility for agriculture, road, charcool production, fire wood collection and timber harvesting process.

The largest stem count/ha in undisturbed category were 412 (34.33 stems/ha) and in this category *Syzygium guineense* (78 stems/ha), *Trema orientalis* (69 stems/ha), *Croton macrostachyus* (50 stems/ha), were contributed the highest woody species density respectively. This was because of the leave fallen down species was highly growth activities in the area. The total woody species density/ha of the study area was much lower than Belete Forest, Jimma Zone, South Western Ethioipia who reported by Kitessa Hundera and Gadissa Tsegaye (2008) that the total woody species density (1482 stem/ha). This was due to illegal disturbance of individual species in study area for agriculture, Fire wood collection, charcool production, roads. In contrast, low stem/ha was observed in both disturbed and semi-disturbed categories this was due to grazing and browsing pressure and cutting of trees for firewood and charcoal production widely.

From study area *Syzygium guineense* were commonly distributed in three categories of natural forest. *Croton macrostachyus* was the highest frequently species with the relative frequency value of (17.1%) followed by *Syzygium guineense* relative frequency value of (15.1%). Similar result reported in this studied area in (2017) by Zinabu Abebe that *croton macrostachyus* was widely distributed than the other. This was due to less consumption of a species for different purpose by the local community. Similar study also conducted from Magada forest, Bule-Hora District, Borena Zone, Oromia Region, Southern Ethiopia by Garuma Gerbaba and Wendawek Abebe (2016) that the *Croton macrostachyus* was highest frequently species as compared with others in that district. Others were found at medium and lower class frequency value. This showed that most of the woody species of the study area were found in lower class frequency and small numbers of woody species were found in higher frequency which indicated that heterogeneity of species. Similar study conducted in Yemrehane Kirstos church natural forest of Lasta Woreda, North Wollo Zone, Amhara Region, Ethiopia (Amanuel Ayanaw, 2018). The reason why the frequency of woody species differ from one category to the other and from species to species should be unequal conservation of forests properly.

The most ecologically important species in the study area indicated the high value of IVI, which was relatively high (dominance, frequenty, and density) which maight be due to their low demand by local community for timber, charcoal production, fire wood collection (*Syzygium guineense, Trema orientalis, Podocarpus falcatus*, and *Tapura fischeri*) was the highest IVI values in the study area. Where as, *Justicia schimperiana*, *Azadirachta indica*, *Ehretia cymosa* were the low IVI values and they required high protection rate. Similar result has been reported from Dallo Mena District, South-East by Bikila Mengistu and Zebene Asfaw (2016) that the highest IVI value of species in that district was *Syzygium guineense*. The IVI values can be used as an input for conservation strategies to protect woody species against anthropogenic factors. Similar report conducted Keja Araba and Tula Forests, South West Ethiopia (Getahun Yakob and Anteneh Fekadu, 2016).

The AGB (4.65 t/ha), AGC (2.32 t/ha) and $AGCO_2$ (8.56t/ha) were calculated in the study area. From these undisturbed category contributed relatively large amount of stored carbon and sequestration potentials where as disturbed category contributed less. As reported by Fentahun *et al.* (2017) for Banja forest Amhara region of Ethiopia the total carbon stock of the forest was 639.87 t/ha and by Alefu Chinasho *et al.*(2015) for Humbo forest in Wolaita Zone, Southern Ethiopia the Above ground carbon stock of our study is by far lower. So, the study area forest was much lower in AGC/ha than the above study area. The main reasons for much variability of carbon storage and sequestration were: low woody species (density, richness, DBH size, height), unproper ways of conservation and utilization by the society. As reported by Ruiz-Jaen *et al*. (2011), the carbon storage and biomass decreases with decreasing species richness. The Hunase Forest is a reservoir of low carbon and thus acts as a less sink of the atmospheric carbon. It can be concluded that the Forests play more or less a great role in climate change mitigation. The variation in AGC among three categories was also analyzed by one way ANOVA.

Undisturbed category (0.164±0.07SE) stored significantly more AGC than semi-disturbed (0.017±0.0095SE) and disturbed (0.0134±0.007SE). This result was much less than the finding of Abiot Molla *et al*. (2017) who reported for diferent patches in a natural forest (201.1±15SE) for AkakoTelamo and (179.3 ±8.7SE) for Arossa Garagalo.

