ADDIS ABABA UNVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

CENTER FOR ENVIRONMENTAL SCIENCE

Woody Plants Diversity, Populations Structure, Carbon Stock and Microbial Dynamics in Gara Duro Natural Forest, West Arsi Zone, Ormia, Ethiopia

M.Sc THESIS

BY: - KEDIR BENO

A THESIS SUBMITTED TO THE CENTER FOR ENVIRONMENTAL SCIENCE PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE ENVIRONMENTAL SCIENCE

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ABSTRACT

Forest and soil carbon storage paly a sginficant role in climate change mitigation. Especial woody species are more importantly store considerable carbon. However in Gara Duro natural forest there was lackof information regarding wood species diversity, their carbon stock, under species soil carbonstock and their impacts on microbial population. This study aimed at documenting woody plants diversity, populations structre, and assessing carbon stock and effect of forest degradation on microbial dynamics in Gara Duro natural forest in Nagelle Arsi District, West Arsi Zone, Oromia, Ethiopia. A systematic sampling method was used to establish sampling plots along altitude. Woody species and soil data were collected from 47 plots of 20 m × 20 m (400 m^2). All woody plant species encountered in each sample quadrats were recorded and their Diameter at Breast Height (DBH) and height were measured. The carbon stock of trees was estimated using an allometric equation. One way analysis of variance was used to test data of carbon in different pools, variations in soil microbial dynamics and soil chemical properties at P=0.05.The results showed that there were 40 woody plants in the natural forest belonging to 38 genera and 31 families. The most frequent species were *Maesa lanceolata, Rubus apetalus, Croton macrostachyus,* and *Podocarpus falcatus. Maytenus addat, Maesa. lanceolata, Podocarphus falcatus, Croton. macrostachyus* and *Pittosporum viridiflorum* had the highest importance value index (IVI), whereas *Ficus vasta, Brucea antidysenterica, Schefflera abyssinica, Hypericum revolutum* and *Erica arborea* were species with lowest IVI. Based on the evaluation of the diameter class, overall structure of woody species structure showed an inverted J-shaped curve.The mean carbon stock of Gara Duro natural forest was found to be 248. tons carbon $ha^{-1,}$ 107.20, 21.44, 2.54 and 116.04 carbon ton ha^{-1} were stored in the above ground, below ground, litter and as soil organic carbon, respectively. There was a significant diference between different carbon pools. The present study revealed that there was significant ($p \leq 0.05$) variation in soil bacterial and fungal population of protected and nonprotected areas of Gara Duro natural forest.The soil chemical properties showed significant variation in protected and non protected areas of Gara duro forest ($p \leq 0.05$). The mean pH value in protected forest was 6.57(1:2.5) while in the nonprotected forest it was 5.95 (1:2.5). Similarily, the Organic Carbon (OC) in protected forest was 1.83% and that of nonprotected forest was 1.20%. Total nitrogen (TN) content was significantly different between protected and non protected forest with 0.525% and 0.45%, respectively. Gara Duro forest was found to be important for plant and microbial biodiversity conservation, climate change mitigation and diverse ecosystem services to the local communities. Designing and implementing in-situ conservation of the forest with priority to identified plant species and promoting ecosystem services through forest management system was recommended.

Key words: Carbon stock, forest degradetion, microbial dynamics and wood plant species.

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DECLARATION

I, the researcher declare that this MSc thesis is my original work and it has not been submitted partially or in full by any other person for an award of a degree in any other University. All the sources of material used for the thesis have been duly acknowledged.

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List of Acronyms

AGB	Aboveground biomass
AGC	Aboveground carbon
BGB	Belowground biomass
BGC	Belowground carbon
CFU	colony forming unit
CRGE	Climate-Resilient Green Economy
DBH	Diameter at Breast Height
PDA	potato Dexterose Agar
GHGs	Greenhouse Gases
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
REDD+	Reducing emissions from deforestation and forestdegradation + Conservation of forests + Sustainableforest management + Enhancing forest carbon stock
SOC	Soil Organic Carbon
SCBD	Secretariat of the Convention on Biological Diversity
TAGB	Total above-ground biomass
TAGC	Total above-ground carbon
TBGB	Total below-ground biomass
TBGC	Total below-ground carbon
RBA	Relative Basal Area
RD	Relative Density
RDO	Relative Dominance
RF	Relative Frequency
FAO	Food Agricultural Organization
NA	Nutrient Agar

1. INTRODUCTION

Background

Forests are extremely important ecosystems. According to FAO (2008), forest degradation is generally defined as the reduced capacity of a forest to provide goods and services. However, in the context of climate change, the International Panel on Climate Change developed a definition of forest degradation that focuses on anthropogenic changes in the carbon cycle in the long run (IPCC, 2003). According to the report by Secretariat of the Convention on Biological Diversity (SCBD) (2011), forests are more biologically diverse than any other land based ecosystems and if these forests are conserved and sustainably used,more than two-thirds of all land-based animal and plant species can be protected. Forests provide economic, socio-cultural and ecological values. A recent Forest Resources Assessment of FAO (2010) estimated the global forest cover at just over 4 billion hectares, which is 31 percent of the total land area of the world. Between 1990 and 2000 there was a net loss of 8.3 million hectares per year, and the following decade, up to 2010, there was a net loss of 6.2 million hectares per year FAO (2010). Ethiopia is considered as one of the top twenty five richest countries in the world in terms of biodiversity. The country has an estimated number of 6000 species of higher plants, of which about 10% are endemic (Ensermu Kelbessa and Sebsebe Demissew, 2014). In relation to forest resource cover change and its impacts, Williams (2002) confirmed that the most important factor that altered the face of the earth in many parts of the world is the clearing of forests.

Vegetation is defined as an assemblage of plants growing together in a particular location and characterized either by its component species or by the combination of structural and functional characters that determine the appearance or physiognomy of vegetation (Goldsmith *et al*., 1986). The vegetation of Ethiopia is complex. There is a variation from region to region; some regions of the countries (Southern and South Western parts of the countries) are relatively richer in biodiversity as compared to other parts of the countries. The complexities of vegetation arise from the great variation in altitude employing equally great spatial difference in moisture regime as well as temperature and also depend on rainfall and altitude variation (Zerihun Woldu, 1999).

According to Williams (2002), the causes of deforestation are complex and often differ in each forest and country. About 60% of the natural high forest was degraded due to human activities (Resuing, 1998). On the other hand, a predicted loss of about 1.33 million hectares of woody plants and natural high forests of many districts was documented from 1990 to 2005 (WBISPP, 2004). Forest degradation, however, are reducing the capacity of forests to contribute to food security, and major benefits, such as fuel wood and fodder and other timber and non- timber forest products (Girma Tadesse, 2001).

Forest degradation involves a change process that negatively affects the characteristics of a forest such as decline in the value and production of its goods and services. This change process is caused by disturbance (although not all disturbances causes degradation), which may vary in extent, severity, quality, origin and frequency. Disturbance may be natural (e.g. that caused by fire, storm or drought), human-induced (e.g. through harvesting, road construction, shifting cultivation, hunting or grazing) or a combination of the two. Human-induced disturbance may be intentional (direct), such as that caused by logging or grazing, or it may be unintentional (indirect), such as that caused by the spread of an invasive alien species (FAO, 2009).

Forest degradation as a result of forest clearing for different purposes releases CO_2 to the atmosphere (Malhi and Grace, 2000; Fearnside and Laurance, 2003 and 2004; Houghton, 2005). Scietific data on wood plant species, vegetation structure and regeneration status of a given forest ecosystem are highly needed for determining the current status and future trend of a given forest and its ecosystem services including biodiversity conservation. Furthermore, such data are critical for designing and implementing appropriate forest conservation and sustainable management methods. There is limited data on the woody plant diversity, structure and carbon stock of Gara Duro natural forest ecosystem. Therefore, the aim of this study was to contribute to filling gap in scientific data on diversity and structure of woody plants, carbon stock and impact of forest degradation on microbial dynamics in Gara Duro natural forest.

1.1 Statement of the problem

In Ethiopia, forest is the most affected resource either by human activities or natural factors. In tropical regions, deforestation and forest degradation are progressive process that are advancing at alarming rates resulting in the conversion of forest land in to a mosaic of mature forest fragments, pasture, and degraded habitats (Laurance, 1999). Due to the high decline of forests plant and animal species that are important both at national and global levels are becoming endangered, this is mainly attributed to lack of proper conservation strategies and practices of forest and forest resources (Ensermu Kelbessa et al., 1992).

As a result of forest clearance or degradedation, the stored carbon is released into the atmosphere as carbon dioxide and aggravate the scenario of climate change (Malhi and Grace, 2000). Forest management activities are increasingly taking into consideration the role of forests as carbon stocks and there is a pressing need for more information about factors that determine carbon storage in forests (McEwan et al., 2011).

Forest degrdation has been a major degrading factor in many natural forests in Ethiopia threaening biodiversity and contributing to reduced ecosystem services. According to EBI (2015), major threats to Ethiopian ecosystems and biodiversity include population growth, agricultural land expansion into forests, deforestation and forest degradation, overgrazing, timber extraction, settlements, shifting cultivation and habitat fragmentation. Forest and soil carbon storage paly a sginficant role in climate change mitigation. Especial woody species are more importantly store considerable carbon. However in Gara Duro natural forest there was lack of information regarding wood species diversity, their carbon stock, under species soil carbon stock and their impacts on microbial population. Like in many other parts of the country, the problem of forest degradation is a very serious anthropogenic factors in Gara Duro natural forest. Study was aimed to address and fill the gaps in data related to woody species composition and structure, impacts of forest degradation on woody plant diversity, microbial dynamics and to estimate the carbon stock capacity of Gara Duro natural forest.

1.3 OBJECTIVES

1.3 .1 General objectives

The main objective of the study is to determine woody plant biodiversity, assess carbon stock and impact of forest degradation on microbial dynamics in Gara Duro natural forest.

1.3.2 Specific objectives

- ✓ To determine diversity and structure of woody plants and also their regeneration status.
- ✓ To estimate above ground biomass (AGB), below ground biomass (BGB) and soil organic carbon (SOC) and leaf litter in Gara Duro forest.
- ✓ To assess the effect of forest degradation on soil microbial dynamics in Gara Duro natural forest .

2.LITRATURE REVIEW

2.1. Definition and Concept of Forest

According to FAO (2006), forest is defined as the presence of trees with land cover more than 0.5 ha. The tree must be able to reach a minimum of 5 m in situ and canopy cover at least 10%. Existing international definitions of forest vary from one another in a number of ways (Margono *et al*., 2012). A recent Forest Resources Assessment of FAO (2010) estimated the global forest cover at just over 4 billion hectares, which is 31% of the total land area of the world, this corresponds to an estimate of average of 0.6 ha.

2.2 Concept of Deforstation and Forest Degradation

2.2.1 Deforestation

Deforestation is defined as the removal of the stand where land is changed in to a non-forest land-use (Hannes *et al*., 2009). Deforestation is expressed as the conversion of forests to other land cover types, if an area is defined as deforested only if it remains without trees for at least 20 years, then a great deal of what has been labeled deforestation should instead be categorized as degradation (Morales-Barquero, 2014). IPCC (2003) defines deforestation as the direct human induced conversion of forested land to non forest land or other land cover types. This alteration of forests for other land-use is broadly for shifting cultivation, agriculture, plantation, and pastures. If forest cover decreases due to logging, fire and the forest is expected to re-grow the crown cover to above the threshold, then this reduced forest area is not considered as deforestation (GOFC-GOLD, 2013).

Deforestation include not only conversion to non-forest, but also degradation that reduces forest quality, density and structure of the trees, the ecological services supplied, the biomass of plants and animals, the species diversity and the genetic diversity (FAO, 2005). It is also used to describe forest clearing for annual crops and forest loss from over grazing. Bayou (2010) cited deforestation in the United Nations Research Institute for Social development (UNRISD) as the loss or continual degradation of forest habitat primarily due to human related causes. According to Williams (2002), the causes of deforestation are complex and often differ in each forest and country. Therefore, the main causes of deforestation in Ethiopia are shifting cultivation, livestock production and fuel wood in drier areas.

2.2.2 Forest Degradation

Forest degradation is the long term reduction in the overall capacity of a forest to produce or provide benefits (goods and services) (ITTO,2002) such as carbon storage, wood, biodiversity, and other products due to environmental and anthropogenic forces. It results in the decrease of species in the forest and in tree cover and/ or the change of the forest structure (Foley *et al*., 2007; Morales-Barquero *et al*., 2014). It is worth noting that forest degradation is not as obviously defined, agreed upon, or understood as is deforestation (Chao, 2012). According to Asner *et al*. (2005), forest degradation is a major source of greenhouse gas emissions.

Forest degradation and deforestation are distinctly different processes. Degradation results when forests remain forests, but lose their ability to provide ecosystem services or suffer major changes in species composition due to overexploitation, exotic species invasion, pollution, fires, or other factors (Millennium Ecosystem Assessment 2005; Sasaki and Putz, 2009**)**.

Forests may be degraded in terms of loss of any of the goods and services that they supply wood, food supply, habitat, water and other protective socioeconomic and social values (Guariguata *et al.*, 2010). The combination of various forest characters or forest qualities can be expressed as the structure or function, which determines the capacity to supply forest products and services. In the context of Reducing Emissions from Deforestation and Forest Degradatio (REDD+), degradation has been grouped together deforestation, but in terms of monitoring it has more features in common within forest activities (sustainable forest management and enhancement of forest carbon stocks). According to FAO (2008), forest degradation is generically defined as the reduced capacity of a forest to provide goods and services. The succession curve of the level of forest degradation given in (Figure 1).

Figure 1 Forest Succession Curve.(Source: Eckert *et al*., 2011 as cited in Morales-Barqueo *et al*., 2014).

2.2.3 Deforestation in Ethiopia

Ethiopia is characterized by a high rate of forest degradation (Alemtsehay Jima, 2010). Around the late 1950s, forests covered 16% of Ethiopia's land area (EPA, 2003). During 1973 to 1976, forests covered 6.08 %, while during 1986–1990, some 10 to 15 years later than 1973–1976, it was around 4.75% of the country. In Ethiopia the major cause of Forest Degradation is use of forest resource for different purposes, Such as, cutting trees for charcoal production, fuel wood, and construction materials. The consequences of forest degradation are decline of productivity of land and decrease household in welfare (FARM/SOS, 2007). This is indicate that at least for two reasons. First, the removal of trees without sufficient reforestation has resulted in drought and this in turn results in reduction of agricultural production as agriculture in Ethiopia highly dependent on rainwater. Second, forest is influential to control soil erosion and land degradation. According to Belay (2002), a group of interacting variables are responsible for the extreme decline of forest land despite the generally anticipated over grazing by live stock and subsequent bush encroachment.

2.2.4 Causes of Forest Degradation

Scholars recognized different causes of forest degradation according to FAO (2006) and Schoene *et al*., (2007) degradation is usually caused by disturbances, which vary in terms of the extent, quality, origin and occurrence of the changing process can be natural Thakur (2013) and

Singh *et al.*, (2014) caused by fire, storm, drought, snow, pest, disease, atmospheric pollution, change in temperature.

2.3 Regeneration of vegetation

Plants maintain and expand their populations in time and space by the process of regeneration (Habtam Getaneh 2012). Regeneration is a complex ecosystem process involving asexual and sexual reproduction, dispersal and establishment in relation to environmental factors (Barnes *et al*., 1998). It is an ecological process that ensures the development of successive generations of plants. According to Habtam Getaneh (2012) natural regeneration refers to the natural process by which plants replace or reestablish themselves by means of self-sown seed or vegetative recovery (sprouting from stumps, rhizomes or roots).

Many plant species possess combinations of regenerative strategies. The existence of multiple forms of regeneration has important roles in the evolutionary and ecological potential of the plant and depends on environmental factors such as physical factors (for example light, temperature, moisture, nutrients and wind), biotic factors (for example competition, herbivore and disease) and disturbance regimes strongly influence regeneration processes, and thereby, determine the abundance and status of the plant species Habtam Getaneh (2012).

In addition, vegetative regeneration can be affected by size, shape and orientation of gap to the sun, soil type, and topography and soil seed bank Habtam Getaneh (2012). Topography affects the soil characteristics and plays a critical role in the variation of stand structure and floristic composition of the forests by causing vegetation, extent of damage to vegetation upon formation of the gap, temperature drainage, moisture, and nutrients to vary from ridge top to valley bottom (Enoki and Abe, 2004). Demel Teketay (2005) report indicated that height and species composition of the surrounding aspects and its spatial disturbances can also affect vegetation regeneration.

According to Taye Bekele *et al.* (2002), a tree species with no seedling and sapling in a forest is under risky condition and it is suggested that these species are under threat of local extinction. Hence, for a successful regeneration and establishment of seedlings, a sufficient volume of viable seeds, appropriate climatic and edaphic conditions are indispensible. Therefore, the study

of regeneration of forest trees and Knowledge of the regeneration status of the plant species is important for developing management strategies of natural forests and setting priorities.

2.3.1 Sampling of population structure

Population structure and woody plant composition are usually measured or estimated on a plant community basis. Barkman (1979) distinguished between texture, the composition of morphological elements and structure. Vegetation structure is the organization in space of individuals that form a vegetation type of plant association. It can be investigated at the level of physiognomic, life form, floristic, biomass and stand vegetation structures, which are hierarchically integrated. In the analysis of vegetation structure, the growth stages of trees as seedlings, saplings and mature trees and distribution of size classes within a population can be one of the elements of diversity that allows or denies the chance of rapid recovery after disturbances.

According to Van der Maarel (2005), among the four overall measurements vegetative structure and floristic composition, the more widely used than others, may be mentioned hear under:

1. Stratification: the arrangement of phytomass in layers. Usually a tall tree, low tree, tall shrub, low shrub, dwarf-shrub, tall herb, low herb and moss layer are distinguished if separated from each other (Mueller-Dombois and Ellenberg, 1974).

2. Cover- percentage cover is the relative area occupied by the vertical projection of all aerial parts of plants, as a percentage of the surface area of the sample plot. This can be determined for the vegetation as a whole or for separate layers (van der Maarel, 2005). Also van der Maarel (2005) describes that cover is usually estimated by eye, but can also be determined more accurately through the line-intercept method in sparse vegetation where contacts between the line and plant parts are counted or the point-intercept method in dense short vegetation where contacts with a cross-wire grid are counted.

3. Phytomass: total phytomass (plant biomass) in the plant community, is expressed as dry-weight g·m2, kg·m2 or t· ha. (t·ha-1 =10 kg·m2) (Barkman, 1988). According to Barkman, (1988), phytomass is usually determined by removing the standing crop, the above-ground phytomass during the period of maximal development. The standing crop is related to, but by no

means identical to, what is produced during the growing season which varies from weeks in arctic to twelve months in moist tropical environments (van der Marel, 2005).

4. Leaf area index- the total area of leaf surface (actually photosynthetic surface) expressed in m^2 per m^2 surface area is known as leaf area index, LAI; it can be determined per layer and can thus also be used for a refined description of the architecture of vegetation (Eddy van der Maarel, 2005). A derivate characteristic is specific leaf area, SLA =leaf (lamina) area vegetation ecology an overview 15 per unit leaf (lamina) dry mass (Eddy van der Marel, 2005).

2.3.2 Sampling of species characteristics

The species composition of a plant community, the key element in its definition, is described in its simplest form by a list of species occurring in the sample plot (Van der Maarel, 2005). The list is mostly restricted to vascular plants, and almost always to their above-ground parts; often easily recognizable mosses, liverworts and lichens are included. According to Van dar Maarel (2005), the quantity of a species attains can be called its performance, but often the term abundance is used, even if this is only one of the following quantitative measures:

1. Abundance: the number of individuals on the sample plot. Because individuality in many (clonally) plant species is difficult to determine the concept of plant unit, a plant or part of a plant (notably a shoot) behaving like an individual, is needed, if only for a quantitative approach of species diversity based on the distribution of plant units over species.
2. Cover-abundance: is a combined parameter of cover in case the cover exceeds a certain level, for example 5% and abundance. This 'total estimate' (Braun-Blanquet, 1932) has been both criticized as a wrong combination of two independently varying parameters and praised as a brilliant integrative approach.

