JIMMA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING MASTERS PROGRAM

ASSESSMENT OF ECOSYSTEM SERVICES OF URBAN TREES: THE CASE OF JIMMA CITY

By: Degaga Abera Feyisa

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Environmental Engineering

March 2021

Jimma, Ethiopia

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Main advisor: Dr.-Ing. Fekadu Fufa

Co-advisor: Mr. Wagari Mosisa

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DECLARATION

This thesis entitled **“Assessment of Ecosystem Services of Urban Trees: A Case of Jimma City”** is my original work and has not been presented for a degree in any other University.

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Signature Date

This research idea has been submitted for examination with my approval as a university advisor

Dr.-Ing. Fekadu Fufa (Main advisor)

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Signature Date

Mr. Wagari Mosisa (Co-advisor)

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Signature Date

ABSTRACT

The rapid growth of urbanization and global climate change calls for the elaboration and evaluation of different adaptation and mitigation strategies in climatic circumstances. One of the most important strategies is the planting and preservation of trees and other green spaces. Trees in the urban environment provide various benefits in climate change mitigation and urban runoff reduction. Therefore, this study aims to assess the ecosystem services of Jimma City trees using the i-Tree Eco model. Urban trees in Jimma city sequestered 16.5 kt of carbon and tree species such as Spatodea campanulata, Grevillea robusta, Borassus aethiopum, Casuarinas cunninghamiana, and Juniperus sequester high percentage of carbon which was approximately 21.20, 17.62, 8.66, 8.30 and 6.16% of all annually sequestered carbon respectively. Besides, urban trees of the city were estimated to store 414.27 kt of carbon; the most carbons were stored by the species such as Grevillea robusta, Spatodea campanulata, Borassus aethiopum, Casuarinas cunninghamiana, and Juniperus procera that stores approximately 15.60, 11.30, 10.50, 9.20 and 7.80% of all stored carbon respectively. Trees in Jimma city were estimated to remove 463.27 tons of air pollution due to CO, NO_2, O_3, SO_2, PM_{10}, and $PM_{2.5}$ per year. Additionally, 23.46 m^3/m^2/yr runoff was avoided. In the city, the monetary value of Jimma urban trees in terms of carbon storage, carbon sequestration, pollution removal and avoid runoff was estimated to 69,540,662, 2,769,027, 156,541.20, and 54.95 USD/yr respectively. To increasing the life quality of urban areas; platforms should be provided to increase the number of urban trees and increase green area spaces

Keywords: Air Pollution; Carbon storage; Carbon Sequestration; Ecosystem service

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ACRONYMS AND ABBREVIATIONS

BVOCs	Biogenic Volatile Organic Compounds
CLE	Crown Light Exposure
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSA	Central Statistical Agency
dB	Decibel
DBH	Diameter at Breast Height
EEDPT	Environmental Engineering Department
ERA	Ethiopian Road Authority
ESs	Ecosystem Services
ETB	Ethiopian Birr
EUR	Euro
GI	Green Infrastructure
GPS	Global Positioning System
ICB	International Conference on Biometeorology;
ICUC	International Conference on Urban Climate
IPCC	Intergovernmental Panel on Climate Change
JIT	Jimma Institute of Technology
Kg	Kilogram
Km	Kilometer
kt	Kiloton
M	Million
MEA	Millennium Ecosystem Assessment
NO_2	Nitrogen Dioxide
O_3	Ozone

PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than 2.5 microns
SE	Standard Error
SO_2	Sulfur Dioxide;
TEEB	The Economics of Ecosystem and Biodiversity
UFORE	Urban Forest Effects
UGI	Urban Green Infrastructures
UK	United Kingdom
UN	United Nation
USA	United State of America
USDA	Unite State Department of Agriculture
VOC	Volatile Organic Compound
WHO	World Health Organization
Yr	Year

CHAPTER ONE

INTRODUCTION

1.1. Background

Trees in urban areas provide several benefits to the public. Besides their aesthetic appeal, they provide many tangible environmental benefits or ecosystem services that often go unrecognized. In recent years, there has been increased research on the quantification of “ecosystem services”, the direct and indirect benefits that natural ecosystems provide to people (MEA, 2005).

Trees have long provided important resources and services for a variety of purposes. They give us building materials, paper, energy, food, recreation as well as several more intangible services such as carbon storage and sequestration, nutrients cycling, and water regulation. Because there are so many different goods and services that a forest can provide there are also opposing views on how the forest should be used (Dobbs, *et al*., 2011) . Most of the harvested round wood is used in the manufacturing of wood products and for pulp and paper, but there is an increasing interest to use the woody resources as an energy source and substitute for fossil fuels. At the same time, some other interests wish to see the trees preserved and turned into nature reserves (Abreu-Harbich, *et al*., 2015). All of these interests conflict with each other to a varying extent and it is impossible to satisfy all actors with an interest in the forest sector. However, finding a balance between the areas of utilization is important (de Groot R., *et* al., 2012).

Trees in the urban environment provide significant ecosystem services to urban residents. Researchers have sought to define these benefits in the context of a broader effort to understand how urban environments function in relationship with natural ecosystems (Costanza, *et* al., 1997). By identifying, quantifying, and valuing the ecological activity that provides services in urban areas, stronger policies, and improved quality of life for urban residents can be obtained (Costanza, *et* al., 1997) . Urban trees and green areas patches contribute to air filtering, micro-climate regulation, noise reduction, rainwater runoff reductions, and improved recreation/cultural values (Bolund & Hunhammar, 1999).

In our world, human population growth and urbanization have adverse environmental impacts such as elevated temperatures, increases in air pollution and stormwater quantity, and decreases in stormwater quality, which poses major environmental and public health problems in cities (Seto & Shepherd, 2009; Rydin, *et* al., 2012). In this regard, the ecosystem of the urban tree plays an important role in providing multiple services and environmental benefits to the urban environment (Forrest, *et* al., 1999; Strohbach & Haase, 2012) . Enumeration of these benefits can raise internationally the government and citizen awareness of the value of their public resources, such as urban trees on publicly owned lands, as well as provide a basis for management to maximize benefits while controlling costs.

Growing trees sequester carbon and store carbon as the primary atmospheric greenhouse gas (Nowak & Crane, 2002). Impervious surfaces in urban areas generate runoff after storms that must be dealt with by stormwater drainage and treatment systems; trees intercept precipitation and reduce this stormwater runoff and the infrastructure costs associated with it. Finally, because of their aesthetic appeal and microclimate effects, the presence of trees increases private real estate market values (McPherson, *et* al., 2005).

Trees improve air quality in other ways as well. They reduce air pollutants such as ozone (O_3), (NO_2), (SO_2), particulate matter less than 10 microns in size (PM_{10}), and particulate matter less than 2.5 microns in size ($PM_{2.5}$) by uptake of gases and interception of airborne particles (Nowak, *et* al., 2006) . While trees emit some volatile organic compounds (VOCs, an ingredient in ozone formation) themselves shading of parking lots reduces VOC emissions from asphalt and parked cars. Tree shade also increases the longevity of pavement (McPherson, et al., 2005).

Another important but often overlooked aspect of ecosystem services is their spatial allocation. For instance, a forest closer to an urban center may hold a higher recreational value than one further away and a remote old forest may have a higher value for biodiversity conservation compared to younger forests. The extent of ecosystem services provided by the forests, and their relative value, will often depend on the forests' location and their geographical composition (Cao, et al., 2010).

Humanity is rapidly urbanizing, and by 2030 more than 60% of the world, the population is expected to live in cities (UN, 1997). But even if humanity is increasingly urban, we are still as dependent on Nature as before. Rapid urbanization is destroying natural ecosystems and degrading the environmental quality of towns, cities, and all worlds (Alberti & Marzluff, 2004; Folke, *et al.*, 1997; Gregg, *et al.*, 2003; Roy, *et al.*, 2012) . Although urbanization promotes rapid social and economic development, at the same time, leads to many problems, such as the concentration of the population, traffic jams, shortages of basic human needs such as housing, clean water, foods, resource shortages, biodiversity reductions, “heat island” effects, noise, air and water pollution (Li, *et al.*, 2005; Onder & Dursun, 2011; Savard, *et al.*, 2000).

In the last few years, and even more for the future, the importance of urban climate and thermal comfort within the cities is increasingly being recognized (Roy, *et al.*, 2012)as can be observed by the growing number of international conferences and sessions in conferences on meteorology and climatology concerning urban climate (for example ICB – International Conference on Biometeorology; ICUC – International Conference on Urban Climate). The increasing interest in urban metro-climatic conditions is related to the growing importance of the consequences of climate change internationally on human health, and it is also related to the increase of the percentage of people that in the future will live in urban areas, as forecasted by the last “State of the World Population” by United Nations Population Fund: “For the first time in history, more than half of human population, 3.3 billion people, will be living in urban areas and by 2030, this is expected to swell to almost 5 billion: in the next few decades we will see an unprecedented scale of urban growth, especially in the developing world” (United Nations Population, 2007).

The rapid growth of urban populations and global climate change call for the elaboration and evaluation of different adaptation and mitigation strategies in these anthropogenically modified climatic circumstances: among these strategies, one of the most important is the planting and maintenance of trees and other green spaces on urban areas. On the one hand, vegetation is directly effective through shading and evapotranspiration, improving the quality of life of the resident population by decreasing heat stress. Several investigations have been carried out on such issues at micro and local scales, based on field measurements, models, or remotely-sensed data (Cao, *et al.*, 2010; Lehmann, *et al.*, 2014). On the other hand, urban tree stands to modify the city’s climatic characteristics and air quality by the sequestration of carbon dioxide, store of carbon dioxide and the removal of various air pollutants, and by reducing stormwater runoff (Jim & Chen, 2014; Kirnbauer, *et al.*, 2013; Nowak, *et al.*, 2013a).

A particular complication when including ecosystem services in forest management is that many of the services are difficult to evaluate in monetary terms. Without proper evaluation, the benefits these services provide are easily overlooked. As a consequence, forest management decisions might be based on incomplete information and could thus do more damage than benefit. For example, decisions might have harmful effects because of the reduction of important ecosystem services. Only by having an understanding of the value of all ecosystem services the forests provide, can an efficient and effective balance between the different uses of forest resources and services be achieved.

Urban ecosystem services of urban trees have been identified, quantified, and assessed to inform taxpayers and support urban planning and decision-making processes. However, urban ecosystem services are rarely involved in actual urban design and planning because of the lack of sufficient basic research about urban trees and urban green space ecosystem services (Haase, *et al.*, 2014). Urban planners and policymakers often lack knowledge of the benchmarks for ecosystem productivity when setting specific planning goals or expectations.

Some several techniques and models have been developed to help quantify ecosystem services, such as i-Tree Eco, i-Tree Hydro i-Tree species, and i-Tree Streets (i-Tree, 2010a). In this work, i-Tree Eco v6 is a software suite that was used for the analysis. i-Tree Eco was designed to use standardized field data from randomly located plots, as well as local hourly air pollution and meteorological data, to quantify urban forest structure, ecological function, and the associated value (Nowak, *et al.*, 2008; McPherson, 2010).

The i-Tree Eco model is an ecosystem service model for urban trees developed by the US Department of Agriculture (USDA) Forest Service for application in the U.S., and it has been adopted by the U.K., Australia, and Canada (Hirabayashi, *et al.*, 2012; Nowak & Crane, 1998) . The model is widely used to evaluate urban vegetation-induced environmental services; e.g. carbon storage and sequestration, air pollution reduction, noise pollution reduction and water runoff reduction, the effects of trees on energy consumed by buildings, and some disservices, such as the emission of biogenic volatile organic compounds (BVOCs) (Nowak, *et al*., 2013b; Russo, *et al*., 2016; Selmi, *et al*., 2016).

