CARBON STOCK ESTIMATION ON FOUR SELECTED URBAN PUBLIC PARKS: IMPLICATION FOR CARBON EMISSION REDUCTION IN ADDIS ABABA

By

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ABSTRACT

Carbon Stock Estimation on Four Selected Urban Public Parks: Implications for Carbon Emission Reduction in Addis Ababa.

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Climate change is one of the grand challenges that have faced humanity. Anthropogenic emission of CO_2 *is the major cause for current global warming. However only few studies have been conducted from emission reduction perspectives on urban public parks offset* CO_2 *in the atmosphere. This study was, therefore, aimed at estimate the carbon stock in four selected public parks in Addis Ababa using non-destructive method. Complete listing for AGB of trees with DBH ≥10cm and systemic sampling method for soil and litter carbon stock estimation was employed. Forty five10m*10m sample plots were laid for soil and litter. The soil and litter carbon was determined by Walkley-Black method and ashing method, respectively. Tree specimens were taken to the National (ETH) Herbarium for identification. The carbon stock of 118.748±82.00 ton/ha, 23.75±16.40 ton/ha, 1.148±0.341ton/ha and 93.93±32.99 ton/ha were recorded in the above ground biomass, below ground biomass, dead litter and soil pool respectively. The corresponding* CO_2*equivalent in different pools were 632.285±596.52 ton/ha, 87.15±60.19 ton/ha, 4.214±1.250 ton/ha and 344.71±121.08 ton/ha. Cupressus lusitanica was the dominant species. It constitutes 39.9% of the total tree found in the study site I. This species has also higher DBH class in the study site II. Altitude and aspects are the two parameters that affect the carbon stocks in soil and litter. The carbon stock in Litter and Soil were higher in the higher altitude with (1.18 t/ha) and (105.32/ha) respectively. The higher carbon stock was recorded in North West aspect for both litter and soil while the lowest was recorded in North East aspect for soil and East aspect for litter carbon. This study conducted that public Parks play a role in offsetting carbon dioxide for beyond its aesthetic value and it is very important in enhancing carbon sequestration potentials.*

Key words: *Climate change, Public Parks, Carbon Stock, Green House Gases,*

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List of Acronyms

AGB	Above-ground biomass
AGC	Above ground carbon
BD	Bulk density
BGB	Below-ground biomass
BGC	Below ground carbon
CRGE	Ethiopia's climate-resilience green economy
DBH	Diameter at breast height
FAO	Food and agricultural organization
FDRE	Federal democratic republic of Ethiopia
FSI	Forest survey of India
GPS	Global positioning system
GHG	Green house gasses
IPCC	Intergovernmental panel for climate change
LB	Litter biomass
LC	Litter carbon
NOAA	National oceanic and atmospheric administration
UN	United Nations
UNEP	United Nations environment program
GOFC-GOLD	Global observation of forest and land-cover dynamics
IUFRO	International union of forest research organizations
SOC	Soil organic carbon
SOM	Soil organic matter
SPSS	Statistical Package for Social Science
UNFCCC	United Nations framework convention on climate change

CHAPTER ONE

1. INTRODUCTION

1.1. Background and justification

Currently, carbon-dioxide emissions and climate change are the worldwide issue. Global warming is more certain and alarming than ever. Most of the observed increase in global surface average temperatures is due to the observed increase in the amount of greenhouse gases in our atmosphere, especially carbon dioxide. According to NOAA (2012) CO_2 is increased from 280 parts per million (ppm) in 1850 to 394 ppm in 2012. This spectacular rise in carbon dioxide concentration is attributed largely to human activities (Samalca *et al.*, 2009).

According to estimate of International Panel on Climate Change IPCC (2000), 1.6 billion tons of carbon is released annually due to land-use change activities, of which a major part results from deforestation and forest degradation (Michael *et al.*, 2009). For this reason, the recent assessment shows the world as a whole carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually from the year 2005–2010, mainly because of a reduction in the global forest area FAO (2010). Loss of forest biomass through deforestation and forest degradation makes up 12 to 20% of annual greenhouse gas emission, which is more than all forms of transport combined (Saatchi *et al.*, 2011). The ultimate result would be climate change, which is the real current problem globally.

Concern about global warming has resulted in investigation of innovation mechanisms that can be used to reduce the effect of green house gasses (Penman *et al.*, 2003; IPCC, 2007). From those mechanisms, carbon sequestration is one of the primary global focuses (IPCC, 2007). Carbon sequestration is defined as the process or mechanism of capturing and storing carbon dioxide from the atmosphere (IPCC, 2000). There are different pools known to sequester carbon-dioxide from the atmosphere. These include ocean sequestration whereby carbon is stored in the oceans through direct injection or fertilization, geologic sequestration in which natural pore spaces in geologic formations serve as reservoirs for long-term carbon dioxide storage,and terrestrial sequestration whereby a large amount of carbon is stored in soil and vegetation (IPCC, 2000).

From terrestrial sequestration, forests play an important role in the global carbon cycle (IPCC, 2001). Their temporal carbon dynamics are characterized by long periods of gradual build-up of biomass (a sink), alternated with short periods of massive biomass loss (Phillips *et al.*, 1998).

Because of this reason, the 1997 Kyoto Protocol, the first major international agreement on climate change, recognized the role of forests in mitigating climate change by naturally taking carbon out of the atmosphere, thereby reducing the impact of CO_2 emissions (Holly *et al.*, 2007; IPCC, 2003; 2007; Perschel *et al.*, 2007;).However, the amount of carbon stored in forest varies greatly based on a large number of factors, including the type of forest. As Judith (2012), mentioned Boreal forests represent the greatest share in terrestrial C stock, containing 26%.Temperate forests account only for 7%, while the C stock in tropical forests amounts to 20% of the terrestrial C stock. The other factor is age of the forest. According to Judith, (2012), older forests contain more C than younger ones. With increasing age, the biomass volume grows and the forest floor develops, thus, accumulates C. Young leaves that have not yet reached 25% of its full size serves as C sink and taking up C through photosynthesis and older leaves, instead, are C sources, exporting C to other parts within the tree (Lorenz & Lal, 2010). During the whole life span of a tree, stem wood represent the largest C stock. Another factor is its net primary production, and its overall composition (Millard, 2007). Carbon storage in forest ecosystems involves numerous components including biomass carbon and soil carbon. As more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in to the plant tissue above and below ground (IPCC, 2003; Gorte, 2009) resulting in growth of different parts (Chavan and Rasal, 2010). Biomass production in different forms plays important role in carbon sequestration in trees (Chavan and Rasal, 2012).

The quality of urban life can be ensured by the proper planning and design of green infrastructures like urban parks. Green infrastructure (urban parks) has many social benefits. Trees and natural environments improve psychological wellbeing over scenes of urban settings. Specially, people viewing visual images of trees and other vegetation have slower heartbeats, lower blood pressure and more relaxed brain wave patterns than people viewing urban scenes without vegetation (Mansfield *et.al,* 2002). Beside the social and psychological benefits mentioned above, the functions of urban nature can provide economic benefits for both municipalities and citizens. Air purification by trees, for example, can lead to reduced costs of pollution reduction and prevention measures. Furthermore, aesthetic, historical and recreational values of urban parks increase the attractiveness of the city and promote it as tourist destination, thus generating employment and revenues (Anna, 2003).

Ethiopia is experiencing the effects of climate change such as an increase in average temperature and change in rainfall patterns. The Government of the Federal Democratic Republic of Ethiopia has therefore initiated Climate-Resilient Green

Economy (CRGE), which promotes protecting and re-establishing forests for their economic, ecosystem services and carbon storage in 2011.

Accordingly, this paper gives emphasis to the importance of urban public parks besides their aesthetic and recreational values in reducing carbon emissions from the atmosphere by identifying carbon stock among different tree species found in the urban public parks so as to provide information for future possibilities of carbon trading and finance and for the wellbeing of the citizens.

1.2. **Statement of the problem**

Nowadays, our planet has faced different environmental changes such as rise of global temperature, change in precipitation patterns, and more frequent sever environmental disturbance. This challenge primarily resulted from the day to day increment of atmospheric CO_2. Fossil fuel combustion, industrial processes, and unprecedented land use conversion that have led to rising levels of CO_2 and other GHGs in the atmosphere Perschel *et al*. (2007). Thus, it is widely recognized that large scale reductions in CO_2 emissions are required. Forests are a current focus for action since they play an important role in mitigating climate change by naturally taking carbon out of the atmosphere (IPCC, 2000).

As Ethiopia is also a climate change vulnerable country, the government of Ethiopia has ratified CRGE in 2011 to achieve sustainable development by means of reconciling the environment, economic and social aspects. Keeping emissions constant by applying abatement measures in sectors such as forestry, agriculture and industry is the major goal of CRGE. Ethiopia has an ambition to become green economy frontrunner by investing into low carbon technology and reducing climate change vulnerabilities in its CRGE strategic framework to achieve the middle income status by 2025. Even though, strategic framework focuses on carbon emission management according to Adugna Feyissa *et al.* (2013), Ethiopia does not have carbon stock data base to monitor and enhance carbon sequestration potential of different forests. Similarly, only small efforts have been done so far to assess urban public parks carbon stock. Carbon stock evaluation in urban Public Parks helps to manage the forests sustainably from the ecological, economic and environmental points of view for the welfare of human society beside their aesthetic and recreational value.

In response to this problem, the purpose of this study is to quantify Carbon stock of urban public parks in above and below ground, dead litter, and soil organic carbon pool. This will help to bridge the current research gap in carbon related study in urban public parks, and give relevant information for local or city administration, policy makers and other conservation organization.

1.3. Objectives of the study

1.3.1. General objective

The overall objective of this study was to estimate the carbon stock of the selected four urban public parks and its implication for the climate change mitigation.

1.3.2. Specific objectives

- To assess the diversity and structure of tree species in the selected parks,
- To estimate the amount of carbon stock in above and below ground biomass, and
- To determine the amount of soil and litter carbon

1.4. Research questions

To meet up the above objectives, the study has tried to answer the following relevant questions:

- Which tree species are found in the selected parks?
- Which carbon pools have more carbon stock?
- What are the environmental factors that affect carbon stock in different pools?

1.5. Organization of the thesis

This thesis consists of six chapters. Chapter one served as general introduction to the research. It defines the research problem and outlined objectives, and organization of the thesis. Chapter two deals with a literature review about the concepts of carbon sequestration potentials from published journals, articles and official publication, and reports of relevant organizations like IPCC. The research methodology i.e. sampling procedure, research method, methods in data collection and analysis are discussed in chapter three. Chapter four covers the result while chapter five deals with the discussion of findings of the study. Chapter six deal about conclusion and recommendations.

CHAPTER TWO

2. REVIEW OF RELATED LITERATURES

2.1. Concept and definition

2.1.1. Urban forestry

According to Jiban *et al*. (2013), urban forestry is a specialized branch of forestry, which means planting and managing trees for the environmental, physiographical and economic wellbeing of urban areas, or for aesthetic beautification of urban landscapes. Also Pradeep *et al*. (2011) added that urban forestry is defined as the art, science and technology of managing trees and forest resources in and around urban community in order to provide for society physiological, sociological, economic and aesthetic benefits. Most of the time people consider urban Public Park as only street trees and ornamental woody plants. However, the urban public park is a complex system of trees and smaller plants, wildlife, associated organisms, soil, water and air quality in and around a city (Meseret, 2013). An urban public park includes roadsides, walkways, city squares, private gardens, cemeteries, school yards, and trees in home landscapes and anywhere else (Margaret, 2008; Eyob, 2010).

At present urban public parks get more attention in developing countries, especially in Ethiopia *(*Margaret, 2008). However, Ethiopia has one of the largest urbanization rates (about 4-5%) in the world, and its urban population is expected to increase from 15% in 2000 to almost 30% in 2030 (UN Population Division, 2004). The population of Addis Ababa is exponentially growing. The vegetation coverage of Addis Ababa including individual trees in private yards is estimated as 7,900 ha by the Urban Agricultural Office, covering 14.6% of the total area (Kuchelmeister, 2000; Thomas, 2013).

Urbanization at a rapid pace is a reality at present (Rama, 2013). Urbanization, in the developing world is frequently accompanied by the deterioration of the urban environment. Especially, this phenomenon in Ethiopia has been associated with environmental problems in most cities, including Addis Ababa. Among the problems are urban sprawl, solid and liquid waste management; water, air, and noise pollution; illegal settlements and the degradation of open green areas (Thomas, 2013).

Properly planned and managed urban green areas can solve the problems such as: water, air, and noise pollution, illegal settlements, and the degradation of open green areas. It is improve the quality of urban life in various ways, by providing tangible (food, energy, timber, fodder) and social benefits (health, employment) to meet local needs as well as important environmental services.

2.1.2. **The Benefits of urban forests**

Urban Forestry besides urban greening in developing countries is an important contributory factor in the cities for environmental enhancement, control of air and noise pollution, microclimatic modification and recreational purposes of the urban population (Rama, 2013; IUFRO, 2014).

In addition, urban forestry benefits can be varying in time and according to the developmental stage of urban public parks in different countries. For example, in developed countries, a prime focus in the past was management of the urban forest for aesthetic purposes. Whereas now, forests have multiple functions in today’s society as urban populations have grown, and expanded, urban public parks are managed for enhancing ecosystem services including biodiversity conservation, removal of atmospheric pollutants, oxygen generation, noise reduction, mitigation of urban heat island effects, microclimate regulation, stabilization of soil, ground water recharge, prevention of soil erosion, and carbon sequestration (Vijai *et al.*, 2010).

In developing countries, a more important focus may be managing vegetation to provide materials, such as firewood, fruit and timber, at very local scales (Margaret, 2008). However, enhancing material and environmental quality benefits on urban climate, energy use, CO_2 emissions and water flow in at both the neighborhood and broader city scales urban forestry has a significant role (Eyob, 2010; Pauleit and Duhme, 2000).

In Ethiopia, energy balance is dominated by biomass fuels (firewood, charcoal, branches, leaves and twigs, agricultural residues and cow dung) which are the main source of energy to both urban and rural areas. Of the total biomass energy supply, about 86% is derived from woody biomass. Ninety three percent (93%) of woody biomass is used for meeting household energy needs for cooking and heating, especially in Addis Ababa. Biomass fuels remain the most important fuel source for the urban population, despite nowadays easier access to modern energy sources. It has also been shown that the urban household consumption accounts for almost 70% of the charcoal consumption in Ethiopia (Arnold, 2003).

Over time, each city and region manage its urban forest for an increasingly broader and more inclusive range of benefits. However, the benefits are frequently overlooked in developing country such as Ethiopia, ecosystem services urban Public Park such as air and water purification, waste detoxification and decomposition of organic matter or offsetting carbon dioxide in the atmosphere, soil protection, and carbon absorption, cultural & aesthetic values (Kuchelmeister and Park, 2000).

2.1.3. **Challenges of urban forests in Addis Ababa**

Sustainable urban development requires a healthy and multifunctional urban green structure like urban public parks to providing a healthy and sustainable living environment with basic services for all.