3. Basal area: the area outline of a plant near the surface is of particular interest for trees and can be used for tree volume estimations (Mueller-Dombois and Ellenberg, 1974). A related measure is tree diameter at breast height (DBH at 1.37 m or 4.5 feet), which is more often used in standard forest descriptions (van der Maarel, 2005).

4. Importance value index (IVI): the important value index (IVI) permits a comparison of species in a given forest type and depict the sociological structure of a population in its totality in the community (Habtam Getaneh 2012). In calculating this index, the percentage values of the relative frequency, relative density and relative dominance are summed up together and this value is designated as the Importance Value Index or IVI of the species (Kent and Coker, 1992). It is also important to compare the ecological significance of a given species. Therefore, it is a good index for summarizing vegetation characteristics and ranking species for management and conservation practices.

2.3.3 Diversity

Species diversity has been identified as one of the key indices of sustainable land use practices and considerable resources are expended to identify and implement strategies that will reverse the current decline in biodiversity at local, regional and international scales (Shackelton, 2000). According to Groombridge (1999), biodiversity is the number, variety and variability of living organisms.

Rosenzweing (1995) pointed out that diversity could be viewed in terms of of alpha, beta and gamma diversity and defined them as follows:

- ✓ Alpha diversity refers the diversity or number of species within a particular habitat or community.
- ✓ Beta diversity is the rate and extent of change in species richness between communities across an environmental gradient over a relatively small distance. It is often estimated by calculating species turn over.
- ✓ Gamma diversity is the total number of unique species recorded in the population of interest, or number of species across a very large area such as a biome or continent and is dependent on the alpha and beta

2.3.4 Species richness and evenness

Species richness is the simplest concept of species diversity implying the number of species in a community where as evenness is a measure of equitability and it attempts to quantify the unequal representation of species in a community against a hypothetical community in which all species are equally common (Eddy van der Maarel, 2005). Heterogeneity is the measure of the

probability of which, two individuals randomly picked from a community belong to different species (Habitam, Getaneh 2012).

Methods for measuring diversity actually consist of two components. The first is species richness, and the second is the relative abundance (evenness or unevenness) of the species within the sample or community difference (Kent and Coker, 1992). These two components of species diversity may be examined separately or combined into some forms of indices. As Kent and Coker (1992), describes that species richness index has a great importance in assessing taxonomic, structural and ecological values of a given habitat, where as evenness is a measure of abundance of the different species that make up the richness of the area. Species diversity is the product of species evenness and richness. Species diversity indices provide information about species endemism rarity and commonness (Mueller Dombois and Ellenberg, 1974).

Kent and Coker (1992), described that both Species diversity and species evenness are often calculated using the Shannon diversity index (H'), which naturally varies between 1.5 and 3.5 and rarely, exceeds 4.5. Shannon diversity index is the most appropriate and the most widely used index for combining species richness and evenness (Krebs, 1999).

2.4 Carbon Emissions from Forest Degradation

The world's forests store 289 Gt of carbon in their biomass (FAO, 2010). Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural solution to climate change. When forests are cleared or degraded, their stored carbon is released into the atmosphere as CO2. Tropical deforestation is estimated to have released 1–2 billion tonnes of carbon per year during the 1990s, roughly 15–25% of annual global greenhouse gas emissions (Malhi and Grace, 2000; Houghton, 2005). The largest source of greenhouse gas emissions in most tropical countries is from deforestation and forest degradation. In Africa, deforestation accounts for nearly 70% of total emissions (FAO, 2005). Moreover, clearing tropical forests also destroys globally important carbon sinks that are currently sequestering CO2 from the atmosphere and are critical to future climate stabilization (Stephens, 2007).

2.4.1 Biomass and Carbon Estimation in Ethiopia

Biomass is defined as the total amount of live organic matter and inert organic matter above-ground and below-ground expressed in tonnes of dry matter per unit area (FAO, 1997). Biomass carbon includes carbon stored in above- and below-ground plant components, down dead woody

debris and litter falls. The calculation of carbon stock consists of multiplying the total biomass by a conversion factor that represents the average carbon content in biomass. A generic conversion factor of 0.47 adopted by IPCC (2006) is widely used internationally. Soil also plays an important role in the carbon cycle as it stores considerable amounts of carbon in the ground. Carbon accumulation in the ground is intense in the top layer of soil profiles (0–30 cm) (Pearson et al., 2007).

Hence, sampling would be concentrated on this section of soil profile (IPCC, 2006). Ethiopia does not have carbon monitoring data bank. Hence, the actual result of the biomass carbon stock has been little known still. In near recent, associated with global consequence of climate change and monetary fund in climate change mitigation activity; Ethiopia has started working in forest monitoring and biomass estimation. Most recent study in carbon stock capacity of Egdu Forest, Menagesha Suba State Forest and Woody Plants of Arba Minch Ground Water Forest can be raised as exemplary as Ethiopia had good reservoir of carbon.

2.5 Measuring Carbon Stock in Different Carbon Pools

2.5.1 Measurement of Above Ground Biomass (AGB)

The AGB pool consists of tree biomass - above stump height – including stem, bark, branches, and needles, twigs (Stihl et al., 2004). The carbon stocks of trees are estimated through the field inventory in which all the trees in the sample plots above a minimum diameter (a function of the forest structure a minimum of 5– 10 cm is commonly used) are measured. Biomass and carbon stock are estimated from Diameter at Breast Height (DBH) or a combination of DBH and total height using locally relevant allometric equations (Brown et al., 2004).

Biomass consists of approximately 50% carbon. Brown et al. (2004) recommended that all the trees within the plots should be measured at DBH of 1.3m above trees by tagging with the placement number. Tree biomass often is estimated from equations that relate biomass to DBH only. The largest cost of most of these general eguation methods is typically labour cost. Even though, the combination of DBH and height as the independent variables is often superior to DBH alone, measuring tree height can be time consuming and will increase the cost of a monitoring program (Brown et al., 2004; Stihl et al., 2004). Kanamaru et al. (2010) listed four

different sources of uncertainty associated with AGB estimates of tropical forests: inaccurate measurements of variables, including instrument and calibration errors, wrong allometric models, sampling uncertainty (related to the size of the study sample area and the sampling design) and poor representativeness of the sampling network. All this lead to inaccurate result and thus should be taken into account from the beginning.

2.5.2 Measurement of Below Ground Biomass (BGB)

The BGB carbon pool consists of all the biomass contained within living roots of trees, and of the biomass in tree stems below 1% height (stump height). Fine roots of less than 2 mm diameter (the suggested minimum) are often excluded because these often cannot be distinguished empirically from soil organic matter (IPCC, 2006). The measurement of BGB is relatively expensive and time consuming as compared to AGB which is relatively simple. Below ground biomass estimation is much more difficult and time consuming than estimating aboveground biomass (Geider et al., 2001). This is due to the wide variability in the way that roots are distributed in the soil. As a result, estimation of BGB is more efficient and effective using a conservative ratio for shoot: root predicts root biomass based on AGB carbon. For example, the lowest shoot to root ratio ever reported for Species X is 5:1(MacDicken, 1997; Watson, 2008). Although, there are different regression models (with less data) that are available for estimation of BGB as a function of AGB recommended by Cairns et al. (1997) for different regions (Pearson et al., 2007). In this regard, studies carried out by Cairns et al. (1997) found that the root to shoot ratios were constant between latitude (temperate and boreal), soil texture (fine, medium and coarse), and tree-type (angiosperm and gymnosperm) even though, roots are believed to depend on climate and soil characteristics as indicated by Brown et al. (2004). They have reviewed 160 studies covering temperate and boreal forests and found a mean root to shoot ratio of 0.26, ranging between 0.18 and 0.30. However, according to MacDicken (1997), for cases in which more accurate estimates of BGB are economically feasible using locally established methods is important.

2.5.3 Measurement of Soil Organic Carbon

The soil organic carbon pool is a mixture of dead plant and animal residues in various stages of decomposition, of substances synthesized microbially or chemically from the breakdown products and of the remains of soil microorganisms in a more or less decomposed state. Soil

organic carbon occurs in the form of a distinct organic layer (35-45% C) on top of the mineral soil (O horizon) or blended with mineral matter (A or B horizons). Soil organic carbon is usually determined for the size fraction <2µ (Stihl et al., 2004).

SOM is obtained in both mineral and organic soils and is a major reserve of terrestrial carbon. Even though, forest management has greater impact on organic carbon and so inorganic carbon impact is largely unaccounted, inorganic forms of carbon are also found in soil. SOM is influenced through land use and management activities that affect the litter input, for example how much harvested biomass is left as residue, and SOM output rates, like tillage intensity affecting microbial survival. This in turn affects the soil organic carbon of the area (Watson, 2008).

Accounting for SOM can also be more costly as local estimation of the carbon contained in this pool commonly relies on laboratory analysis of field samples. At sample sites, the bulk density of the soil and wet weight of the sample must also be recorded so that laboratory results can be translated into per area carbon stock. In order to obtain an accurate inventory of organic carbon stocks in the soil, three variables must be measured: soil depth to which carbon is accounted, (commonly 30cm), soil bulk density (calculated from the oven-dry weight of soil from a known volume of sampled material), and concentrations of organic carbon (Pearson et al., 2007).

2.5.4.Relationship between plant diversity and Carbon stocks

Trees and other woody biomass play an important role in the global carbon cycle. Forest biomass accounts for over 45% of terrestrial carbon stocks, with approximately 70% and 30% contained within the above and belowground biomass, respectively (Cairns et al., 1997; Mokany et al., 2006). Carbon sequestration capacity and the amount of carbon sequestered not only related to the type of vegetation such as Forest, Woodland, Savanna etc., but also with the plant diversity and the type of species within it. The amount of carbon accumulated by a certain tree species is calculated from its biomass. Biomass in its turn is a function of wood density and it is obvious that different tree species have different wood densities which eventually lead to different carbon stock capacity.

According to Hicks et al. (2014), globally there is a generally positive relationship between carbon stocks and biodiversity; tropical moist forests are rich in both biodiversity and carbon

stock. However, within intact tropical forests the patterns are more complex and there is no clear evidence for a correlation between spatial patterns of carbon stocks and biodiversity.

Although, there is established but incomplete evidence supporting the link between species richness and forest carbon stock, in tropical forests it is still uncertain, whether and to what degree biodiversity influences carbon stocks. However, Hicks et al. (2014) generalized that, increased species richness has been shown to increase sequestration, both due to the increased chance of having highly productive species and due to the more efficient use of resources that results from the presence of multiple species with different requirements (a complementarities effect).

2.6 Bacterial and Fungal Colonies

Morphological characteristics are really important when characterizing bacteria and fungi. Colony morphology is a good method commonly used by scientists to identify and describe them. Bacteria grow rapidly on nutrient abundant culture media compared to fungi. Different types of bacteria and fungi produce phenotypically different looking colonies. Colonies differ in size, shape, texture, colour, margins, etc. The microbial colony morphology, bacteria and fungi should be grown on agar in Petri plates by providing all the necessary nutrients and conditions. Bacteria grow as small oily dots on agar media. Fungi grow as powdery mats all over the agar plate. The key difference between bacterial and fungal colonies is that bacterial colonies are visible masses of bacterial cells arising from single bacterial cells while fungal colonies are visible masses of fungi arising from a single spore or mycelial fragment.(N.p.web 02 July 2017)

3 .MATERIALS AND METHOD

3.1 Description of the Study Area

The study was conducted in Gara Duro natural forest, located in Nagelle Arsi Disrcit, West Arsi zone, Oromia regional state. It is one of the most threatened remnant forest in Ethiopia as a result of unregulated Agricultural expansion and settlements. Gara Duro Forest is sources of many important rivers such as Huluka and Dhadhaba that flow into Central Rift Valley Lakes. It is approximately located between 38°4′ and 8°32′ E and 7°3′ and 2°20′ N and extends over an altitudinal range from 2300–2900 m with the total area of 449.6 ha And soil type covers about 52.2% of Arsi Negele, while Nitosols cover the remaining 47.8% Oromia Regional State government (ORS, 2012).

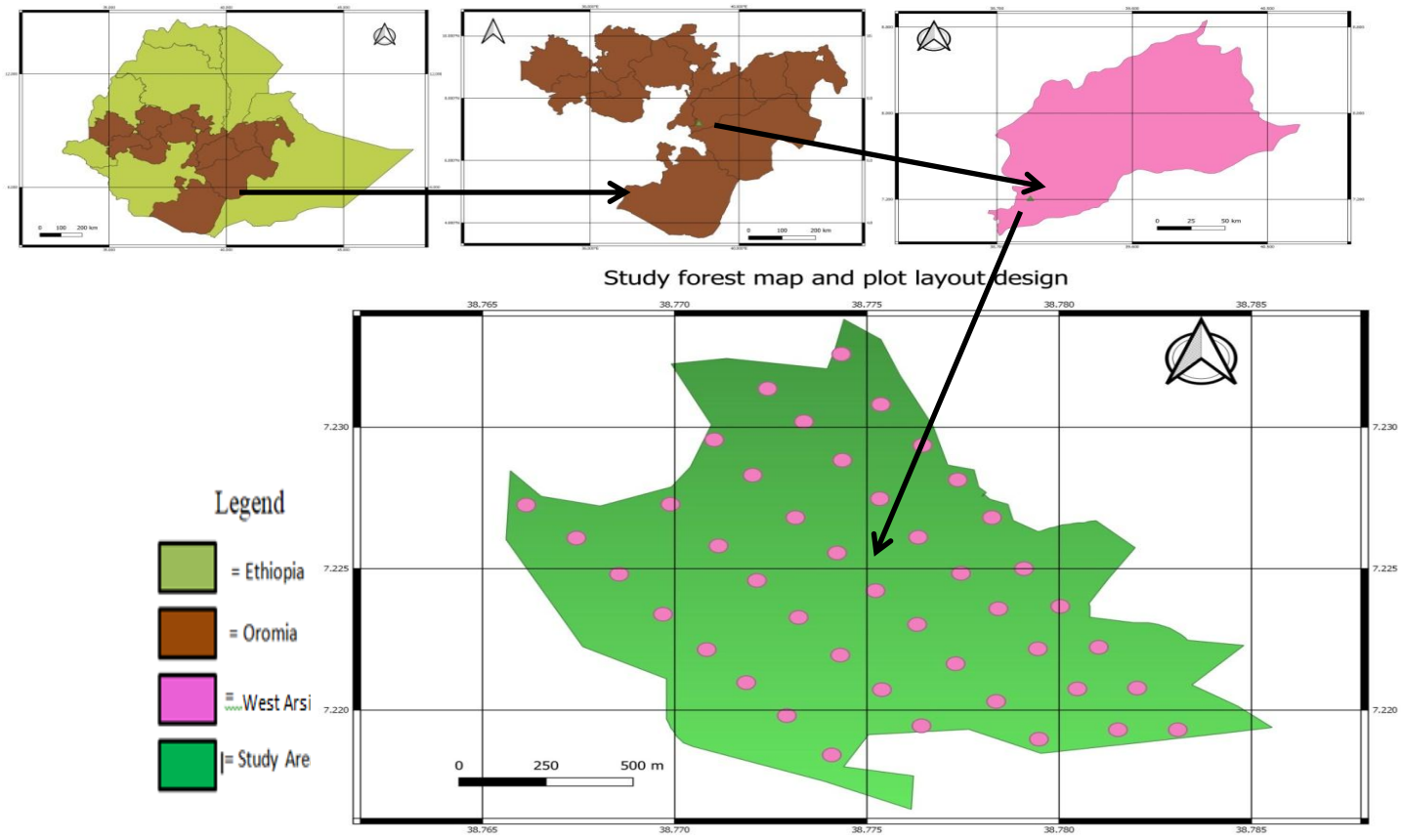

Figure 2 Map of the study Area Gara Duro natural forest Area

Figure 3 Partial view of the Gara Duro natural forest.

3.2. Data Collection

3.2.1. Sampling Techniques

Systematic sampling design was used to collect vegetation data from the study site using plot size of 20 m X 20 m (Figure 3). To get the general view about the vegetation to be studied, reconnaissance survey was conducted before the comecement of the actual vegetation inventory. Line transects and sampling quadrats were laid based on the total area of the study site in four major directions for vegetation data collection following altitudinal gradients. The study area had gentle flat area and five transect were laid along the northwest to North direction at Garaduro forest mountain in Gara Duro natural forest. Data was collected from a total of 39 plots. On the

other hand, one transect line was established along east direction on the other gentle hill or mountain data was collected from a total of 7 plots.

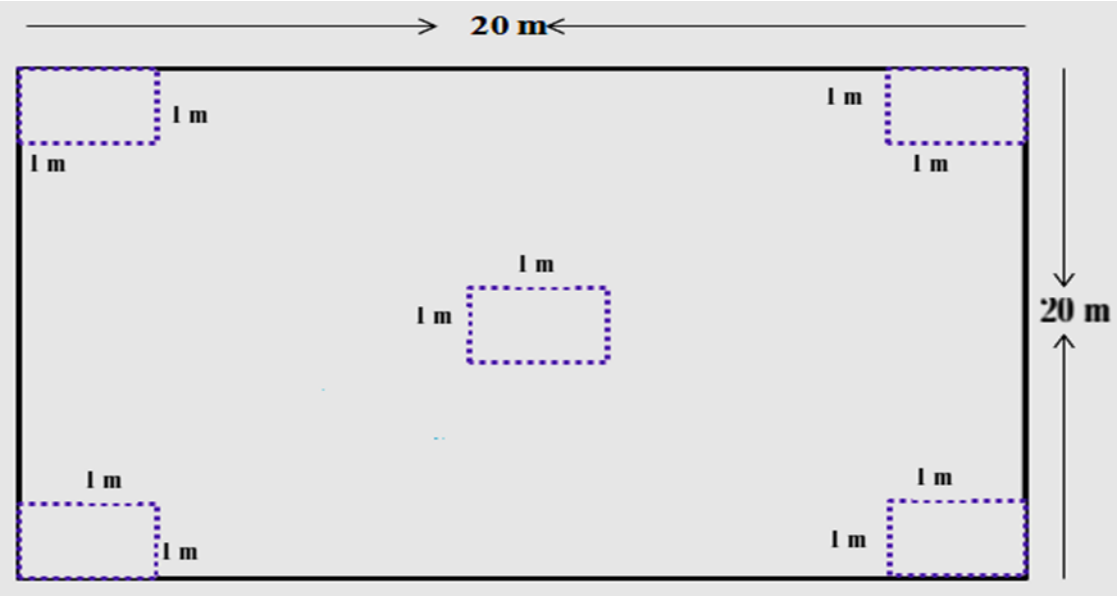

Figure 4 Sample Plot Design(Source: Pearson et al., 2005)

3.2.2. Physiographic and soil data

Physiographic variables such as altitude, latitude, and longitude were recorded for each sampling quadrat using GPS. Prior to the collection of the vegetation data, from each quadrat geographical coordinates and altitude were recorded. Simultaneously, topographic characteristics including slope gradient, slope position and aspect were collected . In addition, disturbance type and level were also collected. These data were registered on the same format used for vegetation inventory.