Syzygium guineense was the species with the highest carbon storage in the study area and it was the most densely populated woody species in the three categories of the study forest. This is due to high population density of the species. The people of the study area also considers the species as useless for socio-economic purpose. This might be the reason for the larger AGC storage in its biomass. The carbon storage calculated for *Syzygium guineense* in this study was much smaller than the carbon storage (17.09 t/ha) reported for the species from Banja Forest in Amhara Region of Ethiopia (Fentahun Abere, 2016).

Table 21. Comparisons of carbon stocks of Hunase Forest with other studies in Ethiopia.

Study sites	AGC/ha	Source
Woody Plants of Arba Minch Ground Water Forest	414.70	Belay Melese *et al*.(2014)
Tara Gedam Forest	306.37	Mohammed Gedefaw *et al*.(2014)
Guangua Ellala Forest	291.78	Alemu Ayen (2015)
Egdu Forest	278.08	Adugna Feyissa *et al*. (2013)
Danaba Community Forest	277.78	Muluken Nega *et al*.(2014)
Woody Plants of Mount Zequalla Monastery	237.20	Abel Girma *et al*. (2014)
Menagasha Suba State Forest	133.00	Mesfin Sahile (2011)
Humbo forest	30.77	Alefu Chinasho *et al*.(2015)
Hunase forest	2.32	Present study

5. Conclusion and recommendation

5.1. Conclusion

The study was conducted in Hunase natural forest, Gibbe Woreda, Hadiya Zone, Southern Ethiopia about assessing woody species diversity and determing aboveground live carbon storage in disturbed, semi-disturbed and undisturbed categories of natural forest. Out of three categories, thirty eight woody species belong to 36 genera and 27 families were collected and identified. Fabaceae family was the most dominant with 5 species and 4 genera followed by Anacardiaceae, Boraginaceae, Celastraceae, Cupressaceae, Euphorbiaceae, Myrtaceae, and Ulmaceae each with two genera and two species.

From the three categories 770 individual woody species recorded in the study area. Out of these, 412 stems/ha were from undisturbed category, 185 stems/ha were from semi-disturbed category and 173 stems/ha were from disturbed category. The highest species diversity and richness obtained from undisturbed category and the list from disturbed category. Majority of recorded and identified stems were trees (728 stems) and a few of them were shrubs (42 stems). Undisturbed category was the highest above ground biomass carbon storage and sequestration potential and incontrast disturbed category was very low in study area. The amount of carbon stored in aboveground live plant biomass varies from species to species. This is due to increasing/decreasing size of tree, DBH and density of species. *Syzygium guineense* was the largest carbon stored and sequestered potential species in its biomass.

5.2. Recommendation

1. The woody species found in the study area plays more or less in carbon storage and sequestration potentials which contributed the minimization of climate change mitigation in the atmosphere. So, all stakeholders should pay attention for the conservation and management system of woody species to reduce carbon emission in the atmosphere.

2. Creating public and other stakeholders' awareness about illegal expansion of : infra-stractural development especially, roads (which leads to edge effect), timber harvesting, charcoal production, agricultural activities (especially animal grazing) in natural forest.

3. This study could be used as a base line for other aspects of study. Especially, for below ground biomass (in the soil) of carbon storage and sequestration potentials of woody species in natural forest.

4. This study did not address the above mentioned carbon pools. Therefore, I recommend further study to fill the above mentioned gaps.

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7. Appendices

Appendix 1: List of species collected from the study area, (Had=Hadigna, Ha= Habit)

