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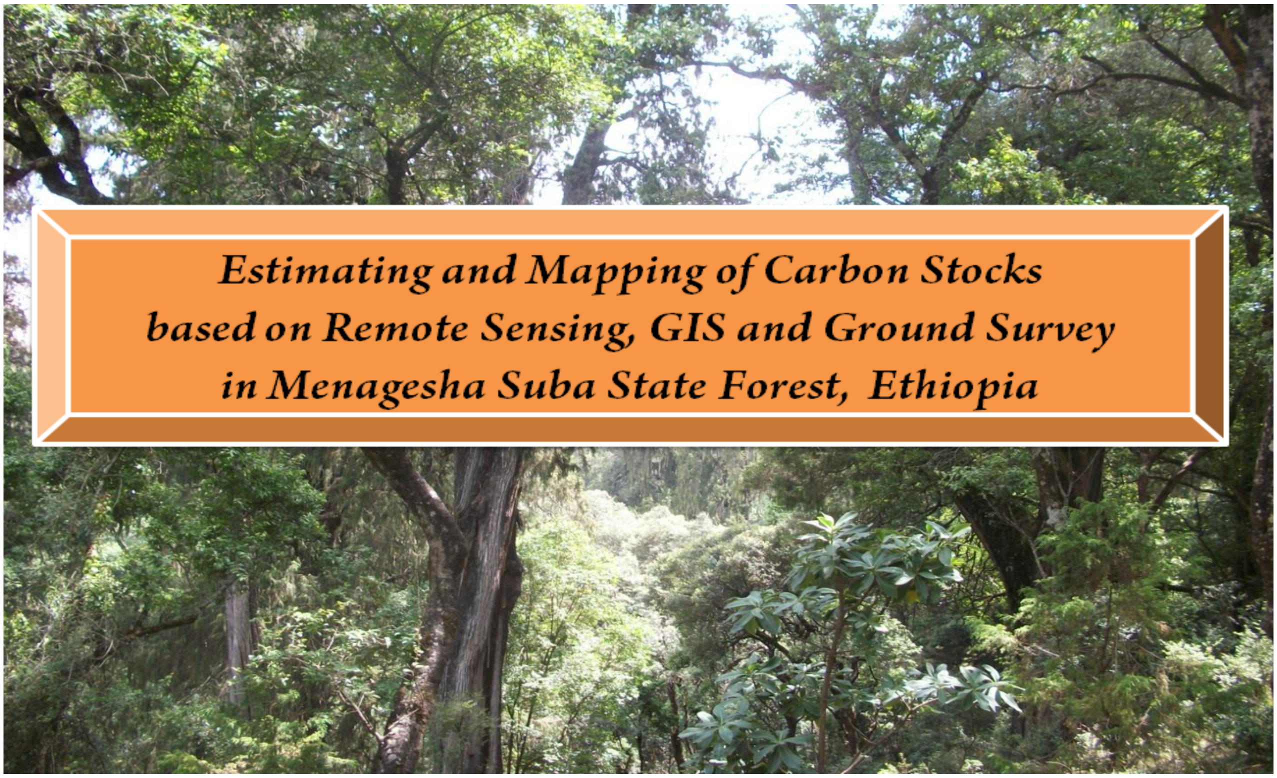

Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in Menagesha Suba State Forest, Ethiopia

By

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Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in the Menagesha Suba State Forest, Ethiopia

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Remote Sensing and Geographic Information System

BY
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Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in the Menagesha Suba State Forest, Ethiopia

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DECLARATION

I hereby declare that the dissertation entitled "**Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in the Menagesha Suba State Forest, Ethiopia**" has been carried out by me under the supervision of Dr. Dagnachew Legesse and Dr. Zewdu Eshetu, Department of Earth Sciences in Addis Ababa University and Ethiopian Forest Research Center respectively, during the year 2010 to 2011 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa

Date: June, 2011 (Mesfin Sahle)

CERTIFICATE

This is certified that the dissertation entitled "**Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in the Menagesha Suba State Forest, Ethiopia**" is bonafied work carried out by Mesfin Sahle under our guidance and supervision. This is the actual work done by Mesfin Sahle for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University, Addis Ababa.

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(Mesfin Sahle)

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Acronyms

AGB: Above-ground biomass

BERSMP: Bale Eco-Region Sustainable Management Program

BGB: Below-ground biomass

CDM: Clean Development Mechanism

DBH: Diameter at breast height

DN: Digital Number

DOM: Dead organic matter

ESP: Environmental Service Program

ETM: Enhanced Thematic Mapper

FAO: World Food and Agricultural Organization

GHG: Green House Gasses

GIS: Geographic information System

GPS: Global Positioning System

GVI: Green Vegetation Index

HWPs: Harvested wood products

I PCC: Intergovernmental Panel for Climate Change

LAI: Leaf area index

LULUCF: Land Use, Land Use Change and Forestry

NDVI: Normalized Difference Vegetation Index

NIR: Near-infrared radiation

PIFs: pseudo invariant features

SOC: Soil organic Carbon

SOM: Soil organic matter

TM: Thematic Mapper

UNFCCC: United Nations Framework Convention on Climate Change

REDD: Reduced Emission from Deforestation and Degradation

USGS: United States Geological Society

Abstract

As carbon dioxide increases in the Earth's atmosphere, the rise in average temperature may provoke changes in the environment. As a result, the need to sequester carbon becomes urgent, and one of the options we have is to use the potential of forests to do it by enhancing assimilation of CO_2 *through photosynthesis. Menagesha Suba forest is one of the oldest conserved forests in Ethiopia which is located about 45 km southwest of Addis Ababa. This research aimed to develop a model for estimating carbon stock at landscape level based on statistical correlation between stock carbon measured at plot level and the associated spectral characteristics. Estimation of carbon stocks in the field was conducted in February at 63 randomly located sample plots each with an area of 250* m^2*. Remote sensing data were used to develop a model with Landsat TM and ETM+ images acquired in January 1984 and 2005 respectively. The following steps were used: 1) All of the data were referenced to the same projection. 2) The carbon stock of the forest fixed samples was calculated. 3) The Landsat images were processed and indices were created from the Landsat images. 4) The model of carbon stock estimation was formulated with the biomass of the forest fixed samples, corresponding to the Landsat TM images. This study concludes that neither spectral bands nor vegetation indices and the texture measures alone are sufficient to establish an effective model for carbon estimation in the study areas. But multiple regression models that consist of spectral and textural signatures improve carbon stock estimation performance. Using these models, the total estimated forest carbon stock of Menagesha forest in 1984 and 2005 were approximately 1,019,704 tons and 1,153,471 tons with the average 265 and 300 tons per ha respectively. During 1984 – 2005, plantation in Menagesha Suba State forest has resulted in increase in forest carbon stocks of about 113,766 tons. From view of forest management and periodic carbon stocking estimation, the study provides substantial evidence for application of GIS and Remote sensing techniques combined with field inventory data sets to produce periodic forest inventory data to develop forest management guide lines for the country at large, and forest enterprises in particular.*

Key words: Carbon density, Carbon stock, GIS, Menagesha Suba, Regression analysis, Remote Sensing, Texture measures, Vegetation Indices

Introduction

1.1 Background of the Study

Carbon sequestration is the process of removing excess carbon dioxide (CO_2) from the atmosphere and depositing it in a reservoir (UNFCCC, 1997). It is a way to mitigate the accumulation of greenhouse gases in the atmosphere released by the burning of fossil fuel and other anthropogenic activities. Through biological, chemical or physical processes, $CO_{2,}$ which is one of the greenhouse gases captured from the atmosphere. While a carbon sink is a reservoir that collects and stores carbon containing chemical compound, it removes CO_2 from the atmosphere through absorption. Forests, soil, oceans, plants and algae are natural sinks (Wulder *et al.*, 2008).

The Kyoto Protocol recognized the importance of forests in mitigating the greenhouse gas emissions (i.e. carbon dioxide, methane and others). Forests and soils are potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets (UNFCCC, 1997). Sustainable forest development and forested landscape expansion is one of the key approaches for reducing atmospheric carbon concentration. It is a safe, environmentally acceptable, and cost-effective way to capture and store substantial amounts of atmospheric carbon. The concurrent development of tradable carbon credits provides financial incentives for considering carbon storage in forest management decisions (Siry *et al.*, 2006).

Carbon sequestration from atmosphere can be advantageous from both environmental and socio-economic perspectives. There are evidences from several studies in Ethiopia and other countries. The environmental perspective includes the removal of CO_2 from the atmosphere (Yitebitu Moges *et al.*, 2010), the improvement of soil quality (Zewdu Eshetu, 2000), and the increase in biodiversity (Batjes and Sombroek, 1997); while socioeconomic benefits include increased yields (Sombroek *et al.*, 1993), monetary incomes from potential carbon trading schemes (McDowell, 2002), normalizing droughts through its potential for creating atmospheric condensation making cloud seeding, as well as reducing flood hazards and increasing ground water recharge by increasing water infiltration through soil columns.

Globally, forests act as a natural storage for carbon, contributing approximately 80% of terrestrial above-ground, and 40% of terrestrial below-ground biomass carbon storage (Kirschbaum, 1996). They play a critical role in reducing ambient CO_2 levels, by sequestering atmospheric carbon into the growth of woody biomass through the process of photosynthesis and also by increasing the soil organic carbon (SOC) content (Brown and Pearce, 1994).

Biomass is an important element in the carbon cycle, specifically carbon sequestration. It is used to help to quantify pools and fluxes of green house gases (GHG) from the terrestrial biosphere to the atmosphere associated with land use land cover changes (Chairns *et al.*, 2003). There are many conventional methods for quantification of sequestered carbon. Many of these methods are complicated, expensive and limited in their coverage. Such limitations impede sound quantification and monitoring of carbon (MacDicken, 1997).

One of such approaches is forest inventory data sets which often provide the required base line data to enable the large area mapping of biomass and subsequent carbon accounting over a range of spatial and temporal scales. However, spatially explicit estimates of biomass over large areas may be limited by the spatial extent of the forest inventory relative to the area of interest (*i.e.*, inventories not spatially exhaustive), or by the omission of inventory attributes required for biomass estimation. These spatial and attributional gaps in the forest inventory may result in an underestimation of large area biomass (Wulder *et al., 2008*).

Remote sensing can provide answers for such measurement and monitoring limitations. The remote sensing approach can meet the requirements of carbon sequestration such as permanent sample plots (MacDicken, 1997) achieved by means of fixed coordinates, coupled with the systematic repetitive characteristic of most satellites. Tucker (1979), Richardson *et al* (1983), and Christensen and Goudriaan (1993) demonstrated that the reflection of the red, green and near-infrared (NIR) radiation contains considerable information about plant biomass.

This study aimed at establishing the relationship between ground data measurements of tree biomass and data generated from remote sensing and GIS for the purpose of estimating carbon stocks in forested ecosystems and based on case studies conducted in the Menagesha Suba State forest.

1.2 Statement of the Problem

Climate change is happening and represents one of the greatest environmental, social and economic threats facing the planet. Greenhouse gas levels are rising and are now at their highest atmospheric concentrations. It is now widely recognized that large scale reductions in carbon dioxide (CO_2) emissions are required in order to limit the extent of climate change modification. Anthropogenic CO_2 emissions are largely results of burning fossil fuel (constituting 80 percent of such emissions) and tropical deforestation. Global warming associated with the later is, however, potentially not as high as that of the fossil fuel burning. Elevated CO_2 concentration in the atmosphere acts as a greenhouse gas causing the mean global temperatures to increase and sea levels to rise, precipitation patterns to change, the frequency and severity of extreme weather events to be potentially enhanced, and the acidification of the oceans to increase. Fossil fuel combustion alone currently accounts for annual emissions into the Earth's atmosphere of about 23 x 109 tones of CO_2 (or 25 giga tones, Gt). This represents a global increase in anthropogenic CO_2 emissions of 70 percent between 1971 and 2002 (Bowling, 2002).

The terrestrial ecosystem is a major biological scrubber of atmospheric carbon dioxide that can be significantly increased by careful management. Absorbing carbon dioxide from atmosphere and moving into the physiological system and biomass of the plants, and finally into the soil is the only practical way of removing large volumes of CO_2 from the atmosphere into the litho-biosphere systems. These systems where atmospheric C is sequestered act finally serve as potential sinks of the terrestrial ecosystems (Ramachandran *et al.*, 2007).

About 500 billion tons of carbons are stored in vegetation worldwide. Deforestation and forest degradation alone accounts for 17.4% of the world's greenhouse gas emissions. The problem is especially acute in tropical and subtropical forests where conversion of forest lands to arable and pasture lands as well natural and anthropogenic forest and savanna fires are decreasing the carbon stocks at the rate of 1-2 billion tons a year (Wulder *et al., 2008*).

At the beginning of the twentieth century around 420,000 square kilometers (35% of Ethiopia's land) was covered by trees but recent research indicates that forest cover is now less than 14.2% due to population growth. Despite the growing need for forested lands, lack of education among locals has led to a continuing decline of forested areas (Parry, 2003). The rough estimation of Ethiopia's forests contains 272 million metric tons of carbon in living forest biomass (Yitebitu Moges *et al*., 2010), which is almost 83% global annual C emission (333) mega tone C per year.

However, Ethiopia is lacking periodic inventory data of forests and carbon stocks, and this makes the country fail to develop sustainable forest management planning that attracts climate finances through enhancing the environmental services of forests for the purpose of financing forest development through forest carbon finance. Some Studies has been made to assess the biomass and soil carbon sequestration at micro-level in Humbo community forest carbon project in Southern Nations and Nationalities Peoples regions in Wolayita zone by World Vision Ethiopia (CCB-AR-PDD, 2009) and in Bale Eco-Region in Oromiya region by Farm Africa and SOS Sahel (BERSMP, 2010). These projects are however, geographically limited and not enough to make inferences about the national forest carbon accounting. Such micro level studies are essential for developing sustainable forest management models that includes carbon as forest products for guiding forest management particles at forest enterprise level. Such interactive forest managing practices are so important especially in a country like Ethiopia, where heavy degradation had been caused by anthropogenic activities and different forest management prescriptions. Carbon stock assessment in state forests like Menagesha Suba State forest helps for managing the forests sustainably from the economic and environmental points of view for the welfare of human society. Therefore, this study was designed to estimate the carbon stock available in natural and plantation forests in Menagesha Suba State forest using integrated approach of remote sensing and GIS techniques accompanied with ground survey of forest stand measurement and quantifying the carbon stock in soils, litter layers, herbaceous plants and dead wood materials, which are the known potential pools for organic carbon.

1.3 Objectives of the Study

1.3.1 General Objective

The overall objective of this study was to estimate carbon stocks in Menagesha Suba state forest using landsat imagery and ground inventory data. This data set will be used as a base-line for further quantification of changes in carbon stock and forest development to make inferences about the carbon sequestration potentials of the Ethiopian montane forests, and hence to develop guidelines for future forest management practices in Ethiopia.

1.3.2 Specific Objectives

- To estimate carbon sequestration in the above and below ground; in litter, herbs and grasses; in dead wood and in soils using survey data.
- To develop a model that determines the correlation between ground survey carbon stock data sets and data derived from different landsat spectral responses for the purpose of estimating carbon stock for different time periods of the past.
- To estimate carbon stocking rates of plantation forests.
- To map the spatial distribution of forest carbon sequestration using best combination of remote sensing and ground truth data.

1.4 Hypothesis

The carbon assimilation in plants is a function of photosynthesis.

$$CO_2 + H_2O \xrightarrow{\underline{\text{Sun Light}}} C_6H_{12}O_6 + O_2$$

Vegetation indices are related to greenness of the plants.

If this general knowledge is true then the landsat imagery spectral values should be related to the carbon content measured by ground survey. Alternatively, if there is no relationship, then satellite imagery data are not in a position to quantify the carbon stock.

1.5 Scope and Limitation of the Study

This study covers only a very small area from the total forest coverage of Ethiopia. Small sample plot areas for ground biomass estimation in Menagesha Suba state forest and landsat imagery were used. Nevertheless, this study provides valuable information and insight that can be of great importance for the relavant information of forests for carbon sequestration and climate change adaptation and mitigation options.

2. Literature Review

2.1 Global Climate Change an Overview

Climate change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average. Climate change may be limited to a specific region, or may occur across the whole Earth (Houghton and Theodore, 2001).

The average temperature of the earth' s near surface and ocean has increased dramatically as compared to the historical data (Figure 2.1) during the last decades which is referred to as global warming. Greenhouse gases including water vapor, carbon dioxide, methane, nitrous oxide, and ozone, are believed to have played an important role in the global climate change (Patenaude *et al*., 2005; UNFCCC, 1997). Sunlight reaches the earth as short wavelength and most are absorbed and warmed the earth. In turn, earth emits long wave radiation back to the atmosphere. The greenhouse gases absorb a fraction of the energy and then emit long wave radiation both towards space and back to the earth. The downward emitted energy further warms the surface of the earth, which results to more warming of the earth's surface. This "greenhouse effect" process is increased by anthropogenic emission of greenhouse gases, a large portion of which is carbon dioxide (Junjie, 2008).

Climate change already has a measurable impact on many natural and human systems. For instance, it is increasingly being observed that snow and ice are melting and frozen ground is thawing, hydrological and biological systems are changing and in some cases being disrupted, migrations are starting earlier, and species geographic ranges are shifting towards the poles. Over the course of the 21st century, many impacts are expected to occur in natural systems. For instance, changes in precipitation and the melting of ice and snow are expected to increase flood risks in some areas while causing droughts in others. If there is significant warming, the capacity of ecosystems to adapt will be exceeded, with consequences such as an increased risk of extinction of species. Mitigation measures that aim to reduce greenhouse gas emissions can help to avoid reduce or delay impacts of climate change (GreenFacts, 2007).

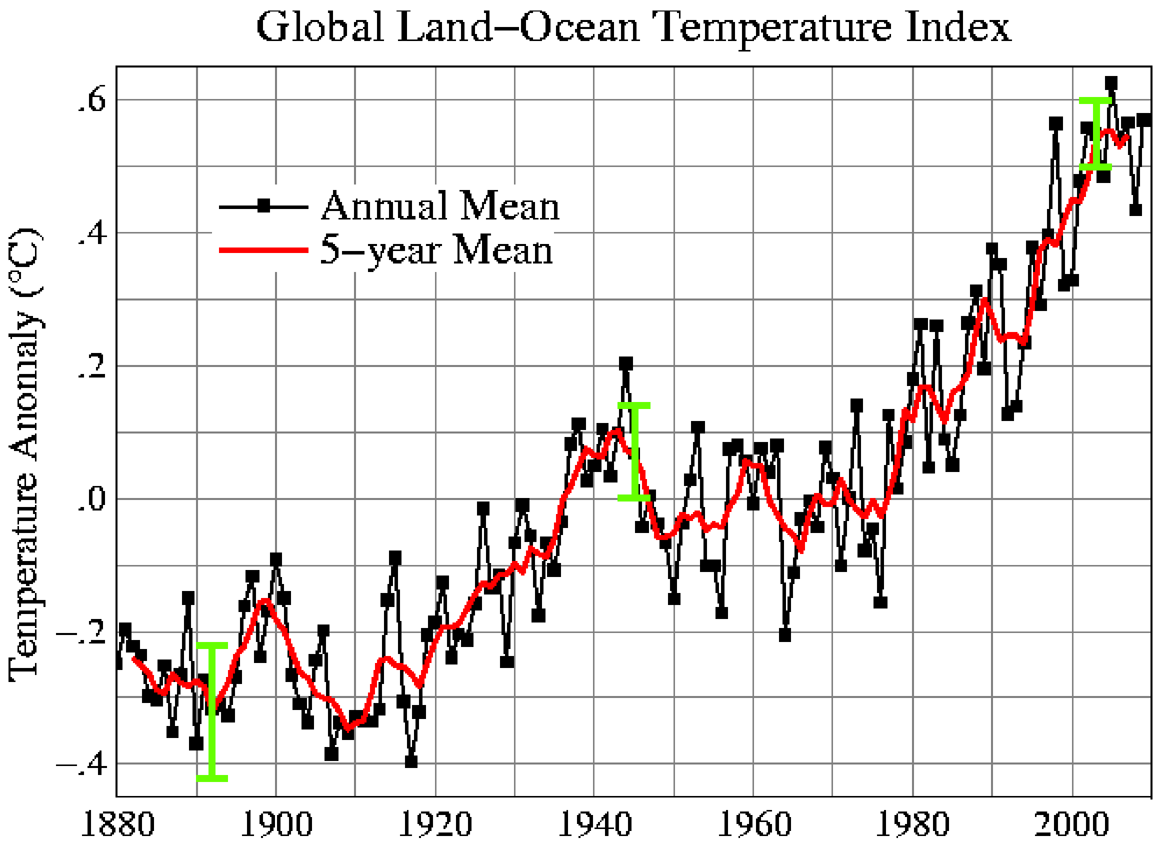

Figure 2.1: Global annual-mean surface air temperature change derived from the Meteorological Station Network (Source: IPCC 2007)

2.2 The meaning and Means of Carbon Sequestration

2.2.1 The meaning of carbon sequestration

Carbon sequestration is a natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations. Before human-caused CO_2 emissions began, the natural processes that make up the global "carbon cycle" maintained a near balance between the uptake of CO_2 and its release back to the atmosphere (Eric *et al.*, 2008).

2.2.2 Means of carbon sequestration

There are different means of carbon sequestration globally. These are oceanic, geologic and terrestrial carbon sequestration (Figure 2.2).

i. Oceanic carbon sequestration

Oceans are natural CO_2 sinks, and represent the largest active carbon sink on Earth, consuming 93% of the world's CO_2. Carbon dioxide dissolves in sea water before being transported in organic and inorganic forms from the sea surface to the ocean's interior. A small fraction of the organic carbon transported to the sea floor is buried in sediments and ultimately forms fossil fuels such as oil and natural gas. CO_2 solubility is temperature dependent; cooling of surface waters tends to drive CO_2 uptake, while warming drives the release of CO_2 into the atmosphere (Eric *et al.*, 2008). In the 1990's, the ocean sink accounted for an uptake of 2.2-2.4 Gt C annually (Richard, 2008).

ii. Geologic carbon sequestration

This method involves injecting carbon dioxide, generally in supercritical form, directly into underground geological formations. Oil fields, gas fields, saline formations, unminable coal seams, and saline-filled basalt formations have been suggested as storage sites. Various physical (e.g., highly impermeable cap rock) and geochemical trapping mechanisms would prevent CO_2 from escaping to the surface (Eric *et al.*, 2008).

iii. Terrestrial carbon sequestration

Terrestrial carbon sequestration is the process through which CO_2 from the atmosphere is absorbed by trees, plants and crops through photosynthesis, and stored as carbon in biomass (tree trunks, branches, foliage and roots) and soils. Agriculture and forestry activities can also release CO_2 to the atmosphere. Therefore, a carbon sink occurs when carbon sequestration is greater than carbon releases over some time period (Mathews and Robertson, 2002).

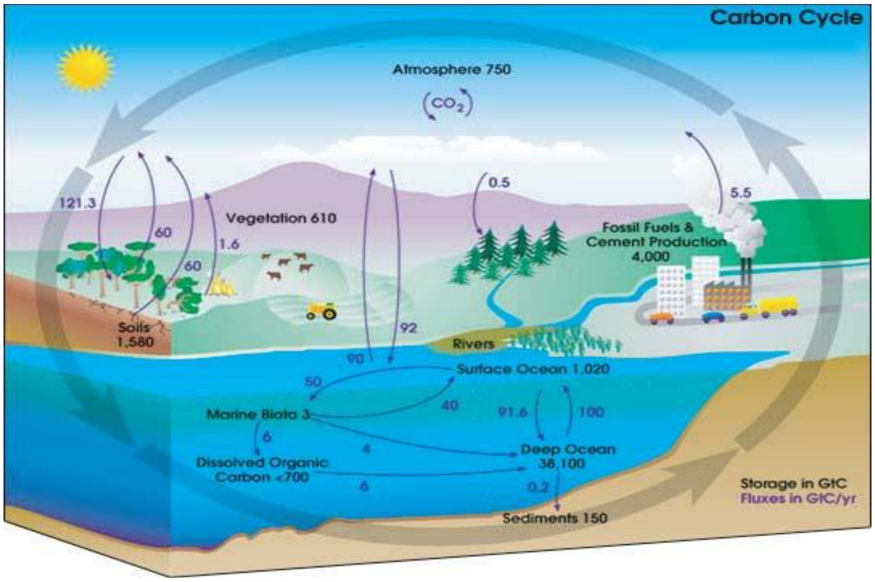

Figure 2.2: Major carbon pools and fluxes of the global carbon balance (FAO, 2004)

Terrestrial ecosystems apparently store a net 1.0-1.5 Gt C annually during the 1990s, a figure that includes the loss from deforestation and thus implies an average gross annual uptake of some 2.5 Gt C during those years. Terrestrial ecosystems, and especially forests, are increasingly valued because of their ability to sequester carbon. Much of this carbon uptake is being attributed to increased rainfall associated with the warming trend in temperature (Richard, 2008).

Major terrestrial carbon pools

Carbon pools are components of the ecosystem that can either accumulate or release carbon and have classically been split into five main categories: living above-ground biomass (AGB), living below-ground biomass (BGB), dead organic matter (DOM) in wood, DOM in litter and soil organic matter (SOM) (Figure 2.3). Classification of carbon pools is not strict and it is not the number of categories that is important but their completeness; pools must not be double-counted and significant pools should not be excluded (Watson, 2008).

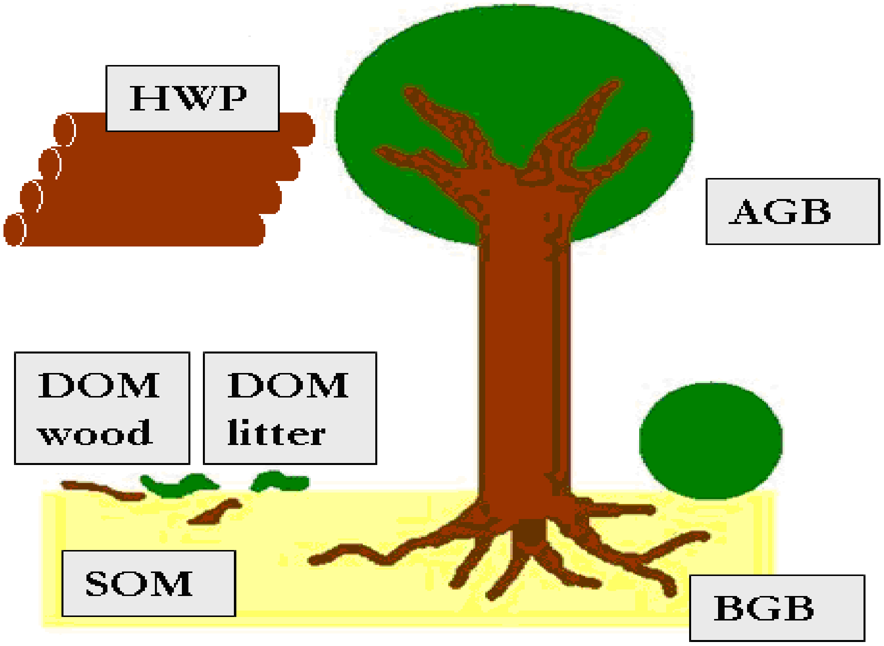

Figure 2.3: Major terrestrial carbon pools (Source: Watson, 2008)

(*AGB above-ground biomass; BGB below-ground biomass; SOM soil organic matter; DOM dead organic matter; HWPs harvested wood products*)

2.3 Global Carbon Cycles and Forests

The world's greatest concern is on CO_2 (Patenaude *et al.*, 2005), hence an understanding of global carbon cycles is one of the fundamental steps in addressing greenhouse gases concerns. Forest plays an important role in the carbon cycle as they dominate the terrestrial vegetation, which exchanges CO_2 with the atmosphere through photosynthesis and respiration (Dixon *et al.*, 1994; Patenaude *et al.*, 2005). The rate at which greenhouse gases are being released into the atmosphere has increased mainly due to the burning of fossil fuels for both domestic and industrial purposes, but also as a result of land clearance and deforestation. All plant materials contain carbon (normally around 50% of dry weight), and burning or decomposition of cleared vegetation releases it to the atmosphere, mainly in the form of CO_2 (Matthews and Broadmeadow, 2003).

Plants and particularly trees, because of their large biomass per unit area of land, continue to make an important contribution to the global carbon cycle (Matthews and Broadmeadow, 2003). The CO_2 absorbed by plants is transformed into carbohydrates that are then stored in plant tissues during growth hence they form a component of plant biomass. As much of the flux is above the ground, estimation of forest structural attributes such as aboveground biomass is therefore an important step in identifying the amount of carbon in terrestrial vegetation pools and is central to global carbon cycle studies (Drake *et al.*, 2002).

The amount of carbon stored in a forest ecosystem depends on the age of forest and forest site productivity. Terrestrial carbon sink may result from the global shift in forest age, when there is regional deforestation of old growth natural forests for the purpose of commercial plantation establishment. In this respect it seems that forest age is one of the points of intervention at which the future evolution of the carbon cycle might be influenced by age dependent forest management practices. Most temperate and boreal forests are actively managed, and forest age depends on the length of harvest cycles there. As biomass increases with stand age, postponing harvesting to the age of biological maturity may result in the formation of a large carbon sink (Alexandrov and Yamagata, 2002; Ahern *et al.*, 1991).

2.4 The Kyoto Protocol and Forest Carbon Stocks

Two important and related international agreements address the pressing issue of reducing anthropogenic greenhouse gas emissions in the atmosphere: the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (UNFCCC, 1997; Patenaude *et al.*, 2005). The UNFCCC is an international environmental treaty with the goal of achieving stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Kyoto Protocol is a Protocol to the United Nations Framework Convention on Climate Change (UNFCCC or FCCC), aimed at fighting global warming (UNFCCC, 2005).