3.2.3 Field Measurements

3.2.4 Woody plant Composition and Vegetation Structure

Plot size 20 m × 20 m (400m^2) was established systematically at every 50 m drop in altitude starting from the peak of the Mountain. All woody plant species encountered in each sample quadrats were recorded using local names.To collect data on seedlings less than 2.5cm and saplings less than 1m, five subquadrats of 1 m × 1m (1m^2) size were located at the four corners and centre of the main quadrat. The regeneration status of the woody plant species was assessed

using data from the sub-quadrats that were established. In general, a total of five transects, 47 quadrates and 235 sub-quadrates were used to collect the inventory data from the Gara duro natural vegetation. Plant specimen was collected, pressed and dried following standard herbarium techniques and identified at the National Herbarium (ETH), Addis AbabaUniversity, were voucher specimen have been deposited.

In each quadrat, heights of trees and shrubs with DBH > 2.5 cm were measured using clinometer and their diameter at breast height (DBH) was measured using diameter tape. For trees and shrubs that were branched around the stamp height, the circumference was measured separately and averaged $c= \pi d$.

3.2.5 Data Analysis

To describe the vegetation structure of the forest, the density, frequency, height, Diameter at Breast Height (DBH), composition, importance value Index and basal area was calculated. Basal area (BA) was the area outline of a plant near ground surface. It is the cross-sectional area of tree stems at DBH. It was a measure of dominance (degree of coverage) of species as an expression of the space it occupies at ground level According to (Muller-Dombois and Ellenberg, 1974).

$$BA= \frac{\pi d^2}{4}$$

Where, BA=Basal Area in m^2 per hectare

d=diameter at breast height (m)

π=3.14

The Importance Value Index was used to express the relative ecological importance of the species in the forest. The greatest IVI shows the dominance and abundance of a given species in relation to the other species in the area and it is used for ranking species management and conservation practices in a certain plant community as dominant or rare species (Kent and Coker, 1992). The IVI were calculated for the woody species of the forest following (Mueller-Dombosis and Ellenberg 1974) by the formula.

IVI = Relative Density (RD) + Relative Dominance (RDO) + Relative Frequency.

Where: RD = number of all individuals of a species x 100

Total number of all individuals of the sample

RDO = basal area of a species x 100

Total basal area of the sample

RF = Frequency (F) of a species x 100

Sum of the frequencies of all species

Where: F= number of quadrates in w/c a species occurs x 100

Total number of quadrates laid

3.3 Method of carbon stocks Assessement

In order to achieve the objectives stated above, the procedures followed to estimate carbon stocks was Following Brown et al., *(*1989). Procedures was based on data collection and analysis of carbon accumulated in the above-ground tree biomass, below-ground biomass, and soil organic carbon of trees forests using verifiable methods. Therefore, during the field data collection the followings steps was followed in carbon measurement .

3.3.1 Above Ground Tree Biomass (AGTB)

For individual woody plants with DBH size of ≥2.5 cm, DBH (at 1.3 m) and height of all woody plants was measured in each 400 m^2 square plot using Haga hypsometer, diameter tape and linear tape and each tree was marked to prevent counting it twice. Each woody plant was recorded individually, together with its species name and ID. According to MacDicken (1997), woody plants on the border was included if > 50% of their basal area falls within the plot, and if < 50% was excluded of their basal area falls outside the plot. In addition, trees overhanging into the plot needed was excluded, but trees with their trunks inside the sampling plot and branches outside was included.

3.3.2.Below ground biomass (BGB)

According to (Macdicken, 1997). below ground biomass living roots includes fine roots ,small large roots (<2 – 10 >mm diameter). However it was calculated by considering 15% of the

above-ground biomass root-to shoots ratio value of 1:5 or 20% of above ground biomass (Macdicken, 1997).

3.3.3 Litter

For litter biomass estimation, a square wooden frame (1 m x1 m) was used as sampling frame. The sample frame was placed randomly at each corner of the plot and one in the middle. All the litter inside the frame was collected, placed in a plastic bag and fresh weight was taken on site by using digital balance. Then, the sample was oven-dried in a conventional oven at 105 ºC to a constant weight and from it the total dry mass was calculated.

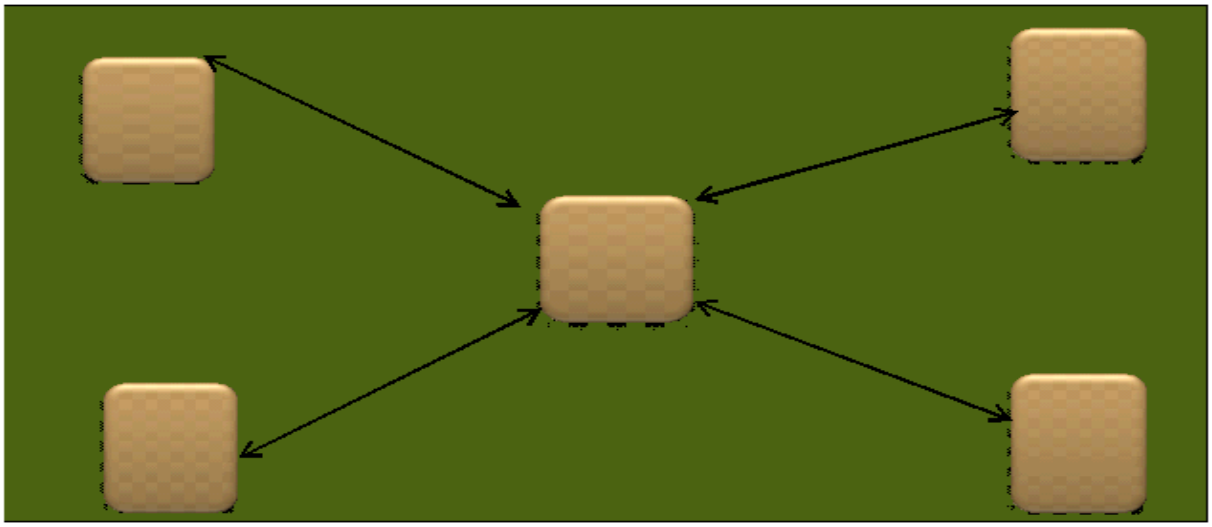

Figure 5. Litter Sample Collection from the Field

3.4 Estimation of Carbon in Different Carbon Pools

3.4. 1. Estimation of Carbon in the Above Ground Biomass (AGB)

There are different allometric equations that have been developed by many researchers to estimate the above ground biomass. Therefore, the application of these equations to the study area is an advantageous in a view of cost and time.

For the study area is categorized under tropical dry forests the suitable equation used to estimate above ground biomass was the model developed by Brown et al., *(*1989).

$Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH_2)$ …… *(equ.1)*

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

3.4. 2 Estimation of Carbon in Below Ground Biomass (BGB)

According to MacDicken (1997), standard method for estimation of below ground biomass was obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 was used. Similarly, , for this study the equation developed by MacDicken (1997) was used.

$BGB = AGB \times 0.2$ …… *(eq.2)*

Where, BGB is below ground biomass, AGB is above ground biomass, 0.2 is conversion factor (or 20% of AGB).

For both AGB and BGB, the biomass stock density was attained in kg/m² by dividing the sum of all individual tree biomass (kg) in a plot by the area of the plot (m²). The value was converted to ton/ha by multiplying it by 10. Since the plot areas are part of tropical region, carbon content in the biomass was estimated by multiplying 0.47 while multiplication factor 3.67 will be used to estimate CO_2 equivalent (Pearson et al., 2005).

3.4.3. Litter

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

$$LB = \frac{Wfield}{A} * \frac{Wsubsample;\ dry}{Wsubsample;\ wet} * \frac{1}{10{,}000}$$

where LB—Biomass of leaf litter (t/ha),

Wfield—weight of wet field sample of Leaf Litter sampled within an area of size 1 m2 (g);

A—Size of the area in which leaf litter were collected (ha),

Wsubsample, dry—Weight of the oven-dry sub-sample of leaf Litter taken to the laboratory to determine moisture content (g), and

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

Carbon stocks in Litter Biomass:

CL =LB%C

where CL is the total carbon stocks in the Leaf litter in t/ha, % C is carbon fraction determined in the laboratory (Pearson et al., 2005).

In this equation % C must be expressed as a decimal fraction; for example, 2.2% C is expressed as 0.022 (Pearson *et al.,* 2007).

3.4. 4 Estimation of Carbon in Soil Organic Carbon (SOC)

The soil samples for soil carbon analysis were air-dried, well mixed and sieved through a 2 mm mesh size sieve. Soil sample were taken Sampling from a constant depth of 30 cm and 500gm of soil taken from protected Area and non protected area of the forest total 47 sample was taken maintaining a constant sample volume rather than mass is a recommended approach for the sake of convenience and cost efficiency. Soil samples were also analyzed following Walkley & Black (1934) and was conducted at Melkasa Agricultural Research Center. Bulk density was determined in Melkasa Agricultural Research Center, after drying the core samples of soil at 105^{o}C and the weight of the soil were divided by the volume of the core sampler and measured using three types of variables: (1)depth, (2) bulk density (was calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon according to (Pearson et al. 2005), maintaining a constant sample volume rather than mass is a recommended approach for the sake of convenience and cost efficiency. The soil organic carbon stock pool was calculated using the formula (Pearson *et al.*, 2005):

*SOC = BD * d * % C …… (eq.2)*

Where, SOC= Soil Organic Carbon stock per unit area (ton/ha-1), BD = soil bulk density (g cm-3), D = the total depth at which the sample was taken (30 cm), and %C = Carbon concentration (%) determined in the laboratory.

According to Pearson *et al.* (2007), in order to obtain an accurate inventory of organic carbon stocks in the soil, the following three variables must be measured: soil depth to which carbon is accounted (usually 30 cm), soil bulk density which is calculated from an oven-dry weight of soil from a known volume of sampled material and concentrations of organic carbon.

Soil samples were collected from the five points used for litter collection by using a 30 cm depth soil augur and soil core sampler and the five sub-samples were mixed and a composite bulk soil sample of 500 gm from each plot was taken to laboratory for chemical analysis. The soil samples were submitted to Melkasa Agricultural research center soil laboratory for different chemical analysis such as Organic carbon, pH,Total Nitrogen.

The soil laboratory analysis was done using standard laboratory techniques, Soil pH were measured in soil: water suspension (1:2.5) ratio (Joshi et al., 2009). Soil organic carbon (OC) and total N (TN) content were determined by dry combustion methods based on (ISO, 1998; ISO.,

1995) respectively. For soil bulk density analysis, a cylindrical core sampler with 5 cm diameter and 5 cm height was used in order to collect a soil sample to calculate the bulk density.

Soil bulk density, which is calculated as the oven dried weight of soil divided by its volume is calculated by using the following equation (Arshad *et al.*, 1996; Pearson *et al.*, 2007).

In this equation % C must be expressed as a decimal fraction; for example, 2.2% C is expressed as 0.022 (Pearson *et al.*, 2007).

3.5. Total Carbon Stock Density

The total carbon stock density were calculated by summing the carbon stock densities of the individual carbon pools According to Pearson et al. (2005) formula following.

Carbon stock density of the study area:

C density = CAGB + CBGB + C Lit+SOC…….. (eq.10)

Where:

C density = Carbon stock density for all pools (t ha-^{1})

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

CBGB = Carbon in below-ground biomass (t C ha-^{1})

C Lit = Carbon in litter (tons of C ha-^{1})

SOC = Soil organic carbon (t C ha-^{1})

The total carbon stock was converted to tons of CO_2equivalent multiplying it by 44/12, or 3.67 According to (Pearson et al., 2007).

3.6 Carbon Stock Statistical analysis

The mean values of tree DBH, height, density, frequency soil organic carbon, litter carbon, both aboveground and belowground biomass, and carbon stock were processed using Microsoft Excel 2010 SAAS and one-way analysis of variance (ANOVA).

3.7. Soil Chemical Analysis

The composite soil samples were air dried, ground and sieved through 2 mm mesh and used for soil physicochemical analysis. Soil pH were measured in soil: water suspension (1:2.5) ratio (Joshi et al., 2009). Soil organic carbon (OC) and total nitrogen (TN) content were determined by dry combustion methods based on (ISO, 1998; ISO., 1995) respectively.

3.8 Soil Fungal and Bacterial Population.

Soil samples were collected for soil fungal and bacterial population growth assessement and kept in plastic sample bags, until transported to the Mycology laboratory of Department of Microbial Cellular and Molecular Biology, AAU. The collected 47 samples were labeled. The soil samples were collected from different land use changes protected Area of the forest and non protected (some farm land and forest distrabance area) from the depth of 30 cm. The soil samples were bulked together to form a composite sample and sieved by 2 mm mesh sieve for fungal and bacterial analysis. Following standard dilution procedures the bacterial,and fungi counts were determined as colony forming unit (CFU) on nutrient agar, zapexs doxs agar, Potato dextrose agar (PDA) respectively at Mycology Laboratory Addis Ababa University Collage of Natural Science (Johnson, 1972).

3.8.1 Preparation of culture media

3.8.1.1 Potato Dextrose Agar (PDA) plates

These was prepared as per the standard method described by Poinars and Thomas, 1984 together with manufacturer‘s instructions for the media preparation. 39g of potato dextrose agar (PDA) where suspended in 1 liter of distilled water and stirred until completely dissolved. The mixture were autoclaved at 121oC and 15 psi (pressure) for 15 minutes. The agar was left to cool to 45-50oC, antibiotics such as chloramphenicol where added to make a selective medium. Twenty ml of this where poured into sterilized disposable Petri dishes under aseptic condition and left to cool and solidify.

3.8.1.2 Fungal population analysis

Serial dilution plate method were followed using (PDA/ZDA) medium. The inoculated Petri plates was incubated in a sterile culture room at 25˚ ± 1˚C. Colony forming units (CFU) were estimated by counting the number of colonies after five days. (No*DF/ml)

3.8.1.3 Bacterial growth determination

Serial dilution techniques were applied to determined the number of bacterial population in the soil. Nutrient agar (NA) was used for scoring bacterial counts. the number of colonies from the solid media were expressed as colony forming unit per gram of soil (CFU/g).

4 RESULTS

4.1 Species diversity and Structure

4.1.1 woody species diversity

From the study Gara Duro a total of 40 plant specimens were collected; belonging to 38 genera and 31 families (See Annex 1). The most frequent species in the forest were *Maesa* (Myrsinaceae), *Rubus* (Rosaceae), *Croton (*Euphorbiaceae), and *Podocarphus* (Podocarphaceae) respectively. On the other hand the families of these genera are also the most frequent and diverse in the inventoried woody species. From each respective genera, *Maesa lanceolata*, *Croton macrostachyus* and *Podocarphus falcatus; Maytenus addat*, and *Trichilia emetica* were found to be good diverse woody plant species.

The distribution of the plant species in terms of the growth forms or habits was resulted as Trees, 17 in number of species (43.6 %), Shrubs, 20 in number of species (51.2 %) and climber or

Lianas, 2 in number of species which accounts to 5.1 % whole growth habits of woody species composition.

4.1.1 Floristic richness by Aspect

The result of the study shows that the species distribution varies with aspects. About 2% of the species were recorded from the northeast, 29.4 % from West, 20.6 % from South, 17.6 % from Southwest, 14.7 % from North, 11.8 % from Southeast, and 5.9 % on East direction of the woodland topographic feature (Figure 6). In terms of the individual species, maximum number of woody plant species was inventoried on the west direction followed by south and southwest aspects respectively.

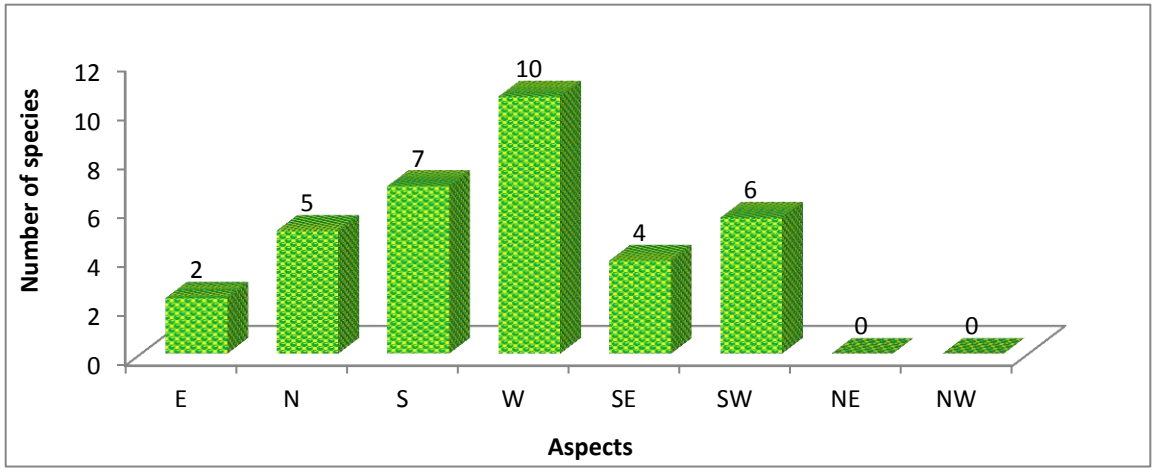

Figure 6 Number of species recorded as per the topographic aspects

4.1.2. Floristic richness by slope gradients

The species occurrence analysis by slope gradient revealed that 91.2 % of the total woody plant species invenoried was recorded from slope gradient class **B;** 5.9 % from class **A;** 2.9 % from **C** and finally no species was recorded from slope gradient class **D** (Figure 7). As illustrated in Figure 7, the number of woody plant species composition or distribution was higher at slope gradient class **B** (3-10)

As illustrated in Figure 7, the relationship between the species richness and slope gradient was non-linear and this is explained by 42% (R^2 = 0.421). It is a bell-shaped type of distribution.

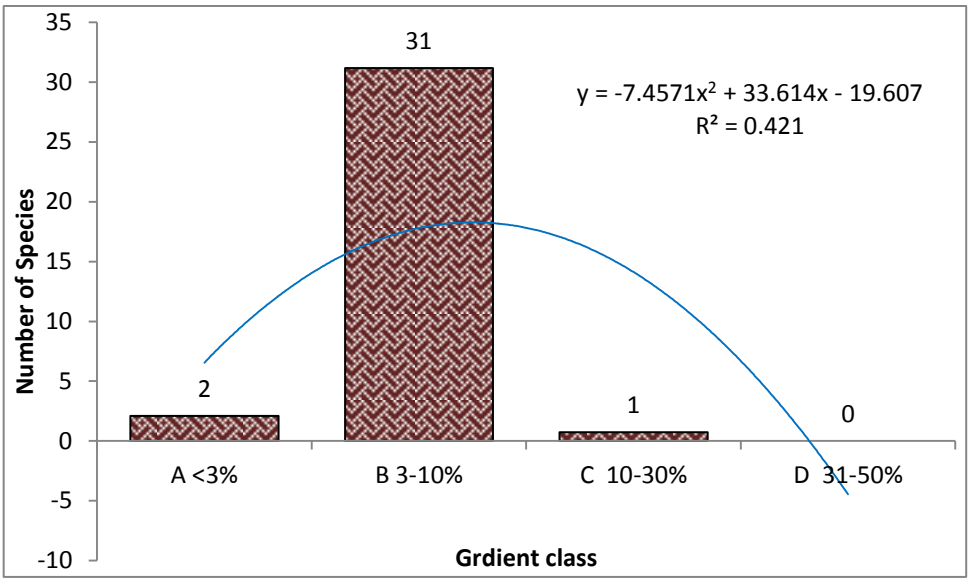

Figure 7 Woody plant species distribution by slope gradient classes

4.2.Structure

4.2.1 Size class Distribution

The measurements of woody plant species that include maximum DBH/DSH, mean DBH/DSH, maximum total height, mean total height and number of stems per species were presented in (Annex 2). The maximum height attained in the forest was 35m while the maximum DBH/DSH was 160cm represented by the *Maytenus addat* tree species. This tree species had mean height of 18.33m and mean DBH/DSH of 59.2 cm.