The majority of the world's population now lives in urban area and that brings further urbanization. Urban areas grow three times faster than their rural counterparts, by 2030, 60% of all people are expected to reside in cities and towns. Urban areas in developing countries will account nearly 90% of the world population increase between 1995 and 2030 and more than half of the developing countries' population will live in urban areas (Cecil *et al.*, 2004). Urbanization is rapidly increasing worldwide, and the scenario of developing countries like Ethiopia is not different. With constant immigration from rural areas to urban areas, nearly half the population would soon be living in urban areas. Therefore, urbanization is one the cause for city environmental pollution. (Parikh *et al.*, 1994) reported that carbon emissions are much higher in urban, consumerist societies than rural, and biomass dependent landscapes. The direct or indirect consumption of each resource including food items, manufactured goods, energy, transport, durable goods, fuel etc. was converted to the carbon emitted during the production and consumption of that resource.

In the case of Addis Ababa, it has a total land area of 520 km^2 and is undergoing a period of rapid population growth. Thus, improving air quality, alleviating water shortages, reducing the urban heat effect, and reducing water runoff are challenges facing Addis Ababa. With a current population of nearly 90 million, rapid growth in Addis Ababa is accelerating these problems. Plagued with traffic problems and poor air quality, Addis Ababa is more often equated with poor urban air quality. These problems need solutions as the city tries to protect and restore environmental quality while enhancing economic opportunity. Therefore, the problems mentioned above the forests in Addis Ababa are almost transformed to urban habitats accommodating excessive population due to a high rate of rural urban migration.

In addition, industrialization within the urban areas and conversion of different land use within the city and the surrounding urban areas has caused the rapid depletion of existing tree cover during the past 100 years. This depletion of green resources has indicated that succeeding city governments had no proper long-term plans to keep the city green with the exception of intervening in some areas such as the establishment of a few parks and roadside plantations under a city beautification programme.

In general, urban forests in Addis Ababa are affected by various problems such as:- the perception of the urban people (Limited understanding and awareness) about on the use and importance of urban forests (green areas and parks) and lack of integration of forestry issues in urban planning, illegal cuttings and Improper tree selection and planting (Eyob Tenker , 2010).

2.1.4. **The potential of urban public parks in Carbon sequestration**

Carbon sequestration is the capture and storage of carbon that would otherwise be or remain in the atmosphere and enhance the greenhouse effect process (Houghton *et al.*, 1996).

Forests can act as sink through the process of trees growth and resultant biological carbon sequestration. Thus, increasing the amount of trees can potentially slow the accumulation of atmospheric carbon (Brown, 2002; Fearnside and Laurance, 2003 and 2004; Houghton, 2005). During productive season, carbon dioxide from the atmosphere is taken up by vegetation and stored as plant biomass. However, when forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (Fearnside and Laurance, 2004; Houghton, 2005).

Although urban areas continue to expand, urban Public Park is not expanding in parallel. Regardless of its significant role in environmental quality only little is known about this resource. As urban public parks both sequester CO_2, and affect the emission of CO_2 from urban areas, urban forests can play a critical role with regard to the carbon cycle and associated climate variability (Nowak and Crane, 2002). Trees moderate the amount of carbon dioxide in the atmosphere through the process of photosynthesis. Carbon that re-mains locked up in trees from year to year is referred to as carbon storage. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue.

As Prachi *et al*. (2010), one tone of carbon storage in the tree therefore represents removal of 44/12 or 3.67 tons of CO_2e (carbon dioxide equivalent) from the atmosphere, and the release of 2.67 tons of oxygen back into the atmosphere. Therefore, the urban trees also remove large amounts of air pollutants that consequently improve urban air quality.

Few studies indicated that 600 trees in the tropics would fill one acre, which could sequester up to 15 tons of CO_2 annually Nowak (1994) other statistics include 40 trees could sequester one tone of CO_2 each year; and that one million trees covering 1,667 acres could capture 25,000 tones of CO_2 annually. For example, in South Africa 115,200 indigenous street trees planted during the period 2002–2008. Between these years it has been estimated that the tree planting would result in 200,492 tons CO_2 equivalent reduction and that 54,630 tones carbon would be sequestrated. However when the urban trees are young the standing carbon stock is not substantial, therefore, the growth of the trees represents a potential increase in biomass and hence carbon sequestration is dependent on the growth rate.

2.1.5. **Biomass and Carbon in Forests**

Forests act as a sink through the process of tree growth and resultant biological carbon sequestration for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass (Nowak and Crane, 2002). Biomass assessments illustrate the amount of carbon that may be sequestered by trees. FAO (2004a), defined biomass as "organic material both above-ground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc." Above-ground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. Below-ground biomass consists of all living roots excluding fine roots (less than 2 mm in diameter).

In forest biomass studies, two biomass units are used, fresh weight (Araujo, *et al.*, 1999) and dry weight (Ketterings *et al.*, 2001; Aboal *et al.*, 2005; Montagu *et al*, 2005; Saint-Andre *et al.*, 2005). For carbon sequestration application, the dry weight is more relevant because 50% of it is carbon (Montagnini and Porras, 1998; Losi *et al.*, 2003; Montagu *et al.*, 2005). Many biomass assessment studies conducted are focused on above-ground forest biomass (Brown, 1997; Kraenzel *et al.*, 2003; Laclau, 2003; Losi *et al.*, 2003; Aboal *et al.*, 2005; Segura and Kanninen, 2005) because it accounts for the majority of the total accumulated biomass in the forest ecosystem.

Biomass is an important indicator in carbon sequestration therefore estimating the biomass in trees is the first step in carbon accounting (Prachi *et al.*, 2010).

Lu (2006) mentioned three approaches to biomass assessment. These are field measurement, remote sensing, and GIS-based approach. The field measurement is considered to be accurate (Lu, 2006) but proves to be very costly and time consuming (De Gier, 2003). In any of these approaches, ground data is important for validation. Two methods of measuring sample tree biomass are available: (1) destructive and (2) non-destructive. Direct or destructive method of tree biomass involves felling an appropriate number of trees and estimating their field- and oven-dry weights, (Zianis and Mencuccini, 2004; Saint – Andre *et al.*, 2005) a method that is accurate however it is impractical. Rather than performing destructive sampling all the time in the field, an alternative method (non- destructive) can be used that predicts biomass given some easily measurable predictor variable, such as "tree diameter" and "height" can be used.

Many studies were conducted to develop biomass equation that relates dry biomass of trees to its biophysical variables (e.g. diameter-at-breast height (DBH), tree height) (Brown, 1997; Ketterings *et al.*, 2001; Zianis and Mencuccini, 2004; Aboal, 2005; Cole and Ewel, 2006; Arevalo, 2007) and basal area.

Therefore an estimate of the vegetation biomass can provide us with information about the nutrients and carbon stored in the vegetation as a whole. To measure the biomass of vegetation which includes trees is not easy, especially in mixed, uneven-aged stands. Thus, it is hardly ever possible to measure all biomass on a sufficiently large sample area by destructive sampling and some form of allometry and hence, Thus, this study considers non destructive sampling methods for large trees greater than or equal to 10 cm in DBH.

2.1.6. **The Forest Carbon Pools**

Carbon pool is a system which has the capacity to accumulate or release carbon. According to the IPCC report IPCC (2006), carbon pools in forest ecosystems comprises of carbon stored in the living trees Above-ground, Below-ground (roots), Leaf litter, dead wood and soil organic matter. The carbon dioxide fixed by plants during photosynthesis is transferred across the different carbon pools.

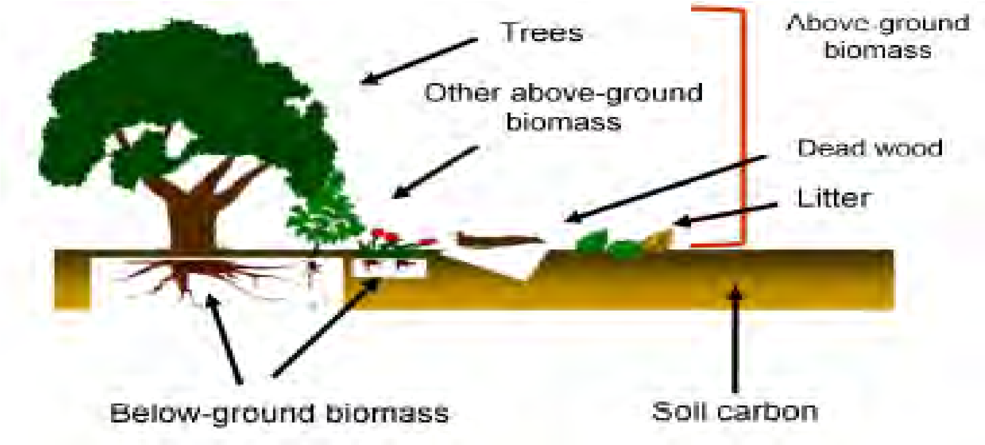

Figure1. Major terrestrial carbon pools (Source: USAD-CIFOR-ICRAF Project, 2009)

The above-ground biomass of a tree constitutes the major portion of the carbon pool. It is the most important and visible carbon pool of the terrestrial forest ecosystem (Ravindranath, *et al.*, 2008). Any changes in the land use system like forest degradation and deforestation has a direct impact on this component of the carbon pool.

The belowground biomass which constitutes all the live roots Eggleston *et al.* (2006) plays an important role in the carbon cycle by transferring and storing carbon in the soil. The dead mass of litter and woody debris are not a major carbon pool as they contribute merely a small fraction to the carbon stocks of forests (Ravindranath, *et al.*, 2008).

Soil organic matter is also a chief contributor to the carbon stocks of forests Kumar *et al.* (2006) next to the above-ground biomass and soils are a major source of carbon emissions following deforestation. Generally, the estimated biomass components are the aboveground live biomass which includes the trees and shrubs excluding the roots, dead above-ground biomass like litters and fallen branches or stem, and the below-ground biomass which comprise of the roots.

2.1.7. **Carbon Storage and Sequestration**

Climate change is an issue of global concern. Trees can help mitigate climate change by sequestering atmospheric carbon in tissue. Carbon dioxide can be controlled by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants (David *et al.*, 2013).

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees (Nowak *et al.*, 2010). According to McHale *et al.* (2007), mature tree size (large >15 m, medium = 10–15 m, small<10 m) and tree type (evergreen vs. deciduous), directly control the maximum potential carbon storage; larger growing trees contain more biomass and generally half of biomass is carbon.

Also as GOFC-GOLD (2010), carbon stocks vary by forest type, for example tropical pine forests have a different stock than tropical broadleaf forests which again have different stock than woodlands or mangrove forests. Even within broadleaf tropical forests, stocks are varying greatly with elevation, rainfall and soil type. Then even within a given forest type in a given location the degree of human disturbance leads to further differences in stocks.

For this reason the UNFCC and its Kyoto Protocol recognized the role of forests in carbon sequestration. Specifically, Article 3.3 and 3.4 of the Kyoto Protocol pointed out forest as potential carbon storage (Brown, 2002; United Nations, 1998).

According to Yitebitu Moges *et al*. (2010), at a national level, forest inventories, woody biomass assessments and scientific research can prove useful data for acquisition of forest carbon accounting. In this context the forest resources of Ethiopia store an estimated 2.76 billion tons of carbon, playing a significant role in the global carbon balance.

The largest store of carbon in the country is found in the woodlands (45.7%) and the shrub lands (34.4%), while the high forests store about 16%. Another report estimated that the national carbon stocks 2.5 billion tons of carbon in 2005 (Sisay *et al*., 2009). However, despite their great potential in influencing carbon balance, these vegetation types are largely neglected in forest related discussions, including carbon negotiations. Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release up to 80% of the stored carbon back to the atmosphere (McHale *et al*., 2007).

Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees keep the carbon stored in trees. When trees die, utilizing the wood in long-term wood products or to help heat buildings or produce energy help reduce carbon emissions from wood decomposition.

2.2. Conceptual frame work of the study

The conceptual model used in this study shows how to determine the carbon stock in the study sites, to achieve the idea of study objectives.

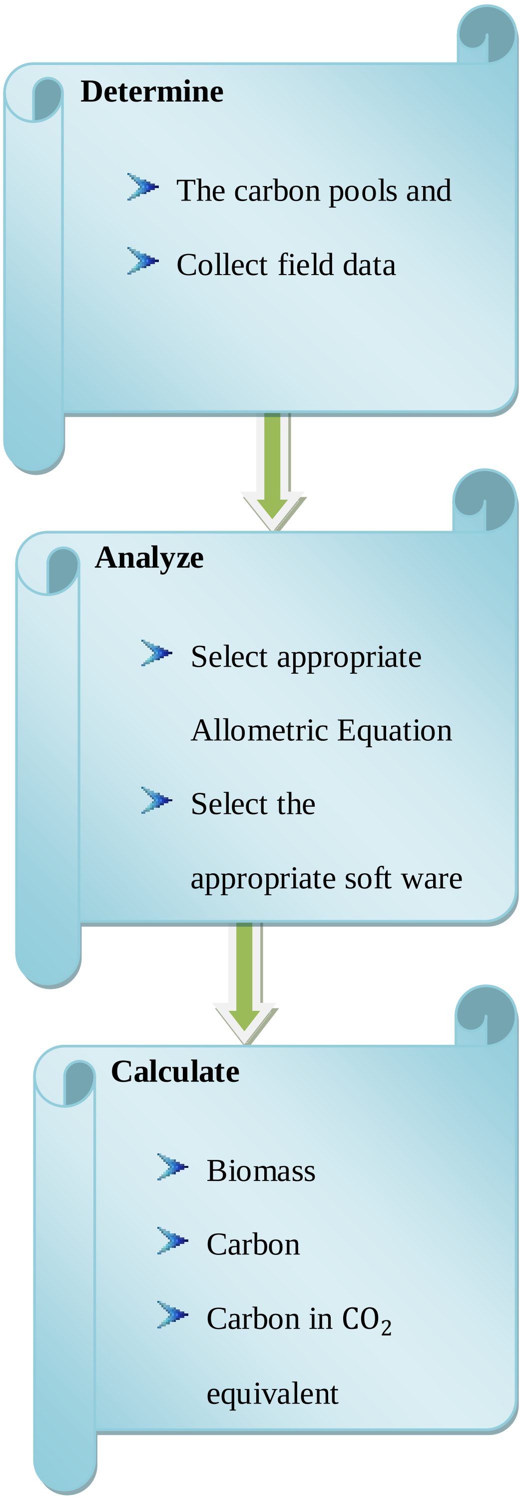

Figure 2.Conceptual Frame work of the study

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Geographical location

The study was conducted in Addis Ababa. There are 10 sub-cities and about 99 kebeles. Addis Ababa is located in the central highlands of Ethiopia. Geographically, it is located at between 9º 38’ 0’’N Latitude and 38º 42’ 0’’E Longitude, with the lowest elevation of 2000 m above sea level at Akaki, in the southern periphery, and the highest over 3000 m at Entoto Mountains, north of the city.

3.1.2. Climate

Addis Ababa has a subtropical highland climate, the average maximum temperature ranges between 17 and 22ºC and the average minimum temperature varies between 11 and 14ºC. The average rainfall is 1200 mm per year, with the major rain season occurring between June and September.

3.1.3. Geology and soil

Addis Ababa city is found at the southern flank of Entoto ridge (3199 m a.s.l.) and expanded in all directions. The hill chain (Entoto) in the northern part of Addis Ababa is composed of basalts, called Entoto silicic and it is covered with volcanic topsoil materials of about one to two meters thick. The center of the city lies on an undulating topography with some flat land areas. In most parts of the city the residual soils are commonly seen with varying thickness.

