FOREST BIOMASS DYNAMICS USING FOREST INVENTORY DATA OF KERALA

by

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THESIS

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2024

DECLARATION

I, **Gopika S Pillai**, hereby declare that the thesis entitled **"FOREST BIOMASS DYNAMICS USING FOREST INVENTORY DATA OF KERALA"** is a bonafide 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 of any degree, diploma, fellowship or other similar title, of any other University or Society.

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iv. ABBREVIATIONS

1. AGB – Above Ground Biomass
2. AGBC - Above Ground Biomass Carbon
3. ArcGIS - Arc Geographic Information System
4. BECCS - Bio energy with Carbon Capture and Storage
5. BECF - Biomass Expansion and Conversion Factors
6. BGB - Below Ground Biomass
7. C - Carbon
8. CO_2 - Carbon dioxide
9. DEMs - Digital Elevation Models
10. EFL - Ecologically Fragile Lands
11. FAO - Food and Agriculture Organization
12. FSI – Forest Survey of India
13. GA – Geographical Area
14. GFW - Global Forest Watch
15. GSV - Growing Stock Volume
16. GIS - Geographic Information System
17. Ha - Hectare
18. IfSAR - Interferometric Synthetic Aperture Radar
19. IPCC - Intergovernmental Panel on Climate Change
20. ISFR - India State of Forest Report
21. KFD - Kerala Forest Department
22. LIDAR - Light Detection and Ranging

23. LULC - Land Use and Land Cover

24. LULUCF- Land Use, Land- Use Change and Forestry

25. MAI - Mean Annual Increment

26. MDF - Moderately Dense Forest

27. MP - Management Plan

28. NDCs - Nationally Determined Contributions

29. NGOs - Non-Governmental Organizations

30. NPP - Net Primary Productivity

31. OF – Open Forest

32. SoI – Survey of India

33. Sq. Km - Square kilometers

34. SRTM - Shuttle Radar Topography Mission

35. TOF - Trees Outside Forests

36. USGS - United States Geological Survey

37. VDF - Very Dense Forest

38. WP - Working Plan

39. WRI - World Resources Institute

CHAPTER 1

INTRODUCTION

The word 'forest' is used to refer to land with a tree canopy cover of more than 10 percent and area of more than 0.5 hectare (ha) (Forest Resources Assessment, 2000). Forest includes natural forests and forest plantations. A natural forest is one that is made up of native trees and isn't categorized as a forest plantation. On the other hand, a forest that is created through planting, seeding, or afforestation - a process that involves the use of either native or introduced species - is known as a forest plantation.

Because they store a significant amount of Carbon (C) in their plants and soils and interact with atmospheric processes through the absorption and respiration of Carbon dioxide (CO_2), forest ecosystems play prominent roles in the global carbon cycle. Approximately 80% of the world's terrestrial above-ground carbon is stored in the vegetation and soils of forests (Noble et al., 2000). Forest biomass accounts for approximately 90% of all living terrestrial biomass on the Earth, and young forests take up CO_2 at higher rates than most other ecosystems. The carbon storage in forest biomass represents the potential amount of C that is sequestered from the atmosphere when forests are managed for meeting emission targets. Estimations of forest biomass and its change are important for assessing historical and present anthropogenic carbon releases from forests and also in evaluating the possibilities of future potential carbon sequestration (Ciais et al., 2014). When disturbed, forested areas can act as sinks for atmospheric carbon or as a source of atmospheric carbon as it is dispersed by natural or human sources (Brown et al., 1996). Thus, they can be managed to alter the magnitude and direction of their carbon fluxes. Balancing ecosystem patters, ensuring food security, nurturing of living beings, their impact and change overtime with climate makes it more important in every aspect. Forests are now exploited rather than sustainably used as the demand has increased over the years with population growth and the never-ending needs. Preservation of biodiversity and ensuring the proper functioning of forest is crucial for the sustenance of human life on the planet.

1.1 Forest of India

As per the definition given by Forest Survey of India (FSI), any land which is more than 1 hectare in area, with a tree canopy density of more than ten percent, can be considered as the forest cover. India State of Forest Report (ISFR) is a biennial publication of FSI. The total forest cover of India as per the latest assessment report is 7,13,789 square kilometers (sq. km) which accounts for approximately 21.71 per cent of the total geographical area of the country. The forest cover of the country has been classified into three canopy density classes, which are Very dense Forest (VDF), Moderately Dense Forest (MDF), and Open Forest (OF). Area covered by the respective density classes are 99,779 square kilometers (3.04 percent), 3,06,890 square kilometers (9.33 percent) and 3,07,120 square kilometers (9.34 percent). Also, around 46,539 square kilometers account for scrub forest and 25,27,141 square kilometers account for the Non- forest areas. Tree species and tree crops are not distinguished in the forest cover data provided by ISFR. It includes all kinds of land, regardless of who owns it or its legal standing. The Forest Survey of India (FSI, 2021) has thus defined "forest cover" as all tree species, along with coconut trees, bamboos, fruit-bearing trees, and all areas, including forests, private, community, government, or institutional land, that meet the above mentioned criteria.

The current assessment shows an increase of 1,540 square kilometers or 0.22% of forest cover at the national level as compared to the previous assessment. The top five states in terms of increase in forest cover are Andhra Pradesh, Telangana, Odisha, Karnataka and Jharkhand.

1.2 Forest of Kerala

The total geographical area of the state is 38,852 square kilometers (FSI, 2021) and the total forest area is estimated to be 11521.993 square kilometers. This is approximately 29.65 percent of the geographical area of the state.

Table 1: Distribution of Forest area according to legal status in square kilometers (Source: Kerala Forest Department website, 2024)

Reserve forests	Proposed Reserve	Vested Forests	Ecologically Fragile Lands	Protected Area	Total area
6450.839	279.495	1589.478	135.997	3066.184	**11521.993**
55.99%	2.42%	13.80%	1.18%	26.61%	**100%**

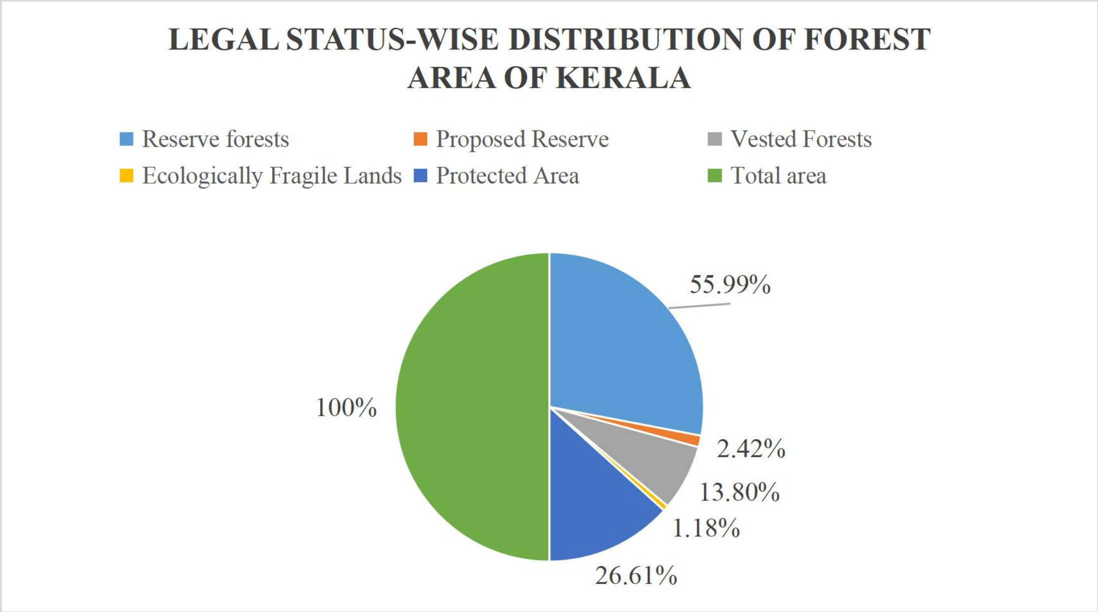


Figure 1: Legal status-wise distribution of forest area of Kerala

1.2.1 Reserved forests

Any land intended to be designated as a reserve forest and designated under Section 19 of the Kerala Forest Act, 1961, following the completion of the procedures outlined in Sections 5 through 18 of the Act, as announced under Section 4 of the Kerala Forest Act, 1961.

1.2.2 Vested forests

Any private forests where the Kerala Private Forest (Vesting & Assignment) Act, 1971's Section 3 grants the government ownership and possession of the forest, and where Section 4 of the Act designates such forests as Reserved Forests.

1.2.3 Ecologically Fragile Lands

Any portion of land held by any person that is adjacent to or surrounded by a reserve forest, vested forest, or other government-owned forest land that primarily supports natural vegetation is referred to as "Ecologically Fragile Lands" (EFL). Additionally, any land that has been designated as such by the government through notification in the official gazette under Section 4 of the Kerala Forest Act, 2003 is also considered EFL (Kerala Forest Department- KFD, 2024).

Table 2: Forest Cover of Kerala (Source: FSI, 2021)

Forest cover class	Area in square kilometers	Percent of Geographical Area
Very Dense Forest	1,944.32	5.00
Moderately Dense Forest	9,472.00	24.38
Open Forest	9,837.17	25.32
Total	**21,253.49**	**54.70**
Scrub	29.90	0.08

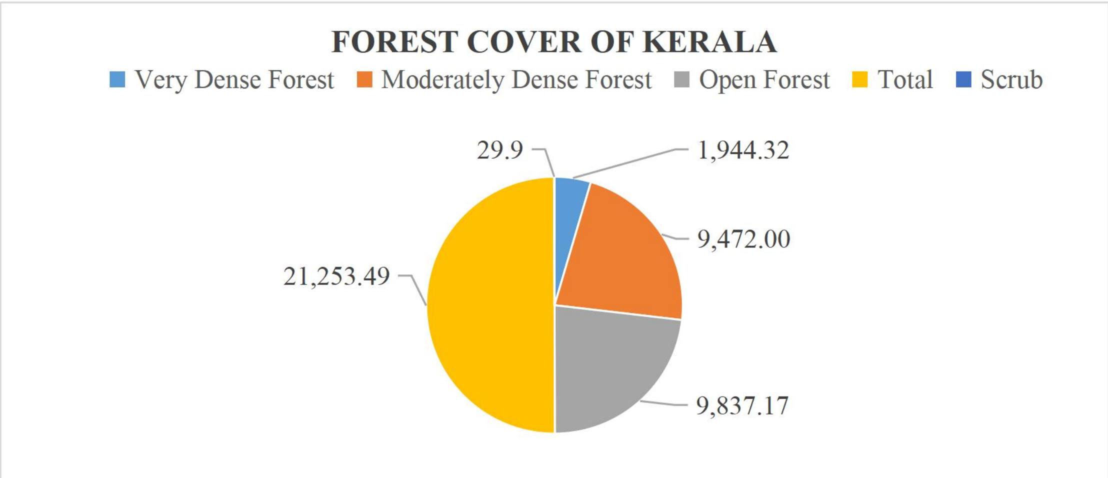


Figure 2: Forest Cover of Kerala

1.3 Forest Plantations in Kerala

The total plantation area is 9838.4 square kilometers, which is approximately 25.32 percent of the total geographical area of the state. The annual revenue of the department comes mainly from the thinning and final felling of these plantations.

Table 3: Species wise distribution of plantation (Source: Kerala Forest Department website, 2024)

Sl No.	**Plantation**	**Area in hectares (ha)**	**Area in Percentage**
1.	Bamboo, cane and reeds	9359.46	5.99
2.	Hardwood	82676.33	52.89
3.	Mangrove	371.06	0.24
4.	Softwood	11784.56	7.54
5.	Others	52124.92	33.34
	State total	**156316.351**	**100%**

1.4 Growing Stock (GS)

Forest inventory is essentially aimed at assessing the growing stock and other quantitative and qualitative parameters of the forests. Growing stock is the volume of all living trees in a forested area. Periodic estimation of the growing stock of wood is essential for developing national policies and strategies for sustainable use of the forest resource. It is a significant,measurable factor that is employed in the computation of the economic value of forests. It is an indicator of productivity and sustainability of forests and serves as the foundation for the computation of carbon stocks and biomass. Growing stock assessment provides information on the volume of timber availability outside the forests. Growing Stock from forest inventories is the primary input for Carbon estimates. The growing stock is utilized from the Working Plans to calculate the sustainable production of forest timber .

The GS of forests and Trees Outside Forests (TOF) have been generated at the national and state level. The total growing stock of wood in the country is estimated as 6,167.50 million cubic meters comprising 4,388.15 million cubic meters inside forest areas and 1,779.35 million cubic meters outside recorded forest areas. There has been a total increase of 251.74 million cubic meters (4.26%) in the GS of the country as compared to the previous estimates. Out of this, the increase in GS inside the forest is 114.68 million cubic meters (2.68%) and 137.06 million cubic meters (8.35%) outside the forest area. The average growing stock per hectare in forest has been estimated as 56.60 cubic meters.

According to the ISFR 2021, among all the states of the country, the highest per hectare GS in forest is in Kerala (139.32 cubic meters per hectare) followed by Uttarakhand and Goa. Among the Union Territories, the highest per hectare (ha) GS in forest is Jammu and Kashmir and Andaman and Nicobar Islands. In respect of the total volume of the GS, Arunachal Pradesh has maximum GS (418.99 million cubic meters) in forests, followed by Uttarakhand, Chattisgarh and Madhya Pradesh.

The trend of the GS, both inside and outside of forests, has been steadily rising over the last three biennial assessments. GS as a has whole increased by 6.92 per cent. According to FSI (2021), the GS inside forests has increased by 4.60 per cent and by 13.09 percent relative to TOF.

1.5 Carbon Stock

Carbon is the most abundant element and is essential for all known living systems. The carbon cycle comprises of a sequence of events, which enable life forms to exist and sustain on the Earth. The cycle can also be described in terms of sources and sinks. Carbon is added to the atmosphere by sources and removed from it by sinks. A certain amount of the energy from the Sun is reflected back into space while it enters the Earth's atmosphere, while the remaining portion is absorbed and re-radiated by greenhouse gases. The sources and sinks help in regulating the amount of greenhouse gases in the atmosphere which are essential for life on Earth. The most important sinks are oceans, forests and soil. The forests and oceans remove around one-fourth of the Carbon that gets added to the atmosphere (FSI, 2021).

Over the last five biennial assessments, the carbon stock of the country's forests has shown an increasing trend. The carbon stock has risen by about 542 million tonnes between the period of 2013 to 2021 (FSI, 2013-2021).

1.6 Forest biomass

Forest biomass serves as an important variable for evaluating carbon sequestration and carbon balance capacity of forest ecosystems. Biomass, in general, is an important indicator of ecological and management processes in the vegetation. According to Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use Land Use Change and Forestry (LULUCF), forest biomass is an organic product of photosynthesis which is divided into two components:

Above Ground Biomass (AGB) contain the part of the vegetation above the ground, for example, stumps, tree and foliage.

Below Ground Biomass (BGB) which includes the parts of the tree situated under the ground.

1.7 Above Ground Biomass (AGB)

The height of the vegetation cover affects how much above-ground biomass can build up on a place. Rainfall causes the cover to expand, reaching a maximum of essentially continuous canopy (Sankaran et al., 2005). Beyond this stage, additional biomass gain depends on growing height. Bio-mechanical factors, such as the tree's capacity to lift water to its leaves and anchor itself against wind, establish the fundamental limits on tree height (Koch et al., 2004).

Because it is useful in estimating forest cover, atmospheric carbon, and greenhouse gas concentrations, AGB is a frequently evaluated parameter. AGB assessment and monitoring is important for national GHG inventory and activities related to forest ecosystem. It provides inputs for policy formulation related to forestry sector and environment management, forest fire risk assessment and many more. AGB is the most visible of all the carbon pools and change in AGB indicates the impact of an intervention of the carbon pool.

1.8 Working Plan and Management Plan

The Working Plan (WP) is a written scheme of management to achieve the objectives of management. It is prepared for each of the forest divisions of a particular district. It separates the area into multiple Working Circles while outlining the overall goals for Working Plan area or division. Every Working Circle, which is often distinguished by unique vegetation and site characteristics, is given specific management objectives and a single set of Working Plan recommendations based on its overall suitability for a specific purpose. As a result, the Plan assigns diverse Working Circles' management objectives more emphasis than others. The Working Circles may even overlap under specific conditions.