The second maximum height attained in the forest was 32m while the maximum DBH/DSH was 140cm represented by the *Pittosporum viridiflorum* tree species. Interms of mean height and mean DBH/BSH this species was greater than *Maytenus addat*, having mean height (21.63m) and mean DBH/DSH (72.13 cm)

As described in Annex 2, the maximum numbers of stems sampled and measured were for those tree species that were the most diverse or frequently appearing in the studied woodland. On the other hand, the least size of DSH/DBH and total height recorded was 2.5 cm and 2.5 m, respectively.

4.2.2 Species frequency

The result of the study showed that the variation of the species frequency ranged between 2.13 – 80.8 %. This implies that there was some heterogeneity in species distribution in the Garaduro forest. Among these, *Maesa lanceolata* (80.8 %), *Croton macrostachyus* (76.6 %), *Podocarpus falcatus* (72.3%) and *Maytenus addat* (63.8 %) were the most frequently appearing or the most widely distributed woody plant species. On the other hand, *Hagenea abyssinica, Schefflera abyssinica, Dovyalis abyssinica, Erica arborea, Buddleja polystachaya, Manilkara butugi, Ekebergia capensis, Olea capensis, Hypericum revolutum,* and *Ficus vasta* had lowest frequency (Annex 3). Hence, there was a high variation in species distribution between the above-mentioned groups of species that showed the highest and the lowest frequency. Nonetheless, the majority of the species fall between the frequency range of 4.26 –29.8 %. In other words, when the distribution of species were interpreted in terms of frequency classes, as indicated in Annex 3, it was only one species, *Maesa lanceolata* (13.8 %), which belonged to the A frequency class (80-100 %). Three species *Croton macrostachyus*, *Podocarpus falcatus* and *Maytenus addat* about 36.5% were in a frequency class B (61-80 %). Further, as illustrated in Figure 8, about 6.93 % one species was included under frequency class C (41-60 %); 18.24 % under frequency class D (21-40 %) while 24.38 % of the species were categorized under frequency class E (1-21 %). Therefore, the falling of highest percentage (or number of species) under low value frequency class implies as the distribution of the species is in the woody species is not generally high.

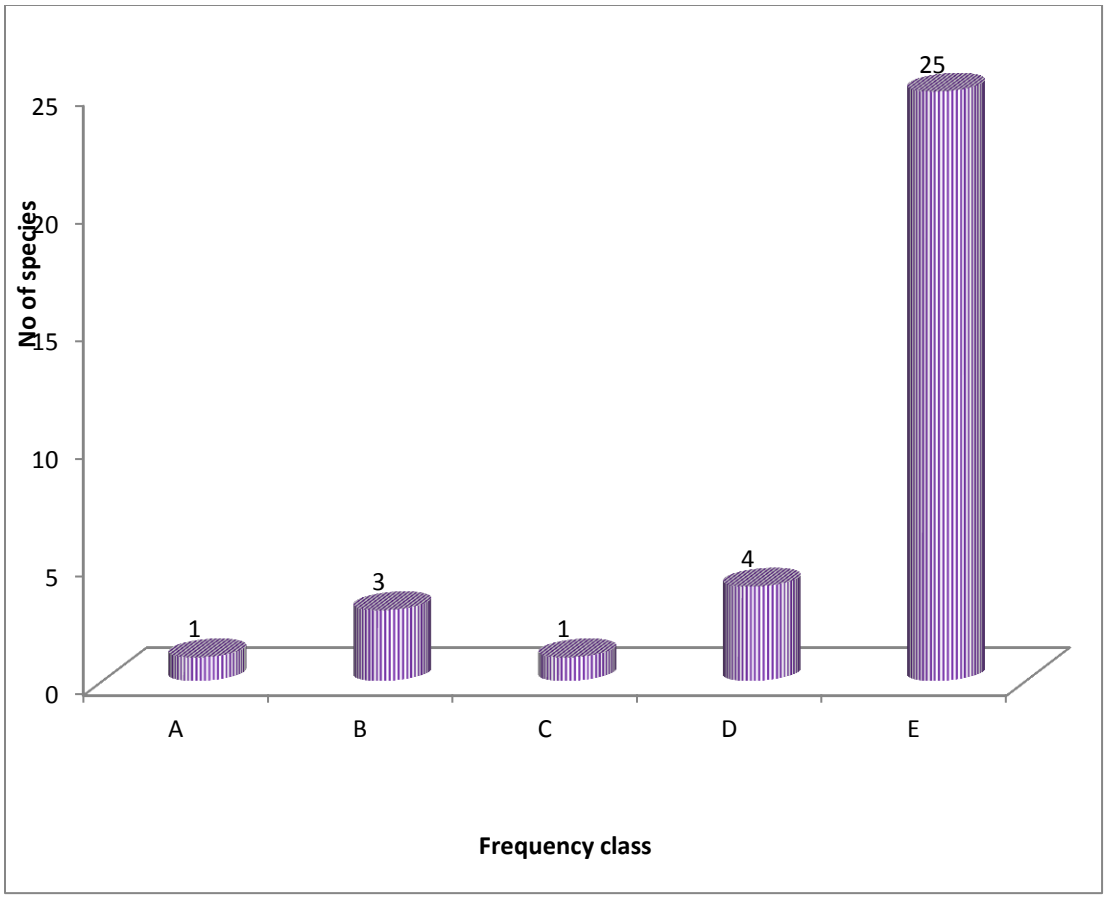

Figure 8 The number of species by frequency class.

4.2.3 Species density

The species density in the forest ranges between 0.43–141.28 per ha. (See Annex 4). The variation of the relative density of the species was also between 0.07 – 22.36 %. The least species density was for *Schefflera abyssinica, Olea capensis, Manilkara butugi, Hypericum revolutum* and *Hagenea abyssinica* while the highest species density (> 100 per ha) was for *Maesa lanceolata* (141.28) and *Podocarpus falcatus* (115.32). This result Pointed out that there was a significant variation among the individual tree/shrub species in density per ha. In the studied forest, the total species density per ha was 627.68. To summarize, the species density was organized by density classes as shown in Table 1. Here, the majority of the species (44.1 %) was belonged to density class D.

Table 1. Species density class and the distribution of species

Species density class	**Total density**	**Relative density**	**Number of species**	**Proportion (%)**
A (>100)	256.6	40.9	2	5.9
B (50.1–100)	95.74	15.3	1	2.9
C (20.1–50)	199.57	31.8	6	17.6
D (1–20)	69.79	11.1	15	44.1
E (<1)	5.98	1.0	10	29.4
Total	**627.68**	**100**	**34**	**100**

The species densities per ha with the diameter size greater than 10 cm DSH/DBH and greater than 20 cm DSH/DBH were 325.6 and 197.5, respectively and their ratio was 38.1

4.3 Size class distribution

4.3.1 DBH distribution

For ease of the comparison and interpretation, the diameter class was formed in to eight groups as: **A** (2.6–7.5 cm); **B** (7.6–12.5 cm); **C (**12.6–17.5 cm); **D** (17.6–22.5 cm); **E** (22.6–27.5); **F** (27.6–32.5 cm); **G** (32.6–37.5 cm), **H** (37.5–42.5 cm) and **I** (>42.5cm). The species density distribution by diameter class was tabled in Annex 5. The result of the analysis of the diameter class data indicated that about 35.3 % (N=20) of the tree/shrub species are those species which have fallen in diameter class **A**; 14.0 %(N=16) in diameter class **B**; 10.9 %(N=15) in diameter class **C**; 10.4 %(N=12) in diameter **D**; 7.9 %(N=12) in diameter class **E**; 8.7 %(N=14) in

diameter class **F**; 4.5 %(N=9) in diameter class **G**; **0.9**% (N5) in diameter class **H** and **7.5**% (N14) in diameter class **I** respectively (See Figure 9)**.**

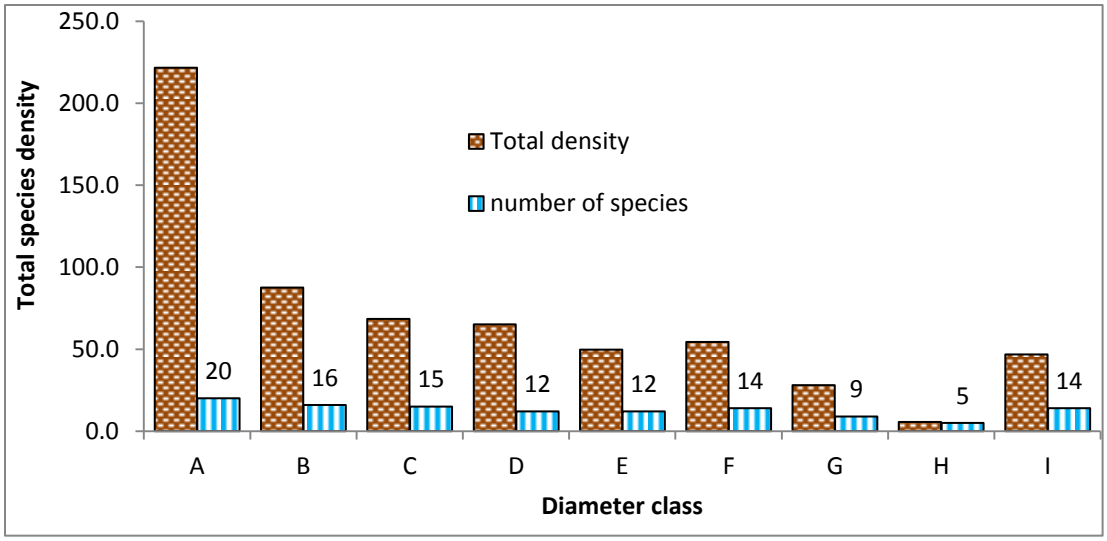

Figure 9. Number and total species density by diameter class

4.3.2 Height distribution

In determining the height distribution , the height class was formed in to seven groups as: **A** (≤ 5 m); **B** (5.1–10 m); **C** (10.1-15m); **D** (15.1-20m); **E** (20.1-25m); **F** (25.1-30m); **G** (>30.1m). The species density distribution by height class was listed in Annex 6. The result of the analysis of the height profile data indicated that about75.2% (N=15) of the tree/shrub species are those species which have fallen in height class **A**; 24.8 % (N=7) in height class **B** and no species recorded in **C** diameter class (See Figure 10)**.**

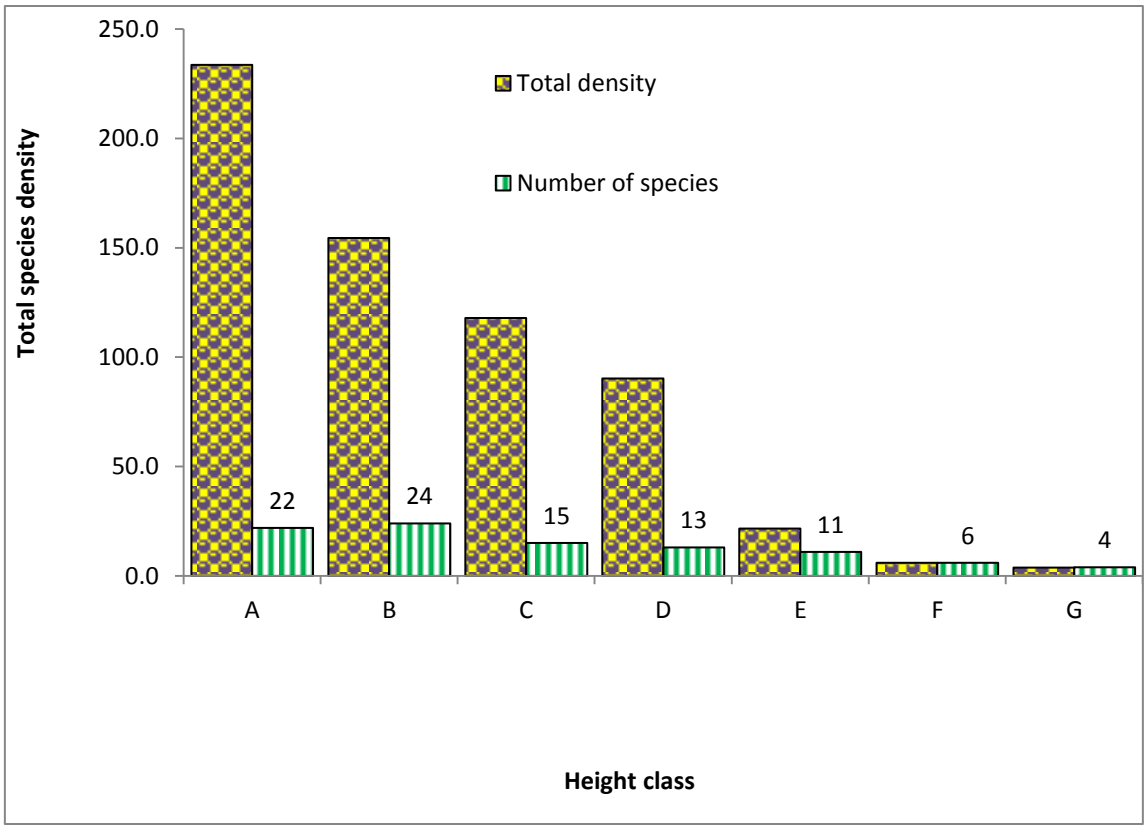

Figure 10 Number and total species density by height class

4.4.Basal Area and Dominance of woody plant species

The total basal area for the inventoried woodland was 7.1 m^2 per ha. As listed in (Annex 7), the biggest basal area recorded was for *Pittosporum viridiflorum* (2.52 m^2 ha^{-1}) while the largest dominance and relative dominance was for *Pittosporum viridiflorum* (17.12 and 31.51 % respectively). The top five dominant woody plant species were *Pittosporum viridiflorum, Millettia ferruginea, Olea capensis, Hagenea abyssinica* and *Maytenus addat*, respectively within the range of 2.52 – 0.35. Here the number of stems of a species plays a crucial role for a certain species is dominant or not besides the mean basal area of the species. The DBH of the majority of the species was in the lowest diameter class (2.5-5.5 cm) this implies that the basal area of the lower diameter class range between 0.0015 – 0.0064.

Impotrant value Index (IVI) is useful to compare the ecological significance of species (Lamprecht, 1989).The important value index of the species indicates how dominant is the species in a certain area and hence helps to compare ecological importance of the species in vegetation's (Curtis and McIntosh, 1951). This reveals that in this forest the species relative frequency, density and dominance differ accordingly.

Table 2 summarizes the IVI class and proportion of woody species in the study area.

Species IVI class	Number of species	Total IVI	Proportion (%)
A (<2)	17	16.29	5.43
B (2.1– 10)	9	46.76	15.58
C (10.1–20)	3	42.04	14.01
D (20.1–30)	0	0	0
E (>30.1)	5	194.92	64.97
Total	34	300	100

The IVI of woody species in Gara Duro Forest varied between 0.44–42.63 as shown in As it was listed in Table 3, the majority of the species (*ca* 50 %) are appearing in the IVI class **A** and **A** contributing around 5.43 % to the total IVI and there is no species record in IVI class **D**. The next dominant species are categorized to the IVI class **B** consisting about 15.58 % from the whole IVI. *Maytenus addat Maesa lanceolate* only by its own contributed 28.33 % to the total IVI, and hence it is the most frequent and dominant species in the forest. On the contrary, since *Erica arborea, Hypericum revolutum, Schefflera abyssinica, Brucea antidysenterica* and *Ficus vasta* possess the lowest IVI, they do not frequently exist and are the most minor or rare species in the forest. In principle, when a certain species receives the lowest IVI, it entails as it demands high priority for endangered species. As presented in Table 3 IVI was lowest for *Erica arborea* and *Hypericum revolutum* and highest for *Maytenus addat*.

Table 3 Importance Value Index of woody species in Gara Duro Forest in Nagelle Arsi District, West Arsi Zone, Oromia, Ethiopia.

No	Scientific name	RD	RDO	RF	IVI	Percent	Rank
1.	*Bersama abyssinica*	0.20	0.01	0.73	0.95	0.32	24
2.	*Brucea antidysenterica*	0.40	0.01	1.46	1.87	0.62	18

3.	*Brucea antidysenterica*	0.13	0.04	0.36	0.54	0.18	30
4.	*Celtis Africana*	0.27	0.15	1.09	1.52	0.51	20
5.	*Citrus aurantiifolia*	7.54	0.13	2.19	9.86	3.29	10
6.	*Croton macrostachyus*	15.15	7.64	13.14	35.93	11.98	4
7.	*Discopodium penninervum*	2.42	0.09	1.46	3.97	1.32	12
8.	*Dovialis abyssinica*	0.34	0.00	0.36	0.70	0.23	27
9.	*Ekebergia capensis*	0.13	0.39	0.36	0.89	0.30	26
10.	*Erica arborea*	0.07	0.00	0.36	0.44	0.15	33
11.	*Ficus vasta*	0.13	0.13	0.36	0.63	0.21	29
12.	*Hagenea abyssinica*	0.07	0.48	0.36	0.91	0.30	25
13.	*Hypericum revolutum*	0.07	0.04	0.36	0.47	0.16	32
14.	Koloasee	0.27	0.02	0.73	1.01	0.34	23
15.	*Trichilia emetica*	4.31	0.61	6.93	11.86	3.95	7
16.	*Galiniera saxifrage*	0.61	0.16	1.46	2.23	0.74	16
17.	*Maesa lanceolata*	22.36	6.15	13.87	42.37	14.12	2
18.	*Manilkara butugi*	0.07	0.22	0.36	0.65	0.22	28
19.	*Maytenus addat*	6.26	25.42	10.95	42.63	14.21	1
20.	*Millettia ferruginea*	0.94	13.75	4.38	19.07	6.36	6
21.	*Myrsine melanophloeos*	4.38	1.52	4.01	9.92	3.31	9
22.	*Nuxia congesta*	0.47	0.14	1.46	2.07	0.69	17
23.	*Olea capensis*	0.07	0.74	0.36	1.18	0.39	22
24.	*Pittosporum viridiflorum*	1.08	31.51	3.28	35.87	11.96	5
25.	*Podocarphus falcatus*	18.25	7.46	12.41	38.12	12.71	3
26.	*Prunus Africana*	0.34	0.88	1.46	2.67	0.89	15
27.	*Rytigynia neglecta*	3.91	0.81	4.74	9.46	3.15	11
28.	*Schefflera abyssinica*	0.07	0.06	0.36	0.50	0.17	31
29.	*Sclerocarya birrea*	1.14	0.81	1.82	3.78	1.26	13
30.	*Teclea nobilis*	0.54	0.05	0.73	1.32	0.44	21
31.	*Terminalia brownie*	0.34	0.37	1.09	1.80	0.60	19
32.	*Vernonea amygidelina*	5.86	0.14	5.11	11.11	3.70	8
33.	*Vernonea auritifoia*	0.13	0.04	0.73	0.91	0.30	26
34.	Workicha jaldessa	1.68	0.02	1.09	2.80	0.93	14

4.4.1 Species population structure

The pattern of diameter size-class distribution has often been used to represent the population structure of a forest (Khan *et al*., 1987). This is because the pattern of diameter class distribution

connotes the general trends of population dynamics and recruitment process of a given species. This was depicted by the evaluation of the diameter class total species density distribution as an inverted J-shape curve (Figure 11A), which shows a pattern where a total species density distribution has the highest density in the lower diameter class and a gradual decrease towards the higher classes.