No	Scientific name	Local name (Had)	Family	Ha
1	*Acacia abyssinica* Hochst ex Benth.	Girara	Fabaceae	T
2	*Acacia seyal* M. Thulin.	Uutam haqqa	Fabaceae	T
3	*Albizia gummifera* (J.F. Gmel.) C.A. Sm.	Mande	Fabaceae	T
4	*Apodytes dimidiata* E.Mey. ex Arn.	Mewwa	Metteniusaceae	T
5	*Azadirachta indica* A.Juss.	Nimma	Meliaceae	T
6	*Calpurnia aurea* (Ait.) Benth.	Senna	Fabaceae	S
7	*Casuarina equisetifolia* L.	Shewashewe	Anacardiaceae	T
8	*Catha edulis* (Vahl)Forssk.exEndl.	Guna	Celastraceae	T
9	*Celtis africana* Burm.f.	Qamli-haqqa	Ulmaceae	T
10	*Clausena anisata* (Wild.) Hook. F.ex.Benth.	Bahit-haqqa	Rutaceae	S
11	*Coffea arabica* L.	Buna	Rubiaceae	S
12	*Cordia africana* Lam.	Wedesha	Boraginaceae	T
13	*Croton macrostachyus* A.Rich.	Messena	Euphorbiaceae	T
14	*Cupressus lusitanica* Mill.	Dolilabhoma	Cupressaceae	T
15	*Dodonaea angustifolia* L. f.	Kitikita	Sapindaceae	T
16	*Dovyalis abyssinica* (A.Rich) Warb.	Gas-koshima	Salicaceae	T
17	*Dovyalis caffra* (Warb).	Dolilabkoshim	Salicaceae	S
18	*Ehretia cymosa* Thonn.	Uulaga	Boraginaceae	T
19	*Eucalyptus globulus* Labill.	Kasharbarizaf	Myrtaceae	T
20	*Ficus sycomorus* L.	Odda	Moraceae	T
21	*Grevillea robusta* R. Br.	Gravilla	Proteaceae	T
22	*Juniperus procera* Hochst.ex Endl.	Gas-homa	Cupressaceae	T
23	*Justicia schimperiana* (Hochst. ex Nees) T.	Tumunga	Acanthaceae	S
24	*Macaranga capensis* (Baill.) Benth.	Bera/odecho	Euphorbiaceae	T
25	*Maesa lanceolata* Forssk.	Kowada	Myrsinaceae	S

26	*Millettia ferruginea* (Hochst.) Bak.	Bilawhaqqa	Fabaceae	T
27	*Olea europaea ssp.* cuspidata.	Weira	Oleaceae	T
28	*Podocarpus falcatus* K.	Digiba	Podocarpusaceae	T
29	*Polyscias fulva* (Hiern) Harms.	Bolife	Araliaceae	T
30	*Phoenix reclinata* Jacq.	Gas-Zimbaba	Arecaceae	T
31	*Prunus africana* (Hook.f) Kalkm.	Arara	Rosaceae	T
32	*Rhamnus prinoides* L.Her.	Gesho’o	Rhamnusaceae	S
33	*Rhus vulgaris* Meikl.	Qamo’o	Anacardiaceae	T
34	*Salacia congolensis* De Wild & Th. Dur.	Olola	Celastraceae	T
35	*Syzygium guineense* (Wild.) DC.	Dubana	Myrtaceae	T
36	*Tapura fischeri* Engl.	Badawacho	Dichapetalaceae	T
37	*Trema orientalis* (L.) Bl.	Ashiminqa	Ulmaceae	T
38	*Vernonia amygdalina* Del.	Hebba	Asteraceae	S
Total	38 species			

Appendix 2: Family, genus, species and their percentage of woody species collected from the study area.

Family Name	No of Genera	%	No of species	%
Acanthaceae	1	2.78	1	2.63
Anacardiaceae	2	5.56	2	5.26
Araliaceae	1	2.78	1	2.63
Arecaceae	1	2.78	1	2.63
Asteraceae	1	2.78	1	2.63
Boraginaceae	2	5.56	2	5.26
Celastraceae	2	5.56	2	5.63
Cupressaceae	2	5.56	2	5.26
Dichapetalaceae	1	2.85	1	2.63
Euphorbiaceae	2	5.56	2	5.26
Fabaceae	4	11.11	5	13.15
Meliaceae	1	2.78	1	2.63
Metteniusaceae	1	2.78	1	2.63
Moraceae	1	2.78	1	2.63
Myrsinaceae	1	2.78	1	2.63
Myrtaceae	2	5.56	2	5.26
Oleaceae	1	2.78	1	2.63
Podocarpusaceae	1	2.78	1	2.63
Proteaceae	1	2.78	1	2.63
Rhamnusaceae	1	2.78	1	2.63
Rutaceae	1	2.78	1	2.63
Rosaceae	1	2.78	1	2.63
Rubiaceae	1	2.78	1	2.63
Salicaceae	1	2.78	2	5.26
Sapindaceae	1	2.78	1	2.63
Ulmaceae	2	2.78	2	5.26
27	36	100	38	100