1.2. Statement of the problem

The practice of changing green spaces designated areas to built-up and other impervious uses has been common in Jimma city largely due to lack of adherence to strict master plan regulation implementation. These in turn lead to the decrease in urban forestry besides the increase in the impervious surfaces due to infrastructural development to satisfy human needs.

Urban trees and green spaces generally offer multiple services and environmental benefits to society. The structures, and consequently the composition, of the urban trees, vary in different land uses, whether public or private. Trees, and the functions and ecosystem services that they offer, such as air quality improvement, carbon storage, and sequestration, or temperature reduction, are directly influenced by management, and actions that affect their structure (the composition of species, number, and location of individuals). Therefore, proper management of urban trees and green spaces may increase the environmental benefits of trees present in our city. The first step to improve the management of urban trees and green spaces is to evaluate their current structure and benefits. Therefore, this study aims to assess the environmental benefits of urban trees in Jimma city. These benefits include carbon storage, carbon sequestration, air pollution, and the removal of runoff. ‘Ecosystem services’ refers to the benefits human populations derive from ecosystems. To give appropriate knowledge of ecosystem service to the community and to give information to stakeholders how its current issue in our city.

1.3. Objective

1.3.1. General Objective

The aim of the study is to assess the ecosystem benefits of urban trees in Jimma City.

1.3.2. Specific Objectives

The specific objectives of the study are;

- to estimate the capacity of climate change reduction of the trees through their carbon storage and sequestration potential;
- to estimate air pollutants removal potential of the urban trees; and
- to analyse the potential of the urban trees to reduce runoff.

1.4. Research Questions

The findings of the study answered the following questions. These questions are:

1. What are the carbon storage and sequestration potential of urban trees in Jimma city?
2. What is the air pollution potential of urban trees in Jimma city?
3. What is the capacity of urban trees in Jimma city to reduce runoff?

1.5. Significance of the study

The assessment of ecosystem service of urban trees is the major issue in the world. The current phenomenon in Ethiopia has been associated with environmental problems in most cities. Due to climatic change across the world and rapid urbanization we have to protect our environment. This practice of changing green space designated areas to built-up and other impervious uses has been common in Jimma largely due to a lack of adherence to strict master plan implementation. The major problems are urban sprawl, solid and liquid waste management; water, air, and noise pollution; Therefore, proper management of urban green spaces may increase the environmental benefits of trees present in our city. The first step to improve the management of urban forests is to evaluate their current structure and benefits.

1.6. Scope

The research work focused objectively on the assessment of the ecosystem services of urban trees in Jimma city including, the carbon storage capacity, carbon sequestration capacity, air pollution removal capacity, and runoff reducing the capacity of Jimma city urban trees.

Spatial and attribute data of the characteristics of the urban tree were analyzed using the i-Tree eco v6 model.

1.7. Limitations of the Study

The types and species of trees in Jimma City are not documented. Spatial changes in the tree population due to the expansion of the city were not recorded. Therefore, the lack of well-documented and recorded data on the trees in the city would compromise the findings of the study. Also, it would be difficult to access certain private compounds during the data collection on the attributes of the tress, which could also impact the study.

CHAPTER TWO

LITERATURE REVIEW

3.1. Ecosystem services

The term ecosystem service was first used in the late seventies and early eighties, though the concept of nature's value to society has been addressed much earlier. An ecosystem service is defined as a function in an ecosystem that directly or indirectly offers a benefit for society. It is therefore an anthropocentric term unlike the more general ecosystem function, and the idea behind the concept is to concretize and valuate nature functions that are important but not traditionally considered in decision-making. The values estimated for these services could be used in cost-benefit analysis and weighed against the benefits of exploiting the ecosystem in question (Gomez-Baggethun, *et al.*, 2010). Though there were studies in the 1970s and 1980s that framed ecological functions in economic terms, the concept of ecosystem services did not gain widespread popularity until the late 1990s and early 2000s. An important study about ecosystem service is a study by Costanza, *et al.* (1997) which attempted to assign value to all the world's ecosystems.

Ecosystem services are defined as the benefits human populations gate, directly or indirectly, from ecosystem functions by Costanza *et al.* (1997) and they also identify 17 major categories of ecosystem services. A number of these ecological services are not consumed by humans directly but are needed to sustain the ecosystems themselves. Such indirect services include pollination of plants and nutrient cycling, but the classification is not obvious. Another aspect of ecosystem services is that they have a different spatial cover. Ecosystem services can be available on the local or global scale according to the scope of the problem they are connected to and the possibility of transferring the service from where it is produced to the city where humans benefits from it. Such a transfer can take place both by man-made means and by natural means (e.g. atmospheric transport). Easily transferred services with a global scope, like Carbon storage and sequestering and air pollution removal, do not necessarily have to be produced close to the source of the problem (Endreny, *et* al., 2017). Services that are impossible to transfer must, however, be generated close to where they are consumed (e.g. noise reduction). Since this paper focuses on issues relevant to urban areas, the attention is on direct and locally generated services relevant for Jimma city. From the 17 groups of services listed by Costanza, *et al.* (1997), some of them are considered to have major importance in urban areas: air filtering (gas regulation), micro-climate regulation, noise reduction (disturbance regulation), rainwater drainage (water regulation), sewage treatment (waste treatment), and recreational/cultural values.

Ecosystems provide vital resources that support a wide set of ecosystem functions and services necessary for the livelihood and well-being of people (Costanza, *et al.*, 1997; TEEB, 2018) . The goods and services provided by ecosystems to people can be provisioning, regulating, and cultural services (MEA, 2005) . Trees and wetlands are among the most productive ecosystems in the world and are important features in the landscape that provide critical and diverse ecosystem services and to human society. These ecosystem services include the provision of food, clean water, and forest products, pollination, the regulation of climate, pests, and diseases, economic, and recreational opportunities. The benefits to human well-being get from these ecosystem services include security, the basic materials for livelihood benefits, aesthetic, health, social, and cultural relationships. The physical, chemical, and biological condition or quality of an ecosystem at a particular landscape is strongly linked to human well-being through ecosystem services (Maes, *et al.*, 2018) . Also, the availability of ecosystem services depends on the tradeoffs and interrelations between different types of ecosystem services (de Groot, *et al.,* 2012; MEA, 2005).

Ecosystems contribute to human well-being through the supply of ecosystem services (Vargas *et al.,* 2019). The sustainable provision of ecosystem services to human well-being at local and global levels is based on the performance of ecosystem conditions (Maes, *et al.*, 2018). However, rapidly growing populations, environmental changes, and social changes all affect the characteristics and processes of ecosystems. The widespread alteration and fragmentation of natural land cover have become the greatest threat to ecosystems. Ecosystem degradation, overexploitation of natural resources, overgrazing, and alien species can lead to a significant reduction of ecosystem conditions. As a result, ecosystem condition determines both the capacity to supply and the flow of ecosystem services. All these environmental pressures greatly affect ecosystem conditions and threaten ecosystem services and values (MEA, 2005).

The Millennium Ecosystem Assessment (MEA) identified four types of ecosystem services (MEA, 2005) . These are provisioning services like food, fuel, genetic resources, and freshwater, regulating services like soil erosion protection, carbon storage and sequestration, water purification, air quality maintenance, pest control, and temperature regulation, while cultural services contribute to the cultural, spiritual, and aesthetic dimensions of people‘s well-being and supporting services maintain basic ecosystem processes and functions such as habitat support to maintain species diversity, soil formation, primary productivity and, nutrient cycles. (MEA, 2005)

Another significant contribution was the UN-sponsored Millennium Ecosystem Assessment published in 2005 (MEA, 2005) . It detailed the human activity that has caused to loss of ecosystem services that, as well as providing a framework for the valuation of these services. In the MEA four categories of ecosystem services are defined: support, provisioning, regulating, and cultural services. Supporting services are ecosystem services necessary for other ecosystem services to function, and as such, they are rarely measured directly. Provisioning implies the products obtained from ecosystems for human consumption. Regulatory services include a wide variety of functions that has positive effects on society, but that are not generally traded, such as soil nutrients cycling or the regulation of atmospheric gases. Cultural services include recreation, education, as well as spiritual and historical values derived from ecosystems. (Andersson-Sköld, *et al*., 2015)

The benefits that ecosystems provide to sustain human well-being and socio-economic stability are defined as Ecosystem Services (ES) (de Groot, *et al*., 2012; MEA, 2005; TEEB, 2010). Among these services, some are essential for a society that lives in cities in a climate change context, which requires citizens to adapt to the new climatic conditions that can be also characterized by extreme events (Gómez-Baggethun & Borton, 2013) . From this basis comes the importance of the urban Green Infrastructure (GI) that forms an interconnected network of green areas and open spaces within the urban texture (Benedict & MacMahon, 2002) . The street trees, lawns, urban parks, and urban forests, and the cultivated lands within the metropolitan areas, are the GIs that provide not only cultural or recreational ES but also regulating ES such as air pollution filtration and the improvement of microclimatic conditions. (Chrysoulakis, *et al*., 2013)

And also ecosystems provide societies with food, fodder, and shelter in addition to many other important services including pollination, natural pest control, soil formation, and erosion control (MEA, 2005) . These benefits are obtained from various ecosystem components and processes that were directly or indirectly beneficial to humans. The Millennium Ecosystem Assessment classified ESs into four groups: provisioning (food, shelter, fiber, water, and genetic resources), regulating (pollination, natural pest control, erosion control, water purification, climate regulation), supporting (nutrient cycling, soil formation), and cultural (aesthetic, spiritual) services. The supporting ESs relate to the primary production through photosynthesis, production of oxygen, absorption of carbon, removing runoff, air pollution removal, soil formation, and nutrient cycling, and are necessary for the production of all other ESs (MEA, 2005).

The ES approach was developed to increase public awareness about the importance of well-functioning ecosystems and how their degradation affects human well-being and to promote sustainable management of ecosystems ((MEA, 2005). Over the past decade, the concept of ESs has been successfully mobilized as a pedagogic tool 'or communication metaphor 'which supports ecosystem and biodiversity conservation (Gómez-Baggethun & Borton, 2013). The approach is also widely used as a framework to understand and analyze the relationships between society and nature.

Table 1: Ecosystem service classification (Costanza *et al.*, 1997).

Ecosystem services	**Corresponding types**
Provisioning	Food production, Raw materials, etc
Regulating	Gas regulation, Climate regulation, disturbance regulation, water regulation, water supply, water treatment, etc.
Supporting	Soil formation, nutrient cycling, erosion control, pollination, biol ogical control, habitat/Refugio, genetic resource
Cultural	Recreation, culture, etc.

To evaluate the characteristics of ecosystem services provided by different stands, it is necessary to investigate their main structural characteristics. From the urban trees in Jimma city, 2738 trees were covered in this study. The data was collecting according to the i-Tree eco standard. Therefore, these typical data were sufficient since it was in agreement with i-Tree, (2010a) that states the sample size did not affect the simulation of ecosystem service. A stratified random sampling technique was employed in conjunction with satellite images. The entire city area was divided into fairly homogeneous units that could reduce the variance of the estimates, thereby leading to more precise results.