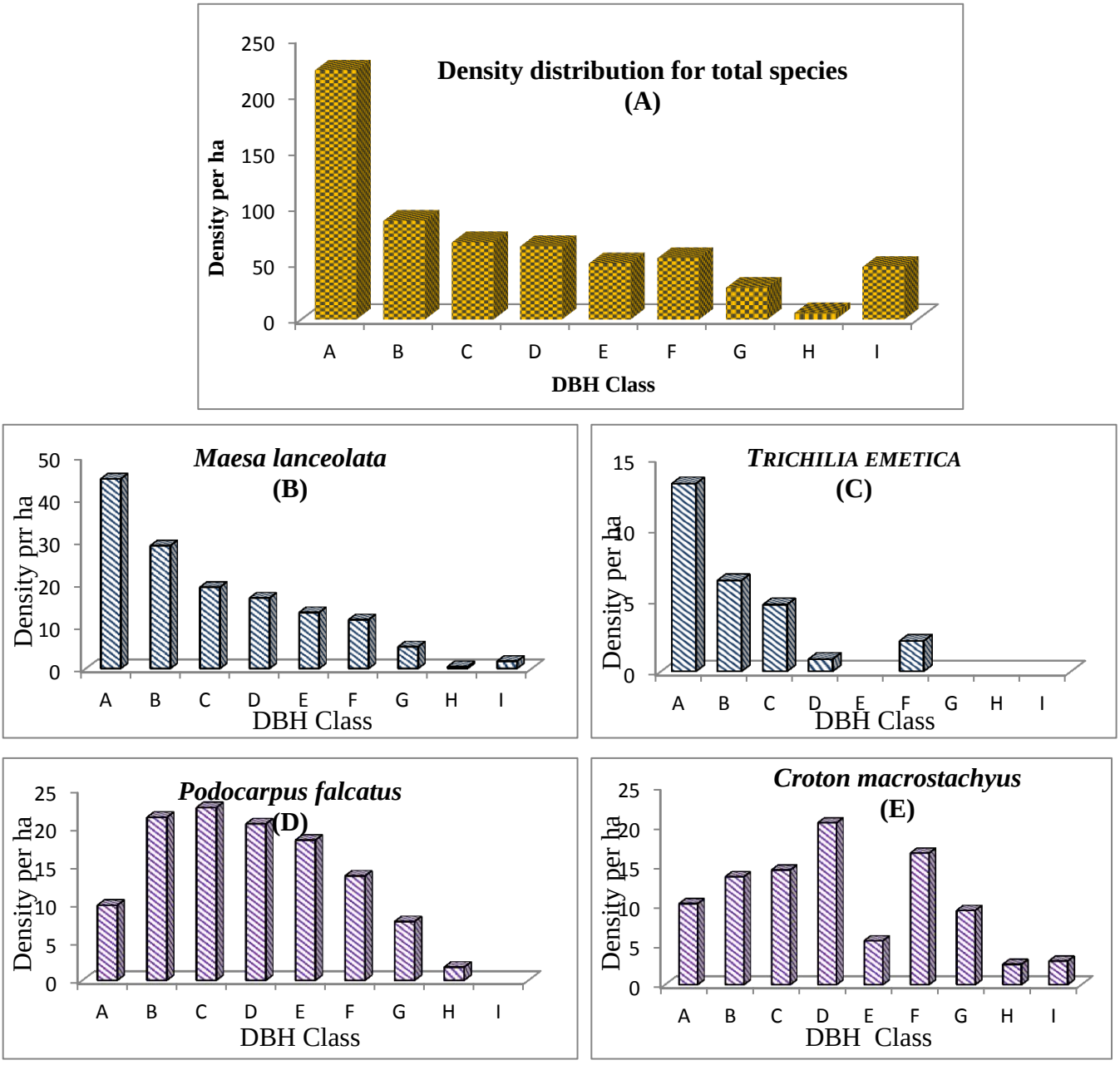

Figure 11 Diameter class density distribution of selected tree species

4.5. Regeneration status

The seedling status woody species was recorded for 24 woody plant species which belong to 24 genera and 22 families. This becomes about 64.1 % when compared to the total matured woody plant species richness inventoried. Moreover, the total seedlings density per ha was 10622.

In terms of species, *Myrsine melanophloeos, Bersama abyssinica*, *Vernonea auritifoia* and *Maesa lanceolata* respectively share the highest seedlings density in the wood plant species. And while it is the least for *Ekebergia capensis* and *Dovyalis verrucosa* woody plant species.

On the other hand, 19 woody plant species existing at the sapling stage were recoded. This is 48.71% from the total tree/shrub species inventoried. These are grouped to 19 genera and 18 families. Besides, in terms of the individual stems per ha or density, 6436 stems per ha were recorded as samplings. Nevertheless, there are about 14 species which neither appear in the seedling or sampling stages. Their seedlings and samplings, as discussed above, could be related with the forest disturbance besides the environmental catastrophes like the occurrence of recurrent drought in the area. Different species cope up with the soil moisture deficit differently.

4.6 Carbon Stocks in Above and Below Ground Biomass

4.6.1. Above ground (ABG) carbon stocks

Among the four carbon pools, the above ground carbon stock includes three or two of them namely:a) the above ground biomass calculated from DBH of the trees using alomertic equations;b). the litter biomass which is calculated by direct harvesting of the litter. While the C)below ground carbon pool includes the live underground ground root biomass and the soil organic carbon.

The above ground biomass of Gara Duro natural forest was calculated by adding the above obtained from each 47 plots and converted into carbon and CO^2 equivalent. The mean above ground carbon stock of Gara Duro natural forest was 107.2 tons of Carbon /ha-^{1}. The maximum and minimum above ground carbon per plot were recorded from plot 9, and 18 with 339.4 and 9.52 respectively, tons of carbon/ ha-^{1} (Annex 11)

4.6.2.Below ground carbon stock (BG)

As that of the above ground biomass, below ground biomass was also showed similar trend in terms of species and plots recorded the maximum and minimum values, since it is a function of the aboveground biomass. Similarly, the maximum and minimum below ground carbon per plot were recorded from plot 9 and 18, respectively with 67.8 and 1.90 tons of Carbon ha-^{1}, As Indicated (Annex 11); whereas, the mean below ground carbon stock of Gara duro natural forest was 21.44 tons of Carbon ha-^{1}.

4.6.3. Carbon Stock in Litter

The result showed that the mean litter carbon density of Gara Duro natural forest was 2.54 tons of carbon ha-^{1} and the maximum litter carbon stock density per plot were recorded from plot 23 followed 29 26 16 and 4 with 5.57, 4.45, 3.95, 3.90 and 3.860 carbon ton/ ha-^{1}, respectively. The minimum litter carbon density was recorded from 41,42,and 34, with 0.784, 0.860,and 0.869 litter carbon ha-^{1} Respectively (Annex 11).

4.6.4.Carbon Stock in the Soil

The mean soil carbon stock density was 116.05. tons of carbon ha-^{1}, while the maximum and the minimum were recorded from plot 23 and 45, respectively with soil carbon stock density of 137.8 and 94.3 tons of Carbon ton/ ha-^{1} (Annex 11)

Table 4 one way Analysis of Variance for carbon stock density of Gara Duro forest

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
AGB ton/ha-^{1}	47	5038.833	107.2092	5339.463
BGBton/ha-^{1}	47	1007.767	21.44184	213.5785
Soilcar/ton/ha-^{1}	47	5454.34	116.0498	164.8287
litter/car/ton/ha^{1}	47	0.001193	2.54E-05	1.07E-10

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	491220.1	3	163740	114.5462	7.12E-42	2.653695
Within Groups	263022	184	1429.467			
Total	754242.2	187				

4.7.Soil chemical Characteristics (pH, OC and Total Nitrogen)

The present study revealed that there was significant ($p \leq 0.05$) variation in soil chemical properties of protected and nonprotected areas of Gara Duro forest. The mean pH value in protected forest was 6.57 while in the nonprotected forest it was 5.95. Similarily, the OC in protected forest as 1.83 and 1.20 in nonprotected forest. A related significant trend was also observed in total nitrogen content between protected and non protected forest 0.52 and 0.45 respectively as indicated in (Figure 12).

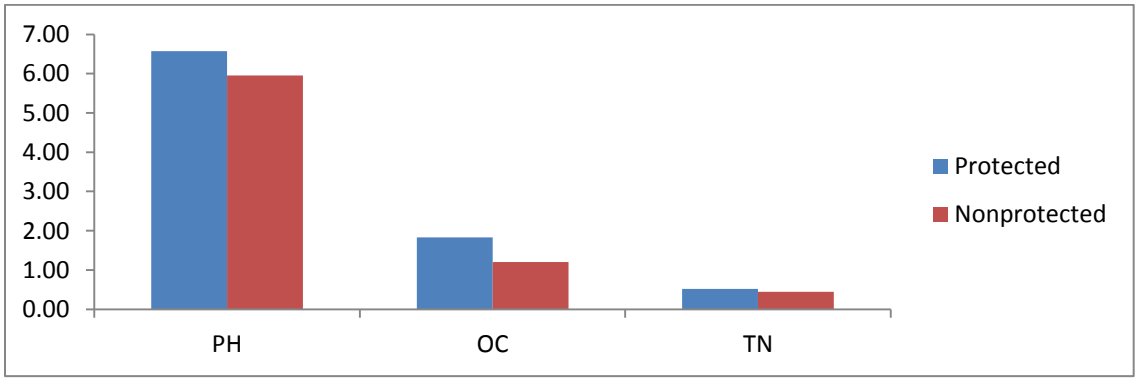

Figure 12Soil physicochemical analysis of protected and nonprotected Gara duro forest.

Table 5 One way analysis of variance in diferent mean of sol chemical properties

Anova: Single Factor pH

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Protected	20	129.08	6.454	0.053246
Nonprotected	27	160.64	5.94963	0.129265

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.92277264	1	2.922773	30.07947	1.81E06	4.056612
Within Groups	4.372576296	45	0.097168			
Total	7.295348936	46				

pH

Table 6 One way analysis of variance in diferent mean of soil chemical properties

Anova: Single Factor OC

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Protected	20	36.5686	1.82843	0.35856
Non protected	27	32.4586	1.20217	0.22888

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.50614057	1	4.50611	15.8878	0.00024	4.05662
Within Groups	12.76351738	45	0.283634			
Total	17.26965795	46				

Single Factor of Total Nitrogen

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Protected	20	10.359	0.51795	0.004258
Non protected	27	12.106	0.44837	0.004802

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.055624	1	0.055624	12.16539	0.0011	4.056612
Within Groups	0.205753	45	0.004572			
Total	0.261377	46				

Total Nitrogen by parcent %

4.8. Fungal and Bacterial dynamics in Gara Duro forest

The present study revealed that there was significant ($p \leq 0.05$) variation in soil fungal population of protected and nonprotected areas of Gara duro forest. The mean Fungal growth population of CFU value in protected forest was 15.78 $x10^3$ while in the nonprotected forest was 7.83 $x10^3$ respectively as indicated in (Figure 13).

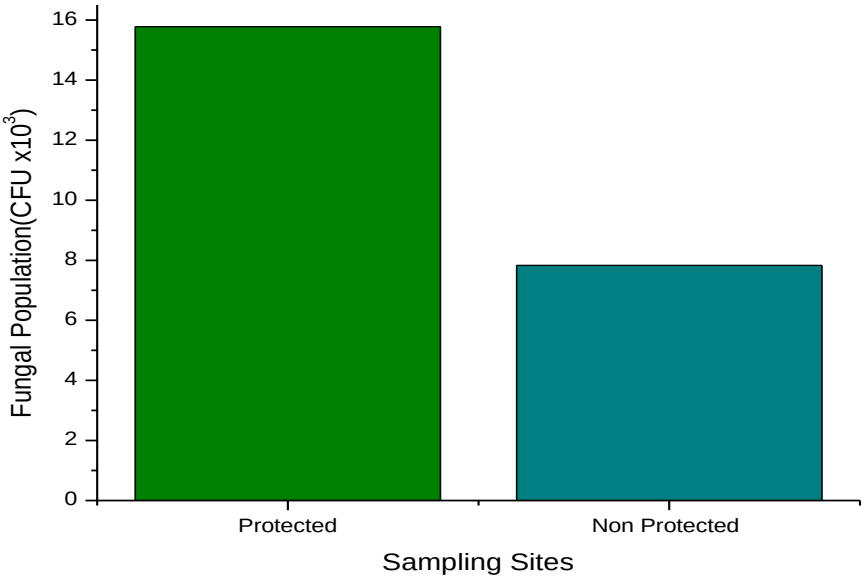

Figure 13 Comparisons of fungal measurement in protected and non protected forest sites.

Table 7 One way analysis of variance in diferent mean of fungal population.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Protected	20	154.05	7.7025	23.23565
Disturbed	27	104.7	3.877778	12.95872

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	168.0721	1	168.0721	9.71635	0.003179	4.056612
Within Groups	778.404	45	17.29787			
Total	946.4762	46				

Fungi

Table 8 One way analysis of variance in diferent mean of bacterial population protected and non protected area in forest

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Protected	20	1302.65	65.1325	3153.856
Disturbed	27	1000.75	37.06481	1238.832

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9051.261	1	9051.261	4.420861	0.041128	4.056612
Within Groups	92132.91	45	2047.398			
Total	101184.2	46				

Bacteria

The present study revealed that there was significant ($p \leq 0.05$) variation in soil of bacterial colonies forming unit (cfu) population of protected and nonprotected areas of Gara duro forest. The mean bacterial growth population of CFU value in protected forest was113.59 $x10^3$ while in the non protected forest was 62.01 $x10^5$ respectively as indicated in (Figure 14).

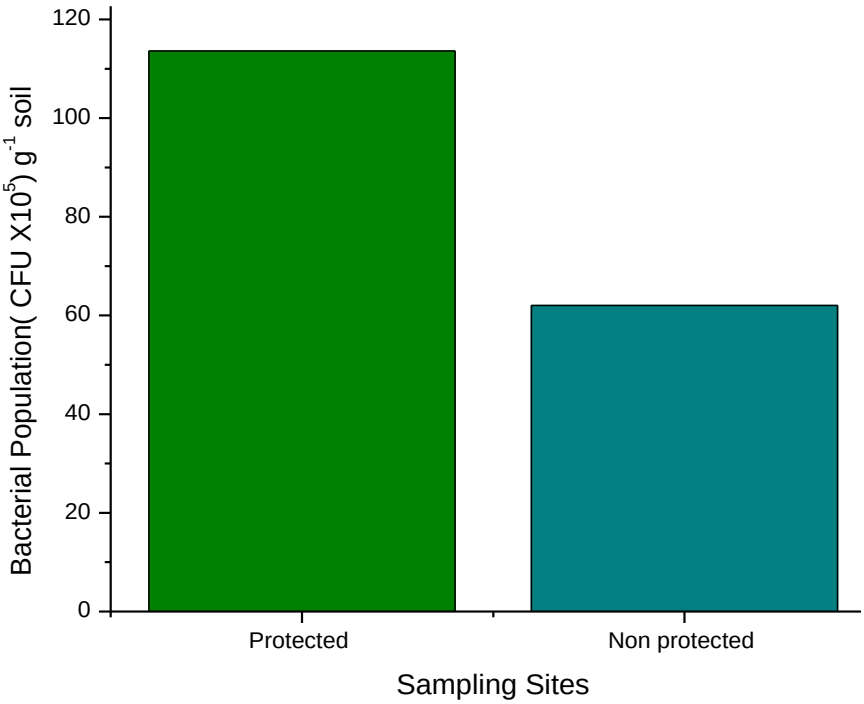

Figure 14 Comparisons of bacterial population in protected and non protected forest sites

Comparisons of bacterial and fungal population in protected and non protected forest sites. Values are mean ± standard error (n= 30). Different letters showed significant difference using Duncan's mean separation test a $p \leq 0.05$.

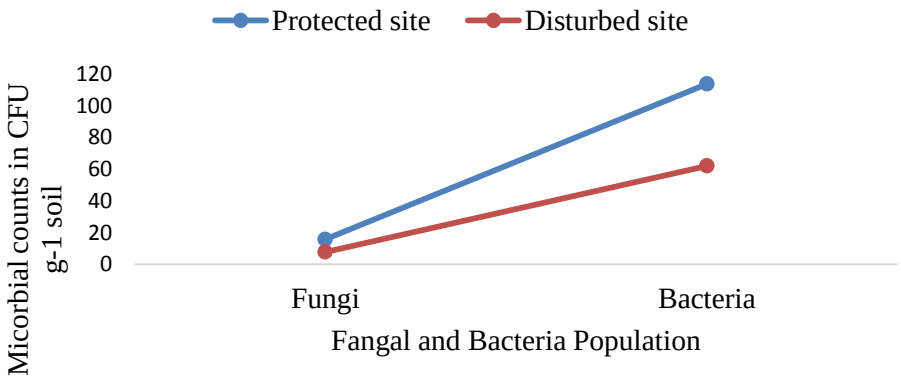

Figure 15 Fungal and Bacterial abundance in the protected and non protected forest of Gara duro forest.

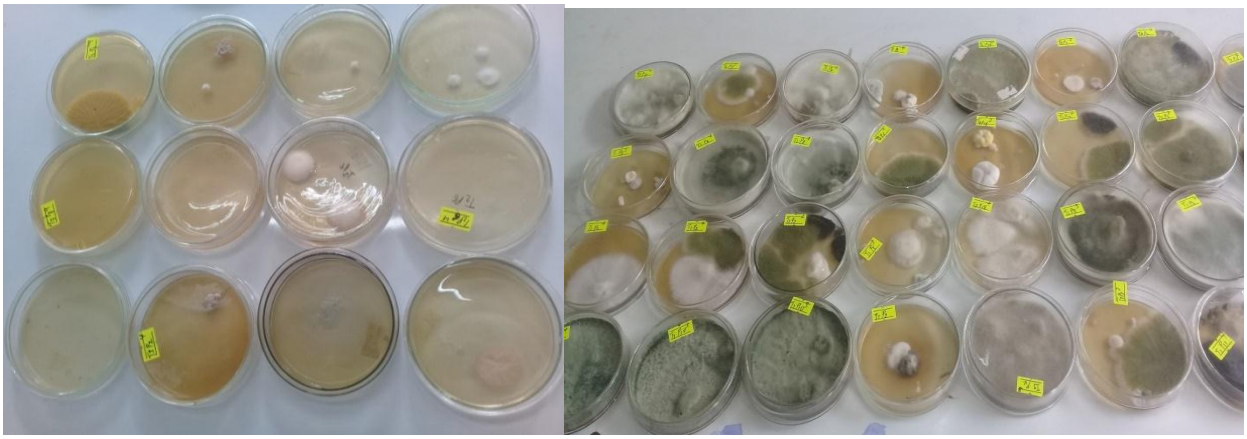

Figure 16 Fungal population which can show protected forest and nonprotected fungal diversity.

Figure 17 Bacterial population of protected forest and non protected forest.

5. Discussion

5.1. Woody species Diversity

A total of 40 woody plants were identified from Gara Duro natural forest which belonged to 38 genera and 31 families . The most frequent species in the forest were *Maesa lanceolata*, *Rubu apetaluss*, *Croton macrostachyus*, and *Podocarphus falcatus* respectively. The evaluation of selected individual species also revealed two main patterns of population structureThese are 1) inverted J-shape curve for *Maesa lanceolate* and *Trichilia emetica*, in similar to the general trend of the diameter class total density distribution, this shows the pattern which has the highest species density distribution in the lower diameter class and a gradual decrease towards the higher classes. The pattern of diameter size-class distribution has often been used to represent the population structure of a forest (Khan et al., 1987). This pattern of DBH classes indicates a good potential of reproduction and recruitment of the forest. Similar results were reported by Ayelew Alemu (2006), Haile Yineger (2008),Feyera Abdena (2010) Fikadu Gurmessa (2010), Fisah Gudine (2013).

Regarding Diameter Breast Height and Height distribution few tree species in high diameter classes might indicate that the mature trees that attained the higher diameter size would have been selectively exploited by the local communities for different purposes like wood logging and charcoal making. This depicts that the majority of the species belongs to the lower height class in similar trend as diameter distribution. The possible reason could be similar with the justification given in the analysis of DBH diameter that selective matured tree cutting, intensive browsing and moisture deficit or recurrent droughts were the determinants for the appearing of the majority of the tree/shrub species in the lower height class. On the other hand, since there is intensive browsing and in addition the area is regularly affected by recurrent drought and wind pressure the big trees could be fall down observed during study time, these impacts might have also hampered the growth from attaining the higher diameter class the number of stems per hectare was higher for species of smaller diameter size than for species of greater diameter size.The slope gradient class is a landscape characterized by near flat slope were usually the soil nutirent movement is slow, while aeration and infiltration is low.