On the other hand, due to intensive erosion activities there is poor soil development (shallow soil profile) or patchy occurrences on most parts of the slope. The dominant soil in the southern part of the city, where erosion is superseded by deposition is a black cotton soil. Moreover, waterlogged areas are found in the central, in the eastern and in other different parts of the city.

3.2. Data type and sources

For this study both primary and secondary data were used in order to achieve the objectives of the study. The primary data were obtained through field measurements and laboratory analysis to estimate carbon stocks of the study area. Secondary data was collected from different sources including published and unpublished materials, books, journals, articles, reports, and electronic web sites.

3.3. Materials

To accomplish the study different essential materials were used. The lists of materials are described under the table.

Table 1.Lists of Materials for field data collection

No.	Items	Purpose
1	GPS	For locating plots
2	Rope	For plot boundary delineation
3	Chalk	For marking the trees to avoid double counting
4	Plastic bags	To collect soil and litter samples
5	Weighing machine	For weighing leaf litter and soil samples
6	Scissors	For cutting sample leaflets
7	Soil sample core	For collecting soil samples from same depths
8	Diameter tape	For measuring the diameter of the tree at breast height
9	Pressing materials	For identification of plant species
10	Clino-meter	For height measurement

Table 2.Lists of equipment for laboratory analysis

No.	Items	Purpose
1	Oven	To dry the soil and litter samples
2	500-mL Erlenmeyer flasks	To prepare the solutions
3	10-mL pipette	To drop the ferroin indicator
4	10-and 20-mL dispensers	To mix the soil and solution
5	Stand	To hang the burette
6	50-mL burette	To titrate the solution
7	Analytical balance	To weigh the samples and solid chemicals
8	Magnetic stirrer	To mix the solution
9	Furnace	To burn the litter samples

3.4. Methods

In order to achieve the objectives stated above, the procedures followed to estimate carbon stocks were simple step-by-step procedures by using standard carbon inventory principles and techniques.

Procedures were based on data collection and analysis of carbon accumulated in the above-ground tree biomass, below-ground biomass, leaf litter, and soil organic carbon of trees. Therefore, during the field data collection the followings steps were followed in carbon measurement.

3.4.1. Selection of the study sites

According to Irvin (2007), the first step to do research is selection of study area. Depending on this principle, there are over 17 public parks in Addis Ababa and 32 privately managed parks. Out of 17 public parks found in Addis Ababa, four public parks were selected systematically from three selected sub-cities, based on their location, existing tree conditions and research gaps. In general, the table below presents information of the parks.

Table 3.Information of study sites

No.	**Sub- cities**	**Study sites**	**Area (ha)**	**Year of establishment**	**Aspects**
1	Yeka	Yeka Park	2.21	1977	E/NW
2	Yeka	Ferensay Park	5.42	1975	N/E
2	Lideta	Ethio-Cuba Park	2.72	1998	NW
4	Akaki-Kality	Akaki-Kality Park	6.25	1996	E/SE/NW

Source: http:/addisgreenspace.org/category/parks-official

3.5. Historical background of the study sites

3.5.1. Farensay Park

This Park is located near the French Embassy in Yeka sub-city, with a total area of 54,201 square meters. It was once the private residence of Dejazmach Gebreselassie Bariya Gabr, a high-ranking official during the reign of Empress Zewditu (1908-1921) and inherited by his son Dejazmach Zewdie GebreSelassie who owned it until 1975.

3.5.2. Yeka Park

Yeka Park is a great place for a picnic. This Park is located around Megenagna Ring Road in Yeka sub-city, with a total area of 22,081 square meters. It was established by the Municipality of Addis Ababa in 1977.

3.5.3. Ethio-Cuba Friendship Memorial Park

Once a monument to the Derg regime, it’s now viewed as historical relic surrounded by grass and trees. It was established in 1977. Situated in the heart of Addis Ababa on Churchill Road in Lideta sub-city, the park was inaugurated in December 1998, with a total area of 27,226 square meters.

3.5.4. Akaki-Kality closed Park

This Park is located in Akaki-Kality sub-city near Tirunesh Bejing General Hospital. The Park covers 62,500 Square meters, and it was from 1977 up to 1997 controlled by the City Administration. Then, in 1998 it was changed it to a Public Park. At that time the compound was on construction to provide a new service for the future and therefore, few trees might have been cut down.

3.5.5. Design of the sample plot shape and size

The size and shape of the sample plots is a trade-off between accuracy, precision, time and cost for measurement. According to Genene *et al*. (2013) there are two types of plots – circles and square or rectangles plots. However, as stated by Genene *et al*. (2013) the square plots can be the most cost-efficient and it includes more of within-plot heterogeneity, and thus be more representative than the circular plots of the same area (Hairiah *et al.*, 2001).

Therefore, for the study sampling quadrats of square shape which have dimensions a 10 m × 10 m was formed. Inside 10 m × 10 m quadrate, five 1 m × 1 m sub-sampling units were located. In each site, sample plots were laid systematically and at each sampling site transect was established at every 50 m horizontally and 30 m vertically in each park by using GPS instrument, i.e., beginning from the lower parts of the parks to the upper parts, to measure vegetation biomass and stock.

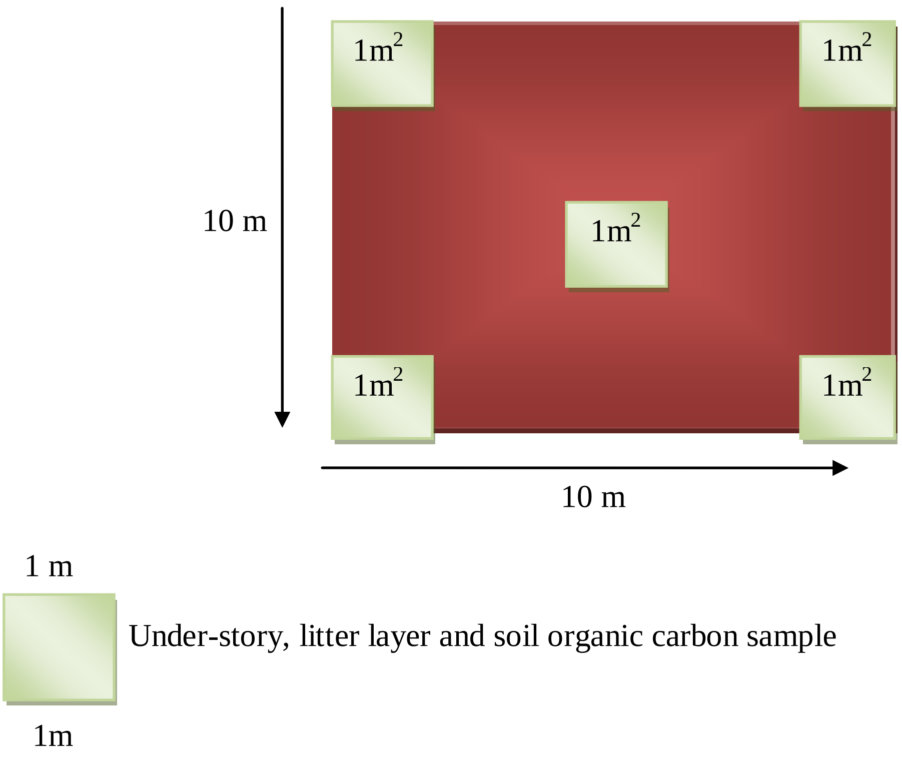

Figure 3.Nested Plot design for collecting soil and litter samples (**Source:** Hairiah*et al.*, 2001).

The above design of nested quadrats was required for collecting the soil sample and litter for estimation of biomass. This means that, within the 10m x 10m quadrate the 1m x 1 m quadrat was used to collect litter and soil samples. The number of nested quadrats varied depending on the area of the parks and homogeneity and heterogeneity of species in the parks.

3.5.6. **DBH Measurement Approach**

For this study, to estimate the carbon stock of each study site, only woody species were taken. All trees that having DBH greater than or equal to 10 cm and height at 1.3 m was measured by using diameter tape.

Diameter at breast height (DBH) is the basic measurement standard for trees. This measurement was record for all trees. (Note that, for stems with irregularities, measurement was carried out according to the principles. Therefore, in this study when the tree was on a slope, always measurements was on the uphill side; when the tree was leaning, the DBH tape was wrapped according to the tree’s natural angle (not straight across, parallel to the ground). In some parts when it is impossible to measure below the fork, DBH of the largest stem was taken. Traditionally forestry dictates that forked stems are measured as two separate trees but when the focus is on biomass, it is more accurate to measure as a single tree (Holly *et al.*, 2007).

3.5.7. Height measurement

The height of all tree species was measured by using Silva Clino-master made by Sweden in a position which is possible to observe the tips as well as the bottom of the trees. A tree with multiple stems at 1.3 m height was treated as a single individual.

3.5.8. Species identification method

Identification of the existing tree species in the field with diameter greater than or equal to 10 cm was done by Useful trees and shrubs for Ethiopian was used Azene Bekele (1993). For those species difficult to identify in the field, 14 fresh specimens were collected, pressed, dried and identified at the National Herbarium (ETH), Addis Ababa University.

3.5.9. Number of sample plots

To be accurate in the study, 45 plots were used to take samples of litter and soil from all four parks by using systematic sampling method. The number of samples varied from site to site due to different existing conditions of the study area like vegetation coverage, availability of litter within the study sites. However, in study sites which have large vegetation coverage the sample plots were somewhat greater than that of smaller ones.

Table 4.Number of sample plots for litter and soil in the different study sites.

Study site	**Name**	**Number of sample plots**
I	Yeka Park	8
II	Ferensay Park	13
III	Ethio-Cuba Park	8
IV	Akaki-Kality Park	16
Total		**45**

3.6. Field data collection and measurements

The study was done to estimate the carbon stocks and changes, using the parameters measured and monitored in the field and in the laboratory. The analysis and calculation of carbon stocks and changes involve conversion of field and laboratory estimates of various parameters from diameter at breast height (DBH), height and sample plots, such as soil organic carbon content and litter carbon content into tones of carbon per hectare.

3.6.1. Field carbon stock measurement methods

3.6.1.1.Above ground tree biomass (AGTB)

Above ground tree biomass consists, all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage (IPCC, 2003). The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation.

Thus, estimating aboveground forest biomass carbon is the most critical step in quantifying carbon stocks (Holly *et al*., 2007). However, the DBH at 1.3 m and height of individual trees greater than or equal to 10 cm DBH was measured in each study site by using diameter tape, starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice in the study site. Each tree was recorded individually, together with its species name.DBH is the most common variable used for biomass calculation.

3.6.1.2. **Below ground biomass (BGB)**

According to Genene *et al*. (2013), below ground biomass comprises dead roots, living roots includes fine roots (< 2 mm diameter), small roots (2 – 10 mm diameter), and large roots (> 10 mm diameter), soil fauna and the microbial community. However it was calculated by considering 15% of the above-ground biomass root-to shoots ratio value of 1:5 or 20% of above ground biomass (Macdicken, 1997).

3.6.1.3.**Litter sampling**

In each study site different quadrats were laid. The litter sample was collected from sub-quadrate of 1 m × 1 m within the large quadrate. A total of five sub-plots (four from the corners of each quadrat and one is at the centre). All litter samples in the sub-quadrat was collected manually.

Each sample was measured for wet weight while 100 gm sub-sample was taken from each sample and mixed manually. One hundred gram of sample for laboratory analysis was placed in a plastic bag and to determine moisture content of the litter.

Laboratory analysis: To estimate biomass carbon stock of the litter, 100 gm of sub-sample wet weight was taken for laboratory, and then dried at 105^0C in the oven for 48 hours to take dry weight of each sample. Then, ashing method was used for estimating carbon percent in litters.

Oven dried grind samples were taken (1 g) in pre-weighted crucibles, and burnt in a muffle furnace at 550^0C for one hour. The ash content the inorganic elements in the form of oxides, left after burning was weighed and carbon content is calculated by using the following equation according to (Allen *et al.*, 1986).

$$Ash\ (\%) = (W3 - W1) / (W2 - W1) \times 100 \qquad (eq.1)$$

$$C\ (\%) = (100 - Ash) \times 0.5 \qquad (eq.2)$$

- Considering 58% carbon in ash-free litter material

Where:

C – Biomass carbon stock,

W_1 – weight of crucible,

W_2 – weight of the oven-dried grind sample and crucible,

W_3 - Weight of ash and crucible.

3.6.1.4.**Soil sampling**

For the purpose of obtaining an accurate inventory of soil organic carbon stocks in mineral or organic soil, three types of variables must be known: **(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 (Pearson *et al.*, 2005).

The soil samples for carbon determination were collected at the same sampling sub-quadrat used for litter sampling. Samples were collected using a 30 cm depth core sampler with a diameter of 5 cm.

Five equal weight of each sample from each quadrant was taken and mixed homogenously while a composite sub sample of 100 gm of wet weight from each plot was submitted to the laboratory analysis. Then Carbon fraction of each sample was measured in the laboratory by using Walkley-Black Method (Walkley and Black, 1934). On the bases of this finally, the bulk density, soil organic carbon and soil organic matter calculated.

Laboratory analysis: The 100 gm of sample was taken for laboratory studies, and then dried at 105^0C in the oven for 24 hours to take dry weight of each sample. Oven dried ground samples were taken 0.10 to 2.00 g (ground to <60 mesh) and transferred to a 500-ml Erlenmeyer flask and add 10 ml potassium dichromate solution (K_2Cr2O_7) followed by addition of 20 ml of concentrated sulfuric acid. The mixture was gently swirled and left at room temperature in a fume hood for 30 minutes and then 200 ml of distilled water, 10 ml of 85% H_3PO_4, and 10 drops of ferroin indicator, was added to the mixture. Then, titrate with 0.5 M Fe^{2+} solution to a burgundy endpoint to see the color of the solution.

The solution color was at the beginning was yellow-orange to dark green, depending on the amount of unreacted $Cr_2O_7^{2-}$ remaining, which shifts to a turbid gray before the endpoint and then changes sharply to a wine red at the endpoint.

Titration method was used for rapid analysis of organic carbon (OC) in soils. The method is based on the oxidation of organic matter by potassium dichromate ($K_2Cr_2O_7$)-sulfuric acid mixture followed by back titration of the excessive dichromate by ferrous ammonium sulfate ($Fe(NH_4)_2(SO_4)_2*6H_2O$).

Blank titration of the acidic dichromate with ferrous ammonium sulfate solution was performed at the beginning of the batch analysis using the same procedure without soil added. The blank was used to standardize the Fe^{2+} solution daily. After titration the percentage of carbon content was calculated according to the following equation:

$$\%C = \frac{(B-S)*M \text{ of } Fe^{2+} *12*100}{g \text{ of soil}*4000} \quad \text{.. (eq.3)}$$

Where,

B- ml of Fe^{2+} solution used to titrate blank

S- ml of Fe^{2+} solution used to titrate sample

12/4000- milli-equivalent weight of C in g

3.7. Estimation of carbon stocks in different carbon pools

3.7.1. Estimation of above ground tree biomass (AGTB)

To estimate the above ground biomass of the trees different mathematical allometric equation has been developed and used by many researchers. The equations are different on the type of species, geographical locations, forest stand types, climate and others (Baker *et al.,* 2004, Brown *et al.,* 1989).