Meanwhile, in the context of forest department, a Management Plan (MP) refers to a detailed, organized framework for the sustainable management as well as conservation of forest resources outlining the strategies and actions to maintain and improve the health of forest ecosystems. The MP ensures the sustainable use of forest products, protect biodiversity and meet the needs of local communities. Designation of specific areas within the forest for different uses, such as conservation zones, recreation area, timber production also comes under the objectives of MP.

1.9 Forest Administrative Set-up

For the purpose of preparation of Working Plans and carrying out forest protection activities, forest areas are divided into various classes. In case of the state of Kerala, the highest category is Circle. There are five Circles- Southern Circle, High Range Circle, Central Circle, Eastern Circle and Northern Circle. Within the Circles, there are Divisions, then Ranges and the smallest class is Beat/ Station/ Section. In order to provide effective protection and with a view to afford more collective strength and security to the forest protective staff, the Kerala Forest Department implemented the Forest Station system in 1988, modeled after the police station beat/ section system.

Table 4: Division/ Range wise details of Forest Stations (Source: KFD Working Plan)

Sl no.	Division	Range	Forest Stations
Southern Circle Kollam			
1	Thenmala	Thenmala	Kadamanpara
2	Achenkovil	Achenkovil	Kumbavarutty
3	Punalur	Pathanapuram	Ambanar
			Punnala

		Anchal	Ezhamkulam
4	Konni	Konni	Kumaramperoor (South)
			Kumaramperoor (North)
		Naduvathumoozhy	Kokkathodu
			Karippanthodu
			Padom
		Mannarappara	Chempala
			Mannarappara
5	Ranni	Ranni	Karikkulam
			Kanamala
			Rajampara
		Vadasserikkara	Chittar
			Gurunathanmannu
			Thannithodu
		Goodrikkal	Plappally
			Kochukoickal
			Pachakkanam
High Range CircleKottayam			
6	Kottayam	Nagarampara	Vazhathoppu
			Vairamony
		Ayyappancoil	Kanchiyar
		Erumeli	Murinjapuzha
			Vandanpathal
			Placherry
7	Kothamangalam	Thodupuzha	Veloor
8	Munnar	Munnar	Pettimudy
		Adimali	Machiplavu
			Panamkutty
		Neriyamangalam	Nagarampara
			Inchathotty

			Valara
9	Marayoor	Marayoor	Marayoor
			Nachivayal
		Kanthalloor	Kanthallor
			Vannanthura
Central Circle Thrissur			
10	Thrissur	Vadakkanchery	Erumapetty
			Poongodu
			Mayannoor
		Machad	Akamala
			Elanad
			Vazhani
		Pattikkad	Pattikkad
			Ponganamkad
			Mannamangalam
			Vaniyamapara
11	Vazhachal	Charpa	Kannamkuzhy
		Vazhachal	Vazhachal
			Mukkumpuzha
		Kollathirumedu	Kollathirumedu
		Sholayar	Malakkappara
			Sholayar
		Athirappally	Athirappally
			Ezhattumugham
12	Chalakudy	Pariyaram	Konnakuzhy
			Chaippankuzhy
		Vellikulangara	Mupliyam
13	Malayattoor	Kodanadu	Perumthodu
			Erumukham
			Mekkappala

		Kalady	Karakkadu
			Kannimangalam
			Evergreen
		Thundathil	Bhothathankettu
			Karimpani
			Edamalayar
			Vadathuppara
		Kuttampuzha	Pooyamkutty
			Anakulam
		Edamalayar	Ennakkal
			Perumuzhy
Eastern Circle Palakkad			
14	Nemmara	Kollengode	Thekkady
		Nelliyampathy	Nelliyampathy
		Alathur	Mangalam dam
15	Mannarkkad	Mannarkkad	Palakkayam
			Mannarkkad
			Thiruvizhamkunnu
		Attappady	Pudur
			Mukkali
		Agali	Ommala
			Sholayar
			Singappara
16	Nilambur (South)	Karulai	Padukka
			Nedumkayam
		Kalikavu	Chakkikuzhi
			Karuvarakundu
17	Nilambur (North)	Edavana	Akampadam
			Edacode
			Kodumpuzha

		Nilambur	Vaniyampuzha
			Kanjirapuzha
		Vazhikkadavu	Nellikuthu
			Pothukallu
Northern Circle Kannur			
18	Wayanad (North)	Mannanthavady	Makkiyad
		Begur	Thirunelly
			Thalapuzha
		Periya	Kunhome
			Varayal
19	Wayanad (South)	Chedleth	Irulam
			Pulpally
		Meppadi	Mundakkai
			Vythiri
20	Kozhikode	Peruvannamoozhi	Kakkayam
			Peruvannamoozhy

1.10 Global Forest Watch (GFW)

Global Forest Watch (GFW) was founded by the World Resources Institute (WRI) in 1997 as an integral part of the Forest Frontiers Initiative. Initially, it was a network of non-governmental organizations (NGOs) that published current reports on the condition of the forests in four pilot nations: Indonesia, Canada, Gabon, and Cameron. GFW is an online platform that offers instruments and data for forest monitoring. It gives individuals access to information in almost real-time, enabling them to manage forests, identify unsustainable activities, protect land and its resources, create sustainable products, and conduct cutting-edge conservation research.

1.11 Forest Survey of India (FSI)

The Forest Survey of India (FSI) is a premier organization under the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India established in 1981. FSI is primarily responsible for conducting comprehensive surveys and assessments of the country's forest resources. FSI conducts biennial national forest resource assessments and publishes a report called India State Forest Report (ISFR) which includes detailed information on forest cover, forest types, forest density and changes in forest cover over time. This report serves as a key resource for policymakers, researchers and conservationists. FSI engages in studies related to climate change impacts on forests and contributes to the country's efforts under the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) mechanism. Therefore, FSI is integral to understanding the dynamics of forest ecosystems in India and addressing challenges related to deforestation , climate change and biodiversity loss.

1.12 Survey of India (SoI)

Under the Department of Science and Technology, Survey of India (SoI) is the National Survey and Mapping Organization of India. It is specifically the duty of the SoI to see to it that the nation's territory is appropriately investigated and mapped in order to produce base maps for integrated development. To better serve the expanding needs of the user community, its specialist directorates, including the Indian Institute of Surveying and Mapping and the Geodetic and Research Branch, have been reinforced.

1.13 Forest Above Ground Biomass (AGB) by Remote Sensing (Maurizio Santoro)

Using a set of Biomass Expansion and Conversion Factors (BECF) and techniques to expand on-ground estimations of wood density and stem-to-total biomass expansion factors, AGB was acquired from Growing Stock Volume (GSV) in order to create a worldwide raster datasets. The volume of all living trees greater than 10 cm in diameter at breast height, measured over bark from ground or stump height to a top stem diameter of 0 cm, is known as the Growing Stock Volume (unit: cubic meter per hectare), excluding smaller branches, twigs, foliage, flowers, seeds, stump, and roots (FAO, 2024). The unit of AGB is tonnes per hectare or Mega grams per hectare and is defined as the mass, expressed as oven-dry weight of the woody parts (stem, bark, branches and twigs) of all living trees excluding stump and roots.

1.14 Publish or Perish (PoP)

Publish or Perish is a software program that retrieves and analyzes scholarly citations. Since 2006, the program has been actively developed by volunteers with the goal of assisting individual academics in effectively presenting their case for research impact. It gathers the raw citations from multiple sources, evaluates them, and displays a number of citation metrics, such as the overall number of citations, the number of papers, and the h-index. A comprehensive guidance file with search advice and more details on the citation metrics is also included. Individual academics, government agencies, Non-Governmental Organizations, and research facilities are some of the users.

1.15 Objectives of Study

1. Estimation of forest biomass dynamics by time series analysis of information regarding forest area, growing stock, forest utilization and plantation data from the forest ranges and divisions of selected districts of Kerala using available maps and remote sensing techniques

2. Analysis of Carbon stock

CHAPTER 2
REVIEW OF LITERATURE

Forests and the associated land use are integral to the way in which the planet's carbon cycle operates and how it may be altered by human actions (Schlunegger et al. 2015). The relationship between forests and carbon dynamics has profound implications for our understanding of global climate change and the role of sustainable land management practices. Forest ecosystems are among the most effective natural carbon sinks on the planet, capable of sequestering and storing vast quantities of atmospheric carbon dioxide (Purves & Pacala, 2008; McDowell et al., 2020). Forests play a crucial role in the global carbon cycle by absorbing approximately 25 percent of anthropogenic carbon dioxide emissions making them significant contributors to carbon uptake and storage, or otherwise called as sinks (Matthew, 2021). Richard and Flint (1994) estimated India's forest area in 1880 and 1980, highlighting a decrease from 102.68 million ha to 64.6 million ha. India's forest carbon densities vary by region, with steady trends in the deciduous forests of Central India, fluctuations in the Western Ghats, and an expansion of the forest carbon pool in the Eastern Himalayan region as a result of increased forest cover. With the highest carbon pools, Arunachal Pradesh, its carbon density remains almost constant, with an increase in its forest area. Forests act as C sources and sinks as deforestation, afforestation, forest management and the natural growth/decay cycle of vegetation compete and overlap in a complex manner. Understanding the spatiotemporal patterns of forest carbon fluxes is crucial for developing effective strategies to mitigate climate change through nature-based solutions. Numerous studies have explored the various drivers and processes that influence the carbon dynamics of forest ecosystems, with a growing body of research highlighting the importance of factors such as nutrient availability, climatic conditions, and human land management practices (Vries, 2014; Dixon et al., 1994; Sedjo & Sohngen, 2012). Slowing deforestation and increasing forestation efforts have been identified as key measures to conserve and potentially enhance forest carbon sinks globally (Dixon et al., 1994). In order to prevent soil deterioration and preserve soil health, carbon management measures must be put into place immediately, which can be demonstrated by the assessment of Land Degradation Index (LDI), which further quantifies the degree of land degradation in the ecosystems.

Human activities have significantly impacted genetic diversity in forest ecosystems by influencing evolutionary processes such as extinction, selection, drift, gene flow and mutation. These impacts have often led to reduction in genetic diversity within species. Rapid changes in forest composition are occurring, potentially surpassing the adaptive capacity of long-lived species (Ledig, 1992). Land uses play a crucial role in global carbon cycles with native forest lands having higher potential to sequester carbon rather than the croplands or plantation areas, directly impacting soil quality and climate change. The conversion of forests to other land uses has led to a significant decline in soil carbon sequestration, highlighting the importance of understanding land use change (LUC) on soil carbon status. Carbon stocks were found to be highest in the forests, followed by plantations (specifically tea plantations) and croplands, emphasizing the differences in carbon storage among different land use types. Microbial Biomass Carbon (MBC) as well as Microbial Biomass Nitrogen (MBN) also showed similar trends on assessment (Jagadesh et al., 2022).

While forests are generally considered carbon sinks, the long-term trends in forest carbon cycling are not always in the same direction and can be influenced by a variety of interacting factors. Factors like small and medium-sized growing trees, invasive species, mixed forests, agroforestry and agrosilviculture significantly contribute to carbon assimilation in the atmosphere. Based on forest types and regions in North, Central, and Southern India showcases the variability in AGB and Carbon stock influenced by climatic and geographic factors (Salunkhe et al., 2018). Derya et al (2021) stated the importance of considering landscape structure in assessing carbon dynamics with factors like forest type, development stage and coverage influencing carbon density. In carbon sinks, anthropogenic incursions such as pollution, deforestation and changes in land use have made the browning of vegetation worse. Under climate change, the intensity and duration of disturbances are the major driving factors of this condition. Due to habitat degradation and fragmentation brought by human activities, the natural landscape has changed, which has an adverse effect on the health and vigor of the plants (Kashyap et al., 2023). Improved forest management practices coupled with increased awareness and economic well-being, reduce pressure on forests, leading to enhanced forest structure quality and a more diverse distribution of carbon dynamics. The carbon dynamics is influenced by factors such as human land-use, human- caused climate change and disturbances, which vary regionally and impact the total amount of carbon stored (Matthew, 2021). Viana (2022) discussed the concept of bio-energy with carbon capture and storage (BECCS) as a potential solution for carbon sequestration, by exploring the idea of growing trees or crops for energy, capturing their carbon content, and permanently sequestering it to mitigate climate change.

Variations in forest area and per hectare changes in forest biomass have an impact on the long-term net flux of carbon between terrestrial ecosystems and the atmosphere. In tropical climates, these uncertainties are more pronounced. According to Houghton (2005), both tropical and temperate forests are important for maintaining the global carbon balance. The Indian tropical deciduous forest contributes dynamic elements to the knowledge of the spatial patterns in AGB and Carbon (AGBC) because of its increased species richness, uneven stem densities and stem cover, multi-storied canopy, and microclimate (Behera et al., 2017). According to Dixon et al. (1994), tropical forests are significant carbon sinks that account for around 40% of the terrestrial carbon storage. The tropical forests are among the most productive ecosystems on the earth, estimated to account for above one-third of global net primary productivity (NPP) (Gaston et al., 1998, Field et al., 1998).

Around 40 per cent of the terrestrial carbon is stored in the natural forests and owing to its diverse species composition and high productivity, these ecosystems contribute significantly to net primary productivity (NPP) (Hareesh and Nagarajaiah, 2019). For evaluating the structural and functional characteristics of forest ecosystems under various environmental circumstances, estimating AGB is a significant criterion (Brown et al., 1996). One of the key variables defining how a forest ecosystem functions is its AGB. Research on the biomass of forest vegetation is crucial for calculating the carbon cycle both locally and globally, as well as for figuring out how much carbon is stored in the dominant tree component. The measurement of AGB of dominant tree species in different forest communities/plant functional types is crucial because these species have a significant impact on the amount and pattern of energy flow that is stored in the form of various organic substances and material that is continuously circulated between biotic and abiotic ecosystem components in the trunks, branches, leaves, and roots. The differential between production through photosynthesis and consumption through respiration, mortality, and harvest determines the amount of AGB in a forest. Hareesh and Nagarajaiah (2019) stated that evergreen forests exhibited higher biomass and carbon content as compared to the dry and moist deciduous forests. This fluctuation is attributed to the variations in stand density and basal area. Other factors that played a significant role are Species richness, diversity and vegetation structure (parameters like GBH classes and Importance Value Index).

With increasing atmospheric carbon dioxide concentration and global warming, there could be a significant increase in NPP (Ravindranath et al., 2006). Monitoring forest biomass allows for better assessment of the overall carbon balance, aiding in the development of effective conservation, climate change mitigation efforts and land management strategies. Soil surface CO_2 flux plays a crucial role in the terrestrial carbon cycle, with soil temperature being a key environmental factor.Understanding the uncertainty in estimating forest biomass is crucial for accurately assessing the global carbon balance (Houghton, 2005). Improved knowledge of forest biomass enables more precise modelling of future climate scenarios, contributing to informed decision making for sustainable development and biodiversity conservation. Nandy et al. (2022) investigated on the spatio-temporal variability of water use efficiency (WUE) in major forest formations across India, which is crucial for sustainable forest management and ecosystem functioning. Water Use Efficiency (WUE) is a critical parameter reflecting the balance between carbon gain through photosynthesis and water loss through transpiration, thereby inflencing the productivity and resilience of forests. With the highest values observed in temperate forests and the lowest in tropical forests, significant variations in WUE could be found, due to several key influential factors such as temperature, precipitation, vapor pressure deficit and solar radiation.

In India, agroforestry systems such as silvopastural systems and agri-silvicultural systems have been found to play a significant role in carbon sequestration and thereby, in climate change mitigation. Factors such as tree species composition, management practices and land-use history influences the carbon capture potential (Murthy et al., 2013). These systems offer additional benefits such as biodiversity conservation, improved soil health and enhanced resilience to climate change.

Conifer tree growth declines under all climate scenarios and management regimes. Pine plantations and white fir trees also experience much more severe reductions in yield. These imply that in temperate conifer forests, growth often declines under projected future climates (Battles et al., 2008). Short rotation plantations can be implied as a method to rapidly produce biomass for energy, contributing to reduced greenhouse gas emissions (Kaul, 2010). For the Earth's carbon cycle and budget to remain intact, the Indian Himalayan Forest Ecosystem (IHFE) is essential as it is made up of different carbon pools important for sequestration, including dead organic matter, below- ground biomass and above-ground biomass. Mismanagement and over exploitation has reduced the potential for biomass buildup and sequestration in the IHFE, posing concerns and could also worsen global warming (Kumar et al., 2023).