At the lower slope gradient class the number of species is few and it increases towards the moderate slope class and then decreases as slope gradient rises to steep slope. This result agrees

with the finding of Feyera Senbeta (2006) that pointed out the relationship between topographic features and species abundance is non-linear in afromontane rainforest areas. Therefore, this confirms that the topographic features significantly affect the species composition and distribution.In general, the regeneration status was high but the survival rate would be low and the profound reason could be the intensive trampling by livestock while browsing and grazing in the woodland. In terms of species, *Myrsine melanophloeos, Bersama abyssinica, Vernonea auritifoia* and *Maesa lanceolata,* respectively share the highest seedlings density in the woody species. And while it is the least for *Ekebergia capensis* and *Dovyalis verrucosa* woody plant species. The species density in the forest ranges between 0.43–141.28 per ha. The variation of the relative density of the species was also between 0.07- 22.36 %. The least species density was for *Schefflera abyssinica, Olea capensis, Manilkara butugi, Hypericum revolutum* and *Hagenea abyssinica* while the highest species density (> 100 per ha) was for *Maesa lanceolata* (141.28) and *Podocarpus falcatus* (115.32). This result Pointed out that there was a significant variation among the individual tree/shrub species in density per ha. In the studied forest, the total species density per ha was 627.68. The mean density of woody species of the study area was less than Achera forest (1034.17 individuals per hectare) (Habtam Getaneh 2012). Due to the reason that some part of the forest changes to farm land, browsing and over grazing in the forest.

The total basal area for the inventoried forest was 7.1 m^2 per ha.The biggest basal area recorded was for *Pittosporum viridiflorum* (2.52 m^2 ha-1) while the largest dominance and relative dominance was for *Pittosporum viridiflorum* (17.12 and 31.51 % respectively), which is almost similar to the result of previous study by Dawit Shiferaw et al. (2011), which was 9.5 m2/ha. Whereas, the total basal area was 17.12.which is much higher than that of Dawit Shiferaw et al. (2011), this may be because of the tree diameter growth of the woody plant species. According to Dawins (1959; cited in Lamprecht, 1989) the normal area of virgin tropical forest in Africa is 23-37m^2/ha. Based on the report the basal area of Gara Duro is related to normal indicating the woody species.The top five dominant woody plant species were *Pittosporum viridiflorum, Millettia ferruginea, Olea capensis, Hagenea abyssinica* and *Maytenus addat*, respectively within the range of 2.52 – 0.35. The basal area of Gara Duro natural forest is less than Menagesha Suba (Beche, D 2012) and Dodola (Hundera k, 2007). with basal area 158.68 and 129.0 m^2ha-1 respectively. This may be due to the presence of plant species having forest

degradation,over grazing, forest disturbance and forest land changes to farm land. The DBH of the majority of the species was in the lowest diameter class (2.5-5.5 cm) this implies that the basal area of the lower diameter class ranger between 0.0015 – 0.0064. This shows that both the basal areas per species and the total were small. This could be due to the stunted diameter growth of the woody plant species in the dry land areas because of both the ecological factors (moisture deficit and high temperature) and intensive forest disturbance due to browsing, grazing and wood exploitation for Logging and charcoal making.

In this study area *Maesa lanceolata, Maytenus addat*,only by its own contributed 28.33 % to the total IVI, and hence it is the most frequent and dominant species in the forest. On the contrary, since *Erica arborea, Hypericum revolutum, Schefflera abyssinica, Brucea antidysenterica* and *Ficus vasta possess* the lowest IVI, they do not frequently exist and are the most minor or rare species in the forest. In principle, when a certain species receives the lowest IVI, it entails as it demands high priority for endangered species. On top of this, there was a physical damage on the seedlings by peeling during grazing and browsing. Important value index (IVI) is useful to compare the ecological significance of species (Lamprecht, 1989).The important value index of the species indicates how dominant is the species in a certain area and hence helps to compare ecological importance of the species in vegetation's (Curtis and McIntosh, 1951). This reveals that in this forest the species relative frequency, density and dominance differ accordingly. On the other hand, the highest Important Value Index of a species the most dominant the species is in an area Shibru Samue (2004).

The regenaration statues seedling woody species was recorded for 24 woody plant species which belong to 24 genera and 22 families. This becomes about 64.1 % when compared to the total matured woody plant species richness inventoried. Moreover, the total seedlings density per ha was 10,622. The number of seedlings and saplings counted from the study area were higher than the seedlings and saplings of Wof-Washa studied by Fisaha Gudina (2013) and Bibita Denu, (2007) which reported 8,796.5, and 2,555.2 respectively. In terms of species, *Myrsine melanophloeos, Bersama abyssinica, Vernonea auritifoia and Maesa lanceolata* share the highest seedlings density in the wood plant species. And while it is the least for *Ekebergia capensis* and *Dovyalis verrucosa* woody plant species. The variation could be as a result of

highly regeneration statues this indicates that the regeneration potential of Gara Duro natural forest is high.

5.2 Role of plant diversity on forest carbon stocks

Carbon stocks capacity and the amount of carbon stocks is not only related to the type of vegetation such as Forest, Woodland, Savanna etc, but also related to the plant diversity and the type of species within it. Hicks *et al*. (2014), also describes that, globally there is a generally positive relationship between carbon stocks and biodiversity. Apart from that, having diverse species may also have a complimentary effect to use different resources as they have different requirements and can generate more biomass by using the same resources as described by Hicks *et al*. (2014). When the tree DBH is smaller could store less carbon but gradually increases in DBH and would accumulate more carbon (Terakunpisut et al., 2007).

Moreover, in the present study the amount of biomass and carbon density per species was significantly different between species. Tree species with the highest carbon stock were tree species stored the having high carbon stock of all carbon pools and were *Bersama abyssinica* 33.35, *Dovialis abyssinica* 34.22, *Citrus aurantiifolia* while low carbon was reconded for 34. with 33.35, 34.22, and 34.06 and lowest carbon store *Pittosporum viridiflorum*, and *Millettia ferruginea* with 24.4, 25.4 tree species.

5.3 Comparison of Carbon Density of Gara Duro Forest with other Forests

Gara duro forest has a moderate carbon densities as compared to other forest ecosystem, though comprehensive information which comprises all carbon pool is lacking for most of the studies. The available information is presented in (Table 9) below, which compares the carbon densities of Gara duro forest with other forests in Ethiopia. However, this result is comparable to those reported for the above-ground mean carbon density estimate from primary data is consistent with global forest ranges of 20 to 400 ton C/ha (Hairiah et al., 2001). In the study area, the maximum and the minimum range of above ground biomass is 29.79 to 642.84 ton/ha.The mean TCSD of all plots in Gara Duro forest was 248.05 tons ha^{-1} (Annex 11) while the mean AGB, BG, litter and soil carbon respectively were 107.77, 21.15, 2.54 and 116.08 ton ha^{-1}. Generally preservation of Ethiopia‟s biodiversity of species and ecosystems is vital to ensure sustainable growth, to

mitigate the effects of climate change and to avoid the collapse of life support systems (James, 2012).

Table 9 Comparison of carbon density of Gara Duro forest with other forests

Ethiopia Study sites	Carbon pools				Source		
	Trees	Wood species		Litter	Soil		
	TAGC	TAGC	TBGC		litter	SOC	
Menagasha Suba State Forest	133.00	26.99	*	*	5.26	121.28	Mesfin Sahile, 2011
Egdu Forest	278.08	55.62	*	*	3.47	277.56	Adugna Feyissa *et al*., 2013
Selected Church Forest	122.85	25.97	*	*	4.95	135.94	Tulu Tolla *et al*., 2013
Tara Gedam Forest	306.37	61.52	*	*	0.90	274.32	Mohammed Gedefaw *et al*., 2014
Woody Plants oMount Zequalla Monaste	237.75	47.60	*	*	6.49	57.62	Abel Girma *et al*., 2014
Woody Plants of Arba Minch Ground Water Forest	414.70	83.48	*	*	1.28	83.80	Belay Melese *et al*., 2014
Gara Duro forest	*107.77*	*21.15*	*	*	2.549	116.08	Present study

5.4 Impacts of Deforestation on Microbial Dynamics

Soil Chemical Properties of protected and non protected area shows significant ($p \leq 0.05$) variation in Gara Duro forest. This study shows the soil PH in protect area has neutral with

average PH value of 6.57 while the non protected area has relatively acidic with an average PH value of 5.95. This could because of farming, overgrazing and other anthropogenic disturbances. As the result the soil pH of protected forest was neutral and non protected forest because of farm land, overgrazing and Antropognic distrabunace moderately acidic soil. According to (Jones & Benton, 2003) values commonly associated with certain ranges in pH are extremely acidic (pH < 4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 5.1-5.5), moderately acidic (pH 5.6-6.0), slightly acid (pH 6.1-6.5), neutral (pH 6.6-7.3), slightly alkaline (pH 7.4-7.8), moderately alkaline (pH 7.9-8.4), strongly alkaline (pH 8.5-9.0) and very strongly alkaline (pH > 9.1).

Organic carbon of study site protected area high class and non protected is medium ranges from1.83 to 1.20 with average respectively. According to Landon, (1991) the organic carbon is categorized as high class from 1.28 to 4.32 with average of 2.44 fall in the class of medium range. The result indicates that protected area in total nitrogen value was 0.52 of while the non protected area has 0.45 ton ha-1. May be the reason that high human interfereance, forest land changes to non forest land, soil erosion. Similarly total nitrogen content between protected and non protected forest decrease under non protected area.

The protected and non protected of bacteria 113.59 $x10^5$ while in the non protected forest was 62.01x 10^5 and fungal that shows there was significant ($p \leq 0.05$) variation colonies forming unit (cfu) population of Gara duro forest. The mean fungal microbial growth population of (cfu) value in protected forest was 15.78 $x10^3$ while in the nonprotected forest was 7.83 $x10^{3.}$ The bacteria and fungal population in protected and non-protected area shows a significant difference ($p \leq 0.05$). The possible reasons in bacterial and fungal population in protected and nonprotected forest might be due to human disturbance of the forest for charcoal, farming, settlments, firewood and these brings soil erosion, nutrient leachate and over grazing. Moreover, the nonprotected forest is without litter which may help in nutrient accumulation for the forest and the microbial population, as aresult, the bacterial and fungal quantities in nonprotected forest is significantly reduced.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The study was aimed to assess plant biodiversity, carbon stock and impact of forest degradation on microbial population in Gara Duro natural forest. It was found about 40 woody plant species wich belongs to 38 genera and 31 families. Among these it was found wood species that have high carbo stock . The soil in the study area has relatively high carbon stock compared to other forest ecosystems found in Ethiopia. Significant difference in protected and non protected areas in terms of total nitrogen, total carbon and pH were obtained. Similarly, protected and non-protected area in terms of microbial population was significantly different which implies that environmental protection plays a pivotal role in ecosystem health. Over all,the total carbon stock in all pools was high, it can play a significant role in mitigating climate change through carbon storage. It could also contribute to Climate-Resilient Green Economy (CRGE) strategy of the country. Therefore, proper management of this forest and enabling the forest to continue such ecosystem services is very important.

6.2 Recommendations

- ✓ Species with low seedling (*Ekebergia capensis* and *Dovyalis verrucosa*) should get priority in order to ensure the perpetuation of species until the seedlings reach to a stage which can tolerate the ecologically adapted of the forest.
- ✓ The *Bersama abyssinica* and *Dovialis abyssinica* woody species were observed with high carbon stock and has to be conserved in order to keep the carbon in woody biomass.
- ✓ There was high human interference dueto farming and overgrazing in the study site leads to forest degradation. So the local and regional government should have to give attention and creating awareness to the local people regarding with forest management and sustainable use of natural resources importance of conserving the forests for mitigation of climate change and ecosystem servies of the forest.

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ANNEXES

Annex 1. List of plant species recorded from Gara Duro Forest, with their family, local name and growth habits. Annex 1. List of species at Garaduro forest

No.	Scientific names	Local names	Family	Habit
1.	*Asparagus africanus* Lam.	Sariitii	Asparagaceae	Liana
2.	*Bersama abyssinica* Fresen.	Koreqqaa	Melianthaceae	Shrub
3.	*Brucea antidysenterica* J. F. Mill.	Ciirotaa	Simarubaceae	Shrub
4.	*Buddleja polystachya*	Bulchaana	Loganiaceae	
5.	*Celtis africana* Burm f.	Hirqamu	Ulmaceae	Tree
6.	*Arundinaria alpina* k schum	Leman	Poaceae	Shrub
7.	*Croton macrostachyus* Del.	Makanisa	Euphorbiaceae	Tree
8.	*Discopodium penninervum* Hochst.	Maraarro	Solanaceae	Shrub
9.	*Dovyalis verrucosa* (A.Rich.)	Dhangagoo	Flacourtiaceae	
10.	*Ekebergia capensis* Sparrm.	Ononuu	Meliaceae	Tree
11.	*Erica arborea* L.	Satro	Ericaceae	Shrub
12.	*Ficus vasta* Vahl.	Oda	Moraceae	Tree
13.	*Hagenia abyssinica* (Bruce) G.F. Gmel.	Hexoo	Rosaceae	Tree
14.	*Hypericum revolutum* Vahl	Garamba	Guttiferae	Shrub
15.	*Kolasaa*			
16.	*Trichilia emetica*			
17.	*Galiniera saxifrage* (Hochst.)	Korraallaa	Rubiaceae	
18.	*Maesa lanceolata* Forssk.	Abayii	Myrsinaceae	Shrub
19.	*Manilkara butugi Chiov.*			
20.	*Maytenus addat* (Loes.) Sebsebe	Kombolcha	Celastraceae	Tree
21.	*Schefflera volkensii (*Engl)Harms	Ansha	Fabaceae	Tree
22.	*Myrsine melanophloeos(* L) R.Br.	Tuullaa	Myrsinaceae	Shrub
23.	*Nuxia congesta* Fresen.	Biixanna	Loganiaceae	Tree
24.	*Olea capensis*	Siigeda	Oleaceae	Tree
25.	*Olinia rochetiana*	Gunaa	Oliniaceae	Shrub
26.	*Pittosporum viridiflorum* Sims	Amshiiqa	Pittosporaceae	Tree/shrub
27.	*Podocarphus falcatus*	Birbirsa	Podocarphaceae	Tree
28.	*Prunus africana* (Hook. f.) Kalkm	Sukee	Rosaceae	Tree
29.	*Rubus apetalus* Poir.	Goraa	Rosaceae	Shrub

S.n.	Scientific names	Local names	Family	Habit
30.	*Rumex nervosus*	Dhangaggoo	Polygonaceae	Shrub
31.	*Rytigynia neglecta* (Hiern) Robyns	Wonte fulesa	Rubiaceae	Shrub
32.	*Schefflera abyssinica* Harms	Gatame	Araliceae	Tree
33.	*Sclerocarya birrea* (A. Rich.) Hochst.	Didessa	Anacardiaceae	Shrub
34.	*Solanum marginatum* L.f.	Hiddii	Solanaceae	Shrub
35.	*Teclea nobilis* Del.	Hadheessaa		Shrub
36.	*Terminalia brownii* Fresen.	Araa	Combertaceae	Tree
37.	*Worqicha jaldesa*			
38.	*Vernonea amygidelina* Del.	Ebicha	Asteraceae	Shrub
39.	*Vernonea auritifoia* Hiern	Rejii	Asteraceae	Shrub

Annex 2. Species Dimensions of Garaduro forest

No	Scientific name	Max DBH/DSH(cm)	Mean DBH/DSH(cm)	Max Height (m)	Mean Height (m)	Stems sampled
1.	*Bersama abyssinica*	14.00	7.67	10.00	6.00	3
2.	*Brucea antidysenterica*	6.00	3.67	5.00	3.50	6
3.	*Buddlejapolystachaya*	18.00	17.00	9.00	8.50	2
4.	*Celtis Africana*	35.00	22.00	20.00	12.50	4
5.	*Citrus aurantiifolia*	5.00	4.30	5.00	3.34	112
6.	*Croton macrostachyus*	48.00	20.91	35.00	13.76	225
7.	*Discopodium penninervum*	16.00	5.83	8.00	3.83	36
8.	*Dovialis abyssinica*	3.00	3.00	3.00	3.00	5
9.	*Ekebergia capensis*	78.00	48.00	20.00	15.00	2
10.	*Erica arborea*	9.00	9.00	3.00	3.00	1
11.	*Ficus vasta*	32.00	32.00	35.00	35.00	2
12.	*Hagenea abyssinica*	88.00	88.00	12.00	12.00	1
13.	*Hypericum revolutum*	25.00	25.00	9.00	9.00	1
14.	Koloasee	12.00	7.50	8.00	5.75	4
15.	*Trichilia emetica*	32.00	10.30	25.00	8.25	64
16.	*Galiniera saxifrage*	32.00	15.17	18.00	8.33	9
17.	*Maesa lanceolata*	46.00	14.40	30.00	9.05	332
18.	*Manilkara butugi*	60.00	60.00	20.00	20.00	1
19.	*Maytenus addat*	160.00	59.28	35.00	18.33	93
20.	*Millettia ferruginea*	125.00	73.07	30.00	20.86	14
21.	*Myrsine melanophloeos*	87.00	12.74	19.00	7.11	65
22.	*Nuxia congesta*	27.00	16.29	15.00	9.14	7
23.	*Olea capensis*	110.00	110.00	25.00	25.00	1
24.	*Pittosporum viridiflorum*	140.00	72.13	32.00	21.63	16
25.	*Podocarphus falcatus*	40.00	19.23	30.00	11.97	271
26.	*Prunus Africana*	88.00	45.60	25.00	16.20	5
27.	*Rytigynia neglecta*	45.00	11.59	8.00	4.24	58
28.	*Schefflera abyssinica*	32.00	32.00	14.00	14.00	1
29.	*Sclerocarya birrea*	65.00	24.88	22.00	14.18	17
30.	*Teclea nobilis*	14.00	9.63	9.00	5.13	8
31.	*Terminalia brownie*	65.00	28.80	22.00	13.40	5
32.	*Vernonea amygidelina*	25.00	16.00	8.00	6.50	87
33.	*Vernonea auritifoia*	28.00	4.18	8.00	3.74	2
34.	Workicha jaldessa	9.00	3.48	8.00	4.08	25

Annex 3. The woody plant species distribution in Garaduro forest

No	Scientific name	Species Frequency	Relative frequency	Frequency class	Frequency Rank
1.	*Bersama abyssinica*	4.26	0.73	E	22
2.	*Brucea antidysenterica*	8.51	1.46	E	15
3.	*Buddlejapolystachaya*	2.13	0.36	E	30
4.	*Celtis Africana*	6.38	1.09	E	19
5.	*Citrus aurantiifolia*	12.77	2.19	E	12
6.	*Croton macrostachyus*	76.60	13.14	B	2
7.	*Discopodium penninervum*	8.51	1.46	E	18
8.	*Dovialis abyssinica*	2.13	0.36	E	28
9.	*Ekebergia capensis*	2.13	0.36	E	32
10.	*Erica arborea*	2.13	0.36	E	29
11.	*Ficus vasta*	2.13	0.36	E	35
12.	*Hagenea abyssinica*	2.13	0.36	E	26
13.	*Hypericum revolutum*	2.13	0.36	E	34
14.	Koloasee	4.26	0.73	E	24
15.	*Trichilia emetica*	40.43	6.93	C	5
16.	*Galiniera saxifrage*	8.51	1.46	E	17
17.	*Maesa lanceolata*	80.85	13.87	A	1
18.	*Manilkara butugi*	2.13	0.36	E	31
19.	*Maytenus addat*	63.83	10.95	B	4
20.	*Millettia ferruginea*	25.53	4.38	D	8
21.	*Myrsine melanophloeos*	23.40	4.01	D	9
22.	*Nuxia congesta*	8.51	1.46	E	16
23.	*Olea capensis*	2.13	0.36	E	33
24.	*Pittosporum viridiflorum*	19.15	3.28	E	10
25.	*Podocarphus falcatus*	72.34	12.41	B	3
26.	*Prunus Africana*	8.51	1.46	E	14
27.	*Rytigynia neglecta*	27.66	4.74	D	7
28.	*Schefflera abyssinica*	2.13	0.36	E	27
29.	*Sclerocarya birrea*	10.64	1.82	E	13
30.	*Teclea nobilis*	4.26	0.73	E	25
31.	*Terminalia brownie*	6.38	1.09	E	20
32.	*Vernonea amygidelina*	29.79	5.11	D	6
33.	*Vernonea auritifoia*	4.26	0.73	E	22
34.	Workicha jaldessa	6.38	1.09	E	21