From the environmental point of view, cost of estimation and time required, it is not possible to cut the trees to estimate their biomass. Thus, according to Brown *et al.* (1989), if the rainfall <1500 mm and DBH range is≥5cm, the below allometric equations model is recommendable to calculate the above ground biomass of the tree.

$$Y = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \quad \text{...................................... (equ.4)}$$

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

According to Pearson *et al.* (2005), since the plot areas are part of tropical region carbon content in the biomass is estimated by multiplying 0.47 while multiplication factor 3.67 is used to estimate CO_2 equivalent. Therefore, the tree biomass was converted into C by multiplying the above ground tree biomass by 0.5 (Brown, 2002).

Biomass C stock = AGB * 0.5, Then Biomass carbon stock was converted in to CO_2 equivalent as follows:

$$CO_2 = \text{biomass } C * 3.67 \ldots\ldots \text{(equ.5)}$$

3.7.2. Estimation of Below Ground Biomass (BGTB)

According to Geider *et al.* (2001), and Genene *et al*. (2013), the below ground biomass estimation is more difficult and time consuming than estimating aboveground biomass. As MacDicken (1997) standard method for estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 is used. In the same way, Pearson *et al.* (2005) described this method as it is more efficient and effective to apply a regression model to determine belowground biomass from knowledge of biomass of AGB. Thus, the equation developed by MacDicken (1997) was used to estimate below-ground biomass of the study. The equation is as follow:

$$BGB = AGB * 0.2 \ldots\ldots \text{(equ.6)}$$

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

3.7.3. Estimation of the Litter Biomass

To determine the biomass of leaf litter, samples were taken from the field to the laboratory. The sub-sample was used to determine an oven-dry-to- wet mass ratio that is used to convert the total wet mass to oven dry mass, and then from the total dry mass, organic carbon can be calculated as (Bhishma *et al*., 2010). The equation is as follow:

$$LB = \frac{Wfield}{A} * \frac{Wsub\_sample(dry)}{Wsub\_sample(fresh)} * \frac{1}{10{,}000} \text{ .... } (equ.7)$$

Where: LB = Litter (biomass of litter ton/ha)

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

A = size of the area from which litter are collected (ha);

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

W sub-sample, fresh = weight of the fresh sub-sample of litter was taken to the laboratory to determine moisture content (g).

Carbon stocks in litter biomass

$$C_L = LB * \% C \text{ .... } (equ.8)$$

Where, C_L is total carbon stocks in the dead litter in t ha^{-1}, % C is carbon fraction determined in the laboratory (Pearson *et al.*, 2005).

3.7.4. Estimation of Soil Organic Carbon (SOC)

To calculate the soil carbon stock density of organic carbon, the equation recommended by Pearson *et al.* (2005) from the volume and bulk density of the soil.

$$V = h * \pi r^2 \text{ .... } (eq.9)$$

Where, V is volume of the soil in the core sampler auger in cm^3, h is the height of core sampler in cm, and r is the radius of core sampler auger in cm. Moreover, the bulk density of a soil sample was calculated as follows (Pearson *et al.*, 2005):

$$BD = \frac{Wav,\ dry}{V} \text{ .... } (equ.10)$$

Where,

BD is bulk density of the soil sample per,

Wav, dry is average air dry weight of soil sample per the quadrant,

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

SOC = BD * D* % C.. (equ.11)

Where, SOC= soil organic carbon stock per unit area (ton/ha),

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

D = the total depth at which the sample will be take (30 cm),

%C = Carbon concentration (%)

3.7.5. Total Carbon Stock Density

The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of the stratum by using the (Pearson *et al.*, 2005) formula. In addition, it is recommended that any individual carbon pool of the given formula can be ignored if it does not contribute significantly to the total carbon stock (Bhishma *et al.*, 2010).

Carbon stock density of a study area:

$$C_{density} = C_{AGB} + C_{BGB} + C_{Lit} + C_{DWS} + SOC \text{.................................. (equ.11)}$$

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

C_{AGTB} = Carbon in above -ground tree biomass [t C ha^{-1}]

C_{BGB} = Carbon in below-ground biomass [t C ha^{-1}]

C_{Lit} = Carbon in dead litter [t C ha^{-1}]

C_{DWS}= Carbon in dead wood and stumps

SOC = Soil organic carbon

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.*, 2007).

3.8. DATA ANALYSIS

After the data collection was completed, data analysis of various carbon pools measured in the study site was accomplished by organizing and recording on the excel data sheet. The data obtained from DBH, height of each species, fresh weight and dry weight of litter, soil and the amount of carbon and CO_2 in each park analyzed by using Statistical Package for Social Science (SPSS) software version 20.

The height and diameter data was arranged in classes for applying appropriate model of biomass estimation equation. The relationship between each parameter was tested by one way ANOVA. Which means analysis of variance (one-way ANOVA) was used to determine statistically significant differences of carbon stocks along altitude and aspect for soil and litter carbon pools.

CHAPTER FOUR

4. RESULTS

4.1. Existing condition of the Parks

There were different tree species in the study parks. The types of species were different from Park to Park. During the data collection period, a total of 3849 individual trees were recorded. The parks constitute 53 species and their DBH range from 10.18 to 154 cm while height ranges from 1.05 to 38 m.

Accordingly, the abundance of tree species from the total 3,849 individual tree, 39 species represented by 1,593 individuals were found in Yek Park, 36 type of species represented by 1,211 individuals were found in Ferensay Park, 15 species represented by 343 individuals were found in Ethio-Cuba Park, and 19 species represented by 702 individuals were found in Akaki-Kality Park.

The most dominant species among the surveyed sites were *Cupressus lusitanica* with 1,540 individuals that are 40% of the total species and it was commonly recorded in all study sites. While *Melia azedarach, Calpurnia aurea, Casimiro aedulis, Dodonea angustifolia, Ficus elastica,* and *Hibiscus rosas-inensis,* had the lowest density with 1 individualthat is 0.03% from the total individuals.

Table 5.List of species, number of trees, average DBH, and average height collected from each study sites

Tree code	Species name	Local name	Family name	Number of trees	Av. DBH (cm)	Av. height (m)
AT1	*Acacia abyssinica* Hochst. ex Benth.	Yeabesha grar	FABACEAE	203	29.71	11.56
AT2	*Acacia brevispica* Harms Notizbl.	Girar	FABACEAE	6	27.47	13.9
AT3	*Acacia mearnsii* De Willd.	Mearnsii	FABACEAE	47	25.88	13.22
AT4	*Acacia melanoxylon* R.Br.	Omedla	FABACEAE	346	21.81	11.52
AT5	*Acacia saligna* (Labill.) Wendl.	Saligna	FABACEAE	3	19.46	10.75
AT6	*Acacia seyal* Del.	Wachu	FABACEAE	9	14.89	5.57
AT7	*Acacia tortilis*	Deweni grar	FABACEAE	117	35.61	14.61
AT8	*Allophylus abyssinicus* (Hochst.) Radlkofer	Embis	ANACARDIACEAE	33	33.44	18.03
AT9	*Apodytes dimidiate* E.Mey.ex Am	Celeqleqqa	ICACINACEAE	10	37.82	21.23
AT10	*Araucaria biramulata* J.Buchholz.	Arokaria	ARAUCARIACEAE	6	13.72	5.33
AT13	*Bersama abyssinica*	Azamir	MELIANTHACEAE	20	27.67	13.91
AT15	*Callistemon citrinus* (Curts) Skeels	Bottle brush	MYRITACEAE	53	17.07	7.57
AT16	*Calpurnia aurea*	Digita	FABACEAE	1	25.22	13.7
AT17	*Carissa spinarum* L.	Agam	APOCYNACEAE	4	17.48	11.55
AT18	*Casimiroa edulis* La Llave	Kazmir	RUTACEAE	1	16.24	7.49
AT19	*Casuarina cunninghamiana* Miq.	Shewshewe	CASUARINACEAE	63	37.58	17.17
AT20	*Cordia africana* Lam.	Wanza	BORAGINACEAE	6	28.97	11.6
AT21	*Croton macrostachyus* Del.	Bisana	EUPHORBIACEAE	13	26.53	14.25
AT22	*Cupressus lusitanica* Mill.	Yeferenje tid	CUPRESSACEAE	1540	18.89	9.01
AT23	*Dodonea angustifolia*	Kitikita	SAPINDACEAE	1	16.55	16.49
AT24	*Dovyalis abssinica* (A. Rick) Warb.	Koshim	FLACOURTISCEAE	119	12.8	4.83
AT25	*Dracaena steudneri* Engler	Etsepatos	DRAEAENACEAE	25	19.17	6.42
AT26	*Ekebergia copensis* Sparrrn.	Lole	MELIACEAE	2	28.05	9.4
AT27	*Erythrina brucei* Schweinf. Emend.	Korch	FABACEAE	39	35.38	14.51
AT29	*Eucalyptus globules* Labill.	Nech bahirzaf	MYRTACEAE	23	39.67	24.1
AT30	*Eucalyptus camaldulinsus* Dehnh.	Key bahirzaf	MYRTACEAE	139	36.65	21.12
AT28	*Eucalyptus citrodora* Hook.	Shito bahirzaf	MYRTACEAE	56	33	18.56
AT31	*Euphorbia ampliphytha*	Kulkual	EUPHORBIACEAE	11	25.05	11.74

Tree code	Species name	Local name	Family name	Number of trees	Av. DBH (cm)	Av. height (m)
AT32	*Ficus elastica*	Yegoma zaf	MORACEAE	1	33.75	11.24
AT33	*Ficus sur* Forssk.	Shola	MORACEAE	15	45.95	21.63
AT34	*Ficus thonningii* Blume	Warka	MORACEAE	4	29.79	19.29
AT35	*Grevillea robusta* R. Br.	Gravilla	PROTEACEAE	236	21.87	11.61
AT36	*Hagenia abyssinica* (Bruce) J.F. Gmel.	Kosso	ROSACEAE	6	13.94	7.36
AT37	*Hibiscus rosa-sinensis* L.	Hibiscus	MALYACEAE	1	14.01	2.99
AT38	*Hyphaene thebaica* (L.) Mart.	Zembaba	ARECACEAE	5	42.76	8.72
AT39	*Jacaranda mimosifolia* D. Don	Yetemenja zafe	BIGNONIACEAE	72	25.61	11.76
AT41	*Juniperus procera* Hochst. ex. Endlicher	Yeabesha tid	CUPRESSACEAE	76	34.56	18.89
AT41	*Maesa lanceolata* Forssk.	Kelewa	MYRSINACEAE	3	15.92	6.09
AT12	*Melia azedarach* L.	Neam	MELIACEAE	1	31.84	8.25
AT43	*Millettia ferruginea* (Hochst.) Bak.	Birbira	FABACEAE	43	23.66	12.26
AT44	*Olea europaea* L. subsp. cuspidata	Woyra	OLEACEAE	283	38.09	24.88
AT45	*Olinia rochetiana* A.Juss.	Tfie	OLINIACEAE	26	30.28	20.07
AT46	*Persea americana* Mill.	Avocado	LAURACEAE	3	10.52	3.09
AT47	*Phoenix reclinata* Jacq.	Zembaba	ARECACEAE	16	33.74	12.53
AT48	*Pinus patula* Schiede ex. Schltdl. & cham.	Patula	PINACEAE	10	29.53	11.39
AT50	*Pinus radiate* D.Don	Radiata	PINACEAE	14	30.59	13.3
AT51	*Pittosporum viridiflorum*	Weyl	PITTOSPORACEAE	15	32.29	21.38
AT52	*Podocarpus falcatus* (Thunb.) R.B.ex.Mirb.	Zigba	PODOCARPACEAE	38	34.79	21.31
AT53	*Prunus africana* Calcm.	Tikur enchet	ROSACEAE	20	19.85	11.36
AT54	*Psidium guajava*	Zeituna	MYRTACEAE	3	20.96	9.5
AT56	*Spathodea campanulata* P. Beauv.	Yechaka nebelbal	BIGNONIACEAE	9	34.76	11.62
AT57	*Tibouchina viminea* (D.Don) cogh.	No name	MELASTOMATIACEAE	2	12.25	7.63
AT58	*Vernonia amygdalina* Del.	Grawa	ASTERACEAE	51	20.75	8.09
				3849		

4.1.1. **Distribution of DBH and Height of the trees in each study sites**

4.1.1.1.**DBH**

The DBH of trees were classified into sub classes as follow:(≥10-20, 20- 40, 40-60, 60-80, 80 - 100, 100-120, 120-140, and >140). Most of the tree species like *Cupressus lusitanica* had the maximum DBH (154.77cm) which was found in Ferensay Park, while minimum DBH was found in Yeka Park with 10.18cm DBH in *Acacia abyssinica, Acacia melanoxylon, Callistemon citrinus, Cuperssus lusitanica, Grevillea robusta, Maesa lanceolata, Persea americana, and Podocarpus falcatus.* The DBH distribution of species is shown in table 5.

From the selected 4 parks a total of 53 species were found and *Ficus sur* with 45.95cm ranked first when compared with other species in their average DBH and *Persea americana* with 10.52 cm had the least average DBH value than the other species (Appendix: 1).

Table 6.Number of trees per DBH class distribution

DBH Classes	**Number of species**
≥10-20	2,007
20-40	1,339
40-60	392
60-80	83
80-100	13
100-120	9
120-140	4
≥140	2
Total	**3,849**

The above table shows that the higher number of species with DBH value was found in the first DBH class (10-20 cm). The lowest number of species with DBH value was recorded in the eighth DBH class (≥140 cm). Therefore, in the first DBH class high density of young vegetation was found.

4.1.1.2.**Height**

Species in selected Parks had different height class like that of their DBH value. The heights of trees were classified into five sub classes as follow:(≤1 - 5, 6 - 10, 11 - 20, 21 - 30, and ≤31 - 40).Tree species with maximum height was *Oleae europaea* with 38m in Ferensay Park and the minimum height was *Cuperssus lustanica* in Yeka Park with 1.05m. *Cupressus lustanica* were among the species with smaller height mainly due to their age and they were seen in Yeka Park.

As the table shown, most of the species were in the range between 11 -20m and small number of individuals had height range (31-40m), of this *Oleae europaea* species were the foremost. The total number of species and their height class is shown in table 3 below.

Table 7.Height distribution of trees

Height Classes	**Number of trees**
≤1-5	246
6-10	1,303
11-20	1,662
21-30	538
≤31 - 40	93
Total	**3,849**

4.2. Biomass and carbon stock in different carbon pools

4.2.1. The aboveground biomass and carbon stock in Yeka Park

Based on the result, the maximum and minimum above ground biomass in Yeka park was 539.577 ton/ha and 22.551 ton/ha respectively with a mean biomass of 163.105 ton/ha and the mean aboveground carbon stocks 81.553 ton/ha with aboveground carbon dioxide an amounting to 299.298 ton/ha (Appendix: 2). The maximum and minimum below ground biomass was 107.916 ton/ha and 4.510 ton/ha respectively with a mean biomass of 32.621 ton/ha and the mean belowground carbon stocks was 16.311 ton/ha and carbon dioxide in below ground biomass was 59.851 ton/ha (Appendix 2).