Appendix 3: Basal area of disturbed forest category from the study area

Species name	BA	BA/ha	RBA
Dovyalis caffra (Warb).	0.0293	0.0024	0.3699
Croton macrostachyus A.Rich.	0.2974	0.02483	3.755
Eucalyptus globulus Labill.	0.445	0.037083	5.61939
Albizia gummifera (J.F. Gmel.) C.A. Sm.	0.17	0.014167	2.1467
Syzygium guineense (Wild.) DC.	4.6162	0.384683	58.2927
Catha edulis (Vahl)Forssk.exEndl.	0.1718	0.014317	2.16946
Podocarpus falcatus K.	0.0178	0.001483	0.2248
Apodytes dimidiata E.Mey. ex Arn.	0.0079	0.000658	0.09976
Maesa lanceolata Forssk.	0.02628	0.00219	0.33186
Macaranga Capensis(Baill.)Sim.	0.02738	0.002282	0.345750
Ficus sycomorus L.	0.0453	0.00775	0.572041
Tapura fischeri Engl.	1.998	0.1665	25.2304
Dodonaea angustifolia L. f.	0.02446	0.002038	0.308877
Ehretia cymosa Thonn.	0.0079	0.000658	0.09976
Polyscias fulva (Hiern) Harms.	0.017	0.001417	0.214673
Trema orientalis (L.) Bl.	0.0097	0.000808	0.12249
Dovyalis abyssinica (A.Rich) Warb.	0.079	0.000658	0.09976
Total	7.919	0.66	100

Appendix 4: Basal area of semi- disturbed forest category from the study area

Species name	BA	BA/ha	RBA
Croton macrostachyus A.Rich.	0.3008	0.02507	3.1042
Eucalyptus globulus Labill.	0.184	0.01533	1.899
Albizia gummifera (J.F. Gmel.) C.A. Sm.	0.2800	0.023337	2.890041
Syzygium guineense (Wild.) DC.	1.5614	0.130117	16.11
Catha edulis (Vahl)Forssk.exEndl .	0.119928	0.009994	1.2376
Apodytes dimidiata E.Mey. ex Arn.	0.0578	0.004817	0.596491
Macaranga Capensis (Baill.)Sim.	0.1067	0.008892	1.10111
Ficus sycomorus L.	0.012739	0.001062	0.1314
Tapura fischeri Engl.	2.5169	0.209742	25.97
Cupressus lusitanica Mill.	0.5033	0.041942	5.194014
Juniperus procera Hochst.ex Endl.	0.0079	0.000658	0.08153
Acacia abyssinica Hochst ex Benth.	0.1814	0.01511	1.8720
Grevillea robusta R. Br.	0.0079	0.000658	0.08152
Polyscias fulva (Hiern) Harms.	0.42117	0.0035098	4.34644
Trema orientalis (L.) Bl	0.219	0.01825	2.2600
Casuarina equisetifolia L.	0.3184	0.026533	3.2858
Phoenix reclinata Jacq.	0.00867	0.000723	0.008948
Podocarpus falcatus K.	2.866	0.2388	29.58
Total	9.69	0.81	100

