MEASURING THE CLIMATE CHANGE MITIGATION POTENTIAL OF FORESTS AND TOF (TREE OUTSIDE FOREST) SYSTEMS IN THRISSUR

By

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(2012-20-111)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Measuring the climate change mitigation potential of forests and TOF (Trees Outside Forest) systems in Thrissur"** is a bona fide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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ABBREVIATIONS

AGB	**Above Ground Biomass**
AGC	**Above Ground Carbon**
BGB	**Below Ground Biomass**
BGC	**Below Ground Carbon**
CDM	**Clean Development Mechanism**
CO_2eq	**Carbon dioxide equivalent**
DBH	**Diameter at Breast Height**
FAO	**Food and Agriculture Organization**
FCC	**False Colour Composite**
FSI	**Forest Survey of India**
GBH	**Girth at Breast Height**
Gt	**Giga tons**
IPCC	**Inter-governmental Panel on Climate Change**
MDF	**Moist deciduous forests**
Pg	**Peta gram**
ppm	**parts per million**
REDD	**Reducing emissions from deforestation and forest degradation**
SD	**Standard deviation**
SOC	**Soil organic carbon**
Tg	**Tera gram**
TOF	**Trees Outside Forests**
UNFCCC	**United Nations Framework Convention on Climate Change**

CHAPTER I

INTRODUCTION

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. The atmospheric concentration of carbon dioxide was 391 ppm in 2011(IPCC, 2014). The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions (IPCC, 2014). Forest degradation, together with deforestation, are placed second to burning of fossil fuels in terms of contributing to greenhouse gas (GHG) emissions; a key driver of global climate change.

The fifth assessment report of the IPCC states that the amount of anthropogenic greenhouse gas emissions has increased since the pre-industrial era and that this increase is driven in particular by economic and population growth. The level of greenhouse gases in the atmosphere is hence higher today than ever before. Emissions of carbon dioxide from fossil fuel combustion and industrial processes contributed about 78% of the total increase in greenhouse gas emissions between 1970 and 2010. The effects of all greenhouse gases and other anthropogenic drivers are extremely likely to have been the dominant cause of the observed global warming since the mid-20th century (IPCC, 2014).

Forests and trees play a role in the conservation of ecosystems, in maintaining quality of water, and in preventing or reducing the severity of floods, avalanches, erosion, and drought. Forests provide a wide range of economic and social benefits, such as employment, forest products, and protection of sites of cultural value (FAO, 2007). However, forests also influence climate and the climate change process mainly by effecting the changes in the quantum of carbon dioxide

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in the atmosphere. They absorb CO_2 from atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as "carbon sinks". Carbon is released back into the atmosphere when forests are cleared or burned. Forests acting as sinks are considered to moderate the global climate. Forests and vegetation constitute a sink for carbon dioxide as they grow. A sink is a reservoir or a stock that takes up a chemical element or compound from another part of its natural cycle (IPCC, 2015). Humans can add to the carbon sink through forest management changes in the form of prolonged rotation periods, intensive forest management, reforestation and conversion of land into forestry.

The role of trees and plantation in stabilizing CO_2 levels and increasing carbon sink potential of soils have taken considerable scientific attention in the recent years The number of trees growing outside the boundary of defined forests play an important role in reducing emissions and enhancing the storage of carbon. Definition of TOF given by FAO in Bellefontaine et al. (2002) reads: "Trees outside forests refer to trees on land not defined as Forest and Other Wooded Land". In India all trees growing outside recorded forest areas are defined as trees outside forests. The recorded forest area means reserve, protected or unclassified forest. Trees growing in private lands in rural/ urban areas and in government non forest land (urban areas, parks garden, canal road etc.).

Assessment of Trees outside forests (TOF) is recognized as a pivotal theme, in sustainable natural resource management, due to their role in offering variety of goods, such as timber, fruits and fodder as well as services like water, carbon, biodiversity. Forest Conservation efforts involving reduction of deforestation and degradation may have to increasingly rely on alternatives provided by TOF in catering to economic demands in forest. Trees outside forests (TOF) in India, mainly growing on private land, are the main source of wood in the country for industry and domestic wood fuel. The current growing stock is about 1.616 billion m3. The concept of "Trees outside Forests" -TOF- emerged in 1995 to designate trees growing outside the forest and not belonging to Forest or Other Wooded Land.

In India, the assessment of carbon pools in forests and other lands and net balance due to various land cover or land use changes is a subject of much debate and uncertainty. Reducing deforestation is the dominant mitigation strategy for tropics. In short term, the carbon mitigation benefits of reducing deforestation are greater than the benefits of afforestation. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions (IPCC, 2014).Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 Gt CO_2 eq/year which is the major reason for more than half of the observed increase in global average surface temperature from 1951 to 2010 (IPCC, 2014).

In Kerala woody trees are incorporated in agro forestry systems, home garden, silvipastoral systems, and as monoculture plantations. These contribute to the timber and wood requirement of the society along with fuel wood requirement of households. According to FSI (2011) total quantity of timber used in household is around 18.5 million cubic meters and fuel wood used per year is 14.543 million tones which is building pressure on the forestry sector. Woody ecosystems on the degraded lands as well as with agroforestry systems will thus enhance as a carbon sink and in time will reduce the pressure on existing forest there by reducing emission from forest degradation. Expanding the size of the global terrestrial sink is one strategy to curb CO_2 build-up in the atmosphere.

Biomass governs the potential carbon emission that could be released to the atmosphere due to deforestation, and regional biomass changes have been associated with important outcomes in ecosystem functional characteristics and climate changes. The active and important role vegetation and soil play in the global carbon cycle and global climate change is now internationally recognized. Vegetation and soil can act as both a net source and a net sink of greenhouse gas (GHG), depending on how the land is managed. Alterations in land use management techniques that result in changes to net GHG emissions are now a significant component to the regulatory and voluntary actions taking place globally to combat climate change.

Due to large uncertainties in tree and forest C estimates, it is unclear exactly how much tropícal deforestation, degradation, and sequestration affect global carbon cycling, how forest conservation may slow the rate of climate change, and how much each hectare is valued in the carbon market. The choice of allometric model used to calculate aboveground biomass (AGB) from forest inventory data is one of the key sources of uncertainty (Chave et al. 2004). Another key issue causing uncertainty in tropical biomass estimates is the poor sampling across geographic and environmental space in the database used to create both regional and pantropical allometric equations (Houghton et al. 2009).

Reporting to international organizations and international conventions emerged over the last half century is another important reason for assessing and monitoring tree and forest resources at the national level. Climate change in terms of higher GHG concentrations and changes in temperature and precipitation levels have the strongest and most comprehensive impacts on the natural system (IPCC, 2014). The effects on the environment in turn have consequences for humans. The negative effects for people, according to the most recent IPCC report (2014), are essentially related to access to water, food production, health and use of land and the environment.

Urgent and decisive action to curb the extent of deforestation and forest degradation, promoting the enhancement of carbon stocks through regeneration and afforestation, and better accounting of CO_2 sources and sinks is important.

CHAPTER II

REVIEW OF LITERATURE

2.1 CLIMATE AND CURRENT SCENARIO

Climate change is the greatest ecological, social and economic challenge of our time. It can be mainly owed to the global warming phenomena that has been observed for the last two centuries. The effect of the increased anthropogenic greenhouse gas concentrations is the main reason for the observed rise in global temperature. Global warming is one of the most coveted issues that humans face today and it is mainly attributed to the increasing greenhouse gas concentration post the industrial era. The main characteristics of climate change include increase in average global temperature, changes in cloud cover, precipitation, melting of ice caps and glaciers and increases in ocean temperatures and ocean acidity, due to seawater absorbing heat and carbon dioxide from the atmosphere (IPCC, 2007). The effects of increasing temperature across the globe is detrimental to different ecosystems and the biodiversity. The erratic nature of precipitation and ever increasing number of extreme events such as hurricane, tropical cyclones, flash floods, cloudburst etc. are the result of changing climatic regimes. There is a slew of international treaties and policies put to pen, and different consensus reached in international conferences mainly to curb the effects of global warming, greenhouse gas emissions.

The historic Paris Agreement, and the adoption of the Sustainable Development Goals for the next 15 years in 2015, are two landmark events that will have a direct impact on the global perception of changing climate. Land use and land cover change mainly owed to the unprecedented hike in the world population are exerting huge pressure on the forests and tree resources across the world. Tropical forests are the most vulnerable in this sense because the population is mainly concentrated in the tropical regions of the globe. The emissions related to the degradation of the forests is only second to the fossil fuel emissions. So land cover changes have direct implication in determining the changing climate at least in the regional scale. Intergovernmental Panel on Climate Change (IPCC) in its fifth

Assessment Report (AR 5) predict that the average global temperatures could increase between 1.4 and 5.8 °C by the year 2100 (IPCC, 2014). Changes resulting from global warming may include rising sea levels due to the melting of the polar ice caps, as well as an increase in occurrence and severity of storms and other severe weather events.

2.2 CARBON AND ROLE OF GHG'S

Carbon is one of the most abundant chemical elements on Earth and is present in all living things. It is also a naturally occurring component of Earth's atmosphere. Carbon is found in large quantities in the leaves, branches, stems, and roots of trees. CO_2 (54.7%) is the most important greenhouse gas that is being affected by human activities among such other greenhouse gases in the atmosphere such as methane (30%), nitrous oxide (4.9%), fluorinated gases (0.6%) and other gases (9.8%) (IPCC, 2007). The terrestrial carbon cycle is a highly dynamic system that includes several storage pools, such as vegetation, soil, debris, black carbon residue from fires, harvested products etc. which can be characterized by their turnover time (Schulze *et al.*, 2000).

The carbon cycle is one of the Earth's major biogeochemical cycles, where vast amounts of carbon continuously cycle between the Earth's atmosphere, oceans and land surfaces in both short-term and long-term cycles (IPCC, 2015). The level of atmospheric carbon is also influenced by man, in particular through the burning of fossil fuels, but also as a result of certain chemical reactions e.g. manufacturing of cement and certain metals. These man-made emissions are termed anthropogenic. Higher concentrations of GHGs in the atmosphere lead to changes in temperature and precipitation, which may have far-reaching consequences for the environment and hence for human well-being Forest clearing, including deforestation and forest degradation, and the burning of solid waste, wood and wood products are all sources of atmospheric carbon dioxide. With continuing increases in GHGs, among which carbon dioxide (CO_2) is the largest contributor, the future of mankind is threatened.

Warming of the climate system is obvious and is unprecedented over decades. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. Of the last 1400 years, the period from 1983 to 2012 was likely the warmest 30-year period in the Northern hemisphere (IPCC, 2014). A warming of 0.85°C is observed over the period, 1880 to 2012. Cumulative anthropogenic CO_2, emissions to the atmosphere were 2040 ± 310 Gt CO_2 between 1750 and 2011. While about 60 percent of these emissions have been removed from atmosphere and stored on land (in plant and soils) and in the ocean, the rest remained in the atmosphere (880 ± 35 Gt CO_2). Oceanic uptake of CO_2 over past decades has resulted in acidification of ocean (26% increase in acidity). About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the period, 1970 to 2010 with larger absolute increases in last 15 years, despite a growing number of climate change mitigation policies. It was found that global anthropogenic emissions have reached 49 ± 4.5 Gt CO2 eq/ year in 2010. The global mean surface temperature change for the period, 2016–2035 relative to 1986–2005 is expected to be in the range of 0.3°C to 0.7°C, which depends on committed warming caused by past, as well as future anthropogenic emissions (IPCC, 2014).

Carbon dioxide is the GHG that constitutes the largest contributor to climate change (IPCC, 2014). It occurs naturally in the atmosphere through plant and animal decay as microorganisms break down the dead material. Other naturally occurring sources include forest fires and volcanoes. The level of atmospheric carbon is also influenced by man, in particular through the burning of fossil fuels, but also as a result of certain chemical reactions e.g. manufacturing of cement and certain metals. These man-made emissions are termed anthropogenic. Forest clearing, including deforestation and forest degradation, and the burning of solid waste, wood and wood products are all sources of atmospheric carbon dioxide.