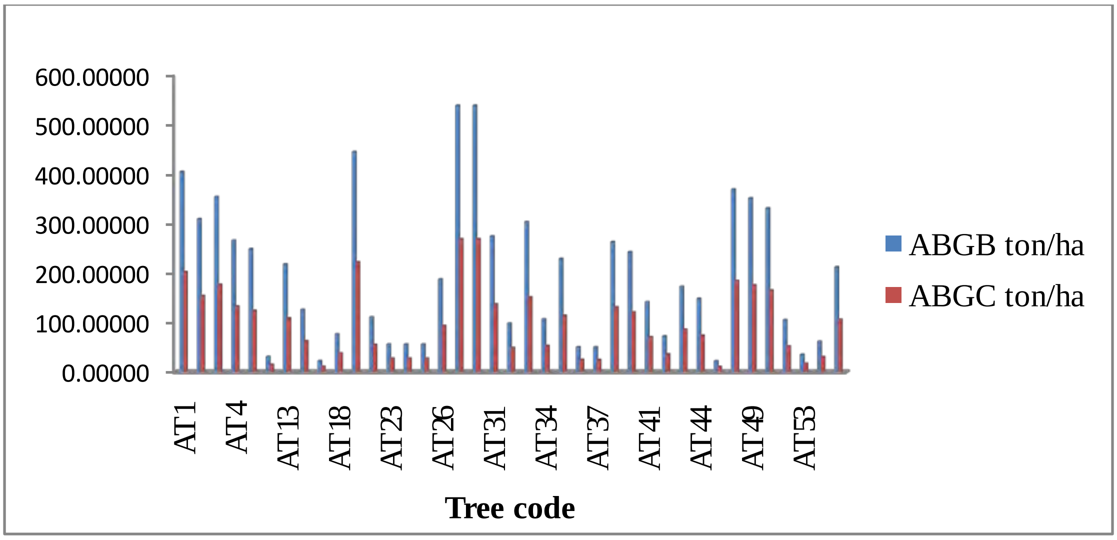

Figure 4.Abovebiomass and aboveground carbon stocks of species (**Source:** Excel output, 2015)

4.2.2. The aboveground biomass and carbon stock in Ferensay park

The maximum and minimum AGB was recorded in Ferensay park 581.763 ton/ha and 34.563 ton/ha respectively with mean biomass of 340.733 ton/ha and a mean carbon stocks of AGC was 170.366 ton/ha with aboveground carbon dioxide value of 1250.489 ton/ha (Appendix 2). The maximum and minimum of BGB was 116.353

ton/ha and6.913 ton/ha respectively with mean biomass of 68.147 ton/ha and the mean carbon stock in BGC was 34.073 ton/ha and belowground carbon dioxide was 125.049 ton/ha (Appendix 2).

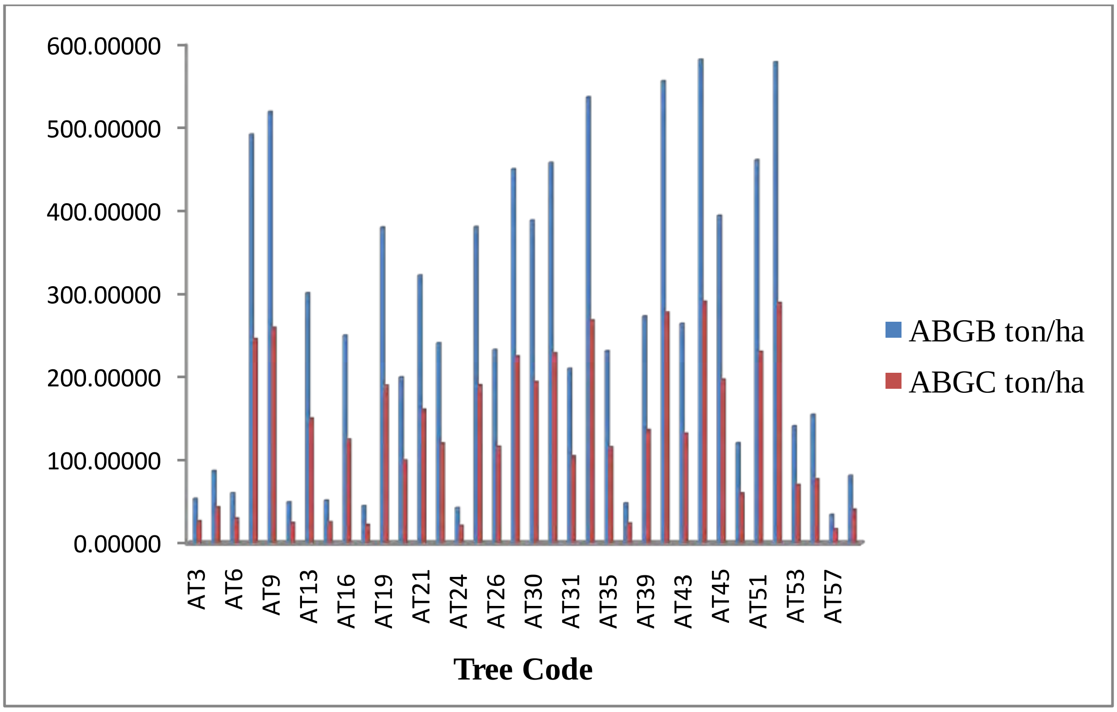

Figure 5.Aboveround biomass and above ground carbon stocks of species (**Source:** Excel output, 2015)

4.2.3. The aboveground biomass and carbon stock in Ethio-Cuba Park

The maximum AGB and minimum AGB in Ethio-Cuba park was 154.033 ton/ha and 21.703 ton/ha respectively. The mean biomass and carbon stocks was 123.139 ton/ha and61.569 ton/ha respectively with the mean aboveground carbon dioxide of 225.951 ton/ha (Appendix 2). The mean belowground biomass in this study site was 24.628 ton/ha with the maximum and minimum biomass of 30.807 ton/ha and4.341ton/ha respectively and a mean carbon stocks and carbon dioxide in BGB was12.314 ton/ha and 45.192 ton/ha respectively (Appendix 2).

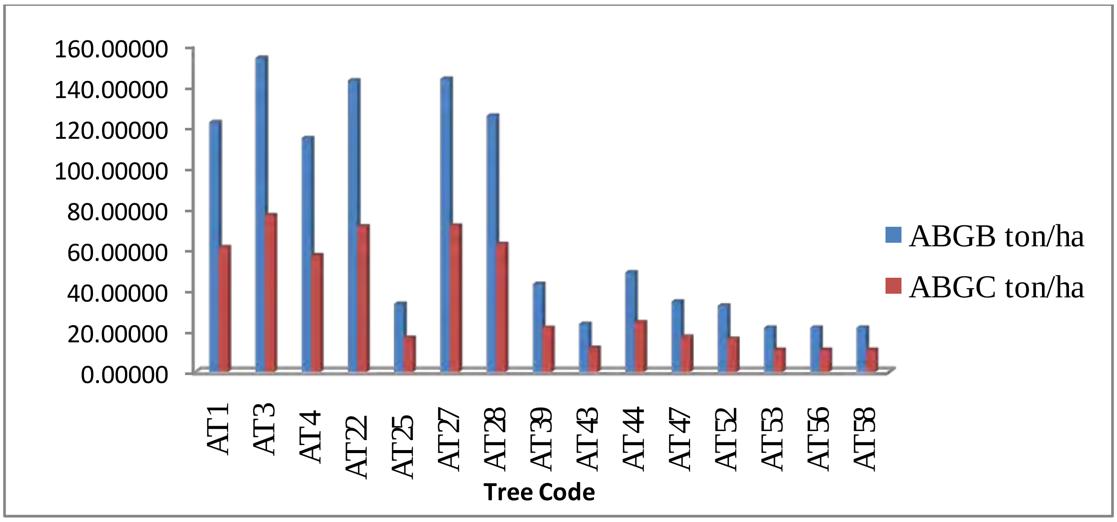

Figure 6.Aboveground biomass and above ground carbon stocks of species (**Source:** Excel output, 2015)

4.2.4. **The aboveground biomass and carbon stock in Akaki-Kality Park**

The maximum and minimum AGB in Akaki-Kality park was 540.531 ton/ha and 26.584 ton/ha respectively with a mean biomass of 284.442 ton/ha and the mean carbon stocks of AGB was 142.221 ton/ha with aboveground carbon dioxide of 521.951 ton/ha (Appendix 2). The mean BGB was 56.889 ton/ha with the maximum and minimum biomass of 108.106 ton/ha and 5.317 ton/ha respectively and mean BGC was 28.44 ton/ha and belowground carbon dioxide was 104.39 ton/ha (Appendix2).

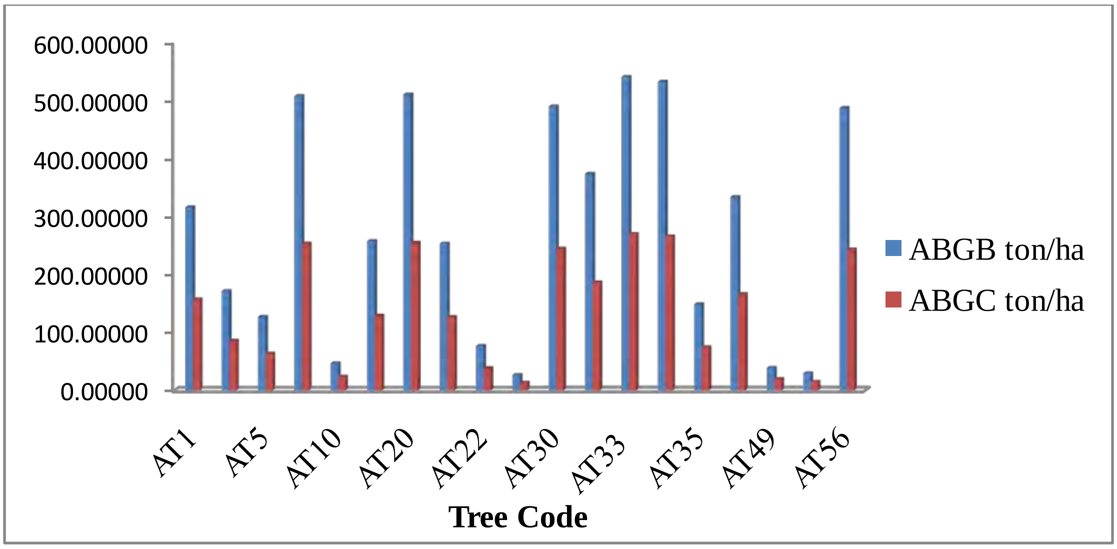

Figure 7.Above and belowground carbon stocks of species (**Source:** Excel output, 2015)

4.2.5. The Carbon stocks in dead litter

The laboratory analysis of litter carbon concentration of the sample plot was with a minimum of 39.16% (Yeka Park) and maximum of 54.19% (Ferensay Park) showing a variation. The mean litter carbon concentration in all sample plots of the study area was 47.85% (Appendix 4). The minimum and maximum carbon stock in dead litter was 0.52 and1.85 ton/ha for study sites Yeka Park and Ferensay Park respectively. The mean total carbon stock of litter biomass in four study sites was 1.15 ton/ha. The mean litter carbon dioxide was 4.21 ton/ha (Appendix 4).

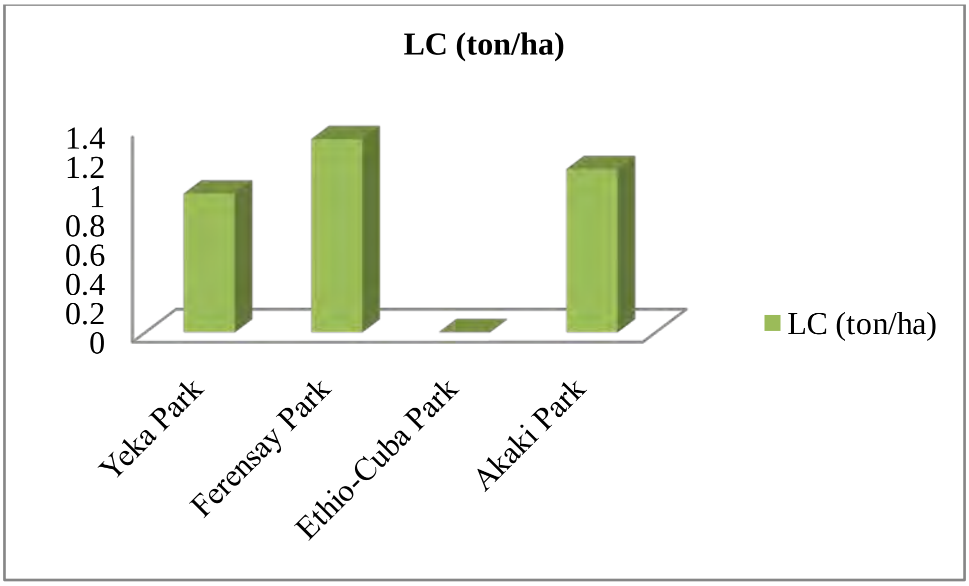

Figure 8.Litter carbon in each site (**Source:** Excel output, 2015)

4.2.6. The Carbon stock in soil

Based on the result, the carbon content of soil carbon ranged from minimum storage of 26.84 ton/ha in Ethio-Cuba Park to a maximum of 156.32 ton/ha in Ferensay Park. The current mean soil carbon stock in four sites was 93.93 ton/ha and this soil carbon pool sequestered a CO_2 value of 344.71 ton/ha which shows a large amount of CO_2captured in the soil. The soil bulk density ranged from 0.85 g cm^{-3} in Akaki-Kality Park of minimum to 1.44 g cm^{-3} in Ferensay Park of maximum value. On the other hand, 1.04 g cm^{-3} was the mean soil bulk density (Appendix 5).

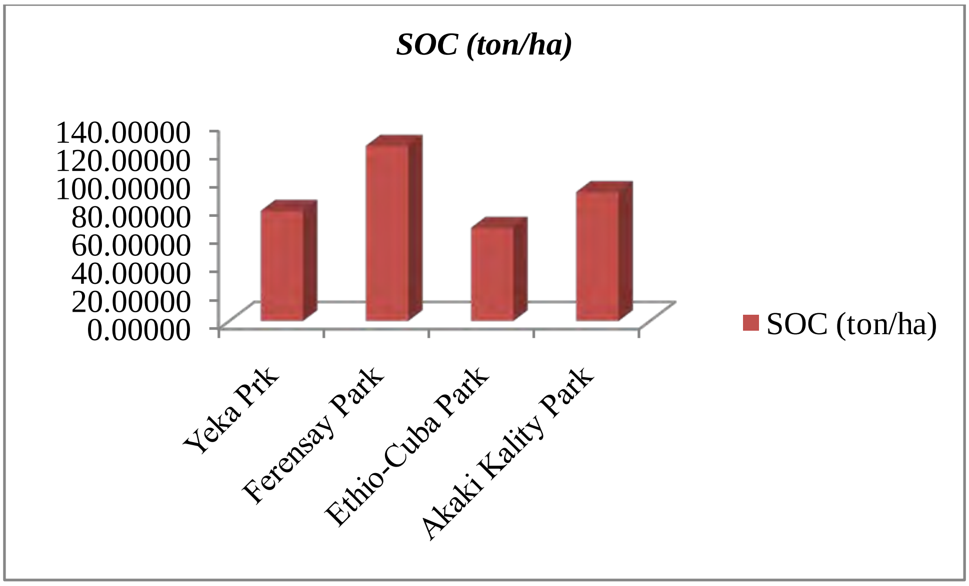

Figure 9.SOC in each site (**Source:** Excel output, 2015)

4.3. Total carbon stocks in above ground biomass, below ground biomass, litter and soil pools

The total carbon stock of above ground biomass, below ground biomass, litter and soil pools in four study sites was 237.36 ton/ha. This result shows high stock in the study sites.