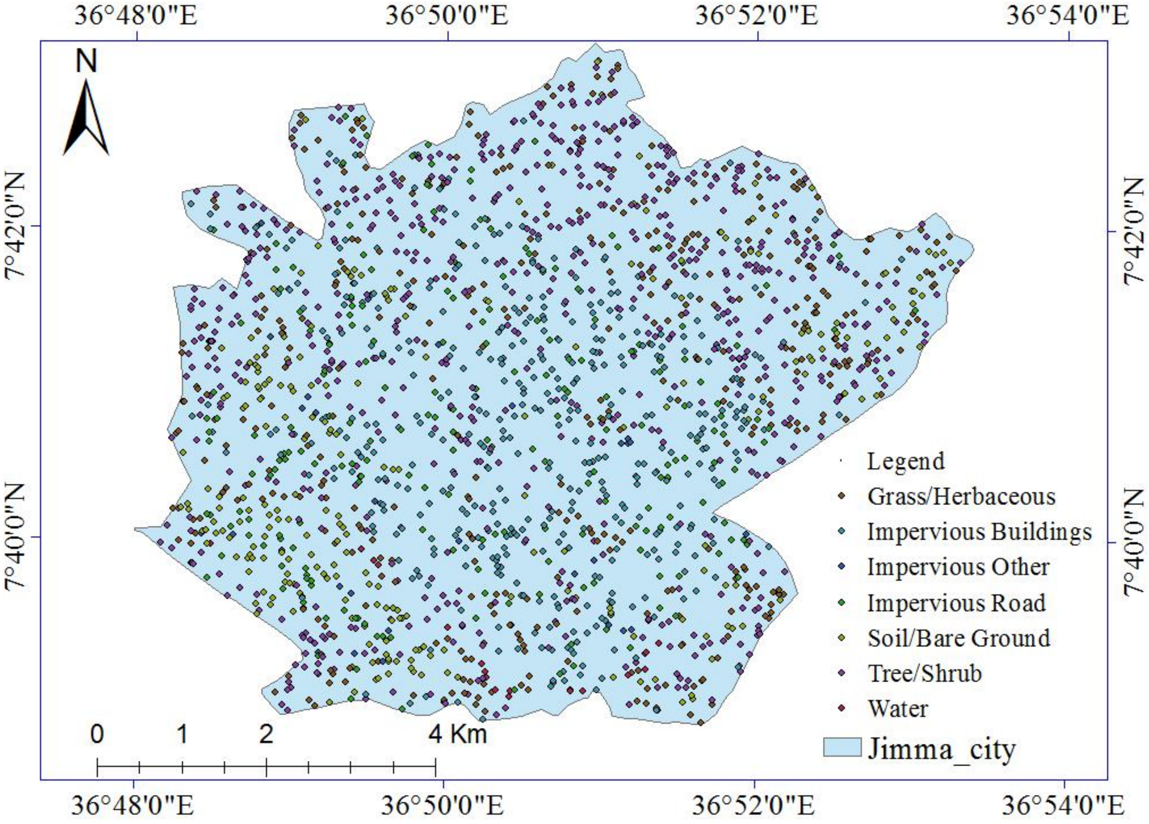

Figure 1: Land use sampling technique with satellite images(Source; i-Tree Canopy)

2.1.1. Carbon storage and sequestration

The impacts of greenhouse gases play an important role in the earth‗s climate system where the temperature of the earth‗s surface is expected to increase following a high concentration of greenhouse gases in the atmosphere (IPCC, 2013). In response to a large proportion of greenhouse gas emissions, urban trees, and green spaces play an important role in air pollution removal, sequestrating carbon, and storing carbon in large cities (McPherson, 2010; Strohbach and Haase, 2012). Several studies observed that trees sequesters and stores more carbon than any other terrestrial ecosystem and are an important natural _brake‗ on climate change. Others also highlighted those significant reductions in the global flux of CO_2 into the atmosphere can potentially be attained through forestry practices (Fahey *et al*., 2010; Gustavsson & Sathre, 2006; Hynynen *et al.,* 2005; Neilson *et al.,* 2006).

Trees in urban areas offer benefits in terms of atmospheric carbon reduction through capturing and retaining carbon over long periods. They contribute to direct carbon storage and sequestration from fossil fuel and other anthropogenic sources, besides the effect of energy conservation by urban trees are momentous on the amount of carbon released to the atmosphere (Nowak & Greenfield, 2012).

Urban trees and shrubs can also contribute to capture, store and transform CO_2 into above and below-ground biomass through photosynthesis, a process called carbon sequestration, and store carbon in the form of stems, branches, and roots (McPherson, *et al*., 2005; Nowak & Crane, 2002). Despite, the urban trees provide significant ecosystem services like storing and sequestering carbon released from fossil fuels and agricultural practices, until recently only limited works have been done that analyze the amount of carbon urban trees and shrubs can store and the amount of carbon released into the atmosphere ((Nowak, *et al*., 2013a) . Therefore, for better decision-making on the development and management of urban trees quantification of carbon (C) storage and sequestered by urban trees and green spaces is critical for the assessment of the actual and potential role of the urban trees in reducing atmospheric CO_2 (Nowak & Crane, 2002; Liu & Li., 2012).

Recently, there has been an increasing interest in estimating the amount of Carbon storage and sequestration by urban trees and green spaces in both developing and developed countries (Yang, *et al*., 2005). Moreover, landscape planners have given more attention to the beneficial impacts of urban trees and shrubs on microclimate improvement, air quality, runoff removal, and carbon storage and sequestration as well as on the conservation of biodiversity. Thus, urban tree carbon assessment could provide multiple opportunities for improving urban development planning as well as for scientific studies (Zhao, *et al*., 2010).

3.2. Urbanization

The development of any nation is closely linked to its level of urbanization. It is estimated that, in the future, about 80% of a country's economy and the population is likely to occur in cities. This is because cities are magnets for population migration, engines of economic development, and centers of information and global connections. (Jim & Chen, 2014) The more cities develop, the more countries prosper and vice versa. However, the urbanization process is, among other causes, commonly associated with the movement of people from rural to urban areas. This results in high population densities relative to their surrounding areas. The focus is on urbanization's local, regional and global environmental consequences and the processes that may lead to increased risk exposure, constrain people in high-risk livelihoods and residences, and generate vulnerabilities in critical infrastructure and services. Understanding urbanization and associated risk and vulnerability distributions are critical for an effective response to climate change threats and their impacts (Romero-Lankao & Qin, 2011).

Urbanization alters local environments with a series of physical phenomena that can result in local environmental stresses. These include urban heat islands (higher temperatures, particularly at night, in comparison to outlying rural locations) and local flooding that can be exacerbated by climate change. It is critical to understand the interplay between the urbanization process, current local environmental change, and accelerating climate change. For example, in the past, long-term trends in surface air temperature in urban centers are associated with the intensity of urbanization (Chen, *et al*., 2011).

Fast urban expansion has led to the replacement of natural vegetated land surfaces by various impervious materials (Xu, 2010). The direct impact of this is the rise of urban temperature, increased air pollution, and worsening of the quality of life for urban dwellers. The vegetation, water, and open spaces within and around cities provide many benefits for their inhabitants through reducing temperatures, cooling through evapotranspiration, storing and reradiating less heat than built surfaces. Research findings reported that increasing the human population would have brought about progress to the nation, but also brought with it the threat of environmental degradation and increased pressure on natural resources (Xu, 2010).

Climate change can influence these microclimates and localized regional climate dynamics. For example, urbanization (micro-scale to mesoscale) can strengthen and/or increase the range of the local urban heat island altering small scale processes, such as a land-sea breeze effect, katabolic winds, etc., and modifying synoptic scale meteorology (e.g., changes in the position of high-pressure systems concerning urban heat island events) (Lehmann, *et al.*, 2014) . Climate modeling exercises indicate an 'urban effect' that leads locally to higher temperatures. Building material properties are influential in creating different urban climate temperature regimes, which can alter energy demand for climate control systems in buildings (Jackson, *et al*., 2010).

Urbanization is associated with changing dimensions of migration and materials flows into and out of cities and also within them (Grimm *et al*., 2008). The level of increase (or in some cases decrease) of these conditions creates a dynamic quality of risk in cities. Rapidly changing cities must try to manage this growth through housing and infrastructure development while simultaneously understanding the relative impact of climate change. For example in sub-Saharan Africa, the combination of relatively high population growth rates and increasing levels of urbanization brings a rise in exposure to climate change impacts (Parnell & Walawege, 2011) . The conflation of local environmental change resulting from urbanization with climate change shifts makes the identification and implementation of effective adaptation strategies more difficult. Water shortages, for instance, already a chronic concern for many cities in low and middle-income nations, typically worsen as the population and demand continues to grow. Climate change-related reductions or uncertainties in supply combine with this existing instability to create the conditions for greater management and governance crises (Gober, 2010).

The increasing size of urban areas will have a great influence on urban climate, and it is for this reason that it is very important to study the relationship between urban trees and ecosystem service distribution. The use of urban trees and any green area located in cities and in areas characterized by different levels of urbanization to study temporal and spatial air temperature distribution is increasingly widespread (Huang, *et al*., 2011) . Air pollution removal is the most important parameter used in the ecosystem service of urban trees, combined with other environmental and subjective parameters, to describe the thermal comfort and the impact of weather conditions on human health in urban areas. (Oudin Åström, *et al.*, 2011)

2.2.1. Urbanization and environmental changes

Human-induced environmental change is a major concern of existence and its impact is most significant in towns and cities where the population is concentrated. Urbanization is considered to be a dynamo in the global economy; and is an accepted reality that the growth of cities cannot be stopped, instead, the challenge is to manage urban growth so that it results in the balance of economic growth and a healthy environment (Van de Voorde *et al.,* 2011).

Urban environmental conditions are different from that of rural, most significantly; the urban landscape is characterized by paving and buildings, modifies the urban micro-climate decreases wind speed, raises temperatures, increases precipitation, lowers relative humidity, and raises contaminants as compared to the rural landscape, though its extent and influences depend on the size of the city and its proportional trees and vegetation. Yang, *et al.,* (2013) Observed that the percentage of the population that lives in urban areas has been increasing rapidly since the 1950s. According to studies by the Organization for Economic Cooperation and Development (OECD, 2010), the urban population grows two to three times faster than the rural population, a trend projected to be maintained over the coming decades.

The urban environment has distinctive biophysical features concerning surrounding rural areas; its energy exchange is altered inducing an urban heat island, increased surface sealing increased surface runoff. These changes are partly due to reductions in urban green spaces of spatial area coverage and composition of trees and vegetation which would provide natural cooling, by shielding building facades and street surfaces from the sun, reducing the amount of energy stored in the built fabric during the day, and mitigate the urban heat island effect (Roberts, *et al.*, 2012) . The principal impacts of climate change in cities include the destruction of infrastructure through flooding hazards, built environment deterioration, and urban heat island intensification which affect the health and livelihood of the urban community (IPCC, 2013) . Land cover changes due to urbanization are drastic where a complete transformation into impervious surfaces has occurred, affecting energy exchange regimes and inducing climate change. The areal extent of urban land is not that large as compared with other land uses such as agriculture or forestry but its impact is significant, due to large concentrations of population, centrality to political, cultural, economic, and industrial activities. (Chrysoulakis, *et al.*, 2013)

Environmental impacts of urbanization can be categorized as direct and indirect; the direct impacts include the expansion of settlements, industrial and infrastructure land uses into natural and or agricultural lands. Urban paved and built-up surfaces absorb heat and re-radiate it at night, creating urban heat islands that affect plants and human physiology, and health. The indirect impacts of urban expansion like the expropriation of resources from large distances, the need for sinks or dumping sites for huge volumes of wastes generated by cities are also crucial. (Currie & Bass., 2008)

2.2.2. Urbanization and Ecological Sustainability

The urbanization-climate change connection has important implications for ecological sustainability. Climate change can accelerate ecological pressures in cities, as well as interact with existing urban environmental, economic, and political stresses (Leichenko, 2011; Wilbanks & Kates, 2010). This is especially important in a world where transgressions of key planetary boundaries such as climate change and biodiversity may take humanity out of the globe's "safe operating" space (Rockström, *et al*., 2009) into an unsafe and unpredictable future. A study by Trusilova *et al*. (2008) analyses the urbanization-induced disturbances of the carbon cycle in Europe through land-use change, local climate modification, and atmospheric pollution. The study shows that urban effects spread far beyond the city's boundaries and trigger complex feedback/responses in the biosphere (Trusilova *et al.,* 2008). Urbanization changes land use cover, generally reduces the amount of ecologically intact land, and causes fragmentation of the remaining land, which reduces habitat value for species and increases the likelihood of further ecological degradation.