Appendix 5: Basal area of undisturbed forest category from the study area

Species	BA	BA/ha	RBA
Croton macrostachyus A.Rich.	0.9488	0.079066667	2.255825012
Syzygium guineense (Wild.) DC.	20.6801	1.723341667	49.1680932
Trema orientalis (L.) Bl.	7.2618	0.60515	17.26533524
Millettia ferruginea (Hochst.) Bak.	0.1248	0.0104	0.296718973
Macaranga Capensis (Baill.)Sim.	2.11724	0.1764	5.03385
Podocarpus falcatus K.	0.061711	0.005142583	0.14672135
Ficus sycomorus L.	1.308766	0.109064	3.188224
Apodytes dimidiata E.Mey. ex Arn.	2.4133	0.201108333	5.737755587
Prunus africana (Hook.f) Kalkm.	2.138	0.178166667	5.083214456
Ehretia cymosa Thonn.	0.0163	0.001358333	0.038754161
Cordia africana Lam.	0.0916	0.007633333	0.217784118
Albizia gummifera (J.F. Gmel.) C.A. Sm	0.2624	0.021866667	0.623870661
Polyscias fulva (Hiern) Harms.	2.1424	0.178533333	5.093675701
Olea europaea ssp. Cuspidata	0.02525	0.002104167	0.060033286
Coffea arabica L.	0.0244	0.002033333	0.058012363
Tapura fischeri Engl.	1.686	0.1405	4.008559201
Vernonia amygdalina Del.	0.03287	0.002739167	0.078150262
Eucalyptus globulus Labill.	0.041	0.003416667	0.097479791
Celtis africana Burm.f.	0.02497	0.002080833	0.05936757
Justicia schimperiana (Hochst. ex Nees)T.	0.0079	0.000658333	0.018782691
Catha edulis (Vahl)Forssk.exEndl.	0.016	0.001333333	0.038040894
Acacia abyssinica Hochst ex Benth.	0.016	0.001333333	0.038040894
Salacia congolensis De Wild & Th. Dur.	0.12955	0.010795833	0.308012363
Acacia seyal M. Thulin.	0.016	0.001333333	0.038040894
Phoenix reclinata Jacq.	0.087	0.00725	0.206847361
Dovyalis abyssinica (A.Rich) Warb.	0.134	0.011166667	0.318592487
Azadirachta indica A.Juss.	0.0127	0.001058333	0.03019496
Rhamnus prinoides L.Her.	0.0326	0.002716667	0.077508321

Rhus vulgaris Meikl.	0.0818	0.006816667	0.19448407
Clausena anisata (Wild.) Hook. F.ex.Benth.	0.082	0.006833333	0.194959582
Calpurnia aurea (Ait.) Benth.	0.032	0.002666667	0.076081788
Total 31	42.06	3.505	100

Appedix 6: Frequency, Relative frequency, Density and Relative density of species from disturbed forest category.

Species	F	RF	D	D/ha	RD
Dovyalis caffra (Warb).	1	1.5625	3	0.25	0.143678
Croton macrostachyus A.Rich.	11	17.1875	32	2.666667	1.532567
Eucalyptus globulus Labill.	7	10.9375	38	3.166667	1.819923
Albizia gummifera (J.F. Gmel.) C.A. Sm.	8	12.5	20	1.666667	0.957854
Syzygium guineense (Wild.) DC.	9	14.0625	38	3.166667	1.819923
Catha edulis (Vahl)Forssk.exEndl.	7	10.9375	20	1.666667	0.957854
Podocarpus falcatus K.	2	3.125	2	0.166667	0.095785
Apodytes dimidiata E.Mey. ex Arn.	1	1.5625	1	0.083333	0.047893
Maesa lanceolate Forssk.	4	6.25	4	0.333333	0.191571
Macaranga capensis (Baill.)Sim	3	4.6875	3	0.25	0.143678
Ficus sycomorus L.	3	4.6875	3	0.25	0.143678
Tapura fischeri Engl.	2	3.125	2	0.166667	0.095785
Dodonaea angustifolia L. f.	2	3.125	3	0.25	0.143678
Ehretia cymosa Thonn.	1	1.5625	1	0.083333	0.047893
Polyscias fulva (Hiern) Harms.	1	1.5625	2	0.166667	0.095785
Trema orientalis (L.) Bl.	1	1.5625	1	0.083333	0.047893
Dovyalis abyssinica (A.Rich) Warb.	1	1.5625	1	0.083333	0.047893
Total 17	174	100	64	100	100

Appendix 7: Frequency, Relative frequency, Density and Relative density of species from semi-disturbed forest category.