The Kyoto Protocol divides the world into two economic groups: industrialized nations and economies in transition and developing countries with no binding limits. Under the Kyoto Protocol, countries must reduce their human induced GHG emissions by at least 5 % below their 1990 emission levels during the first commitment period of 2008-2012. They are allowed to do this reduction through the conservation and enhancement of the carbon stored in forest ecosystems (UNFCCC, 1997; Patenaude *et al.,* 2005). UNFCCC requires Parties to periodically report on biomass and carbon stock changes in their forests. To use the sink capacity of forests to meet their reporting requirements, Parties must therefore establish their levels of carbon stocks (UNFCCC, 1997). The challenges that have to be addressed to meet this requirement include acceptable methods, skills and terminology (FAO, 2005).

2.5 An Overview of Carbon Market

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

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

2.6 Forest Biomass and Carbon Sequestration Assessment

Biomass is the total mass of all living organisms; most of it on the Earth is produced by green plants through photosynthesis. It is of fundamental significance in ecosystems, it provides the entire basis of energy flow and food chain. Biomass is also vital for human being the largest portion of our food supply is from plants (Hua *et al.*, 1996).

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

Forest biomass assessment is important for national development planning as well as for scientific studies (Zianis and Mencuccini, 2004). It is an important element in the carbon cycle, specifically carbon sequestration; it is used to help quantify pools and fluxes of GHG from the terrestrial biosphere to the atmosphere associated with land-use and land cover changes (Cairns *et al.*, 2003). The concentration of atmospheric carbon dioxide, which is the major constituent of GHG, has increased from 278 ppm in the pre-industrial era (1750) to 379 ppm in 2005 (IPCC, 2007; UNEP, 2007) an average of 0.4 ppm/year. The process of CO_2 emission was slow until early 1900s. With the increasing concern for rising CO_2 concentrations, the role of forests, as a sink, for assimilation of elevated atmospheric CO_2 is being increasingly realized; hence several studies across the globe are currently undertaken to characterize and determine the natural and planted forest ecosystems for their potential in sequestrating atmospheric CO_2 in relation to forest management and utilization as well as land use land cover changes.

Intergovernmental Panel on Climate Change (IPCC, 2006) provided guidelines to assist countries in developing carbon assessment methodologies. These guidelines are organized into three `Tiers', each providing successively increased accuracy and thus potentially higher financial returns for monitoring and verifying carbon stocks and emissions. The Tier I approach is the most general, based on simple nationwide estimates of forest cover and generic forest carbon density values (e.g., tons of carbon per hectare). Tiers II and III provide increased detail on carbon stocks and emissions at regional and national levels using a combination of plot inventory, satellite mapping and carbon modeling approaches. To achieve Tier III levels of accuracy, both aboveground and belowground live and dead carbon stocks must be estimated and modeled (Gibbs *et al.*, 2007).

Detailed estimations of biomass of all land cover types are necessary for carbon accounting, although reliable estimates of biomass in the literature are few. Biomass productivity and rate of carbon sequestration are generally high in tropical forests, reflecting their influence on the global carbon cycle, if land use change kept minimal. Tropical forests also have great potential for the mitigation of CO_2 through appropriate conservation and management (FAO, 2005). This is, however, so far a challenge, because, carbon emission form land use land cover change is substantially high.

2.7 Forest Carbon Accounting

2.7.1 Above ground biomass (AGB)

The AGB carbon pool consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. For accounting purposes, it can be broadly divided into that in trees and that in the understory. The most comprehensive method to establish the biomass of this carbon pool is destructive sampling, whereby vegetation is harvested, dried to a constant mass and the dry-to-wet biomass ratio established. Destructive sampling of trees, however, is both expensive and somewhat counter-productive in the context of promoting carbon sequestration. Two further approaches for estimating the biomass density of tree biomass exist and are more commonly applied. The first directly estimates biomass density through biomass regression equations. The second convert’s wood volume estimates to biomass density using biomass expansion factors (Brown, 1997).

2.7.2 Below ground biomass (BGB)

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

2.7.3 Dead wood biomass

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

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

2.7.4 Dead organic matter (litter)

The DOM litter carbon pool includes all non-living biomass with a size greater than the limit for soil organic matter (SOM), commonly 2mm, and smaller than that of DOM wood, 10cm diameter. This pool comprises biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM. Local estimation of the DOM litter pool again relies on the establishment of the wet-to-dry mass ratio. Where this is not possible default values are available by forest type and climate regime from IPCC ranging from 2.1 tons of carbon per hectare in tropical forests to 39 tons of carbon per hectare in moist boreal broadleaf forest (IPCC, 2006).

2.7.5 Soil organic matter (SOM)

SOM includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal and Bruce, 1999). Inorganic forms of carbon are also found in soil: however, forest management has greater impact on organic carbon and so inorganic carbon impact is largely unaccounted. SOM is influenced through land use and management activities that affect the litter input, for example how much harvested biomass is left as residue, and SOM output rates, for example tillage intensity affecting microbial survival. In SOM accounting, factors affecting the estimates include the depth to which carbon is accounted, commonly 30cm, and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years (Watson, 2008).

2.8 Methods for Assessment of Forest Biomass and Forest Carbon Stock

Application of appropriate biomass estimation methods and transparent and consistent reporting of forest carbon inventories are needed in both scientific literature and the GHG inventory measures (Somogyi *et al.,* 2006). A variety of approaches and data sources have been used to estimate forest biomass and forest carbon stocks in different pools. Such approaches are remote sensing-based estimates of AGB (Wulder *et al.* (2008) combined with field measurement of forest stand characters such as height, diameter and basal area measurements

2.8.1 Field measurement

Forest inventory measurements and direct estimation of aboveground biomass through destructive harvesting could greatly improve our quantification of forest carbon stocks. Measurements of diameter at breast height (DBH) and diameter at stump height (DSH) alone or in combination with tree height can be converted to estimates of forest carbon stocks using linear relationships derived from various allometric equation, volume tables and yield tables (Wulder *et al.,* 2008). Measurements of diameter at breast height (DBH) alone or in combination with tree height can be converted to estimates of forest carbon stocks using linear relationships (Gibbs *et al.,* 2007).

The linear and multiple linear regression equation approach require the selection of the regression equation that is best adapted to the conditions in the study area. Linear and multiple linear regression models have been fitted to data in various situations of variable site and ecological conditions globally (Ponce-Hernandez, 2004).

Stratification of systematic and random sampling schemes by broad forest types greatly increases survey efficiency by reducing unnecessary sampling and ensuring that major variation has been captured. It is important to assess how forest carbon stocks vary across an area before designing a stratified sampling scheme. This information is used to define sampling strata or broad forest categories with similar forest carbon stocks. Information on soil types, drainage class, elevation, topography and land-use history are likely universally important to understanding the spatial distribution of carbon stocks (Gibbs *et al.*, 2007).

2.8.2 Remote sensing application

Remotely sensed data are the data generated by sensors from a platform not directly touching or in close proximity to the forest biomass. Therefore, these data comprise images sensed from both aircraft and satellites. Remote-sensing imagery can be extremely useful, particularly where validated or verified with ground measurements and observations (Gibbs *et al.,* 2007).

Remote-sensing images can be used in the estimation of carbon stock in at least three ways according to win-win scenario of carbon sequestration for assessing carbon stocks and modelling of Ponce-Hernandez (2004):

1. Classification of vegetation cover and generation of a vegetation type map. This partitions the spatial variability of vegetation into relatively uniform zones or vegetation classes. These can be very useful in the identification of groups of species and in the spatial interpolation and extrapolation of biomass estimates.
2. Indirect estimation of biomass through some form of quantitative relationship (e.g. regression equations) between band ratio indices (NDVI, GVI) or other measures such as direct radiance values per pixel or digital numbers per pixel, with direct

measures of biomass or with parameters related directly to biomass, e.g. leaf area index (LAI).

3. Partitioning the spatial variability of vegetation cover into relatively uniform zones or classes, which can be used as a sampling framework for the location of ground observations and measurements.

A variety of remotely sensed data sources continue to be employed for biomass mapping including coarse spatial resolution data such as SPOT-VEGETATION and AVHRR (González-Alonso *et al.*, 2006) and MODIS (Feng *et al.*, 2006). To facilitate the linkage of detailed ground measurements to coarse spatial resolution remotely sensed data (*e.g.*, MODIS, AVHRR, IRS-WiFS), several studies have integrated multi-scale imagery into their biomass estimation methodology and incorporated moderate spatial resolution imagery (*e.g.*, Landsat, ASTER) as an intermediary data source between the field data and coarser imagery (Tomppo *et al.*, 2002; Zheng *et al.*, 2007). Research has demonstrated that it is more effective to generate relationships between field measures and moderate spatial resolution of remotely sensed data (e.g., Landsat), and then extrapolate these relationships over larger areas using comparable spectral properties from coarser spatial resolution imagery (e.g., MODIS) (Wulder *et. al.*, 2008). Similarly, high spatial resolution data such as QuickBird (Leboeuf *et al.*, 2007) and IKONOS (Proisy *et al.*, 2007) have been used for forest biomass estimation. Numerous studies have generated stand attributes from LIDAR data. Then they used these attributes as input for allometric biomass equations (Bortolot and Wynne, 2005; McRoberts and Tomppo, 2007). Other studies have explored the integration of LIDAR and RADAR data for biomass estimation (Nelson *et al.*, 2007).

The major advantages of using Landsat images for the AGB estimation compared to ground biomass measurements as clearly stated by Hayashi and Bettinger (2006) are:

1. Cost of Landsat image: Landsat images are cost free and easily download from USGS.
2. Coverage of a Landsat image: The image covers an area of 170×185 km (3,145,000 ha), which is far greater than the area captured by conventional aerial

photographs using 9×9 inch format film, as well as with most other remote sensors.

3. Temporal resolution: Landsat revisits the same area to capture an image every 16 days. This enables frequent assessment of subtle AGB changes, such as those caused by natural disasters. Also, it increases the probability of capturing images under cloud-free condition.
4. Available classification methods: A wide variety of image classification methods for AGB estimation using TM images have been developed over the past three decades. On the other hand, one simple method, regression analysis, has shown the potential for moderately accurate AGB estimation in various types of forestlands.

The major disadvantage of using Landsat images is that it could not capture all the carbon pools such as soil organic carbon, litter layer, and carbon stock in dead wood. Therefore, in order to increase the accuracy of carbon stock estimation, the Landsat images should be combined with ground and laboratory measurements of the carbon pools other than AGB.

2.9 Change Detection of Carbon Storage Based on Remote Sensing

Change detection based on remote sensing is a process of identifying changes in the state of an object or phenomenon by observing images at different times (Singh, 1989). There is a basic assumption that land-cover changes result in changes in the radiance value of the remotely sensed data (Ingram *et al.*, 1981). Therefore, extraneous factors, such as different (or changing) sensor calibration, should be minimized or removed in advance (Hall *et al.*, 1991; Yuan and Elvidge, 1996).

Satellite sensing in the visible and near infrared portion of the spectrum is desirable to generate mosaics of images taken at different times or to study the changes in the reflectance of ground feature at different times or locations. In such applications, it is usually necessary to apply a sun elevation correction and an earth-sun distance correction. Through this process, image data acquired under different solar illumination angles are normalized by calculating pixel brightness values assuming the sun was at the zenith on each date of sensing (Lillesand and Kiefer, 1994).

Satellite imagery from different sensors and acquisition dates needs to be corrected for differences between satellite calibrations and environmentally introduced radiometric effects. Correction methods that do not rely on information regarding atmospheric conditions are needed as such data rarely exist for historic satellite imagery. Radiometric correction methods based on pseudo invariant features (PIFs) show potential for imagery-to imagery radiometric normalization (Salvaggio, 1993; Yuan and Elvidge, 1996). Once multitemporal imagery is appropriately corrected, remote sensing can then be used to monitor changes over wide areas for improved estimates of carbon storage, for better assessment of damage from natural or anthropogenic events, and for effective environmental management support (Myeong *et al.*, 2005).

3. Materials and Methods

3.1 Description the Study Site

3.1.1 History

Menagesha Suba State Forest is one of the oldest conserved forests in Africa. Detailed accounts on the history of the Menagesha forest and its floristic composition are found in Sebsebe Demissew (1988) and Zewdu Eshetu (2000). Its demarcation as forest conservation site dated back to the 15th century, when the forest was designated as the ‘crown forest’ of the country. It was planting seeds from trees in the Wefwasha forest near Debre sina was ordered by King Zera Yakob (1434-1468). The forest has been protected by Imperial edict since the 1600’s. At that time the forest was degraded and then replanted with *Juniperus procera* by the orders of the king. Later, Emperor Menelik II (1888-1912), in order to protect the forest, employed guards and proclaimed that no one was allowed to cut trees without his approval. Special mention was made to the three important trees in the forest, Tid (*Juniperus procera)*, Zigba (*Podocarpus gracilor*), and Weyra (*Olea europea*).

3.1.2 Location

Menagesha Suba state forest is located about 45 km southwest of Addis Ababa. It is found between 38°30’ and 38° 35’ East and 8°56’ and 9 °1’ North in the West Shewa Administrative Zone of Wolemera Woreda, Central Ethiopia (Figure 3.1). It covers 3418 ha.

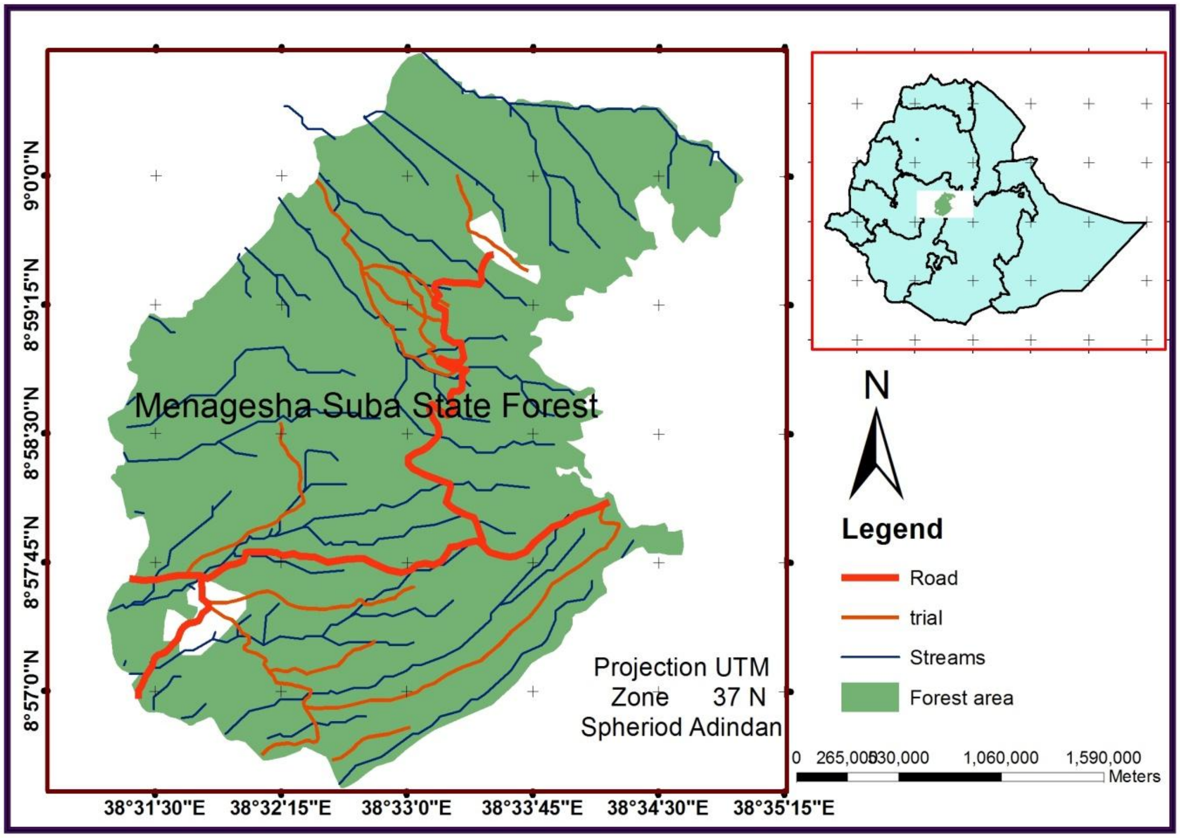

Figure 3.1: The location of the study site

3.1.3 Physiography and Geology

The physiography and geology of the Wochecha mountain peak is described by Miller and Moher (1966). The area is part of the fairly well preserved volcanic dome of Mt. Wachacha which covers an area approximately 100 km^2 and culminates in a broad, flat northern summit at about 3,350 m and a sharp southern peak (3000 m). Mt. Wachacha is an extinct volcano; it has a very complex tectonic setting, being situated where the western margin of the Ethiopian rift is topographically barely defined. The rock types vary from a white, coarsely porphyritic trachyte forming the Wachacha summit to an extensive series of pale to dark green or green trachytes, often porphyritic with feldspar phenoocrysts. The Wachacha lavas have yielded an average age of 4.5-4.6 millions years, which is about the last phase of volcanic activity in the upper Pliocene.

3.1.4 Climate

There is no metrological station in Menagesha suba forest. But there are two station i.e. Addis Ababa and Sebeta town nearest to the forest. The altitude of the lower part of the forest has a similarity with Sebeta's town altitude which is only 12 km away from the forest. The annual rainfall of the Sebeta station in the last 30 years in every decades indicate that it had 950-1050 mm. Addis Ababa, which has 2500m average elevation had area has annual rainfall of the last 30 years of 4 decades was between 1200 to 1350 mm (figure 3.2).

Menagesha Suba state forest is found in altitude ranges from 2200 m in the lower part to 3000 m in highest peak (Appendix 3). From this two station data, the annual rainfall in the forest area is between 900mm and 1500mm. The small rains occur from March to May and the high rains from June to September, with the higher concentration in July to August. August to October comprises the wet season and November to March the dry season.

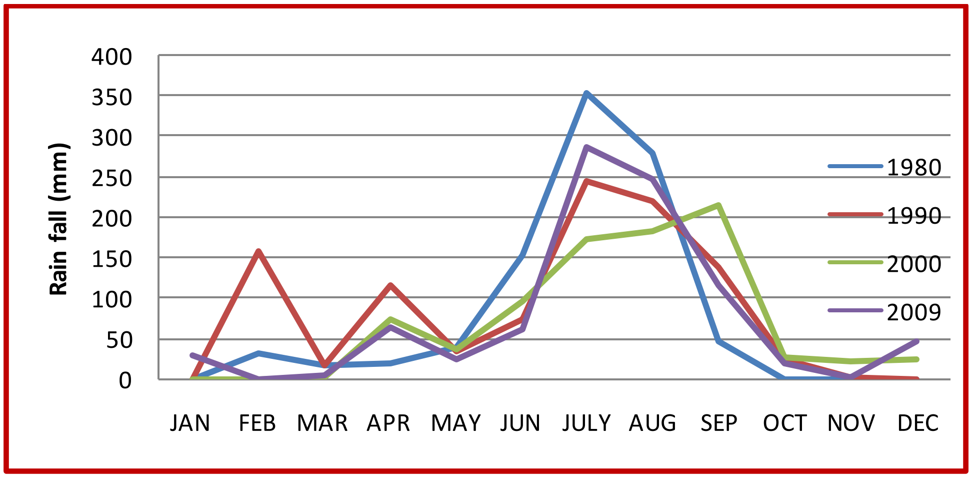

Figure 3.2: Monthly rainfall trends of Sebeta station

The average temperature of Addis Ababa is 17°C. Employing a temperature lapse rate of 1°C for each 180 m in increase altitude (Fantoli, 1965; Sebesibe Demissew, 1988), the mean annual temperature would be 18°C in the lower part of 2300 m and 15°C in the highest altitude. Therefore, the areas temperature ranges from 15°C to 18°C, with a mean of 16.5°C (Figure 3.3).

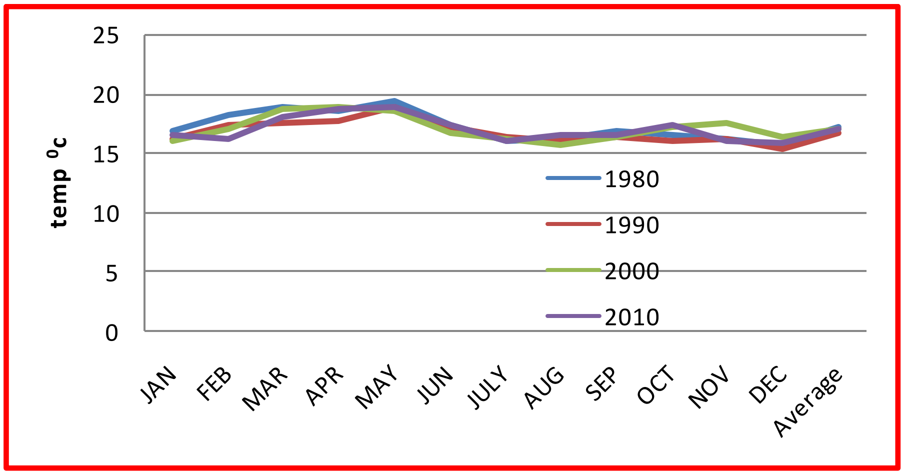

Figure 3.3: Monthly average temperatures trends of Sebeta station

3.1.5 Soils

Detailed accounts of the forest site history and soil characteristics are found in Zewedu Eshetu (2000). Accordingly, the soils in Menagesha Suba forest are shallow brown soils, Chromic Luvisol, on steep slopes and deep red soils profiles Rhodic Nithiosols, mainly in the depressions and on gentle sloping sites. The soil profiles consist of about 3 cm thick litter layer, about 15 cm mollic A horizon and understanding argic B horizon. In the Luvisoils, the argic B horizon is overlaying a C horizon of gray cemented volcanic ashes. The soil texture varies from silt clay loams in the surface soils to clay or silt clay loams in the B horizon.

3.1.6 Vegetation

Menagesha Suba Forest covers 3,418 ha of both natural and plantation forests as accounted in 2005. From the total, 2,350 ha forest coverage were existed before 1973. The additional 1,068 ha coverage of the forest was plantation forests and planted after 1973. Detailed data on the floristic composition and forest dynamics of the Menagesha forest is available from studies conducted by Sebesibe Demissew (1988). Some of the dominant species are *Olea africana*, *Allophylus abyssinicus*, *Maytenus* spp., *Euphorbia ampliphylla*, *Podocarpus falcatus, Juniperus procera, Erica arborea, Rosa abyssinica, Jasminum stans, Lobelia gibberoa, Solanecio gigas* and *Scadoxus multiflorus*.

3.2 Data Type and Sources

Primary data were generated from extraction of satellite image and field data collection. Much of secondary data sources were obtained from published and unpublished materials such as books, journals, articles, reports, and electronic web sites.

3.2.1 Satellite images

Landsat TM

Landsat TM satellite data have spatial resolution of 30 meters and it includes two middle infrareds and one thermal channel. These high-resolution scanners have seven spectral bands and cover a 185-by-185km area. For this study area, a single scene path/row 169/54, taken in January 1984 by TM sensor on board was used.

Landsat ETM

Landsat-7, which carries onboard the Enhanced Thematic Mapper (ETM) instrument, was launched on January 15, 1999 as part of the global research program of NASA's Earth Science Enterprise. The sensor has six spectral bands in the visible, near-infrared, and shortwave infrared regions of the electromagnetic spectrum (at 30m spatial resolution), one thermal infrared band (60 m and 120 m spatial resolution products), and one panchromatic band (at 15m spatial resolution). For this study a single scene path/row 169/54) was used that had been acquired by this sensor in January 2005.

SPOT: Système Probatoire d'Observation de la Terre

The acronym of SPOT stands for 'Earth Observation Test System' was the first earth Observation satellite launched by an European country. It was developed and operated by the CNES: Centre National d'Études Spatials at Toulouse. SPOT has a near-polar, sun-synchronous, 832 k high orbit with a repeat time of 26 days. However, the direction of the sensors of SPOT can be changed up to 27°, enabling the SPOT-sensors to make oblique views of the earth. This capability increases the repeat time considerable, up to several days. SPOT-1 was launched on 21 February 1986. SPOT-2 and SPOT-4 have already been launched with identical orbits and sensor systems. The spatial resolution is very large: the panchromatic mode has a pixel size of 10 m with a very high geometric accuracy.

3.2.2 Topographic map

Topographic map at the scale of 1:50,000 published in 1973 obtained from the Ethiopian Mapping Agency (EMA) were used for georeferencing, digitizing the roads and to interpret the changes in forest boundary.

3.3 Tools and Software

Different instruments and materials were used to carry out forest carbon measurement. Garmin GPS was used for locating plots with the help base map. Linear tape and diameter tape were used for locating plot boundary and for distance measurement and for measuring the diameter of the trees at breast height. Cutting the herbs and grasses under taken through sickle. White plastic bags were used to collect samples and big plastic bags to collect and weigh soils, herbs, grass, and leaf litter and weighted in weighing machine. The heights of the trees were measured using Haga hypsometer.

Various images processing and analysis software, which assist in calculating carbon stock estimation, were utilized. ERDAS IMAGINE 9.2, ArcGIS 10, Global Mapper 11, 3DEM and EASY GPS software were used for processing images and for mapping purpose. Microsoft Excel and SPSS software were used for presenting and analyzing the data collected from field and landsat imagery spectral responses.

3.4 Research Methods

In this study, remote sensing and ground based methods were used in combination. The procedures were described as follows.

3.4.1 Field Data Collection

The methods and procedures to be used to estimate carbon stocks in forests are simple step-by-step procedures using standard forest and carbon inventory guide lines and techniques. The following procedures were used.

i. ***Preliminary Field Data Collection***

a. Delineation of project boundaries

Spatial boundaries of the particular area need to be clearly defined to facilitate accurate measuring, monitoring, accounting, and verification. From many tools available for identifying and delineating study site boundaries, satellite imagery of SPOT was used with the help of ERDAS IMAGINE 9.2 and ArcGIS 10 software.

b. Stratification and boundary mapping of stratum

Once the project area has been delineated, the study site was divided into three blocks to make strata as homogeneous as possible using the ages of the forest as natural and planted forests before 1973, forest planted between 1973 and 1984 and the plantation after 1984 (Figure 3.4). This stratification was done by using 1973 published topographic map, 1984 landsat TM image and 2005 landsat ETM and SPOT images.

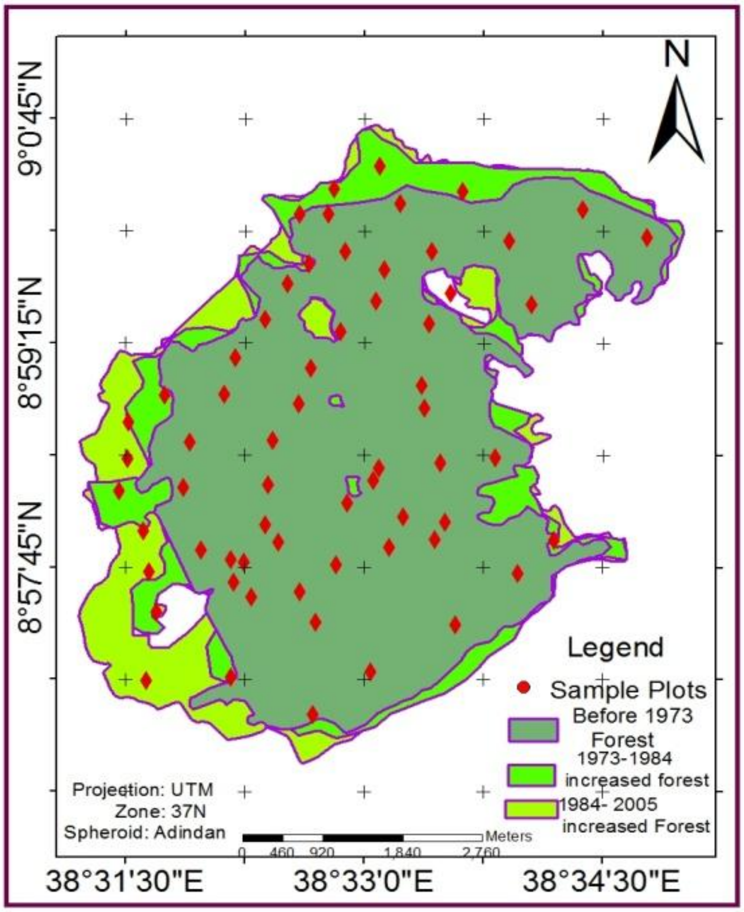

Figure 3.4: Map of Menagesha Suba forest stratified based on forest age.

c. Pilot inventory for variance estimation

A preliminary inventory was needed to complete to estimate the variance of the carbon stock in each forest stratum and to provide a basis for calculating the number of permanent plots required for the inventory. It was carried out within three circular plots randomly in each forest block and/or stratum within the study boundary. The radius and the area of the circular plot were 8.92 m and 250 m^2, respectively. Random selection was taken in order to cover the natural variability present within the different forest blocks and /or stratum. In this study, all trees above and equal to 5 cm in diameter at breast height (DBH) within 250 m^2 sample. Plots were measured and recorded on the data sheet.

d. Determining Type and Number of Measurement Plots

Shape and size of plots

Forest carbon measurement can be carried out in both rectangular and circular plots. Nevertheless, circular plots are recommended for this study because they are relatively easy to establish, and has less edge effect. The radius of each plot is dependent on the density of the forest as shown in Appendix 1 (MacDicken, 1997). Because of the study site is moderately densely vegetated, a circular plot of 8.92 m (250m^2) was chosen to conduct field data collection.