4.4. Litter and Soil Carbon stocks along altitude classes

The mean litter and soil carbon stock responds differently along altitudinal gradient within the study sites (Table: 3). The carbon stock in litter pool was higher in the higher altitudinal classes (2350-2502a.s.l) 1.18 ton/ha than the other two classes and the higher altitude class contains larger amount of SOC (105.32 ton/ha) than the other two classes. As a whole the higher part of altitude contains higher amounts of carbon stocks in both LC and SOC. But there was not much significance difference noticed at 95% confidence interval ($\alpha=0.05$) ($F=0.861$, $P=0.653$) for SOC and ($F=2.456$, $P=0.160$) for litter carbon stocks (Appendix: 9).

Table 8.The mean carbon stocks in dead litter and soil on different altitudinal classes.

Altitude class	**Altitude range (m.a.s.l)**	**LC (ton/ha)**	**SOC (ton/ha)**	**TC (ton/ha)**
Lower	2048-2199	1.112	91.356	92.469
Middle	2199-2350	-	63.983	63.983
Higher	2350-2502	1.176	105.323	106.446
F-value		2.456	0.861	
P-value		0.16	0.653	

4.5. **Litter and Soil Carbon stocks and aspects**

Aspect was another parameter that affects the carbon stock of the study sites. Based on the results, the higher carbon stock was recorded in northwest aspect for both litter biomass and for SOC. On the other hand, the lowest carbon stock was recorded in northeast aspect for soil and east aspect for litter carbon stock. Like that of altitude, there was not much significance difference noticed in the different aspects at 95% confidence interval (α=0.05) (F=1.049, P=0.415) for SOC and (F=0.650, P=0.712) for litter carbon stocks (Appendix 9).

Table 9.Themeans carbon stock (t ha-1) in dead litter and soil in different aspects

Aspect	SOC (ton/ha)	Litter carbon (ton/ha)	TC ton/ha
N	85.5225	1.3302	86.8526
S	86.3493	1.1453	87.4946
E	101.019	1.0529	102.072
W	100.734	1.0822	101.816
NE	76.875	1.2236	78.0987
NW	156.321	1.7593	158.08
SE	105.527	1.1658	106.693
SW	90.9133	1.1239	92.0372

F-value	1.049	0.65
P-value	0.415	0.712

4.6. **Comparison of mean carbon stocks between four selected study sites**

The potential of each study sites in carbon stocks are vary from site to site due to their area coverage and DBH of the trees (Appendix 2 and 3).

Table 10.The means value of the carbon stock in all study sites.

Study sites	AGC	BGC	LC	SOC	Total
I	81.553	16.311	0.945	78.012	206.719
II	170.366	34.073	1.318	124.066	329.823
III	61.569	12.314	-	66.006	139.889
IV	142.221	28.444	1.112	91.356	263.134

Based on the result, Figure 11 shows the carbon stock potentials of study sites II and IV was higher than other sites by above and soil organic carbon stock amount. On the other hand, the carbon stock potentials of site III was lower than the rest of the study sites in both AGC and the SOC stocks. Therefore, site II and IV have higher potentials of carbon sequestration as compared to the rest of the study site while site I had low carbon stock range.

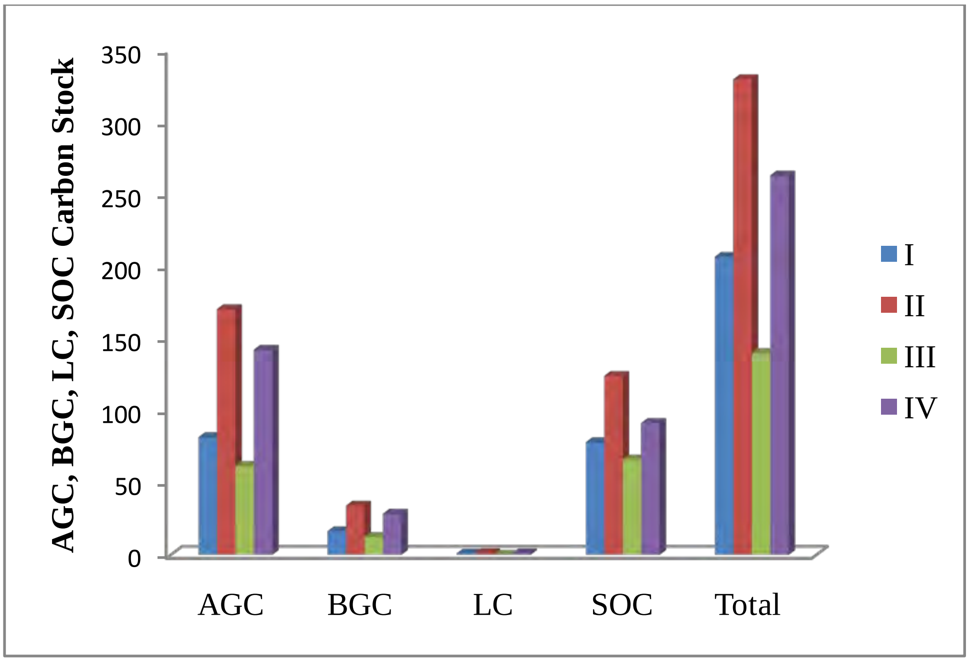

Figure 10.Total carbon stocks in 4 sites (**Source:** Excel output, 2015)

4.7. Comparison of mean carbon stock of the present result with different studies

The different studies were conducted on the carbon stock estimation of forests in different parts of Ethiopia. The result of all studies shows the significance of forests for climate change mitigation and adaptation.

Table 11.Comparison of the present study with different studies.

Study places	**AGC**	**BGC**	**LC**	**SOC**	**TC**
Egdu Forest (Adugna Feyissa*et al.*, 2013)	278.08	55.62	3.47	277.56	616.73
Menagasha Suba State Forest (Mesfin Sahile, 2011)	133	26.99	5.26	121.28	286.53
Church Forest (Tulu Tolla, 2011)	122.85	25.97	4.95	135.94	289.71
Park Forests (Meseret Habtamu, 2013)	143.3	28.1	10.5	69.2	251.1

Park Forests (Marshet Tefera, 2013)	25.4	5.1	5.17	113.55	149.22
Selected public parks (Present Study)	118.74	23.75	1.15	93.93	237.36

CHAPTER FIVE

5. DISCUSSION

The present study has calculated the standing biomass of the above ground wooded parts of the trees on four selected parks in Addis Ababa. The estimations regarding carbon stock and sequestration potential of the study sites were also made.

Accordingly, the abundance of tree species Yeka Park covers an area of 2.21 ha and Ethio-Cub Park with area coverage 2.72 ha was the smallest sized parks. However, in Yeka site there was high number of young tree species because of to keep the variety of the species and for beautification purpose. On the other hand these young tree species indicates plating or regenerating of this species in the study sites were very weak, and it needs attention. Ferensay park and Akaki-Kality park with an area of 5.42 ha and 6.25 ha respectively. Akaki-Kality Park has a long age but at this time it built by a new design because of this reason few trees might be cleared. And in Ferensay Park there was a high aged different tree species due to its establishment and has high protection.

Based on the result, the AGB of species depend on their DBH value and also on their age. The older trees with large DBH value will have large AGB. As age of tree increase biomass also increase (Negash, 2007). In general, gymnosperms (coniferous trees) contain lower wood densities than angiosperms (broad-leaved trees), varying with the height within the tree as well as within individuals (Jandl *et al.*, 2006).

The study sites are highly rich in biomass, holding almost a mean of 237.47 ton/ha. This is quite comparable with tropical dry and wet forests ranged between 30-273 ton/ha and 213- 1173 ton/ha, respectively (Murphy and Lugo, 1986). Below ground biomass followed the same trend as the above ground biomass with the mean 47.49 ton/ha (Appendix 8).

The mean AGC of current parks result was (118.74 ton/ha), it was closed to the AGC of Menagasha Suba State Forest Mesfin Sahile (2011) 133 ton/ha, Selected Church Forest Tulu Tolla (2011) 122.85 ton/ha, and Selected Park Forests Meseret Habtamu (2013) 143.3 ton/ha. In the same way also greater values recorded when it was compared with the Selected Park Forests Marshet Tefera (2013) 25.4 ton/ha. This indicates the significance of urban public parks. Therefore, this result is also comparable to those reported for the global above ground carbon stock in tropical dry and wet forests ranged between 13.5-122.85 ton/ha and 95-527.85 ton/ha, respectively (Murphy and Lugo, 1986).

The result of carbon stock in litter pool of the present study range was 0.52-1.85 ton/ha. According to Brown and Lugo (1982), litter fall in dry tropical forests range between 2.52- 3.69 ton/ha. Which is the present study indicates smaller values as compared to the values recorded on this study. Thus, the lowest carbon stock in litter pool could due to small amount of litter fall (Adugna Feyissa, 2013). The litter quantity and quality varies with tree species and hence for forest types (Lorenz & Lal 2010; Jandl*et al.*, 2007). Similarly, the trees in the study site I was relatively young and this could result in low amount of litter fall. However, study site II had a better litter accumulation than the other Parks and study site III was the next. In general, litter in parks was not accessible. The main reason for low litter amount within the study sites could be the number of samples taken because the fallen litters are always cleaned for the sake of sanitation. Especially in Ethio-Cuba Park there was no litter at all because the significance of litter was not well understood rather it was considered as a waste and it was removed from the Parks in all study sites.

This study also observed that, to estimate the carbon content of the soil in the parks were very complicated. And it was difficult to find untouched soil because most soils come from another place to increase the park soil fertility which means it was a disturbed soil.

The soil bulk density ranged from 0.85g cm^{-3} to 1.44 g cm^{-3} with a mean value of 1.04 g cm^{-3}in this study site. As Meseret Habtamu (2013) park forests in Addis Ababa the average bulk density was 0.72 g cm^{-3}. On the other hand the amount of soil organic carbon in Park Forests Meseret Habtamu (2013) varied from 38.6 ton/ha to 102.1ton/ha with average carbon stock of 69.238 ton/ha. The mean soil carbon stock in Park Forests were Marshet Tefera (2013) 113.55 ton/ha.

In the case of this study the soil carbon ranges between 26.84ton/ha - 156.32 ton/ha with the mean of 93.93 ton/ha which is better than the estimates of park forests (Meseret Habtamu, 2013) and less than the estimate of Park Forests (Marshet Tefera, 2013).

This indicates that the study site had high organic matter content in the soil. The higher mean SOC stock may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock (Sheikh *et al.,* 2009).

5.1.1. Litter and soil carbon stock along Altitudes

The two main variables which affect the carbon stocks of different pools were altitude and aspect. Altitudinal gradients are the most powerful ‘natural experiments’ for testing ecological and evolutionary responses of biota to environmental changes (Fang *et al*., 2004; Korner, 2007). The mean carbon density in litter pool for the present study showed no clear pattern with respect to altitudinal gradient. Thus, the litter carbon density of the four study sites showed relatively peaked in higher altitude class that means the carbon stock in LC was higher in the higher altitude class than the other two altitudinal classes which were not statistically significant. On the other hand, the higher altitude class contains larger amount of SOC than any other two classes just like that of litter carbon stocks no statically significant relationship. As a whole the higher part of altitude contains higher amounts of carbon stocks in both LC and SOC. Globally, SOC density increased with precipitation and clay content and decreased with temperature (Jobbagyand Jackson, 2000), which has been confirmed on regional and local scales (Yang *et al.*, 2007).

5.1.2. **Soil and litter carbon stock along Aspects**

Similarly aspect could also have effect on carbon stock of forests in the different carbon pools. According to Sharma (2011), it was also revealed that higher amounts of SOC are available on cooler and moister northern aspects. Despite of the fact that in most of the studies larger amount of soil organic carbon was found on the northern aspect, similarly, for this particular study the higher amount of carbon stock was recorded on northwestern aspect. The lowest SOC was found on the north eastern aspect. Also similar pattern was followed by litter carbon with that of soil organic carbon. As Sharma (2011), mentioned the forest growing on the southern aspects are generally exposed to various natural disturbances like wind fall. Thus, the presence of high wind fall on the southern aspects could probably be the cause for higher values of litter biomass and carbon on the southern aspects. In addition, the absence of high decomposition rate of litter on southern aspects may contribute for the presence of high litter biomass and carbon than the northern aspects. But due to cleaning and young trees, the litter biomass and carbon stocks in the present study were recorded higher values on the northwestern aspects than the southern aspects. On the other hand, at the northern part there were species that having broad leaves and aged trees found.

CHAPTER SIX

6. Conclusion and recommendations

6.1. Conclusion

The result of this study has indicated that from the selected four public parks a total of 53 species were recorded. All the species have stored high amount of carbon. The highest DBH was recorded at Frensay Park. The species *J. procera* was found to contain the highest biomass. Depending on the result the carbon stock amount increased with the DBH of trees. The higher number of species was found in the first DBH class (≥10-20 cm). The lowest number of species was recorded in the eighth DBH class i.e. (DBH≥140 cm). Therefore, in the first DBH class high density of young vegetation was found especially in Yeka Park. The study sites together had the potential to store118.74 ton/ha carbon and 632.283 ton/ha of carbon dioxide equivalent. This has its own contribution on the national effort of curbing CO_2 in the atmosphere. Therefore, if appropriate managements of the urban public park are implemented, there is a high potential of increasing biomass/carbon stock in the future and which ultimately helps to lessen the CO_2 concentration in the atmosphere.

6.2. Recommendations

The finding of the study shows poor management of the parks under consideration. The study sites need better protection, conservation and management to enhance carbon storage process. Because management of public parks provide better climate change mitigation for fast growing cities like Addis Ababa and urban public parks integration to urban planning practice needs to be strengthened.

- The study areas are highly dominated by exotic tree species. Therefore, the area has to be mixed with indigenous trees which best fits with ecology of the study area.

- In order to fully exploit the benefit from urban public parks to fighting climate change further studies are required.

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APPENDIXES

Appendix 1.Mean above and below ground biomass and carbon stocks of trees collected from four parks.