Species	F	RF	D	D/ha	RD
Dovyalis caffra (Warb).	1	1.515152	2	0.166667	1.081081
Croton macrostachyus A.Rich.	7	10.60606	21	1.75	11.35135
Eucalyptus globulus Labill.	2	3.030303	10	0.833333	5.405405
Albizia gummifera (J.F. Gmel.) C.A. Sm.	9	13.63636	20	1.666667	10.81081
Syzygium guineense (Wild.) DC.	10	15.15152	49	4.08	26.48649
Catha edulis (Vahl)Forssk.exEndl.	3	4.545455	12	1	6.486486
Podocarpus falcatus K.	1	1.515152	1	0.083333	0.540541
Apodytes dimidiata E.Mey. ex Arn.	6	9.090909	7	0.583333	3.783784
Macaranga capensis (Baill.)Sim.	4	6.060606	9	0.75	4.864865
Ficus sycomorus L.	1	1.515152	1	0.083333	0.540541
Tapura fischeri Engl.	2	3.030303	3	0.25	1.621622
Cupressus lusitanica Mill.	3	4.545455	18	1.5	9.72973
Juniperus procera Hochst.ex Endl.	1	1.515152	1	0.083333	0.540541
Acacia abyssinica Hochst ex Benth.	4	6.060606	12	1	6.486486
Grevillea robusta R. Br.	1	1.515152	1	0.083333	0.540541
Polyscias fulva (Hiern) Harms.	1	1.515152	1	0.083333	0.540541
Trema orientalis (L.) Bl.	8	12.12121	15	1.25	8.108108
Casuarina equisetifolia L.	1	1.515152	1	0.083333	0.540541
Phoenix reclinata Jacq.	1	1.515152	1	0.083333	0.540541
Total 19	66	100	185	15.08333	100

Appendix 8: Frequency, Relative frequency, Density, and Relative density of species from undisturbed forest category.

Species	F	RF	D	D/ha	RD
Croton macrostachyus A.Rich.	8	6.779661	50	4.166667	12.13592233
Syzygium guineense (Wild.) DC.	11	9.322034	78	6.5	18.93203883
Trema orientalis (L.) Bl.	11	9.322034	69	5.75	16.74757282
Millettia ferruginea (Hochst.) Bak.	5	4.237288	14	1.166667	3.398058252
Macaranga capensis (Baill.)Sim	7	5.932203	26	2.166667	6.310679612
Podocarpus falcatus K.	3	2.542373	6	0.5	1.45631068
Ficus sycomorus L.	9	7.627119	18	1.5	4.368932039
Apodytes dimidiata E.Mey. ex Arn.	7	5.932203	12	1	2.912621359
Prunus africana (Hook.f) Kalkm.	3	2.542373	3	0.25	0.72815534
Ehretia cymosa Thonn.	2	1.694915	2	0.166667	0.485436893
Cordia africana Lam.	4	3.389831	10	0.833333	2.427184466
Albizia gummifera (J.F. Gmel.) C.A. Sm	7	5.932203	23	1.916667	5.582524272
Polyscias fulva (Hiern) Harms.	4	3.389831	12	1	2.912621359
Olea europaea ssp. Cuspidata.	2	1.694915	3	0.25	0.72815534
Coffea arabica L.	1	0.847458	3	0.25	0.72815534
Tapura fischeri Engl.	4	3.389831	10	0.833333	2.427184466
Vernonia amygdalina Del.	3	2.542373	4	0.333333	0.970873786
Eucalyptus globulus Labill.	1	0.847458	5	0.416667	1.213592233
Celtis africana Burm.f.	3	2.542373	3	0.25	0.72815534
Justicia schimperiana (Hochst. ex Nees)T.	1	0.847458	1	0.083333	0.242718447
Catha edulis (Vahl)Forssk.exEndl.	2	1.694915	2	0.166667	0.485436893
Acacia abyssinica Hochst ex Benth.	2	1.694915	2	0.166667	0.485436893
Salacia congolensis De Wild & Th. Dur.	4	3.389831	10	0.833333	2.427184466
Acacia seyal M. Thulin.	2	1.694915	2	0.166667	0.485436893
Phoenix reclinata Jacq.	1	0.847458	5	0.416667	1.213592233
Dovyalis abyssinica (A.Rich) Warb.	1	0.847458	10	0.833333	2.427184466
Azadirachta indica A.Juss.	1	0.847458	1	0.083333	0.242718447

Rhamnus prinoides L.Her.	1	0.847458	4	0.333333	0.970873786
Clausena anisata (Wild.) Hook.F.ex.Benth.	2	1.694915	10	0.833333	2.427184466
Rhus vulgaris Meikl.	4	3.389831	10	0.833333	2.427184466
Calpurnia aurea (Ait.) Benth.	2	1.694915	4	0.333333	0.970873786
Total 31	118	100	412	34.33333	100

Appendix 9: No of Plots, Altitude, AGB, AGC, $AGCO_2$, Density, and Richness in disturbed forest category.