Number of Plots

It was impossible to measure every tree within a forest. Statistical sampling theory explains how measuring only a fraction of the trees provides a measure of the biomass that is good enough to be used in carbon accounting.

Because of satellite image techniques combined with few numbers of ground survey sample plots have the ability to interpolate large areas with high level of precision, 63 randomly selected points which represent the whole area was taken. The distribution of the sample was made systematic sampling based on their strata and random sampling after stratification. Off 63 plots, 48 were distributed in strata natural and planted forests before 1973, 7 plots in a year between 1973 and 1984 and the remaining 8 plots were in strata after 1984. The numbers of well distributed sample plots are shown in Figure 3.4.

2 Field Data Collection

a. Above-ground tree biomass (AGTB)

The DBH (at 1.3m) and height of individual trees greater than or equal to 5cm DBH were measured in each circular 250 m^2 plot that is 8.92 m in radius using Haga hypsometer, diameter tape and linear tape, starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice.

Plate 3.1: DBH measurement of the tree in field (Photo: Mesfin, 2011)

b. Leaf litter, herbs, and grass (LHG)

Four rectangular sub plot of 1 square meter in size was established at the center of each plot. All the litter (dead leaves, twigs) within the 1 m^2 sub plots were collected and weighed. 100 gm of evenly mixed sub-samples are brought to the laboratory to determine oven dry mass from which total dry mass was calculated. Likewise, herbs and grass (all non woody plants) within the plots were collected by clipping all the vegetation use to the mineral soils, weighing it, placing in a sample weighing bag and brought it to the laboratory to determine the oven dry weight of the biomass.

Plate 3.2: Grass, herbs and litter collection in field (Photo: Mesfin, 2011)

c. Carbon in dead wood

Carbon in dead wood was measured in the sample area within 8.92 m radius. There are three types of dead woods and each of them existed in the plot areas were measured and recorded.

I. Standing dead trees

Standing dead trees are important carbon sinks and also carbon sources which need to be accounted for. The height and the DBH of each tree above 5 cm was measured and recorded.

II. Logged trees

Stumps may be dead or alive. The stumps taller than 1.3 m was measured in the same way as standing dead trees while less than 1.3 m tall the diameter was measured as close as possible to the top. In addition, the height of the stump was recorded.

III. Downed and dead wood

Fallen branches and stems were divided into sections of roughly one meter and the exact length and diameter at the middle of each section was recorded. For stems and / or branch fragments that were < 1 meter long, the length and diameter at the middle was measured.

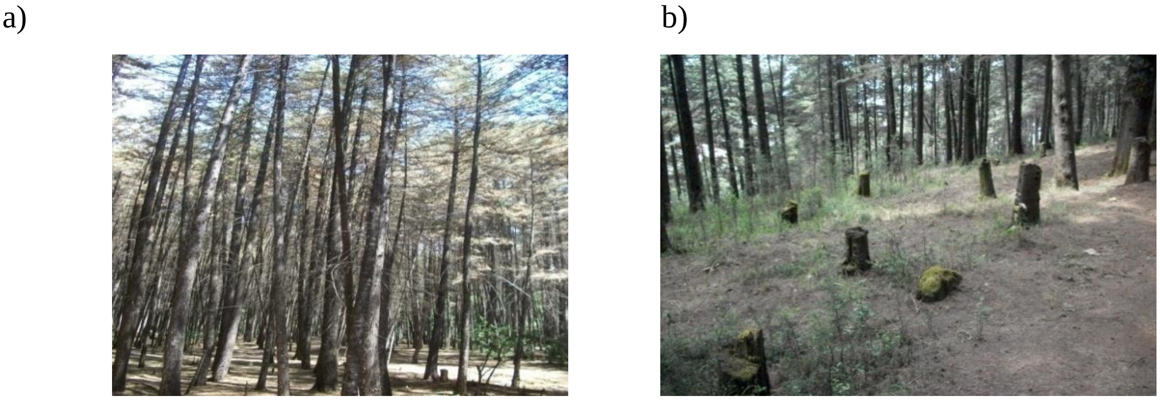

Plate 3.3: Standing (a) and logged trees (b) dead wood (Photo: Mesfin, 2011)

d. Soil organic carbon (SOC)

Soil organic carbon was determined through samples collected from the default depth of 30 cm as prescribed by the IPCC (2006). Near the center of each plot and/or sub-plot four pits of up to 30 cm in depth were dug to best represent forest types in terms of slope, aspect, vegetation, density, and cover. For the purpose of estimating bulk density, three individual soil samples of approximately 100 or 300 cm^3, one each from three depths (0-10 cm, 10-20 cm, and 20-30 cm) were collected with the help of a standardized 100 or 300 cm^3 metal soil sampling corer. Similarly, one composite sample was collected mixing soils from all the three layers in order to determine concentrations of organic carbon and then weighed at a precision of 0.1 gm. Around 100 gm of composite sample were measured and taken into laboratory from each plot which represents for all four pits within 250 m^2.

Plate 3.4: Digging (a) and measuring (b) of sample Soil (Photo: Mesfin, 2011)

3.4.2 Image Processing

i. Pre processing

a. Geometric Correction

For this study multi-temporal images and topographic maps were used. The 1:50,000 topographic maps of the study area were scanned, georeferenced and projected to UTM coordinate system, map zone 37 N of clack 1880 spheroid and Adindan datum. The satellite images were georeferenced to topographic map. Road and river layers were digitized from the georeferenced topographic maps.

b. Band selection

Band selections were made in order to obtain the most important information from remotely sensed data through the analyses of reflectance properties of objects or features. Spectral reflectance curve of the different vegetation types of the area and the histogram behavior of the bands were used for the purpose of image processing of Landsat satellite images the ERDAS IMAGINE 9.2 software was used.

c. Image enhancement and interpretation

Satellite image contains a detailed record of features on the ground at the time of data acquisition. In relation to this, Lillesand and Kiefer (1994) suggested that image interpreters should have good power of observations coupled with imagination and it is important that the interpreters have a careful understanding of the phenomenon being studied as well as knowledge of the geographic region under study. To do so, digital image enhancement and interpretation techniques were used in this study.

To increase the visual interpretability of the satellite images and the amount of information that can be visually interpreted from the data both True Color Composite (TCC) and False Color Composite (FCC) were produced. Digital image enhancement techniques such as contrast stretching, band ratios and NDVI analysis were done.

3.4.3 Data extraction using landsat multispectral satellite imagery

In each plot in which the coordinate has been previously identified, a number of spectral characteristics from the Landsat image were extracted. These data were then used as input in statistical analysis. The spectral characteristics used in this study consist of single band data (i.e. the digital number of band 1, 2, 3, 4, 5 and 7), different band ratios, combination of different spectral bands as well as some vegetation indices and texture measures.

Statistical analysis

The model was constructed using stepwise multiple regressions in a similar fashion (Lu, 2002). The number of independent variables for starting the analysis was 39 variables consisting of 6 single band values, 5 different band ratios, 10 combinations of different spectral bands, 6 vegetation indices and 12 texture measures. The dependent variable was carbon stock per pixel derived from inventory data. The analysis was conducted to select a formula (equation) that uses variables but having high correlation coefficient.

3.4.4 Carbon stock estimation by the derived model

The resulting model, i.e. an equation to estimate carbon stock at pixel level, was then applied for calculating the landscape level carbon stock in the Menagesha Suba forest in 1984 and 2005. The subset of Landsat 1984 image was geometrically corrected using the map-to-map rectification with the 2005 image as the reference. In each image subset, the carbon stock of each pixel was calculated based on the equation developed during this study. The general approaches taken in this study were shown in the flow chart below (Figure 3.4).

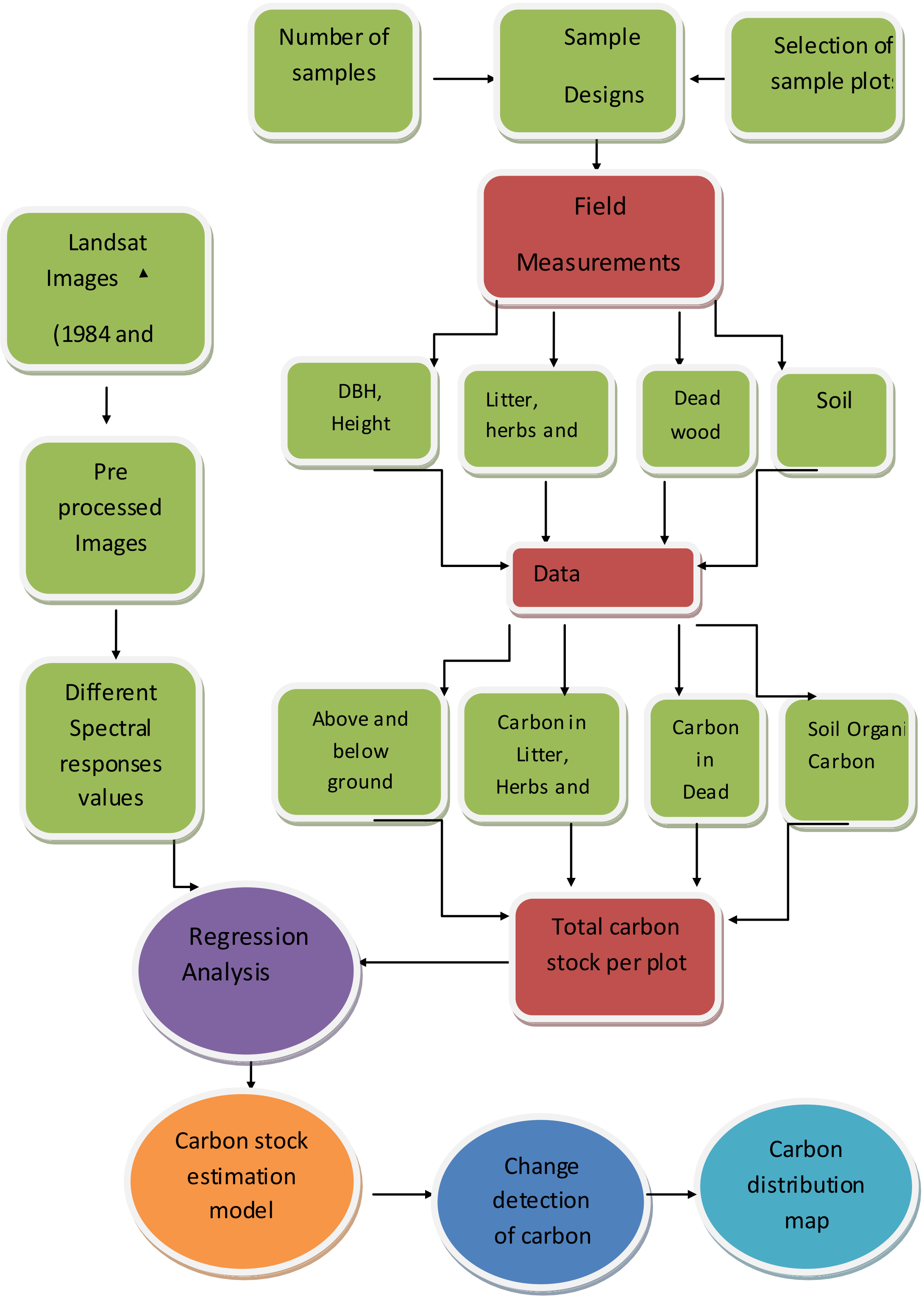

Figure 3.5: General approach for carbon sequestration estimation

3.5 Data Analysis

The collected data was organized and recorded on the excel data sheet. The quantitative structure analysis was made using Microsoft excel of 2007 and SPSS software 16 version from data DBH, length, diameter, height of each species fresh weight and dry weight of litter, herbs and grasses and soil. The frequencies of each tree species in all 63 sample plots were analyzed. Biomass of each tree species in all sample area was made using data from diameter class distribution, referred to as above ground biomass. The relationship between different parameter was tested by linear regression and descriptive statistics. The height and diameter data were arranged in classes for applying appropriate model of biomass estimation equation. Different linear and multi linear relationship correlation were made from inventory data and pixel reflectance value. Finally, model was developed using multi linear regression analysis after examining the different linear regression analysis.

3.5.1 Data analysis for inventory data

i. Determination of basal area (BA)

Basal area is calculated, for all trees with a diameter at breast height ≥ 5 cm, by using the formula (Yitebitu Moges *et al.*, 2010):

$$BA = (\pi/4 * DBH)^2 \text{ OR } 0.785\ DBH^2$$

Where, BA is basal area and DBH is the diameter of the trees at breast height.

3.5.2 Estimation of carbon in different pools

i. Estimation of carbon in above ground pool

The above ground biomass of all tree species in the sample plot was estimated. For above ground biomass estimation different mathematical equation has been developed and used by many researchers (Brown *et al.*, 1989; Negi *et al.*, 1988). These equations are species specific, particularly in the tropics. The general equation has been developed in modified form. It is more general in nature (Alves *et al.*, 1997; Brown 1997and Schroeder *et al.*, 1997) and applicable in field. Some of this equation is life zone dependent others are not specified. It is not possible to cut all the trees to estimate their biomass. Considering the mathematical terms and the models are developed by FAO (1997), Negi *et al.* (1988) and Brown *et al.* (1989) (Appendix 3). The model developed by Brown *et al.* (1989) to estimate above ground biomass has been used in present investigation due to accuracy and life zone of the study is fitted with the life zone recommended for the equation. The allometric equation is suitable for rain fall less than 1500mm and the DBH > 5 cm. The literature revealed that this method is nondestructive and is most suitable method (Alves *et al.*, 1997; Brown, 1997; Schroeder *et al.*, 1997; FAO, 1997). The equation taken for the present study was shown as follows:

$$Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH^2)$$

Where, Y is above ground biomass, DBH is Diameter at Brest Height .Details of the equation is presented in Appendix3

The amount of biomass in each species using the above equation was calculated. They were sum up to get total carbon stock in each plot and then converted to hectare and pixel size (30m×30m) by using conversion factor.

Since the pilot areas are part of the tropical and sub-tropical region, the biomass stock density of a sampling plot will be converted to carbon stock densities after multiplication with the IPCC (2006) default carbon fraction of 0.47, as the dry biomass contains 47% organic carbon.

ii. Estimation of belowground carbon pool

One of the most common descriptors of the relationship between root (below-ground) and shoot (above-ground) biomass is the root-to-shoot ratio, which has become the standard method for estimating root biomass from the more easily measured shoot biomass. Belowground biomass estimation is much more difficult and time consuming than estimating aboveground biomass. Measurements of root biomass are indeed highly uncertain, and the lack of Guidelines for measuring carbon stocks in forests empirical values for this type of biomass has for decades been a major weakness in ecosystem models. To simplify the process for estimating below-ground biomass, ratio of root-to-shoot ratio of was 1:5 was used (MacDicken, 1997) because 20% of the above ground biomass is below ground biomass. Thus below ground biomass was estimated by multiplying the above ground biomass by a factor of 0.2

Belowground biomass = Aboveground forest biomass × 0.2.

Because the carbon content of the biomass is about 47% by dry weight, the carbon stock in the biomass was estimated using the formula:

Biomass C stock = Biomass x 0.47

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

CO2 eq = biomass C × 3.67

iii. Estimating organic carbon in dead litter, herbs and grass pool

The forest floor, or litter layer, is defined as all dead organic surface material on top of the mineral soil. Some of this material will still be recognizable (for example, dead leaves, twigs, dead grasses and small branches) and some will be unidentifiable decomposed fragments of organic material. In addition dead wood with a diameter of less than 5 cm is included in the litter layer (Subuied *et al.,* 2010).

$$B_{LHG} = \frac{W\ field}{A} * \frac{Wsubsample\ \ (dry)}{Wsubsample\ \ (fresh)} * \frac{1}{10000}$$ (Subuied *et al.,* 2010)

Where*: LB = Litter biomass (t* ha^{-1}*)*

W_{field} *= weight of wet field sample of litter, destructively sampled within an area of Size 1* m^2 *(g);*

W subsample, dry= weight of the oven-dry sub-sample of leaf litter, and herbs taken To the laboratory to determine moisture content (g), and

W subsample, fresh= weight of the fresh sub-sample of litter, taken to the Laboratory to determine moisture content (g)

Carbon stock in herbs and grasses were estimated in similar equation as litter biomass estimation. The average of carbon in dead litter and in herb and grass were used to know the amount of carbon in litter, herb and grass pool.

The carbon content in LHG was calculated by multiplying LHG with the IPCC (2006) default carbon fraction of 0.47, assuming there is no substantial decomposition of the litter layer to cause substantial losses of carbon.

iv. Estimation of dead wood pool

The amounts of biomass found in dead wood were measured according to the types of dead wood. For standing dead wood which have branches were measured similar to the biomass estimation allometric equation of above ground biomass. As this standing dead wood have not leaves, there was a subtraction of 5-6 percent for softwood/ conifer species and 2-3 percent of hardwood/ broadleaved species (Pearson *et al.*, 2005). Most of the existing species were conifer, and hence 5-6 percent reduction from the total above ground biomass of each tree provided estimates of the dead wood carbon stock.

The allometric equation stated in REDD methodology (2009) was used in this study to estimate the amount of biomass in standing stump dead wood.

$$BSDW_2 = \sum_{i=0}^{n} \frac{1}{3} \left(\frac{D}{200}\right)^2 h * s$$

Where, *biomass is expressed in kg, h = length (m), D = tree diameter (cm) and s = specific gravity (g cm^{-3}) of wood. The specific density is estimated at 0.5 g cm^{-3} as default value, but can be around 0.8 for dense hard woods and around 0.3 for very light species in tropical regions (Hairish et al., 2001).*

The volume of lying dead wood per unit area is estimated using the equation (Warren and Olsen, 1964) as modified by Van Wagner (1968) separately for each density state:

$$V = \pi^2 (D^2/8L)$$

Where, *V is the volume in* m^3/ha; *D is diameter of the dead wood tree and L is the length of the dead wood.*

$$\text{BDLW} = \sum_{i=0}^{n} V * s$$

Where, *BDW = Biomass down lying wood, V= volume and s = specific density*

$$TBDW = SBDW1 + SBDW2 + DLDW$$

Where, *TBDW = Total biomass of dead wood in a given plot; SBDW1= Biomass of standing dead wood which have branches; BSDW2 = Biomass of Standing dead wood which has no branches and BDLDW= Biomass of down lying dead wood*

The carbon content in dead wood is calculated by multiplying TBDW with the IPCC (2006) default carbon fraction of 0.47.

v. Estimation of soil organic carbon pool

To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample. Soil was sampled constant depth of 30 cm.

$$Wav,wet = \frac{w1 + w2 + w3 + w4}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Wav,dry = \frac{w1 + w2 + w3 + w4}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, *Wav, wet and Wav, dry are average wet weight and oven dry weight of soil in gm per 250* m^2 *sampling quadrant respectively, w1, w2, w3, and w4 are wet weight and oven dry weight of soil sample in gm per 1 m × 1 m sampling unit.*

$$V = h \times \pi r^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, *V is volume of the soil in the core sampler augur in* cm^3*, h is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm.*

$$BD = \frac{wav \quad dry \quad wt}{V} \text{ ……………………………………. (4)}$$

Where, *BD is bulk density of the soil sample per plot,* W_{av}*, dry is average oven dry weight of soil sample per* $250m^2$ *quadrant, and V is volume of the soil sample in the core sampler auger.*

$$SOC = BD * d * \% C \text{ ……………………………………..(5)}$$

Where, *SOC= soil organic carbon stock per unit area (t* ha^{-1}*),*

BD = soil bulk density (g cm^{-3}*),*

D = the total depth at which the sample was taken (30 cm), and

%C = Carbon concentration (%)

Percentage of carbon concentration in the sample soil was calculated from percentage of carbon in Menagesha Suba forest soil obtained by Zewdu Eshetu (2000). The concentration of carbon in the forest ranges from 6% - 14% in different altituditional profiles (Figure 4.1). Form the altitude obtained from field using GPS then the concentration of carbon for each plot was derived.

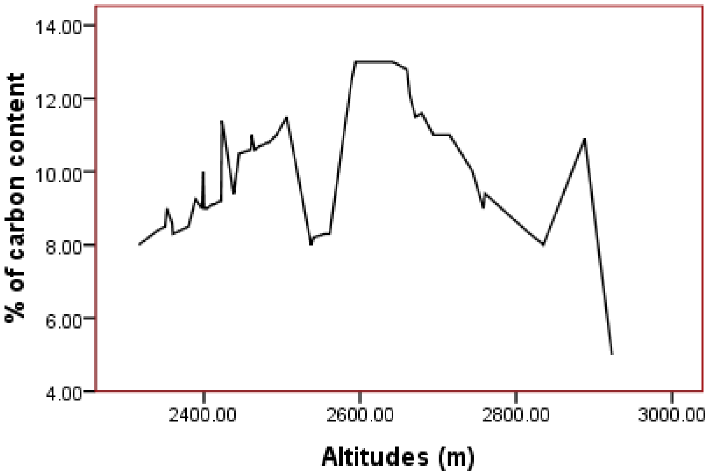

Figure 3.6: Percentage of carbon content versus altitude in Menagesha forest (Source: Zewdu Eshetu, 2000)

vi. Total carbon stock density

The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of that stratum using the following formula (Subuied *et al.*, 2010).

Carbon stock density of a stratum:

$$C_{density} = C_{AGB} + C_{BB} + C_{LHG} + CDW + SOC$$

Where,

$C_{density}$ = Carbon stock density for all pools for each plot [ton ha^{-1}]

C_{AGB} = Carbon in above -ground tree [ton C ha^{-1}]

C_{BB} = Carbon in below-ground [ton C ha^{-1}]

C_{LHG} = Carbon in litter, herbs and grasses [ton C ha^{-1}]

$C\ soc$ = Carbon in organic soil [ton C ha^{-1}]

CDW = Carbon in dead wood [ton C ha^{-1}]

The total carbon stock is then converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al.*, 2005).

3.5.3 Development of spectral responses using landsat images

Different types of spectral responses were tested for regression analyses (Lu, 2005).

1. Single band DN (6 TM bands)
2. Linear Combination of multiple bands
    - MID57 =TM 5 + TM 7
    - Albedo = TM 1 + TM 2 + TM 3 + TM 4 + TM 5 + TM 7
    - VIS123 = TM 1 + TM 2 + TM 3
    - Veg. Index = NIR-R
    - KT1=0.304TM1+0.279TM2+0.474TM3+0.559TM4+0.508TM5+0.186TM7
    - KT2= -0.285TM1-0.244TM2-0.544TM3+0.704TM4+0.084TM5-0.18TM7
    - KT3 = 0.151TM1+0.197TM2+0.328TM3+0.341TM4-0.711TM5-0.457TM7
    - Principal component analysis(PCA1-PCA3)
3. Simple Ratio
    - TM 4/3 = TM 4/TM 3
    - TM 5/3 = TM 5/TM 3
    - TM 5/4 =TM 5/TM 4
    - TM 5/7 = TM 5/TM 7
    - SQRT(NIR/R)
4. **Normalization ratios**
    - ND32= (TM3-TM2)/(TM3+TM2)
    - ND57= (TM5-TM7)/(TM5+TM7)
    - ND53= (TM5-TM3)/(TM5-TM3)
    - ND54= (TM5-TM4)/(TM5-TM4)
    - TNVI= Sqrt ((NIR-IR)/(NIR+IR)+0.5)
    - NDVI = (IR - R)/(IR + R)
5. **Texture analysis**

The variance and skewness of landsat thematic images with window 7×7 were analyzed for this study.

3.5.4 Development of carbon stock estimation models

Remotely sensed data are comprehensive responses of vegetation stand structure, vegetation density, and vegetation species composition. Different forest stand structures have different reflectance and texture patterns in various wavelengths, and the relationships between biomass and remotely sensed data are different.

All the sample data had accurate coordinates that were provided by Global Positioning System (GPS) devices and geometrically rectified TM color composites during the fieldwork. These sample data were linked to image variables to extract the mean value for each sample. A window size of 3×3 pixels was used to read each sample. Retrieval of pixel value for each sample was conducted based on inquiry cursor on corresponding TM spectral image, vegetation indices, or textures. After the image values for these samples were extracted, Pearson’s correlation coefficient was used to analyze such relationships. It measures the strength of linear relationships between two variables. If the coefficient was close to 1, it means there was a strong relationship between them.

In this research, one variable was carbon estimated in ground survey; another variable was the remotely sensed data, such as single TM band, band ratios, vegetation indices, and texture measures. Using carbon as a dependent variable and remote-sensing data as independent variables, linear and multiple regression models were used to establish the relationships between biomass and remote-sensing data. The critical steps were to find the appropriate independent variables to the combination of multiple independent variables can provide the best-estimated results. The coefficient of determination (R^2) was an indicator that can be used to determine whether or not the regression model was good, as R^2 measures the percent of variation explained by the regression model. Enter regression analysis was used to find the best independent variable combination.

The temporal changes of carbon stock were derived from the procedure as model of 2005 landsat TM satellite images. After 1984 TM image which was resample and corrected to 2005 Landsat TM, by using reflectance value the carbon stock was estimated.

4. Results and Discussion

4.1 Results

4.1.1 Existing forest conditions

Juniperus procera, Olea africania, Cupressus lusitanica, Pinus radiata, Eculaptus spp., Podocarpus falcatus, Erica areborea, Sideroxylon oxyacantha, Scalopia thiefolia, Prunus africana, Haygenia abyssinia, Rapanea simensis, Carisa edulis, Calpurnia subdicandra, Tecela nobilis, Ekebergia capensis, Myrsine africana, Eragrostis abyssinica and Euclea schimperi were the major tree species observed in the plots (Fig 4.1). *Juniperus procera* was the most dominant species in both plantation and natural forests. It covers 33% of the tree in the study plot sites. *Sideroxylon oxyacantha, Eculaptus spp. and Podocarpus falcatus* were the 2nd, 3rd and 4th most abundant tree species in the sample plots, and their relative coverage was 13%, 9% and 8% respectively. *Carisa edulis, Calpurnia subdicandra, Tecela nobilis, Ekebergia capensis and Myrsine africana* were the least abundant species with relative abundance of 1%.

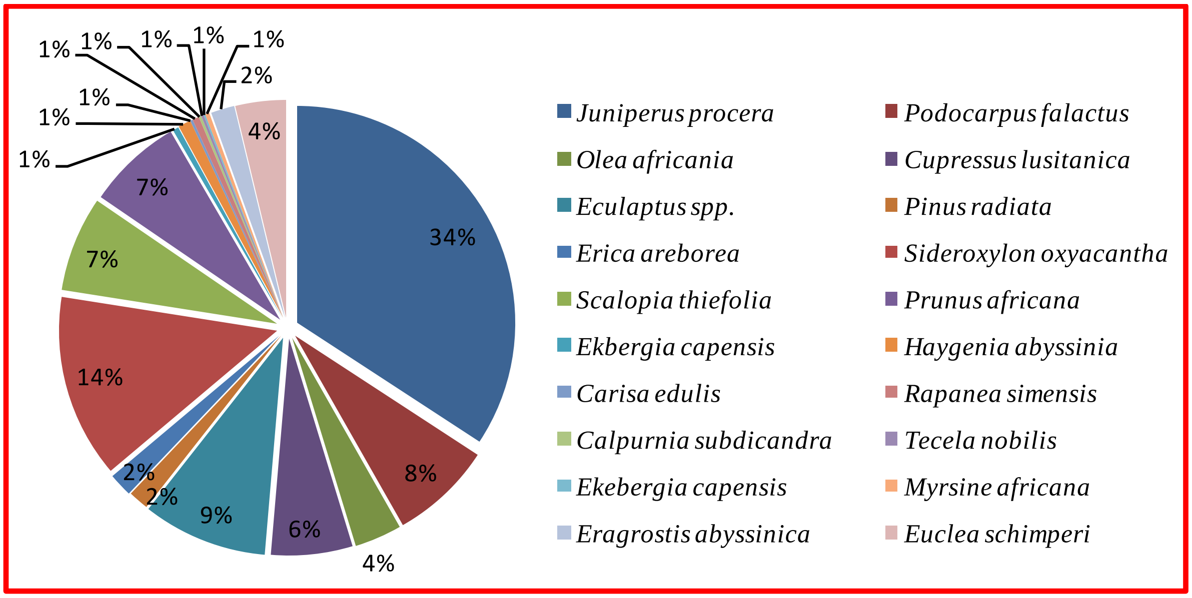

Figure 4.1: Relative abundance of tree species composition in the Menagesha Suba State forest.

A total of 1490 trees >5 cm DBH were measured for estimating above ground tree biomass, as per IPCC guide line. The average DBH in all species was 20 cm. From the measured data, majority of the trees fall in range of 10-26 cm DBH class (Figure 4.2). The DBH of the trees less than 10 cm were the next largest range. The smallest numbers of trees were those with DBH class greater than 100 cm. These trees were belonging to the old growth forests.