The fifth assessment report of the IPCC states that the amount of anthropogenic greenhouse gas emissions has increased since the pre-industrial era and that this increase is driven in particular by economic and population growth.

The level of greenhouse gases in the atmosphere is hence higher today than ever before. Emissions of carbon dioxide from fossil fuel combustion and industrial processes contributed about 78% of the total increase in greenhouse gas emissions between 1970 and 2010. The effects of all greenhouse gases and other anthropogenic drivers are extremely likely to have been the dominant cause of the observed global warming since the mid-20th century (IPCC, 2014).

Climate change in terms of higher GHG concentrations and changes in temperature and precipitation levels have the strongest and most comprehensive impacts on the natural system (IPCC, 2014). The effects on the environment in turn have consequences for humans. The negative effects for people, according to the most recent IPCC report (2014), are essentially related to access to water, food production, health and use of land and the environment. There are large variations in these effects across the globe.

The 1997 Kyoto Protocol is framed on the principle that CO_2 from the air can be sequestered in the soil and biomass and is a practical way of mitigating climate change.

2.3 FORESTS AND ITS IMPLICATIONS ON CLIMATE CHANGE

Forests provide a wide range of goods and services. Goods include timber, fuelwood, as well as food products (berries, mushrooms, etc.) and fodder. As regards important services, forests and trees play a role in the conservation of ecosystems, in maintaining quality of water, and in preventing or reducing the severity of floods, avalanches, erosion, and drought. Forests provide a wide range of economic and social benefits, such as employment, forest products, and protection of sites of cultural value (FAO, 2006). The capacity of forests to sequester carbon varies with species, site, spacing, climate and age.

Forests, like other ecosystems, are affected by climate change. The impacts due to climate change may be negative in some areas, and positive in others. However, forests also influence climate and the climate change process mainly by effecting the changes in the quantum of carbon dioxide in the atmosphere. They absorb CO_2 from atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as "carbon sinks". Carbon is released back into the atmosphere when forests are cleared or burned. Forests by acting as sinks are considered to moderate the global climate. Overall, the world's forest ecosystems are estimated to store more carbon than the entire atmosphere (FAO, 2006).

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change. When forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (CO_2). Tropical deforestation is estimated to have released of the order of 1–2 billion tons of carbon per year during the 1990s, roughly 15–25% of annual global greenhouse gas emissions (Malhi and Grace 2000, Fearnside and Laurance2003, 2004, Houghton 2005). The largest source of greenhouse gas emissions in most tropical countries is from deforestation and forest degradation. In Africa, for example, deforestation accounts for nearly 70% of total emissions (FAO 2005). Moreover, clearing tropical forests also destroys globally important carbon sinks that are currently sequestering CO_2 from the atmosphere and are critical to future climate stabilisation (Stephens *et al.,* 2007).

Land use, land use change and forestry particularly deforestation contribute to greenhouse gas emission (UNFCCC, 2016a) and livelihoods play major role in driving deforestation and forest degradation. It is unique to country's national circumstances, capacities and capabilities (UNFCCC, 2016b). On an average, about 28 percent of anthropogenic CO_2 emissions were collected and stored by the land based sinks between 2002 and 2011 (Peters *et al.,* 2012). Carbon dioxide removal by increasing tree cover is recommended as a cost-effective method and plays a major role in many mitigation scenarios where it reduces net emissions and enhances carbon sinks in land-based sectors (IPCC, 2014).

The forests of tropical America, Africa, and Asia represent enormous storehouses of carbon yet they are being cleared at a rate of nearly 8.0 million hectares per year. Tropical forests play an important role in the global carbon (C) cycle based both in terms of regulating the carbon flux between the biosphere and the atmosphere, and in terms of the amount of carbon stored. India ranks tenth amongst the most forested nations of the world (FAO, 2010) and has stabilized its forest and tree cover which is about 24.01 per cent of its total geographical area (FSI, 2013).Indian forests are a major tropical forest ecosystem constituting nearly 67.83 million ha (Mha), 20.66% of the geographical area of country (329 Mha; FSI 2003). Indian forests are known to be one of the richest in terms of vegetation types and species diversity.

To cover the basic needs of the population, forests in India have been exploited not only for timber, fuel and fodder extraction but have also been subjected to overgrazing, shifting cultivation and conversion to non-forestry purposes such as roads, industries, mining, irrigation, hydroelectric projects, transmission lines etc. there by contributing to deforestation and degradation. It is estimated that between 1950 and 1980, the forest area converted for other purposes was 4.3 million ha in total, with an annual rate of 0.14 million ha (Lal 1989).Forests and vegetation constitute a sink for carbon dioxide as they grow. A sink is a reservoir or a stock that takes up a chemical element or compound from another part of its natural cycle (IPCC, 2015). The carbon cycle is one of the Earth's major biogeochemical cycles, where vast amounts of carbon continuously cycle between the Earth's atmosphere, oceans and land surfaces in both short-term and long-term cycles (IPCC, 2015).

Tropical forests comprise 86% of the forested area in India, in which 53% is dry deciduous, 37% moist-deciduous and the rest is wet-evergreen or semi evergreen forests (Chathurvedi *et al.*, 2011).Forests, which are the main component of so-called ''land sinks,'' play a vital role in the global carbon cycle through the absorption of 2.9 6 0.8 Pg of carbon (C) per year (in the period 2004–2013), thus mitigating climate change related to the increase of anthropogenic carbon dioxide (CO_2) in the atmosphere (Le Que´re´ *et al.*, 2014). Abstract Forests can contribute to the reduction of carbon emissions by storing carbon in standing biomass or in products made of wood. Alternatively, harvested biomass can be used as bioenergy and replace fossil fuels.

2.4 TOF AND THE GROWING IMPORTANCE

The concept of "Trees Outside Forests" first appeared in 1995 to indicate trees growing outside the forest and not belonging to forest or other wooded land (Bellefontaine *et al.,* 2002). Trees outside forests (TOF) play important roles in national economies, ecosystem services, and international efforts for mitigating climate warming. In recent decades, trees outside forests (TOF) have begun to attract more and more attention with growing acknowledgements of their potential economic importance and political interest in their environmental services (de Foresta *et al*., 2013). Improving our understanding of the status and dynamics of all tree resources, including TOF for the better evaluation of trees and the services they provide is a major challenge (FAO, 2001; de Foresta *et al.,* 2013). The trees outside forests in various models of agroforestry, farm forestry and social forestry are contributing a major portion of pulp and small timber requirements in India (FSI, 2001). For instance, in Kerala, TOF are the major source of local wood production, accounting for 90.1% of the timber production and meeting 89.2% of local fuelwood supply during the year 2000–2001 (Krishnankutty *et al*., 2008).

Zomer *et al.* (2009) made the first global-scale TOF assessment, and concluded that agroforestry is a significant feature of agriculture in all regions, with 46% of the total agricultural land (about 1×109 ha) having more than 10% tree cover. The growing importance of trees outside forests is gaining attention for their role in carbon sequestration, biodiversity conservation, anti desertification, and poverty alleviation (Nair, 2011; de Foresta et al., 2013).

The increasing forest cover loss and its fragmentation on one hand, the need to conserve remnants of representative forest ecosystems and the increasing demand of forest products in developing countries (Mateo 1998, Rodríguez 1998, Salas 1998) on the other hand, make the development of innovative sustainable management tools imperative for other less studied tropical forest resources such as trees outside forest. Acting as both sources and sink of GHGs, trees can contribute to an extent to the mitigation of climate change. In terms of atmospheric carbon reduction, trees outside forest offer the double benefit of direct carbon storage and stability of natural ecosystem with increased recycling of nutrient along with maintenance of climatic conditions by the biogeochemical processes (B. L. Chavan, G. B. Rasal, 2010).

Trees Outside Forests (TOF) play an important role in carbon cycle regulation, since they are large pools of carbon as well as potential carbon sinks and sources to the atmosphere (Singh and Chand, 2012). The area occupied by TOF, the species composition, the volume, as well as specific characteristics such as the geometry and spatial distribution, can change depending of the biophysical, socioeconomic and political characteristics of a particular landscape.

TOF include trees in cities, on farms, along roads, canals, railway tracks and in many other locations which by definition are not forests. Trees outside forests have been making a major contribution in meeting the needs of timber and fuel wood. The total growing stock of wood in India is estimated to be 6,414 million m3 comprising 4,782 million m^3 inside forests and 1,632 million m^3 outside recorded forest area (FSI 2003). Maximum growing stock in TOF is observed in Andhra Pradesh followed by Maharashtra and Gujarat. Most of the studies conducted so far have not considered the role of trees outside forests in carbon balance. Trees outside forests store about 934 Tg C or 4 Mg C ha^{-1}, in addition, to the Indian forests.

Trees outside forests, a combination of perennials and annuals, provide multiple benefits such as fuel, fodder, small timber, etc., which are the common tangible benefits, while soil fertility improvement, biodiversity enhancement, carbon sequestration, environmental amelioration, etc. are intangible benefits. Trees on agricultural landscape are commonly considered to be carbon sinks (Dixon 1995; Swami and Puri 2005; Sileshi et al. 2007; Murthy *et al.*, 2013) because the integration of trees results in greater CO_2 sequestration from the atmosphere through the process of photosynthesis and lead to an enhancement of carbon storage in tree components for long term storage and soil including below ground biomass.

2.5 DIFFERENT CARBON POOLS WITHIN AN ECOSYSTEM

According to IPCC the main carbon pools in tropical forest ecosystems are the living biomass of trees and understory vegetation and the dead mass of litter, woody debris and soil organic matter.

2.5.1 Above ground biomass

The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation. The most direct way to quantify the carbon stored in aboveground living forest biomass is to harvest all trees in a known area, dry them and weigh the biomass. The dry biomass can be converted to carbon content by taking half of the biomass weight (carbon content ≈50% of biomass; Westlake 1966). While this method is accurate for a particular location, it is prohibitively time-consuming, expensive, destructive and impractical for country-level analysis (Gibbs *et al.,* 2007).

Accurately quantifying the aboveground carbon stocks of tropical forests is essential to understand the role of these ecosystems in the global carbon cycle and to successfully implement payments for ecosystem services, such as those proposed in the United Nations Collaborative Program on Reducing Emissions from Deforestation or Degradation (REDD/REDD) (Ebeling and Yasue 2008). Tropical forests store large, but still remarkably uncertain, quantities of carbon (C) in living biomass, with recent estimates ranging from 175 to 340 Pg C (Houghton *et al.*, 2009; FAO, 2010; Pan *et al.,* 2011; Saatchi *et al.,* 2011; Baccini *et al.*, 2012; Feldpausch *et al.*, 2012).

2.5.2 Below ground biomass

Below-ground biomass is defined as the entire biomass of all live roots, although fine roots less than 2 mm in diameter are often excluded because these cannot easily be distinguished empirically from soil organic matter. Below-ground biomass is an important carbon pool for many vegetation types and land-use systems and accounts for about 20% to 26% (Cairns *et al.*, 1997) of the total biomass. Below-ground biomass accumulation is linked to the dynamics of aboveground biomass. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface. Revegetation of degraded land leads to continual accumulation of below-ground biomass whereas any disturbance to topsoil leads to loss of below-ground biomass. Since below-ground biomass could account for 20– 26% of the total biomass, it is important to estimate this pool for most carbon mitigation as well as other land based projects.

2.5.3 Deadwood carbon

Coarse woody debris (CWD), comprising standing dead trees and fallen trunks and branches, is important for various ecological functions in tropical forest ecosystems. Dead wood provides a habitat for wildlife such as wood-feeding termites, cavity-nesting birds, saproxylic beetles and bats. Carbon stored in the dead wood of a forest stand is one of the five carbon pools identified by the Intergovernmental Panel on Climate Change that should be measured and monitored for carbon book-keeping (IPCC, 2006). Inclusion of dead organic matter pool makes the estimated changes in total carbon stock more accurate. Most of the biomass not harvested or burnt is added to the deadwood, litter and soil carbon pools. The dynamics of dead organic matter vary with the type of forest or plantation as well as with the purpose behind protecting a forest or raising a new forest. In fuelwood plantations or community forestry projects, the woody part of the dead organic matter is likely to be removed and used as fuelwood. However, in the case of avoided deforestation projects involving protection of forests, dead organic matter accumulates on the forest floor.