Disturbed category									
Plot	Altitude	AGB in kg	AGB in ton	AGC in ton	AGC /ha	$AGCO_2$	D	D/ha	Richnes
p1	2029	38.43	0.0384	0.01921	0.0016	0.0028	9	0.75	4
p2	2021	26.56	0.0266	0.013	0.00011	0.098	24	2	5
p3	2023	67.62	0.06762	0.0338	0.00028	0.124	15	1.25	2
p4	2011	65.49	0.065	0.0327	0.00027	0.12	17	1.41	7
p5	2015	1994.6	1.9946	0.9973	0.083	3.66	19	1.58	6
p6	2007	7.030	0.00703	0.0035	0.00019	0.0128	15	1.25	7
p7	2002	10.45	0.01045	0.00522	0.00043	0.1915	11	0.91	7
p8	2018	803.7	0.8037	0.401	0.033	1.4712	21	1.17	9
p9	2037	6.149	0.0061	0.003	0.00025	0.011	14	1.17	5
p10	2032	12.03	0.012	0.006	0.0005	0.02202	13	1.08	5
p11	2048	3.2030	0.0032	0.0016	0.00013	0.0058	6	0.5	3
p12	2033	1195.6	1.196	0.598	0.0498	2.194	9	0.75	3

Appendix 10: No of Plots, Altitude, AGB, AGC, $AGCO_2$, Density, and Richness in sem-disturbed forest category

Semi- disturbed category									
Plot	Altitude	AGB in kg	AGB in ton	AGC in ton	AGC /ha	$AGCO_2$	D	D/ha	Richness
p1	2045	24.37	0.02437	0.0121	0.00101	0.0444	26	2.17	6
p2	2050	27.17	0.02715	0.0135	0.00112	0.049	22	1.83	6
p3	2030	17.06	0.017	0.0085	0.0007	0.0311	14	1.17	3
p4	2045	254.7	0.254	0.127	0.0105	0.47	10	0.83	4
p5	2036	18.43	0.0184	0.092	0.0077	0.34	12	0.91	4
p6	2050	66.24	0.067	0.033	0.0028	0.121	26	2.25	6
p7	2025	218.2	0.218	0.109	0.009	0.40	23	1.67	8
p8?	2050	1350	1.35	0.675	0.056	2.48	8	0.67	5
p9	2030	56.0	0.056	0.028	0.0023	0.102	12	1	5
p10	2044	140.0	0.14	0.07	0.0058	0.257	11	0.917	6
p11	2028	2667	2.67	1.335	0.111	1.23	15	1.25	7
p12	2050	7.57	0.0075	0.00375	0.00031	0.0137	6	0.2	5

Appendix 11: No of Plots, Altitude, AGB, AGC, $AGCO_2$, Density, and Richness in undisturbed forest category.

Undisturbed category									
Plot	Altitude	AGB in kg	AGB in ton	AGC in ton	AGC /ha	$AGCO_2$	D	D/ha	Richness
p1	2023	1871.9	1.871	0.94	0.078	3.45	29	2.41	8
p2	2015	4991.7	4.991	2.5	0.20	9.18	52	4.33	15
p3	2025	2361.9	2.36	1.18	0.098	4.33	52	4.33	11
p4	2015	6968	6.97	3.45	0.29	12.67	56	4.67	13
p5	2036	7213.9	7.22	3.61	0.30	13.25	52	4.33	7
p6	2033	20977?	20.977	10.49	0.87	38.49	22	1.83	8
p7	2049	49.12	0.049	0.025	0.020	0.091	24	2	8
p8	2006	49.90	0.0499	0.025	0.020	0.092	24	2	9
p9	2018	1355	1.355	0.678	0.057	2.49	21	1.75	9

p10	2007	45.66	0.457	0.228	0.019	0.837	21	1.75	9
p11	2008	544.70	0.545	0.273	0.022	1.002	25	2.08	9
p12	2000	57.50	0.058	0.029	0.0024	0.106	34	2.83	12