Combining spectral responses and image textures has shown to enhance biomass estimation performance. Geometric accuracy of field sample plots and remotely sensed data are essential to avoid spurious relationships between AGB and remote sensing data (Lu, 2006). Digital Elevation Models (DEMs) are crucial for various disciplines as it is the raster representation of the bare ground topographic surface of the Earth excluding surface objects. DEMs are represented in a two-dimensional grid, considering the atmosphere, hydrosphere, cryosphere, biosphere and anthrosphere (Guth et al., 2021).

Pasha et al (2023) stated the importance of remote sensing in mapping and characterizing plantations to estimate carbon stocks. Human activities influence phytomass and soil carbon pools. Orchards and plantation crops have a significant impact in contributing to terrestrial carbon pools, but often lack attention. Trees outside forests (TOF) offers products and services, particularly to rural communities and wood-based industries. The disturbance of natural forests in India due to large-scale commercial and horticulture crops, affects the overall forest and tree estimates in the country. Urban forests also play a crucial role in offsetting carbon emissions from industries, highlighting their significance in maintaining environmental balance

(Mandal et al., 2022). Different land cover types within the urban forests, such as dense forests, open forests, and scrub lands, contributes variably to carbon sequestration, with dense forests exhibiting the highest carbon storage capacity per unit area. Policymakers and urban planners can implement targeted measures to enhance carbon capture and storage in urban forest ecosystems, supporting sustainable development and environmental quality. Due to restrictions on tree felling and conservation initiatives, the production of round wood from Indian forests has declined over time, necessitating the importation of timber to meet demand.

We should emphasize the importance of incorporating climate change considerations in the long-term planning process of the forest sector to mitigate the potential impacts on forest ecosystems in India (Ravindranath et al., 2006). The global concern over climate change has led us to focus on reducing greenhouse gas emissions, especially carbon dioxide, and measuring the carbon sequestration capacity of forests and soils (Kaul, 2010). Forests can be managed to alter the magnitude and direction of Carbon fluxes. Biomass is an important indicator of ecological and management processes in vegetation. Meanwhile, AGB is considered as one of the inputs considered while policy formulation and is the most visible of all Carbon pools. India was found to have the capacity to balance environmental concerns with economic development by utilizing marginal lands to build more sinks. Integrating trees with agricultural crops in agroforestry can lead to increase in productivity and income for farmers, simultaneously contributing to mitigation efforts (Murthy et al., 2013). We must also emphasize on the need to overcome financial, technical and institutional barriers. India is committed to meet its targets under Nationally Determined Contributions (NDCs) in Paris Agreement (2015), which is to increase the carbon dioxide equivalent from 2.5 to 3 billion tonnes by 2030. National policies have prioritized the conservation and sustainable management of forests, resulting in the growing significance of forests and plantations in the context of climate change mitigation.

CHAPTER 3
MATERIALS AND METHODS

2.1 Study areas

The districts selected for the purpose of the study are Idukki and Palakkad districts.

2.1.1 Idukki District:

Idukki which lies in the Western Ghats of Kerala, is the largest district of the State. It was formed on 26th January 1972 and accounts for about 12.9% of the total geographical area of the State but has the lowest population density. This High range district of Kerala is geographically renowned for its mountainous hills and dense woods. About 66 percent of the State's power needs come from the Hydroelectric Power projects in Idukki.

It features large tracts of forest reserves, and while villages are sparsely populated, urban areas are heavily populated. It's also referred to as Kerala's Spice Garden.

Table 5: Idukki district - Geographic, Administrative and Demographic data
(Source: Idukki district information website, 2024)

Sl No.	Feature	Characteristics
1.	Total geographical area	1,971.14 sq miles or 5,105.75 sq km
2.	Geographical coordinates	9.85°N, 76.9528°E
3.	Population	1108974
4.	Blocks	8
5.	Grama Panchayats	52
6.	Villages	68
7.	Municipalities	2

The district shares its boundaries with the districts of Kottayam in the South-West, Pathanamthitta in the South, Thrissur in the North, Ernakulam in the North-

West and Theni in the East (Tamil Nadu). The district is home to the Western Ghats mountain ranges, which includes the tallest peak in South India, Anamudi Peak. The major rivers of the district are Thodupuzhayar, Periyar and Thalayar.

The climatic conditions of Idukki exhibit a considerable fluctuation from West to East. The westerly divisions of Idukki receive moderate weather, temperature altering from 21 degree Celsius to 27 degree Celsius with minimal seasonal variation. Meanwhile, the easterly divisions situated in the upland region, have a fairly low temperature altering between 7 to 15 degree Celsius. The district gets abundant rainfall from North- East and South- West monsoon and the annual rainfall is about 240 mm.

The biggest Arch dam in Asia is situated in Idukki, known as Idukki Dam, between two mountains- 'Kuravanmala' and 'Kurathimala'. Other dams of Idukki are Mullaperiyar Dam, Cheruthoni Dam, Ponmudy Dam Anayirangal Dam, Kallarkutty Dam, Kochu Pampa Dam, Kundala Dam and many more. The major cultivations carried out in the district are Pepper, Cardomom, Tea, Rubber and Coffee. Neelakurinji, scientifically known as *Strobilanthes kunthiana* is a re purple-blue colored flower which only blossoms once in every twelve years in the Neelakurinji hills of Munnar.

From 2000 to 2020, the district gained 739 hectares of tree cover region-wise equal to 4 percent of all tree cover gain in Kerala, out of which 92% of the gain occurred outside of plantations.

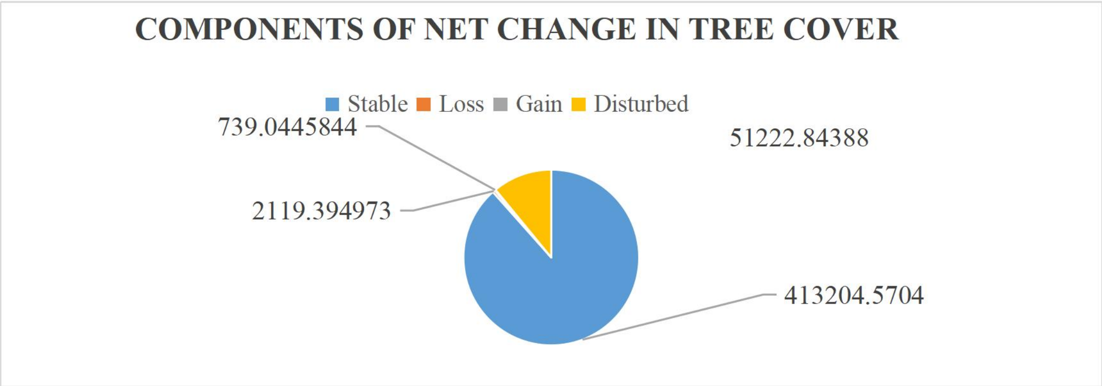


Figure 3: Components of net change in tree cover in Idukki district(Source: Global Forest Watch, 2024)

Table 6: List of Division- Range- Section- Beats of Idukki District

Sl No.	Division	Range	Section	Beats
1	Marayoor	Marayoor		Marayoor
				Nachivayal
		Kanthalloor		Kanthalloor
				Vannanthura
2	Kottayam	Erumely		Plachery
				Vandampanthal
		Kumily		Chinnar
				Kallar
				Vandanmedu
				Puliyanmala
				Cumbummettu
		Ayyappankovil		Kattappana
				Kanchiyar
		Nagarampara		Vazhathoppu
				Kulamavu
3	Mankulam	Mankulam		Mankulam
				Munipara
				Kallar
				Viripara
		Anakulam		Anakulam
				Kadalar
4	Kothamangalam	Kothamangalam	Thattekkad	Thattekkad
				Valiyachal
			Kothamangalam	Oonukal

				Neriyamangalam
		Mullaringad	Chullikandam	Chullikandam
				Vellakkayam
			Mullaringad	Chattamattom
				Venmony
		Kaliyar	Naduvakkad	Naduvakkad
				Thommankuthu
			Kaliyar	Thencodam
				Pachila
		Thodupuzha	Arakulam	Arakulam
				Thodupuzha
			Kulamavu	Kulamavu
				Pannimattom
			Peringassery	Peringassery
				Nedumpara
			Veloor	Veloor
				Keeriplavu
5	Munnar	Neriyamangalam	Nagarampara	
			Karimanal	
			Inchathotty	
		Adimaly	Machiplavu	
			Panamkutty	

		Devikulam	Bodimettu	
			Pathinettampady	
			Pallivasal	
			Aruvikadu	
		Munnar	Pettimudi	

2.1.2 Palakkad District:

Palakkad district, formed on 1st January 1957, is the second largest district in the state of Kerala. It accounts for about 11.53% of the total land area of the State with its share of population as 8.2%. It is often called as the Gateway of Kerala as the district opens the state to the rest of the country through the Palakkad Gap with a width of 32 to 40 kilometers, bordered by The Sahya Mountain Ranges. The district's distinct features, including its climate and the cultural and commercial exchanges between the State and the rest of the nation, are mostly attributed to the mountains.

In addition, Palakkad holds the distinction of being one of the state's most significant industrial and agricultural districts. This district is one of the main granaries of Kerala and its economy is primarily agricultural. Over 65 per cent of the workforce is employed in agriculture, and 88.9 per cent of people living in the district are rural.

The district is bounded on the North by Malappuram district, in the East by Coimbatore district of Tamil Nadu, in the South by Thrissur district and in the West by Thrissur and Malappuram district. Bharathapuzha, the longest river in Kerala, originates from the highlands and flows through the entire district. The other important rivers in this districts are Gayathripuzha, Kannadipuzha, Kalpathypuzha, Thoothapuzha, Bhavanipuzha and Kunthipuzha.

This district is gifted with the beauty of Nelliyampathy hills, the Silent Valley National Park, the Parambikulam Wildlife Sanctuary, Attappady hills and more than half a dozen dams like Malampuzha, Mangalam, Pothundi, Kanjirapuzha, Siruvani, Parambikulam, etc. Lion-tailed macaque is a main attraction in the Silent Valley National Park region.

Table 7: Palakkad district - Geographic, Administrative and Demographic data (Source: Palakkad district information website, 2024)

Sl No.	Feature	Characteristics
1.	Total geographical area	1,752 sq miles or 4,542.91 sq km
2.	Geographical coordinates	10.7867° N, 76.6548° E
3.	Population	29,52,254
4.	Blocks	13
5.	Taluks	7
6.	Villages	157
7.	Muncipalities	7

Located at an elevation of 97.24 meters above sea level, Palakkad has a tropical wet and dry climate. The district's yearly temperature is 28.05 degree Celsius and it is 2.08 percent higher than India's averages and typically receives about 242.81 millimeters of precipitation and has approximately 229 rainy days annually.

From 2000 to 2020, Palakkad experienced a net change of 3.83 kha (1.1 percent) in tree cover.

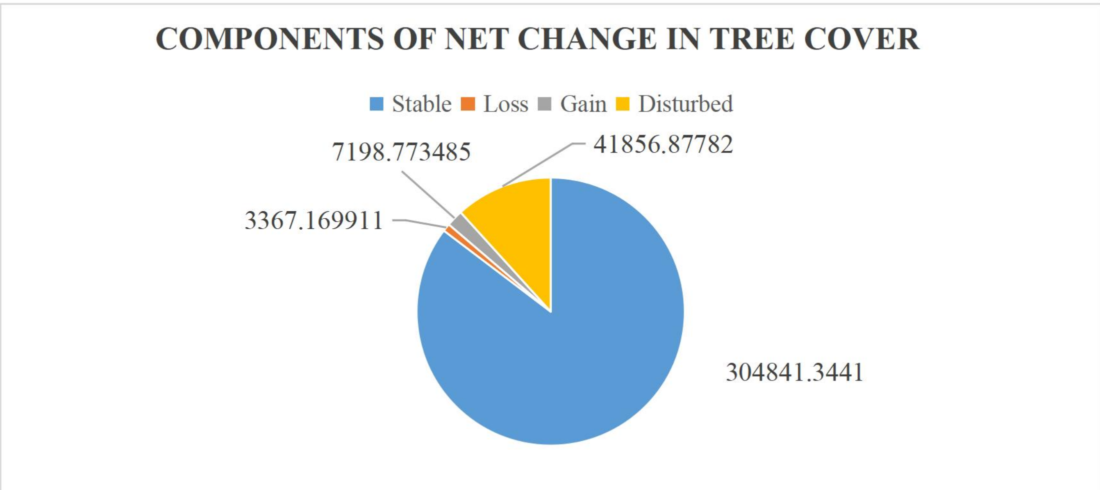


Figure 4: Components of net change in tree cover in Palakkad district (Source: Global Forest Watch, 2024)

Table 8: List of Division- Range-Section- Beats of Palakkad District

Sl No.	Division	Range	Section	Beats
1	Mannarkkad	Mannarkkad		Palakkayam
				Thiruvizhamkunnu
				Mannarkkad
		Agali		Sholayar
				Ommala
				Singappara
		Attappady		Mukkali
				Pudur
2	Nemmara	Alathur		Kuthanur
				Peringottukurissi
				Tarur
				Kadappara
				Vizhumala
				Palakkuzhy
		Kollengode		Koduvayur
				Kollengode
				Anamala
		Nelliyampathy		Kaikatty
				Pothundy
				Karadikunnu
				Kalchady
				Anjilur
3	Palakkad	Olavakkode	Dhoni	Dhoni
				Puliampally
				Kalladikode

			Mundur	Mundur
			Elival	Elival
				Sappal
			Palakkad	Palakkad
		Walayar	Akathethara	Akathethara
			Pudussery	Pudussery
			Malampuzha	Malampuzha
				Kottekkad
			Walayar	Pallumpara
				Varalli
		Ottappalam	Thiruvazhiyode	
			Kulappully	

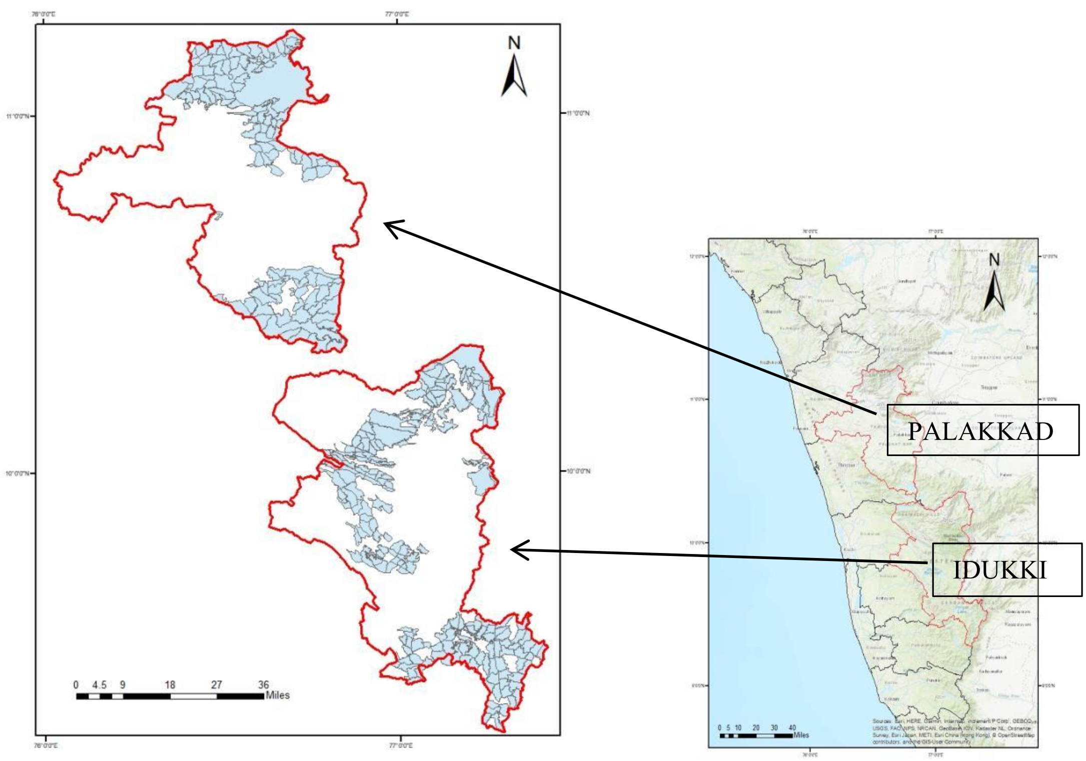


Figure 5: Map demonstrating the study areas- Idukki and Palakkad Districts (with their beat boundaries)

2.2 Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) is a raster representation of the bare ground (bare earth) topographic surface of the Earth excluding any surface objects such as trees, buildings, etc. DEMs are created from a variety of sources. United States Geological Survey DEMs (USGS DEMs) used to be derived primarily from topographic maps which are being systematically replaced with DEMs derived from high-resolution Light Detection and Ranging (LIDAR) and Interferometric Synthetic Aperture RadaR (IfSAR) (Alaska only) data. The resolution—the separation between sample points—determines the accuracy of the DEM data. The actual sampling surface used to create the original DEM and the type of data (floating point or integer) are the other factors affecting accuracy. The errors in DEMs are often categorized as either sinks or peaks. A sink, also referred as a depression or pit, is an area surrounded by higher elevation values. Likewise, a spike or peak is an area surrounded by cells of lower value. These are more typical examples of natural features and are less detrimental to the calculation of flow direction.