2.5.4 Dead mass of litter

The changes in the litter carbon (C) pool have important implications for global carbon budgets and carbon emissions reduction targets and negotiations. Litter accounts for an estimated 5% of all forest ecosystem carbon stocks worldwide. Given the cost and time required to measure litter attributes, many of the signatory nations to the United Nations Framework Convention on Climate Change report estimates of litter carbon stocks and stock changes using default values from the Intergovernmental Panel on Climate Change or country-specific models. Intergovernmental Panel on Climate Change defaults and country-specific models used to estimate litter carbon in temperate forest ecosystems may grossly overestimate the contribution of this pool in national carbon budgets.

2.5.5 Soil organic carbon

Soil carbon is the largest terrestrial carbon pool and it plays an important role in the global carbon cycle. Globally, forest ecosystems contained 652 billion tons of carbon stocks in 2010, with 292 billion tons of carbon stocks in soil (FAO, 2010). Soil organic matter contains the largest terrestrial reservoir of carbon in the biological global carbon cycle and plays a major role in the control of carbon dioxide levels in the atmosphere (Follett *et al.*, 2007). The total soil organic carbon stocks estimated for forests of India was 4327.36 million tons in 1995 and 4680.25 million tons in 2007.

CHAPTER III

MATERIALS AND METHODS

3.1 STUDY AREA

Thrissur District (10° 46' to 10° 7' N and 75° 57' to 76° 55' E) is the central part of Kerala State, India, spanning an area of about 3,032 km^2. The District has a tropical humid climate and plentiful seasonal rainfall. The dry period extends for nearly four months, which starts from December and ends by March/April. The high rainfall supports a wide range of vegetation types. Highest rainfall is obtained in the months of June and July. Temperature varies from 23°C to 31°C. Different varieties of soil namely laterite, sandy loam, alluvial, black and clayey are found.

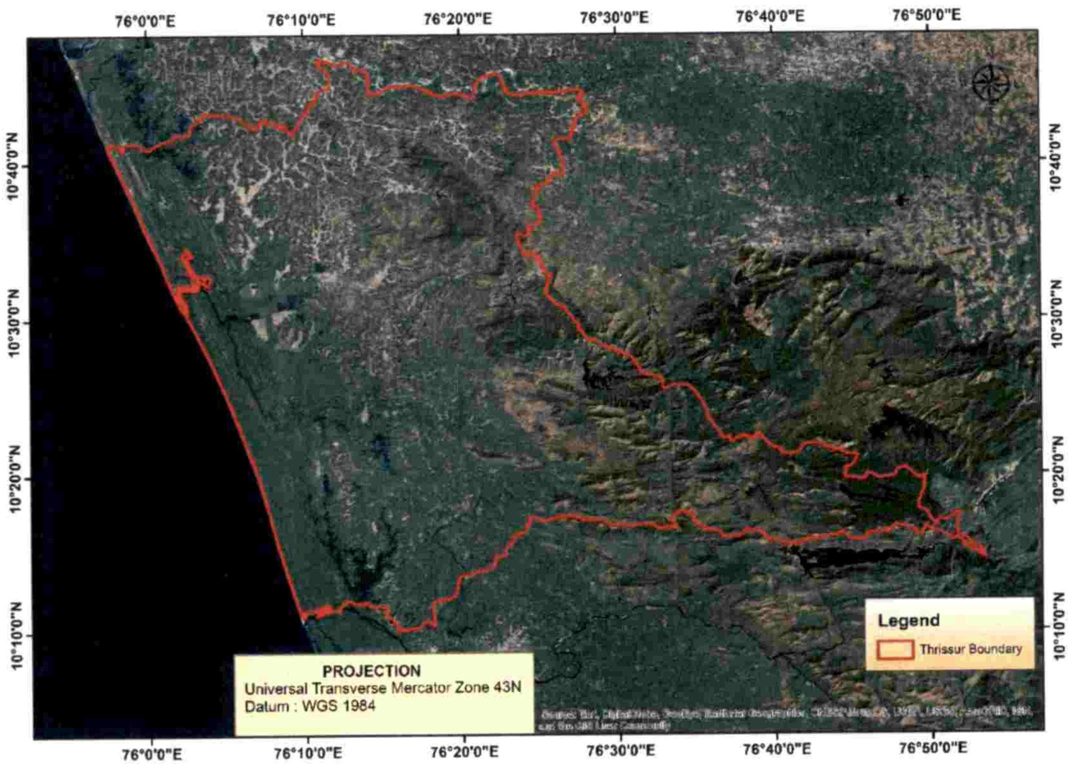

Figure 1. Location map of the study area

3.1.1 Vegetation types

Natural forest: Based on the Revised Forest Types of India by Champion and Seth (1968), the following types of forests are seen in Thrissur District.

1. Tropical wet evergreen forests

2. Tropical semi-evergreen forests

3. Tropical moist deciduous forests

TOF systems include homesteads with coconut as main crop in coastal areas plantations comprising coconut, rubber, cashew, teak, mango etc. and home gardens with 2 or 3 crops as mixed crops in comparably high elevation areas.

3.2 FIELD WORK AND DATA COLLECTION

The field biomass data was collected as per the Forest Survey of India protocol. A total of 40 sample plots in the study area were inventoried during February to June 2017. There are 26 plots in heterogeneous landscapes, 10 plots in moist deciduous forests and 4 plots in evergreen forests. The samples were a size of 0.1ha (31.62m × 31.62 m).

3.2.1 Layout of plot

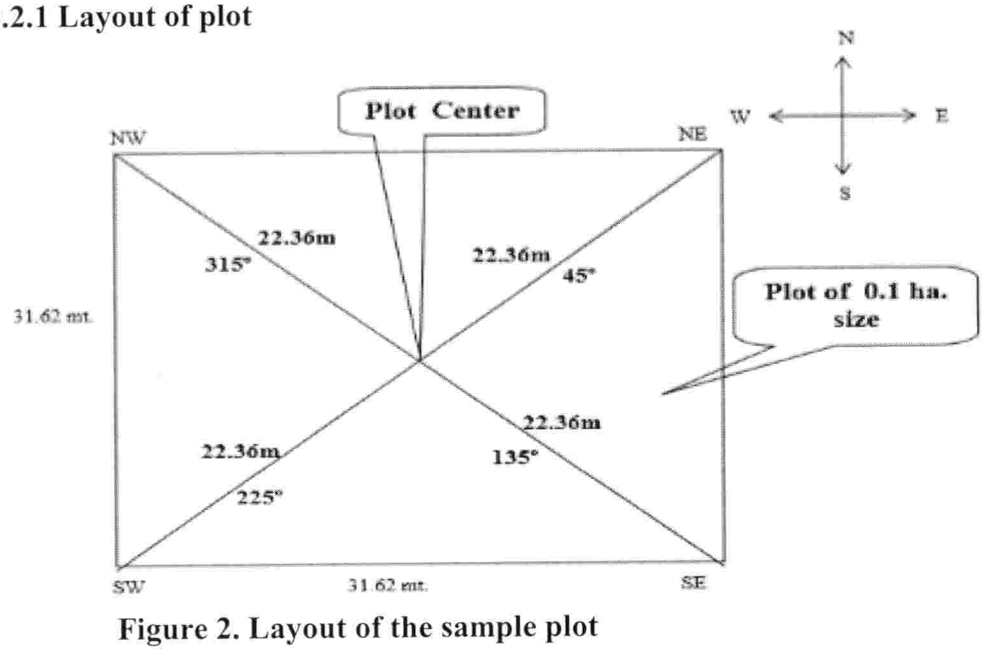

Figure 2. Layout of the sample plot

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After marking the plot center, the measurements were made at NE at 450°, SE at 135°, SW at 285° & NW at 315° corners of the plot by measuring 22.36 m horizontal distance (i.e. half of the diagonal) by Steel tape in all four directions. The dimensions of the plot were checked to ensure that all sides are 31.62 meters in length.

Figure 3. Establishment of sample plot

3.2.2 Measurement of trees

All trees that have been determined to be inside a sample plot with GBH ≥ 20 were measured. The following basic information about the trees subjected to measurements was recorded so as to facilitate any subsequent quality control work:

- Tree species: Local name and scientific (Latin) name
- Tree status: Live standing: Leaning in/out of the plot;
- Dead: Standing or lying

3.2.3 Tree diameter

Diameter at breast height or DBH is the most commonly used tree diameter in forest inventories. The diameter of all the trees falling in the plot was measured at a height of 1.37 meters from ground level (i.e. at breast height) measuring on uphill side of the tree and recorded to the nearest centimeter using a diameter tape or diameter calipers. Dead trees, if not rotten and provided 70% of their wood is utilizable, were also enumerated.

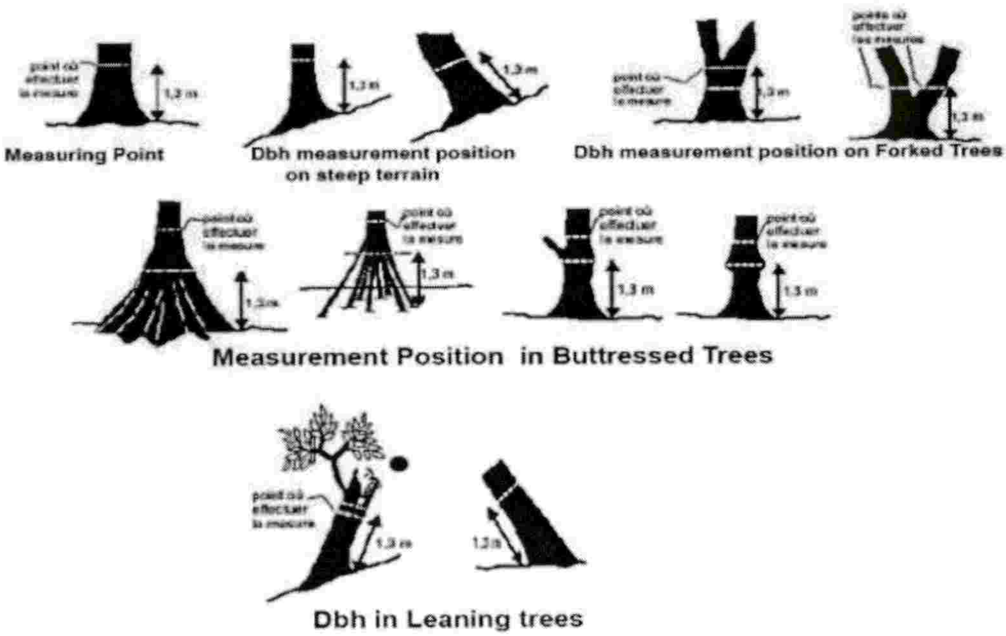

Figure 4. Measurement of diameter at breast height of trees in different situations

3.2.4 Tree height

A hypsometer was used to measure the tree height. Hypsometer measures tree height in terms of angle subtended at a known distance. The instrument used was 'TRUPULSE 200', clinometer with a range accuracy of about +/- 0.3 m (1ft).

Figure 5. Measurement of tree height

3.2.5 Collection of forest floor (litter and humus) data

In each plot for Forest Floor data fresh, partially and fully decomposed leaves, twigs and branches were collected and weighed in kg rounded up to one decimal place. Then the forest floor (litter & humus) collected from all the four plots was mixed thoroughly and a sample of 200g was taken from it. These samples were kept in separate transparent polythene bags, and properly labeled. This sample bag was tied up with a rubber band and stored in proper place.