The linkage between urbanization, ecological sustainability, and climate change is well illustrated by the example of New Orleans. This city's geophysical vulnerability is shaped by its low-lying location, accelerating subsidence, rising sea levels, and heightened intensity and frequency of hurricanes - a combination of natural phenomena exacerbated by "settlement decisions, canal development, loss of barrier wetlands, extraction of oil and natural gas, and the design, construction, and failure of protective structures and rainfall storage" (Wilbanks & Kates, 2010). For cities in arid regions, already struggling with water shortages often in the context of rising demand, climate change may further reduce water availability because of shifts in precipitation and/or evaporation (Gober, 2010).

2.2.3. Urbanization and Human Health

WHO/WMO (2012) and Barata, *et al.,* (2011) conclude that climate change may affect the future social and environmental determinants of health, including clean air, safe drinking water, sufficient food, and secure shelter. There is good evidence that temperature extremes (heat and cold) affect health, particularly mortality rates. Increased warming and physiological stress on human comfort levels are predicted in a variety of cities in sub-tropical, semiarid, and temperate sites (Blazejczyk, *et al*., 2012; Thorsson, *et al*., 2011).

Recent studies have illustrated the impact of heat stress on urban populations in low-income and middle-income countries (Egondi, *et al*., 2012). Hot days are known to have significant impacts on health that can be exacerbated by both drought conditions and high humidity. Studies in high-income countries show the elderly more vulnerable to heat-related mortality (Oudin Åström, *et al*., 2011) . In urban settings where child mortality is high, extreme temperatures have been shown to have an impact on mortality (Egondi, *et al*., 2012). People in some urbanization areas are more at risk, as they are exposed to higher temperatures for long durations and low-income households are more at risk when heat waves disrupt or limit income-earning opportunities (Kovats & Akhtar, 2008).

Climate change has implications for urban air quality. air pollution, and health policy (Athanassiadou, *et al.*, 2010). The impacts on urban air quality in particular urban areas are highly uncertain and may include increases and decreases of certain pollutants. Urban air quality in most cities already is compromised by localized air pollution from transport and industry, and often commercial and residential sources. Emerging literature shows strong evidence that climate change will generally increase ozone in the US and Europe, but that the pattern of that change is not clear, with some areas increasing and some areas decreasing (Jacob & Winner, 2009). The effects on particulate matter (PM) are also unclear, as are the effects on ozone and PM outside of the US and Europe (Dawson, *et al.*, 2013).

The incidence of asthma exacerbation may be affected by climate-change-related increases in ground-level ozone exposures (Barata, *et al.*, 2011); other pollutants may also be affected, particularly in cities with particulate matter ($PM_{2.5}$ and PM_{10}) and ozone levels far above World Health Organization guidelines (WHO, 2013). Climate change may change the distribution, quantity, and quality of pollen in urban areas, as well as the timing and duration of pollen seasons. WHO/WMO (2012) observe that diarrhea diseases, malnutrition, malaria, and dengue are climate-sensitive and in the absence of appropriate adaptation, could be adversely affected by climate change.

3.3. Urban trees

With 55% of the world's human population residing in cities (UN, 2017) urban environments are crucially important for sustaining human well-being (Endreny, et al., 2017; Nikodinoska, *et al.*, 2018). The recognition of the importance of the natural components of urban environments ecosystem for the wide range of public benefits they provide, however, has lagged behind rural environments. For example, they were not included in the MEA (Haase, *et al.*, 2014). Urban trees are a key feature of urban environments, providing important public benefits, including cooling, thereby ameliorating the urban heat island effect, reducing pollution, sequestering and storing carbon, mitigating flooding, and providing recreational opportunities and inspiration for culture, art, aesthetic, and design (Davies, *et al.*, 2017a; O'Brien, *et al.*, 2017). Until recently, the importance of these benefits has not been fully recognized by human beings (Davies, *et al*., 2017a; Willis & & Petrokofsky, 2017) . Understanding the structure of the urban environment is also an essential element to devise indicators for assessing trends in the quantity and quality of ecosystem services as well as used to understand the extent, to which these services are being sustained or lost over time, thereby helping to devise appropriate policy responses.

Urban trees protect the quality of life such as the quality of streams, rivers, and water supplies, support species diversity, wetlands, fish, and wildlife habitat, contribute to ecological, social, cultural, and overall improved health and quality of life of citizens (Stiftel & Vanessa, 2004). All these services referred to as ecosystem services contribute to the city`s economy by increasing property values, avoiding costly environmental clean-ups, and provide services at no cost to the public. Parks, gardens, and street trees can help to reduce the impact of hot temperature by providing natural cooling, by shielding building facades and street surfaces from the sun; the amount of energy stored in the built fabric during the day is reduced, and mitigate the urban heat island effect (Hsieh, *et al.*, 2016).

According to the Danish Forest and Landscape Research Institute (DFLRI, 2011), urban trees are increasingly recognized as most important to the overall quality of human life due to their significant ecological, social, and aesthetic impacts on the urban population. In the urban where landscape paving and buildings characterize the city, in which wind speed is decreased, temperature and precipitation are raised and the humidity is lowered. With more than half of the world population has become an urbanite, the quality of the urban environment and its urban trees and green spaces are increasingly recognized as the key issue to the redevelopment of cities. (OECD, 2010)

Urban trees, encompassing all trees, shrubs, lawns, and other vegetation in cities, provide a variety of ecosystem services to city-dwellers directly or indirectly, such as social, ecological economical, air purification, global climate regulation, urban temperature regulation, noise reduction, runoff mitigation, filtration of dust and noise, and reduction of the urban heat island effects, recreational opportunities, as well as ecosystem disservices, such as air quality problems, allergies, and infrastructure damages (Gomez-Baggethun & Barton, 2013).

Urban tree planting initiatives are being actively promoted as an urban planning solution to reduce the environmental degradation caused by urbanization, enhance urban sustainability, mitigate and adapt to climate change, and improve human health and well-being (Andersson-

Sköld.y, *et al*., 2015) . The public perception of the value of urban trees, green spaces, and green infrastructure (especially trees) within cities has prompted several initiatives to promote the 'greening' of cities through urban reforestation and protection programs to increase the percentage of tree canopy cover, such as the New York City 'Million Trees' program [(Rae, *et al*., 2015), or the City of Melbourne's 40 % tree canopy cover target. Such projects have stemmed from a wide range of different organizational bodies encompassing local to international-scale governance, community-based, charitable and regulatory approaches. Here, the broader arguments for increased tree density stem from benefits for public health and quality of life, and the sustainability and resilience of cities in light of climate change (Kremer, *et al*., 2015).

2.3.1. Land use land cover of the study area

The fundamental prerequisite for land surface cover assessment which land cover types are traced from the i-Tree canopy statistical techniques. The methodology statistical techniques where classification of primarily typical land surface covers types are established using specific defining characteristics. A stratified random sampling technique was employed in conjunction with satellite image interpretation of the different surface cover types. The entire city area was divided into fairly homogeneous units that could reduce the variance of the estimates, thereby leading to more precise results (Nowak *et al.,* 2003).

The use of different sample sizes for different proportional covers resulted in different level of standard errors and demonstrated that a random distribution of 2001 sample points within a given unit achieved a maximum standard error to achieve the required 95% confidence, where the true value is within ±5% of that sample.

Based on satellite image through which it was possible to visualize the major land surface cover types where some are found to be dominated by Tree/shrubs impervious Buildings, and or grass/herbaceous cover. However, a given satellite image is found to include many land surface cover types. The methodology including the determination of sample points to representative land cover classes with source image characteristics. The seven land surface cover categories developed for Jimma city include impervious buildings, tree/shrubs, impervious roads, grass/herbaceous, soil, impervious water, and impervious others.

Determining the type of land surface cover classes depends mainly on the intended resolution of the image. The resolution of the satellite image to identify different land cover classes was an important criterion in defining the current seven land surface cover classes for Jimma using an i-tree canopy. The methodology involved several steps including the determination of sample points to each class; finally, each point was traced to by the appropriate land surface cover class to which it belongs.

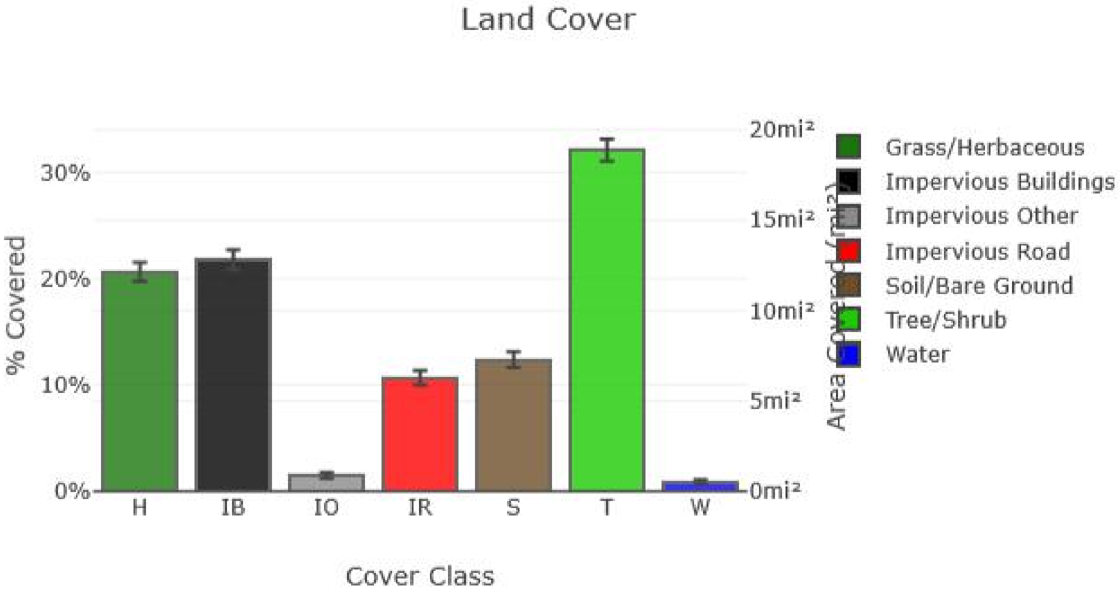

Figure 2: Land cover (percent covered vs. cover class vs. area covered) of Jimma city (Source; i-Tree canopy)

3.4. Benefits of urban trees

The urban tree is a woody perennial plant growing in towns and cities, typically having a single stem or trunk − and usually a distinct crown - growing to a considerable height, and bearing lateral branches at some height from the ground. Urban trees include individual trees as well as those occurring in stands, patches, and groups within publicly accessible green spaces. Here the term urban tree relates to a growth form rather than to a vegetation type, thus defining the scope of the study. According to Bolund P. & Hunhammar S(1999), urban trees are stand-alone trees, often surrounded by buildings and paved ground. Lawns: parks are managed green areas with a mixture of grass, larger trees, and other plants.

Urban trees and green spaces can improve the quality of life of residents in two ways. First, urban trees and green spaces provide residents and visitors with additional recreation and wildlife areas. Secondly, trees and green space provide significant advantages in terms of psychological and physical well-being. Additionally, urban trees and green spaces also provide free ecosystem services that help maintain the ecological integrity of expanding cities like carbon sequestration, watershed management, and biodiversity conservation. According to Mansfield, *et al*., (2002) and Sailor, (1997), increasing the forest cover in a city reduces su mmertime heat more that it increases wintertime cold.

Economically, urban trees, once mature, can be a source of raw materials for local handicrafts and small-scale commercial activities. Similarly, in poor urban areas, where food purchasing makes up a large part of a household's income, the produce from urban agriculture or gardens can be used for home consumption and as an effective way of supplementing income, thus contributing towards poverty reduction.