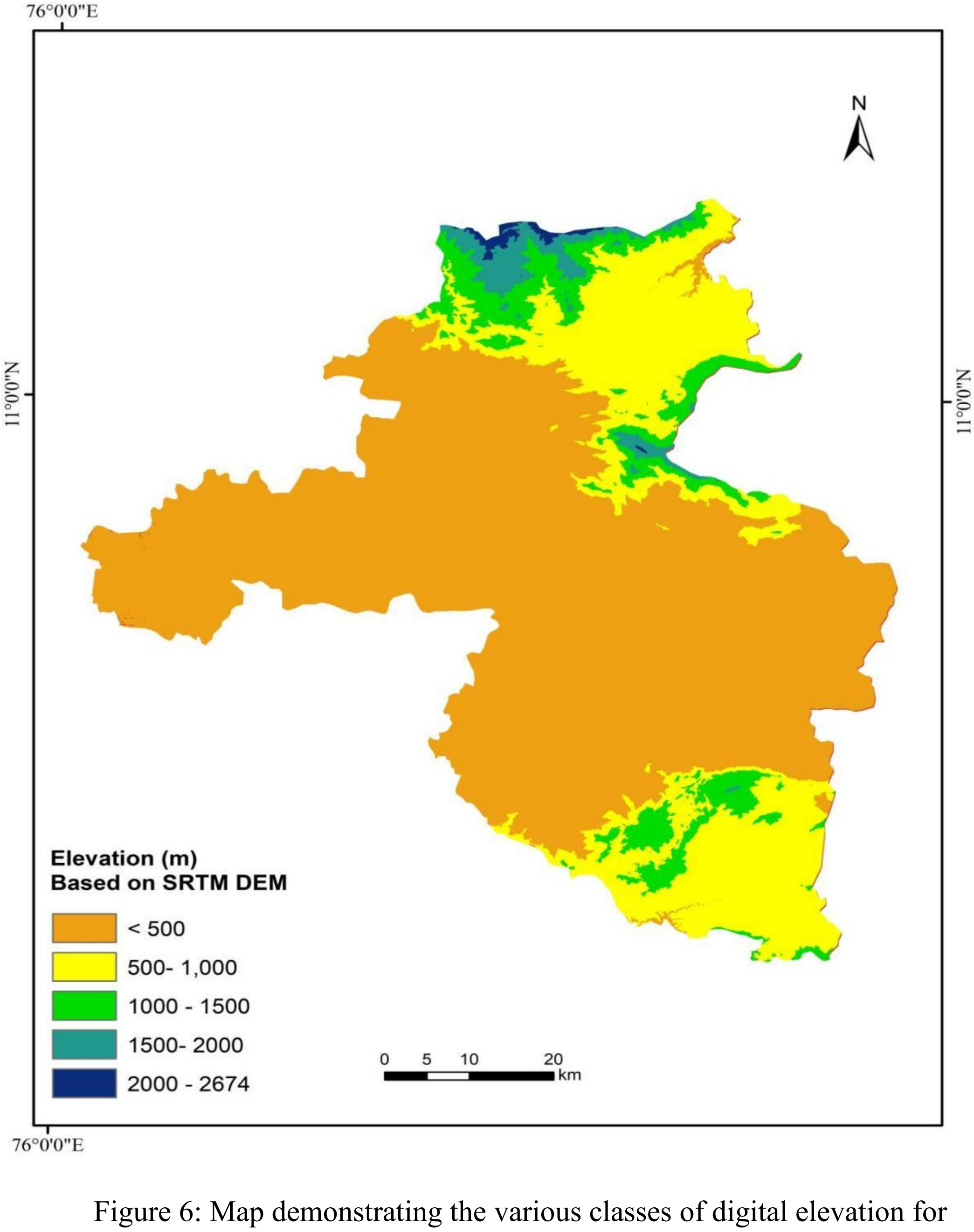


Figure 6: Map demonstrating the various classes of digital elevation for Palakkad District

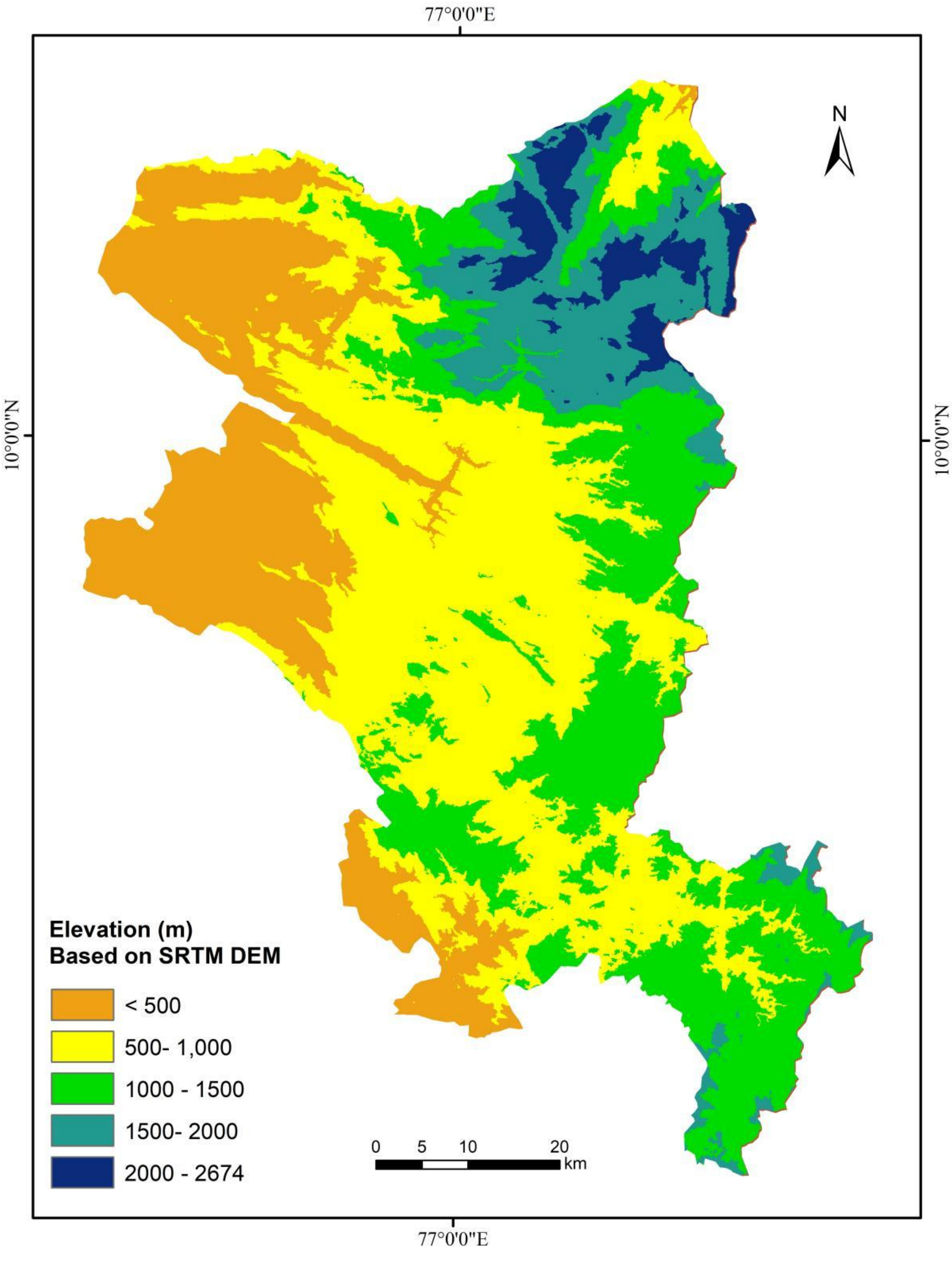


Figure 7: Map demonstrating the various classes of digital elevation for Idukki District

2.3 Mapping of plantations

While mapping the different plantations for both the districts, for ease of understanding, codes were assigned to each of the plantation type.

Table 9: Plantation types and their respective vegetation codes

Sl No.	Vegetation type	Vegetation code or Id
1.	Bamboo	4
2.	Teak	7
3.	Eucalyptus	8
4.	Mango	9
5.	Rubber	10
6.	Coconut	11
7.	Cashew	12
8.	Banana	13
9.	Coffee	15
10.	Tea	16
11.	Sandal	19
12.	Casuarina	20
13.	Miscellaneous	22
14.	Cardamom	23
15.	Eucalyptus and softwood	24
16.	Cardamom and coffee	25
17.	Cardamom and tea	28
18.	Pine	40
19.	Wattle	41
20.	Betel	47
21.	Eucalyptus and wattle	50
22.	Bamboo and eucalyptus	53
23.	Bamboo and sandal	54
24.	Tea and rubber	55

25.	Gum tree plantation	39
26.	Sandalwood	56
27.	Cinchona	57
28.	Rosewood	58
29.	Teak and softwood	62
30.	Tea and coffee	63
31.	Neem	70
32.	Eucalyptus and teak	73
33.	Rosewood	89
34.	Acacia	90
35.	Oil palm	97
36.	Pepper	91
37.	Cocoa	92
38.	Mulberry	93
39.	Pineapple	94
40.	Softwood	38
41.	Reserve Forest (RF)	27

2.4 Methodology

In order to understand the forest carbon dynamics in the best way possible, we chose the two districts which comes first and second in terms of the forest cover in the state of Kerala- Idukki and Palakkad respectively. For this purpose, we obtained quantitative data from the Forest Working Plans of both the districts. Some of the Working Plans available were downloaded from the website of Kerala Forest Department. Data which were not available were collected manually from the Forest Library at Kerala Forest Department Headquarters in Thiruvananthapuram. The data that were collected spans over the period of 2000 to 2030. Along with the Working Plan data, data from India State Forest Report, published by Forest Survey of India and data from a few of the published literatures were also considered for the study.

Toposheets of both the districts were downloaded from the Survey of India (SoI) website and geo rectification was done using Arc Geographic Information System (ArcGIS) software. The scale of the toposheets is 1: 50,000. GIS layers were created by digitizing the toposheets. From these digitized toposheets, the extent of all plantation types and Reserve Forests were calculated. The forest cover area obtained from the digitized polygons is compared with the forest cover data reported in the Forest Survey of India 2021 reports.

The Working Plan data is prepared for each of the forest divisions accordingly. Data used from the Working Plans include:

a. Planted and Harvested year of teak plantations
b. Volume of teak plantations
c. Dimensions of each species in the natural forests' of the selected ranges (radius and height)
d. Volume of timber
e. Mass of firewood
f. Natural tree cover and Plantation tree cover

The natural and plantation tree cover extent of Idukki and Palakkad districts from the year 2000 to 2023 is calculated from the Working Plan data and the unavailable data was retrieved from Global Forest Watch website.

Palakkad district is selected for studying the correlation between age and Growing Stock (GS)/ Mean Annual Increment (MAI)/ Volume of timber and/or Mass of firewood. MAI is calculated from the volume and age of the plantation. The data is then graphically plotted with age on x-axis and the dependent parameter on the y-axis. The correlation between age and the variable is studied using these plots.

From the dimensions as per given in the Working Plan for the species of natural forests of the selected divisions of Idukki district, volume of the particular species were calculated.

Basal Area (m^2/ha)= Sum of Cross Sectional Area of all trees/ Area (ha)

Volume (m^3)= [Tree Basal Area (m^2) * Height (m)]/ 3

MAI (m^3/ha/year)= Volume (m^3/ha)/ Age (years)

The Above Ground Biomass (AGB) data for the year 2010 published by Maurizio Santoro is spatially plotted for both the districts and studied for the analysis of the change in biomass with the prominence of vegetation.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 IDUKKI DISTRICT

4.1.1 Plantations

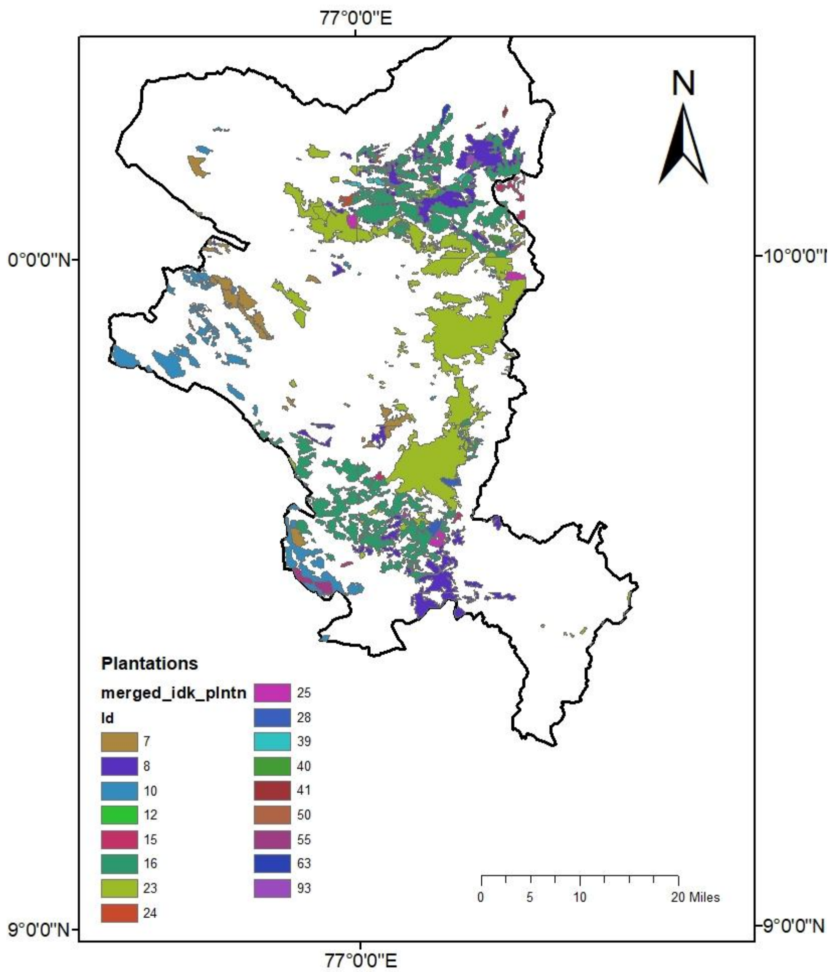


Figure 8: Map demonstrating the different plantations of Idukki district

The geographical area of the district is 5,105 sq. km approximately. Plantations occupy about 1,126.652 sq. km of this area, that is about 22 per cent of the geographical area. Similarly, it can be concluded that about 35 per cent of the forest cover is occupied by the plantations. Among the different plantations that has been mapped, Tea, Cardamom and Eucalyptus plantations occupy the most area, which is, 407.42 sq. km, 317.33 sq. km and 163.93 sq. km respectively. Tea, Cardamom and Eucalyptus occupy 36.16 per cent, 28.16 per cent and 14.55 per cent respectively.