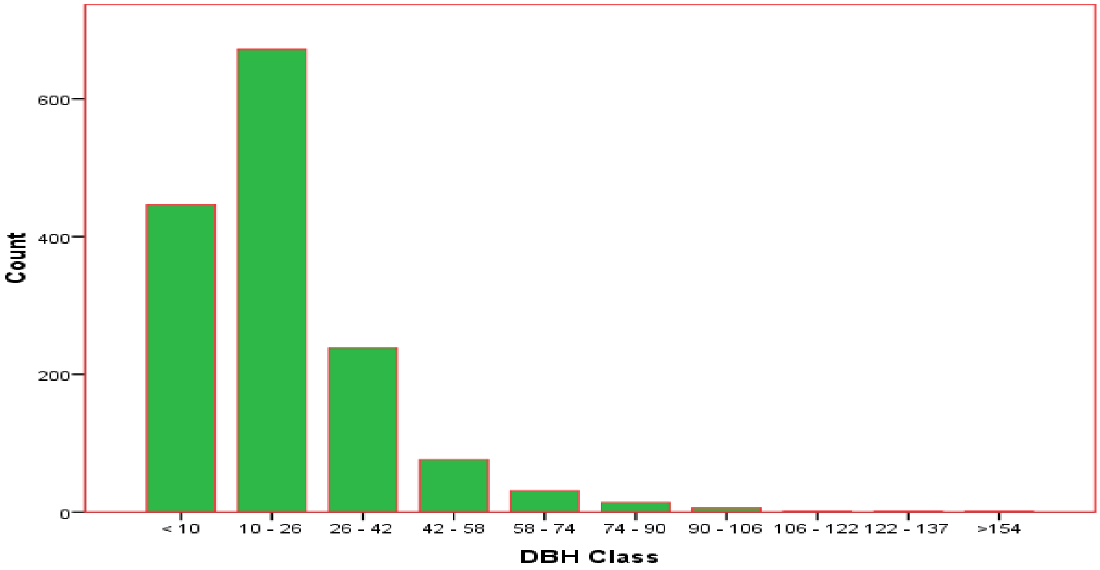

Figure 4.2: DBH class distribution of existed trees in Menagesha forests

It was observed that there was a strong difference among tree species in their size classes (Figure 4.3). The DBH value was largest for *Pinus radiata* with the average value of 42.34 cm. The 2nd and 3rd largest DBH average value were *Cupressus lustanica and Myrsine africania* with average DBH of 28 cm and 26.7 cm, respectively. Smallest DBH of 5.66 cm was observed from *Carisa edulis*. The DBH for other species ranged between 5.66 cm and 42.34 cm.

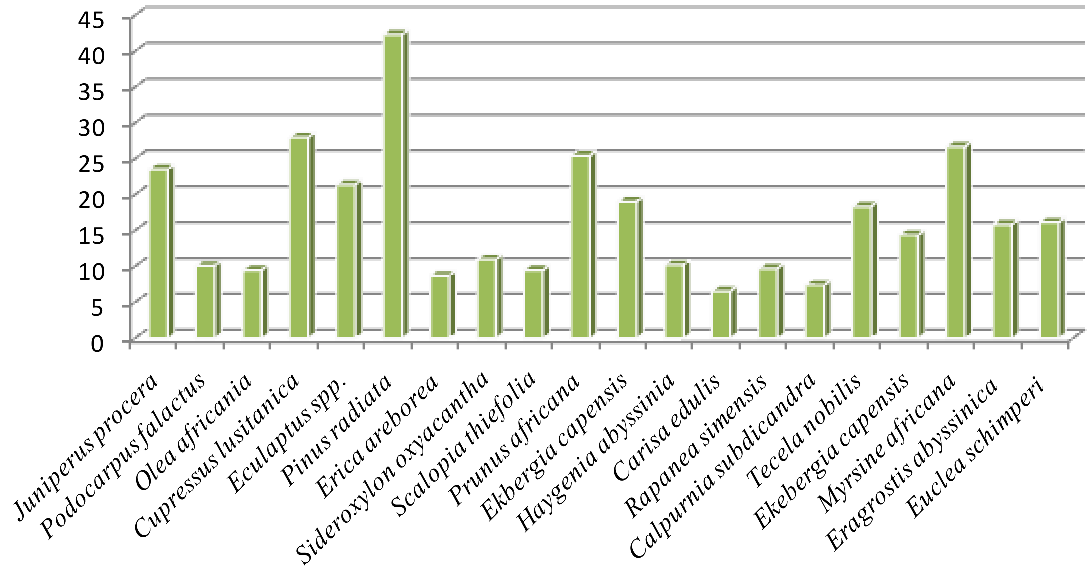

Figure 4.3: Average DBH class for each species

The basal area varied between 0.14 m^2 and 226.86 m^2 per tree with the mean value of 3.15 m^2 per tree.

4.1.2 Forest carbon stock in different pools

i. Above ground carbon pool

The average carbon storage in all species was 0.213 tons per tree. The maximum and minimum carbon content in a single tree was 17.705 and 0.00978 tons. From each trees carbon stock, the average of each species was calculated and 0.561 tons of the largest carbon stock was observed in *Pinus radiata* species. 0.263 tons, 0.207 tons, 0.196, 0.171 tons of next largest average carbon stock were observed in species of *Cupressus lusitanica, Prunus africana, Juniperus procera and Sideroxylon oxyacantha* respectively (Figure 4.4). In *Carisa edulis* the lowest average above ground carbon stock with a value of 0.005 tons was observed.

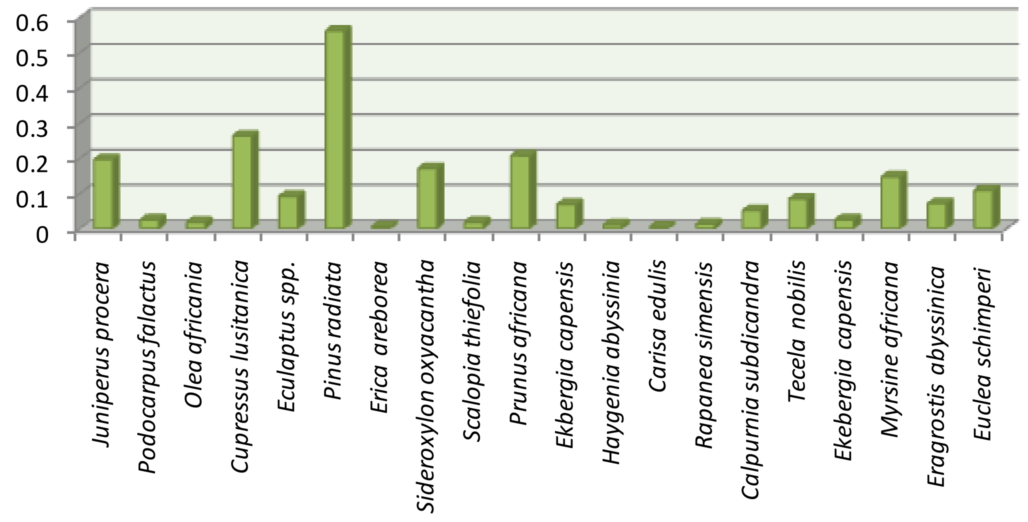

Figure 4.4 Average above ground carbon for each species

Carbon stock in each sample plot was calculated by summing up the carbon stock in each species existed within the sample plot (Appendix 6). The minimum and maximum carbon stock of this study was 0.363 and 28.110 tons per plot. The average carbon stock was 7.225 tons. The minimum and maximum carbon stocks per pixel were 1.31 tons and 101.2 tons respectively and the mean was 26.1 tons. 133 ± 99 tons ha^{-1} was the average above ground carbon stock in the study area (Figure 4.5).

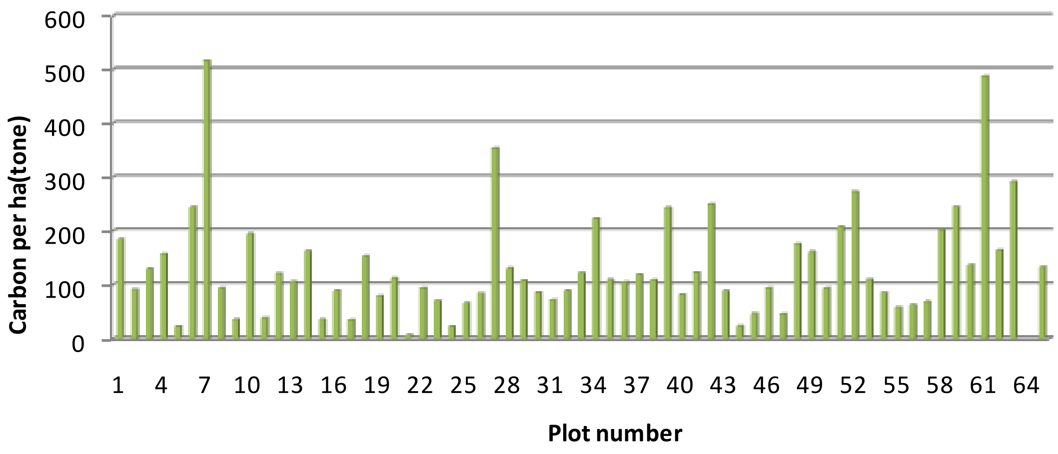

Figure 4.5: Above ground carbon stock per hectare

i. *Below ground carbon stock*

The minimum and maximum below ground carbon stock per hectare were 1.3 tons in plot 21 and 103 tons in plot 7 respectively (figure 4.6). Plot 61 had also the largest below ground carbon stock with 97.5 tons ha^{-1}. The others plots were the carbon stock between these ranges. The average below ground carbon stock was 26.99 ± 19.8 tons ha^{-1} (Appendix 7).

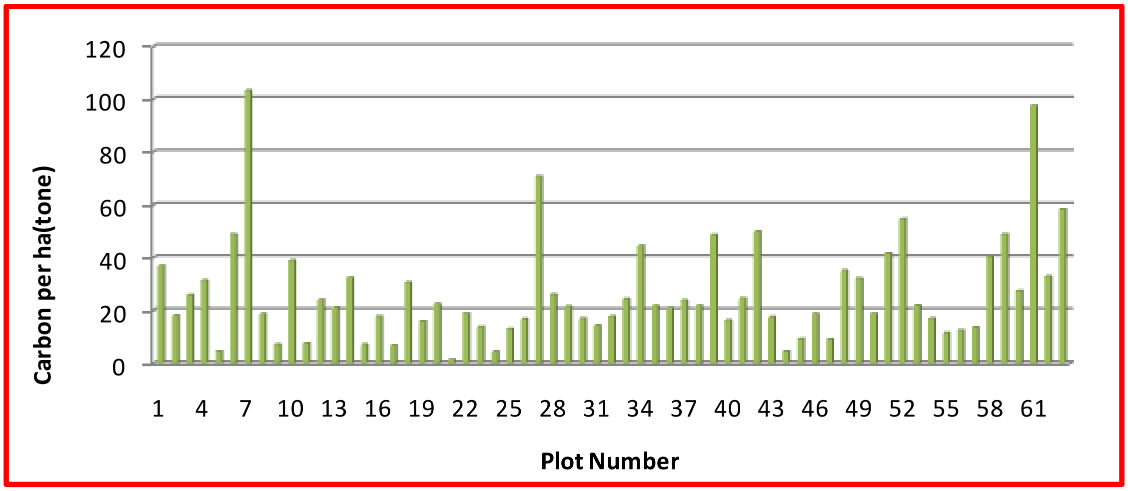

Figure 4.6: Below ground carbon stock in the study plot areas

ii. *Carbon stock in litter, herbs and grasses (CLHG)*

The largest Carbon Stock in Litter, Herbs and Grasses were observed in plot 35 (Figure 4.7). The highest and lowest carbon stock was observed in plot 44 with carbon stock per hectare of 30 tons and 1.7 tons respectively (Appendix 8). The average carbon stock in litter, herbs and grasses from all plots was 11.5 tons ha^{-1}. Mean total carbon stock in the litter layer and herbaceous vegetation was estimated to be 6.5 and 4.3 ton/ha respectively.

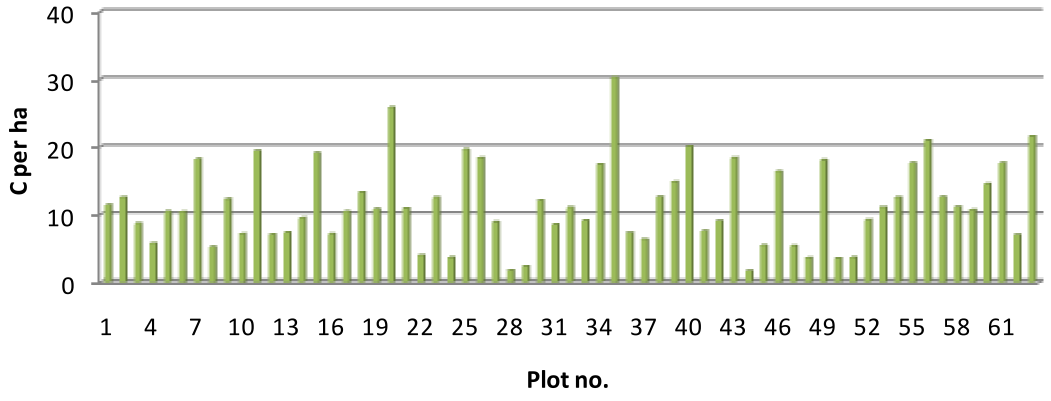

Figure 4.7**:** Carbon stocks in the sample plots of litter, herbs and grasses.

iii. Carbon stock in dead wood pool

The maximum dead wood carbon was observed in plot 20 with a carbon stock of 297 tons ha^{-1} (Figure 4.8). This plot had the largest because of large DBH size standing dead wood trees. The 2nd largest was in plot 57 with 69.5 tons ha^{-1}. The average carbon stock of dead wood in plots was 6.34 ± 38 tons ha^{-1}(Appendix 9).

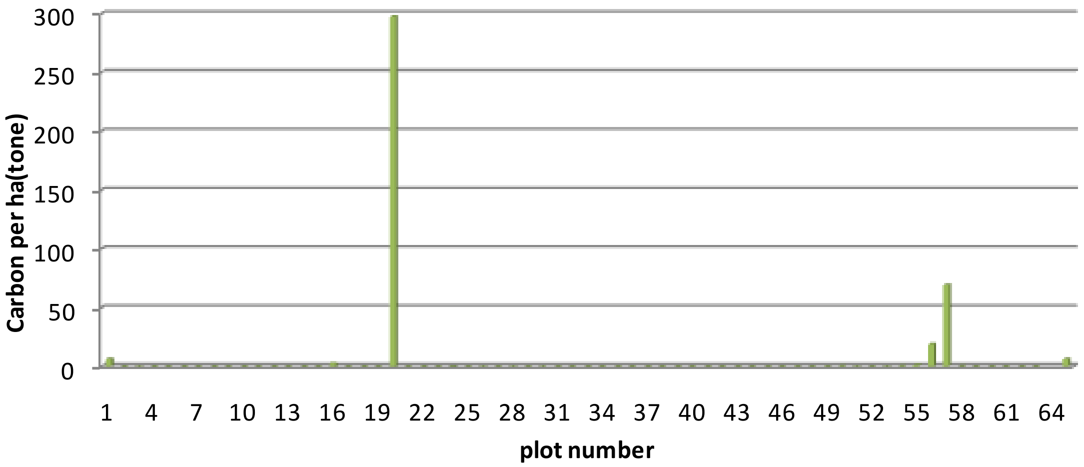

Figure 4.8: Dead wood carbon stock in the Menagesha forest

iv. Soil organic carbon pool

The average bulk density of soil investigated in Menagesha Suba forest was 0.414 gm/cm^3, suggesting high soil organic matter in the mineral soils. The highest and the lowest were

0.352 gm/cm^3 and 0.449 gm/cm^3 in plot 56 and 22 respectively. Most of the sites in the observed plots had similar values of bulk density.

The carbon content of the soil in Menagesha Suba forest was ranges from 5% to 13%. The lowest in plot 8 was a new plantation site after 1973 and found at the highest altitude above 2700 m (Figure 4.9). Plot 22 had the highest carbon content found in the old growth with expected age of > 400 years. The average soil organic carbon investigated in the study area was 9.78 % by oven-dry weight (Appendix 10).

Data on soil organic carbon of the study presented in Appendix 9 indicate that the maximum was 175 tons ha^{-1} in plot 22.64 tons ha^{-1} was the minimum soil organic carbon found in plot 8. The average carbon in organic soil in the present study was 121.28 ± 21tons ha^{-1}(Figure 4.9).

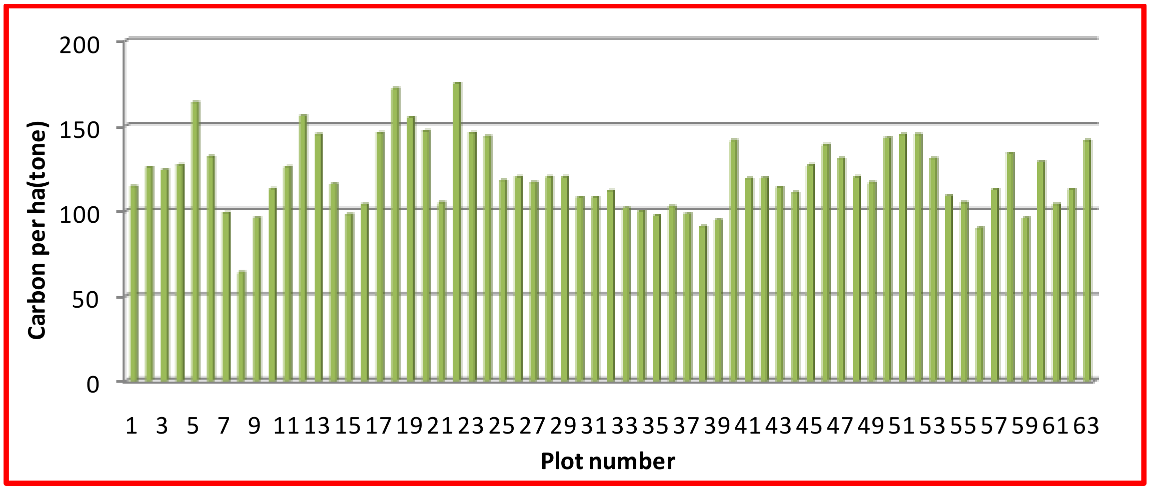

Figure 4.9: Soil organic carbon investigated in Menagesha Suba Forest

4.1.3 Total Carbon stock and carbon density

The largest total carbon stock was observed in plot 7 with a value of 728 tons ha^{-1} (Appendix 11). 697.5 tons ha^{-1} was the 2nd largest stock in the study plot sites. In plots 21, 24 and 5 contain the lowest carbon stock with 118, 173 and 179 tons ha^{-1} respectively. The average carbon stock was 293± 124 tons ha^{-1} (Figure 4.10).

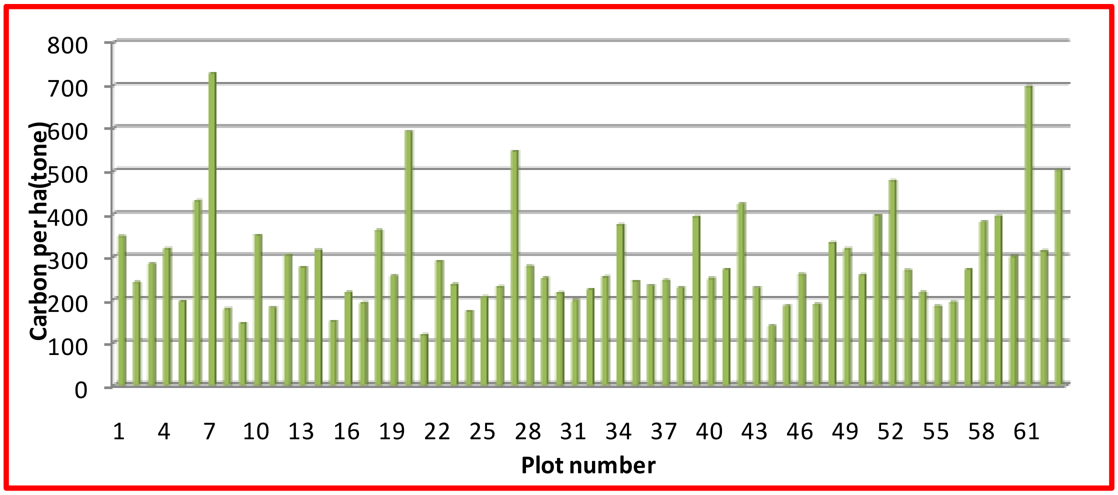

Figure 4.11: Total carbon stock in sample plots of Menagesha Suba State forest

4.1.4 Comparison of different carbon stock pools

In the present study, the largest carbon stock covered by above ground carbon and which accounts averagely 46% of the four carbon pools (Figure 4.11). This carbon stock was mainly derived from the forest biomass. 41% of the carbon storage was in soil organic carbon pool. Sufficient amount of carbon was observed below ground. Carbon pools in litter, herbs and grasses and in dead wood stores a small part of the total coverage and they accounts 2% each (Appendix 11).

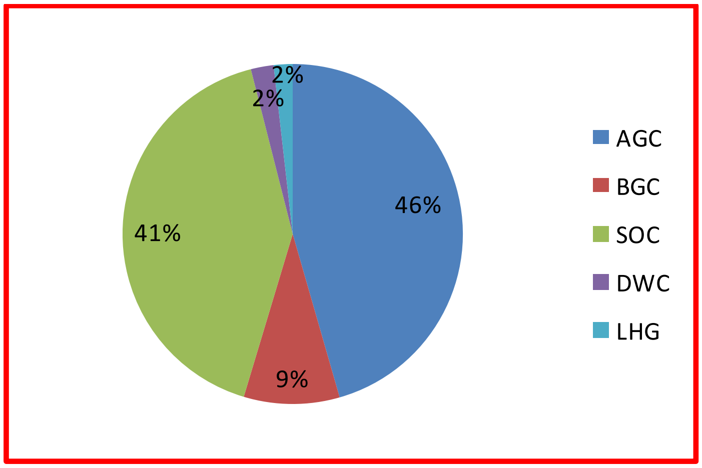

Figure 4.11: Comparisons of various carbon pools

4.1.5 Relationship between above ground carbon stock pools with grasses, herbs and litter carbon stock pools

Table 5.1 below shows the relationship between grasses and herbs with above ground carbon pools. Accordingly, the relationship was described by a correlation coefficient of 0.002, indicating that the effect of trees on biomass productivity of ground vegetation cover was not significant. When we observe the relationship between litter carbon stock and above ground carbon stock with coefficient values of 0.03 was 15 times higher than the correlation between litter, herbaceous and tree biomass, indicating that the tree growth promote the biomass productivity understory vegetation. This suggested that in the Menagesha forest higher amount of carbon in litter layer and herbaceous vegetation was higher in sties dominated by large trees.

Table 5.1: The relationship between carbon stock in herbs, grasses and litter pools with above ground carbon pools

Type	Beta value	R^2	Adjusted R^2	Std. error of estimate
Grasses and herbs carbon stock	0.04	0.002	-0.015	5.4
Litter carbon stock	0.172	0.03	0.014	5.38
Grasses, herbs and litter combination carbon stock	0.138	0.019	0.03	5.3

4.1.6 Carbon stock in different forest age

As shown in Table 5.2, the average carbon stock in a < 25-year old plantation established after 1984 was 196.29 tons ha^{-1}. The years between 1973 and 1984 plantations had a carbon density value of 267.24 tons ha^{-1}. It had a larger amount of carbon storage in all pools than the forest planted after 1984 except for carbon in litter, herbs and grasses. The average carbon stock of old growth forests (i.e., before 1973) had the largest carbon storage in all pools. It accounts for an average value of 313 tons ha^{-1}. Therefore, the average carbon stock observed in the study Menagesha forest was greater in old growth forest sites than young growth new plantation forests (Appendix 12).

This study showed an increase of 46 tons ha^{-1} during 11 years of forest growth period between 1973 and 1984. The difference in carbon stock between a 30-years old plantation (1973-1984) and a 20-years old plantation (after 1984) was 71 tons ha^{-1}. An average difference of 117 tons ha^{-1} of carbon stock was observed between old growth forest (> 400 years) and young growth forests (mainly plantations forests).

Table 5.2: Comparison of carbon stock estimation in different pools under different forest age groups

Age Groups	No of sample	AGC tons ha^{-1}	BGC tons ha^{-1}	SOC tons ha^{-1}	CDW tons ha^{-1}	CLHG tons ha^{-1}	Total C tons ha^{-1}
Before 1973	48	146.23	29.21	123.69	5.47	8.29	313
1973-1984	7	116.8	23.34	122.6	0.15	4.22	267.24
After 1984	8	71.36	14.25	105.71	0.002	4.88	196.29

4.1.7 Linear regression analysis of ground survey total carbon stock with different Landsat spectral response values

In this study all the individual landsat ETM bands spectral values had negative relation with carbon stock per pixel (tons) in the sample plot. As appendix 15 shows the blue band (TM1) had large negative correlation than red (TM3), NIR (TM4) and MIR (TM5) which have high reflectance for forest canopy. Red band had the highest correlation coefficient than all landsat TM bands.

Linear combinations of multiple bands are the summation of different landsat bands. In the present study examined the summation of Landsat TM of 1, 2 and 3, TM 5 and 7, TM 1, 2, 3, 4, 5 and 7 (albedo) and the subtraction of NIR and red. From this investigation, all the combination of TM bands had negative correlation with the total carbon stocks investigated in sample plots. The largest negative correlation was with alebedo and the lowest with vegetation index (Appendix 15).

For each principal component analysis their linear relationship with carbon stock per pixel in ton with the plot area reflectance DN value were derived and shown in appendix 15. It shows only PCA3 had positive relation with carbon stock per pixel. None the combinations of tasseled caps had positive correlation with the carbon stock estimated in each sample plots.

Like the above two types of spectral response, in band ratios the spectral response value of in the present study had negative correlations. Even though it had negative correlation with the data gathered from the ground, it had a better correlation. The lowest was in the ratio of TM5/3 and the highest with TM5/7. Appendix 15 shows the linear relation of each of the band ratio with the investigated carbon stock on the field sample plots.

Appendix 15 shows all the different vegetation indices had negative correlations with the ground inventory data of carbon stock in sample plots. Normalized difference vegetation index of landsat TM 5 and 7 had in a small amount of positive correlation.

Skewness texture shows the relation between carbon stocks per pixel (tone) against the reflectance DNs skewness texture measures. SkewTM1_7, SkewTM2_7 and SkewTM4_7 had positive relation and the other 3 relation had negative correlation (Appendix 15).

The variance linear relationships developed by carbon stock per pixel (tone) with all landsat bands in window 7×7. The correlation coefficients and the linear relationships equations were shown Appendix 15. In this study all of relation had negative correlation.

Most of the 39 spectral responses had negative correlation with carbon stock in the sample plot. Even though some of the spectral responses had positive relation, they had small amount of correlation with the R^2 value less than 0.1. So all of the single relationships were rejected because of it was difficult to build model with this linear relationships in order to estimate carbon stock in the study area that had similar results as measured from inventory data in the sample plots.

4.1.8 Multiple linear regression analysis

Different Landsat ETM bands, band ratios, normalized indices, linear combination of multi bands, Principal Component Analysis, tasseled cap and texture measures of variance and skewness as independent variable and carbon stock per pixel (tone) (dependent variable) to made better correlations.

Using the pixel value of the different spectral responses of Landsat TM year 2005, the best equation for estimating carbon stock at pixel level was shown below derived from SPSS software.

$$
\begin{gathered}
C = -347.502+2.9\,TM1+11.332TM2-22.25TM3+2.046TM4+11.052\,TM5-18.534TM7- \\
0.214VIS123-0.832Alebedo-0.367VI+0.272TM4/3-0.62TM5/3+0.327TM5/4+2.713TM5/4 \\
+111.893SQRT-421.218NDVI+14.569TNDVI+1.652ND32-1.026ND53-0.732ND54- \\
2.889ND57+10.699PCA2+0.47PCA3+2.319KT1+0.176KT2-0.608KT3+2.836SkewTM1\_7- \\
3.547SkewTM2\_7-0.724SkewTM3\_7+0.18SkewTM4\_7+0.008Skew\,TM5\_7- \\
1.147SkewTM7\_7+5.122VarTM1\_7-8.792VarTM2\_7+0.002VarTM3\_7 \\
+0.063VarTM4\_7+0.557VarTM5\_7-0.074VarTM7\_7 \ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 5.1}
\end{gathered}
$$

Where, *TM1- TM7 are Landsat the six bands; TM4/3 is ratios of band 4 and 3; TM5/3 is ratios of band 5 and 3; TM5/4 is ratios of band 5 and 4; TM5/7 is ratios of band5 and 7; SQRT(TM4/3)) is square root of the ratios of band 4 and 3; NDVI is normalized difference indices; TNDVI is Transformed normalize difference vegetation indices; ND32 is normalized difference of band 3 and 2; ND53 is normalized differences of band 5 and 3; ND54 is normalized differences of band 5 and4; ND57 is normalized differences of band 5 and7; linear combination of multi bands; VIS123 is the sum of band 1, 2 and 3; Alebedo is the sum of 1, 2, 3, 4, 5 and 7; VI is the difference of NIR and Red; PCA2 and PCA3 are principal component analysis of 2 and 3; KT1, KT2 and KT3 are tasseled cap of 1,2 and 3;*

VarTM1_7-VarTM 7_7 are variance texture measures in different TM bands of and SkewTM1_7-SkewTM7_7 are skewness texture measures of different TM bands.

This model had a beta value 0.878 and a correlation coefficient (R^2) of 0.771with standard error of estimate was 8.45 (Appendix 14, Figure 4.12). Through combination of all the spectral response a better correlation was resulted. This indicated multiple linear relations had a better correlation than single linear relationships in the study area, and can be applied to estimate the carbon stocks.