Huang *et al*., (1990) observe that planting trees and vegetables located around residential stru ctures may reduce both cooling and heating costs due to reduced summer heating and a wind shielding effect. According to other studies, urban trees have various economic benefits. Simpson & McPherson, (1998) found that savings of 1.9%–2.5% on cooling costs have been estimated per residential tree, providing a strong financial incentive to choose housing locations with tree cover. According to Morancho AB, (2003) and the ‘‘hedonic technique’’, the price of the housing relates inversely with the distance that separates it from urban green space. Bolitzer & Netusil, (2000) concluded that proximity to open space has a statistically significant effect on home selling price. Tyrvainen & Miettinen, (2000) Demonstrated that a 1 km increase in the distance from the nearest forested area leads to an average 5.9% decrease in the market price of the dwelling.

Ecosystems services however are not only environmental and health “issues”: they also represent important economic value. The presence or absence of functional ecosystems and their ES have an impact on the strength of the economy and the wellbeing of people of urban areas (e.g. air purification, noise reduction, urban cooling, and absorbing storm/floodwater runoff) (Bolund & Hunhammar, 1999) . For instance, the air purification performed by ecosystems in Barcelona represents economic values of over EUR 1 million of avoided costs for the city (Gomez-Baggethun and Barton, 2013). In Chicago, the cooling value of each tree corresponds to USD 15 of avoided air conditioning costs and hospitalization expenditures due to heat-related diseases (Gomez-Baggethun & Barton, 2013) . Even higher costs and values are related to flood mitigation. Hence, the presence of functional urban ecosystems represents significant economic and health benefits, while their absence implies costs.

Climate change will alter ecosystem functions affected by changes in temperature and precipitation regimes, evaporation, humidity, soil moisture levels, vegetation growth rates (and allergen levels), water tables and aquifer levels, and air quality. It will also accentuate the value of ecosystem services and green infrastructure for adaptation. “Green infrastructure” refers to interventions to preserve the functionality of existing green landscapes (including parks, forests, wetlands, or green belts), and to transform the built environment through phytoremediation and water-management techniques and by introducing productive landscapes (Foster, *et al.*, 2011b; Zhang, *et al.*, 2011). These can influence the effectiveness of pervious surfaces used in stormwater management, green/white/blue roofs, coastal marshes used for flood protection, urban agriculture, and overall biomass production. Mombasa will experience more variable rainfall as a result of climate change, making the expansion of green infrastructure more difficult (Kithiia & Lyth, 2011) . Trees in British cities will be increasingly prone to heat stress and attacks by pests, including new non-native pathogens and pests that can survive under warmer or wetter conditions. Urban coastal wetlands will be inundated with sea-level rise. In New York City, remnant coastal wetlands will be lost to sea-level rise because bulkheading and intensive coastal development will prevent their natural movement inland (Gaffin, *et al.*, 2012).

3.5. Ecological Benefits of Urban Trees

It is well known that urban trees have various types of benefits with offering more than just beauty and shade; trees provide intangible benefits, such as removal of atmospheric carbon dioxide and pollution, stormwater reduction, temperature modification, and more. Through these properties, trees and open spaces make an important contribution to the improvement of the artificial climate of towns. (Maes, *et al.*, 2018)

Green spaces in cities are beneficial for absorbing rainfall and moderating high temperatures. Urban forests and trees can provide shading, evaporative cooling, and rainwater interception, storage, and infiltration services for cities (Pramova, *et al.*, 2012) . Increasing tree cover is proposed as a way to reduce urban heat islands. Cooling effects are especially high in large parks or areas of woodland but the land these are on faces competition from developers, as well as management challenges. The rapid and often unregulated expansion of cities in low- and middle-income nations may also have left a much lower proportion of the urbanized area as parks and other green spaces. (Gómez-Baggethun & Borton, 2013)

Surface runoff is a cause for concern in many urban areas as it can increase pollution in streams, wetlands, rivers, lakes, and oceans. When it rains, some portion of the precipitation is intercepted by vegetation (trees and shrubs), while the remainder reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi, et al., 2012). In urban areas, the extensive area covered by impervious surfaces increases the amount of surface runoff.

Ecologically, urban trees are significant for nature conservation as they provide habitats for a wide range of flora and fauna. The very presence of plants in a city improves the visual appearance of the urban environment, contributes towards climate change prevention, creates lower densities of development, and reduces levels of activity in an area. This contributes to a more peaceful and relaxed ambiance, a benefit equally important in commercial and residential areas (Hirabayashi, *et al.*, 2012).

There is also a lack of detailed knowledge on the climatic effects of specific urban plants and vegetation structures and other important aspects such as the influence of green areas in local circulation patterns and impact on urban fluxes and urban metabolism (Chrysoulakis, *et al.*, 2013) . Also, green infrastructure projects may select plant material for particular purposes that do not support habitat values or large ecosystem function and greater ecosystem services.

Some city governments have focused on green infrastructure within built-up areas. In the USA, Portland and Philadelphia have encouraged green roofs, porous pavements, and disconnection of downspouts) to reduce stormwater at a much lower cost than increasing stormwater capacity (Foster, *et al.*, 2011b). Some cities have invested in green infrastructure linked to both regeneration and climate change adaptation. The Green Grid for East London seeks to create “a network of interlinked, multi-purpose open spaces” to support the wider regeneration of the sub-region, enhancing the potential of existing and new green spaces to connect people and places, absorb and store water, cool the vicinity and provide a mosaic of habitats for wildlife. New York has a well-established program to protect and enhance its water supply through watershed protection. This includes city ownership of crucial natural areas and working with landowners and communities to balance the protection of drinking water with facilitating local economic development and improving wastewater treatment. There is also an ambitious green infrastructure plan, including porous pavements and streets, green and blue roofs, and other measures to control stormwater. The program is costly, compared to constructing and operating a filtration plant, but is the most cost-effective choice for New York (Foster, *et al*., 2011b).

The coastal city of Quy Nhon in Vietnam is reducing flood risks by restoring a 150-hectare zone of mangroves (Brown, *et al*., 2012). Singapore has used several anticipatory plans and projects to enhance green infrastructure including its Streetscape Greenery Master Plan, constructed wetlands or drains, and community gardens (Newman, 2010) . Authorities in England and the Netherlands are recognizing the linkages between spatial planning and biodiversity but without much direct response to climate change adaptation. Barriers to action include short-term planning horizons, the uncertainty of climate change impacts, and problems of creating habitats due to inadequate resources, ecological challenges, or limited authority and data (Wilson & Piper, 2008).

In Mombasa, the Bamburi Cement Company rehabilitated by trees 220 hectares of quarry land (Kithiia & Lyth, 2011). The resulting Haller Park attracts over 150,000 visitors per year and has the potential to create adaptation co-benefits. Cape Town has initiated community partnerships to conserve biodiversity, including the Cape Flats Nature project with the para-statal South African National Biodiversity Institute. Participating schools and organizations explore ecosystem services (such as flood mitigation and wetland restoration), and the project facilitates “champion forums” to support conservation efforts (Ernstson *et al*., 2010).

Dedicated green areas within urban environments compete for space with other city-based needs and developer priorities. The role of strategic urban planning in mediating among competing demands is potentially useful for the governance of adaptation as demonstrated in London, Toronto, and Rotterdam (Mees & Driessen, 2011). The experience in Durban also faces many challenges (Roberts, *et al*., 2012), including an assumption that ecosystem-based adaptation is an easy alternative to the constraints that limit the implementation and effectiveness of “hard engineering” solutions (Kithiia & Lyth, 2011). Experience in Durban shows that implementing an ecologically functional and well-managed, diverse network of bio-infrastructure requires data collection, expertise, and resources, and to have direct and immediate co-benefits for local communities and ensure integration across institutional and political boundaries. There are substantial knowledge gaps such as determining where the limits or thresholds lie; many ecosystems have been degraded to the point where their capacity to provide useful services for the environment was reduced (TEEB, 2010).

They lower the temperature considerably by evaporative cooling. A beech forest evaporates 83.8% of its radiated energy. In a town, 60% of the radiated energy serves to warm the air. A small green area in Frankfurt lowered the temperature by 3-3.5 °C and intensified the relative humidity by 5 - 10% ventilated the overheated, dirty, and polluted town center, and provided fresh air. Parks can filter up to 80% of the pollution from the air, and trees in avenues by up to 70%. Even without leaves (in winter) the plants still retain 60% of their efficiency: they reduce the lead content of the air, reduce noise by up to 12 dB and provide a supply of oxygen under calm weather conditions. In consequence, grassed areas and trees should be planted more systematically in towns (Bernatzky, 1982). According to (Nowak, *et al.,* 2006), urban trees and shrubs offer the ability to remove significant amounts of air pollutants and consequently improve environmental quality and human health. Urban areas also faced a common problem called the heat island effect. Public-space plantings and parks have become a crucial countermeasure for decreasing urban temperatures (Hsieh, *et al.,* 2016).

The cooling effects of urban streets and courtyards with trees have been investigated, and the benefits of plantings in the surrounding areas have been identified in several studies (Abreu-Harbich, *et al.*, 2015; Hsieh, *et al.*, 2016; Kong, *et al.*, 2014; Shashua-Bar & Hoffman, 2000; Shashua-Bar & Hoffman, 2004).

2.5.1. The Effects of Trees and Green Areas

The effects of trees and green areas must be understood in the context of the steadily deteriorating climatic situations. In summary, they involve (i) air cooling; (ii) increase in the relative air humidity; (iii) fresh air supply; (iv) air filtration; (v) noise absorption; and (vi) oxygen production (Bernatzky, 1982).

According to Giannas (2001) and Georgi and Dimitriou (2010), the attributes of green urban spaces that affect the urban microclimate positively are: (a) The high rate of absorption of solar radiation; (b) The low heat capacity and thermal conductivity compared to the structural materials of buildings and urban open spaces; (c) The reduction of air temperature via transpiration; (d) The decreased infrared radiation; (e) The reduction of wind speed around the soil; (f) The detention of dust and pollutants from the air; and (g) The sound protection that the presence of trees provides.

3.6. Urban Trees Models and Ecosystem Services

There is an increasing interest in measuring, modeling, and valuing ecosystem services, the benefits that nature provides to people. Ecosystem services (ES) include regulating services such as climate regulation, regulation of water flows, and water purification; provisioning services such as firewood, fisheries, and raw materials; and cultural services such as recreation, scenic values, spiritual values, or values that are important for cultural heritage or identity (Nowak, *et al*., 2013b) . ES are produced as a result of ecosystem processes and functions such as soil formation, nutrient cycling, and primary production. Scientists have developed biophysical process models to understand the function of forests, particularly to explicitly represent the complex interplay between the local environment and each individual in the community (Deutschman, *et al.*, 1997). Urban trees, however, are often excluded from many ecosystem models, as most aim to understand the interactions present in a natural forest environment and are often implemented at a spatial resolution not useful in diverse and complex urban environments. (Leichenko, 2011)

The need for models that incorporate explicit species information combined with information on changes through time and of carbon stocks is growing as more cities adopt policies that promote trees as ways to augment ecosystem services in the region (McPherson, *et al.,* 2005; Peters, *et al.,* 2010) . The impact of changing atmospheric chemistry and temperatures on trees will become increasingly important in the efforts of tree managers to estimate stock replacement and management strategies.