Figure 6. Collection of litter

3.2.6 Collection of Soil data

Soil sample data were also collected from the same marked four sub plots in the following manner. The area from which the soil sample was taken had been cleared of vegetation with the help of bill hook or axe. Then with the help of crowbar/ spade a pit of 30cm x 30cm x 30cm was dug in each plot and the soil sample of 250g was collected after mixing thoroughly. The soil so collected from all the four corners of the plot was mixed thoroughly and a sample of 200g was taken and kept as described above.

Figure 7. Collection of soil from sample plot

3.2.7 Capturing GPS points

GARMIN-MONTANA-680 GPS of ±10m accuracy was used to capture the GPS location of the plot.

3.3 ESTIMATION OF ABOVE GROUND CARBON

Above ground biomass (AGB) of each sampled tree in the plots were estimated using the allometric models. Generalized allometric model proposed by Chave *et al.* (2014) was used for the estimation of biomass as there were no specific equations available for the species studied.

Best-fit allometric equations for mixed species is:

$AGB = 0.0673\times (\rho\times DBH^2\times H)$ ^0.976

Where DBH (cm), H (m) and WD or ρ in (g/cm^3) are defined above AGB are in kg.

The carbon fraction of the above ground biomass is obtained by multiplying the default factor of 0.47 (McGroddy et. al, IPCC, 2006).

3.4 ESTIMATION OF BELOW GROUND CARBON

Below ground carbon is estimated using ratio of below-ground biomass to above-ground biomass (R). The value of R in different domain is given below,

Tropical rainforest, 0.37 (Fittkau and Klinge, 1973, IPCC, 2006)

Tropical moist deciduous forest above-ground biomass,

<125 tons/ha, 0.20 (0.09 – 0.25) (Mokany et al., 2006, IPCC, 2006).

>125 tons/ha, 0.24 (0.22 - 0.33) (Mokany et al., 2006, IPCC, 2006).

In the case of TOF systems, the default value for tropical moist deciduous forests were taken for conversion of above ground biomass into below ground biomass and then into below ground carbon, according to the value of above ground biomass quantified.

3.5 ESTIMATION OF DEADWOOD CARBON

3.5.1 Standing deadwood

For the following two categories of standing dead wood, the biomass of standing dead wood is estimated by applying a biomass reduction factor to whole tree biomass:

(a) Dead trees which have lost only leaves and twigs. Dead wood biomass is equal to whole tree biomass multiplied by a biomass reduction factor equal to 0.975; 1

(b) Dead trees which have lost leaves, twigs and small branches (diameter < 10 cm). Dead wood biomass is equal to whole tree biomass multiplied by a biomass reduction factor equal to 0.80 (UNFCCC, 2013).

3.5.2 Lying deadwood

Carbon stock in lying deadwood was estimated using conservative default-factor method. For all plots to which the default-factor based method is applied, the carbon stock in dead wood is estimated as,

$C_{DW,p} = C_{Tree} \times DF_{DW}$

Where $C_{DW,p}$ =Carbon stock in dead wood in plot p: t CO_2e

C_{Tree}= Carbon stock in trees biomass in plot p: t CO_2e

DF_{DW} = conservative default factor expressing carbon stock in deadwood as a percentage of carbon stock in tree biomass: per cent

The conservative default factor value used is 6% (UNFCCC, 2013).

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3.6 ESTIMATION OF LITTER CARBON

Litter carbon is estimated by gravimetric method.

3.6.1 Procedure

The litter sample collected from various plots were grinded in a mixer. 0.5g of that was weighed along with the crucibles and was kept inside a muffle furnace for 8 hours at 600°C. Then the crucibles were weighed again and the change in the weight was recorded.

The decrease in the weight after the combustion was the percentage of biomass content in the sample. The percentage value was multiplied with the default value of 0.5 to get the carbon content of the litter in a particular plot.

Now, litter carbon content in Mg/ ha = (C_{litter}× amount of litter/ ha)/ 100.

Where, C_{litter} = percentage carbon content in the litter.

In heterogeneous landscapes the collection of litter was not done because there was negligible amount of litter to collect in certain homesteads across the study area. Assuming that, this may lead to bias in the final result a conservative default factor method was used to estimate litter carbon content. The default-factor based method is applicable only if litter remains in situ and is not removed through any type of anthropogenic activities.

The litter carbon content using conservative default factor method

$C_{litter, p} = C_{tree, p} \times DF_{litter}$

Where, $C_{litter, p}$ = carbon content in the litter in plot p; t CO_2e

$C_{tree, p}$ = Carbon stock in trees biomass in plot p; t CO_2e

DF_{litter}= Conservative default factor expressing carbon stock in litter as a percentage of carbon stock in tree biomass; percent

The value of the conservative default factor is 1% (UNFCCC, 2013).

3.7 ESTIMATION OF SOIL ORGANIC CARBON

Soil organic carbon was estimated by Walkley – Black Wet Digestion Method (Walkley, 1947).

3.7.1 Reagents

1. Potassium dichromate ($K_2Cr_2O_7$) - 1N: Dissolve 49.04g of regent grade $K_2Cr_2O_7$ (dried at 105^0 C) in water and the dilute the solution to a volume of 1000 mL.
2. Ferrous ammonium sulphate hexahydrate solution-0.5N: Dissolve197g of reagent grade $Fe(NH_4)_2SO_4.6H_2O$ in water, add 15 mL of concentrated sulfuric acid, cool the solution and dilute it to a volume of 1000 mL. Standardize this reagent daily by titrating against 10ml of 1N potassium dichromate.
3. O-phenanthrolin-ferrous complex (ferroin)-0.025M: Dissolve 14.85g of O-phenanthrolin monohydrate and 6.95 g of ferrous sulphate heptahydrate ($FeSO_4.7H_2O$) in water. Dilute the solution to a volume of 1000 mL. The O-phenanthrolin-ferrous complex is available under the name of ferroin.
4. Sulfuric acid $H_2SO_{4\ concentrated}$: If Cl^- is present in soil, add Ag_2SO_4 to the acid @ 15 g/L.

3.7.2 Procedure

The soil was ground and passed through a 0.5 mm sieve avoiding iron or steel mortars. Transferred 1 g soil sample, into a 500 ml wide mouth conical flask. 10 ml of 1N $K_2Cr_2O_7$ was added to it and swirled the flask gently to disperse the soil in the solution. Then rapidly 20 ml of concentrated H2SO4 was added. Immediately swirled the flask gently until the soil and the reagents were mixed, then more vigorously for a total of one minute. Allowed the flask to stand on an asbestos sheet for about 30 minutes. Then 200 ml of water was added to the flask. 3-4 drops of o-phenanthroline indicator was added and titrated the determination in the same manner, but without soil, to standardize the $K_2Cr_2O_7$- (Walkley and Black, 1945).

As the end point approaches, the solution takes on a greenish cast and then changes to a dark green colour. At this end point add the ferrous ammonium sulphate drop by drop until the colour changes sharply from blue to red. Make a blank determination in the same manner, but without soil, to standardize the $K_2Cr_2O_7^{2-}$.

Now, soil carbon mass in Mg/ ha = SOC%×B.D ×D×10^{4},

Where SOC% = percentage of soil organic carbon determined; g C/100g

B.D = Bulk density of the soil with default value 1.2; g/cc

D = depth of soil; m

3.8 PREPARATION OF LAND USE LAND COVER MAP FOR THRISSUR DISTRICT

The Landsat 8 image used in the study was acquired in the month of February 15th 2017 as it was a cloud-free post monsoon data. A supervised classification technique was used for analysing the forest and tree resources distribution in Thrissur district. For the purpose of classifying the tree resources into desired classes 4 land use classes were selected for further processing. These are evergreen forests, moist deciduous forests, trees outside forests and non-tree landscapes. Then the spectral bands downloaded from the earth explore were layer stacked to obtain the false colour composite (FCC) of the image. The FCC was clipped with Thrissur district boundary shape file to extract the satellite image of the Thrissur district. Further to this, the spectral signatures belonging to the above land use classes were identified in the satellite image, and training sites were digitized for detection of similar areas in other parts of the image. A Maximum Likelihood classifier algorithm was used for the pattern recognition. The classified output was filtered through 5X5 majority filter algorithm to avoid the salt and grain problem normally associated with the remote sensing images.

CHAPTER IV

RESULTS

A total of 40 sample plots were laid on different ecosystems, and the average carbon stock, its standard deviation and the range are given in Table 1. A total of four sample plots were laid in the evergreen forests where the mean carbon stock was 623.68 tons/ha with a SD of 95.37 tons/ha. The range in carbon stocks of evergreen forests varied from 481.41tons/ha to 680.15 tons/ha. In the moist deciduous forests there were ten sample plots where the mean carbon stock was 306.71tons/ha with a SD of 104.52tons/ha. The range of the total carbon stock varied from 170.13 tons/ha to 473.65 tons/ha. A total of 26 sample plots were laid in the TOF systems (heterogeneous landscapes) where the mean carbon stock was 150.15 tons/ha with a SD of 39.65tons/ha. The range in total carbon stock varied from 78.51 tons/ha to 228.30 tons/ha.

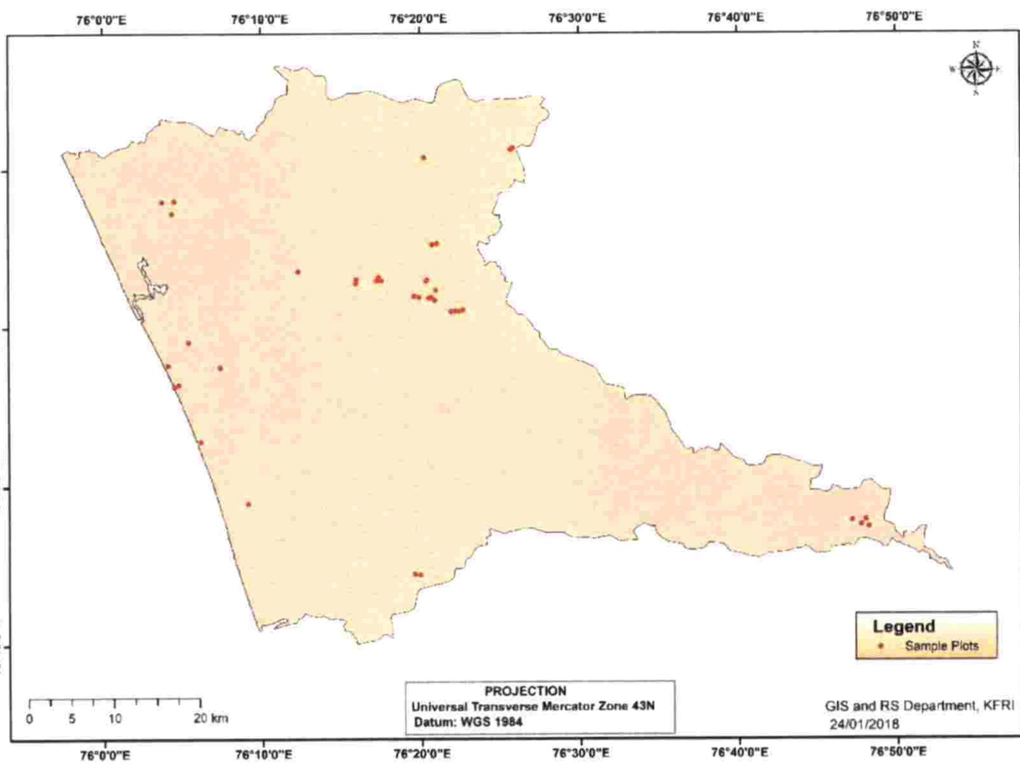

Figure 8. Map showing sample plots in Thrissur district.