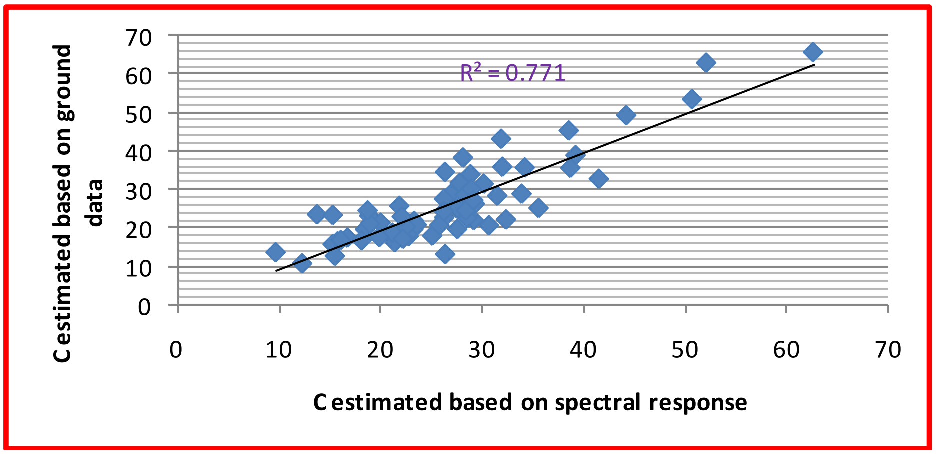

Figure 4.12: Multiple linear relations between the combined spectral responses and carbon stock estimates from ground survey

4.1.9 Multiple linear regression analysis of above ground carbon stock estimation with different landsat ETM spectral response values

After examing multiple linear relationships and better correlation was investigated in this study, the relationship of above ground carbon stock estimated in ground survey was correlated with spectral response values. Model was derived with a beta value of 0.882 and a correlation coefficient (R^2) of 0.777.

Therefore, carbon stock estimation using landsat imagery became more accurate for above ground carbon stock.

4.1.10 Application of the model to estimate total carbon stock

The model developed from the correlation between combination spectral responses and the total carbon stock estimated from ground survey data were found good and acceptable to quantify carbon stock in large forest areas. Carbon stock in 2005 landsat ETM imagery was estimated for each plots of one pixel size. The maximum and minimum total carbon stock per pixel was 62.72 tons and 9.96 tons respectively (Figure 4.13). The highest was in plot 7 in which the area was covered by large *Pinus radiata* and the lowest was in plot 15. The mean carbon stock in the study area was 26.99 tons per pixel size. Most of the plot area had 10-30 tons of carbon per pixel.

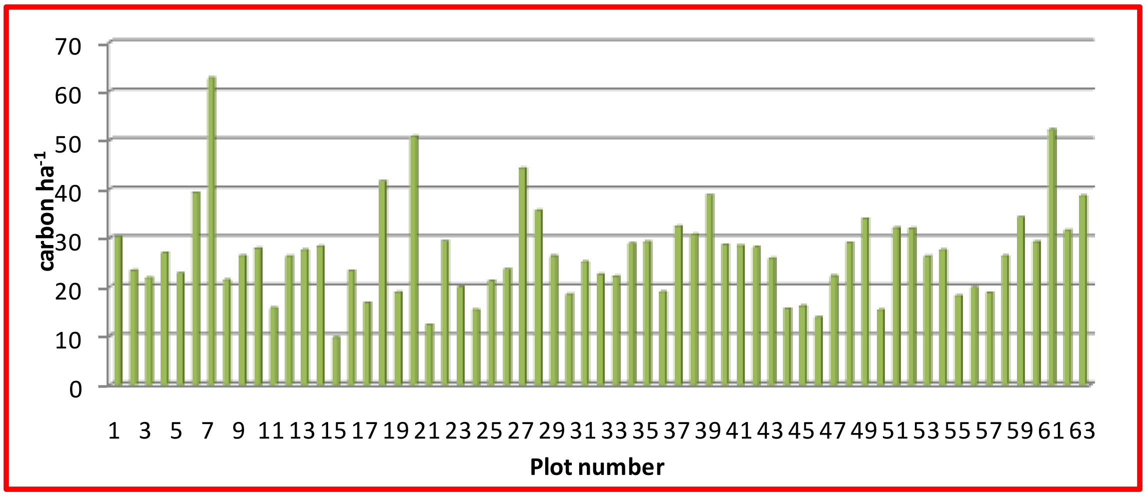

Figure 4.13: The amount of carbon stock estimated at each plot using the regression model

The carbon stock in 2005 was estimated using landsat ETM of 2005 image (Table 5.3). Accordingly, 34% of the estimated forest areas had carbon stocks between 150-300 tons ha^{-1}, while 28% of the forest areas had carbon stock values within the range between 300 and 450 tons ha^{-1}. The carbon stocking class of < 150 and 450- 600 tons ha^{-1} were in the order of 16% and 14% of the total study area. The lowest percentages (8%) of the areas have carbon stock density value of above 600 tons ha^{-1}.

Table 5.3: Percentage share of 2005 carbon stock in different ranges

ID	Carbon per ha(tons)	No. Pixel	Percentage (%)
1	<150	5752	16
2	150-300	12314	34
3	300-450	10301	28
4	450-600	5232	14
5	>600	2895	8

4.1.11 Comparison of model estimated and ground measured carbon stock

Carbon stock estimated based on landsat TM imagery reflectance response estimation had a similar result as ground inventory data. The estimation based on satellite imagery in some plot sites had a less amount than the ground estimation and in some plots the reverse (appendix). The highest carbon stocks were estimated in both cases in plot 7 and plot 61 (figure 4.14).

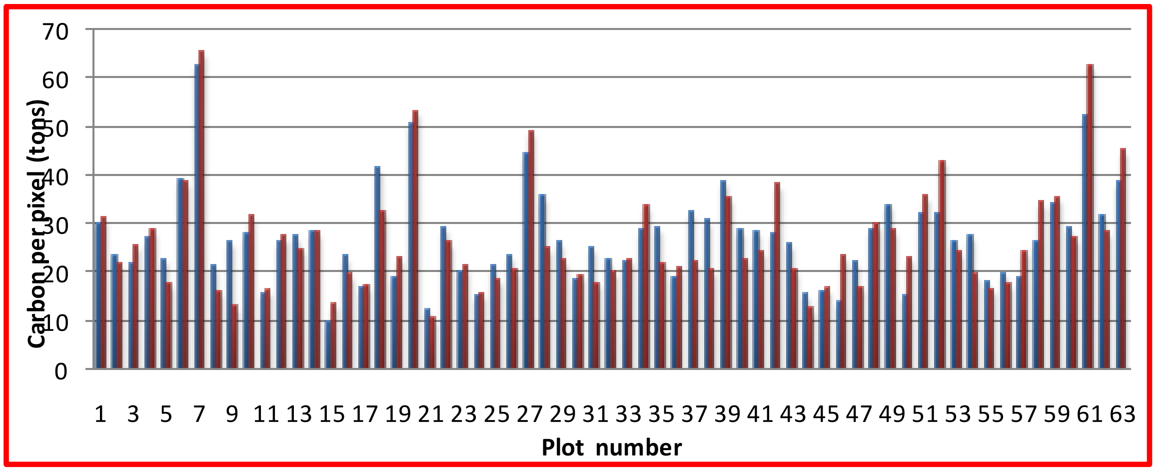

Figure 4.14: Comparison of carbon estimated based on ground and the developed model (Where, *red color for ground estimation and blue color for remote sensing estimation)*

4.1.12 Carbon stock estimation model of 1984

This model was resulted with a beta(R) value of 0.872, correlation coefficient (R^2) of 0.759 ± 9 (Appendix 15). The figure 4.15 shows their relationships. The following multiple linear relationships used to estimate the carbon stock during 1984.

$$\begin{aligned}
&C=135.936-2.045\mathit{TM1}-3.519\mathit{TM2}+3.892\mathit{TM3}+0.098\mathit{TM4}-0.769\mathit{TM5}-1.137\mathit{TM7}+\\
&0.75\mathit{VIS123}-0.085\mathit{MID57}-0.194\mathit{Alebedo}+0.799\mathit{VI}-0.005\mathit{TM4/3}+0.183\mathit{TM5/3}-1.11\mathit{TM5/4}-\\
&0.122197\mathit{TM5/7}-10.936\mathit{SQRT}-141.447\mathit{NDVI}-92.951\mathit{TNDVI}-0.092\mathit{ND32}+\\
&0.336\mathit{ND53}+0.334\mathit{ND54}+0.226\mathit{ND57}+1.774\mathit{PCA1}-1.345\mathit{PCA2}-0.955\mathit{PCA3}-0.033\mathit{KT1}-\\
&2.149\mathit{KT2}+0.425\mathit{KT3}6.228\mathit{SkewTM1\_7}+6.664\mathit{SkewTM2\_7}-0.911\mathit{SkewTM3\_7}+1.198\\
&\mathit{SkewTM4\_7}-0.473\mathit{SkewTM5\_7}0.13\mathit{SkewTM7\_7}+4.253\mathit{VarTM1\_7}-4.543\mathit{VarTM2\_7}-\\
&0.524\mathit{VarTM3\_7}+0.019\mathit{VarTM4\_7}-0.014\mathit{VarTM5\_7}+0.392\mathit{VarTM77}\ldots\ldots\mathit{Equation}\ 5.2
\end{aligned}$$

Where*, C means carbon stock , TM1- TM7 are Landsat six bands; TM4/3 is ratios of band 4 and 3; TM5/3 is ratios of band 5 and 3; TM5/4 is ratios of band 5 and 4; TM5/7 is ratios of band5 and 7; SQRT(TM4/3)) is square root of the ratios of band and 3; NDVI is normalized difference indices; TNDVI is Transformed normalize difference vegetation indices; ND32 is normalized difference of band 3 and 2; ND53 is normalized differences of band 5 and 3; ND54 is normalized differences of band 5 and4; ND57 is normalized differences of band 5 and7; linear combination of multi bands; VIS123 is the sum of band 1, 2 and 3; MID57 is the sum of band 5 and 7; Alebedo is the sum of 1, 2, 3, 4, 5 and 7; VI is the difference of NIR and Red; PCA1, PCA2 and PCA3 are principal component analysis of 1, 2 and 3; KT1, KT2 and KT3 are tasseled cap of 1,2 and 3; VarTM1_7-VarTM 7_7 are variance texture measures in different TM bands of and SkewTM1_7-SkewTM7_7 are skewness texture measures of different TM bands.*

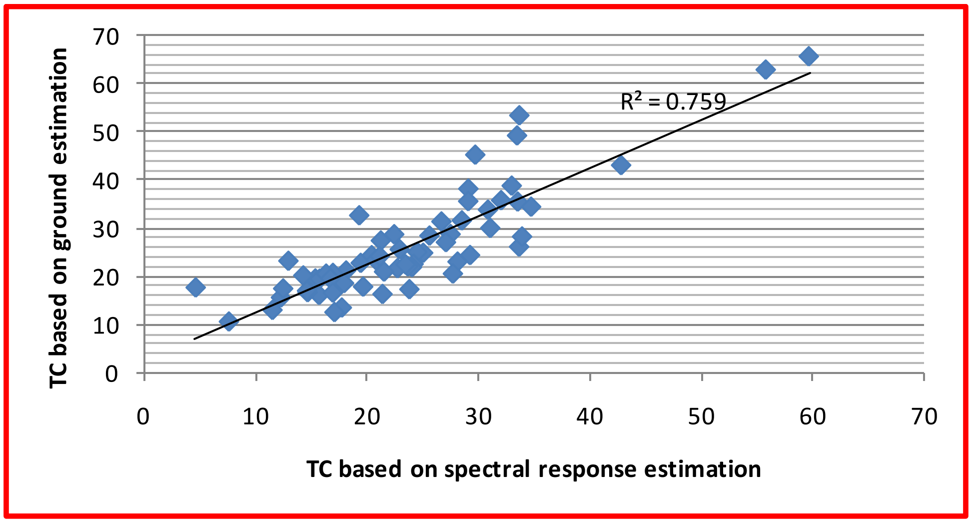

Figure 4.15: Graphs of the carbon stock estimation relation between ground data and regression model

From equation 5.2 above the minimum carbon stock estimation of pixel size area was 4.48 tons and the maximum value of 59.7 tons. The mean carbon stock from the whole plot sites in the study area was 23.86 tons. Most of carbon stocks estimated in plot areas were less than 30 tons per pixel (Figure 4.16). The stock above 30 tons was observed in small sites around 10 plots.

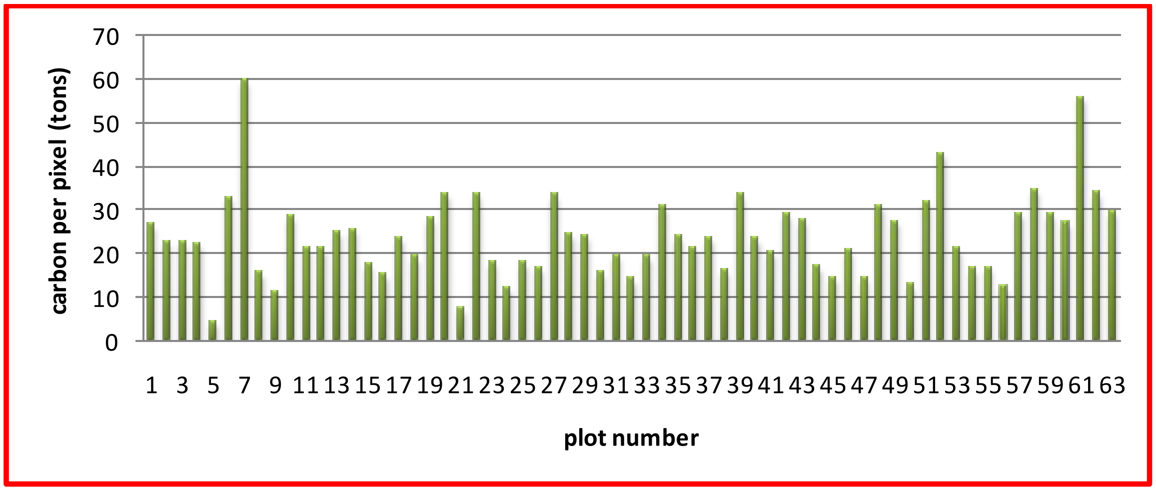

Figure 4.16: The amount of 1984 carbon stock estimated at each pixel using the model developed by regression analysis

Using landsat TM of 1984 image as the table 5.4 below shows 38% of the forest areas have carbon stock of 150-300 tons ha^{-1}. The lowest percentages (11%) of the areas have carbon stock above 600 tons ha^{-1}. 20% of the forest area falls in ranges 300 – 450 tons ha^{-1}. The carbon stock amount less than 150 and between 450 and 600 tons ha^{-1} accounts 17% and 11% of the total forest area.

Table 5.4: Percentage share of 1984 carbon stock in different ranges

ID	Carbon per ha(tons)	No. Pixel	Percentage (%)
1	<150	6890	17
2	150-300	15481	38
3	300-450	7813	20
4	450-600	5731	14
5	>600	4443	11

4.1.13 Temporal changes in carbon storage

There was a change between a year 1984 and 2005 in carbon stock density. It was increased from 23.86 tons to 26.99 tons per pixel ($900m^2$). Therefore, every year there was an increment of carbon storage by 0.149 tons/ pixel (Figure 5.16 and 5.17).

The carbon stocks classes of the two years had changed. Table 5.2.1and 5.2.2 showed a carbon stock of <150 tons ha^{-1} of 1984 decreased from 17% coverage to 16% coverage in 2005. The wide range of Carbon stock between 150 and 300 tons ha^{-1} decreased to a narrow range of values between 38% and 34% coverage. The increased carbon stock amount was observed in the range of 300-450 tons ha^{-1} (20%-28%).

4.1.14 Total carbon stock estimation using spectral response model

The total amount of carbon stock estimated by using spectral response method was calculated by multiplication of average carbon stock per pixel (26.99 tons) and the number of pixel existed in the study area. There were 42,737 pixels in Menagesha Suba State Forest. Therefore, the amount of the total carbon stock in the study area in 2005 was 1,153,471 tons.

The amount of carbon stock in 1984 for the whole area was calculated by the multiplication of the average 23.86 tons per pixel and the total number of pixels in the study area was 42,737 pixels. The total of 1,019,704 tons of carbon stock was investigated in this year study.

The amount increased in 1984 (1,019,704) to 1,153,471 tons in 2005 within 21 years. Therefore, the carbon stock was increased by 113,766 tons with an average increment value of 5,417 tons /ha/yr. The increase in carbon stock was due to increased forest cover in the study area as result of yearly plantation and increasing the ages of the trees. In 1984, the forested area was 2946 ha without including the vegetation in agricultural and settlement areas near the forest. In a year 2005, these areas were covered by vegetation due to new plantation.

During the year 2005, these much of carbon stock can offset 4,233,238 tons of CO_2. The current market for 1 ton carbon credit is 15- 40 US dollar. From this forest only the country can gets 63,498,570 US dollar if one take the minimum voluntary carbon market price (15 dollar). So this forest has a great contribution to solve this century climate change problem and to get income.

4.1.15 Carbon stock distribution map

Maps for the distribution of total carbon stock were produced using the equations 5.1 and 5.2. After estimation of average carbon stock density for each plot area, it was distributed on landsat ETM classified images.

Carbon stock density map for 1984 was prepared in order to show the difference. According to 1984 landsat TM imagery in the south western part had less than 150 tons ha^{-1}. This was because of the area at that time was not covered by vegetation. The highest density was found in the middle of the forest where natural forests were existed. The other areas were between the two ranges (Figure 4.17).

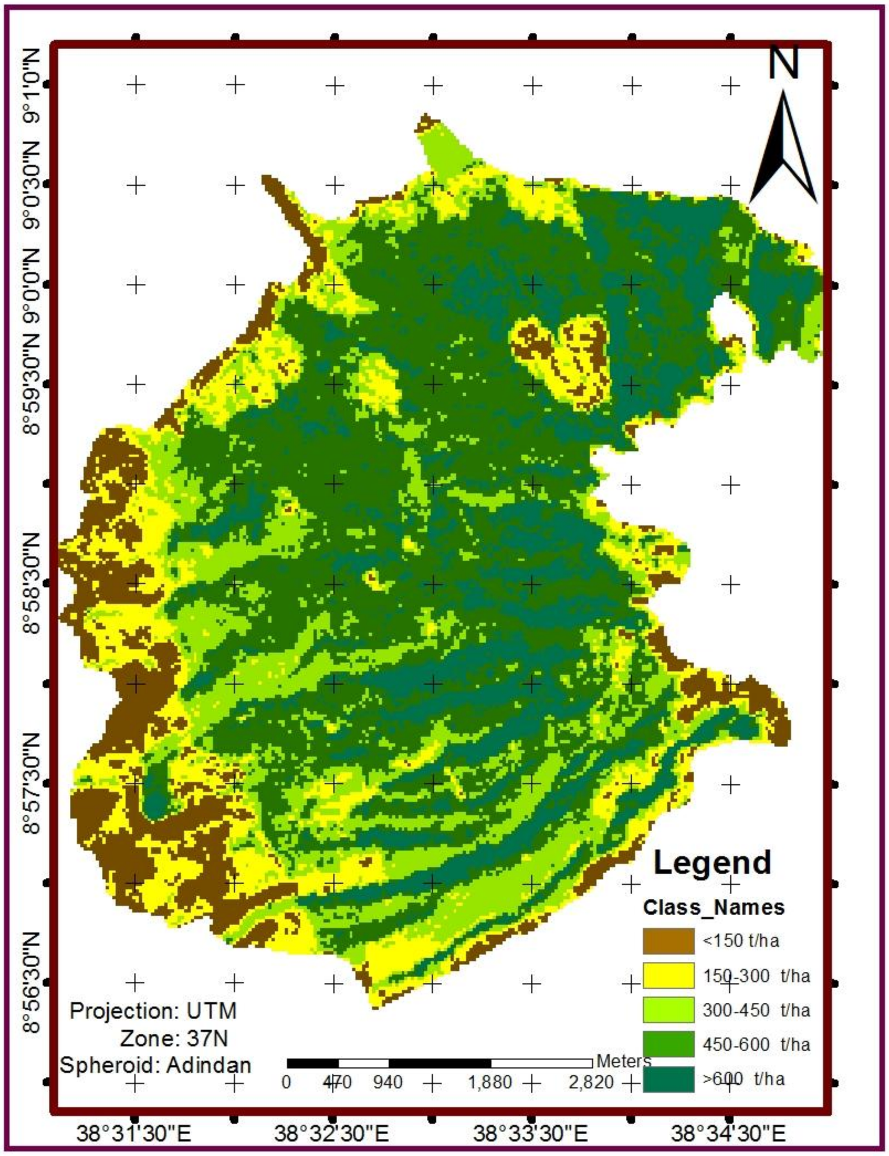

Figure 4.17: Carbon distribution map of Menagesha Suba State forest in 1984

In this study using 2005 landsat ETM image the highest average carbon density distribution was in the middle part of the forest area (Figure 4.18). The area around the highest altitude of eastern and northern parts had lower density. In the middle part, which contains most of natural forest had relatively >300 tons per pixel carbon density. The lowest part was in the areas around the peripherals, settlements and harvested areas.

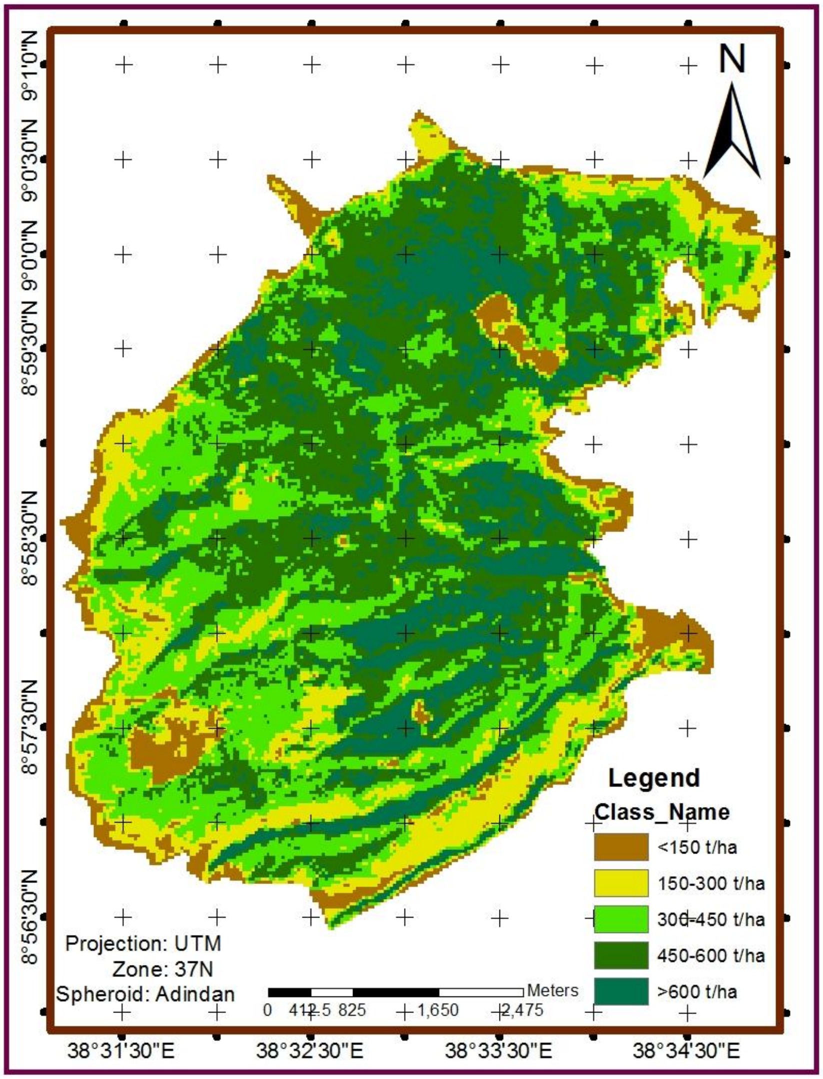

Figure 4.18: Carbon distribution map of Menagesha Suba State forest in 2005

4.2 Discussion

4.2.1 Carbon estimation based on field data collected

According to different literature, global above ground carbon stock in tropical dry and wet forests ranged between 13.5-122.85 t ha^{-1} and 95- 527.85 t ha^{-1}, respectively (Murphy and Lugo, 1986). Above ground carbon in Amazonian Brazil forests ranged between 130- 223 t ha^{-1} (Alves *et al.*, 1997). Similarly, the above ground carbon reported in the present study (23

– 517 t ha^{-1}) was within the range reported for various mixed and old growth forests and evergreen moist tropical forests (Brown and Lugo, 1982; Brown, 1997).

The average above ground carbon in the Menagesha Suba State forest (133 t ha^{-1}) was more than twice higher than the previous estimates (about 45.45 t ha^{-1}) of plant biomass for forests of Ethiopia (Brown, 1997). On the other hand, above ground carbon in tropical and subtropical forests in Puerto Rico ranged between 36 – 85.5 t ha^{-1} (Weaver and Murphy, 1990). Above ground carbon stock estimated in this study was more similar to the amount of carbon stock estimated in selected church forests around in Addis Ababa. The average carbon stock in church forest is 122.85 tons ha^{-1} (Tulu Tolla, 2011).

Below ground carbon stock of this study was 0.2 times above ground which ranges from 1.3-103 t ha^{-1}. It had a similarity with the above mentioned studies because of the fact that it was derived from above ground carbon.

According to Brown and Lugo (1982) litter fall in dry tropical forests range between 2.52-3.69 t ha^{-1}/ year. The dead litter carbon stock estimated in Addis Ababa church forests ranged from 3.37 to 7 t/ ha (Tulu Tolla, 2011).). Dead litter carbon in the present study forest ranged from 0.78 to 13.94 tons which is almost twice than the values reported for dry tropical forests (Brown and Lugo, 1982).

According to Zewedu Eshetu (2000) Menagesha Suba State forest the average bulk density was 0.1 gm/cm^3 at 3 cm depth litter layer, 0.7 gm/cm^3 at 0-15 cm mineral soil and 1.2 gm/cm^3 at 15-100 cm mineral soil depth. In present study the average bulk density of soil investigated in Menagesha Suba forest is 0.414 gm/cm^3. The lowest and the highest were 0.352 gm/cm^3 and 0.449 gm/cm^3. This study has lowest amount of bulk density than the previous study because it was conducted from the average soil within 30 cm depth.

SOC density of different forest types of Kolli hills in India ranges from 63.37 to 273 t ha^{-1} and the average SOC density was 96.05 t/ha (Ramachandran *et al.*, 2007). In Ethiopia, in the case of Addis Ababa church forests, the amount of SOC density ranges from 99.77 to 162 t ha^{-1} (Tulu Tolla, 2011). The amount of soil organic carbon in this study varied from 26.64 t/ha to 175 t ha^{-1} with average carbon stock of 121.28 t ha^{-1}.

Understanding the relationship between the age of a forest stand and its biomass/carbon stocking potentials is essential for managing the forest component of the global carbon cycle. Since biomass increases with stand age, postponing harvesting schedule to the age of biological maturity may result in the formation of a large carbon sink (Alexandrov, 2007). The annual magnitude of the sink induced by delayed harvest lies in the range of 1–2% of the baseline carbon stock. This investigation showed an increase of 46 tons ha^{-1} between 1973 and 1984 forest growth. The new plantation aged around 30 years (1973-1984) and 20 years (after 1984) had a difference of 71 tons ha^{-1}of carbon stock.177 tons ha^{-1} of carbon stock difference was observed between the old aged forests and the new plantation after 1984. The average carbon stock observed in this study area was greater in old aged forest than in new plantation forests, which is in close agreement with the findings of Zewdu Eshetu (2000). The results of this study imply that forest age could be used as an easily understood and scientifically sound measure of the progress in complying with national targets on the protection and enhancement of forest carbon sinks.

4.2.2 Relationships between spectral bands, spectral indices, texture measures and carbon stock

A variety of vegetation indices and texture measures have been developed. A logical question to ask however is which spectral responses and which texture measure can be used to establish biomass estimation models using remotely sensed data? Vegetation indices can partially reduce the impacts on reflectance caused environmental conditions and shadows. Different vegetation indices have been developed and used for classification or biomass estimation (Anderson and Hanson, 1992; Anderson *et al.*, 1993 and Eastwood *et al.*, 1997). Bannari *et al.* (1995) reviewed more than forty indices presented through literature. However, not all vegetation indices are significantly correlated with biomass.

In Ethiopia, no remote sensing based carbon stock estimation have not done up to now. So development of new model is necessary. Before choosing the final model it is necessary to assess sensitivity of spectral response to atmospheric and plant phonological conditions. This helps in deciding the wavebands or indices which can be given more weight age for choosing the final model for biomass estimation. It is evident that biomass is well correlated to the spectral response. Different factors must be taken into account to decide dependency on the different wavebands/indices for building regression model.

Initially a least square regression equation was used to develop regression model (Ripple *et al.,* 1991) which yielded low correlation between biomass and spectral value. There is a strong negative relationship between the biomass and the value in all wavebands. This inverse relation was expected to be caused by (1) increased canopy shadowing within larger stands (2) decreased under storey brightness (soil brightness) due to increased density with which biomass increases (Spanner *et al.*, 1990). (3) Atmospheric scattering, having additive effect to the radiance recorded by satellite sensors in the visible part of the spectrum and (4) changing canopy condition in dry deciduous forest reduces utility of spectral indices that are sensitive to canopy vigor (Roy and Ravan., 1996).

These results agree with the finding of Alchrona (1988) who stated that there is an inverse relationship between amount of shadow and reflectance in all wavebands. It also agrees with Horler and Ahern (1986), who suggested that shadowing is a factor at least as important as leaf moisture content in influencing the spectral reflectance of forests in the shortwave infrared spectral region. Thus, the higher spectral radiances of the sample point with less biomass can explain partially by smaller amount of shadows which will result in a higher contribution to the spectral radiance from the soil.