Study site	Tree codes	Number of trees	Average DBH(cm)	Average height(m)	ABGB ton/ha	ABGC ton/ha	ABG (CO_2) ton/ha	BGB ton/ha	BGC ton/ha	BG (CO_2) ton/ha
I	AT1	23	30.64	13.52	405.8308	202.9154	744.6995	81.1662	40.5831	148.9399
	AT2	6	27.47	13.90	309.9920	154.9960	568.8353	61.9984	30.9992	113.7671
	AT3	20	29.01	12.02	354.9940	177.4970	651.4141	70.9988	35.4994	130.2828
	AT4	137	25.87	12.63	266.7894	133.3947	489.5586	53.3579	26.6789	97.9117
	AT8	3	25.19	15.54	249.4363	124.7182	457.7156	49.8873	24.9436	91.5431
	AT12	1	11.84	8.25	31.3302	15.6651	57.4908	6.2660	3.1330	11.4982
	AT13	5	23.94	7.34	218.8882	109.4441	401.6598	43.7776	21.8888	80.3320
	AT15	47	19.45	7.57	126.8147	63.4073	232.7049	25.3629	12.6815	46.5410
	AT17	1	10.61	9.45	23.0610	11.5305	42.3169	4.6122	2.3061	8.4634
	AT18	1	16.24	7.49	77.1800	38.5900	141.6253	15.4360	7.7180	28.3251
	AT19	56	31.85	17.28	446.0311	223.0155	818.4670	89.2062	44.6031	163.6934
	AT22	869	18.55	6.99	111.4925	55.7463	204.5887	22.2985	11.1493	40.9177
	AT23	1	14.55	16.49	56.6308	28.3154	103.9175	11.3262	5.6631	20.7835
	AT24	113	14.55	4.78	56.6308	28.3154	103.9175	11.3262	5.6631	20.7835
	AT25	5	14.55	3.62	56.6303	28.3152	103.9166	11.3261	5.6630	20.7833
	AT26	1	22.59	8.54	188.3897	94.1949	345.6951	37.6779	18.8390	69.1390
	AT29	2	34.48	18.07	539.5774	269.7887	990.1246	107.9155	53.9577	198.0249
	AT28	1	34.48	24.74	539.5774	269.7887	990.1246	107.9155	53.9577	198.0249
	AT31	10	26.19	12.26	275.2568	137.6284	505.0962	55.0514	27.5257	101.0192
	AT32	1	17.75	11.24	98.8985	49.4492	181.4787	19.7797	9.8898	36.2957
	AT33	5	27.16	14.90	303.8913	151.9457	557.6406	60.7783	30.3891	111.5281
	AT34	2	18.31	13.12	107.5929	53.7964	197.4330	21.5186	10.7593	39.4866
	AT35	90	24.39	11.28	229.7087	114.8543	421.5154	45.9417	22.9709	84.3031
	AT36	4	14.03	8.99	50.9905	25.4952	93.5675	10.1981	5.0990	18.7135
	AT37	1	14.01	2.99	50.7418	25.3709	93.1112	10.1484	5.0742	18.6222
	AT38	5	25.76	8.72	263.8413	131.9207	484.1488	52.7683	26.3841	96.8298
	AT39	57	24.95	10.57	243.2961	121.6480	446.4483	48.6592	24.3296	89.2897
	AT41	18	20.31	8.29	142.3483	71.1741	261.2091	28.4697	14.2348	52.2418
	AT42	3	15.92	6.09	73.0018	36.5009	133.9582	14.6004	7.3002	26.7916
	AT43	14	21.88	9.71	173.3421	86.6711	318.0828	34.6684	17.3342	63.6166
	AT44	20	20.66	9.48	149.0920	74.5460	273.5838	29.8184	14.9092	54.7168
	AT46	3	10.52	3.09	22.5507	11.2753	41.3804	4.5101	2.2551	8.2761
	AT47	15	29.51	13.06	370.1944	185.0972	679.3067	74.0389	37.0194	135.8613
	AT49	8	28.92	11.98	352.3598	176.1799	646.5801	70.4720	35.2360	129.3160
	AT50	13	28.24	13.58	332.0100	166.0050	609.2383	66.4020	33.2010	121.8477
	AT52	7	18.20	7.51	105.9206	52.9603	194.3643	21.1841	10.5921	38.8729

	AT53	1	12.41	22.49	35.8667	17.9333	65.8154	7.1733	3.5867	13.1631
	AT56	1	15.05	4.64	62.3147	31.1574	114.3475	12.4629	6.2315	22.8695
	AT58	23	23.68	8.32	212.9377	106.4688	390.7406	42.5875	21.2938	78.1481
II	**Mean**				163.1053	81.5526	299.2981	32.6211	16.3105	59.8596
	Std. Deviation				97.3316	48.6658	178.6035	19.4663	9.7332	35.7207
	Minimum				22.5507	11.2753	41.3804	4.5101	2.2551	8.2761
	Maximum				539.5774	269.7887	990.1246	107.9155	53.9577	198.0249
	AT3	11	14.29	13.66	53.7738	26.8869	197.3499	10.7548	5.3774	19.7350
	AT4	143	16.97	9.58	87.3051	43.6525	320.4096	17.4610	8.7305	32.0410
	AT6	9	14.89	5.57	60.4905	30.2452	222.0000	12.0981	6.0490	22.2000
	AT8	30	33.17	18.28	491.7210	245.8605	1804.6160	98.3442	49.1721	180.4616
	AT9	10	33.92	21.23	518.9651	259.4826	1904.6021	103.7930	51.8965	190.4602
	AT10	2	13.89	4.78	49.5914	24.7957	182.0005	9.9183	4.9591	18.2001
	AT13	15	27.14	16.00	300.9580	150.4790	1104.5159	60.1916	30.0958	110.4516
	AT15	6	14.09	6.29	51.6287	25.8143	189.4772	10.3257	5.1629	18.9477
	AT16	1	25.22	13.70	250.0248	125.0124	917.5909	50.0050	25.0025	91.7591
	At17	3	13.43	12.25	45.0014	22.5007	165.1553	9.0003	4.5001	16.5155
	AT19	3	29.82	15.45	379.9433	189.9716	1394.3919	75.9887	37.9943	139.4392
	AT20	4	23.11	10.03	199.8659	99.9329	733.5077	39.9732	19.9866	73.3508
	AT21	6	27.90	17.38	322.2065	161.1032	1182.4977	64.4413	32.2206	118.2498
	AT22	369	24.85	12.15	240.8761	120.4381	884.0153	48.1752	24.0876	88.4015
	AT24	6	13.19	5.75	42.7382	21.3691	156.8491	8.5476	4.2738	15.6849
	AT25	3	29.85	12.50	380.6058	190.3029	1396.8231	76.1212	38.0606	139.6823
	AT26	1	24.52	10.25	232.7163	116.3582	854.0689	46.5433	23.2716	85.4069
	AT29	21	31.97	24.68	450.0483	225.0241	1651.6772	90.0097	45.0048	165.1677
	AT28	48	32.19	18.46	457.6911	228.8456	1679.7264	91.5382	45.7691	167.9726
	AT31	1	23.56	6.50	210.1589	105.0795	771.2832	42.0318	21.0159	77.1283
	AT33	9	34.40	25.55	536.4917	268.2458	1968.9244	107.2983	53.6492	196.8924
	AT35	11	24.46	15.32	231.3150	115.6575	848.9262	46.2630	23.1315	84.8926
	AT36	2	13.77	4.09	48.2971	24.1485	177.2503	9.6594	4.8297	17.7250
	AT39	1	26.11	12.95	272.9868	136.4934	1001.8616	54.5974	27.2987	100.1862
	AT41	58	34.91	22.18	555.8925	277.9463	2040.1256	111.1785	55.5893	204.0126
	AT43	25	25.77	14.34	264.1053	132.0527	969.2666	52.8211	26.4105	96.9267
	AT44	251	35.59	26.99	581.7625	290.8812	2135.0684	116.3525	58.1762	213.5068
	AT45	26	30.28	20.07	394.1833	197.0916	1446.6526	78.8367	39.4183	144.6653
	AT49	1	19.10	11.30	120.7945	60.3972	443.3158	24.1589	12.0794	44.3316
	AT51	15	32.29	21.38	460.9370	230.4685	1691.6388	92.1874	46.0937	169.1639
	AT52	25	35.50	28.25	578.5831	289.2916	2123.4001	115.7166	57.8583	212.3400
	AT53	18	20.23	10.67	140.9426	70.4713	517.2594	28.1885	14.0943	51.7259
	AT54	3	20.96	9.50	154.8470	77.4235	568.2886	30.9694	15.4847	56.8289
	AT57	2	12.25	7.63	34.5633	17.2816	126.8473	6.9127	3.4563	12.6847
	AT58	24	16.55	7.55	81.4548	40.7274	298.9390	16.2910	8.1455	29.8939
	Mean				340.7326	170.3663	1250.4887	68.1465	34.0733	125.0489
	Std. Deviation				183.1812	91.5906	672.2750	36.6362	18.3181	67.2275
	Minimum				34.5633	17.2816	126.8473	6.9127	3.4563	12.6847

	Maximum				581.7625	290.8812	2135.0684	116.3525	58.1762	213.5068
III	AT1	32	19.20	14.32	122.4616	61.2308	224.7171	24.4923	12.2462	44.9434
	AT3	16	20.92	14.40	154.0328	77.0164	282.6502	30.8066	15.4033	56.5300
	AT4	35	18.74	14.93	114.6405	57.3202	210.3653	22.9281	11.4640	42.0731
	AT22	166	20.34	12.05	142.9640	71.4820	262.3389	28.5928	14.2964	52.4678
	AT25	16	12.12	6.30	33.4684	16.7342	61.4145	6.6937	3.3468	12.2829
	AT27	39	20.38	14.51	143.7464	71.8732	263.7746	28.7493	14.3746	52.7549
	AT28	6	19.38	17.84	125.6147	62.8073	230.5030	25.1229	12.5615	46.1006
	AT39	4	13.24	12.75	43.1842	21.5921	79.2431	8.6368	4.3184	15.8486
	AT43	4	10.70	8.22	23.5747	11.7874	43.2596	4.7149	2.3575	8.6519
	AT44	12	13.83	6.52	48.8928	24.4464	89.7183	9.7786	4.8893	17.9437
	AT47	1	12.25	4.54	34.5633	17.2816	63.4236	6.9127	3.4563	12.6847
	AT52	6	11.99	8.47	32.5057	16.2528	59.6479	6.5011	3.2506	11.9296
	AT53	1	10.38	12.49	21.7030	10.8515	39.8251	4.3406	2.1703	7.9650
	AT56	1	10.38	10.24	21.7030	10.8515	39.8251	4.3406	2.1703	7.9650
	AT58	4	10.38	10.02	21.7030	10.8515	39.8251	4.3406	2.1703	7.9650
IV	**Mean**				123.1387	61.5694	225.9596	24.6277	12.3139	45.1919
	Std. Deviation				37.4068	18.7034	68.6414	7.4814	3.7407	13.7283
	Minimum				21.7030	10.8515	39.8251	4.3406	2.1703	7.9650
	Maximum				154.0328	77.0164	282.6502	30.8066	15.4033	56.5300
	AT1	148	27.65	10.67	315.2411	157.6206	578.4675	63.0482	31.5241	115.6935
	AT 4	31	21.79	11.79	171.6295	85.8148	314.9402	34.3259	17.1630	62.9880
	AT5	3	19.46	10.75	127.0537	63.5268	233.1434	25.4107	12.7054	46.6287
	AT7	117	33.61	14.61	507.5736	253.7868	931.3975	101.5147	50.7574	186.2795
	AT10	4	13.63	5.60	46.9459	23.4729	86.1457	9.3892	4.6946	17.2291
	AT19	4	25.53	12.53	257.9015	128.9508	473.2493	51.5803	25.7902	94.6499
	AT20	2	33.68	14.74	510.3593	255.1796	936.5093	102.0719	51.0359	187.3019
	AT21	7	25.36	11.57	253.7000	126.8500	465.5395	50.7400	25.3700	93.1079
	AT22	136	16.21	9.65	76.8246	38.4123	140.9731	15.3649	7.6825	28.1946
	AT25	1	11.17	4.25	26.5842	13.2921	48.7819	5.3168	2.6584	9.7564
	AT30	91	33.11	21.86	489.7236	244.8618	898.6429	97.9447	48.9724	179.7286
	AT28	1	29.61	21.50	373.3419	186.6709	685.0823	74.6684	37.3342	137.0165
	AT33	1	34.50	19.99	540.5308	270.2654	991.8739	108.1062	54.0531	198.3748
	AT34	2	34.28	24.85	532.2824	266.1412	976.7382	106.4565	53.2282	195.3476
	AT35	135	20.65	11.53	148.8104	74.4052	273.0672	29.7621	14.8810	54.6134
	AT39	10	28.28	18.03	333.3023	166.6511	611.6097	66.6605	33.3302	122.3219
	AT49	1	12.76	6.80	38.8522	19.4261	71.2939	7.7704	3.8852	14.2588
	AT50	1	11.59	6.05	29.4526	14.7263	54.0455	5.8905	2.9453	10.8091
	AT56	7	33.04	12.81	487.1521	243.5761	893.9241	97.4304	48.7152	178.7848
	Mean				284.4420	142.2210	521.9511	56.8884	28.4442	104.3902
	Std. Deviation				167.4330	83.7165	307.2396	33.4866	16.7433	61.4479
	Minimum				26.5842	13.2921	48.7819	5.3168	2.6584	9.7564
	Maximum				540.5308	270.2654	991.8739	108.1062	54.0531	198.3748

Appendix 2.Location of the sample plots for litter and soil (UTM)

Plot No	Study site	Field code	Altitude (m)	Latitude	Longitude	Aspect
1	Yeka Park	K1S1	2414	477564	997413	W
2	Yeka Park	K1S2	2401	477597	997382	E
3	Yeka Park	K1S3	2400	477623	997414	SW
4	Yeka Park	K1S4	2402	477648	997428	E
5	Yeka Park	K1S5	2404	477694	997451	NE
6	Yeka Park	K1S6	2403	477642	997474	W
7	Yeka Park	K1S7	2406	477608	997487	W
8	Yeka Park	K1S8	2405	477607	997499	SW
9	Ferensay Park	K2S1	2477	475105	999985	SW
10	Ferensay Park	K2S2	2472	475138	999961	W
11	Ferensay Park	K2S3	2492	475176	999936	E
12	Ferensay Park	K2S4	2493	475223	999904	W
13	Ferensay Park	K2S5	2491	475298	999868	NW
14	Ferensay Park	K2S6	2502	475322	999908	W
15	Ferensay Park	K2S7	2481	475293	1000046	S
16	Ferensay Park	K2S8	2481	475259	1000055	SE
17	Ferensay Park	K2S9	2489	475221	1000033	NE
18	Ferensay Park	K2S10	2489	475178	1000042	E
19	Ferensay Park	K2S11	2486	475140	1000050	E
20	Ferensay Park	K2S12	2485	475130	1000043	S
21	Ferensay Park	K2S13	2485	475118	1000032	S
22	Ethio-Cuba Park	K3S1	2376	472642	996804	SE
23	Ethio-Cuba Park	K3S2	2376	472595	996802	SW
24	Ethio-Cuba Park	K3S3	2356	472555	996806	SW
25	Ethio-Cuba Park	K3S4	2359	472553	996843	NE
26	Ethio-Cuba Park	K3S5	2369	472546	996884	NE
27	Ethio-Cuba Park	K3S6	2381	472527	996979	N
28	Ethio-Cuba Park	K3S7	2371	472520	996974	N
29	Ethio-Cuba Park	K3S8	2360	472513	996969	NE
30	Akaki Closed Park	K4S1	2068	476515	981121	N
31	Akaki Closed Park	K4S2	2064	476487	981119	N
32	Akaki Closed Park	K4S3	2069	476456	981125	E
33	Akaki Closed Park	K4S4	2062	476482	981158	SW
34	Akaki Closed Park	K4S5	2066	476503	981187	SW
35	Akaki Closed Park	K4S6	2067	476517	981231	SE
36	Akaki Closed Park	K4S7	2071	476544	981249	SW
37	Akaki Closed Park	K4S8	2074	476584	981282	SW
38	Akaki Closed Park	K4S9	2074	476607	981315	SE