Table 1. Total carbon stocks of various land use types

Sl. No.	Land use types	Mean Carbon Stock (tons/ha)	SD (tons/ha)	Range (tons/ha)
1	Evergreen forests	623.68	95.37	481.41-680.15
2	Moist deciduous forests	306.71	104.52	170.13-473.65
4	TOF	150.15	39.65	78.51-228.30

4.1 CARBON POOLS IN EVERGREEN FORESTS

The distribution of various carbon pools in evergreen forest is given in Figure 9. AGC pool had a mean value of 294 tons/ha with a SD of 58.97 tons/ha. AGC formed almost half of the total carbon stock in an evergreen ecosystem. BGC pool had a mean value of 70.56 tons/ha with SD of 14.15 tons/ha. They constituted nearly 12% of the total carbon stock of this system. DWC pool had a mean value of 18.77 tons/ha with a SD of 3.72 tons/ha. DWC virtually represented 6% of the whole carbon stock. LC pool in evergreen ecosystem had a mean value of 3.23 tons/ha with a SD of 0.05 tons/ha. LC had the lowest share of carbon stock in the whole ecosystem comprising of just 1% of the entire carbon stock. SOC pool in this ecosystem had a mean value of 198.90 tons/ha with a SD of 12.63 tons/ha. SOC made the second largest contribution to the whole carbon stock making up to 31% of the carbon stock in an evergreen ecosystem.

Table 2: Different carbon pools in evergreen forests

Carbon Pools	Mean (tons/ha)	SD (tons/ha)
AGC	294	58.97
BGC	70.56	21.82
DWC	18.17	3.61
LC	3.23	0.05
SOC	198.9	12.63

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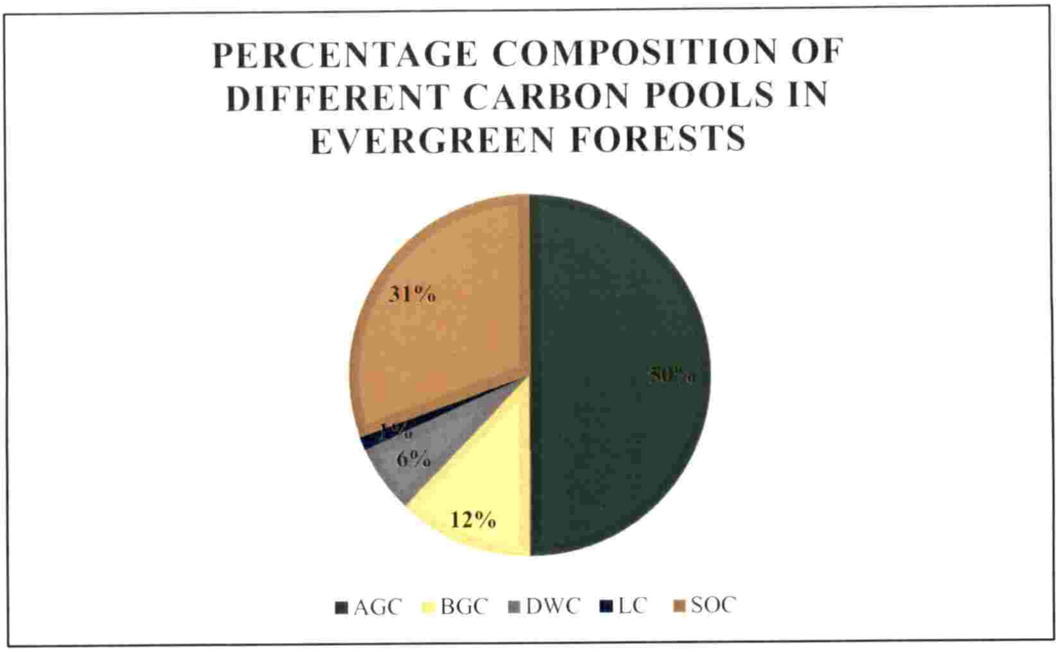

Figure 9. Distribution of different carbon pools in evergreen forests

4.2 CARBON POOLS IN MOIST DECIDUOUS FORESTS

The distribution of various carbon pools in moist deciduous forests is given in Figure 10. AGC pool in MDF had a mean value of 150.01 tons/ha with a SD of 75.40 tons/ha. AGC formed almost half (49%) of the total carbon stock in MDF. BGC pool had a mean value of 35.79tons/ha with a SD of 18.40 tons/ha. It constituted nearly 12% of the total carbon stock of this system. DWC pool had a mean value of 12.83 tons/ha with a SD of 6.12 tons/ha. DWC virtually represented 4% of the entire carbon stock. LC pool in MDF ecosystem had a mean value of 3.93 tons/ha with a SD of 0.21 tons/ha. LC had the lowest share of carbon stock in the whole ecosystem containing just 1/100th of the total carbon stock. SOC pool in this ecosystem had a mean value of 104.13 tons/ha with a SD of 18.66 tons/ha. SOC made the second largest contribution to the whole carbon stock making up to 34% of the carbon stock in MDF.

Table 3: Different carbon pools in MDF

Carbon Pools	Mean	SD
AGC	150.01	75.4
BGC	35.79	18.4
DWC	12.83	6.12
LC	3.93	0.21
SOC	104.13	18.66

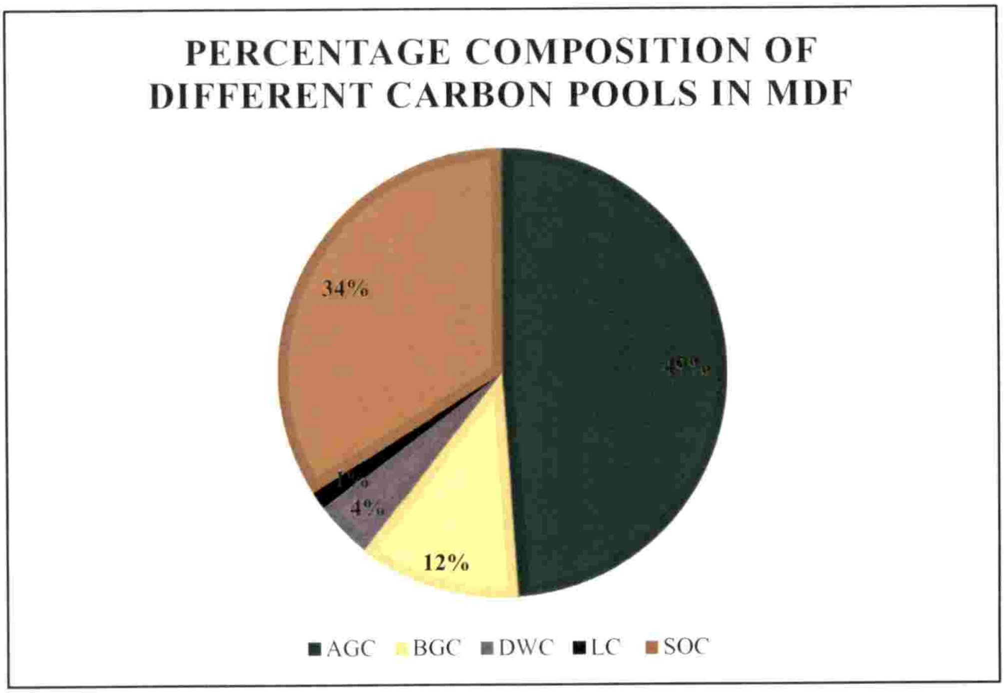

Figure 10. Distribution of different carbon pools in moist deciduous forests

4.3 CARBON POOLS IN TOF SYSTEMS

The distribution of various carbon pools in TOF systems is given in Figure 11. AGC pool in TOF systems had a mean value of 74.20 tons/ha with a SD of 28.92 tons/ha. AGC almost made half (49%) of the total carbon stock in this ecosystem. BGC pool had a mean value of 17.81 tons/ha with a SD of 6.94 tons/ha.

It consist of nearly 12% of the total carbon stock of this system. DWC pool had a mean value of 0.97 tons/ha with a SD of 1.82 tons/ha. DWC virtually represented 1% of the entire carbon stock. LC pool in TOF system had a mean value of 0.53 tons/ha with a SD of 1.02 tons/ha. LC had the lowest share of carbon stock in the whole ecosystem with practically a negligible fraction of the complete carbon stock in TOF systems. SOC pool in this ecosystem had a mean value of 56.92 tons/ha with a SD of 18.76 tons/ha. SOC made the second largest contribution to the whole carbon stock holding up to 38% of the carbon stock in this system.

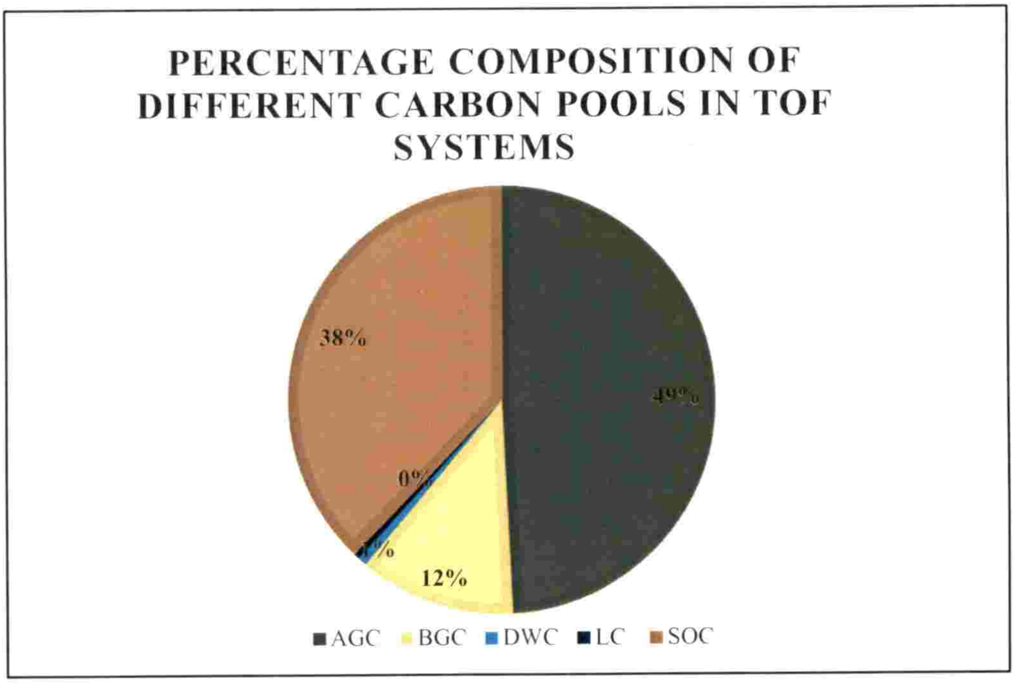

Figure 11. Distribution of different carbon pools in TOF systems

26 plots in TOF systems have been further classified into 4 categories:

- Plantations
- Mixed Plantations
- Homesteads (coastal)
- Homesteads (inland)

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4.3.1 Plantations

The distribution of various carbon pools in plantations is given in Figure 12. AGC pool in plantations had a mean value of 46.03 tons C/ha with a SD of 26.76 tons C/ha. AGC made approximately 40% of the total carbon stock in the ecosystem. BGC pool in plantations had a mean value of 9.78 tons C/ha with a SD of 6.75 tons C/ha. BGC formed nearly 9% of the entire carbon stock in plantations. DWC pool did not had any share in the plantation system mainly because of anthropogenic management. LC pool had a negligible share in the whole carbon stock with an average value of about 0.46 tons C/ha with a SD of 0.26 tons C/ha. The SOC pool had a mean value of 59.33 tons C/ha with a SD of 25.37 tons C/ha. SOC was the major contributor to the total carbon stock in plantations forming 51% of the whole.