As urban and suburban areas grow, the area that needs to be excluded from process models designed for use in natural ecosystems becomes larger. In the Chesapeake Bay watershed, for example, the total amount of urban area in the Bay watershed increased by 14 percent, or 355,146 acres, between 1984 and 2006. Tree canopy decreased from 62.6 percent of the watershed in 1984 to 61.5 percent in 2006, a loss of 439,080 acres (Claggett, 2010). Also, urban land is projected to increase from 3.1 to 8.1 percent of the conterminous United States between 2000 and 2050 given urban growth patterns of the 1990s (Nowak & Walton, 2005). Tree cover in urban areas is also a significant resource covering 35.0 percent of urban areas in the United States (Nowak & Greenfield, 2012) . Forests in this region are fragments managed by private, federal, and state entities that have limited resources but extensive mandates to prevent urban tree loss. Tree species in these urban and suburban environments are often exotic and of varying ages. At the landscape and regional scales, species of trees composition is an important factor controlling the magnitude and seasonality of evapotranspiration, growth of biomass, and carbon sequestration and storage (Fan, *et al.*, 1998; Goetz & Prince, 1998).

3.7. i-Tree Eco Model

The i-Tree Eco model is an ecosystem service model for urban trees developed by the US Department of Agriculture (USDA) Forest Service for application in the U.S., and it has been adopted by the U.K., Australia, and Canada. The model is widely used to evaluate urban vegetation-induced environmental services, e.g., carbon storage and carbon sequestration air pollution reduction, noise reduction, oxygen production, and water runoff reduction, the effects of trees on energy consumed by buildings, and some disservices, such as the emission of biogenic volatile organic compounds (BVOCs).

i-Tree Eco requires information concerning the species and the stem diameter at breast height (DBH) as the input data. Additional data, including Species, Status, Stratum, Address, Land use criteria, total tree height, crown size (height to live top, height to the crown base, crown width, and percentage of crown missing), crown health (crown dieback percentage or condition), CLE(Crown Light Exposure), GPS coordinates, and competition status, can improve the model accuracy. Most of these input data are usually determined in the field by explicit visual inventories. This determination method is relatively easy to learn but remains subjective and prone to errors. For large areas, sample plots are required to be investigated and scaled to the whole region, leading to considerable uncertainties when the species distribution is non-homogeneous. (Westfall, 2015)

The main advantages of the i-Tree Eco model stem from the reliance on locally measured field data and standardized peer-reviewed procedures to measure urban forest regulating ecosystem services in cities (Nowak, *et al.*, 2008a). Favored by its status as an open-access model, it has been widely applied across the world (Currie & Bass., 2008; Dobbs, et al., 2011; Escobedo & Nowak., 2009; Liu & Li., 2012; Nowak, *et al.*, 2006; Nowak & Crane, 2002; Yang, *et al.*, 2005) . However, i-Tree Eco has some limitations that should be taken into account when analyzing its outcomes. First, the model is specially designed for US case studies and its application in other countries is subject to some restrictions, as stated in the user's manual. For instance, although the i-Tree Eco database has over 5000 species, it did not include some tree and shrub species sampled in Ethiopia, which then needed to be added to the database.

Another important limitation applying to i-Tree Eco and most dry deposition models is the level of uncertainty involved in the quantification of the air pollution removal rates due to the complexity of this process (Pataki, *et al.*, 2011) . For instance, some sources of uncertainty include non-homogeneity in the spatial distribution of air pollutants, particle re-suspension rates, transpiration rates, or soil moisture status (Manning, 2008). Though the model outputs match well with field measured deposition velocities for urban forests, the model analyzes average effects across a city, not local variations in removal caused by local meteorological and pollution differences. However, these local fine-scale input data are often missing from urban areas and empirical data on the actual uptake of pollutants by urban vegetation are still limited (Pataki, *et al.*, 2011; Seta, *et al.*, 2013), which makes more accurate modeling of this ecosystem service unfeasible at the moment. For a sensitivity analysis of the i-Tree Eco, deposition model sees (Hirabayashi, *et al.*, 2011).

Estimation errors in climate regulation service values include the uncertainty from using biomass equations and conversion factors as well as measurement errors (Nowak, *et al.,* 2008a). For example, there are limited biomass equations for tropical tree species (e.g., palm trees), some of them present in Ethiopia. Estimates of carbon sequestration and storage also include uncertainties from factors such as urban forests maintenance (e.g., the intensity of pruning), tree decay, or restricted rooting volumes, which are not accounted for in the model's estimations (Nowak, *et al.*, 2008a; Pataki, *et al.*, 2011).

Table 2: Strengths and weaknesses of I-Tree Eco

Strengths	**Weaknesses**
High resolution	Labor Intensive field data collection requirements
Species-Specific	Error estimation based only on sampling error
User-friendly	Simulates data only for one year
Incorporation of local meteorological and pollution data	Does not provide carbon allocation information.
Applicable to small and large regions	Takes time to add data into the database

CHAPTER THREE

MATERIALS AND METHODS

4.1. Study area

The study was conducted in Jimma city. Jimma city is located 352 km southwest of Addis Ababa. The total population of the city in 2007 was about 120,960, of whom 60,824 were men and 60,136 women (CSA, 2007). It has an area of 50.52 km^2; the elevation of the city is 1,780 m and the coordinate of the city is 7.6587 E and 36.8384 N latitude and longitude, respectively. The average temperature ranges from 20 - 30^{o}C. It is characterized by a long annual wet season from March to October. Temperatures at Jimma are with the daily mean staying between 20 °C and 25 °C year-round.

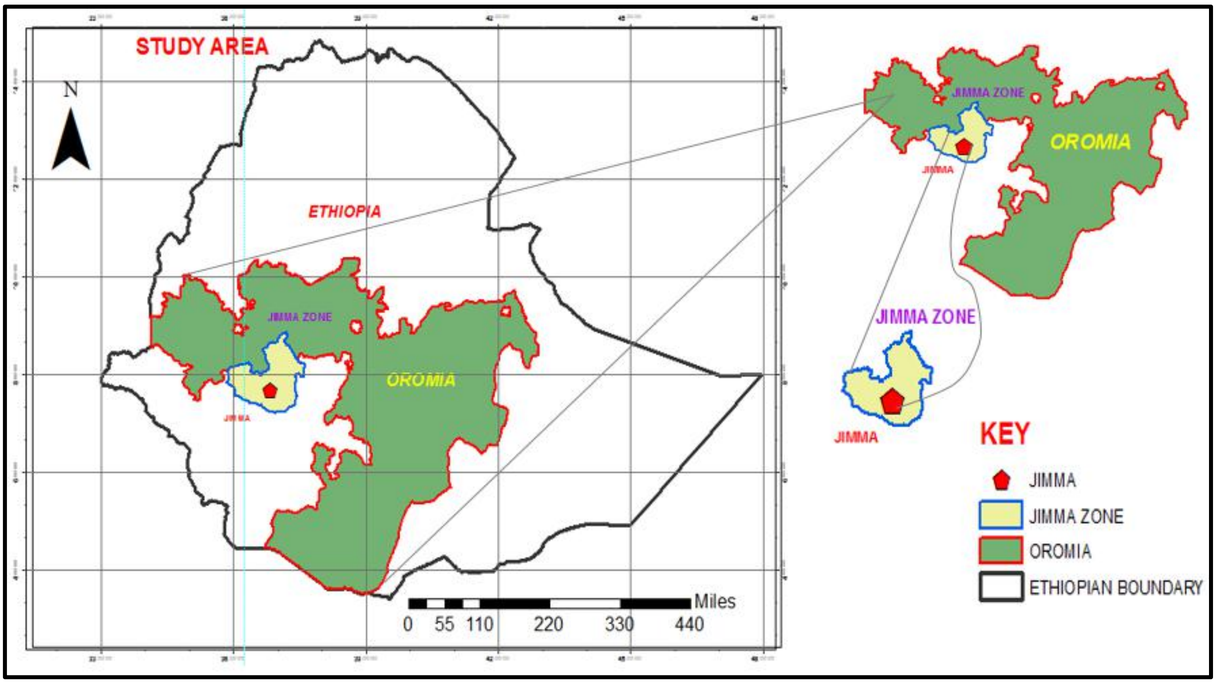

Figure 3: Map of the study area

4.2. Economic activities of the city

The city is known for its coffee production and handicraft production, but there are various other crops grown in the area. Such as avocado, mango, maize, sorghum, barley, pulses, root crops, and fruits. According to the report of the Finance and Economic Development Office of Jimma (2010), the main economic activities in the town are commerce and small-scale manufacturing enterprises. Jimma The local urban-rural exchange in the area has contributed to significant business activities in Jimma. The industries in the town are small scales and cottage industries like grain mils, wood and metal workshops, coffee hullers hollow block manufacturing, bakeries, and pastries. The dominant manufacturing activities that account for 70% of the total number of manufacturing enterprises in the town are grain mills and woodworks.

Jimma city industrial park, inaugurated in 2018, stretches over 150 ha, of which 75 ha has been inaugurated, and hosts nine manufacturing sheds. It was built by a Chinese construction company and focuses on attracting investors in the light manufacturing and agro-processing sectors.

4.3. The vegetation cover of Jimma city

In Jimma city, there are many green areas and street trees. The coverage of the vegetation in the city contains trees, grass, and shrubs. Jimma city has undistributed natural vegetation. The vegetation composition in Jimma city the areas of the study components are briefly described in appendix 1. The original vegetation of these cities has been modified by human activities grass and shrubs, most of which are secondary vegetation. The dominant tree species in the area that the data collected(public institution compounds like University compound, along streets or protected areas like along Awetu river bank, religious compounds like Orthodox church compound, etc)were *Grevillea robusta* (grevillea), *Casuarina cunninghamiana* (Australian beefwood), *Borassus aethiopum* (palm tree), *Spathodea campanulata* (tulip tree), and *Juniperus procera* (African juniper). The vegetation type which the community used for income is Coffee, ‘Chat’, and fruits trees such as avocado, banana, papaya, and orange. Tree species of the city are given in Figure 2.

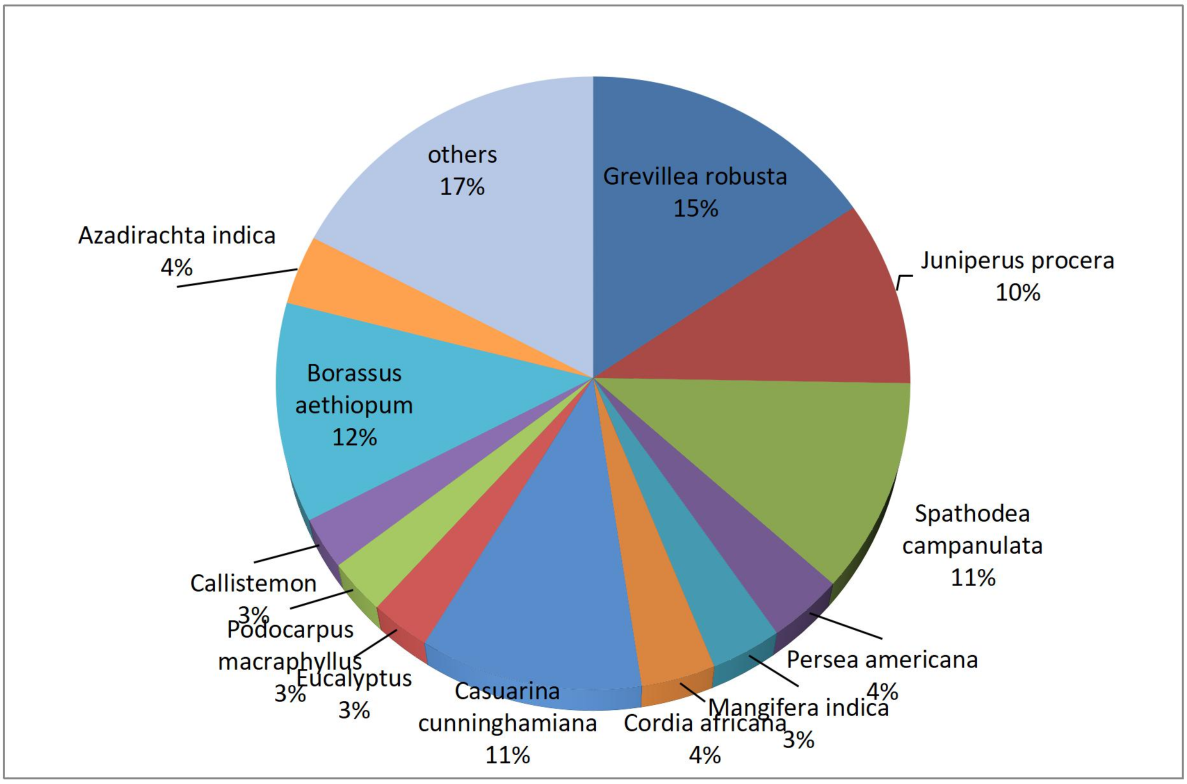

Figure 4: Sampled Tree species composition in Jimma city

4.4. Materials

In this study, a tape meter was used to measure tree height, crown height, and GPS (GARMIN 62S) was used to record the point locations of each of the sampled trees. The model i-Tree eco was used to model the ecosystem services of the trees to evaluate the benefits of these urban trees of Jimma city. Materials were used during data collection to get tree measurement data.