In a selected study area, it is not easy to effectively and quickly determine one or more vegetation indices that are appropriate for use in the model development. Lu (2005) analyzed and compared 23 vegetation indices and identified that linear TM band combinations (e.g., the first components of PCA or Tasseled Cap transform) have stable and good relationships with biomass. The previous analysis indicated that vegetation indices alone are not sufficient to establish an effective model for biomass estimation. This is especially true in a study area with complex stand structure, largely because complex stand structure and canopy shadow negatively impacted biomass and spectral signature relationships.

The enter regression techniques were used for estimation of carbon stocks. This method is useful when trying to find the best subset of predictors (Shaw and Wheeler, 1996). Different research papers used multiple linear regression analysis (Roy and Raven, 1996); Attula, 2008; Lu, 2005) to develop model. Yang (2001) used a combination of more than 20 types of spectral responses to develop model by using multi linear regression analysis. In this study by using a combination of 39 spectral responses are used to develop carbon stock estimation model and a better correlation coefficient was resulted i.e. $r^2 = 0.771$.

Model transferability is a major concern after models are developed but, in reality, it is often difficult to transfer one model developed in a specific study area to other study areas because of the limitation of the model itself and the nature of remotely sensed data. Foody *et al.* (2003) discussed the problems encountered in model transfer. Many factors, such as uncertainties in the remotely sensed data (image preprocessing and different stages of processing), carbon calculation based on field measurements, the disparity between remote sensing acquisition date and field data collection date, and the size of sample plot compared with the spatial resolution of remotely sensed data, could affect the success of model transferability. Each model has its limitation and optimal scale for implementation. When using a regression model, attention should be given to understanding the applicable scale implemented in the original models.

Models developed in one study area may be transferred to (1) across-scene data, which have similar environmental conditions and landscape complexity, to estimate carbon stock in a large area; and (2) multi-temporal data of the same study area for carbon dynamical analysis if the atmospheric calibration is accurately implemented. The spectral signatures, vegetation indices, and textures are often dependent on the image scale and environmental conditions.

Caution must be taken to ensure that there is consistency between the images used in scale, atmospheric and environmental conditions. Calibration and validation of the estimated results may be necessary using reference data when using transferred models (Foody *et al.*, 2003).

Landsat TM data mainly capture the canopy information instead of individual tree information due to its spatial resolution. Other sensor data such as radar data and hyper spectral data can give new insights about biomass estimation. In a large study area such as the Amazon basin, AVHRR or MODIS data, incorporating high spatial resolution data such as Landsat TM images, can be useful in estimating biomass or carbon emission. Some high-resolution data such as IKONOS and Lidar also has the potential to estimate biomass with higher accuracy, providing a means to validate the results derived from TM images

The different biophysical conditions affect vegetation growth status and result in different vegetation reflectance captured by remote-sensing sensors. A model that incorporates remotely sensed data and associated ancillary data has the potential to improve model performance and is more applicable to a large study area. Such a model is best developed through integration of geographic information system (GIS) and remote-sensing techniques, and should be especially valuable if the required ancillary data can be captured.

Forests play an important role in the global carbon cycle because they store a large amount of carbon in vegetation biomass and soil (Falkowski *et al.*, 2000), and they serve long term sink if forest fire and forest degradation is strictly precluded. Therefore, plantation, afforestation and preservation as happened in Menagesha suba forest could serve as a potential sink for urban carbon emission. This suggests that the mountain forests of Ethiopia could play significant role in the carbon cycle of east African region because it could lead to decrease atmospheric CO_2 via increasing in CO_2 uptake by plants. This finding is again consistent with the earlier findings that the Menagesha forest serves as nuclei for wet and dry atmospheric deposition (Zewdu Eshetu, 2000). The results of this study and others illustrate the extent of forest conservation and plantation establishment should synchronize the economic and ecological benefits of such forests in a manner where conventional forest management should consider the carbon stock as a product of the forest itself.

5. Conclusions and Recommendations

5.1 Conclusions

The remote sensing technique facilitates the creation of database for regular biomass monitoring. Keeping in view the need to device operational methodology for biomass estimation and monitoring, one should aim to develop spectral response based models. The spectral response of natural forest recorded by satellite sensor is a function of vegetation density/basal area, vegetation column thickness, phenology and physiography of the area. The attempt made in this study showed a possibility of using spectral response based models for carbon stock estimation. Landsat imagery of different spectral response values has a significant correlation with carbon stock estimated in ground survey. It is possible to develop model, to estimate and to map spatial and temporal changes of carbon stock using satellite imagery.

The amount of carbon stocks in different species was varied and the average total carbon stock was large. Carbon stock amount increases with the age of the trees. The amount increased from 1984 to 2005 within 21 years with an average increment value of 5,417 tons /ha/yr. This study indicates forest has potential for emission reduction to tap climate finance opportunities that would support government development plan

5.2 Recommendations

Based on the findings of this study the following recommendations were forwarded.

- The amount of carbon sequestered in this study site was significant. In Ethiopia, there are large forests conserved in different parts of the country so conducting similar research in those resources to benefit is recommendable.
- The carbon stock sequestered in all carbon pools in the present study site is significant so considering all carbon pools during carbon estimation is recommendable.
- Most of the existing trees in the study site were aged and they have sequestered large amount of carbon. Even if the area is conserved, planting new generations are needed to continue with this amount.

- By Integrating inventory data and remote sensing data, the study become more effective for different years carbon stock estimation and mapping the carbon density so it is recommendable to use the two types of data.
- Even though landsat imagery has a capacity for estimation, future research will be needed to improve the carbon estimation using remotely sensed data. Hyper spectral images may improve carbon estimation performance because of its large number of spectral bands with very narrow wavelengths. The potential of forest carbon stock mapping has also been explored using RADAR along with JAXA ALOS-PALSAR L-band. According to FAO (2008), BIOMASS mission, which is expected to launch around 2014 by ESA uses a longer wavelength (68 cm) and shows potential of estimating higher levels of carbon.
- Finally, fostering cooperation between communities and government, to promote knowledge and understanding of forest conservation and to find methods for rehabilitation of the degraded forests will help increase the potentiality of forests as a carbon sink to meet the challenge of global climate change and to get benefit from the preserved forests.

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7. Appendices

1. Plot radii for carbon inventory plots

Plot size	Plot Radius	Typical Area per tree(m2)	Size of Plots used for
100	5.64	0-15	Very dense vegetation, stands with large numbers of small diameter steams, uniform distribution of larger stems.
250	8.92	15-40	Moderately dense woody vegetation
500	12.62	40-70	Moderately sparse woody vegetation
66.7	14.56	70-100	Sparse woody vegetation
1000	17.84	>100	Very sparse vegetation

(Source: MacDicken, 1997, pp54)

2. Different equations for estimation of biomass collected from Different literatures

Equation	Species group	source	Rainfall	Max dbh
Biomass = 0.2035 x $dbh^{2.3196}$	General	Brown(unpublished)	Dry (900-1500 mm)	63cm
Biomass = $10^{(-0.535+\log10 \text{basal area})}$	General	Brown(1997)	Dry (<900mm)	30m
$Y=-12.05 + 0.876(BA)$	General	*Muraliks (2005)*	*1378 ± 116.86 mm*	Not specified
$Y= 34.4703 -8.0671(DBH) +0.6589(DBH^2)$	*General*	*Winrock (from Brown etal.,1989)*	*Dry (rainfall < 1 500 mm)*	*> 5 cm*
$Y = e^{[-3.141 + 0.9719 * Ln(DBH*DBH*H)]}$	*General*	*FAO(1997)*	*1500 mm to 4000 mm*	*5 to 40 cm*
$Y =10^\wedge(-0.535 + log(BA))$	*General*	*Brown (1997)*	*Dry < 900 mm rainfall*	*30cm*
$Y = 0.139 * DBH^{2.32}$	*General*	*Brown(1997)*	Dry < 1500 mm	*5-40cm*
$\ln (DW1) = -2.5202 + 2.14\ln (D) + 0.4644 * \ln (H)$	*General*	*Nelson et.al(1999)*	*Around 2000 mm*	*<25*
$\ln (DW2) = -3.843 + 1.035\ln (D2H)$	*General*	*Overman et.al(1994)*	*Around 2000 mm*	*>25 cm*

3. Temperature and Rainfalls of Sebeta and Addis Ababa Stations

Sebeta Rainfall(mm)													
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	RF
1980	0	32.1	17.2	19.5	40.1	153	353	279	47.9	0	0	0	941.2
1990	0	157.9	18.6	116	33.5	74.3	245.6	221	138	23.8	3.4	0	1031.7
2000	0	0	3.2	75.7	37.3	96.3	173.7	183	216	26.8	21.4	24.6	857.5
2009	30.1	0	4.2	65.3	24.4	62.8	287.5	247	115	20.2	1.5	47.4	905.6
													934
Addis Ababa Rainfall (mm)													
1980	23.2	36.6	45.3	88.5	54.2	126	385.1	297	112	51.5	0	0	1219
1990	0.8	155.9	59.2	106	20	88.8	218.7	269	184	16.2	6	0	1124
2000	0	0	17.6	49.9	110	145	244.8	306	251	46.4	21.1	0	1191
2010	2.6	79.8	55.5	97.8	73.8	231	313.9	206	238	1.8	25.7	15	1216
Temperature (^{0}c)													
year	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	mean
1980	23.6	24.9	25.2	24.6	25.6	22.9	20.6	20.8	21.9	22.2	22.8	23.4	23.4
	9.9	11.3	12.6	12.5	13.1	11.9	11.5	11.5	11.8	10.8	9.4	7.9	7.9
mean	16.8	18.1	18.9	18.6	19.4	17.4	16.05	16.2	16.9	16.5	16.1	15.7	15.65
1990	23.3	22.6	23.5	23.5	25.4	23.5	21.2	20.9	21.2	22.5	23	22.9	22.9
	9.1	11.9	11.4	11.9	12.2	10.9	11.4	11.1	11.3	9.5	9.2	7.7	7.7
mean	16.2	17.25	17.45	17.7	18.8	17.2	16.3	16	16.3	16	16.1	15.3	15.3
2000	24.9	26.1	27.3	25.7	25.3	23	21.6	20.5	21.5	22.2	23	23.8	23.8
	7.4	8.2	10.2	12.1	11.7	10.6	11	11	11.3	12.3	12.1	8.9	8.9
mean	16.2	17.15	18.75	18.9	18.5	16.8	16.3	15.8	16.4	17.3	17.55	16.4	16.35
2010	9.3	11	12.3	13.	13.5	12	11.6	12.2	11.	11.2	9.5	8.9	8.9

				3					7				
	23.8	21.5	23.5	24.1	24.1	22.8	20.4	20.8	21.3	23.5	22.5	22.8	22.8
mean	16.6	16.25	17.9	18.7	18.8	17.4	16	16.5	16.5	17.4	16	15.9	15.85

(**Source:** National Metrological Service Agency, Feb. 2011)

4. Location of the sample plots (UTM)

ID	X- Coordinate	Y- Coordinate	Altitude (m)
MP1	449158	990709	2399
mp2	448058	990588	2399
MP3	449003	989297	2389
MP4	449949	988835	2445
MP5	450622	989356	2589
MP6	451600	989938	2694
MP7	452309	990567	2815
mp8	452731	990981	2923
MP9	452060	991995	2815
MP10	451419	991935	2758
MP11	450716	991874	2696
MP12	450350	991445	2628
mp13	449403	991169	2423
mp14	448669	990863	2352
mp15	448149	990096	2316
MP16	449035	990464	2397
MP17	450655	991721	2715
MP18	451236	992610	2642
mp19	451206	992887	2664
MP20	451299	993654	2660
MP21	451544	994023	2835
MP22	451330	994545	2594
MP23	450965	995129	2506
MP24	450721	995590	2461
MP25	450202	995314	2404
MP26	450140	995007	2438
MP27	449804	995007	2400
MP28	449981	989971	2421
MP29	449438	991668	2400

MP30	448002	991101	2380
MP31	447719	991592	2380
MP32	447822	992443	2380
MP33	447813	991989	2360
MP34	449495	992216	2556
MP35	449795	992669	2558
MP36	449930	993104	2555
MP37	450270	993558	2540
MP38	450685	993936	2561
MP39	450780	994314	2560
MP40	450326	994540	2482
MP41	449911	994389	2410
MP42	449665	994144	2412
MP43	449400	993709	2400
MP44	449060	993236	2422
MP45	448928	992783	2483
MP46	448531	992197	2471
MP47	448031	989246	2888
MP48	452212	994677	2400
mp49	452475	993887	2760
MP50	451685	995286	2493
MP51	453068	995056	2671
MP52	453808	994710	2679
MP53	448456	991630	2460
MP54	448243	992776	2341
MP55	449555	990960	2350
MP56	449005	990746	2359
MP57	449249	990285	2389
MP58	449799	990345	2465
MP59	450226	990683	2537
mp60	450991	991265	2664
mp61	451479	991203	2760
mp62	451357	990989	2744
MP63	450837	990897	2664

(Source; Field Navigation (Feb, 2011))

5. Summary of the existing trees in sample plots of number of trees, Average dbh class, average height and average above ground Carbon per species

ID	Name of species	Number of Trees	Average DBH per species	Average height/ species	Average above ground C/ species (tons)
1	*Juniperus Procera*	547	23.57	16	0.196
2	*Podocarpus Falactus*	121	10.1	8.1	0.025
3	*Olea Africania*	56	9.485	9.07	0.018
4	*Cupressus Lusitanica*	97	28	16	0.263
5	*Eculaptus Spps.*	148	21.4	20.46	0.092
6	*Pinus Radiata*	24	42.34	28.13	0.561
7	*Erica Areborea*	28	8.707	5.535	0.006
8	*Sideroxylon Oxyacantha*	218	11	5.14	0.171
9	*Scalopia Thiefolia*	113	9.5	8	0.018
10	*Prunus Africana*	113	25.45	10.9	0.207
11	*Ekbergia Capensis*	7	19.04	12.857	0.069
12	*Haygenia Abyssinia*	15	10.24	3.66	0.011
13	*Carisa Edulis*	3	6.566	4.16	0.005
14	*Rapanea Simensis*	8	9.71	9.37	0.013
15	*Calpurnia Subdicandra*	3	7.43	8	0.051
16	*Tecela Nobilis*	3	18.35	10	0.084
17	*Ekebergia Capensis*	2	14.4	10	0.025
18	*Myrsine Africana*	5	26.7	15.7	0.147
19	*Eragrostis abyssinica*	28	15.83	11.08	0.071
20	*Euclea schimperi*	60	16.17	11.075	0.108

6. Above ground carbon stock Estimation

plot	AGB / plot (tone)	AGB /pixel (tone)	Carbon/ pixel (tone)	AGB / ha (tone)	Carbon/ ha (tone)
MP1	10.052	36.187	16.64602	402.08	184.9568
mp2	4.947	17.812	8.19352	197.914	91.04044
MP3	7.066	25.439	11.70194	282.657	130.0222
MP4	8.566	30.837	14.18502	342.64	157.6144
MP5	1.256	4.521	2.07966	50.24	23.1104
MP6	13.308	47.908	22.03768	532.32	244.8672
MP7	28.11	101.196	46.55016	1124.4	517.224
mp8	5.107	18.387	8.45802	204.305	93.9803
MP9	1.952	7.027	3.23242	78.08	35.9168
MP10	10.604	38.177	17.56142	424.195	195.1297
MP11	2.103	7.57	3.4822	84.12	38.6952
MP12	6.571	23.655	10.8813	262.84	120.9064
mp13	5.786	20.829	9.58134	231.44	106.4624
mp14	8.845	31.842	14.64732	353.8	162.748
mp15	1.962	7.065	3.2499	78.504	36.11184
MP16	4.846	17.445	8.0247	193.84	89.1664
MP17	1.881	6.771	3.11466	75.24	34.6104
MP18	8.346	30.045	13.8207	333.84	153.5664
mp19	4.336	15.609	7.18014	173.44	79.7824
MP20	6.15	22.14	10.1844	246	113.16
MP21	0.363	1.307	0.60122	14.532	6.68472
MP22	5.135	18.486	8.50356	205.4	94.484
MP23	3.786	13.629	6.26934	151.44	69.6624
MP24	1.253	4.51	2.0746	50.12	23.0552
MP25	3.59	12.924	5.94504	143.6	66.056
MP26	4.591	16.527	7.60242	183.64	84.4744
MP27	19.247	69.292	31.87432	769.912	354.1595
MP28	7.119	25.628	11.78888	284.76	130.9896
MP29	5.867	21.123	9.71658	234.7	107.962
MP30	4.654	16.756	7.70776	186.18	85.6428
MP31	3.91	14.078	6.47588	156.424	71.95504
MP32	4.845	17.443	8.02378	193.816	89.15536
MP33	6.644	23.918	11.00228	265.76	122.2496
MP34	12.117	43.621	20.06566	484.68	222.9528
MP35	5.963	21.466	9.87436	238.52	109.7192

MP36	5.732	20.635	9.4921	229.28	105.4688
MP37	6.5	23.4	10.764	260	119.6
MP38	5.942	21.391	9.83986	237.68	109.3328
MP39	13.237	47.653	21.92038	529.48	243.5608
MP40	4.469	16.088	7.40048	178.76	82.2296
MP41	6.699	24.116	11.09336	267.96	123.2616
MP42	13.599	48.956	22.51976	543.96	250.2216
MP43	4.795	17.262	7.94052	191.8	88.228
MP44	1.263	4.546	2.09116	50.52	23.2392
MP45	2.535	9.126	4.19796	101.4	46.644
MP46	5.124	18.446	8.48516	204.96	94.2816
MP47	2.514	9.05	4.163	100.56	46.2576
MP48	9.579	34.484	15.86264	383.16	176.2536
mp49	8.784	31.622	14.54612	351.36	161.6256
MP50	5.118	18.424	8.47504	204.72	94.1712
MP51	11.337	40.813	18.77398	453.48	208.6008
MP52	14.878	53.56	24.6376	595.12	273.7552
MP53	5.997	21.589	9.93094	239.88	110.3448
MP54	4.636	16.689	7.67694	185.44	85.3024
MP55	3.173	11.422	5.25412	126.92	58.3832
MP56	3.412	12.283	5.65018	136.48	62.7808
MP57	3.746	13.485	6.2031	149.84	68.9264
MP58	10.993	39.574	18.20404	439.72	202.2712
MP59	13.318	47.944	22.05424	532.72	245.0512
mp60	7.467	26.881	12.36526	298.68	137.3928
mp61	26.513	95.446	43.90516	1060.52	487.8392
mp62	8.949	32.216	14.81936	357.96	164.6616
MP63	15.877	57.157	26.29222	635.08	292.1368
	7.254984	26.1179048	12.01424	290.2035	133.4936

(Source; Field Data (Feb, 2011))

7. Below Ground Carbon Estimation

ID	BGB / plot (tone)	BGB / pixel (tone)	Carbon/ pixel (tone)	BGB / ha (tone)	Carbon/ ha (tone)
MP1	2.01	7.237	3.32902	80.4	36.984
mp2	0.989	3.562	1.63852	39.57	18.2022
MP3	1.413	5.087	2.34002	56.51	25.9946

MP4	1.713	6.167	2.83682	68.51	31.5146
MP5	0.251	0.904	0.41584	10.04	4.6184
MP6	2.661	9.581	4.40726	106.44	48.9624
MP7	5.622	20.239	9.30994	224.85	103.431
mp8	1.021	3.677	1.69142	40.85	18.791
MP9	0.39	1.405	0.6463	15.6	7.176
MP10	2.12	7.635	3.5121	84.82	39.0172
MP11	0.42	1.514	0.69644	16.82	7.7372
MP12	1.314	4.731	2.17626	52.56	24.1776
mp13	1.157	4.165	1.9159	46.27	21.2842
mp14	1.769	6.368	2.92928	70.74	32.5404
mp15	0.392	1.413	0.64998	15.69	7.2174
MP16	0.969	3.489	1.60494	38.76	17.8296
MP17	0.376	1.354	0.62284	15.04	6.9184
MP18	1.669	6.009	2.76414	66.75	30.705
mp19	0.867	3.121	1.43566	34.67	15.9482
MP20	1.23	4.428	2.03688	49.19	22.6274
MP21	0.072	0.261	0.12006	2.89	1.3294
MP22	1.027	3.697	1.70062	41.07	18.8922
MP23	0.757	2.725	1.2535	30.27	13.9242
MP24	0.25	0.902	0.41492	10.02	4.6092
MP25	0.718	2.584	1.18864	28.7	13.202
MP26	0.918	3.305	1.5203	36.71	16.8866
MP27	3.849	13.858	6.37468	153.96	70.8216
MP28	1.423	5.125	2.3575	56.93	26.1878
MP29	1.173	4.224	1.94304	46.92	21.5832
MP30	0.93	3.351	1.54146	37.22	17.1212
MP31	0.782	2.815	1.2949	31.27	14.3842
MP32	0.969	3.488	1.60448	38.75	17.825
MP33	1.328	4.783	2.20018	53.13	24.4398
MP34	2.423	8.724	4.01304	96.92	44.5832
MP35	1.192	4.293	1.97478	47.69	21.9374
MP36	1.146	4.127	1.89842	45.85	21.091
MP37	1.3	4.68	2.1528	51.99	23.9154
MP38	1.188	4.278	1.96788	47.52	21.8592
MP39	2.647	9.53	4.3838	105.87	48.7002
MP40	0.893	3.217	1.47982	35.74	16.4404
MP41	1.339	4.823	2.21858	53.58	24.6468
MP42	2.719	9.791	4.50386	108.778	50.03788
MP43	0.959	3.452	1.58792	38.35	17.641

MP44	0.252	0.909	0.41814	10.09	4.6414
MP45	0.507	1.825	0.8395	20.275	9.3265
MP46	1.024	3.689	1.69694	40.98	18.8508
MP47	0.502	1.81	0.8326	20.1	9.246
MP48	1.915	6.896	3.17216	76.61	35.2406
mp49	1.756	6.324	2.90904	70.25	32.315
MP50	1.023	3.684	1.69464	40.92	18.8232
MP51	2.267	8.162	3.75452	90.67	41.7082
MP52	2.975	10.712	4.92752	119.01	54.7446
MP53	1.199	4.317	1.98582	47.96	22.0616
MP54	0.927	3.337	1.53502	37.07	17.0522
MP55	0.634	2.284	1.05064	25.37	11.6702
MP56	0.682	2.456	1.12976	27.28	12.5488
MP57	0.749	2.697	1.24062	29.96	13.7816
MP58	2.198	7.914	3.64044	87.92	40.4432
MP59	2.663	9.588	4.41048	106.52	48.9992
mp60	1.493	5.376	2.47296	59.72	27.4712
mp61	5.302	19.089	8.78094	212.07	97.5522
mp62	1.789	6.443	2.96378	71.58	32.9268
MP63	3.175	11.431	5.25826	126.99	58.4154
	1.450587	5.223206	2.402675	58.02465	26.69134

(Source; Field Data (Feb, 2011))

8. Carbon estimation in litter, grasses and herbs

plot no	W field	Fresh wt	Dry wt	HB	HC	W field	Fresh wt	Dry wt	LB	LC	sum
1	130	73	67.2	119.6712	56.24548	500	112.9	102.5	453.9415	213.3525	286
2	0	0	0	0	0	700	127.5	114.9	630.8235	296.4871	315
3	87.2	87.2	75.7	75.7	35.579	400	125.4	113.1	360.7656	169.5598	218
4	118.7	118.7	108.9	108.9	51.183	200	114.8	103.5	180.3136	84.74739	144
5	100	81.8	61.6	75.30562	35.39364	500	155.9	140.4	450.2886	211.6357	262
6	200	65.6	61.1	186.2805	87.55183	400	102.4	86.3	337.1094	158.4414	261
7	110	100.3	66.3	72.71186	34.17458	1000	72.8	61.2	840.6593	395.1099	456
8	0	0	0	0	0	500	125.5	66.4	264.5418	124.3347	132
9	100	84	72.7	86.54762	40.67738	700	95.3	72.3	531.0598	249.5981	308
10	300	54.7	49.3	270.3839	127.0804	100	54.7	49.3	90.12797	42.36015	180
11	800	53.3	47	705.4409	331.5572	300	81.1	72.5	268.1874	126.0481	486
12	0	0	0	0	0	400	131.8	117.1	355.3869	167.0319	177

13	0	0	0	0	0	400	95.9	88.8	370.3858	174.0813	185
14	250	110.6	100.2	226.4919	106.4512	300	122.6	102	249.5922	117.3083	238
15	200	131.9	114.9	174.2229	81.88476	800	149.6	146.3	782.3529	367.7059	478
16	100	88.2	80.5	91.26984	42.89683	300	118.9	106.8	269.4701	126.651	180
17	600	99.2	87.5	529.2339	248.7399	0	0	0	0	0	264
18	100	60.7	56.3	92.75124	43.59308	700	90.9	74.6	574.4774	270.0044	333
19	100	65.9	59.4	90.13657	42.36419	500	113.5	103.2	454.6256	213.674	272
20	1600	58.7	47.5	1294.719	608.5179	0	0	0	0	0	647
21	400	77	70.8	367.7922	172.8623	200	69	62.2	180.2899	84.73623	274
22	90	124.5	114.8	82.98795	39.00434	130	29.2	27.1	120.6507	56.70582	101
23	0	0	0	0	0	700	87.1	78.2	628.473	295.3823	314
24	0	0	0	0	0	200	85.2	78.7	184.7418	86.82864	92
25	1100	61.5	55.1	985.5285	463.1984	0	0	0	0	0	492
26	1000	59.5	54.8	921.0084	432.8739	0	0	0	0	0	460
27	100	76.2	71.1	93.30709	43.85433	400	99.2	87.5	352.8226	165.8266	223
28	100	78.9	71.5	90.62104	42.59189	0	0	0	0	0	45
29	0	0	0	0	0	150	114.7	92.3	120.7062	56.73191	60
30	0	0	0	0	0	700	87.2	75.7	607.6835	285.6112	303
31	0	0	0	0	0	500	104	89.4	429.8077	202.0096	214
32	0	0	0	0	0	600	86.1	79.7	555.4007	261.0383	277
33	0	0	0	0	0	500	103.8	95.4	459.5376	215.9827	229
34	400	106.1	96.4	363.4307	170.8124	600	113.9	97	510.9745	240.158	437
35	1100	95.9	86.9	996.7675	468.4807	600	112.5	97.4	519.4667	244.1493	758
36	0	0	0	0	0	400	126.3	116.3	368.3294	173.1148	184
37	15.5	15.5	13.9	13.9	6.533	400	121.7	93.4	306.9844	144.2827	160
38	100	51.7	49.9	96.51838	45.36364	600	69.4	62.1	536.8876	252.3372	316
39	600	80	57.4	430.5	202.335	400	108.5	85.2	314.1014	147.6276	372
40	1000	46.6	42.7	916.309	430.6652	100	85.8	77	89.74359	42.17949	503
41	114	114	105.5	105.5	49.585	300	114	105.5	277.6316	130.4868	191
42	100	55.3	50.9	92.0434	43.2604	400	107.9	97.8	362.5579	170.4022	227
43	900	102.3	93.1	819.0616	384.9589	100	105.6	108.6	102.8409	48.33523	460
44	100	97.3	86	88.38643	41.54162	0	0	0	0	0	44
45	0	0	0	0	0	300	118.1	109	276.884	130.1355	138
46	800	106.2	96.7	728.4369	342.3653	100	103	94.6	91.84466	43.16699	410
47	100	96	87.3	90.9375	42.74063	200	117.8	107.2	182.0034	85.5416	136
48	100	90.2	82.8	91.79601	43.14412	100	65.4	59.6	91.1315	42.8318	91
49	100	98.9	88.9	89.88878	42.24772	900	120.1	108.9	816.0699	383.5529	452
50	100	13.1	11.8	90.07634	42.33588	100	110.6	99.5	89.96383	42.283	90
51	100	76	69	90.78947	42.67105	100	69.5	65	93.52518	43.95683	92
52	100	89.3	82.9	92.83315	43.63158	400	89.3	82.9	371.3326	174.5263	232

53	100	95.3	88.2	92.54984	43.49843	500	129.6	120.3	464.1204	218.1366	278
54	400	89.9	80.8	359.5106	168.97	300	102.3	92.6	271.5543	127.6305	315
55	150	89.1	94.1	158.4175	74.45623	800	101	91.5	724.7525	340.6337	441
56	100	60.3	43.7	72.47098	34.06136	1100	117.7	104.5	976.6355	459.0187	524
57	100	59.3	51.9	87.52108	41.13491	600	110.4	100.2	544.5652	255.9457	316
58	0	0	0	0	0	600	101.9	95.1	559.9607	263.1816	279
59	100	88.1	81.5	92.50851	43.479	500	115.3	102.6	444.9263	209.1154	268
60	700	82.5	75.8	643.1515	302.2812	100	113.5	99.5	87.6652	41.20264	365
61	800	105	92.5	704.7619	331.2381	200	130.9	116.5	177.9985	83.65928	441
62	200	62.7	56	178.6284	83.95534	200	99.2	86.6	174.5968	82.06048	176
63	100	51.8	46.9	90.54054	42.55405	1100	100.3	90.4	991.4257	465.9701	540

(Source; Field Data (Feb, 2011))