Table 4. Different carbon pools in plantations

Carbon Pools	Mean	SD
AGC	46.03	26.76
BGC	9.78	6.75
DWC	0	0
LC	0.46	0.26
SOC	59.33	25.37

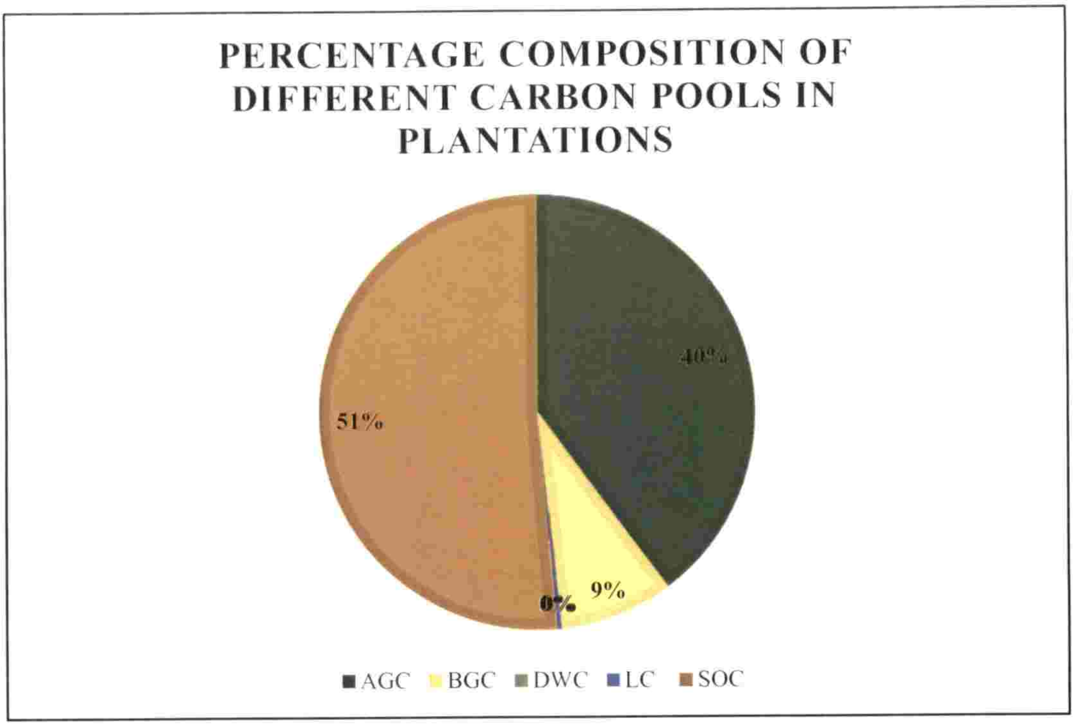

Figure 12. Distribution of different carbon pools in plantations

4.3.2 Mixed plantations

Distribution of different carbon pools in mixed plantations is given in Figure 13. AGC pool in mixed plantations had a mean value of 82.01 tons C/ha with a SD of 23.08 tons C/ha. AGC formed nearly 47% of the entire carbon stock in mixed plantations. BGC pool had a mean value of 18.94 tons C/ha with a SD of 6.81 tons C/ha. BGC made approximately 11% of the total carbon stock. DWC pool had an average value of 1.84 tons C/ha with a SD of 2.49 tons C/ha. LC pool had a mean value of 0.82 tons C/ha with a SD of 0.23 tons C/ha. Both DWC and LC constituted 2% of the total carbon stock. SOC pool had a mean value of 70.2 tons C/ha with SD of 20.26 tons C/ha. SOC made almost 40% of the whole carbon stock in mixed plantations forming the second largest contributor to the entire carbon stock.

Table 5. Different carbon pools in mixed plantations

Carbon Pools	Mean	SD
AGC	82.01	23.08
BGC	18.94	6.81
DWC	1.85	2.49
LC	0.82	0.23
SOC	70.2	20.26

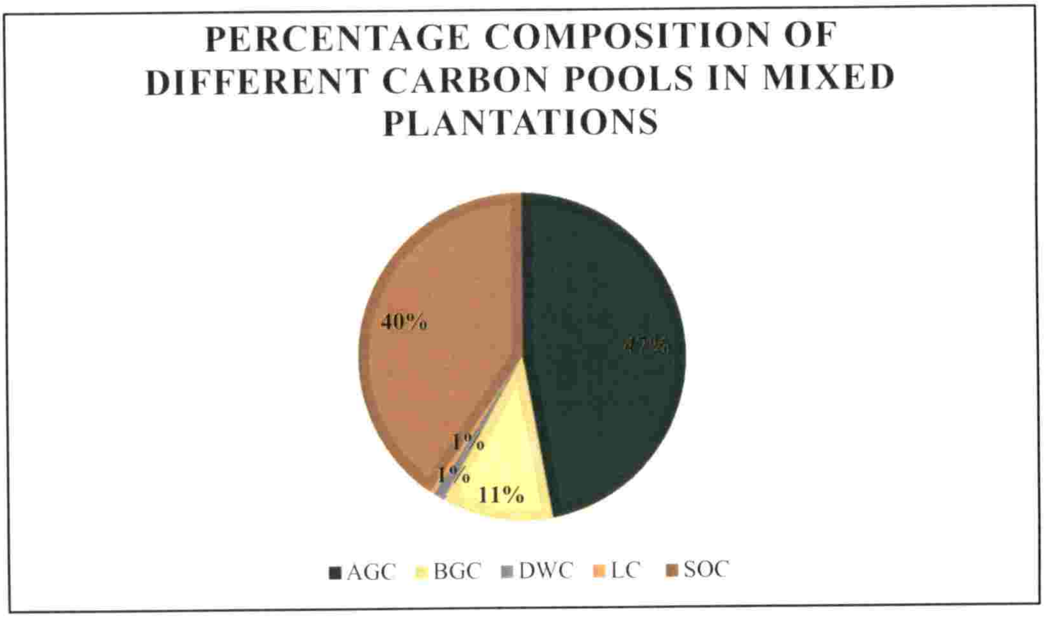

Figure 13. Distribution of different carbon pools in mixed plantations

4.3.3 Homesteads (coastal)

Distribution of different carbon pools in homesteads (coastal) is given in Figure 14. AGC pool in coastal homesteads had a mean value of 100.87 tons C/ha with a SD of 30.24 tons C/ha. AGC formed nearly 60% of the entire carbon stock in mixed plantations. BGC pool had a mean value of 24.21 tons C/ha with a SD of 7.25 tons C/ha. BGC made approximately 14% of the total carbon stock. DWC pool

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had an average value of 0.46 tons C/ha with a SD of 0.53 tons C/ha. LC pool had a mean value of 1.00 tons C/ha with a SD of 0.30 tons C/ha. Both DWC and LC together constituted 1% of the total carbon stock. SOC pool had a mean value of 42.12 tons C/ha with SD of 9.61 tons C/ha. SOC made almost 25% of the whole carbon stock in mixed plantations forming the second largest contributor to the entire carbon stock.

Table 6. Different carbon pools in homesteads (coastal)

Carbon Pools	Mean	SD
AGC	100.87	30.24
BGC	24.21	7.25
DWC	0.46	0.53
LC	1	0.3
SOC	42.12	9.61

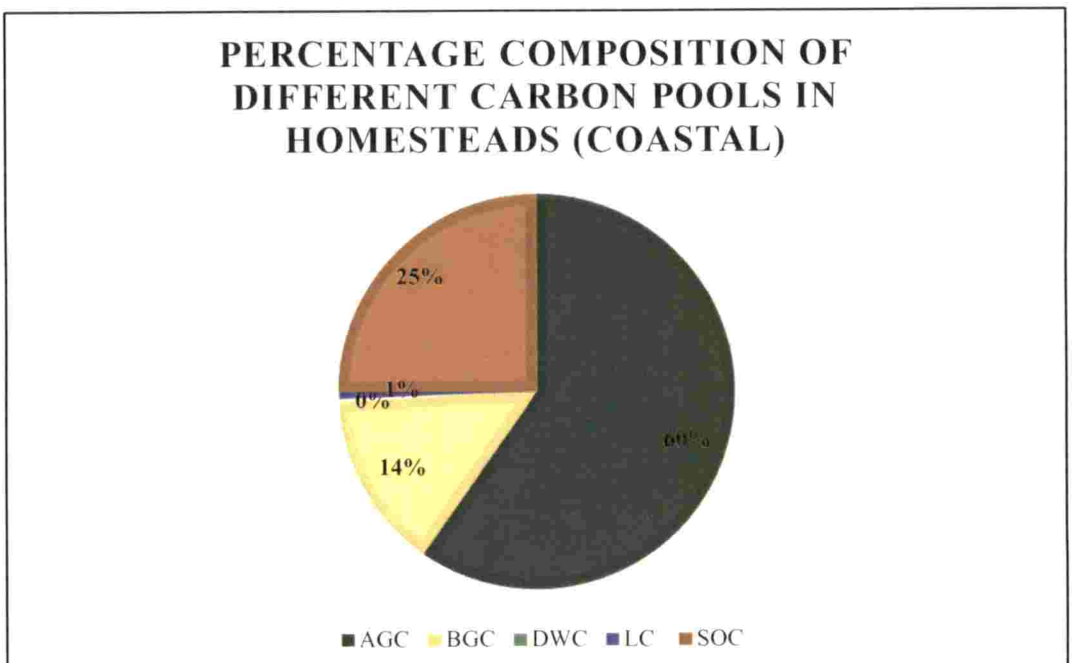

Figure 14. Distribution of different carbon pools in coastal homesteads

4.3.4 Homesteads (inland)

The distribution of various carbon pools in homesteads (inland) is given in Figure 10. AGC pool in inland homesteads had a mean value of 77.88 tons C/ha with a SD of 15.67 tons C/ha. AGC made approximately 50% of the total carbon stock in the ecosystem. BGC pool in plantations had a mean value of 18.48 tons C/ha with a SD of 4.10 tons C/ha. BGC formed nearly 12% of the entire carbon stock in plantations. DWC pool had a mean value of 0.53 tons C/ha with a SD of 0.72 tons C/ha. LC pool had an average value of about 0.77 tons C/ha with a SD of 0.15 tons C/ha. Both DWC and LC together formed merely 1% of the entire carbon stock. The SOC pool had a mean value of 58.5 tons C/ha with a SD of 14.32 tons C/ha. SOC was the second largest contributor to the total carbon stock in plantations forming 37% of the whole.

Table 7. Different carbon pools in homesteads (inland)

Carbon Pools	Mean	SD
AGC	77.88	15.67
BGC	18.48	4.1
DWC	0.53	0.72
LC	0.77	0.15
SOC	58.5	14.32

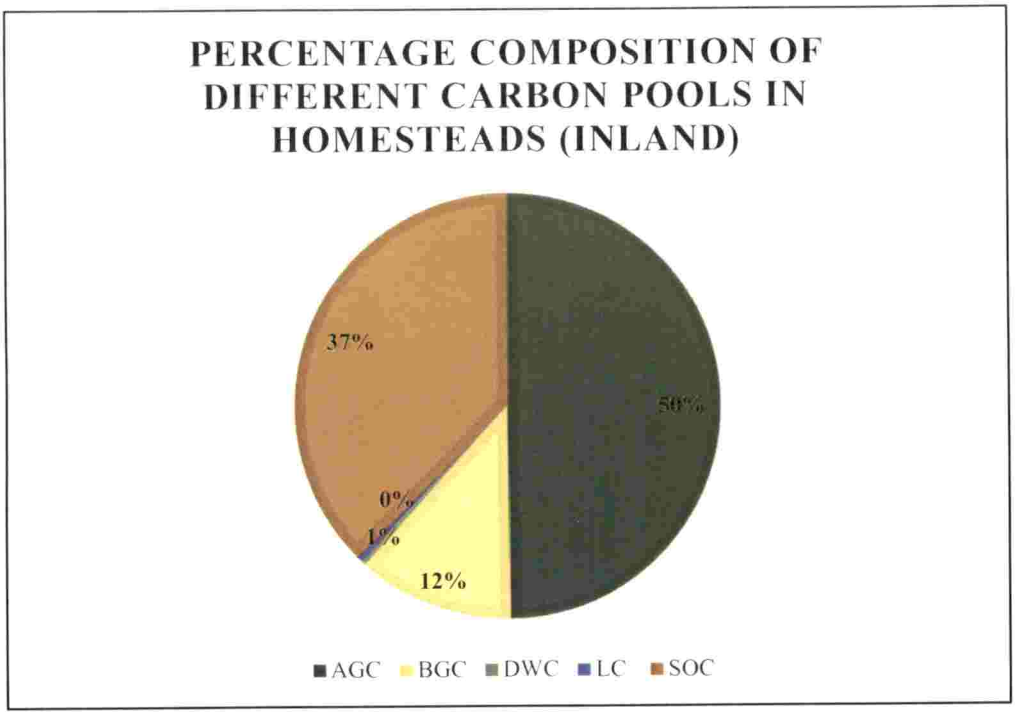

Figure 15. Distribution of different carbon pools in inland homesteads

4.4 LAND USE LAND COVER MAP OF THRISSUR

A map of Thrissur district showing four different land use classes is shown in Figure 11. Thrissur district was classified into four land use groups and the extent of the respective areas are given in Table 8. Trees outside forests formed the largest area with 169410.83 ha followed by non-tree landscapes 71.46.64, moist deciduous forest 43325.61 and evergreen forest 23142.61 ha.