4.1.2 Reserve Forest

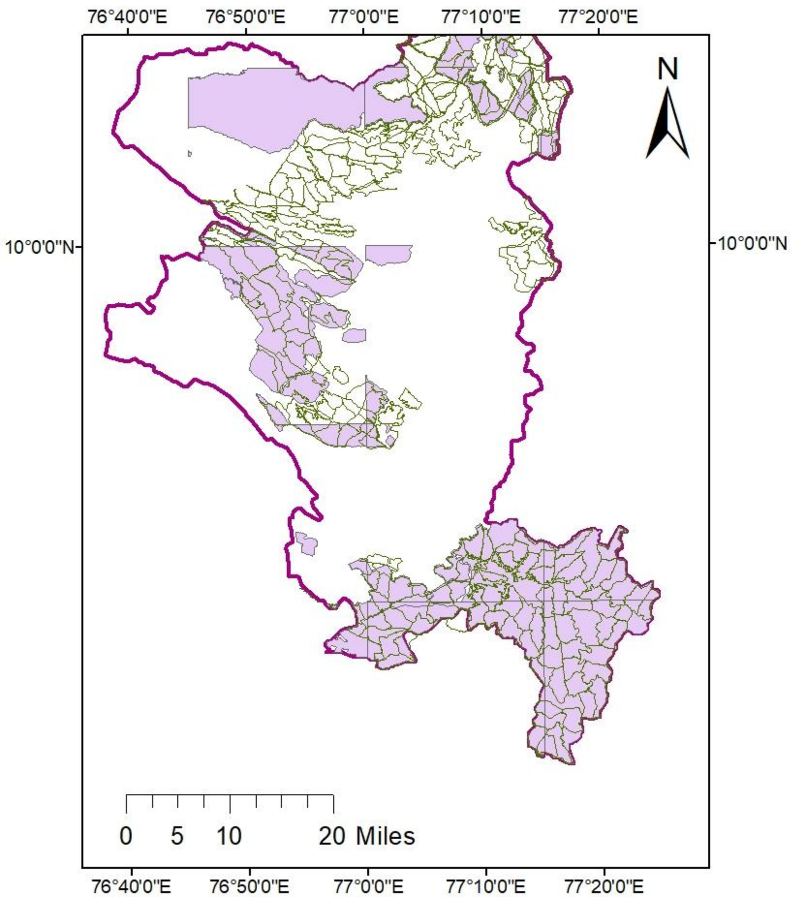


Figure 9: Map demonstrating the Reserve Forest (RF) area of Idukki district

As per mapping of the toposheets, it could be found that about 2,804.82 sq. km is occupied by the Reserve Forests. This accounts for about 55 percent of the geographical area of the district. The Reserve Forests with the largest area are Malayattur Reserve Forest, Periyar RF and Thodupuzha Reserve Forest.

4.1.3 Natural and Plantation tree cover loss statistics

From 2001 to 2023, Idukki lost 13.4 kilo hectare (kha) of tree cover, equivalent to 3.2% decrease in tree cover since 2000. 935 of tree cover loss occurred within the natural forest.

Table 10: Natural tree cover loss in Idukki district from 2001-2023

Tree cover loss year	Tree cover loss (ha)
2001	190.845
2002	215.468
2003	804.806
2004	422.738
2005	157.578
2006	458.865
2007	527.758
2008	451.772
2009	62.157
2010	4.550
2011	891.055
2012	862.672
2013	475.245
2014	666.718
2015	551.174
2016	728.187
2017	909.726
2018	913.651
2019	898.405
2020	763.094
2021	572.350
2022	791.213
2023	1106.834

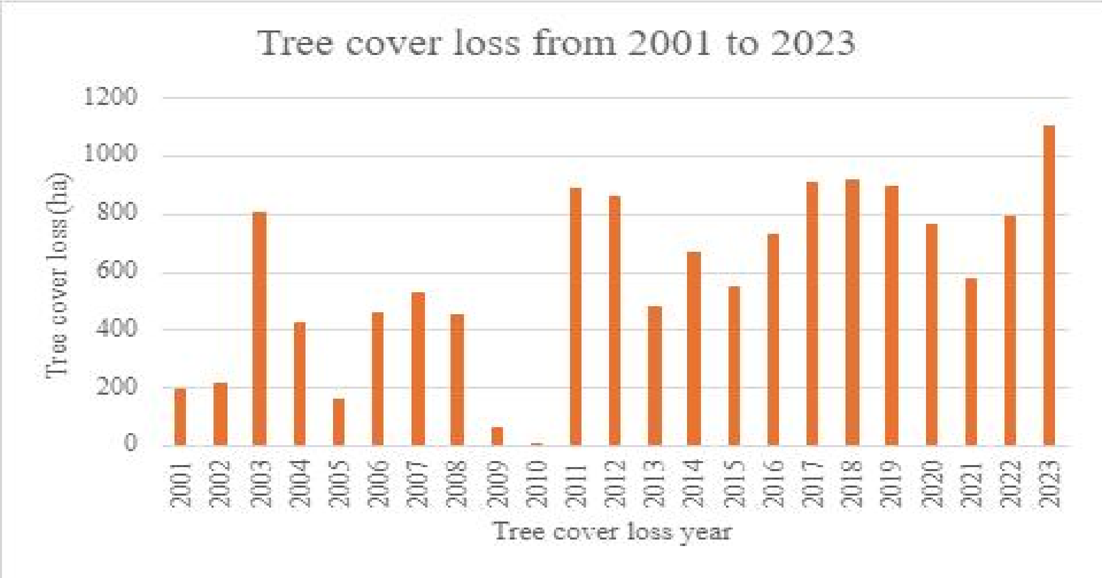


Figure 10: Natural tree cover loss in Idukki district from 2001 to 2023

Table 11: Plantation cover loss in Idukki district from 2001-2023

Plantation tree cover loss year	Plantation tree cover loss (ha)
2001	10.991
2002	12.127
2003	75.174
2004	27.071
2005	13.494
2006	52.769
2007	45.644
2008	59.892
2009	2.351
2010	0.682
2011	115.494
2012	104.657
2013	45.714
2014	63.227
2015	39.955

2016	57.328
2017	80.456
2018	60.344
2019	50.724
2020	49.132
2021	25.172
2022	43.897
2023	74.711

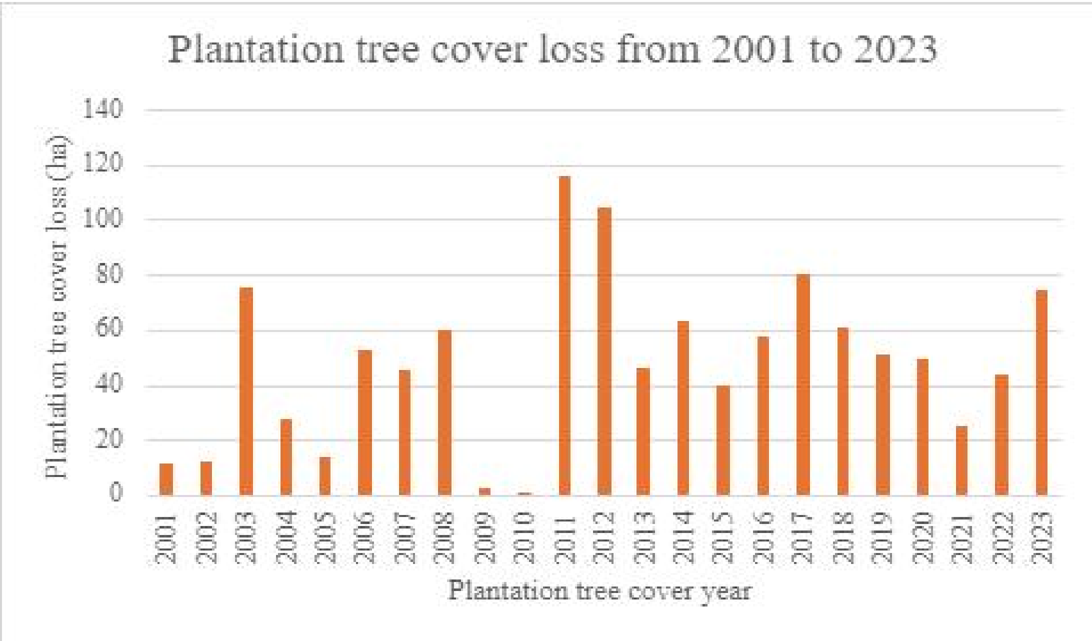


Figure 11: Plantation tree cover loss in Idukki district from 2001 to 2023

Highest natural tree cover loss is calculated to be in the year 2011-'12 and 2018-'19. The expected loss for the year 2023 has been plotted from the Working Plan data. The loss is estimated to be around 900 hectares and is majorly concentrated in areas such as Kandalur, Mankulam, Kumili and Devikulam. Whereas in the case of plantation tree cover loss, with an estimation of approximately 120 hectares, the year 2011-'12 was found to bear the highest loss.

4.1.4 Above Ground Biomass (AGB) map

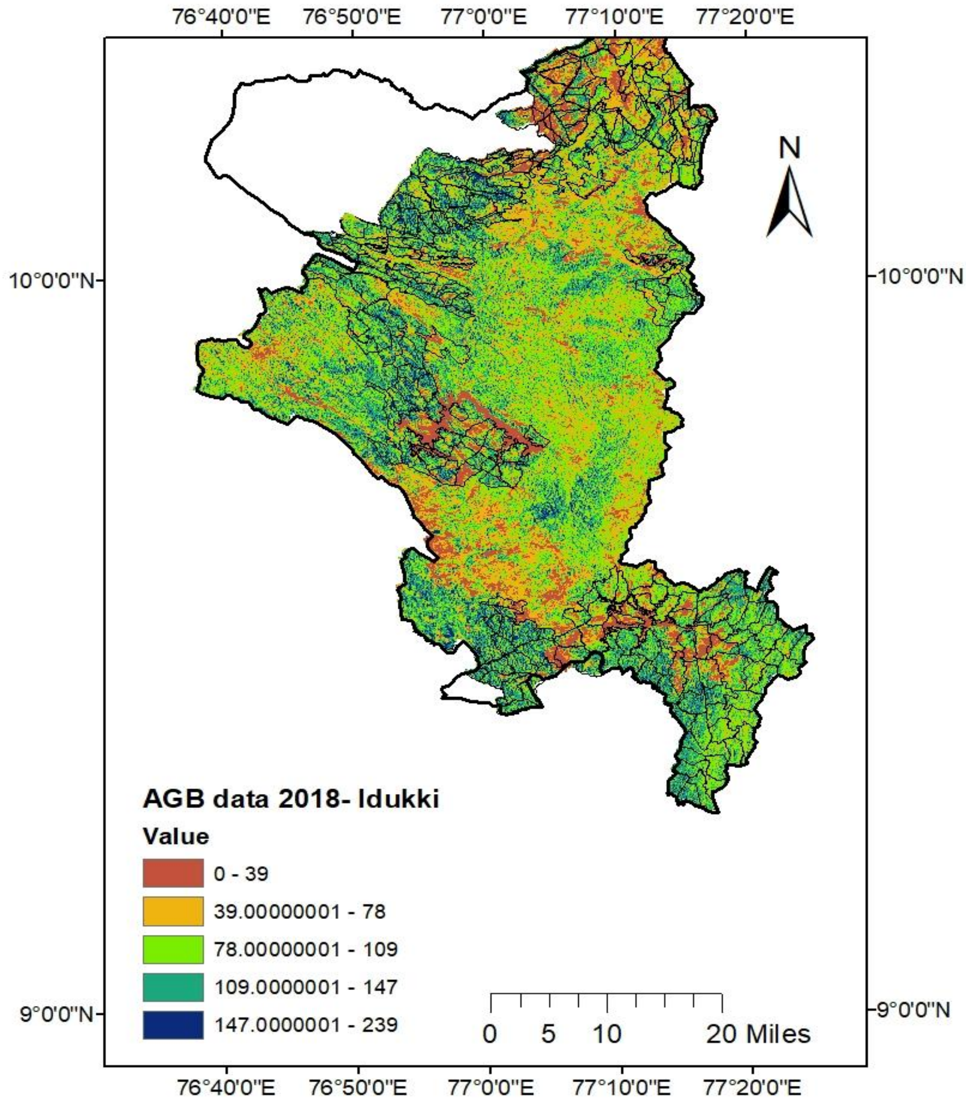


Figure 12: Map demonstrating the Above Ground Biomass (AGB) over Idukki district

The unit of Above Ground Biomass data is million tonnes. Around 109 to 239 million tonnes is concentrated around the forest beat regions owing to the high productivity of these regions.

4.1.5 Natural Forest species of selected ranges and their volume

a) Kothamangalam Division 2001-2011

Table 12: Species-wise volume in Kothamangalam division

Sl No	Species	Botanical name	Volume as per 2% growing stock in m^3
1.	**Pali**	***Palaquium ellipticum***	**2609.48**
2.	**Irul**	***Xylia xylocarpa***	**1880.20**
3.	**Venga**	***Pterocarpus marsupium***	**1646.02**
4.	**Cheeni**	***Tetrameles nudiflora***	**1288.66**
5.	**Thembavu**	***Terminalia tomentosa***	**1134.84**
6.	Thellipine	*Canarium*	1117.74
7.	Thambakam	*Hopea parviflora*	1106.97
8.	Venteak	*Lagerstroemia lanceolata*	993.82
9.	Vellapine	*Vateria indica*	937.91
10.	Eetty	*Dalbergia latifolia*	829.03
11.	Pullamaruth	*Terminalia paniculata*	754.85
12.	Vellaakil	*Dysoxylum malabaricum*	728.34
13.	Thanni	*Terminalia bellirica*	676.21
14.	Myla	*Vitex altissima*	661.31
15.	Vetty	*Dalbergia latifolia*	660.92
16.	Cheru	*Holigarna arnottiana*	648.32
17.	Chandanavayambu	*Chukrasia tabularis*	643.20
18.	Punnappa	*Calophyllum polyanthum*	621.06
19.	Marotti	*Hydnocarpus pentandra*	595.72
20.	Vatta	*Macaranga peltata*	435.67

The species with the highest volume in the Kothamangalam division of Idukki district are Pali (*Palaquium ellipticum*), Irul (*Xylia xylocarpa*), Venga (*Pterocarpus marsupium*), Cheeni (*Tetrameles nudiflora*) and Thembavu (*Terminalia tomentosa*).

b) Mankulam Division 2001-2011

i. Anakulam Range

Table 13: Species-wise volume in Anakulam range of Mankulam Division

Sl No	Name of species	Botanical Name	Volume in m^3
1.	**Nanku**	***Mesua ferrea***	**287.190**
2.	**Pali**	***Dichopsis elliptica***	**172.560**
3.	**Vediplavu**	***Cullenia execelsa***	**153.790**
4.	**Vellapine**	***Vateria indica***	**111.240**
5.	**Miscellaneous**	**-**	**94.494**
6.	Poovam	*Schleichera oleosa*	67.572
7.	Pathri	*Myristica attenuata*	59.779
8.	Njaval	*Eugenia jambolana*	55.767
9.	Bhadraksham	*Elaeocarpus tuberculatus*	40.136
10.	Plavu	*Artocarpus heterophyllus*	36.571
11.	Punnappa	*Calophyllum tomentosum*	35.491
12.	Kara	*Elaeocarpus serratus*	26.838
13.	Vatta	*Macaranga peltata*	24.307
14.	Karuna	*Gordemia pinnata*	18.509
15.	Akil	*Dysoxylum malabaricum*	17.782
16.	Velakil	*Dysoxylum malabaricum*	15.518
17.	Karuva	*Cinnamomum verum*	13.361
18.	Nasakam	*Evodia lunu-ankanda*	10.729
19.	Varangu	*Carallia integerrima*	9.226
20.	Vettananku	*Asteriastigma macrocarpa*	6.917
21.	Kanapa	*Evodia lunu-ankanda*	3.841

22.	Chora Pine	*Myristica attenuata*	3.539
23.	Karakil	*Dysoxylum purpureum*	3.286
24.	Unnam	*Grewia tiliaefolia*	3.136
25.	Edana	*Olea dioica*	2.857
26.	Ambazham	*Spondias pinnata*	2.840
27.	Chandana Vembu	*Toona ciliata*	2.531
28.	Karingazha	*Stereospermum chelonoides*	2.369
29.	Cheeni	*Tetrameles nudiflora*	1.545
30.	Manjakadambu	*Haldina cordifolia*	1.500

The species with the highest volume in the Anakulam Range of Mankulam division of Idukki district are Nanku (*Mesua ferrea*), Pali (*Palaquium ellipticum*), Vediplavu (*Cullenia excelsa*), Vellapine (*Vateria indica*) and Miscellaneous species.