Annex 4. Species density in Garaduro forest

No	Scientific name	Species Density per ha	Relative Density	Density >10DBH	Density >20DBH	Ratio A to B
1.	*Bersama abyssinica*	1.28	0.20	0.43		
2.	*Brucea antidysenterica*	2.55	0.40			
3.	*Buddlejapolystachaya*	0.85	0.13	0.85		
4.	*Celtis Africana*	1.7	0.27	1.28	0.85	1.5
5.	*Citrus aurantiifolia*	47.66	7.54			
6.	*Croton macrostachyus*	95.74	15.15	74.47	45.96	1.62
7.	*Discopodium penninervum*	15.32	2.42	0.85		
8.	*Dovialis abyssinica*	2.13	0.34			
9.	*Ekebergia capensis*	0.85	0.13	0.85	0.43	2
10.	*Erica arborea*	0.43	0.07			
11.	*Ficus vasta*	0.85	0.13	0.43	0.43	1
12.	*Hagenea abyssinica*	0.43	0.07	0.43	0.43	1
13.	*Hypericum revolutum*	0.43	0.07	0.43	0.43	1
14.	Koloasee	1.7	0.27	0.43		
15.	*Trichilia emetica*	27.23	4.31	8.51	2.13	4
16.	*Galiniera saxifrage*	3.83	0.61	2.13	0.85	2.5
17.	*Maesa lanceolata*	141.28	22.36	74.04	35.74	2.07
18.	*Manilkara butugi*	0.43	0.07	0.43	0.43	1
19.	*Maytenus addat*	39.57	6.26	37.02	35.32	1.05
20.	*Millettia ferruginea*	5.96	0.94	5.53	5.53	1
21.	*Myrsine melanophloeos*	27.66	4.38	8.94	5.53	1.62
22.	*Nuxia congesta*	2.98	0.47	2.55	0.85	3
23.	*Olea capensis*	0.43	0.07	0.43	0.43	1
24.	*Pittosporum viridiflorum*	6.81	1.08	6.81	6.81	1
25.	*Podocarphus falcatus*	115.32	18.25	83.83	45.53	1.84
26.	*Prunus Africana*	2.13	0.34	2.13	1.7	1.25
27.	*Rytigynia neglecta*	24.68	3.91	1.7	0.85	2
28.	*Schefflera abyssinica*	0.43	0.07	0.43	0.43	1
29.	*Sclerocarya birrea*	7.23	1.14	6.81	4.26	1.6
30.	*Teclea nobilis*	3.4	0.54	0.85		
31.	*Terminalia brownie*	2.13	0.34	1.7	1.7	1
32.	*Vernonea amygidelina*	0.85	5.86	0.43	0.43	1
33.	*Vernonea auritifoia*	37.02	0.13	0.85	0.43	2
34.	Workicha jaldessa	10.64	1.68			

Annex 5. Basal Area and Dominance of woody plant species

No	Scientific name	Mean Basal area (M^2)	Dominance(M^2/ha)	Relative Dominance (%)	Rank
1.	*Bersama abyssinica*	0.01	0.01	0.01	25
2.	*Brucea antidysenterica*	0.00	0.00	0.01	25
3.	*Buddlejapolystachaya*	0.02	0.02	0.04	23
4.	*Celtis Africana*	0.05	0.08	0.15	17
5.	*Citrus aurantiifolia*	0.00	0.07	0.13	19
6.	*Croton macrostachyus*	0.04	4.15	7.64	4
7.	*Discopodium penninervum*	0.00	0.05	0.09	20
8.	*Dovialis abyssinica*	0.00	0.00	0	
9.	*Ekebergia capensis*	0.25	0.21	0.39	13
10.	*Erica arborea*	0.01	0.00	0	
11.	*Ficus vasta*	0.08	0.07	0.13	19
12.	*Hagenea abyssinica*	0.61	0.26	0.48	12
13.	*Hypericum revolutum*	0.05	0.02	0.04	23
14.	Koloasee	0.01	0.01	0.02	24
15.	*Trichilia emetica*	0.01	0.33	0.61	11
16.	*Galiniera saxifrage*	0.02	0.09	0.16	16
17.	*Maesa lanceolata*	0.02	3.34	6.15	6
18.	*Manilkara butugi*	0.28	0.12	0.22	15
19.	*Maytenus addat*	0.35	13.81	25.42	2
20.	*Millettia ferruginea*	1.25	7.47	13.75	3
21.	*Myrsine melanophloeos*	0.03	0.83	1.52	7
22.	*Nuxia congesta*	0.02	0.07	0.14	18
23.	*Olea capensis*	0.95	0.40	0.74	10
24.	*Pittosporum viridiflorum*	2.52	17.12	31.51	1
25.	*Podocarphus falcatus*	0.04	4.06	7.46	5
26.	*Prunus Africana*	0.22	0.48	0.88	8
27.	*Rytigynia neglecta*	0.02	0.44	0.81	9
28.	*Schefflera abyssinica*	0.08	0.03	0.06	21
29.	*Sclerocarya birrea*	0.06	0.44	0.81	9
30.	*Teclea nobilis*	0.01	0.03	0.05	22
31.	*Terminalia brownie*	0.09	0.20	0.37	14
32.	*Vernonea amygidelina*	0.00	0.08	0.14	18
33.	*Vernonea auritifoia*	0.03	0.02	0.04	23
34.	*Workicha jaldessa*	0.00	0.01	0.02	24

Annex 6. Stand diameter profile and species density distribution

No	Scientific name	Diameter class									
		2.6-7.5cm	7.6-12.5cm	12.6-17.5cm	17.6-22.5cm	22.6--27.5cm	27.6-32.5cm	32.6-37.5cm	37.6-42.5cm	>42.5	Total
1.	*Bersama abyssinica*	0.85		0.43							1.28
2.	*Brucea antidysenterica*	2.55									2.55
3.	*Buddlejapolystachaya*			0.43	0.43						0.86
4.	*Celtis Africana*		0.85				0.43	0.43			1.71
5.	*Citrus aurantiifolia*	47.66									47.66
6.	*Croton macrostachyus*	10.21	13.62	14.47	20.43	5.53	16.60	9.36	2.55	2.98	95.75
7.	*Discopodium penninervum*	14.04	0.85	0.43							15.32
8.	*Dovialis abyssinica*	2.13									2.13
9.	*Ekebergia capensis*				0.43					0.43	0.86
10.	*Erica arborea*		0.43								0.43
11.	*Ficus vasta*						0.85				0.85
12.	*Hagenea abyssinica*									0.43	0.43
13.	*Hypericum revolutum*					0.43					0.43
14.	*Kolasaa*	1.28	0.43								1.71
15.	*Trichilia emetica*	13.19	6.38	4.68	0.85		2.13				27.23
16.	*Galiniera saxifrage*		2.13	0.43	0.43	0.43	0.43				3.85
17.	*Maesa lanceolata*	44.68	28.94	19.15	16.60	13.19	11.49	5.11	0.43	1.70	141.29
18.	*Manilkara butugi*									0.43	0.43
19.	*Maytenus addat*	1.28	1.28	0.85	0.85	1.70	2.98	2.13	0.43	28.09	39.59
20.	*Millettia ferruginea*	0.43				0.43		0.85		4.68	5.96
21.	*Myrsine melanophloeos*	15.74	3.83	1.70	2.13		2.55	0.85		0.85	27.65
22.	*Nuxia congesta*	0.43	0.43	0.85	0.43	0.85					2.99
23.	*Olea capensis*									0.43	0.43
24.	*Pittosporum viridiflorum*						0.85	0.85	0.43	4.68	6.81
25.	*Podocarphus falcatus*	9.79	21.28	22.55	20.43	18.30	13.62	7.66	1.70		115.33
26.	*Prunus Africana*			0.43		0.43	0.43			0.85	2.14
27.	*Rytigynia neglecta*	13.19	4.68			6.38				0.43	24.68
28.	*Schefflera abyssinica*						0.43				0.43
29.	*Sclerocarya birrea*	0.43		1.28	1.70	1.28	1.28	0.85		0.43	7.25
30.	*Teclea nobilis*	1.28	1.70	0.43							3.41
31.	*Terminalia brownie*		0.43		0.43	0.85				0.43	2.14
32.	*Vernonea amygidelina*	0.43				0.43					0.86
33.	*Vernonea auritifoia*	31.91		0.43			0.43				32.77
34.	*Workicha jaldessa*	10.21	0.43								10.64
	Total	221.71	87.69	68.54	65.14	50.23	54.5	28.09	5.54	46.84	627.85

Annex 7. Stand Height profile and Species Density distribution

No.	Scientific name	<= 5	5_1 - 10	10_1 - 15	15_1 - 20	20_1 – 25	25_1 - 30	> 30.1	Total
1.	*Bersama abyssinica*	0.85	0.43						1.28
2.	*Brucea antidysenterica*	2.55							2.55
3.	*Buddlejapolystachaya*		0.85						0.85
4.	*Celtis Africana*		0.85	0.43	0.43				1.70
5.	*Citrus aurantiifolia*	47.66							47.66
6.	*Croton macrostachyus*	11.91	24.26	26.81	24.68	4.68	1.70	1.70	95.74
7.	*Discopodium penninervum*	14.04	1.28						15.32
8.	*Dovialis abyssinica*	2.13							2.13
9.	*Ekebergia capensis*		0.43		0.43				0.85
10.	*Erica arborea*	0.43							0.43
11.	*Ficus vasta*							0.85	0.85
12.	*Hagenea abyssinica*			0.43					0.43
13.	*Hypericum revolutum*		0.43						0.43
14.	Koloasee	1.28	0.43						1.70
15.	*Trichilia emetica*	14.04	6.81	3.40	1.70	1.28			27.23
16.	*Galiniera saxifrage*	0.85	2.55		0.43				3.83
17.	*Maesa lanceolata*	40.43	60.43	26.38	12.34	0.85	0.85		141.28
18.	*Manilkara butugi*				0.43				0.43
19.	*Maytenus addat*	1.70	2.13	5.96	22.13	6.38	0.43	0.85	39.57
20.	*Millettia ferruginea*	0.43	0.43	0.43	1.70	2.55	0.43		5.96
21.	*Myrsine melanophloeos*	17.02	5.11	2.55	2.98				27.66
22.	*Nuxia congesta*	0.43	1.28	1.28					2.98
23.	*Olea capensis*					0.43			0.43
24.	*Pittosporum viridiflorum*			0.85	3.40	0.85	1.28	0.43	6.81
25.	*Podocarphus falcatus*	11.91	36.60	45.96	16.60	2.98	1.28		115.32
26.	*Prunus Africana*		0.43	0.85		0.85			2.13
27.	*Rytigynia neglecta*	20.43	4.26						24.68
28.	*Schefflera abyssinica*			0.43					0.43
29.	*Sclerocarya birrea*	0.43	2.13	1.28	2.98	0.43			7.23
30.	*Teclea nobilis*	2.55	0.85						3.40
31.	*Terminalia brownie*		0.85	0.85		0.43			2.13
32.	*Vernonea amygidelina*	0.43	0.43						0.85
33.	*Vernonea auritifoia*	31.91	0.85						32.76
34.	Workicha jaldessa	10.21	0.43						10.64
	Total	**233.61**	**154.47**	**117.87**	**90.21**	**21.70**	**5.96**	**3.83**	**627.65**

Annex 8. Important Value Index (IVI)

No	Scientific name	RD	RDO	RF	IVI	Percent	Rank
35.	*Bersama abyssinica*	0.20	0.01	0.73	0.95	0.32	24
36.	*Brucea antidysenterica*	0.40	0.01	1.46	1.87	0.62	18
37.	*Buddlejapolystachaya*	0.13	0.04	0.36	0.54	0.18	30
38.	*Celtis Africana*	0.27	0.15	1.09	1.52	0.51	20
39.	*Citrus aurantiifolia*	7.54	0.13	2.19	9.86	3.29	10
40.	*Croton macrostachyus*	15.15	7.64	13.14	35.93	11.98	4
41.	*Discopodium penninervum*	2.42	0.09	1.46	3.97	1.32	12
42.	*Dovialis abyssinica*	0.34	0.00	0.36	0.70	0.23	27
43.	*Ekebergia capensis*	0.13	0.39	0.36	0.89	0.30	26
44.	*Erica arborea*	0.07	0.00	0.36	0.44	0.15	33
45.	*Ficus vasta*	0.13	0.13	0.36	0.63	0.21	29
46.	*Hagenea abyssinica*	0.07	0.48	0.36	0.91	0.30	25
47.	*Hypericum revolutum*	0.07	0.04	0.36	0.47	0.16	32
48.	Koloasee	0.27	0.02	0.73	1.01	0.34	23
49.	*Trichilia emetica*	4.31	0.61	6.93	11.86	3.95	7
50.	*Galiniera saxifrage*	0.61	0.16	1.46	2.23	0.74	16
51.	*Maesa lanceolata*	22.36	6.15	13.87	42.37	14.12	2
52.	*Manilkara butugi*	0.07	0.22	0.36	0.65	0.22	28
53.	*Maytenus addat*	6.26	25.42	10.95	42.63	14.21	1
54.	*Millettia ferruginea*	0.94	13.75	4.38	19.07	6.36	6
55.	*Myrsine melanophloeos*	4.38	1.52	4.01	9.92	3.31	9
56.	*Nuxia congesta*	0.47	0.14	1.46	2.07	0.69	17
57.	*Olea capensis*	0.07	0.74	0.36	1.18	0.39	22
58.	*Pittosporum viridiflorum*	1.08	31.51	3.28	35.87	11.96	5
59.	*Podocarphus falcatus*	18.25	7.46	12.41	38.12	12.71	3
60.	*Prunus Africana*	0.34	0.88	1.46	2.67	0.89	15
61.	*Rytigynia neglecta*	3.91	0.81	4.74	9.46	3.15	11
62.	*Schefflera abyssinica*	0.07	0.06	0.36	0.50	0.17	31
63.	*Sclerocarya birrea*	1.14	0.81	1.82	3.78	1.26	13
64.	*Teclea nobilis*	0.54	0.05	0.73	1.32	0.44	21
65.	*Terminalia brownie*	0.34	0.37	1.09	1.80	0.60	19
66.	*Vernonea amygidelina*	5.86	0.14	5.11	11.11	3.70	8
67.	*Vernonea auritifoia*	0.13	0.04	0.73	0.91	0.30	26
68.	*Workicha jaldessa*	1.68	0.02	1.09	2.80	0.93	14

Annex 9. Seedlings and Saplings density (per ha)

No	Scientific name	Seedlings		Saplings		Totals		Rank
		Density	Relative Density	Density	Relative Density	Density	Relative Density	
1.	*Asparagus africanus*	664.89	6.26			664.89	3.90	7
2.	*Bersama abyssinica*	2,037.23	19.18	468.09	7.27	2505.32	14.69	2
3.	*Brucea antidysenterica*	351.06	3.30	212.77	3.31	563.83	3.31	9
4.	*Buddlejapolystachaya*			132.98	2.07	132.98	0.78	18
5.	*Citrus aurantiifolia*			244.68	3.80	244.68	1.43	14
6.	*Croton macrostachyus*	308.51	2.90	484.04	7.52	792.55	4.65	6
7.	*Discopodium penninervum*	207.45	1.95	292.55	4.55	500	2.93	11
8.	*Dodonaea angustifolia*	10.64	0.10			10.64	0.06	24
9.	*Dovialis abyssinica*	138.3	1.30	63.83	0.99	202.13	1.18	16
10.	*Ekebergia capensis*	5.32	0.05	15.96	0.25	21.28	0.12	22
11.	*Erica arborea*	42.55	0.40			42.55	0.25	20
12.	*Hypericum revolutum*	351.06	3.30			351.06	2.06	13
13.	Koloasee	21.28	0.20	15.96	0.25	37.24	0.22	21
14.	*Trichilia emetica*	228.72	2.15	324.47	5.04	553.19	3.24	10
15.	*Maesa lanceolata*	781.91	7.36	962.77	14.96	1744.68	10.23	4
16.	*Maytenus addat*	324.47	3.05	111.70	1.74	436.17	2.56	12
17.	*Myrsine melanophloeos*	2,500.00	23.54	1,287.23	20.00	3787.23	22.20	1
18.	*Nuxia congesta*	15.96	0.15			15.96	0.09	23
19.	*Podocarphus falcatus*	58.51	0.55	53.19	0.83	111.7	0.65	19
20.	*Prunus Africana*	111.7	1.05			111.7	0.65	19
21.	*Rubus apetalus*	654.26	6.16			654.26	3.84	8
22.	*Rytigynia neglecta*	404.26	3.81	478.72	7.44	882.98	5.18	5
23.	*Solanum marginatum*	180.85	1.70	53.19	0.83	234.04	1.37	15
24.	*Teclea nobilis*	58.51	0.55	79.79	1.24	138.3	0.81	17
25.	*Vernonea auritifoia*	1,148.94	10.82	1,058.51	16.45	2207.45	12.94	3
26.	*Workicha jaldessa*	15.96	0.15	95.74	1.49	111.7	0.65	19