4.5. Methods

3.5.1. Field data collection

To evaluate the characteristics of ecosystem services provided by different stands, it is necessary to investigate the tree's main structural characteristics. Tree measurement data used in this study were obtained from field measurements following i-Tree Eco protocols and coordinated by the Sacramento Tree Foundation (Nowak and Crane, 2002). Tree measurement data used in this study were obtained from two thousand and seven hundred and thirty-eight trees. This Field data collection within plots includes land use, ground and tree cover, as well as individual-tree attributes such as species, status, stratum, address, land use, stem diameter at breast height at 1.37 m, tree height, height to base of the live crown, crown width, percent crown dieback, CLE, GPS coordinates, and distance and direction from buildings. This was done during the leaf-on season to properly assess tree canopies. Therefore, these typical data were sufficient since it was in agreement with i-Tree, (2010a) that states the sample size did not affect simulations of ecosystem service (i-Tree, 2010a).-

The height and crown diameter of these trees were measured using tape. The diameters of all sampled trees were measured at breast height 1.37 m above ground using a diameter tape. Both height and diameter at breast height (dbh) of these trees were used in allometric biomass equations to estimate tree biomass.

3.5.2. Allometric Biomass Equation

Both height and diameter at breast height (dbh) of these trees were used in allometric biomass equations adopted to analyze tree biomass. There is a great deal of uncertainty associated with the application of biomass equations across a population of trees in a city or urban region. The development and application of generalized equations is one approach to resolving the high variability and uncertainty associated with the application of these allometric equations in both urban and forested environments. Forest-based general equations have been developed for hardwoods, softwoods, and other types of trees, but no general equations have been developed using urban-based biomass equations (Aguaron & McPherson, 2012). In this study allometric equations, i-Tree Eco (formerly Urban Forest Effects, UFORE) were used to analyze parameters.

$$\text{Biomass} = a^*(\text{dbh})^{b}{}^*(\text{height})^{c} \quad \text{..}(1)$$

Where; dbh is the diameter at the breast height

(h) Height of the tree
a, b, and c are the model parameter estimated from empirical data

4.6. i-Tree Eco

Forest-based biomass equations and the 0.80 multipliers are used to calculate carbon storage and sequestration (Nowak *et al*. 2002). Hahn's (1984) volumetric formulas are applied to calculate biomass for deciduous trees greater than 94 cm dbh and coniferous trees greater than 122 cm dbh (Nowak *et al*. 2002). Most equations produce dry-weight biomass, some equations compute fresh-weight biomass and are multiplied by species or genus-specific conversion factors to convert to dry-weight biomass. When a formula is not available for a species, Eco uses the average of results from equations of the same genus. If no genus equations are found, it uses an average of results from all broadleaf or conifer equations (Aguaron & McPherson, 2012).

In this study carbon storage and sequestration, pollutant removal, and avoiding runoff were estimated using allometric biomass and growth equations. For 26 species, specific allometric equations have been developed for city trees,

To carry out national estimates of carbon storage and sequestration, the carbon data is standardized per unit of tree cover. Eco estimates standardized tree growth based on the number of frost-free days and adjusts this base value based on tree condition and location (CLE) to calculate sequestration (Nowak 1994; Nowak *et al*. 2008). Frost-free days are assumed to be 305 for Sacramento, and annual dbh growth ranges from 0.8 to 1.0 cm across all dbh classes. Average height growth is calculated based on formulas from Fleming (1988) and the specific dbh growth factor used for the tree. Growth rates are adjusted based on tree conditions as follows: fair to excellent condition – multiplied by 1 (no adjustment), poor condition – 0.76, critical condition – 0.42, dying – 0.15, dead – 0. These growth adjustment factors are based on percent crown dieback and the assumption that less than 25% crown dieback had a limited effect on dbh growth rates (Nowak *et al*. 2002). Crown light exposure (CLE) provides information on the number of sides of the tree receiving sunlight and ranges from 0 (no full light) to 5 (full light from top and 4 sides).

Gross sequestration is estimated from annual tree growth. Net sequestration incorporates CO_2 emissions due to decomposition after tree death. Emissions are based on the probability of the tree dying within the next year and being removed. Annual removal rates range across dbh classes from 1.4% to 1.9% for condition good to excellent, 3.3% for fair condition, 8.9% for poor condition, 13% for critical, 50% for dying, and 100% for dead (Hoehn 2010).

Model results were validated and verified against test data sets and field measurements. The model also translated ecological measurements such as kilograms of carbon sequestered per year into estimated economic savings, helping to link model information to the scientific and policy-making communities.

4.7. Data Analysis

Following the i-Tree Eco data collection protocol, field data such as tree information were collected via field survey to identify and measure the trees properly. To be more specific, information includes total height, diameter at breast height (DBH, 1.37 m from the base), canopy missing percentage, crown size, crown health condition, crown light exposure, etc. A total of 2738 trees were investigated. All the field data were imported from Excel files to Access files in the i-Tree Eco model to further analyze and assess vegetation structures of urban green spaces and associated ecosystem services.

i-Tree model is a software suite developed by the USDA Forest Services to help managers and researchers quantify urban forest structure and ecological functions (**www.itreetools.org**). i-Tree Eco (formerly called UFORE, Urban Forest Effects Model) is designed to utilize standardized field data from sample plots or complete inventories, together with local hourly air pollution and meteorological data to analyze a detailed characterization of urban forest structure and quantify numerous ecological services for cities. The i-Tree model has been widely used in case studies across the world to assess total ecosystem services for whole research areas without stratification or to compare one single stratum within a research area. This research represents an innovative application of i-Tree Eco, using a pre-stratified random sample. Pollution data including hourly concentrations of NO_2, SO_2, CO, O_3, PM_{10}, and $PM_{2.5}$ were obtained from the online national database.. weather data from 2019 were used in this study.

4.8. Dissemination of plan

The final result of this study will be submitted to Jimma University institute of technology, school of Civil and Environmental Engineering and the result will be disseminated to all concerning bodies and will be published in a national and international peer-reviewed journal.

CHAPTER FOUR

RESULTS AND DISCUSSION

5.1. Characteristics of the Jimma city urban Trees

To evaluate the characteristics of ecosystem services provided by different stands, it is necessary to investigate their main structural characteristics. From the urban trees in Jimma city, 2738 trees were covered in this study. This data collection includes land use, individual tree attributes of species, stem diameter, height, crown width. This was done during the leaf-on season to properly assess tree canopies. Therefore, these typical data were sufficient since it was in agreement with i-Tree, (2010a) that states the number sample size did not affect the assessment of ecosystem service (i-Tree, 2010a).

In this work, from these 2738 trees, a total of 26 tree species have been identified and their height, crown width, crown condition, coordinates, stratum, status, DBH were measured as indicated in chart 2. From these covered trees 62% of the whole stand was the top five species most widely dominated in Jimma city. It includes *Grevillea robusta (16%), Spatodea campanulata (12%), Borassus aethiopum(12%), Casuarina cunninghamiana (12%), and Juniperus procera(10%).*

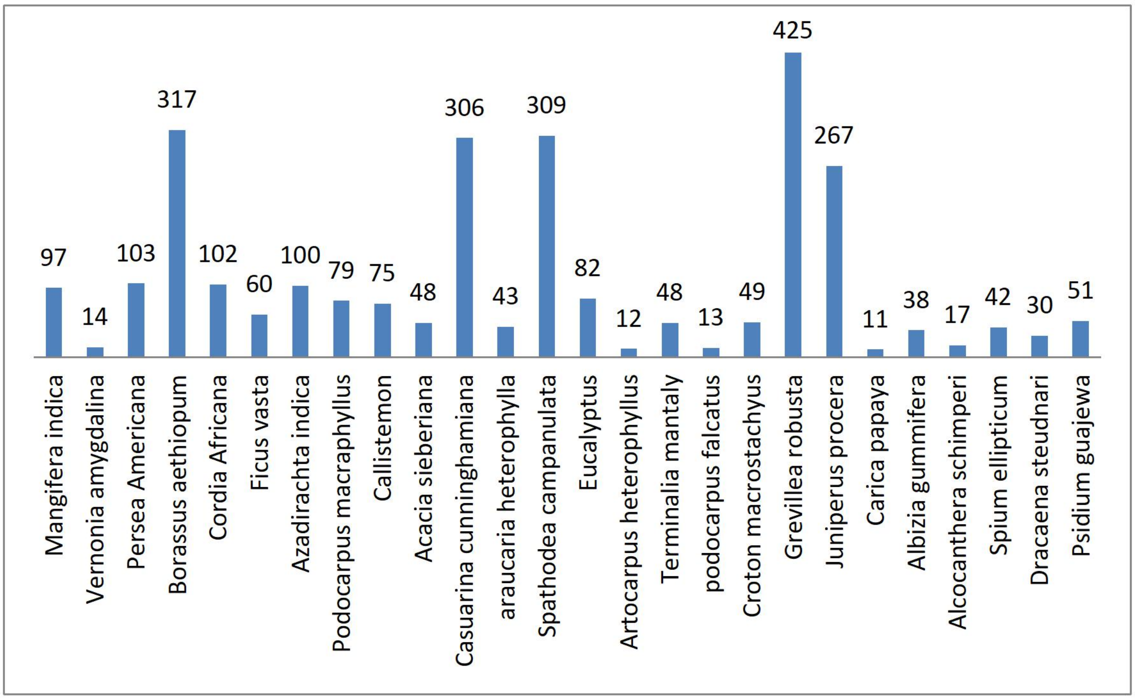

Figure 5: Species and relative frequency of collected data

5.2. Carbon Storage and Sequestration

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees.

The modeled gross carbon sequestration and storage of Jimma city trees were 16.5 and 414.27 thousand tons per year with an associated value of 2,769,027 and 69,540,662 USD respectively (Table 3).

Table 3: Carbon sequestered and stored annually

Description	**Carbon (kt) ± SE**	**CO (kt) ± SE**	**Value (USD) ± SE**
Sequestered	16.50 ± 0.53	60.48 ± 1.96	2,769,027 ± 89,718.58
Stored	414.27 ± 13.42	1,518.98 ± 49.22	69,540,662 ± 2,253,170

The carbon sequestration and storage capacity of Jimma city trees were greater than carbon sequestration and storage of Adama, Padua, Bolzano and Florence, Lisbon, Portugal, Zurich Switzerland, Munich city, New York, Chicago, and Jersey cities (Crema 2008; Paoletti et al. 2011; Wälchli 2012; Nowak and Crane, 2002). This difference in ecosystem services of the urban tree can be due to the high difference in the socio-economic activities in those cities which can contribute to different factors unproportionate to urban trees that badly harm the environment. In Jimma city, the socio-economic activity was lesser when compared with that of developed countries. This can minimize factors that negatively impact the environment. Furthermore, the socio-economic movements in Jimma city have a positive impact on the factors that changes climatic conditions in the city. Also, the majority of tree species in Jimma city and their urban forest structure were different from other cities in developed countries. This indicates that the climatic conditions, compositions of tree species, and urban forest structures can significantly affect carbon storage and sequestration. Thus, they directly affect the ecosystem service of urban trees.