Table 8. Land use classes and extent of area

Land use type	Extent of area (in ha)
Evergreen Forest	22113.01
Moist deciduous Forest	43325.61
Trees Outside Forest	169410.83
Non-Tree landscape	71565.12

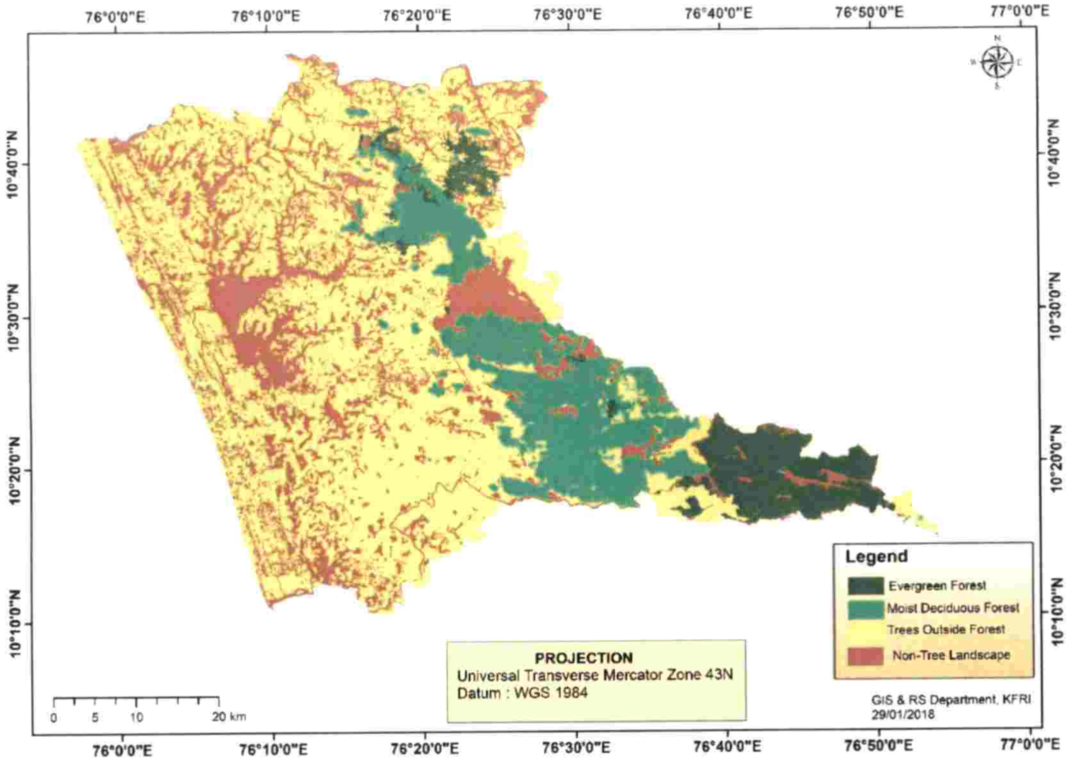

Figure 16. Map showing different land use types of Thrissur district

5.4 Mitigation potential of forests and TOF in Thrissur

The total carbon stocks of different ecosystem types in Thrissur district have been found out. The extent of area under different land use types have also been identified. The corresponding carbon dioxide equivalent (CO_2eq) was calculated for all land cover zones and all carbon pools by multiplying the amount of carbon by 3.66 value. The mitigation potential of forests and TOF systems is given in Table 9.

Table 9: Land use type and CO_2 eq for Thrissur district

Land use type	Extent of area (in ha)	Mitigation Potential (CO_2 eq)
Evergreen Forest	22113.01	50476678
Moist deciduous Forest	43325.61	48635536.1
Trees Outside Forest	169410.83	93099552.21

Thus, the forests and TOF systems of Thrissur had a storage capacity of a whopping 19.22 million tons of carbon dioxide.

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CHAPTER V

DISCUSSION

5.1 CARBON STOCK IN TROPICAL WET EVERGREEN FORESTS

Tropical wet evergreen forest ecosystem forms one of the pristine ecosystems with nothing or less activity year round. They are also home to highest biodiversity seen in the terrestrial ecosystem. A total of 363 trees was inventoried in four different plots in evergreen ecosystem of Thrissur district. The average standing biomass in evergreen forests observed from this study was 625.33 tons/ha which was almost similar with the results of 607.7 ton/ha (Ravindranath *et.al*, 1997) for the year 1986. One of the main reason for increased biomass in trees was because of the geographical position of the sites under study. Usually the trees in forests of tropical Asia tend to have more morphological superiority when compared to tropical forests globally (Chave et.al, 2005, Goodman et.al, 2014).

The 2 plots in evergreen forests of the Uttara Kannada district had 291.37 and 239.34 tons/ha respectively in 1994 (Bhat et.al, 2003). According to Kale et.al, 2009, the mixed moist deciduous forests of Radhnagiri Wildlife Sanctuary in 2006 had AGB of 209.25, 188.87 and 115.50 tons/ha at high, medium and low elevation respectively. According to Devagiri et.al, 2013, the evergreen forests of Kodagu district in Karnataka has Area Weighted AGB of 176.73 tons/ha. All the estimated above ground biomass and carbon stocks in similar studies before showed values which are very much low compared to the present study. This may be mainly owed to the fact that different allometric equations were used in other studies. The equations used in previous studies mainly considers basal area as a major parameter in calculating biomass but the present study incorporates tree diameter, height and wood density as major parameters.

The major tree types observed in the evergreen ecosystem were, *Agrostistachys borneensis* Becc, *Palaquium ellipticum* (Dalz.) Baill, *Vateria indica L*, *Drypetes malabarica* (Bedd.) Airy Shaw, *Drypetes wightii* (Hook. f.) Pax &

Hoffm. The FSI report 2011 had a mean value for the carbon stock in AGC of tropical wet evergreen forest pool as 70.67 tons C/ha at national level. This value was very much contrasting to the values that was observed in our study which was more than 4 times the value in FSI report. The average AGB in tropical wet evergreen forests of the Anamalai hills, southern Western Ghats, was found to be 236.80 tons/ha (Joseph et.al, 2010) which was again very low compared to present study. AGC pool formed almost 50% of the total carbon stored in evergreen ecosystem. AGC in evergreen forests of Uttara Kannada district in Karnataka had an average value of 135.33 tons C/ha. At the same time the average value of BGC was 35.16 tons C/ha (Murthy et.al, 2016).

BGC was measured using the above-ground below-ground ratio. The ratio used in this study for calculating BGC was 0.37 (IPCC, 2006). Tree biomass, both above ground and below ground components accounted for almost 62% of the total carbon stock. So tree biomass formed the major contributor to the total carbon storage in evergreen ecosystem. The mean BGC pool in tropical wet evergreen forests was found to be 70.56 tons C/ha. The average BGC pool for Western Ghats was found to be 24.45tons C/ha (FSI, 2011).

The mean DWC pool in the tropical wet evergreen forests was 18.77 tons C/ha. FSI report of 2011 shows 4.10tons C/ha in DWC pool for the tropical wet evergreen forests of Western Ghats which again is more than 4 times lower than the value of current study. Litter is one of the major terrestrial carbon pools in a forest ecosystem. LC pool in the tropical evergreen forests had a mean value of 3.23 tons C/ha. The mean national stock of LC in evergreen ecosystem of southern Western Ghats as per FSI 2011, is 7.18 tons C/ha. This result was more than two times the value obtained during the present study. The density of the biomass in the forest ecosystem plays a major role in determining the amount of litter fall and hence effect the carbon stored in litter at any time of the year. There are only few studies estimating LC pool in India. The total litter fall carbon flux for the year 1980-82 was estimated as 210 ± 20 Tg C per year (Chhabra and Dadhwal, 2004).

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SOC pool in tropical wet evergreen forests had a mean value of 198.90 tons C/ha in this study compared to the mean value 100.57 tons C/ha of the whole nation (Singh et.al, 2016). The very dense forests of Western Ghats had more SOC pool compared to the national average (FSI, 2011). According to Kishwan *et al.*, 2009, mean SOC pool for tropical evergreen forests of India was calculated to be 101.404 tons C/ha. From various references in Ravindranath et.al, (1997) the mean soil organic carbon in tropical wet evergreen forests was 125.19 tons C/ha. The SOC density estimated for tropical evergreen forests of India at a depth of 50cm for the year 1980-82 was 90.7 tons C/ha (Chhabra and Dhadhwal, 2004). According to data from National Carbon Project, mean SOC was found to be 71.37 tons C/ha up to 30 cm depth in tropical evergreen forests. In the present study SOC formed 31% of the total carbon stock in an evergreen ecosystem thus making it the second largest contributor after the tree biomass.

5.2 CARBON STOCK IN MOIST DECIDUOUS FORESTS

Tropical MDF are the most abundant forest ecosystem in Kerala and also in Thrissur. Thus tropical MDF is also the most vulnerable ecosystem prone to deterioration or degradation mainly because of the increased population. A total of 599 trees with GBH $\geq$ 20cm was inventoried across 10 plots at different locations of tropical MDF in Thrissur. The average AGB of the MDF was estimated to be 319.16 tons/ha in the present study. Ravindranath *et.al*, (1997) assessed the AGB of tropical MDF to be 409.3 tons/ha. In the deciduous forests plots of Uttara Kannada district in 2011 was found to be 104.16 tons C/ha and the mean BGC calculated was 28 tons C/ha (Murthy et.al, 2015). From Devagiri et.al, 2013 the Area Weighted AGB for moist deciduous forests in Kodagu was estimated at 85.64 tons/ha and for Mysore it was 92.62 tons/ha. The results from Padmakumar et.al, the AGC from four different plots in mixed moist deciduous forests in Periyar Tiger Reserve was 129.45, 74.89, 137.64 and 279.98 respectively. Average biomass was 327.36 tons/ha and mean AGC was 155.49 tons C/ha.

The FSI report of 2011 quantified that the mean AGC pool in tropical MDF to be 37.16 tons C/ha. The average AGC pool quantified in the present study is

150.01 tons C/ha. This indicates that the value enumerated in the present study was almost 4 times the value of FSI, 2011. Although the number of trees per plot was comparably lower, higher AGB in certain plots were noted because of the larger girth and height in trees of tropical MDF. The major tree types noted in MDF system were, *Tectona grandis, Xylia xylocarpa, Terminalia sp, Bombax ceiba* and so on. The assessed AGC pool of tropical MDF in the Anamalai hills of southern Western Ghats was 70.85 tons C/ha which was an underwhelming result considering it only achieved less than half of the present study. The AGC pool of MDF formed almost 49% of the total carbon stock of the ecosystem.

The BGC pool was evaluated using the above-ground below-ground ratio. The ratio used in this study for calculating BGC was 0.24(AGB $\geq$ 125 tons/ha) and 0.20(AGB $\leq$ 125 tons/ha) (IPCC, 2006). The typical BGC pool of tropical MDF was valued at 35.79 tons C/ha (Fig 18.). The average BGC calculated for the Western Ghats were 7.69 tons C/ha which roughly estimates to five times the value obtained in the present study (FSI, 2011). The BGC pool made almost 12% of the total carbon stock in a tropical MDF ecosystem. Thus tree biomass formed almost 61% of the total carbon stock, which makes it the major contributor of carbon stock in MDF systems.