9. Carbon estimation in Dead wood

Plot no	DW per plot(kg)*10^{-3}	DW per pixel(tone)	C pixel (tone)	DW / ha(tone)	C/ ha (tone)
MP1	349	1.256	0.57776	13.96	6.4216
mp2	0.146	0.00052	0.000239	0.00584	0.002686
MP3	0	0	0	0	0
MP4	0	0	0	0	0
MP5	0.162	0.00058	0.000267	0.00648	0.002981
MP6	0	0	0	0	0
MP7	4.47	0.016	0.00736	0.1788	0.082248
mp8	0	0	0	0	0
MP9	0.83	0.002988	0.001374	0.0332	0.015272
MP10	5.96	0.02145	0.009867	0.238	0.10948
MP11	0.31	0.0011	0.000506	0.0124	0.005704
MP12	0	0	0	0	0
mp13	0	0	0	0	0
mp14	2.289	0.0082	0.003772	0.091	0.04186
mp15	0.44	0.0015	0.00069	0.017	0.00782
MP16	150.65	0.542	0.24932	6.026	2.77196
MP17	0.239	0.00086	0.000396	0.00956	0.004398
MP18	0.981	0.00353	0.001624	0.039	0.01794
mp19	6.38	0.0229	0.010534	0.2552	0.117392
MP20	16179	58.244	26.79224	647.16	297.6936
MP21	0	0	0	0	0
MP22	0	0	0	0	0
MP23	2.96	0.01	0.0046	0.1184	0.054464

MP24	9.12	0.032	0.01472	0.3648	0.167808
MP25	10.71	0.038	0.01748	0.4284	0.197064
MP26	0	0	0	0	0
MP27	0	0	0	0	0
MP28	0	0	0	0	0
MP29	0	0	0	0	0
MP30	0	0	0	0	0
MP31	0.845	0.003	0.00138	0.0338	0.015548
MP32	0	0	0	0	0
MP33	0.675	0.0024	0.001104	0.027	0.01242
MP34	2.174	0.0078	0.003588	0.08696	0.040002
MP35	2.36	0.0084	0.003864	0.0944	0.043424
MP36	4.82	0.017	0.00782	0.1928	0.088688
MP37	0.86	0.003	0.00138	0.0344	0.015824
MP38	6.331	0.02279	0.010483	0.253	0.11638
MP39	0	0	0	0	0
MP40	0	0	0	0	0
MP41	0	0	0	0	0
MP42	0	0	0	0	0
MP43	2.916	0.01	0.0046	0.116	0.05336
MP44	0.214	0.00077	0.000354	0.008	0.00368
MP45	0	0	0	0	0
MP46	0	0	0	0	0
MP47	0	0	0	0	0
MP48	4.16	0.014	0.00644	0.166	0.07636
mp49	1.276	0.00459	0.002111	0.051	0.02346
MP50	2.48	0.0089	0.004094	0.992	0.45632
MP51	0	0	0	0	0
MP52	2.8	0.01	0.0046	0.112	0.05152
MP53	0	0	0	0	0
MP54	1.87	0.0067	0.003082	0.748	0.34408
MP55	71.97	0.259	0.11914	2.878	1.32388
MP56	1035	3.726	1.71396	41.4	19.044
MP57	3780	13.608	6.25968	151.2	69.552
MP58	15.85	0.057	0.02622	0.634	0.29164
MP59	0.492	0.00177	0.000814	0.0196	0.009016
mp60	1.386	0.00498	0.002291	0.554	0.25484
mp61	0	0	0	0	0
mp62	1.06	0.0038	0.001748	0.042	0.01932
MP63	0.462	0.0016	0.000736	0.018	0.00828

Mean	343.8674	1.237827	0.569401	13.78738	6.342196

(Source; Field Data (Feb, 2011))

10. Soil Organic Carbon Estimation

plot	Altitude	fresh wt	Dry wt	Rad Ius	Depth (m)	Volume Cm3	BD (gm)	% C	SOC/ PIXEL (tone)	SOC/ ha (tone)
MP1	2399	100	81.2	1.5	0.3	212.14	0.382	10	10.31	115
mp2	2399	100	88.9	1.5	0.3	212.14	0.419	10	11.31	126
MP3	2389	100	91.5	1.5	0.3	212.14	0.431	9.6	11.17	124
MP4	2445	100	86.1	1.5	0.3	212.14	0.405	10.5	11.43	127
MP5	2589	100	93.2	1.5	0.3	212.14	0.439	12.5	14.76	164
MP6	2694	100	85.3	1.5	0.3	212.14	0.401	11	11.88	132
MP7	2815	100	82.9	1.5	0.3	212.14	0.39	8.5	8.91	99
mp8	2923	100	91.9	1.5	0.3	212.14	0.433	5	5.76	64
MP9	2815	100	83	1.5	0.3	212.14	0.391	8.2	8.64	96
MP10	2758	100	89	1.5	0.3	212.14	0.419	9	10.17	113
MP11	2696	100	81.3	1.5	0.3	212.14	0.383	11	11.34	126
MP12	2628	100	85.5	1.5	0.3	212.14	0.402	13	14.04	156
mp13	2423	100	90	1.5	0.3	212.14	0.424	11.4	13.05	145
mp14	2352	100	91.8	1.5	0.3	212.14	0.432	9	10.44	116
mp15	2316	100	87.1	1.5	0.3	212.14	0.41	8	8.82	98
MP16	2397	100	81.9	1.5	0.3	212.14	0.386	9	9.36	104
MP17	2715	100	94.1	1.5	0.3	212.14	0.443	11	13.14	146
MP18	2642	100	94.1	1.5	0.3	212.14	0.443	13	15.48	172
mp19	2664	100	86.5	1.5	0.3	212.14	0.407	12.7	13.95	155
MP20	2660	100	81.6	1.5	0.3	212.14	0.384	12.8	13.23	147
MP21	2835	100	93.2	1.5	0.3	212.14	0.439	8	9.45	105
MP22	2594	100	95.3	1.5	0.3	212.14	0.449	13	15.75	175
MP23	2506	100	90	1.5	0.3	212.14	0.424	11.5	13.14	146
MP24	2461	100	93.2	1.5	0.3	212.14	0.439	11	12.96	144
MP25	2404	100	93	1.5	0.3	212.14	0.438	9	10.62	118
MP26	2438	100	90.4	1.5	0.3	212.14	0.426	9.4	10.8	120
MP27	2400	100	92.5	1.5	0.3	212.14	0.436	9	10.53	117
MP28	2421	100	92.5	1.5	0.3	212.14	0.435	9.2	10.8	120
MP29	2400	100	94.9	1.5	0.3	212.14	0.447	9	10.8	120
MP30	2380	100	90.3	1.5	0.3	212.14	0.425	8.5	9.72	108
MP31	2380	100	90	1.5	0.3	212.14	0.424	8.5	9.72	108

MP32	2380	100	93.7	1.5	0.3	212.14	0.441	8.5	10.08	112
MP33	2360	100	87.7	1.5	0.3	212.14	0.413	8.3	9.18	102
MP34	2556	100	85.1	1.5	0.3	212.14	0.401	8.3	8.98	99.8
MP35	2558	100	83.3	1.5	0.3	212.14	0.392	8.3	8.78	97.6
MP36	2555	100	87.7	1.5	0.3	212.14	0.413	8.3	9.25	103
MP37	2540	100	84.9	1.5	0.3	212.14	0.4	8.2	8.85	98.4
MP38	2561	100	77.7	1.5	0.3	212.14	0.366	8.3	8.19	91
MP39	2560	100	81	1.5	0.3	212.14	0.381	8.3	8.53	94.8
MP40	2482	100	92.8	1.5	0.3	212.14	0.437	10.8	12.73	142
MP41	2410	100	92.7	1.5	0.3	212.14	0.437	9.1	10.73	119
MP42	2412	100	92.9	1.5	0.3	212.14	0.438	9.1	10.73	120
MP43	2400	100	90	1.5	0.3	212.14	0.424	9	10.26	114
MP44	2422	100	85.7	1.5	0.3	212.14	0.404	9.2	9.99	111
MP45	2483	100	83.8	1.5	0.3	212.14	0.395	10.8	11.43	127
MP46	2471	100	92.4	1.5	0.3	212.14	0.435	10.7	12.51	139
MP47	2888	100	85.2	1.5	0.3	212.14	0.401	10.9	11.79	131
MP48	2400	100	95	1.5	0.3	212.14	0.447	9	10.8	120
mp49	2760	100	92	1.5	0.3	212.14	0.433	9	10.52	117
MP50	2493	100	92.6	1.5	0.3	212.14	0.436	11	12.87	143
MP51	2671	100	89.7	1.5	0.3	212.14	0.422	11.5	13.05	145
MP52	2679	100	88.8	1.5	0.3	212.14	0.418	11.6	13.05	145
MP53	2460	100	88.1	1.5	0.3	212.14	0.415	10.6	11.79	131
MP54	2341	100	92.5	1.5	0.3	212.14	0.435	8.4	9.81	109
MP55	2350	100	88.1	1.5	0.3	212.14	0.415	8.5	9.45	105
MP56	2359	100	74.9	1.5	0.3	212.14	0.352	8.6	8.1	90
MP57	2389	100	89.9	1.5	0.3	212.14	0.423	8.9	10.16	113
MP58	2465	100	89.7	1.5	0.3	212.14	0.422	10.6	12.06	134
MP59	2537	100	85.4	1.5	0.3	212.14	0.402	8	8.64	96
mp60	2664	100	79.4	1.5	0.3	212.14	0.374	11.5	11.61	129
mp61	2760	100	75.2	1.5	0.3	212.14	0.354	9.8	9.36	104
mp62	2744	100	80	1.5	0.3	212.14	0.376	10	10.15	113
MP63	2664	100	83.5	1.5	0.3	212.14	0.393	12	12.72	141
						Mean	0.352	5	5.76	64
						Max	0.449	13	15.75	175
						Min	0.4143	9.784	10.91476	121

(Source; Field Data (Feb, 2011))

11. Carbon Stock Estimation in Different pools

ID	AGC	BGC	SOC	DWC	LHG	$\mathrm{Tc}_{\text{density Per tone(ha)}}$
MP1	185	36.9	114.6	6.4	5.2	348.22
mp2	91	18.2	125.7	0.002	5.7	240.74
MP3	130	26	124.12	0	4	284.14
MP4	157.6	31.5	127	0	2.6	318.77
MP5	23.1	4.6	164	0.002	4.8	196.55
MP6	244.8	48.9	132	0	4.8	430.63
MP7	517.2	103.4	99	0.08	8.4	728.12
mp8	94	18.8	64	0	2.4	179.2
MP9	35.9	7.1	96	0.01	5.6	144.77
MP10	195.1	39	113	0.1	3.3	350.56
MP11	38.7	7.7	126	0.005	8.9	181.38
MP12	120.9	24.1	156	0	3.25	304.34
mp13	106.4	21.3	145	0	3.4	276.15
mp14	162.7	32.5	116	0.04	4.37	315.7
mp15	36.1	7.2	98	0.007	8.79	150.13
MP16	89.1	17.8	104	2.7	3.3	217.07
MP17	34.6	6.9	146	0.004	4.8	192.35
MP18	153.5	30.7	172	0.01	6.1	362.41
mp19	79.8	15.9	155	0.11	5	255.85
MP20	113.1	22.6	147	297.69	11.9	592.38
MP21	6.7	1.3	105	0	5	118.05
MP22	94.5	18.9	175	0	1.8	290.23
MP23	69.6	13.9	146	0.05	5.7	235.41
MP24	23	4.6	144	0.16	1.7	173.52
MP25	66	13.2	118	0.19	9	206.5
MP26	84	16.8	120	0	8.4	229.8
MP27	354.1	70.8	117	0	4.1	546.08
MP28	131	26.2	120	0	0.8	278
MP29	107.9	21.6	120	0	1.1	250.64
MP30	85.6	17.1	108	0	5.5	216.33
MP31	71.9	14.4	108	0.01	3.9	198.29
MP32	89.1	17.8	112	0	5	224
MP33	122.2	24.4	102	0.01	4.2	252.91
MP34	222.9	44.6	99.8	0.04	8	375.41
MP35	109.7	21.9	97.6	0.04	13.9	243.24
MP36	105.4	21	102.8	0.08	3.4	232.83

MP37	119.6	23.9	98.4	0.01	2.9	244.875
MP38	109.3	21.8	91	0.1	5.8	228.12
MP39	243.5	48.7	94.8	0	6.8	393.9
MP40	82.2	16.4	141.5	0	9.2	249.42
MP41	123.2	24.6	119.3	0	3.5	270.72
MP42	250.2	50	119.5	0	4.1	423.93
MP43	88.2	17.6	114	0.05	8.4	228.38
MP44	23.2	4.6	111	0.003	0.7	139.66
MP45	46.6	9.3	127	0	2.5	185.5
MP46	94.2	18.8	139	0	7.5	259.67
MP47	46.2	9.2	131	0	2.5	189
MP48	176.2	35.2	120	0.07	1.6	333.24
mp49	161.6	32.3	116.9	0.02	8.3	319.18
MP50	94.2	18.8	143	0.4	1.6	258.1
MP51	208.6	41.7	145	0	1.7	397
MP52	273.7	54.7	145	0.05	4.2	477.82
MP53	110.3	22	131	0	5.1	268.52
MP54	85.3	17	109	0.3	5.8	217.49
MP55	58.4	11.6	105	1.3	8.1	184.49
MP56	62.7	12.5	90	19	9.6	194
MP57	68.9	13.7	112.9	69.5	5.8	270.97
MP58	202.3	40.4	134	0.3	5.1	382.13
MP59	245	49	96	0.009	4.9	394.99
mp60	137.4	27.4	129	0.2	6.7	300.83
mp61	487.8	97.5	104	0	8.1	697.5
mp62	164.6	32.9	112.8	0.01	3.2	313.64
MP63	292.1	58.4	141.4	0.008	9.9	501.89
	133.4556	26.66032	121.288	6.334444	5.265238	293.1058

(Source; Field Data (Feb, 2011))

12. Carbon Estimation in Different Years

Before 1973

plot no	AGB / pixel (tone)	BGB/ pixel (tone)	DW / pixel (tone)	LHG / pixel (tone)	TB / pixel (tone)	TC / pixel (tone)	TC / pixel (tone)
2	17.812	3.562	0.00052	1.134	22.50852	10.579	10.5
3	25.439	5.087	0	0.784	31.31	14.7157	14.7
4	30.837	6.167	0	0.518	37.522	17.63534	17.6
5	4.521	0.904	0.00058	0.943	6.36858	2.993233	3

6	47.908	9.581	0	0.939	58.428	27.46116	27.5
8	18.387	3.677	0	0.475	22.539	10.59333	10.5
9	7.027	1.405	0.002988	1.108	9.542988	4.485204	4.5
10	38.177	7.635	0.02145	0.648	46.48145	21.84628	21.8
11	7.57	1.514	0.0011	1.749	10.8341	5.092027	5
12	23.655	4.731	0	0.637	29.023	13.64081	13.6
13	20.829	4.165	0	0.666	25.66	12.0602	12
15	7.065	1.413	0.0015	1.72	10.1995	4.793765	4.8
16	17.445	3.489	0.542	0.648	22.124	10.39828	10.4
17	6.771	1.354	0.00086	0.943	9.06886	4.262364	4.3
18	30.045	6.009	0.00353	1.198	37.25553	17.5101	17.5
21	1.307	0.261	0	0.986	2.554	1.20038	1.2
22	18.486	3.697	0	0.363	22.546	10.59662	10.6
25	12.924	2.584	0.038	1.771	17.317	8.13899	8.1
27	69.292	13.858	0	0.802	83.952	39.45744	39.5
28	25.628	5.125	0	0.162	30.915	14.53005	14.5
33	23.918	4.783	0.0024	0.824	29.5274	13.87788	13.9
34	43.621	8.724	0.0078	1.573	53.9258	25.34513	25.3
35	21.466	4.293	0.0084	2.728	28.4954	13.39284	13.3
36	20.635	4.127	0.017	0.662	25.441	11.95727	12
37	23.4	4.68	0.003	0.576	28.659	13.46973	13.5
38	21.391	4.278	0.02279	1.137	26.82879	12.60953	12.6
39	47.653	9.53	0	1.339	58.522	27.50534	27.5
41	24.116	4.823	0	0.687	29.626	13.92422	13.9
42	48.956	9.791	0	0.817	59.564	27.99508	28
43	17.262	3.452	0.01	1.656	22.38	10.5186	10.5
44	4.546	0.909	0.00077	0.158	5.61377	2.638472	2.6
45	9.126	1.825	0	0.496	11.447	5.38009	5.4
47	9.05	1.81	0	0.489	11.349	5.33403	5.3
48	34.484	6.896	0.014	0.327	41.721	19.60887	19.6
50	18.424	3.684	0.0089	0.324	22.4409	10.54722	10.5
51	40.813	8.162	0	0.331	49.306	23.17382	23
52	53.56	10.712	0.01	0.835	65.117	30.60499	30.6
54	16.689	3.337	0.0067	1.134	21.1667	9.948349	10
55	11.422	2.284	0.259	1.587	15.552	7.30944	7.3
56	12.283	2.456	3.726	1.886	20.351	9.56497	9.6
57	13.485	2.697	13.608	1.137	30.927	14.53569	14.5
58	39.574	7.914	0.057	1	48.545	22.81615	22.8
59	47.944	9.588	0.00177	0.964	58.49777	27.49395	27.5
60	26.881	5.376	0.00498	1.314	33.57598	15.78071	15.8

61	95.446	19.089	0	1.587	116.122	54.57734	54.6
62	32.216	6.443	0.0038	0.633	39.2958	18.46903	18.5
63	57.157	11.431	0.0016	1.944	70.5336	33.15079	33.1
1973-1984							
24	4.51	0.902	0.032	0.331	5.775	2.71425	2.7
25	12.924	2.584	0.038	1.771	17.317	8.13899	8.1
27	69.292	13.858	0	0.802	83.952	39.45744	39.5
31	14.078	2.815	0.003	0.77	17.666	8.30302	8.3
41	24.116	4.823	0	0.687	29.626	13.92422	13.9
50	18.424	3.684	0.0089	0.324	22.4409	10.54722	10.5
54	16.689	3.337	0.0067	1.134	21.1667	9.948349	10
1984-2005							
2	17.812	3.562	0.00052	1.134	22.50852	10.579	10.5
8	18.387	3.677	0	0.475	22.539	10.59333	10.5
15	7.065	1.413	0.0015	1.72	10.1995	4.793765	4.8
21	1.307	0.261	0	0.986	2.554	1.20038	1.2
30	16.756	3.351	0	1.09	21.197	9.96259	10
32	17.443	3.488	0	0.997	21.928	10.30616	10.3
33	23.918	4.783	0.0024	0.824	29.5274	13.87788	13.9
47	9.05	1.81	0	0.489	11.349	5.33403	5.3

13. 2005 Landsat ETM various Spectral responses Value

Plot	TM 1	TM2	TM3	TM4	TM5	TM7	VIS 123	MID 57	Aleb edo	VI	TM 4/3	TM 5/3	TM 5/4
1	34	26	22	51	30	20	82	48	181	29	128	153	101
2	34	27	22	56	30	19	83	49	188	34	141	149	89
3	37	27	23	66	34	19	90	53	206	43	159	161	92
4	34	26	20	51	28	15	80	43	174	31	141	153	91
5	34	25	21	45	25	16	80	41	166	24	119	130	92
6	35	26	24	47	33	21	85	54	186	23	108	150	116
7	32	24	19	40	20	14	75	34	149	21	117	115	83
8	36	31	31	59	47	31	98	78	235	28	105	165	132
9	34	26	23	50	32	19	83	51	184	27	120	152	106
10	35	26	22	55	33	20	81	53	189	33	139	163	99
11	34	26	19	47	28	16	79	44	171	28	137	161	99
12	34	27	22	50	32	18	83	50	183	28	126	158	106

13	36	27	22	58	36	19	85	55	198	36	146	178	103
14	34	28	23	57	36	20	87	56	197	30	137	163	110
15	37	30	27	65	40	26	94	66	225	38	133	161	102
16	36	27	22	57	35	20	85	55	197	38	144	173	95
17	33	27	25	46	33	22	83	52	181	21	102	163	119
18	32	24	21	43	28	17	77	45	165	22	113	145	108
19	37	27	22	53	33	19	86	52	191	31	134	163	103
20	33	26	21	43	27	17	79	44	170	22	113	140	104
21	43	41	48	74	72	50	132	122	255	26	85	163	161
22	33	26	22	40	26	17	81	43	164	18	101	129	108
23	34	27	23	46	30	19	84	49	179	23	111	142	108
24	36	29	30	51	37	26	95	63	209	21	94	134	120
25	35	27	24	51	30	18	86	47	185	27	118	137	98
26	34	27	24	46	31	19	85	50	181	22	106	144	112
27	35	28	27	52	33	18	90	51	193	25	107	133	105
28	34	25	21	44	27	18	80	45	169	23	116	140	102
29	33	27	21	53	31	17	81	48	182	32	140	161	97
30	34	27	24	60	33	19	85	52	197	36	139	150	91
31	34	27	21	49	30	19	82	49	180	28	129	156	101
32	34	28	22	58	32	20	84	52	194	36	146	158	91
33	34	28	22	54	33	19	84	52	190	32	136	163	101
34	33	25	20	43	28	17	78	45	166	23	119	153	108
35	33	25	21	44	27	16	79	43	166	23	116	140	102
36	35	28	25	48	38	24	88	62	198	23	106	166	131
37	33	26	20	48	27	15	79	42	169	28	133	147	93
38	36	27	22	50	29	18	85	47	182	28	126	144	99
39	32	25	20	44	27	16	77	43	164	24	122	145	102
40	33	26	21	43	28	17	80	45	168	22	111	145	108
41	36	28	25	47	36	22	89	58	194	22	104	157	127
42	34	25	20	42	26	15	79	41	162	22	116	142	103
43	35	26	21	48	30	19	82	49	179	27	127	156	104
44	34	27	21	50	30	18	82	48	180	29	132	156	100
45	33	26	21	47	28	17	80	45	172	26	124	145	99
46	35	29	24	57	35	21	88	56	201	33	132	159	102
47	36	30	24	63	36	20	90	56	209	39	146	163	95
48	34	25	21	45	28	17	80	45	170	24	119	134	99
49	32	25	22	50	30	17	79	47	176	28	126	149	99
50	35	25	21	49	30	18	81	48	178	28	129	156	101
51	33	26	21	47	28	15	80	43	170	26	124	145	99
52	34	27	23	56	34	20	84	54	194	33	135	161	101

53	35	28	23	52	32	19	86	51	189	29	125	152	102
54	34	26	22	55	31	17	82	48	185	33	139	153	93
55	35	25	20	50	30	17	80	47	177	30	139	163	99
56	33	26	22	54	32	19	80	51	186	28	123	158	98
57	34	27	21	56	32	19	82	51	189	35	148	166	95
58	34	26	23	72	30	17	83	47	202	49	174	142	69
59	33	25	20	44	27	15	79	42	172	28	122	153	97
60	32	25	21	42	31	18	78	49	169	21	111	161	122
61	31	23	20	38	24	15	74	39	151	18	105	131	105
62	32	25	21	45	28	17	78	45	168	24	119	145	103
63	33	26	21	45	26	16	80	42	167	24	121	135	96
	34.2	26.7	22.7	50.7	31.5	19	83.6	50.4	184	28	125	151	103

(Source; Data extracted from landsat ETM of 2005)

Continued…………………

Plot	TM 5/7	SQRT	NDVI	TNDVI	ND32	ND53	ND54	ND57	PCA1	PCA2	PCA3	KT1	KT2	KT3
1	125	2.14	0.4	0.95	123	174	121	140	78.3	-5.36	0.62	75	7	49
2	108	1.6	0.44	0.97	116	169	104	113	81.9	-7.22	-1.71	78	10	49
3	123	1.67	0.48	0.99	124	183	98	136	91.4	-10.2	-6.34	87	16	56
4	128	1.6	0.44	0.97	104	173	107	144	75.9	-8.65	0.55	72	8	47
5	107	1.46	0.36	0.93	121	146	109	110	71.1	-6.74	4.76	67	3	43
6	108	1.4	0.32	0.91	140	170	141	112	78.7	-0.24	4.09	76	2	48
7	98	1.45	0.36	0.93	110	124	95	93	63.6	-8.07	6.48	60	2	37
8	104	1.38	0.31	0.9	155	187	159	105	99	8.52	-1.05	96	5	61
9	116	1.47	0.37	0.93	131	172	128	125	79	-3.05	1.43	76	5	48
10	113	1.58	0.43	0.96	123	185	119	121	82.1	-4.15	-2.6	78	10	50
11	120	1.57	0.42	0.96	95	182	118	132	73.4	-6.7	2.78	70	6	45
12	122	1.51	0.39	0.94	116	180	128	135	78.7	-3.97	1.43	75	6	49
13	130	1.62	0.45	0.97	116	199	124	147	86.5	-5.54	-2.82	83	11	54
14	124	1.5	0.38	0.94	117	185	126	137	86	-3.64	-2.84	81	10	54
15	106	1.55	0.41	0.96	135	183	123	107	97.3	-2.03	-4.37	93	11	59
16	126	1.63	0.44	0.97	116	195	122	132	87.9	-6.73	-4.82	84	10	53
17	119	1.45	0.35	0.92	140	185	144	103	76.9	-1.15	3.72	74	3	48
18	113	1.43	0.34	0.92	129	165	130	121	70.3	-2.85	3.82	67	3	43
19	119	1.55	0.41	0.96	116	185	124	131	82.5	-5.37	1.43	79	7	50
20	111	1.43	0.34	0.92	114	159	125	114	70.9	-3.98	5.33	69	2	43
21	99	1.24	0.21	0.84	186	185	189	95	135	26.9	-1.39	134	0	83
22	105	1.35	0.29	0.89	123	144	130	106	68.9	-2.89	7.59	66	0	41
23	108	1.41	0.33	0.91	124	161	131	113	75.9	-2.49	4.57	73	2	46

24	98	1.3	0.26	0.87	162	152	146	92	87.4	3.92	4.46	85	0	52
25	111	1.46	0.36	0.93	132	154	116	123	79.5	-5.26	2.38	74	5	48
26	113	1.38	0.31	0.9	132	160	135	119	76.6	-1.63	4.63	74	2	47
27	126	1.39	0.32	0.9	148	150	127	141	82.6	-3.21	2.28	80	4	52
28	103	1.45	0.35	0.92	121	159	122	103	71.9	-4.19	5.12	68	4	42
29	125	1.59	0.43	0.97	107	182	116	140	79.2	-6.29	-1.16	76	2	49
30	119	1.58	0.43	0.96	132	170	107	131	86.3	-6.7	-4.2	83	9	53
31	108	1.53	0.4	0.95	107	177	122	113	77.2	-4.45	2.25	73	12	46
32	110	1.62	0.45	0.97	109	180	108	115	84.6	-6.6	-2.9	80	5	51
33	119	1.57	0.42	0.96	109	185	122	131	82.2	-4.79	-0.77	79	11	51
34	113	1.47	0.37	0.93	112	173	130	121	70.7	-3.64	4.54	67	8	43
35	116	1.45	0.35	0.92	121	159	122	125	70.9	-4.82	4.32	68	3	43
36	109	1.39	0.32	0.9	133	187	158	113	83.2	3.69	3.65	80	2	51
37	124	1.55	0.41	0.95	104	167	110	137	73.2	-7.5	1.91	70	6	45
38	111	1.51	0.39	0.94	116	163	114	116	78.2	-6.38	3.32	74	5	47
39	116	1.48	0.38	0.94	112	165	118	125	70.3	-4.76	3.42	67	4	45
40	113	1.43	0.34	0.92	114	165	130	121	71.3	-3.43	5.13	68	2	43
41	112	1.37	0.31	0.9	133	178	154	119	81.6	1.66	5.14	79	1	50
42	119	1.45	0.35	0.92	112	161	123	130	69.1	-5.68	6.03	66	2	42
43	108	1.51	0.39	0.94	114	177	125	113	76.7	-4.28	3.17	73	5	46
44	116	1.54	0.41	0.95	107	177	120	123	77.6	-5.39	1.57	74	5	47
45	118	1.5	0.37	0.93	116	174	118	129	73.8	-5.19	2.72	70	5	47
46	114	1.54	0.41	0.95	119	180	122	123	86.8	-3.85	-1.33	83	9	52
47	124	1.62	0.45	0.97	112	185	112	137	91.5	-6.93	-4.24	87	14	57
48	113	1.46	0.36	0.93	121	165	124	121	72.7	-4.58	4.24	70	3	44
49	121	1.51	0.39	0.94	130	169	119	134	76.2	-4.62	-0.21	73	7	47
50	114	1.53	0.4	0.95	121	177	122	123	76.7	-5.12	2.15	73	6	46
51	128	1.5	0.38	0.94	114	165	118	144	73.3	-6.2	2.57	70	5	46
52	117	1.56	0.42	0.97	124	183	121	127	84.2	-4.2	-2.17	81	9	52
53	116	1.5	0.39	0.94	117	172	123	125	81.3	-4.52	1.54	78	6	50
54	125	1.58	0.43	0.96	123	174	111	140	80.8	-7.13	-1.8	77	10	50
55	121	1.58	0.43	0.96	112	185	119	134	76.8	-6.38	1.22	73	7	47
56	116	1.57	0.42	0.94	123	180	117	125	79.6	-4.1	1.08	77	6	49
57	116	1.63	0.45	0.98	107	188	112	125	82.5	-6.43	-2.36	78	10	50
58	121	1.77	0.52	1.01	131	161	71	134	91.4	-14.9	-11.6	87	21	55
59	113	1.48	0.38	0.94	112	173	115	121	70.4	-5.64	3.98	67	4	45
60	118	1.41	0.33	0.91	121	183	148	129	71.5	-0.35	4.24	69	2	44
61	110	1.38	0.31	0.9	128	147	126	115	63.9	-3.69	6.24	61	0	38
62	113	1.46	0.36	0.93	121	165	124	121	71.9	-3.83	2.95	69	4	44
63	111	1.46	0.36	0.93	114	152	114	118	71.5	-5.92	4.25	68	3	43