39	Akaki Closed Park	K4S10	2077	476643	981332	SW
40	Akaki Closed Park	K4S11	2072	476678	981360	NE
41	Akaki Closed Park	K4S12	2070	476658	981370	NE
42	Akaki Closed Park	K4S13	2065	476635	981361	E
43	Akaki Closed Park	K4S14	2059	476620	981377	E
44	Akaki Closed Park	K4S15	2048	476650	981389	S
45	Akaki Closed Park	K4S16	2048	476670	981310	S

Appendix 3.Litter Carbon Stock Estimation Data

Lab No	**Field code**	**Wet wt (gm)**	**fresh wt (gm)**	**Oven dry wt (gm)**	**LB**	**%OC**	**LC (ton/ha)**	**CO_2 (ton/ha)**
A-ES-2053/2015	K1S1	120	100	96.55	0.01159	47.13	0.54605	2.004
A-ES-2054/2015	K1S2	215	100	93.57	0.02012	52.17	1.04953	3.85178
A-ES-2055/2015	K1S3	250	100	96.95	0.02424	47.27	1.14571	4.20474
A-ES-2056/2015	K1S4	165	100	97.08	0.01602	51.51	0.8251	3.02811
A-ES-2057/2015	K1S5	320	100	94.67	0.03029	48.09	1.45686	5.34667
A-ES-2058/2015	K1S6	265	100	92.63	0.02455	50.89	1.24919	4.58454
A-ES-2059/2015	K1S7	175	100	88.75	0.01553	49.05	0.76181	2.79583
A-ES-2069/2015	K1S8	130	100	86.68	0.01127	46.31	0.52184	1.91515
A-ES-2070/2015	K2S1	280	100	98.58	0.0276	53.78	1.48446	5.44796
A-ES-2071/2015	K2S2	230	100	97.51	0.02243	45.23	1.01439	3.7228
A-ES-2072/2015	K2S3	235	100	97.13	0.02283	45.79	1.04518	3.83582
A-ES-2073/2015	K2S4	253	100	94.52	0.02391	51.59	1.2337	4.52768
A-ES-2074/2015	K2S5	355	100	96.32	0.03419	54.14	1.85124	6.79406
A-ES-2075/2015	K2S6	230	100	84.93	0.01953	50.04	0.97748	3.58734
A-ES-2078/2015	K2S7	235	100	99.43	0.02337	54.16	1.26551	4.6444
A-ES-2079/2015	K2S8	253	100	89.31	0.0226	53.81	1.21586	4.46221
A-ES-2080/2015	K2S9	355	100	91.45	0.03246	54.19	1.75926	6.4565
A-ES-2081/2015	K2S10	370	100	99.11	0.03667	47.53	1.74296	6.39666
A-ES-2082/2015	K2S11	290	100	81.88	0.02375	54.13	1.28533	4.71715
A-ES-2083.2015	K2S12	250	100	83.22	0.02081	51.71	1.07583	3.94828
A-ES-2084/2015	K2S13	300	100	80.93	0.02428	48.68	1.1819	4.33758
A-ES-2093/2015	K4S1	305	100	97.19	0.02964	39.64	1.17505	4.31242
A-ES-2094/2015	K4S2	250	100	98.71	0.02468	49.03	1.20994	4.44047
A-ES-2095/2015	K4S3	165	100	95.35	0.01573	46.49	0.73142	2.6843
A-ES-2096/2015	K4S4	320	100	98.87	0.03164	48.18	1.52434	5.59432
A-ES-2097/2015	K4S5	265	100	97.61	0.02587	43.04	1.1133	4.08581
A-ES-2098/2015	K4S6	175	100	93.87	0.01643	41.09	0.675	2.47723
A-ES-2099/2015	K4S7	130	100	90.45	0.01176	47.48	0.55829	2.04894
A-ES-20100/2015	K4S8	210	100	97.04	0.02038	39.16	0.79802	2.92873
A-ES-20101/2015	K4S9	330	100	99.84	0.03295	45.08	1.48526	5.4509
A-ES-20102/2015	K4S10	350	100	98.86	0.0346	41.49	1.4356	5.26864

A-ES-20103/2015	K4S11	405	100	95.48	0.03867	39.27	1.51855	5.57307
A-ES-20104/2015	K4S12	290	100	91.28	0.02647	47.23	1.25023	4.58836
A-ES-20105/2015	K4S13	345	100	96.09	0.03315	45.08	1.49445	5.48463
A-ES-20106/2015	K4S14	235	100	90.47	0.02126	47.07	1.00073	3.67268
A-ES-20107/2015	K4S15	195	100	94.24	0.01838	47.97	0.88154	3.23523
A-ES-20108/2015	K4S16	210	100	97.87	0.02055	46.09	0.94727	3.4765
Mean					**0.0241**	**47.8538**	**1.1483**	**4.2144**
Std. Deviation					**0.0071**	**4.3143**	**0.3407**	**1.2504**
Min.					**0.0113**	**39.1600**	**0.5218**	**1.9151**
Max.					**0.0387**	**54.1900**	**1.8512**	**6.7941**

Appendix4.Carbon stock estimation in soil pool

Lab No	Field code	volume	Soil depth (cm)	Bulk density (g/cm^3)	% of Organic Carbon	SOC (ton/ha)	CO_2 ton/ha
A-ES-2053/2015	K1S1	98.125	30	1.008	2.780	84.042	308.433
A-ES-2054/2015	K1S2	98.125	30	1.019	3.150	96.277	353.336
A-ES-2055/2015	K1S3	98.125	30	.995	3.410	101.794	373.585
A-ES-2056/2015	K1S4	98.125	30	1.002	2.290	68.816	252.553
A-ES-2057/2015	K1S5	98.125	30	1.014	2.950	89.758	329.412
A-ES-2058/2015	K1S6	98.125	30	1.008	2.030	61.375	225.245
A-ES-2059/2015	K1S7	98.125	30	.942	2.150	60.743	222.928
A-ES-2069/2015	K1S8	98.125	30	.924	2.210	61.290	224.934
A-ES-2070/2015	K2S1	98.125	30	1.007	4.020	121.491	445.872
A-ES-2071/2015	K2S2	98.125	30	1.018	4.100	125.263	459.716
A-ES-2072/2015	K2S3	98.125	30	1.443	3.030	131.151	481.323
A-ES-2073/2015	K2S4	98.125	30	1.065	4.800	153.416	563.037
A-ES-2074/2015	K2S5	98.125	30	1.086	4.800	156.321	573.698
A-ES-2075/2015	K2S6	98.125	30	1.077	3.700	119.565	438.803
A-ES-2078/2015	K2S7	98.125	30	1.110	3.250	108.251	397.281
A-ES-2079/2015	K2S8	98.125	30	1.134	3.600	122.493	449.548
A-ES-2080/2015	K2S9	98.125	30	1.019	2.450	74.914	274.934
A-ES-2081/2015	K2S10	98.125	30	1.116	4.200	140.608	516.032
A-ES-2082/2015	K2S11	98.125	30	.982	5.050	148.806	546.117
A-ES-2083.2015	K2S12	98.125	30	1.238	3.980	147.794	542.405
A-ES-2084/2015	K2S13	98.125	30	1.031	2.030	62.779	230.399
A-ES-2085/2015	K3S1	98.125	30	.980	3.300	97.028	356.091
A-ES-2086/2015	K3S2	98.125	30	1.015	3.100	94.426	346.545
A-ES-2087/2015	K3S3	98.125	30	1.016	2.230	67.987	249.514
A-ES-2088/2015	K3S4	98.125	30	.978	2.220	65.144	239.079
A-ES-2089/2015	K3S5	98.125	30	.966	2.220	64.364	236.214
A-ES-2090/2015	K3S6	98.125	30	1.001	2.670	80.169	294.222

A-ES-2091/2015	K3S7	98.125	30	.860	1.040	26.842	98.511
A-ES-2092/2015	K3S8	98.125	30	.955	1.120	32.088	117.764
A-ES-2093/2015	K4S1	98.125	30	1.002	3.450	103.758	380.793
A-ES-2094/2015	K4S2	98.125	30	1.057	4.140	131.320	481.943
A-ES-2095/2015	K4S3	98.125	30	1.075	2.550	82.220	301.749
A-ES-2096/2015	K4S4	98.125	30	.895	2.330	62.559	229.592
A-ES-2097/2015	K4S5	98.125	30	1.053	3.600	113.743	417.437
A-ES-2098/2015	K4S6	98.125	30	1.023	3.830	117.599	431.589
A-ES-2099/2015	K4S7	98.125	30	.903	2.180	59.085	216.842
A-ES-20100/2015	K4S8	98.125	30	1.032	4.030	124.729	457.755
A-ES-20101/2015	K4S9	98.125	30	1.064	2.780	88.723	325.615
A-ES-20102/2015	K4S10	98.125	30	.850	4.430	112.909	414.377
A-ES-20103/2015	K4S11	98.125	30	1.053	3.450	109.035	400.158
A-ES-20104/2015	K4S12	98.125	30	1.131	3.030	102.822	377.358
A-ES-20105/2015	K4S13	98.125	30	1.097	2.010	66.126	242.681
A-ES-20106/2015	K4S14	98.125	30	1.194	2.070	74.152	272.138
A-ES-20107/2015	K4S15	98.125	30	1.220	2.120	77.624	284.879
A-ES-20108/2015	K4S16	98.125	30	1.079	1.090	35.299	129.546
Mean				**1.039**		**93.927**	**344.711**
Std. Deviation				**0.103**		**32.992**	**121.081**
Min.				**0.850**		**26.843**	**98.511**
Max.				**1.443**		**156.321**	**573.698**

Appendix5.Summary of biomass and carbon dioxide in AG and BG biomass of the Study sites

Study site	AGB	AGC	AGCO$_2$	BGB	BGC	BGCO$_2$
I	144.22	72.11	264.65	28.84	14.42	52.93
II	407.71	203.85	748.15	81.54	40.77	149.63
III	328.12	164.06	602.09	65.62	32.81	120.42
IV	337.84	168.92	619.94	67.57	33.78	123.99

Appendix 6.Thecurrent mean carbon stock in AGB and BGB biomass in four study sites.

	Above ground bio-mass (ton/ha)	Above ground carbon (ton/ha)	Above ground CO2 (ton/ha)	Below ground bio-mass (ton/ha)	Below ground carbon (ton/ha)	BGCO2
Mean	237.471	118.735	632.283	47.494	23.747	87.152

Std. Deviation	164.015	82.008	596.519	32.803	16.402	60.194
Minimum	21.703	10.852	39.825	4.341	2.170	7.965
Maximum	581.762	290.881	2135.068	116.352	58.176	213.507

Appendix 7. One way ANOVA

A. One way ANOVA by altitude

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
SOC (ton/ha)	Between Groups	40472.967	38	1065.078	0.861	0.653
	Within Groups	7420.387	6	1236.731		
	Total	47893.353	44			
Litter carbon (ton/ha)	Between Groups	3.922	31	0.127	2.456	0.16
	Within Groups	0.258	5	0.052		
	Total	4.179	36			

B. One way ANOVA by aspect

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
SOC (ton/ha)	Between Groups	7933.052	7	1133.293	1.049	.415
	Within Groups	39960.301	37	1080.008		
	Total	47893.353	44			
Litter carbon (ton/ha)	Between Groups	.566	7	.081	.650	.712
	Within Groups	3.613	29	.125		
	Total	4.179	36			

WALKLEY-BLACK METHOD

Equipment:

1. 500-mL Erlenmeyer flasks.
2. 10-mL pipette.
3. 10-and 20-mL dispensers.

4. 50-mL burette.
5. Analytical balance.
6. Magnetic stirrer.
7. Incandescent lamp.

Reagents:

1. H_3PO_4, 85%.
2. H_2SO_4 concentrated (96%).
3. NaF, solid.
4. Standard 0. 167M $K_2Cr_2O_7$: Dissolve 49.04 g of dried (105^oC) $K_2Cr_2O_7$ in water and dilute to 1 L.
5. 0.5 M Fe^{2+} solution: Dissolve 196.1 g of Fe $(NH_4)_2(SO_4)$ •$6H_2O$ in 800 mL of water containing 20 mL of concentrated H_2SO_4 and dilute to 1 L. The Fe^{2+} in this solution oxidizes slowly on exposure to air so it must be standardized against the dichromate daily.
6. Ferroin indicator: Slowly dissolve 3.71 g of o-phenanthroline and 1.74 g of $FeSO_4$•$7H_2O$ in 250 mL of water.

Procedure:

1. Weigh out 0.10 to 2.00 g dried soil (ground to <60 mesh) and transfer to a 500-ml Erlenmeyer flask. The sample should contain 10 to 25 mg of organic C (17 to 43 mg organic matter). For a 1 g soil sample, this would be 1.2 to 4.3% organic matter. Use up to 2.0 g of sample for light colored soils and 0.2 g for organic soils.
2. Add 10 mL of 0.167 M $K_2Cr_2O_7$ by means of a pipette.

3. Add 20 mL of concentrated H_2SO_4 by means of dispenser and swirl gently to mix. Avoid excessive swirling that would result in organic particles adhering to the sides of the flask out of the solution.
4. Allow to stand 30 minutes. The flasks should be placed on an insulation pad during this time to avoid rapid heat loss.
5. Dilute the suspension with about 200 mL of water to provide a clearer suspension for viewing the endpoint.
6. Add 10 mL of 85% H_3PO_4, using a suitable dispenser, and 0.2 g of NaF. The H_3PO_4 and NaF are added to complex Fe^{3+} which would interfere with the titration endpoint.
7. Add 10 drops of ferroin indicator. The indicator should be added just prior to titration to avoid deactivation by adsorption onto clay surfaces.
8. Titrate with 0.5 M Fe^{2+} to a burgundy endpoint. The color of the solution at the beginning is yellow-orange to dark green, depending on the amount of unreacted $Cr_2O_7^{2-}$ remaining, which shifts to a turbid gray before the endpoint and then changes sharply to a wine red at the endpoint. Use of a magnetic stirrer with an incandescent light makes the endpoint easier to see in the turbid system (fluorescent lighting gives a different endpoint color). Alternatively use a Pt electrode to determine the endpoint after step 5 above. This will eliminate uncertainty in determining the endpoint by color change. If less than 5 mL of Fe^{2+} solution was required to backtitrate the excess $Cr_2O_7^{2-}$ there was insufficient $Cr_2O_7^{2-}$ present, and the analysis should be repeated either by using a smaller sample size or doubling the amount of $K_2Cr_2O_7$ and H_2SO_4.
9. Run a reagent blank using the above procedure without soil. The blank is used to standardize the Fe^{2+} solution daily.

10. Calculate %C and % organic matter:

A. % Easily Oxidizable Organic C

$$\%C = \frac{(B-S) \times M \text{ of } Fe^{2+} \times 12 \times 100}{\text{g of soil} \times 4000}$$

where:

B = mL of Fe^{2+} solution used to titrate blank

S = mL of Fe^{2+} solution used to titrate sample

12/4000 = milliequivalent weight of C in g.

B. $$\% \text{ Organic Matter} = \frac{\% \text{ total C} \times 1.72}{0.58}$$