Annex 10 Total carbon stock density of the Garaduro natural Forest

plot no	AGBc/ha[1]	Car/ton/ha[1]	$Co_{2ton/ha}$[1]	BGBton/ha[1]	Car/ton/ha[1]	$CO_{2t/ha-}$[1]	Soc bt/ha[1]	carbont/ha[1]	$CO_{2/t/ha}$	liter bmast/ha[1]	Carton/ha[1]	$CO_{2ton/ha}$	Total mean t/ha
1	167.6782	1676.782	6153.79	33.53564	335.3564	1230.758	98.736	117.269	362.3611	7.85E-05	3.69E-05	0.000135	848.0223
2	116.7566	1167.566	4284.968	23.35133	233.5133	856.9936	90.222	107.1569	331.1147	6.09E-05	2.86E-05	0.000105	600.9703
3	140.2242	1402.242	5146.229	28.04484	280.4484	1029.246	95.634	113.5847	350.9768	3.04E-05	1.43E-05	5.25E-05	715.5525
4	142.7683	1427.683	5239.598	28.55367	285.5367	1047.92	91.476	108.6463	335.7169	8.22E-05	3.86E-05	0.000142	725.6582
5	184.7084	1847.084	6778.797	36.94167	369.4167	1355.759	94.71	112.4873	347.5857	5.67E-05	2.67E-05	9.78E-05	927.2909
6	111.2476	1112.476	4082.788	22.24953	222.4953	816.5577	96.822	114.9957	355.3367	4.11E-05	1.93E-05	7.09E-05	577.9141
7	102.651	1026.51	3767.292	20.5302	205.302	753.4585	97.68	116.0148	358.4856	2.91E-05	1.37E-05	5.02E-05	537.3271
8	193.3968	1933.968	7097.664	38.67937	386.7937	1419.533	99	117.5825	363.33	4.72E-05	2.22E-05	8.14E-05	970.8289
9	339.4065	3394.065	12456.22	67.88131	678.8131	2491.244	87.45	103.8646	320.9415	3.27E-05	1.54E-05	5.64E-05	1661.657
10	90.52604	905.2604	3322.306	18.10521	181.0521	664.4611	109.296	129.8111	401.1163	6.54E-05	3.08E-05	0.000113	485.1612
11	87.12844	871.2844	3197.614	17.42569	174.2569	639.5228	93.324	110.8411	342.4991	7.51E-05	3.53E-05	0.000129	461.158
12	279.0747	2790.747	10242.04	55.81494	558.1494	2048.408	87.252	103.6294	320.2148	5.54E-05	2.6E-05	9.56E-05	1373.778
13	102.5958	1025.958	3765.266	20.51916	205.1916	753.0531	106.854	126.9107	392.1542	2.78E-05	1.31E-05	4.79E-05	541.5418
14	71.65405	716.5405	2629.704	14.33081	143.3081	525.9407	108.636	129.0272	398.6941	7.72E-05	3.63E-05	0.000133	394.8196
15	17.50073	175.0073	642.2768	3.500146	35.00146	128.4554	91.806	109.0382	336.928	8.05E-05	3.78E-05	0.000139	128.2929
16	32.93631	329.3631	1208.762	6.587261	65.87261	241.7525	100.386	119.2287	368.4166	8.31E-05	3.9E-05	0.000143	206.1088
17	39.68161	396.8161	1456.315	7.936321	79.36321	291.263	97.02	115.2309	356.0634	3.9E-05	1.83E-05	6.73E-05	236.6408
18	9.525043	95.25043	349.5691	1.905009	19.05009	69.91382	107.052	127.1459	392.8808	2.63E-05	1.24E-05	4.53E-05	97.69103
19	116.2475	1162.475	4266.284	23.24951	232.4951	853.2569	95.634	113.5847	350.9768	3.56E-05	1.67E-05	6.14E-05	601.1837
20	205.541	2055.41	7543.355	41.1082	411.082	1508.671	106.788	126.8323	391.912	3.86E-05	1.81E-05	6.65E-05	1032.558
21	29.30082	293.0082	1075.34	5.860164	58.60164	215.068	106.326	126.2836	390.2164	3.77E-05	1.77E-05	6.5E-05	191.6671
22	142.0765	1420.765	5214.207	28.4153	284.153	1042.841	97.218	115.466	356.7901	5.61E-05	2.64E-05	9.68E-05	725.1611
23	62.96571	629.6571	2310.841	12.59314	125.9314	462.1683	116.028	137.8067	425.8228	0.000119	5.57E-05	0.000205	356.9846
24	100.3185	1003.185	3681.688	20.06369	200.6369	736.3376	104.808	124.4807	384.6454	4.5E-05	2.11E-05	7.75E-05	529.6803
25	158.6291	1586.291	5821.686	31.72581	317.2581	1164.337	94.314	112.017	346.1324	3.2E-05	1.5E-05	5.51E-05	802.6992
26	52.5907	525.907	1930.079	10.51814	105.1814	386.0158	100.386	119.2287	368.4166	8.4E-05	3.95E-05	0.000145	299.8603

27	134.2949	1342.949	4928.624	26.85899	268.5899	985.7249	96.624	114.7605	354.6101	5.74E-05	2.7E-05	9.89E-05	687.7531
28	81.35165	813.5165	2985.606	16.27033	162.7033	597.1211	114.048	135.4551	418.5562	4.82E-05	2.26E-05	8.31E-05	443.719
29	225.6901	2256.901	8282.825	45.13801	451.3801	1656.565	112.662	133.8089	413.4695	9.46E-05	4.45E-05	0.000163	1131.537
30	201.6684	2016.684	7401.231	40.33369	403.3369	1480.246	112.728	133.8873	413.7118	6.78E-05	3.19E-05	0.000117	1016.986
31	140.473	1404.73	5155.36	28.09461	280.9461	1031.072	116.028	137.8067	425.8228	7.46E-05	3.51E-05	0.000129	726.6945
32	205.3696	2053.696	7537.066	41.07393	410.7393	1507.413	96.294	114.3686	353.399	6.46E-05	3.04E-05	0.000111	1026.618
33	118.1976	1181.976	4337.851	23.63952	236.3952	867.5702	86.922	103.2375	319.0037	6.03E-05	2.84E-05	0.000104	606.2327
34	138.9306	1389.306	5098.752	27.78611	277.8611	1019.75	112.002	133.025	411.0473	1.85E-05	8.69E-06	3.19E-05	717.3717
35	50.46099	504.6099	1851.918	10.0922	100.922	370.3837	115.368	137.0228	423.4006	6.25E-05	2.94E-05	0.000108	297.0149
36	42.42447	424.2447	1556.978	8.484894	84.84894	311.3956	110.748	131.5357	406.4452	5.63E-05	2.65E-05	9.71E-05	256.4255
37	147.3153	1473.153	5406.473	29.46307	294.6307	1081.295	107.514	127.6946	394.5764	6.67E-05	3.13E-05	0.000115	755.1763
38	15.66813	156.6813	575.0203	3.133626	31.33626	115.0041	84.744	100.6506	311.0105	5.41E-05	2.54E-05	9.34E-05	116.1041
39	80.55032	805.5032	2956.197	16.11006	161.1006	591.2393	81.444	96.73122	298.8995	5.19E-05	2.44E-05	8.95E-05	423.9813
40	18.76694	187.6694	688.7468	3.753388	37.53388	137.7494	79.662	94.61474	292.3595	7.8E-05	3.67E-05	0.000135	128.4047
41	60.66628	606.6628	2226.452	12.13326	121.3326	445.2905	86.79	103.0807	318.5193	1.67E-05	7.84E-06	2.88E-05	331.744
42	25.50218	255.0218	935.9301	5.100437	51.00437	187.186	83.556	99.23965	306.6505	1.83E-05	8.6E-06	3.16E-05	162.4326
43	58.20837	582.0837	2136.247	11.64167	116.4167	427.2495	85.14	101.121	312.4638	4.6E-05	2.16E-05	7.93E-05	319.2144
44	47.75569	477.5569	1752.634	9.551139	95.51139	350.5268	85.602	101.6697	314.1593	2.74E-05	1.29E-05	4.73E-05	269.5806
45	33.59774	335.9774	1233.037	6.719547	67.19547	246.6074	79.398	94.30118	291.3907	4.38E-05	2.06E-05	7.55E-05	199.0187
46	35.50574	355.0574	1303.061	7.101148	71.01148	260.6121	83.16	98.76932	305.1972	4.99E-05	2.35E-05	8.61E-05	209.9563
47	79.30512	793.0512	2910.498	15.86102	158.6102	582.0996	87.054	103.3942	319.4882	4.39E-05	2.06E-05	7.57E-05	420.7801
Total Carbon	5038.833	50388.33	184925.2	1007.767	10077.67	36985.04	4592.346	5454.34	16853.91	0.002538	0.001193	0.004377	26276.95
Mean	107.77	1007.767	3698.504	21.15533	201.5533	739.7008	116.84692	109.0868	337.0782	5.4E-05	2.549E-05	8.75E-05	525.5385
Total Mean	248.26												

Annex 11: Location of sample plots

plot no	plotcode	Latitude North	Longitude East	Elevation (m.a.s.l
1	T1P1	$7^0$13’09.5’’	$38^0$46’59.1’’	2389
2	T1P2	$7^0$13’14.8’’	$38^0$46’55.3’’	2398
3	T1P3	$7^0$13’20.0’’	$38^0$46’51.7’’	2420
4	T1P4	$7^0$13’25.2’’	$38^0$46’48.1’’	2462
5	T1P5	$7^0$13’30.0’’	$38^0$46’44.7’’	2453
6	T1P6	$7^0$13’36.5’’	$38^0$46’41.7’’	2457
7	T1P7	$7^0$13’41.3’’	$38^0$46’38.5’’	2480
8	T1P8	$7^0$13’45.7’’	$38^0$46’35.2’’	2475
9	T1P9	$7^0$13’50.9’’	$38^0$46’31.3’’	2480
10	T1P10	$7^0$13’57.3’’	$38^0$46’27.6’’	2489
11	T1P11	$7^0$14’03.1’’	$38^0$46’24.0’’	2550
12	T1P12	$7^0$14’06.9’’	$38^0$46’20.3’’	2535
13	T2P1	$7^0$13’09.5’’	$38^0$46’53.5’’	2590
14	T2P2	$7^0$13’14.7’’	$38^0$46’49.7’’	2575
15	T2P3	$7^0$13’19.8’’	$38^0$46’46.0’’	2560
16	T2P4	$7^0$13’24.9’’	$38^0$46’42.3’’	2555
17	T2P5	$7^0$13’29.4’’	$38^0$46’38.8’’	2550
18	T2P6	$7^0$13’34.0’’	$38^0$46’34.8’’	2565
19	T2P7	$7^0$13’38.9’’	$38^0$46’31.2’’	2563
20	T2P8	$7^0$13’43.8’’	$38^0$46’27.7’’	2547
21	T2P9	$7^0$13’48.7’’	$38^0$46’24.1’’	2528
22	T3P1	$7^0$13’08.3’’	$38^0$46’46.1’’	2340
23	T3P2	$7^0$13’13.1’’	$38^0$46’42.1’’	2339
24	T3P3	$7^0$13’17.9’’	$38^0$46’38.3’’	2388
25	T3P4	$7^0$13’22.9’’	$38^0$46’34.7’’	2390
26	T3P5	$7^0$13’27.2’’	$38^0$46’30.8’’	2387
27	T3P6	$7^0$13’32.0’’	$38^0$46’27.3’’	2395
28	T3P7	$7^0$13’36.5’’	$38^0$46’23.3’’	2405
29	T3P8	$7^0$13’41.9’’	$38^0$46’19.3’’	2426
30	T3P9	$7^0$13’46.4’’	$38^0$46’15.3’’	2436
31	T3P10	$7^0$13’49.7’’	$38^0$46’11.4’’	2427
32	T3P11	$7^0$13’54.1’’	$38^0$46’08.2’’	2432
33	T3P12	$7^0$13’20.5’’	$38^0$46’19.2’’	2448
34	T3P13	$7^0$13’18.6’’	$38^0$46’20.1’’	2445
35	T3P14	$7^0$13’18.1’’	$38^0$46’22.4’’	2459
36	T3P15	$7^0$13’16.9’’	$38^0$46’27.6’’	2486

37	T3P16	$7^0$13’17.2’’	$38^0$46’29.9’’	2500
38	T3P17	$7^0$13’17.6’’	$38^0$46’33.4’’	2512
39	T3P18	$7^0$13’16.9’’	$38^0$47’45.2’’	2530
40	T4P1	$7^0$14’16.4’’	$38^0$47’45.9’’	2471
41	T4P2	$7^0$14’17.2’’	$38^0$47’47.0’’	2759
42	T4P3	$7^0$14’21.5’’	$38^0$47’48.4’’	2783
43	T4P4	$7^0$14’22.3’’	$38^0$47’49.1’’	2801
44	T4P5	$7^0$14’26.1’’	$38^0$47’51.3’’	2847
45	T4P6	$7^0$14’28.7’’	$38^0$47’22.8’’	2873
46	T4P7	$7^0$14’29.7’’	$38^0$47’26.9’’	2882
47	T4P8	$7^0$14’30.6’’	$38^0$47’30.2’’	2900

Annex 12. Mean above ground carbon density per species of Garaduro natural forest.

Species Name	Biomass/spp.(t/ha)	carb/spp(t/ha)	Co2-e/spp(t/ha)
Bersama abyssinica	33.35382	3.335382	12.24085
Brucea antidysenterica	33.98865	3.398865	12.47383
Buddlejapolystachaya	33.03957	3.303957	12.12552
Celtis africana	31.72753	3.172753	11.644
Citrus aurantiifolia	34.06859	3.406859	12.50317
Croton macrostachyus	30.7499	3.07499	11.28521
Discopodium penninervum	33.19643	3.319643	12.18309
Dovialisabyssinica	34.22888	3.422888	12.562
Ekebergia capensis	28.57884	2.857884	10.48843
Erica arborea	33.7496	3.37496	12.3861
Ficus vasta	31.9563	3.19563	11.72796
Hageneaabyssinica	27.8815	2.78815	10.23251
Hypericum revolutum	32.49471	3.249471	11.92556
Koloasee	33.51174	3.351174	12.29881
Trichilia emetica	31.9563	3.19563	11.72796
Galinierasaxifrage	31.9563	3.19563	11.72796
Maesa lanceolata	30.89886	3.089886	11.33988
Manilkara butugi	29.86724	2.986724	10.96128
Maytenus addat	23.24972	2.324972	8.532649
Millettiaferruginea	25.41596	2.541596	9.327656
Myrsine melanophloeos	27.95064	2.795064	10.25789
Nuxia congesta	32.34022	3.234022	11.86886
Olea capensis	26.39376	2.639376	9.68651
Pittosporum viridiflorum	24.4678	2.44678	8.979684
Podocarphus falcatus	31.34888	3.134888	11.50504
Prunus africana	27.8815	2.78815	10.23251
Rytigynia neglecta	30.97353	3.097353	11.36729
Schefflera abyssinica	31.9563	3.19563	11.72796
Sclerocarya birrea	29.50507	2.950507	10.82836
Teclea nobilis	33.35382	3.335382	12.24085
Terminalia brownii	29.50507	2.950507	10.82836
Vernonea amygidelina	32.49471	3.249471	11.92556
Vernonea auritifoia	32.26317	3.226317	11.84058
Workicha jaldessa	33.7496	3.37496	12.3861
mean t/car/ha	30.88396	3.088396	11.33441

Annex 13 Environmental Variables and carbon stock densities in different carbon pools of Gara Duro Forest.

plot no	AGB ton/ha-^{1}	BGBton/ha^{1}	Soil Car/ton/ha^{1}	Litter/ton/ha^{1}	Total mean car/ha^{1}	Altitude	Aspect
1	167.6782	33.53564	117.269	3.69E-05	848.0223	2389	SE
2	116.7566	23.35133	107.1569	2.86E-05	600.9703	2398	E
3	140.2242	28.04484	113.5847	1.43E-05	715.5525	2420	SE
4	142.7683	28.55367	108.6463	3.86E-05	725.6582	2462	S
5	184.7084	36.94167	112.4873	2.67E-05	927.2909	2453	SW
6	111.2476	22.24953	114.9957	1.93E-05	577.9141	2457	SW
7	102.651	20.5302	116.0148	1.37E-05	537.3271	2480	W
8	193.3968	38.67937	117.5825	2.22E-05	970.8289	2475	W
9	339.4065	67.88131	103.8646	1.54E-05	1661.657	2480	W
10	90.52604	18.10521	129.8111	3.08E-05	485.1612	2489	S
11	87.12844	17.42569	110.8411	3.53E-05	461.158	2550	SE
12	279.0747	55.81494	103.6294	2.6E-05	1373.778	2535	SW
13	102.5958	20.51916	126.9107	1.31E-05	541.5418	2590	W
14	71.65405	14.33081	129.0272	3.63E-05	394.8196	2575	W
15	17.50073	3.500146	109.0382	3.78E-05	128.2929	2560	SW
16	32.93631	6.587261	119.2287	3.9E-05	206.1088	2555	W
17	39.68161	7.936321	115.2309	1.83E-05	236.6408	2550	S
18	9.525043	1.905009	127.1459	1.24E-05	97.69103	2565	N
19	116.2475	23.24951	113.5847	1.67E-05	601.1837	2563	N
20	205.541	41.1082	126.8323	1.81E-05	1032.558	2547	N
21	29.30082	5.860164	126.2836	1.77E-05	191.6671	2528	E
22	142.0765	28.4153	115.466	2.64E-05	725.1611	2340	S
23	62.96571	12.59314	137.8067	5.57E-05	356.9846	2339	S
24	100.3185	20.06369	124.4807	2.11E-05	529.6803	2388	W

						2390	W
25	158.6291	31.72581	112.017	1.5E-05	802.6992		
						2387	N
26	52.5907	10.51814	119.2287	3.95E-05	299.8603		
						2395	N
27	134.2949	26.85899	114.7605	2.7E-05	687.7531		
						2405	S
28	81.35165	16.27033	135.4551	2.26E-05	443.719		
						2426	W
29	225.6901	45.13801	133.8089	4.45E-05	1131.537		
						2436	W
30	201.6684	40.33369	133.8873	3.19E-05	1016.986		
						2427	SE
31	140.473	28.09461	137.8067	3.51E-05	726.6945		
						2432	N
32	205.3696	41.07393	114.3686	3.04E-05	1026.618		
						2448	W
33	118.1976	23.63952	103.2375	2.84E-05	606.2327		
						2445	SW
34	138.9306	27.78611	133.025	8.69E-06	717.3717		
						2459	SW
35	50.46099	10.0922	137.0228	2.94E-05	297.0149		
						2486	W
36	42.42447	8.484894	131.5357	2.65E-05	256.4255		
						2500	W
37	147.3153	29.46307	127.6946	3.13E-05	755.1763		
						2512	W
38	15.66813	3.133626	100.6506	2.54E-05	116.1041		
						2530	S
39	80.55032	16.11006	96.73122	2.44E-05	423.9813		
						2471	S
40	18.76694	3.753388	94.61474	3.67E-05	128.4047		
						2759	S
41	60.66628	12.13326	103.0807	7.84E-06	331.744		
						2783	W
42	25.50218	5.100437	99.23965	8.6E-06	162.4326		
						2801	W
43	58.20837	11.64167	101.121	2.16E-05	319.2144		
						2847	S
44	47.75569	9.551139	101.6697	1.29E-05	269.5806		
						2873	SW
45	33.59774	6.719547	94.30118	2.06E-05	199.0187		
						2882	SE
46	35.50574	7.101148	98.76932	2.35E-05	209.9563		
						2900	E
47	79.30512	15.86102	103.3942	2.06E-05	420.7801		

Anex 14 Aspect along altitude In Gara Duro, Nagelle Arsi District, West Arsi Zone, Oromia, Ethiopia

Plot No	plot code	Aspect	Elivation
1	T1P1	SE	2389
2	T1P2	E	2398
3	T1P3	SE	2420
4	T1P4	S	2462
5	T1P5	SW	2453
6	T1P6	SW	2457
7	T1P7	W	2480
8	T1P8	W	2475
9	T1P9	W	2480
10	T1P10	S	2489
11	T1P11	SE	2550
12	T1P12	SW	2535
13	T2P1	W	2590
14	T2P2	W	2575
15	T2P3	SW	2560
16	T2P4	W	2555
17	T2P5	S	2550
18	T2P6	N	2565
19	T2P7	N	2563
20	T2P8	N	2547
21	T2P9	E	2528
22	T3P1	S	2340
23	T3P2	S	2339
24	T3P3	W	2388
25	T3P4	W	2390

26	T3P5	N	2387
27	T3P6	N	2395
28	T3P7	S	2405
29	T3P8	W	2426
30	T3P9	W	2436
31	T3P10	SE	2427
32	T3P11	N	2432
33	T3P12	W	2448
34	T3P13	SW	2445
35	T3P14	SW	2459
36	T3P15	W	2486
37	T3P16	W	2500
38	T3P17	W	2512
39	T3P18	S	2530
40	T4P1	S	2471
41	T4P2	S	2759
42	T4P3	W	2783
43	T4P4	W	2801
44	T4P5	S	2847
45	T4P6	SW	2873
46	T4P7	SE	2882
47	T4P8	E	2900

Figure 18 Disturbance of forest degradetion in Gara Duro natural forest

Figure 19 Carbon stock mesurement in Gara Duro natural forest .