	115	1.51	0.38	0.94	122	172	123	123	79.3	-3.95	1.4	75.9	5.83	48.5

(Source; Data extracted from landsat ETM of 2005)

Continued………………

Plot	Ske TM17	Ske TM27	Ske TM37	Ske TM47	Ske TM57	Ske TM77	Var TM17	Var TM27	Var TM37	Var TM47	Var TM57	Var TM77
1	-0.27	-0.52	0.09	-0.5	-0.96	-0.48	0.06	0.59	0.61	3.38	2.45	0.64
2	2.48	4.26	9.06	2.53	21.6	18.6	3.52	5.75	31.6	4.4	129	93.5
3	-0.1	-0.28	-0.22	3.1	0.5	-0.17	1.7	4.17	2.71	65.7	50.9	12.6
4	0.38	-1.36	3.23	7.38	3.17	3.99	1.89	1.21	8.78	17.8	6.11	5.46
5	1.99	2.37	4.88	1.2	9.8	7.47	3.16	10.4	26.8	31.1	128	64.3
6	0.26	-0.21	1.47	-4.22	2.48	3.52	4.53	12.1	30.1	76.8	177	91.1
7	1.33	2.49	3.81	1.65	11.8	7.52	1.01	2.17	4.39	31.5	23.8	7.19
8	-0.18	-0.37	-0.15	-0.14	-1.63	-0.35	6.41	13.2	51.1	45.1	175	84.3
9	-0.18	-0.35	0.04	-0.72	1.36	0.92	0.58	1.31	1.61	10.1	6.93	3.64
10	0.19	0.24	0.46	0.38	1.3	1.67	0.82	0.72	1.02	13.3	3.96	1.74
11	-0.06	-0.83	-0.1	0.92	-0.75	0.16	0.45	0.96	0.76	4.66	3.37	1.62
12	-0.16	-0.73	-0.37	-3.17	-3.26	-1.78	0.25	0.67	0.27	0.54	3.21	1
13	0.12	-0.32	0.08	-0.59	0.26	0.35	0.94	0.89	0.83	21.1	8.09	1.97
14	0.93	0.74	2.76	-4.16	4.39	4.71	0.26	0.99	1.06	47.1	12.1	1.64
15	0.09	0.33	-0.13	0.53	0.77	0.13	3.42	8.38	41.9	25.1	105	67.6
16	0.03	-0.69	1.4	0.63	-1.52	-0.96	0.47	0.58	0.53	7.21	2.96	1.47
17	0.05	0.14	0.09	1.83	-0.18	0.2	0.58	0.67	1.23	7.33	6.9	3.25
18	0.87	-0.52	-0.77	3.97	0.55	-0.68	0.37	0.74	0.63	20.6	4.34	0.99
19	-0.06	0.35	0.45	0.95	3.29	2.3	0.93	1.11	1.29	27.4	11.7	2.57
20	-0.85	-0.96	-2.21	8.07	-7.2	-3.61	0.93	0.56	0.93	3.2	3.71	1.9
21	0.2	-0.03	0.34	-0.42	0.43	0.56	0.93	0.56	0.93	3.2	3.71	1.9
22	-0.14	-0.11	-0.14	-2.77	0.35	0.95	9.2	17.1	75.6	226	144	107
23	1.25	1.5	4.03	5.16	8.74	6.02	0.72	0.49	1.66	0.63	2.96	3.74
24	-23.2	-16.5	-10.3	-33.1	-9.79	-3.11	0.45	0.62	0.96	4.55	3.49	1.59
25	-0.31	0.39	1.57	0.12	1.53	1.05	181	121	133	369	240	121
26	0.96	1.2	2.22	2.16	5.54	5.1	0.7	0.76	1.5	1.5	4.46	2.99
27	0.2	0.58	0.06	6.56	3.15	-0.68	2.38	4.04	12.8	29.9	61	31.5
28	0.36	0.04	-0.01	0.66	-0.54	0	0.63	1.5	2.19	26.2	9.93	4.11
29	1.34	0.49	3.26	1.88	3.66	1.88	0.87	0.31	0.33	8.48	5.89	0.92
30	0.32	0.44	1.62	-0.46	3.57	2.61	0.78	2.19	4.17	26.1	19.2	8.86
31	0.04	-0.3	0.17	1.41	0.67	0.5	0.96	1.33	2.95	17.5	17.8	6.83
32	-0.08	-0.06	-0.34	4.84	1.52	0.38	0.5	0.42	0.93	10.4	6.14	1.71
33	0.13	-0.04	-0.03	3	0.93	0.18	0.49	0.58	0.59	7.15	4.04	1.46

34	0.35	0.18	-0.23	0.59	-0.43	0.17	0.67	0.45	0.73	8.36	3.78	1.18
35	-0.29	0.93	3.15	-1	4.47	4.5	0.75	0.26	0.3	3.03	1.4	0.54
36	-0.12	0.35	-0.23	0.1	0.14	0.53	1.04	1.16	3.43	4.59	6.49	5.33
37	-0.03	-0.23	0.06	-0.25	0.61	-0.59	1.04	0.94	0.49	6.54	5.13	1.01
38	-0.21	0.24	-0.2	2.38	1.56	0.57	0.75	0.46	0.46	4.85	1.43	0.82
39	-0.1	-0.26	-0.72	-0.1	0.2	0.08	1.25	0.75	0.9	8.92	3.7	1.34
40	-0.01	0.19	-0.58	2.12	0.97	0.96	0.46	0.34	0.34	1.68	0.63	0.49
41	-0.28	0.15	0.15	1.86	1.05	0.05	1.03	0.68	3.82	7.37	9.77	6.85
42	-0.2	0.93	1.09	4.16	2.18	1.31	0.48	0.7	0.56	7.13	7.13	2.02
43	-0.07	-0.06	0.76	2.1	0.16	0.45	0.87	0.29	1.2	6.49	4.98	2.76
44	0.7	1.69	2.73	5.33	9.81	6.71	0.5	0.4	0.95	7.81	2.95	2.39
45	0.31	0.47	3.7	0.23	6.77	5.42	0.9	0.67	2.52	9	22.4	10.2
46	0.17	0.42	2.85	-1.11	4.95	3.77	0.62	0.9	3.17	2.93	8.66	6.75
47	-0.63	-0	-0.07	-0.52	0.77	0.46	1.04	1.32	3.13	9.35	15.7	7.19
48	-0.22	0.69	0.44	-0.74	1.11	1.81	0.8	1.33	1.28	9.85	5.79	1.97
49	0.35	0.73	-0.27	-0.53	0.1	0.67	0.54	0.78	1.62	22.4	10.1	3.1
50	0.2	-0.72	0.11	0.13	-0.29	-0.13	2.26	3.11	3.06	6.84	7.67	4.21
51	0.49	-0.37	0.31	-1.01	-0.26	0.19	1.18	1.29	1.38	5.21	5.8	3.36
52	0.08	-0.58	-0.32	0.02	0.87	0.87	0.83	1.35	2.7	22.4	11.5	4.29
53	0.28	0	0.3	0.48	1.76	1.17	0.63	0.54	1.33	5.46	5.03	2.44
54	0.33	0.44	0.37	-1.02	-0.25	-0.81	0.36	0.56	1.51	4.77	4.11	2.66
55	-0.28	0.02	0.29	0.66	0.11	-0.47	0.71	0.84	0.94	9.46	3.53	1.38
56	0.1	-0.09	-0.51	0.21	-0.21	-0.08	0.36	0.53	0.81	6.18	1.63	0.7
57	-0.17	-0.14	-0.65	-8.24	3.41	1.07	0.7	0.42	1.05	3.68	3.17	2.89
58	0.11	0.02	-0.09	-3.86	-1.15	-0.23	0.76	3.07	3.43	92.6	31.7	6.54
59	0.45	0	0.22	0.18	-0.95	-0.66	0.65	0.65	0.47	8.12	2.39	0.71
60	-0.61	-0.12	-0.65	1.45	-0.17	-0.5	0.91	1.13	0.6	26.9	12.3	2.12
61	-0.3	0.51	-0.1	-0.9	-0.22	0.29	0.67	0.57	0.41	18.1	5.48	1.39
62	-0.11	-0.38	-0.19	-3.27	-0.51	-0.32	1.21	1.92	1.12	22.6	9.83	2.53
63	0.09	-0.14	0.04	-0.06	0.61	-0.28	0.39	0.67	0.67	12.3	3.34	1.09
	-0.19	-0.06	0.6	0.13	1.63	1.36	4.06	3.91	7.78	24.7	25.5	13.2

14.1984 Landsat TM different spectral responses value

Plot	TM1	TM2	TM3	TM4	TM5	TM7	VIS 123	MID 57	Alebedo	VI	TM 4/3	TM 5/3	TM 5/4	TM 5/7	SQRT
1	60	24	21	64	44	122	106	61	231	42	149	166	86	99	1.7
2	75	36	50	77	106	136	158	136	255	29	79	144	140	93	1.3
3	66	16	28	72	73	130	118	92	255	43	123	173	107	114	1.6
4	61	24	23	56	47	123	108	63	234	40	136	148	84	112	1.6

5	60	23	21	42	33	119	110	68	236	27	101	142	109	114	1.4
6	60	23	24	42	41	119	106	61	210	19	89	133	115	99	1.3
7	55	23	22	50	41	118	112	71	230	21	89	140	120	91	1.3
8	69	32	44	77	84	125	107	61	232	39	127	131	79	107	1.6
9	59	23	22	50	45	117	102	62	215	29	115	149	100	101	1.5
10	55	22	21	53	41	117	98	54	205	32	125	129	87	105	1.6
11	57	21	20	39	37	118	98	52	189	19	96	134	107	94	1.4
12	60	25	24	56	52	122	109	74	245	33	115	157	105	103	1.5
13	62	24	22	65	52	123	109	69	243	43	146	175	92	126	1.7
14	62	25	23	70	55	124	109	71	249	50	162	171	81	121	1.8
15	70	34	43	72	72	127	149	134	255	22	73	148	156	89	1.2
16	60	24	21	70	50	122	108	59	219	28	107	133	95	112	1.5
17	59	26	25	50	44	121	110	62	222	25	99	128	99	93	1.4
18	56	23	21	48	36	115	100	49	197	27	113	124	85	105	1.5
19	59	23	23	60	44	119	107	66	233	37	129	158	94	119	1.6
20	58	23	22	56	43	118	102	55	214	37	141	152	83	123	1.7
21	75	39	59	74	89	135	171	160	255	11	62	109	177	79	1.1
22	58	23	22	47	39	118	101	46	191	24	106	127	89	121	1.5
23	59	24	22	48	46	119	102	57	209	29	118	149	97	117	1.5
24	67	29	33	80	67	126	113	68	255	51	147	140	73	106	1.7
25	66	28	32	77	65	126	127	87	255	37	105	141	103	106	1.5
26	61	24	24	54	44	122	117	79	255	25	94	145	119	93	1.4
27	63	27	29	60	59	121	108	53	214	30	114	129	87	130	1.5
28	60	23	22	63	39	119	103	54	211	32	121	135	86	120	1.6
29	62	25	23	52	44	122	105	61	221	33	124	155	96	128	1.6
30	88	48	73	86	129	142	190	192	255	31	74	162	167	92	1.2
31	71	31	41	66	83	127	133	97	255	27	88	149	131	110	1.3
32	77	37	49	84	90	137	149	136	255	33	86	157	139	88	1.3
33	82	42	64	77	111	136	188	161	255	9	56	122	167	77	1.1
34	59	23	19	48	42	118	101	54	203	29	125	161	99	133	1.1
35	59	22	19	48	39	117	101	49	204	32	125	134	77	117	1.6
36	63	27	33	44	52	120	107	65	222	26	103	145	108	108	1.4
37	59	24	23	50	37	120	97	44	191	27	116	120	79	114	1.5
38	58	23	20	57	42	118	102	55	213	37	141	152	83	126	1.7
39	57	22	21	51	40	118	103	55	215	27	134	142	81	130	1.6
40	62	24	24	49	41	119	105	55	212	27	108	133	95	123	1.5
41	66	28	31	52	65	124	117	83	251	27	90	158	119	106	1.4
42	60	23	21	50	40	118	101	48	194	25	111	134	93	128	1.5
43	61	24	24	50	41	119	109	59	218	26	103	139	104	135	1.4
44	59	24	20	49	40	119	102	52	217	31	119	145	94	120	1.6

45	59	24	20	49	36	118	104	75	208	29	115	132	88	127	1.5
46	64	26	27	59	70	124	111	109	242	33	121	174	111	105	1.6
47	68	31	38	80	80	134	137	48	255	42	104	153	113	105	1.5
48	56	22	18	53	38	117	96	55	197	35	146	153	81	145	1.7
49	56	22	19	47	37	115	96	79	204	33	131	152	89	123	1.6
50	61	23	23	52	45	121	117	79	255	34	106	143	104	112	1.5
51	57	22	21	53	37	117	99	52	203	33	136	153	87	127	1.7
52	53	22	19	48	28	117	102	60	216	33	127	152	92	105	1.6
53	63	29	29	58	57	124	118	71	248	32	108	140	99	104	1.5
54	62	26	25	72	54	123	105	53	241	46	153	122	61	128	1.8
55	58	21	18	51	41	120	97	54	241	26	121	161	103	109	1.6
56	59	25	21	59	42	121	104	58	221	38	139	145	89	107	1.7
57	58	22	19	59	34	121	100	45	203	40	154	130	65	118	1.8
58	63	25	26	84	57	123	112	66	255	58	165	148	70	130	1.8
59	58	24	20	60	44	120	103	58	212	30	120	149	95	109	1.6
60	60	23	23	47	50	118	103	65	211	22	101	166	126	108	1.4
61	56	20	18	43	34	117	94	46	183	25	118	137	89	108	1.5
62	56	23	21	54	48	117	109	69	238	36	124	154	96	108	1.6
63	58	23	23	50	40	119	100	55	201	25	108	145	103	123	1.5

(Source; Data extracted from landsat TM of 1984)

Continued……….

Plot	NDVI	TNDVI	ND32	ND53	ND54	ND57	PCA1	PCA2	PCA3	KT1	KT2	KT3
1	0.5	1	73	188	99	189	161	-17	-7	97	45	70
2	0.2	0.9	200	162	172	147	210	28	4.7	155	70	111
3	0.4	1	129	205	131	176	180	0.7	-6	121	58	89
4	0.5	1	86	168	96	169	161	-16	-6	98	46	69
5	0.3	0.9	109	160	134	172	159	-12	4.8	97	42	67
6	0.3	0.9	133	148	143	152	150	-19	11	85	32	59
7	0.3	0.9	120	157	149	140	157	-13	11	93	36	64
8	0.4	1	119	145	87	164	158	-15	-7	97	48	68
9	0.4	0.9	85	160	122	155	150	-16	3	88	38	62
10	0.4	0.9	96	172	100	161	145	-23	4.1	89	38	62
11	0.3	0.9	96	150	132	145	143	-25	12	76	27	52
12	0.4	0.9	98	178	129	158	163	-10	1.3	101	44	71
13	0.5	1	85	197	109	184	164	-12	-7	102	47	73
14	0.5	1	74	193	91	179	171	-10	-14	105	52	75
15	0.2	0.8	207	168	188	139	197	28	10	145	61	103
16	0.4	0.9	98	148	115	169	155	-19	3.6	90	39	63

17	0.3	0.9	98	141	120	144	154	-18	6.2	90	38	62
18	0.4	0.9	84	136	97	161	143	-23	3	80	35	55
19	0.4	1	109	179	112	177	158	-13	-3	97	44	69
20	0.5	1	71	173	94	181	151	-19	-4	89	40	63
21	0.1	0.8	230	111	205	127	215	41	20	155	67	108
22	0.4	0.9	71	139	99	179	144	-28	7.7	77	30	54
23	0.4	1	84	168	117	175	151	-21	3.5	86	36	61
24	0.4	1	131	173	76	162	171	-12	-16	109	57	76
25	0.4	0.9	154	159	126	162	181	-2	-3	119	55	85
26	0.3	0.9	129	164	148	144	163	-7	7.7	102	41	71
27	0.4	0.9	97	143	101	188	154	-23	1.6	88	39	63
28	0.4	1	109	151	99	178	151	-21	-0	87	39	62
29	0.4	1	74	176	116	186	156	-17	0.1	92	41	66
30	0.2	0.8	204	183	197	143	242	63	6.9	208	85	143
31	0.3	0.9	151	169	162	167	179	5.2	5.6	121	52	88
32	0.3	0.9	179	178	171	136	205	27	3.4	150	66	106
33	0.1	0.8	223	133	197	117	219	45	19	172	72	119
34	0.4	1	57	182	120	191	148	-22	3.9	83	34	60
35	0.4	1	59	164	84	181	150	-20	0.2	87	39	62
36	0.4	0.9	109	164	133	164	154	-15	5.8	91	38	64
37	0.4	1	83	128	87	172	145	-29	3.8	78	33	54
38	0.5	1	71	173	94	184	151	-19	-2	89	41	63
39	0.4	0.9	84	160	101	178	151	-19	-2	86	38	62
40	0.4	0.9	86	147	114	181	151	-20	3.8	87	38	62
41	0.3	0.9	140	170	148	162	165	-8	5.4	103	40	74
42	0.4	0.9	71	150	110	186	146	-26	6.1	79	32	56
43	0.4	0.9	109	156	127	192	154	-18	4.9	90	38	63
44	0.4	1	74	164	112	178	152	-18	1.1	89	39	64
45	0.4	0.9	97	147	103	185	150	-23	2.2	86	37	61
46	0.4	0.6	99	168	137	161	163	-11	2.9	99	41	61
47	0.4	0.9	165	173	140	161	196	11	-6	99	66	99
48	0.5	1	54	174	90	201	146	-24	-2	82	37	59
49	0.5	1	96	173	105	181	147	-19	-1	85	38	60
50	0.4	0.9	148	161	127	170	168	-4	-2	109	51	78
51	0.5	1	69	173	101	185	148	-22	-0	84	36	60
52	0.4	1	73	172	109	161	151	-17	-0	89	39	62
53	0.4	0.9	99	157	121	160	165	-12	1.2	102	46	72
54	0.5	1	97	132	51	186	164	-18	-23	104	49	65
55	0.4	1	67	183	125	166	147	-25	7.5	79	30	55
56	0.5	1	61	164	89	178	155	-20	-1	90	41	63

57	0.5	1	69	144	67	176	151	-28	-7	85	41	56
58	0.5	1	120	168	82	188	172	-11	-22	113	61	80
59	0.4	0.9	96	168	114	166	152	-20	3.1	87	36	61
60	0.3	0.9	73	188	156	164	149	-16	11	85	31	61
61	0.4	1	80	154	105	165	141	-28	6.3	74	29	51
62	0.4	1	98	175	115	181	159	-10	-3	99	45	70
63	0.4	0.9	84	164	126	181	148	-21	6.2	82	34	59

(Source; Data extracted from landsat TM of 1984)

Continued………

Plot	Skew TM27	Skew TM37	Skew TM47	Skew TM57	Skew TM77	Var TM17	Var TM27	Var TM37	Var TM47	Var TM57	Var TM77
1	-1	0.2	-1	-0	0.6	1.9	1	1.9	19	10	3.6
2	-1	-4	-6	-13	-4	28	19	68	31	234	58
3	4.7	10	15	22	7.8	17	17	61	145	310	45
4	3.7	9.1	4	22	10	14	7.9	38	88	236	51
5	0.6	2.4	-4	5	3.8	5.5	5.7	13	68	131	24
6	-0	0.2	-1	-0	0.7	10	6.5	18	135	119	23
7	-1	0.5	-6	5.6	6.1	15	8.9	27	35	348	125
8	3.9	11	2.2	16	6.6	32	19	106	196	551	95
9	-1	-0	-3	-2	-0	2.8	1.8	3.5	26	37	7.6
10	-1	-0	-1	-3	-0	1.8	1	0.7	9.8	12	12
11	0.2	0.8	-0	2.1	1.4	2.5	1.5	3.7	8.6	26	8.3
12	0.5	-0	2.7	1.3	-0	1.9	1.2	1.5	23	14	1.9
13	-1	-0	-3	-4	-1	3.2	1.2	2.1	64	32	2.9
14	-1	-1	-10	-6	-2	3	1.8	2.1	83	44	6.1
15	1.2	2.1	-2	4.1	1.8	45	34	163	79	723	182
16	1	3.6	1.8	1.2	1.9	2.3	1	3.5	29	15	3.6
17	0.9	1.7	0.6	4.6	3.1	3.5	2.3	6.5	34	63	12
18	0.1	-0	-2	1.1	-0	1.7	1.2	1	37	22	3.3
19	-1	-0	-2	-1	-1	2.8	1.9	2.3	50	39	6.1
20	0.2	-0	-1	0.2	0.5	1.9	0.6	0.8	10	3.5	1.3
21	-0	-2	0.2	-2	-2	17	12	42	50	171	49
22	0	0.1	-1	0.5	0.1	1.8	0.5	0.7	3.6	6.6	1.7
23	0.1	0.6	0.8	1	0.4	1.2	0.6	1.6	3.5	6.9	1.5
24	1.1	2.8	-5	5.7	2.9	7.1	7.3	24	39	88	24
25	7.2	13	5.7	23	13	51	41	139	503	13	124
26	-1	-0	1.7	0.2	0.1	2.2	0.9	4.2	5.6	27	7
27	0.6	2.7	6.3	4.9	1.2	2.5	0.9	6.6	39	41	7.3
28	0.3	2.6	2.3	16	7.7	3.7	3.2	7.5	165	111	16

29	-0	0.1	3.7	-0	-0	2	1.1	1.3	33	16	2.7
30	-2	-3	-1	-16	-6	101	76	311	166	806	205
31	2.7	1.5	10	17	6	8.2	7.5	21	72	205	39
32	6.2	9.3	3.2	17	6.2	42	29	134	42	386	111
33	-3	-9	4.4	-13	-10	39	26	146	38	220	84
34	0.1	0.2	2.1	-1	0.5	2	0.9	1.2	28	15	2.3
35	-0	0.3	-0	0.7	-0	1.3	0.6	0.7	21	6.5	1.4
36	0.9	5.4	-2	2.2	3.5	1.5	0.8	6.4	20	10	7.1
37	6.6	12	12	26	11	11	5.3	27	45	136	22
38	-0	-0	-4	-3	-1	1.1	0.8	0.6	36	12	1.3
39	0.3	-0	-0	1.2	-0	1.1	0.7	0.6	13	4.9	1.1
40	-0	0.3	0.6	0.1	0.6	1.5	0.4	1	5	3	1.4
41	0.1	1.5	0.4	0.8	0.8	8.5	5.3	27	33	157	33
42	1.5	4.8	5.7	9.4	7.7	2.1	0.9	3.2	22	20	5.8
43	-0	0.5	-0	3.4	1.2	1.3	0.6	1.6	3.4	11	3.7
44	0.3	-0	-0	-1	-0	2	0.4	0.6	10	4.4	1.4
45	-1	2.2	-0	3.8	3.4	2	1.2	3.9	7.3	21	8
46	0.5	5.7	-4	9.1	5.1	6.1	4.5	17	30	159	34
47	5.8	13	-1	19	12	10	6.1	36	6.2	128	44
48	-0	-0	0.8	-0	0.4	1.9	1.1	1.3	24	15	2.1
49	-0	-0	1.1	-2	-1	2	0.9	0.8	19	12	1.8
50	-1	-2	-4	-5	-2	9.5	7.3	27	94	183	30
51	-1	-0	-0	-0	-0	1	0.8	0.9	28	12	1.8
52	-0	-1	0.8	-0	-0	2.4	1.5	2.5	46	37	5.9
53	-1	0.7	9.7	3.4	-1	3	2.3	4.4	42	31	6.2
54	0.9	1.9	-8	3.6	1.2	3.1	1.9	5.5	81	47	9.2
55	-0	0	6.7	4.3	0.5	1.7	1.2	1.6	49	16	1.8
56	0.5	0.9	-1	0.1	0.7	2	0.7	2.2	20	15	3.3
57	-0	0.2	-3	-5	1	2	0.9	1.1	18	13	2.7
58	-0	-1	0.3	0.4	0.7	9	7.2	15	154	187	21
59	0.1	-1	4.6	-1	0.1	1.8	0.7	0.8	54	15	1.9
60	-1	-1	1.3	-1	-1	2	1.1	1.6	30	24	3.9
61	0.4	-1	7.8	-0	0	4.4	2.3	4.2	74	46	5
62	-1	-1	-0	-1	-0	4	2.4	4.2	63	40	5
63	-0	-0	-2	0.4	-0	1.6	0.6	0.7	26	13	2.8

(Source; Data extracted from landsat TM of 1984)

15. Linear regression analysis results of total carbon stock and different spectral values

ID	Spectral Response type	Linear Equation	Beta (R)	R^2	Adjusted R^2	Std. Error of the Estimate
1	TM1	C=-2.85TM1+123.84	-0.444	0.197	0.184	10.1
2	TM2	C=-0.425TM2+80.427	-0.425	0.181	0.167	10.2
3	TM3	C=-0.863TM3+45.91	-0.305	0.093	0.078	10.74
4	TM4	C=-0.595TM4+56.491	-0.392	0.154	0.14	10.37
5	TM5	C=-0.715TM5+48.868	-0.425	0.181	0.167	10.2
6	TM7	C=-0.886TM7+43.215	-0.388	0.15	0.136	10.39
7	VIS123	C=-0.561VIS123+73.232	-0.387	0.149	0.135	10.4
8	MID57	C=-0.401MID57+46.577	-0.41	0.168	0.154	10.28
9	Alebedo	C=-0.288Alebedo+79.317	-0.474	0.224	0.212	9.93
10	VI	C=-4.492VI+40.153	-0.268	0.072	0.056	10.86
11	TM43	C=-0.076TM43+35.797	-0.108	0.012	-0.005	11.21
12	TM53	C=-0.463TM53+96.386	-0.496	0.246	0.233	9.79
13	TM54	C=-0.194TM54+46.37	-0.221	0.049	0.033	11
14	TM57	C=-0.026TM57+29.374	-0.017	0	-0.016	11.27
15	SQRT	C=-6.195SQRT+35.719	-0.068	0.005	-0.012	11.25
16	NDVI	C=-25.383NDVI+35.938	-0.122	0.015	-0.001	11.19
17	TNDVI	C=-38.93TNDVI+62.868	-0.1	0.01	-0.006	11.22
18	ND32	C=-0.097ND32+38.244	-0.127	0.016	0	11.18
19	ND53	C=-0.422ND53+98.86	-0.522	0.272	0.26	9.62
20	ND54	C=-0.154ND54+45.32	-0.226	0.051	0.036	10.98

21	ND57	C=0.007ND57+25.55	0.008	0	-0.016	11.27
22	PCA1	C=-0.481PCA1+64.531	-0.441	0.194	0.181	10.12
23	PCA2	C=-0.499PCA2+24.434	-0.228	0.052	0.036	10.98
24	PCA3	C=0.892PCA3+25.133	0.28	0.078	0.063	10.82
25	KT1	C=-0.462KT1+61.427	-0.426	0.182	0.168	10.2
26	KT2	C=-0.456KT2+29	-0.167	0.028	0.012	11.12
27	KT3	C=-0.756KT3+63	-0.435	0.189	0.176	10.15
28	SkewTM17	C=0.437SkewTM17+26.456	0.117	0.014	-0.002	11.2
29	SkewTM27	C=0.588 SkewTM27+26.4	0.12	0.014	-0.002	11.19
30	SkewTM37	C=-0.104 SkewTM37+26.4	-0.021	0	-0.016	11.27
31	SkewTM47	C=0.318 SkewTM47+26.33	0.144	0.021	0.005	11.16
32	SkewTM57	C=-0.084 SkewTM57+26.5	-0.032	0.001	-0.015	11.27
33	SkewTM77	C=-0.234 SkewTM17+26.7	-0.066	0.004	-0.012	11.25
34	VarTM17	C=-0.045 VarTM17+26.556	-0.091	0.008	-0.008	11.23
35	VarTM27	C=-0.068 VarTM27+26.64	-0.094	0.009	-0.007	11.229
36	VarTM37	C=-0.066 VarTM37+26.885	-0.123	0.015	-0.001	11.19
37	VarTM47	26.366	0.001	0	-0.016	11.27
38	VarTM57	-0.016 VarTM57+26.791	-0.073	0.005	-0.011	11.248
39	VarTM77	-0.038 VarTM77+26.868	-0.97	0.009	-0.007	11.22

16. Multi-linear Regression analysis of 2005 landsat ETM image and sample plot estimation

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.878[a]	.771	.433	8.425437

a. Predictors: (Constant), VARTM77, SkewTM47, PCA3, PCA2, SkewTM77, VARTM17, ND53, ND57, TM1, SQRT, SkewTM27, ND32, KT2, VARTM47, TM2, SkewTM37, TM57, SkewTM57, TM54, VARTM57, SkewTM17, TM53, VARTM37, NDVI, TNDVI, ND54, VI, Alebedo, TM43, KT3, VIS123, TM4, KT1, VARTM27, TM7, TM3, TM5

17. Multi linear regression analysis of 1984 Landsat TM with Carbon stock estimated in sample plots

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.872[a]	.760	.352	9.00471

a. Predictors: (Constant), VARTM77, SkewTM47, ND53, SkewTM77, TNDVI, TM4, VARTM47, TM57, SQRT, Alebedo, SkewTM17, TM2, VARTM57, ND32, PCA3, MID57, TM7, ND57, TM53, SkewTM37, TM5, SkewTM27, SkewTM57, KT2, TM43, VARTM37, TM1, VI, TM54, TM3, NDVI, VARTM27, KT1, ND54, VIS123, VARTM17, KT3, PCA2, PCA1

b. Dependent Variable: TC