ii. Mankulam Range

Table 14: Species-wise volume in Mankulam range of Mankulam Division

Sl. No	Local name	Botanical name	Volume in m^3
1.	**Miscellaneous**	**-**	**627.740**
2.	**Pali**	***Dichopsis elliptica***	**176.390**
3.	**Njaval**	***Syzygium cumini***	**163.250**
4.	**Vellakil**	***Dysoxylum malabaricum***	**157.090**
5.	**Vediplavu**	***Cullenia excelsa***	**141.310**
6.	Vellapine	*Veteria indica*	126.170
7.	Punnappa	*Calophyllum tomentosu*	97.102

8.	Pathry	*Myristica attenuata*	69.615
9.	Nanku	*Mesua ferrea*	62.523
10.	Pala	*Alstonia scholaris*	48.204
11.	Chamba	*Jambosa mundagam*	44.902
12.	Kattukara	*Elaeocarpus serratus*	30.741
13.	Cheru	*Holygarna arnottiana*	27.007
14.	Manthipuly	*Diacium travancoricum*	22.295
15.	Vatta	*Macaranga peltata*	19.495
16.	Karuna	*Gordonia obtusa*	19.480
17.	Kulamavu	*Machilus macrantha*	18.883
18.	Poovam	*Schleichera oleosa*	17.992
19.	Karaki	*Dysoxylum ficiforme*	16.802
20.	Bhadraksham	*Elaeocarpus tuberculatus*	15.869
21.	Eroly	*Actinodaphne hookeri*	15.105
22.	Kattuplavu	*Autocarpus heterophyllus*	12.719
23.	Varaly	*Dodonaea viscosa*	12.495
24.	Kanala	*Evodia roxburghiana*	10.710
25.	Karuva	*Cinnamomum verum*	8.802
26.	Katturubber	*Evodea lunu-ankenda*	5.578
27.	Puly	*Garcinia cambogia*	5.047
28.	Chandana vembu	*Toona ciliata*	4.112
29.	Anjily	*Artocarpus hirsutes*	4.004
30.	Kattutheyila	*Eurya japonica*	3.706

The species with the highest volume in the Mankulam Range of Mankulam division of Idukki district are Miscellaneous species, Pali (*Dichopsis elliptica*), Njaval (*Syzygium cumini*), Vellakil (*Dysoxylum malabaricum*) and Vediplavu (*Cullenia excelsa*)

4.2 PALKKAD DISTRICT

4.2.1 Plantations

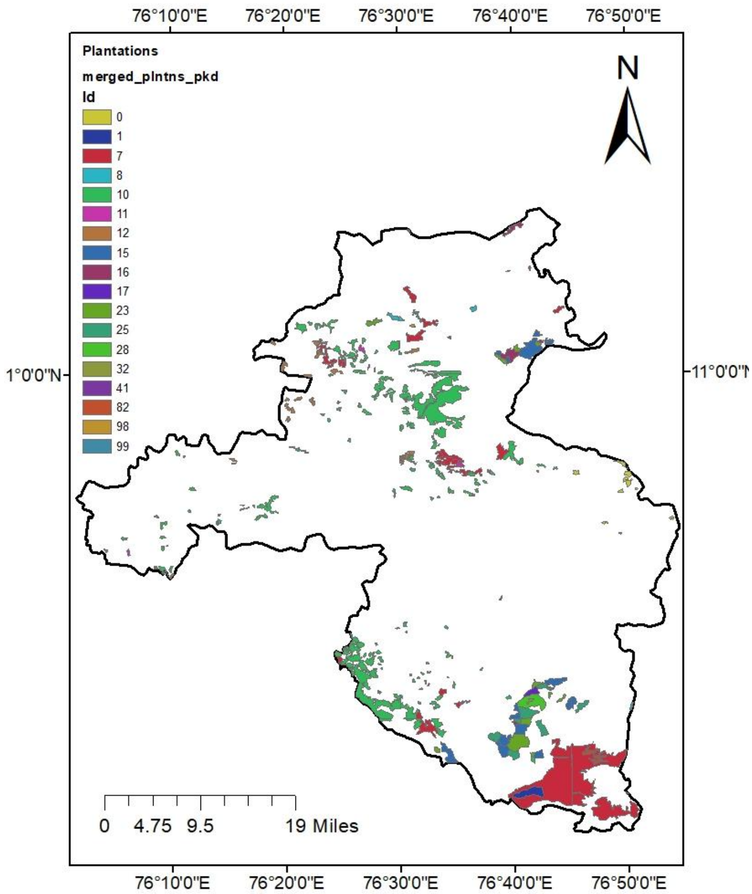


Figure 13: Map demonstrating the different plantations of Palakkad district

The geographical area of the district is 4,530 sq. km approximately. Plantations occupy about 367.50 sq. km of this area, that is about 8 per cent of the geographical area. Similarly, it can be concluded that about 17 per cent of the forest cover is occupied by the plantations. Among the different plantations that has been mapped, Teak, Rubber and Cashew plantations occupy the most area, which is, 133.353 sq. km, 128.83 sq. km and 10.528 sq. km respectively. Tea, Cardamom and Eucalyptus occupy 36.28 per cent, 35.05 per cent and 2.9 per cent respectively.

4.2.2 Reserve Forest

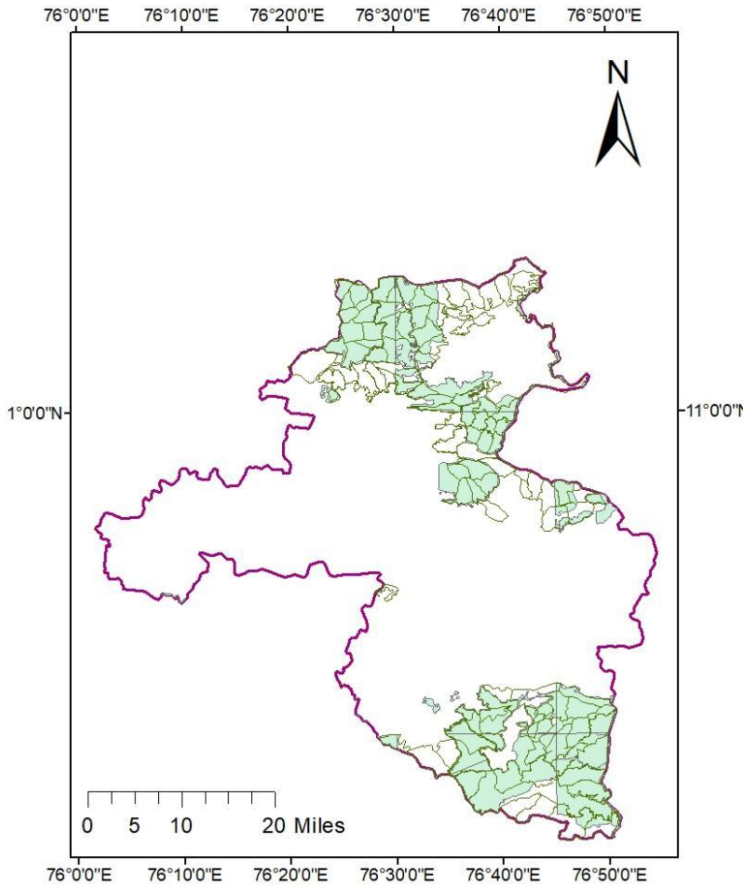


Figure 14: Map showing the Reserve Forest (RF) area of Palakkad district

As per mapping of the toposheets, it could be found that about 2,113.22 sq. km is occupied by the Reserve Forests. This accounts for about 46.51 percent of the geographical area of the district. The Reserve Forests with the largest area are Kodassery and Athirappally Reserve Forest, Kodasseri RF and Nelliyampathy RF.

4.2.3 Natural and Plantation tree cover loss statistics

From 2001 to 2023, Palakkad lost 7.53 kilo hectare (kha) of tree cover, equivalent to a 3.5 percent decrease in tree cover since 2000. In the last decade, 69 percent of the tree cover loss occurred within the natural forest.

Table 15: Tree cover loss of Palakkad District from 2001 to 2023

Tree cover loss year	Tree cover loss (ha)
2001	18.228
2002	44.098
2003	72.318
2004	59.512
2005	105.577
2006	91.815
2007	245.429
2008	157.146
2009	67.157
2011	293.641
2012	200.356
2013	254.851
2014	276.154
2015	195.766
2016	525.116
2017	482.446
2018	720.984
2019	771.420
2020	677.512
2021	565.682
2022	562.435
2023	1144.861

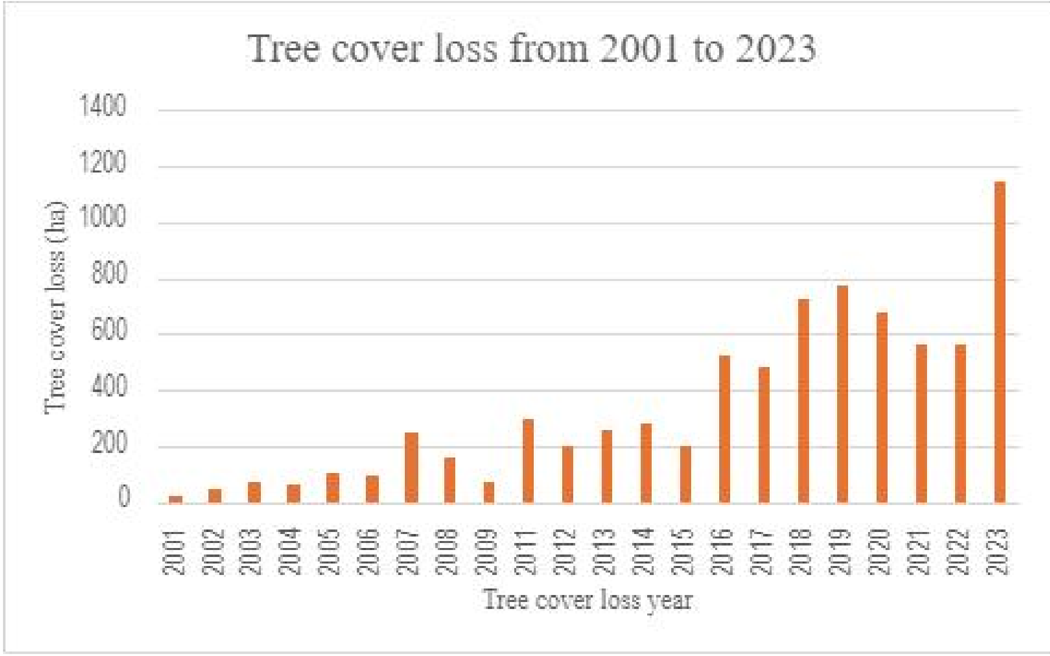


Figure 15: Tree cover loss from 2001 to 2023

Table 16: Plantation tree cover loss of Palakkad District from 2001 to 2023

Plantation tree cover loss year	Plantation tree cover loss (ha)
2001	2.041
2002	7.869
2003	15.358
2004	14.442
2005	13.689
2006	19.365
2007	42.735
2008	30.925
2009	17.169
2011	56.637
2012	37.736
2013	89.898
2014	83.336
2015	65.024
2016	180.921

2017	149.393
2018	249.169
2019	236.479
2020	217.804
2021	181.243
2022	168.761
2023	295.994

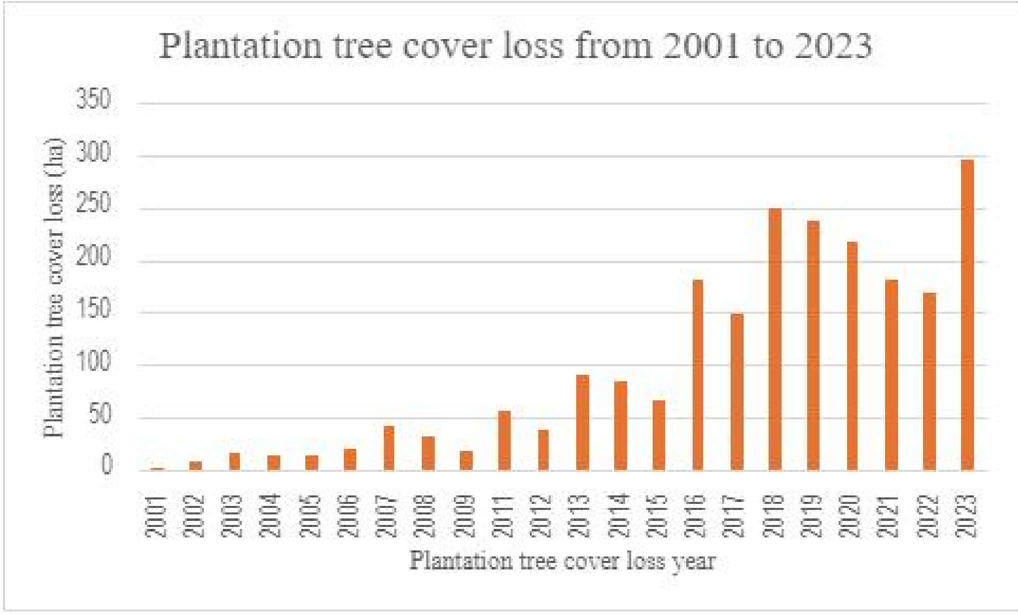


Figure 16: Plantation tree cover loss from 2001 to 2023

Natural and plantation tree cover loss is calculated to be highest in the year 2018-'19 which is approximately 800 hectares and 250 hectares respectively. The expected loss for the year 2023 has been plotted from the Working Plan data. The loss is majorly concentrated on areas such as Pudur, Mangalam dam region and Nelliyampathy.

4.2.4 Above Ground Biomass (AGB) map

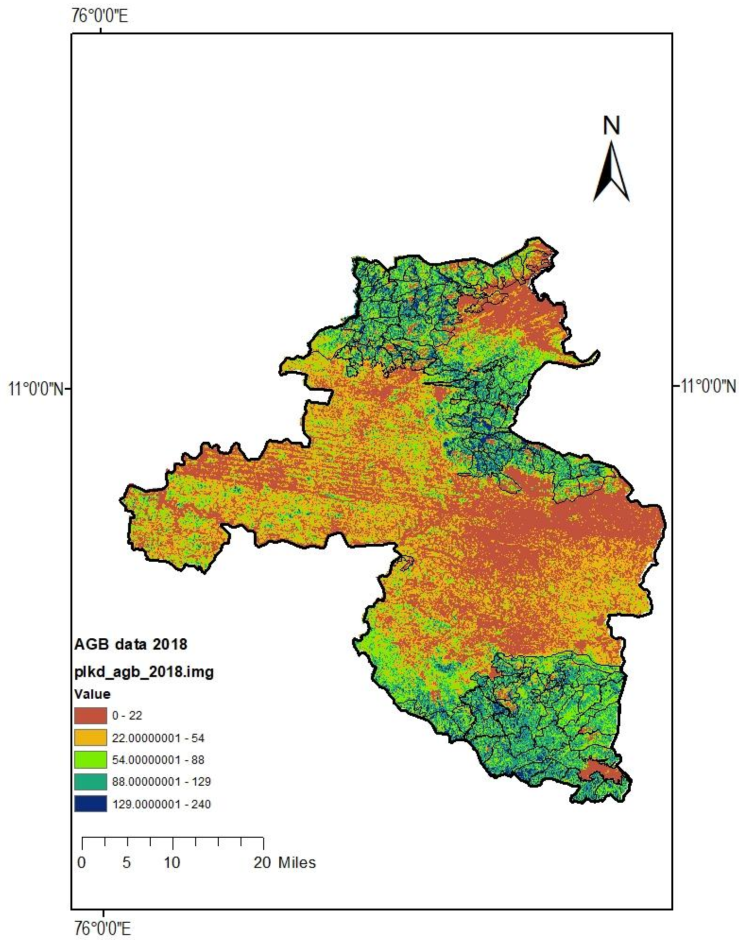


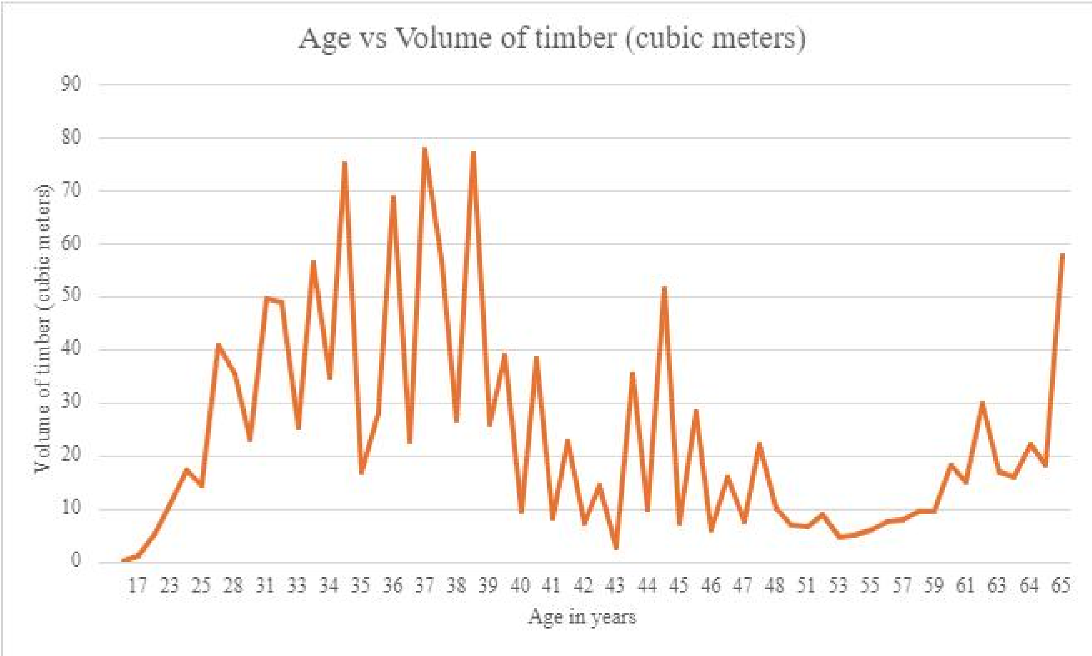
Figure 17: Map demonstrating the Above Ground Biomass (AGB) over Palakkad district

The unit of Above Ground Biomass data is million tonnes. Around 88 to 240 million tonnes is concentrated around the forest beat regions.