DWC pool enumerated was 12.83 tons C/ha. The DWC pool quantified by FSI, 2011 was 1.17 tons C/ha for tropical MDF in Western Ghats which is very contrasting to the value obtained in the present study. The variation observed may be attributed to the default conservative factor used in this study to estimate the lying deadwood carbon. The DWC pool formed 4% of the whole carbon stock in MDF ecosystem. LC pool in the tropical MDF tend to have slightly higher value than the evergreen forests because of the characteristic shedding of leaves during winter. This increased litter fall helps in maintaining large amount of microbial activity in the forest floor which in turn results in high decomposition rate of organic matter which is also a source of emission from forests. The mean LC pool of present study was quantified as 3.93 tons C/ha. According to FSI report 2011, the mean LC pool for tropical MDF was 2.74 tons C/ha which is somewhat comparable. LC pool make up only 1% of the entire carbon stock in MDF systems.

The mean SOC stock in the tropical MDF systems have been assessed as 104.13 tons C/ha. The mean national SOC stock in tropical MDF was calculated as 55.01 tons C /ha which translates into roughly half of the results obtained in present study (Singh *et al.*, 2016). Kishwan *et al.*, (2009) returned similar value of 55.009 for SOC in tropical MDF. Ravindranath *et al.*, 1997 compiled many references which showed a mean SOC pool of 57.14 tons C/ha. The mean carbon density of SOC up to 50cm depth in Indian tropical MDF system for the year 1980-82 was 73.2 tons C/ha. This values are comparable since the depth taken for our study is 30cm while the latter is 50cm which explains the dip in SOC value. The National Carbon Project, assessed a mean SOC of 60.92 tons C/ha. SOC stock of the present study make up almost 34% of the entire carbon stock of tropical MDF ecosystem, which makes it second largest contributor of carbon storage in MDF system.

5.3 CARBON STOCK IN TREES OUTSIDE FORESTS

A sum total of 1773 trees were inventoried across 26 plots in the district of Thrissur. The sample plots included different vegetation systems including homesteads and plantations. Coconut based heterogeneous landscapes were the typical land use in coastal areas of the district. Different land use patterns were visible moving away from the coastal areas to higher elevation. Homesteads with nutmeg, coconut, arecanut cultivation were common in areas other than coastal strip. Plantations such as coconut, cashew, rubber and mango were inventoried for the purpose of the study. Mean AGC pool of different heterogeneous landscapes enumerated was 74.20 tons C/ha. AGC pool formed almost 49% of the total carbon stock in TOF systems. The present results is contradictory to the estimated phytomass in TOF's of Haryana where an average of 18.24 tons/ha in block stratum was observed which is very lower compared to 157.87 tons/ha obtained in present study (Singh and Chand, 2012).

BGC of different TOF systems was quantified using the above-ground below-ground ratio. The ratio used in this study for calculating BGC was 0.24(AGB $\geq$ 125 tons/ha) and 0.20(AGB $\leq$ 125 tons/ha) (IPCC, 2006), which was the same ratio taken for MDF systems because of the lack of available datasets. Mean of the BGC pool computed for TOF systems in Thrissur was 17.81 tons C/ha. The BGC pool formed nearly 12% of the entire carbon stock in TOF systems. The tree component (both AGC and BGC) contributed approximately 61% of the total carbon stock of TOF systems.

The average DWC pool enumerated for TOF systems across Thrissur was 0.53 tons C/ha. At the same time the average value of LC pool was 0.74 tons C/ha was higher than DWC pool. This contrast can be mainly owed to the fact that deadwood (both standing and lying) was removed from the sites because of anthropogenic activities but at the same time removal of litter was not as frequent. The DWC pool contributed 1% of the total carbon stock but that of LC pool was very little and when taken wholly contributed less than DWC pool.

The average SOC carbon pool measured in TOF system of Thrissur was 56.93 tons C/ha. The lesser values observed in the SOC pool was mainly due to the soils of coastal areas where the amount of organic carbon is generally low. In contrast with other ecosystems here the SOC pool almost contributed 38% of the whole carbon stock of TOF systems while in both the other systems it was 34%.

5.3.1 Plantations

For the purpose of the study a total of 7 plantations were inventoried which included 3 rubber, 2 coconut and one each of cashew and mango. The highest carbon stock in the plantations was found in the mango plantation (178.60 tons C/ha). The age of the mango plantation was 25 years. The lowest carbon stock among plantations was noticed in 7 year old rubber plantation (78.51 tons C/ha). The two coconut plantation showed marked variation in the SOC pool, with the coconut plantation on the seashore having a SOC stock of 17.55 tons C/ha compared to the SOC pool of inland coconut, 76.05 tons C/ha. The lowest AGC pool was noticed in the cashew plantation with 17.22 tons C/ha which was also a 25 year old plantation.

5.3.2 Mixed Plantations

A total of 3 mixed plantations were inventoried for the study. The highest mean carbon stock was found in coconut and arecanut mixed plantation with 205.38 tons C/ha. The lowest observed was in a system of arecanut and nutmeg with 118.87 tons C/ha. The mixed plantation consisting of coconut attained higher carbon stock than under arecanut based system. In the case of arecanut and nutmeg based mixed plantation the spacing for nutmeg was greater than normal thus leading to less number of trees which lead to lower amount of AGC.

5.3.3 Homestead (coastal)

A total of 5 homesteads were inventoried across the coastal areas of Thrissur for the purpose of this study. Coconut was one of the main tree component in every homestead. Three plots had in addition different fruit crops like mango, jack fruit, while in some plots cashew and nutmeg was also noticed. One of the salient feature of the coastal homesteads was the lower value of SOC pool which was a normal characteristic of the coastal soil. The average value of the SOC pool was 42.12 tons C/ha. AGC pool had an average value of 100.00 tons C/ha. The lowest observed AGC was 59.84 tons C/ha compared to the highest value, which is almost 2 times the lowest value (145.20 tons C/ha).

5.3.4 Homestead (inland)

For the purpose of the study a total of 11 plots were inventoried in different homesteads apart from the coastal areas of Thrissur. Coconut, arecanut, nutmeg, mango etc. where the main trees in inland homesteads. The mean value of SOC pool was 58.50 tons C/ha which is higher than the SOC pool found in coastal homesteads. The mean value of AGC in inland homesteads was 77.88 tons C/ha which was lower than the coastal homesteads. According to Kumar (2011), the mean AGC in the home gardens of 10 panchayats of Thrissur district was 16.91, 16.31, 16.96, 16.57, 23.89, 21.67, 25.23, 23.27, 23.77/ 20.68 tons C/ha. From

Padmakumar et.al, 2017, the AGB and AGC of home gardens in Thodupuzha, Idukki was found to be 52.97 tons/ha and 25.16 tons C/ha.

There was obvious difference in the species diversity in both homesteads with coastal homesteads showing more species per plot than inland homesteads more often. This may also be a reason for lower AGC pool in inland homesteads.

CHAPTER VI

SUMMARY AND CONCLUSION

In the present study an attempt was made to estimate the carbon stock of Forest and Trees Outside Forest systems, in Thrissur district of Kerala. Estimating forest biomass carbon is the most critical step in quantifying carbon stocks and fluxes. Field work included 40 sample plots laid across Thrissur in different ecosystem types. The ecosystem types inventoried include evergreen forests, moist deciduous forests and different TOF systems. A total of 2735 trees were inventoried across 40 plots in 3 different ecosystem types. 4 plots were laid in the evergreen ecosystem together with 10 plots in moist deciduous forests and 26 plots across the length and breadth of Thrissur district. Different pools of emission/removals were identified and inventoried viz above ground biomass, below ground biomass, leaf litter, deadwood and soil organic carbon. Carbon stocks in various carbon pools were quantified and analysed. Above ground biomass was estimated using allometric equations in Chave et.al, (2014). Different default factors from IPCC, (2006) were used in determining the below ground, leaf litter and deadwood carbon of the inventoried ecosystems. A land use land cover map comprising of 4 classes was made using satellite images, namely evergreen forests, moist deciduous forests, trees outside forests and non-tree landscapes. Climate change mitigation potential of different ecosystem types were assessed using the mean carbon stock and the extent of area calculated from the land use map and tabulated.

The area under TOF systems is much larger and obviously the CO_2 eq of TOF system is an important contributor in the total carbon budget. Thus the degradation of TOF systems may cause GHG emissions that are higher than the level of our perception. TOF systems have multidisciplinary uses which are highly significant in local level. The TOF is especially utilized for several purposes particularly for firewood, fodder, timber, non-timber forest products and so on. Thus, different in-depth researches regarding the scopes like carbon assessment and contribution of TOF in livelihood promotion at different levels are required in future. There are many difficulties in the accurate assessment of different carbon

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pools in ecosystem level. The lack of availability of regional allometric equations for calculating AGB may lead to over/ under estimation of carbon stock in regional level. In this study the generalised equations were used for estimating AGB due to the lack of datasets available.

The forests of the state of Kerala is said to play a great role in sequestering and storing carbon. The potential for sequestering carbon depends on the composition, soil type, region etc. This study involving many plots in the heterogeneous landscapes may shed light to future research in this regard and shift the limelight from the established forest systems to the lesser regarded TOF systems. Kerala is also one of the richest state in the case of forest/tree cover abundance. So the way towards a more integrated management of the forests and TOF systems is to be made by the government in order to reduce the effect of global climate change. The accurate and precise measurement of the carbon stored and sequestered in the forests were of great demand in the wake of the Kyoto Protocol and to comply with the guidelines of the UNFCCC. The number of projects registered under the CDM are in a declining phase owing to the low ambition in the pre-2020 period. Since the historic Paris Agreement and the adoption of the Sustainable Development Goals for the next 15 years in 2015 the need for change in the way we perceive the nature is imminent and it can pave way for in depth and quality research. So it is necessary to analyse new geographic regions under forests/ tree cover for potential carbon trading and policy interventions.

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MEASURING THE CLIMATE CHANGE MITIGATION POTENTIAL OF FORESTS AND TOF (TREE OUTSIDE FOREST) SYSTEMS IN THRISSUR

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ABSTRACT OF THE THESIS

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ABSTRACT

Inventorying of terrestrial carbon stock is important in understanding the role of forests and tree resources in the mitigation of climate change and its consequences. For this purpose, a total of 40 sample plots of 0.1ha area were inventoried. The sample plots included 4 plots within evergreen forests, 10 plots in moist deciduous forests and 26 plots in TOF (Trees Outside Forests) systems of Thrissur district in Kerala, Southern India. Five carbon pools, namely, above ground biomass, below ground biomass, deadwood, leaf litter and soil organic carbon were estimated. Chave's generalised allometric model was used to estimate the above ground biomass. Below ground biomass component and deadwood carbon was calculated using IPCC default values. Litter carbon in forest systems were measured using gravimetric method while in TOF systems litter carbon was appropriated using UNFCCC guidelines. Soil organic carbon in every soil samples was measured using the Walkley black wet digestion method.

A land use land cover map of Thrissur district for the same land use classes was also prepared using spectral signatures obtained from the GPS coordinates during field work. From the study, the mean carbon stock of evergreen forests, moist deciduous forests and TOF systems calculated were 623.68, 306.71, 150.15 tons/ha respectively. Above ground biomass was the major contributor in every land use type except in the case of plantations in TOF systems where soil organic carbon was the major contributor. The other major contributor included soil organic carbon, followed by below ground biomass while dead wood and litter carbon formed the least.

The mitigation potential of forests and TOF systems in Thrissur district was calculated to be 19.22 million tons of CO_2. The major contributor was the TOF systems which shows the immense potential of Kerala in mitigating the change in climate with its large population of trees outside forests.