Table 4: Carbon storage and sequestration potential of species of the Jimma city urban trees

Tree species	Carbon storage		Carbon sequestration	
	kT	%	kT	%
Borassus aethiopum	43.50	10.50	1.43	8.66
Casuarinas cunninghamiana	38.11	9.20	1.37	8.30
Grevillea robusta	64.63	15.60	2.91	17.62

Juniperus procera	32.31	7.80	1.02	6.16
Spathodea campanulata	46.81	11.30	3.48	21.12

5.3. Removal of Air Pollution

The sampled trees removed 463.24 tons of air polluting agents such as ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter greater than 2.5 microns (PM_{10}), particulate matter less than 2.5 microns ($PM_{2.5}$), and sulfur dioxide (SO_2) per year with an estimated associated value of 156,541 USD.

Air pollutants like CO, NO_2, O_3, $S0_2$, PM_{10}, and $PM_{2.5}$ of Jimma city removed by urban trees were 5.45, 29.71, 295.88, 18.72, 99.11, and 14.38 tons per year with an associated value of 456.25, 785.48, 40,905.83, 137.28, 29,696.58, and 84,559.83 USD respectively (Table 5). In Jimma city urban trees, such as *Borassus aethiopum, Grevillea robusta, Juniperus Procera, Spathodea campanulata, and Azadirachta indica* respectively have a higher potential to remove air pollution. (Appendix 2).

The result of air pollution of Jimma city was appeared lower than the result reported from the City of Baton Rouge which was 860 tons/year. The work of Nowak *et al*. (2014) recently analyzed the effects of urban forests on air quality and human health in the United States, they found that in highly vegetated areas, trees can improve air quality by as much as 16% (Kroeger *et.al* 2014). Baumgardner *et al*. (2012) conclude that around 2% of the ambient PM10 in Mexico City is removed from the study area. In a study carried out in the city of Barcelona (Spain), Barò *et al.* (2014) reported that urban forest services reduce PM_{10} air pollution by 2.66%. Moreover, in the Mediterranean city of Tel-Aviv, Cohen *et al.* (2014) observed that an urban park significantly mitigated nitrogen oxides (NOx) and PM_{10} concentrations, with a greater removal rate being observed in winter and increased troposphere ozone levels during summer.

This difference can be merged due to the numbers of trees data collected during the study, due to the high difference in the movements of socio-economic activities in those cities which can boost different factors unproportionate to urban trees that badly harm the environment. Additionally, this difference can be merged due to the difference in climatic conditions, different species composition, and urban forest structures in Jimma city. Those factors can affect the result of ecosystem service as stated in the study conducted by (Strohbach & Haase 2012).

Table 5: Air Pollution

Abbr.	Description	Amount (t) ±SE	Value (USD) ±SE
CO	Carbon Monoxide removed annually	5.45 ± 0.18	456.25 ±14.775
NO_2	Nitrogen Dioxide removed annually	29.71 ± 0.96	785.475 ±25.45
O_3	Ozone removed annually	295.88 ± 9.59	40,905.83 ±1,325.38
SO_2	Sulfur Dioxide removed annually	18.72 ± 0.61	137.275±4.45
PM_{10}	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	99.11±3.21	29,696.58±962.2
$PM_{2.5}$	Particulate Matter less than 2.5 microns removed annually	14.38±0.47	84,559.83 ±2739.8
Total		463.24 ± 15.01	156,541.2 ±5072.05

5.4. Hydrological benefits of the Urban Tree

Urban trees, however, are beneficial in reducing surface runoff. Trees intercept precipitation, while their root systems promote infiltration and storage in the soil. Table 6 indicates that the reducing surface runoff of Jimma city urban trees was 23.46 $m^3/m^2/yr$ with an associated value of 54.95 USD.

The result of reducing surface runoff of Jimma city was appeared lower than carbon assessment work conducted in cities such as Luohe city in China which is 51 $m^3/m^2/yr$. (Song, *et al.*, 2020) . Since various types of urban tree species had different runoff avoiding capacities This difference can be merged due to the high difference in the movements of socio-economic activities in those cities and the study in the luohe city was specifically considering the green area and parks. Additionally, this difference can be merged due to the difference in climatic conditions, different species composition, and urban forest structures in Jimma city. Those factors can affect the result of ecosystem service as stated in the study conducted by (Strohbach & Haase 2012).

Table 6: Hydrological benefits of trees in Jimma city

Benefit	Amount (Kgal) ±SE	Value (USD) ±SE
Avoided Runoff	6.25 ±0.20	54.95 ±1.78
Evaporation	515.93 ±16.72	N/A
Interception	518.81 ±16.81	N/A
Transpiration	698.13 ±22.62	N/A
Potential Evaporation	3,909.41 ±126.67	N/A
Potential Evapotranspiration	3,189.75 ±103.35	N/A

5.5. Comparison of Ecosystem Services of Jimma City Urban Trees

Table 7 indicates that the comparison of ecosystem services in some countries from 6 continents that assessed using i-Tree eco. The carbon storage and sequestration, runoff results from this study were difficult to assess in terms of accuracy and quantity to compare with other studies because of the use of different estimation methodologies, numbers of trees data collected during data collection, climatic condition, different species composition, and urban forest structures the high difference in the socio-economic activities in those cities which can contribute to different factors unproportionate to urban trees that badly harm the environment (Jo and McPherson 1995; Strohbach and Haase 2012). Due to these factors, the result from the different cities is so different.

Table 7: The comparison of ecosystem services of Jimma city urban trees

Location	Carbon storage(t)	Carbon sequestration(t)	Runoff reduction	Sources
Adama	116000	8291	29000	(Hingabu, et al., 2020)
Barcelona	113437	5187	-	(Lydia & Terradas, 2019)
Luohe	54329	4973	122636.8	(Peihao, *et al.*, 2020)
roanake	97508	2091	120000	(Kim, 2016)
scotlandville	88700	3888	121.20	(Zhu, et al., 2016)
Australia	100003	36068	236.355	(Sorada, et al., 2021)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The purpose of this study is to determine the ecosystem benefits of Jimma City urban trees using the i-Tree eco model. The investigation included 2738 trees. This stand is characterized by the high species richness of 26 species. Accordingly, the results of the i-Tree Eco model indicate that the Jimma city urban trees sequester 16.5kT carbon, stored 414.27kT of carbon, removed 463.27 tons of air pollutants such as CO, NO_2, O_3, SO_2, PM_{10}, and $PM_{2.5}$ per year, and avoided 23.46m^3/m^2/yr runoff. The monetary value of Jimma city urban trees in terms of carbon storage, carbon sequestration, air pollution removal, and avoided runoff was estimated to 69,540,662, 2,769,027, 156,541.2, and 54.95 USD/yr respectively.

The result from this study reveals that the urban trees are a significant and increasingly vital component of the urban environment that can impact human lives. Thus, urban trees have a positive effect on human health and well-being by improving air quality and reducing greenhouse gases, mainly through reducing air temperatures and energy use and through direct pollution removal and carbon sequestration. Understanding the value of an urban forest can give decision-makers a better understanding of urban tree management.

These results provide baseline information for management recommendations to maximize the ecological benefits provided by trees. By understanding the effects of urban trees on the atmospheric environment, urban forest managers and policymakers can decide on the policy and strategic planning of urban greening. Subsequently, it will help for designing appropriate and healthy urban tree structures in cities to improve air quality and consequently human health and well-being for current and future generations.

Jimma city's urban trees are a diverse and valuable part of the city's infrastructure. Although the benefits of urban trees are often unrecognized, they provide several valuable ecosystem services for the public, as enumerated here. Quantifying these services can help provide a basis for sound urban forest management and minimizing cost to benefit ratios, as well as providing citizens a better sense of the value of the natural resources where they live.

6.2. Recommendation

In terms of avoiding the above-mentioned problems, having ecology friendly cities, and increasing the life quality in urban areas, this process should be completed with the following substances:

- Involved more green area in urban design and planning
- Platforms should be provided to increase the number of urban trees
- Proper management of urban trees and green spaces may increase the environmental benefit of urban trees present in our city.
- The local governments should be in a coordinated manner with the experts of the related disciplinary.

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Appendixes

1. The attributes of tree species

No	Species	Frequency	percentage
1	Mangifera indica	97	3.542732
2	Vernonia amygdalina	14	0.511322
3	Persea Americana	103	3.76187
4	Borassus aethiopum	317	11.57779
5	Cordia Africana	102	3.725347
6	Ficus vasta	60	2.191381
7	Azadirachta indica	100	3.652301
8	Podocarpus macraphyllus	79	2.885318
9	Callistemon	75	2.739226
10	Acacia sieberiana	48	1.753104
11	Casuarina cunninghamiana	306	11.17604
12	araucaria heterophylla	43	1.570489
13	Spathodea campanulata	309	11.28561
14	Eucalyptus	82	2.994887
15	Artocarpus heterophyllus	12	0.438276
16	Terminalia mantaly	48	1.753104

17	podocarpus falcatus	13	0.474799
18	Croton macrostachyus	49	1.789627
19	Grevillea robusta	425	15.52228
20	Juniperus procera	267	9.751644
21	Carica papaya	11	0.401753
22	Albizia gummifera	38	1.387874
23	Alcocanthera schimperi	17	0.620891
24	Spium ellipticum	42	1.533966
25	Dracaena steudnari	30	1.09569
26	Psidium guajewa	51	1.862673
Total		2738	100

2. The relative ecosystem services of each tree species concerning carbon storage, sequestration, and air pollutant removal

No	Species	Carbon Storage	Carbon sequestration	Air Pollution Removal
1	Mangifera indica	14.75085	0.364165	24.75085
2	Vernonia amygdalina	2.128988	0.095859	4.289882
3	Persea Americana	15.66327	0.505247	19.66327
4	Borassus aethiopum	48.20638	2.070518	52.48638
5	Cordia Africana	15.5112	0.5984	25.5112

6	Ficus vasta	9.124235	0.310824	12.74235
7	Azadirachta indica	15.20706	0.584706	25.20706
8	Podocarpus macraphyllus	12.01358	0.440918	13.01358
9	Callistemon	11.40529	0.413529	11.40529
10	Acacia sieberiana	6.299388	0.228659	6.299388
11	Casuarina cunninghamiana	46.5336	2.0952	36.3336
12	araucaria heterophylla	6.539035	0.294424	7.749035
13	Spathodea campanulata	46.98981	2.015741	42.98981
14	Eucalyptus	11.46979	0.461459	13.69788
15	Artocarpus heterophyllus	1.824847	0.082165	3.624847
16	Terminalia mantaly	7.299388	0.228659	11.99388
17	podocarpus falcatus	1.976918	0.089012	2.769176
18	Croton macrostachyus	7.451459	0.335506	10.84146
19	Grevillea robusta	64.63	2.81	44.63
20	Juniperus procera	40.60285	1.428165	43.60285
21	Carica papaya	1.672776	0.075318	4.872776
22	Albizia gummifera	5.778682	0.210188	7.486824
23	Alcocanthera schimperi	2.5852	0.1164	3.2852
24	Spium ellipticum	6.386966	0.217647	9.636966
25	Dracaena steudnari	4.562118	0.205412	9.562118
26	Psidium guajewa	7.6556	0.2492	14.6556