4.2.5 Teak plantations

a) Mannarkkad Division 2001-2011

(i)



(ii)

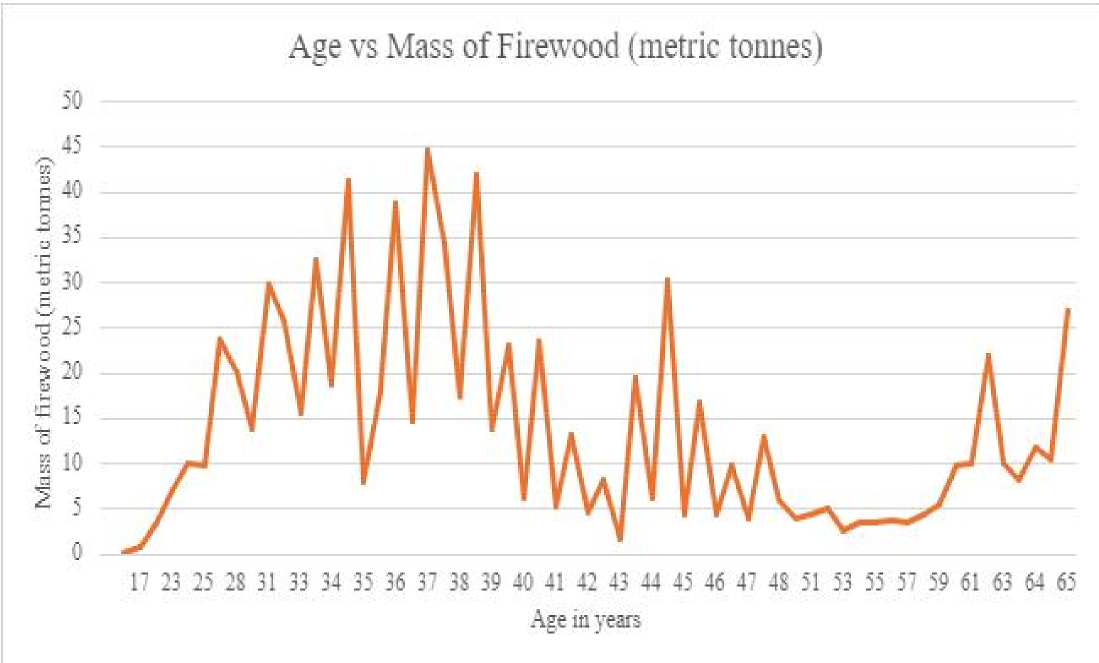
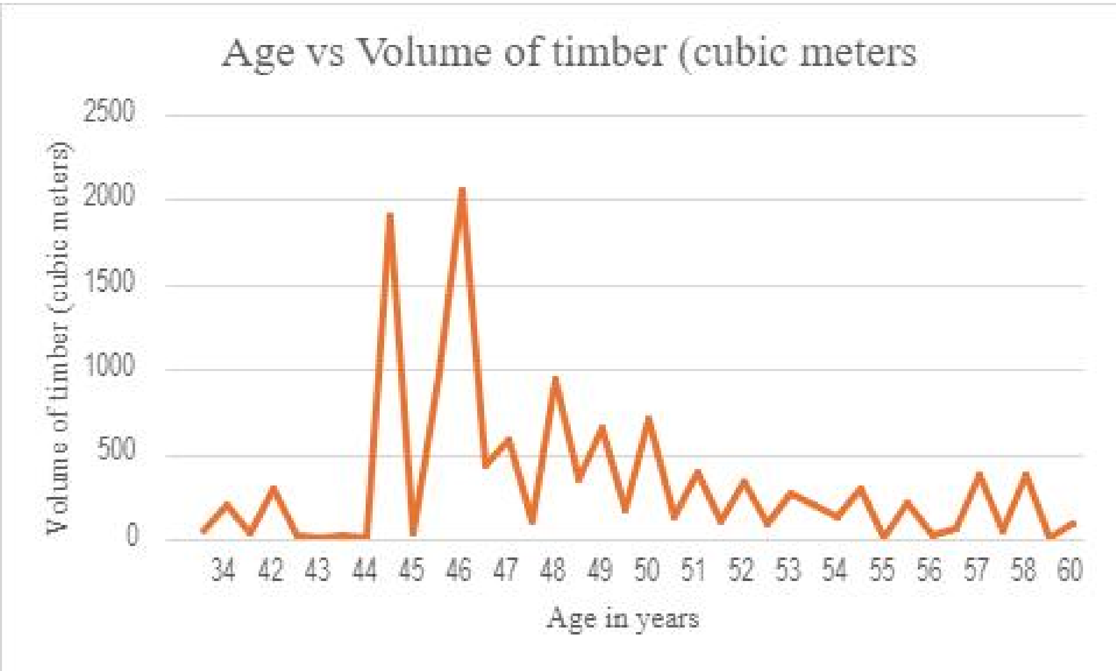


Figure 18: Graph demonstrating (i) Age vs Volume of timber and (ii) Age vs Mass of firewood

The Working Plan data belongs to the period of 2001-2011. The age of the teak plantation is computed from the year of plantation as mentioned in the Working Plan to 1999 (the year on which the Working Plan was prepared) (Year of preparation of WP- Planted year). The graphs have been plotted with Age on X-axis and Volume of timber or Mass of firewood on Y-axis. It could be noted that volume of timber extracted and mass of firewood obtained is maximum around the mid 30-40 years of plantation age.

b) <u>Mannarkkad Division 2012-2023</u>

(i)



(ii)

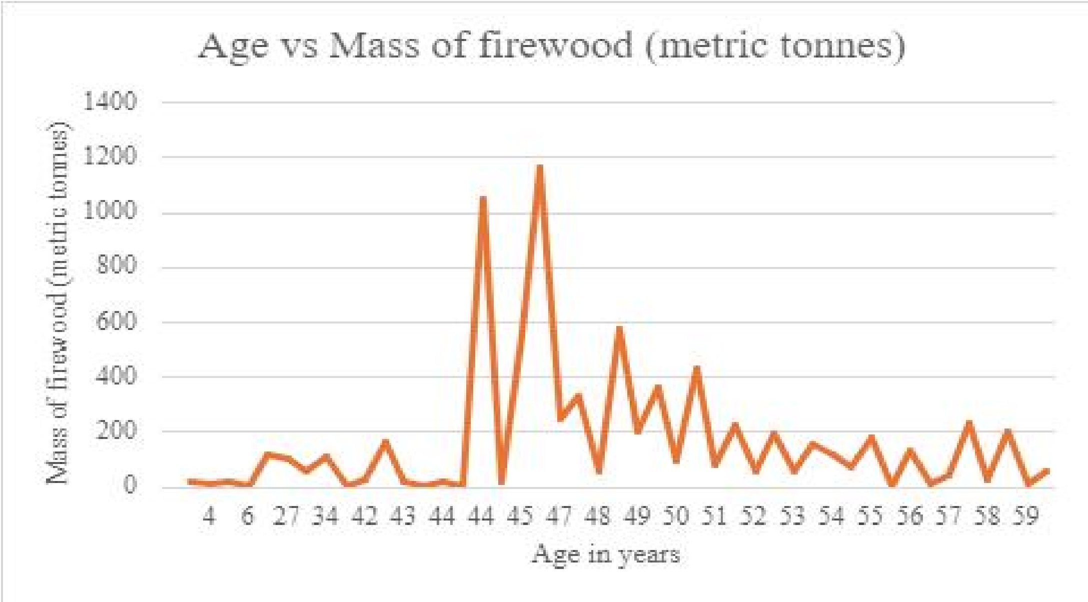
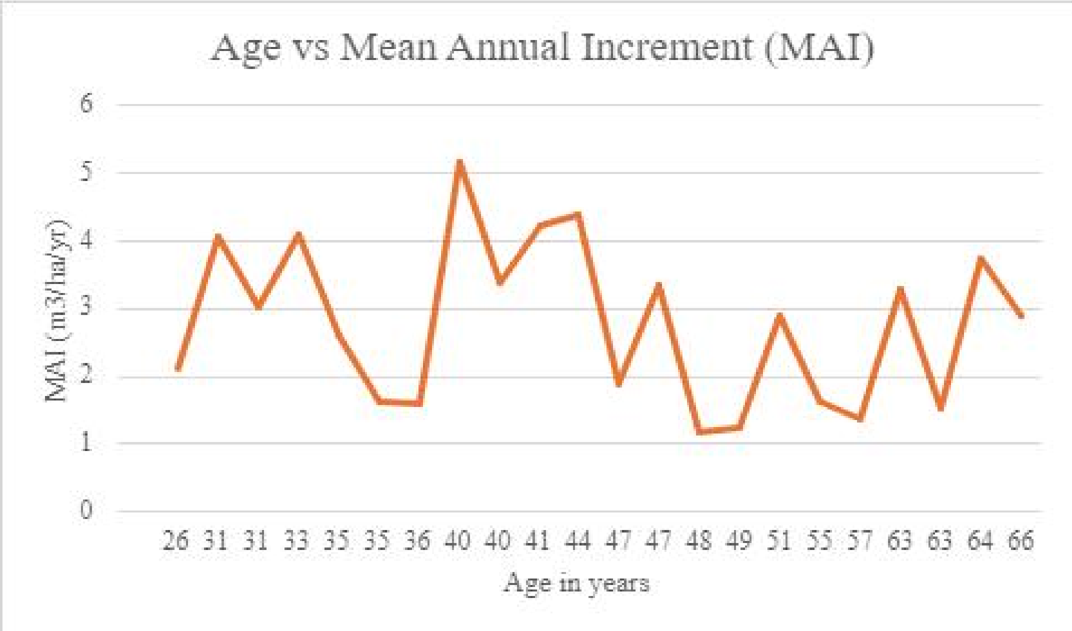


Figure 19: Graph demonstrating (i) Age vs Volume of timber and (ii) Age vs Mass of firewood

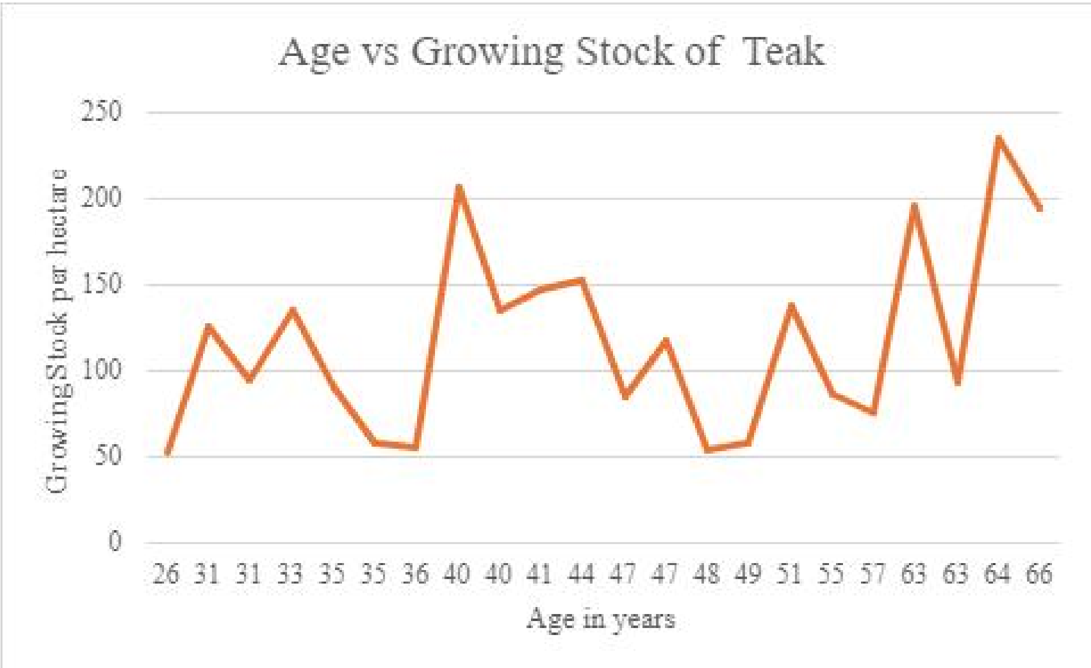
The Working Plan data belongs to the period of 2012-2023. The age of the teak plantation is computed from the year of plantation as mentioned in the Working Plan to 2000 (the year on which the Working Plan was prepared) (Year of preparation of WP- Planted year). The graphs have been plotted with Age on X-axis and Volume of timber or Mass of firewood on Y-axis. It could be noted that volume of timber extracted and mass of firewood obtained is maximum around the mid 40 years of plantation age.

c) **<u>Nemmara Division 2015-2025</u>**

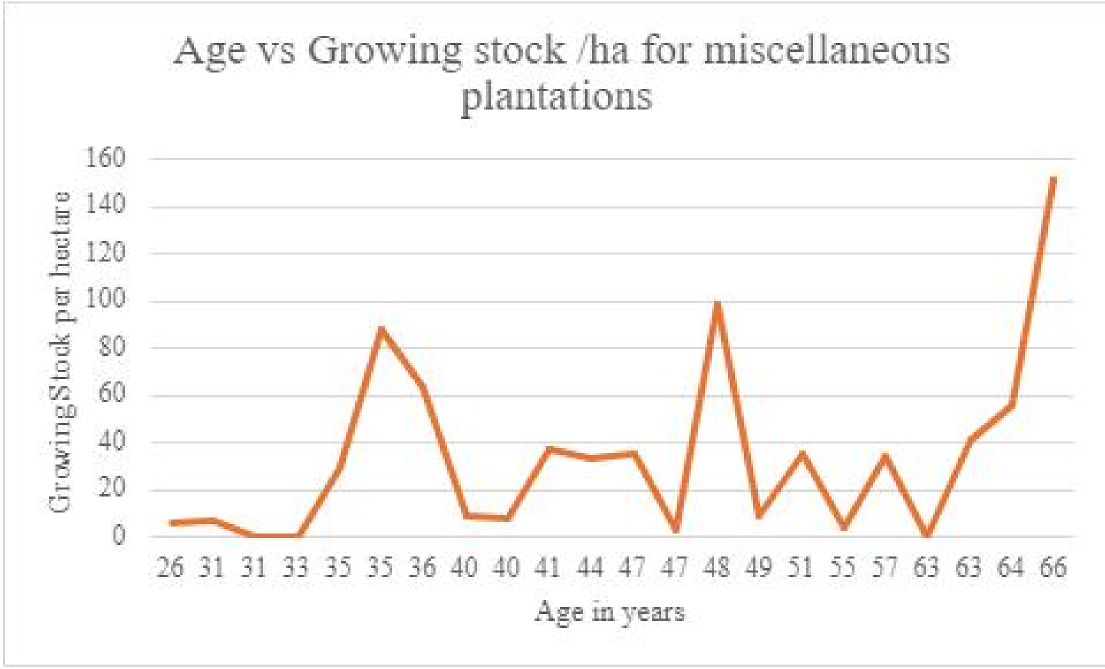
(i)



(ii)



(iii)



(iv)

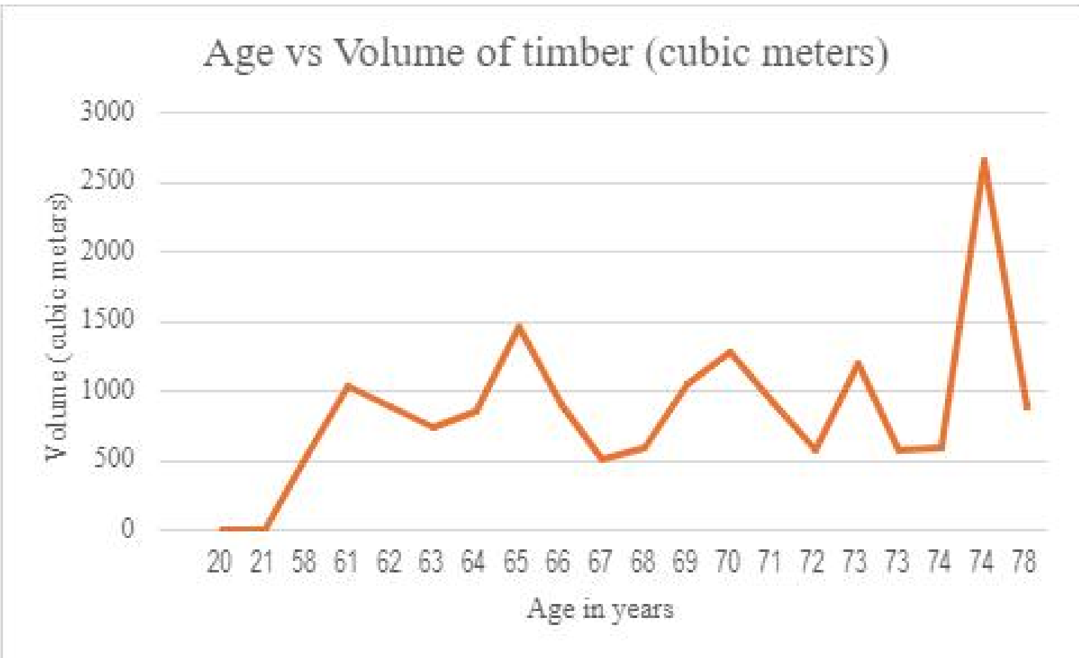
Figure 20: Graph demonstrating (i) Age vs Mean Annual Increment (ii) Age vs Growing Stock of Teak (iii) Age vs Growing Stock for miscellaneous plantations and (iv) Age vs Total Growing Stock

The Working Plan data belongs to the period of 2015-2025. The age of the teak plantation is computed from the year of plantation as mentioned in the Working Plan till 2013 (the year on which the Working Plan was prepared). The graphs have been plotted with Age on x-axis and Mean Annual Increment (MAI) and Growing Stock of teak, miscellaneous plantations and total GS on y-axis.

From the plotted graphs, it could be inferred that, the MAI is maximum around mid 30s to mid 40s. The GS of teak is maximum around mid 30 to mid 40 years of plantation age and increases again after about 60 years of age and for miscellaneous plantation , GS is maximum around mid 30 years of age and increases again after 60 years of plantation age. Adding both GS of teak and miscellaneous plantation, the total GS of the Nemmara division is calculated and plotted. From the same, it could be concluded that the GS remains almost steady throughout the calculated plantation years, but particularly increases after 60 years of age.

d) Palakkad 2020-2030

(i)



(ii)

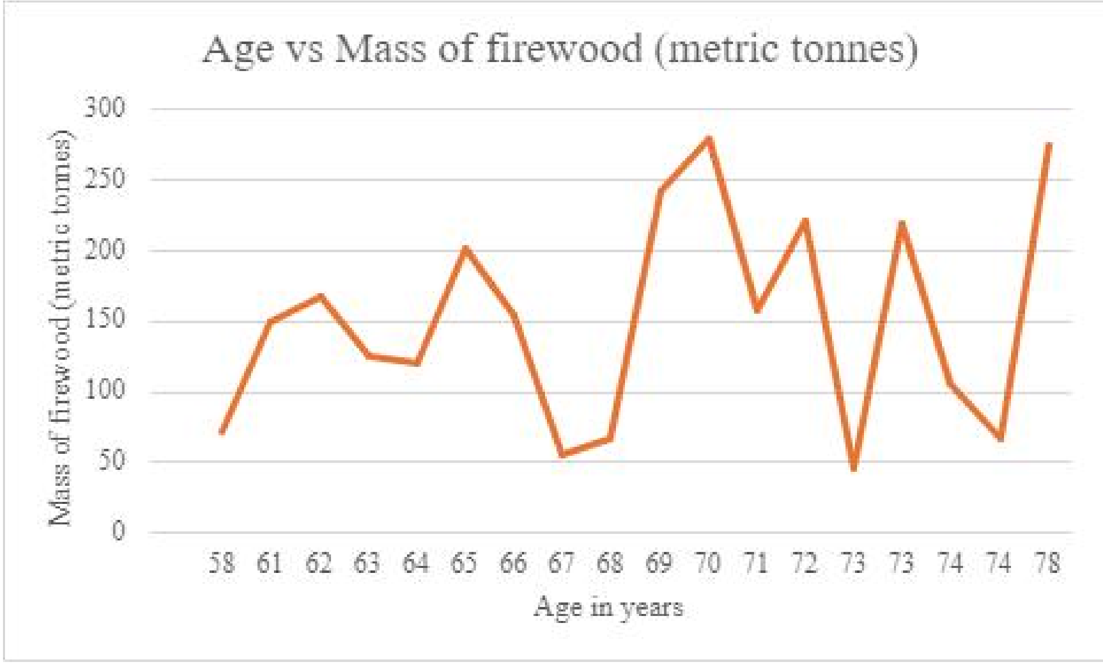


Figure 21: Graph demonstrating (i) Age vs Volume of timber and (ii) Age vs Mass of firewood

The Working Plan data belongs to the period of 2020-2030. The age of the teak plantation is computed from the year of plantation as mentioned in the Working Plan to 2017 (the year on which the Working Plan was prepared). The graphs have been plotted with Age on x-axis and Volume of timber or Mass of firewood on y-axis. It could be noted that volume of timber that could be extracted remains almost same after 60 years of age (around 500-1200 cubic meters). Meanwhile, the mass of firewood obtained keeps fluctuating with the plantation age.

4.3 Discussion

According to FAO (2010), forests preserve biodiversity, produce timber, sequester carbon dioxide, protect soil, and conserve water. One of the main factors contributing to the rise in atmospheric carbon dioxide concentration is the indiscriminate destruction of forests. Additionally, mismanagement and climate change have a significant direct and indirect influence on them (Kirilenko and Sedjo, 2007). Teak is the second most planted species in India, with 6.3 to 8.9 Mega hectares of natural and 1.5 to 2.5 Mega hectares of planted teak (Palanisamy et al., 2009). Natural teak forests are mostly found in Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, Kerala and Rajasthan. According to Nolte et al. (2018), extending rotation times and reducing thinning intensity could be applied as management strategies to boost carbon storage in teak plantations. More carbon can be stored in the main stem wood, bark, branches, foliage, roots, and soil of tree plantations. The carbon stored in the main stem wood is stored for a longer period of time, while the carbon released by the decomposition and natural pruning of other components is stored for a shorter period of time. Thus, tree species' capacity to sequester carbon becomes relevant.

The WPs of natural forests and plantations differ in the ecological, management, and conservation goals associated. In the case of natural forests, the prime objective in the formulation of the WP is to maintain the natural ecosystem, enhancing biodiversity, protecting endangered species and preserving ecological processes. The interventions are often limited to controlled burns, selective logging, management of non-timber forest product (NTFP) or invasive species management.

Meanwhile, for plantations, the objective is to produce timber, pulp or other forest product with low-cost. Management is focused on increasing yield and making it more profitable by practicing planting, thinning, pruning and harvesting. Other high-intensity management practices includes monoculture (season planting), short rotation cycles and replanting post- harvest. The economic focus is to practice cost-effective planting, maintenance and harvesting methods guided by market demands and profitability.

The primary productivity of a species or ecosystem is influenced by the strongest ecological parameters, such as age and climate, therefore changes in these variables can cause changes in amount of carbon sequestered.

As the study indicates, the plantations of Palakkad district majorly consists of Rubber plantations, followed by Teak plantations, meanwhile, in Idukki district, Tea, Eucalyptus and Cardamom plantations.

Primary productivity and biomass gain which are directly proportionate to carbon stored in a plant or an ecosystem varies with the availability of resources and characteristics of the environment in which they grow (Houghton, 2005). The biomass of any plantation is directly related to its age (Pasha et al., 2023). The harvesting period of each plantation is different. The mature or old low productive plantations is either harvested or uprooted which is followed by replanting.

As the study indicates, the MAI, GS, Volume of timber and Mass of firewood depends primarily on age. From the plotted graphs, it could be concluded that the maximum value of the parameters of study is observed particularly during the mid 40 years of plantation age and noticeably increases after about 60 years of age. Along with age, other factors like site quality, topography, and health of the tree species also influence timber and firewood extraction quantity and quality.

In Palakkad district, about 8 per cent of the GA is covered with plantations. Tea, Cardamom and Eucalyptus occupy 36.28 per cent, 35.05 per cent and 2.9 per cent of the total plantation cover respectively. About 2,113.22 sq. km is occupied by the Reserve Forests. This accounts for about 46.51 percent of the GA. Whereas in Idukki district, about 22 percent of the Geographical Area is covered with plantations out of which, Tea, Cardamom and Eucalyptus occupy 36.16 per cent, 28.16 per cent and 14.55 per cent of the area respectively. About 2,804.82 sq. km is occupied by the Reserve Forests accounting for approximately 55 percent of the GA.

The natural and plantation tree cover loss is concentrated during the period of 2018-2019 in both the districts. The loss can be accounted mainly due to the occurrence of Flood in Kerala. Idukki was one of the major districts to be badly affected by the flood.

Due to the high productivity of forest, AGB is concentrated around the forest regions with much higher value as compared to the rest of the regions.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The forest area is significantly changing in both the Idukki and Palakkad districts and have been undergoing noticeable land conversions over the years. These conversions are majorly due to human involvements in the natural forest area such as Teak, Rubber, Coffee, Cardamom plantations. Since there are many national parks and wildlife sanctuaries in both the districts, the Growing Stock and Above Ground Biomass of such protected areas needs to be considered for better understanding of the Carbon stock of the districts as a whole. For further advancement in the study, along with the Management plans for the protected area network, there must be Working plans for the estimation of Mean Annual Increment (MAI), Growing Stock (GS), Volume of timber and firewood, Above ground Biomass (AGB) and other parameters. There would be a decrease in Mean Annual Increment (MAI) under constant carbon dioxide concentration. But with increasing carbon dioxide concentration, the MAI, carbon dioxide concentration in teak would increase in the future. Large areas of natural and planted teak vegetation, with high growth rates could act as significant Carbon sinks contributing to global climate change mitigation (FAO, 2015).

Periodic forest carbon assessment helps in monitoring carbon flow in different pools. The study could be expanded in the future for further analysis of carbon stock for the districts as a whole with the availability of data and advanced remote sensing techniques. There needs to be more certainty in the data from Working Plans for future prospects of the study. By combining remote sensing methods with geo spatial analysis, soil carbon stocks can be assessed more extensively, giving rise to more concrete knowledge about the spatial distribution of carbon pools under various land uses.

Long-term monitoring studies to assess the soil carbon dynamics under different land uses provide insights into the temporal changes in carbon stocks and soil health. Employment of various effective land management practices, such as cover cropping and agroforestry should be undertaken and studied for its ability to improve the ecosystems. Examining how soil microbial communities contribute to carbon cycle in a variety of land uses emphasizes on the soil carbon storage and general health of ecosystems. Studying forest carbon dynamics has several practical utility applications such as assessing forest health, climate change mitigation, forest management, carbon trading, biodiversity conservation and policy development. Research will continue to explore the broader ecosystem services provided by forests. It is also essential to comprehend the intricate relationships that exist between anthropogenic activities, vegetation health, and climate change in order to create strategies that effectively safeguard and repair India's carbon sink regions. In spite of continuous environmental challenges, it is possible to protect these vital regions for carbon sequestration and biodiversity conservation by addressing the root causes and fostering ecosystem resilience.

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FOREST BIOMASS DYNAMICS USING FOREST INVENTORY DATA OF KERALA

by

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ABSTRACT OF THE THESIS

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ABSTRACT

The study focuses on the dynamics of forest carbon. The objectives of the study is to estimate the forest carbon dynamics using Working Plans and Geographic Information System (GIS) techniques and analysis of carbon stock. Idukki and Palakkad districts of the state of Kerala are chosen as the study areas since they are the two districts with the highest forest cover in the state. Working plans (WP) prepared by Kerala Forest department, India State Forest Report prepared by Forest Survey of India (FSI) and data from published literatures are being used for the study. GIS technologies are used for the mapping and the estimation of the area of different plantation types and Reserve Forest of both districts. The forest beat boundaries of both the districts are mapped as well. The area obtained through mapping is corroborated with forest cover area as mentioned in the FSI reports.

Around 1130 square kilometers of plantation area is present in Idukki district, which accounts for about 22 per cent of its geographical area. Tea, Cardamom and Eucalyptus occupy the largest areas of plantation respectively. Reserve Forests (RF) spans around an area 2800 square kilometers of the district accounting for approximately 55 per cent of its Geographical Area. The largest reserve forests are Malayattur, Periyar and Thodupuzha RF. In case of Palakkad district, around 370 sq. km of plantation area is present, accounting for about 8 per cent of the district’s geographical area. Teak, Rubber and Cashew occupy the largest area among all of the plantation types respectively. About 2130 sq. km of Reserve Forest area is present in Palakkad district which is around 47 per cent of the geographical area. From the estimation of natural forest tree cover loss and plantation tree cover loss (of the past two decades), it could be noted that the highest natural forest tree cover loss was during 2018-19 period in both the districts- around 900 ha and 750 ha in Idukki and Palakkad districts respectively. Whereas in the case of plantation tree cover loss, the highest loss was noted during the period of 2011-12 in Idukki district (100-120 ha) and 2018-19 in Palakkad district (220-250 ha). Spatial mapping of Above Ground Biomass (AGB) from the published data of Santoro indicates that the highest AGB is found in forest beat areas which is around 109 to 239 million tonnes and 88 to 240 million tonnes in Idukki and Palakkad districts respectively. For the teak plantation

analysis, the age of the teak plantations of each range is calculated from the year of plantation and year of harvesting as mentioned in the WPs of the respective ranges. Whether the parameter is Mean Annual Increment (MAI) or Growing Stock (GS) or Volume of timber or Mass of firewood, they are heavily influenced by the age of the plantation tree along with certain other components like site quality and topography. The productivity of plantation trees is maximum around the mid 40 years of age and also, increases considerably after 60 years of age. The volume of different species belonging to the natural forests of the selected ranges of Idukki district are estimated. In the Kothamangalam division, Pali occupies the highest volume, meanwhile in the Anakulam and Mankulam ranges of Mankulam division, Nanku and Miscellaneous species occupy the highest volume respectively.

APPENDIX

Table 1: Total number of trees in the Ranni Reserve of Kottayam Division (Idukki district)

Sl No	Name of species	Botanical name	Total
1.	Mavu	*Mangifera indica*	11
2.	Cheru	*Holigarna aarnotiana*	16
3.	Murukku	*Erythrina stricta*	23
4.	Cheeni	*Tetrameles nudiflora*	26
5.	Nelli	*Phyllanthus emblica*	29
6.	Eetti	*Dalberigia latifolia*	31
7.	Pala	*Wrightia tinctoria*	41
8.	Kambagam	*Hopea parviflora*	49
9.	Anjily	*Artocarpus hirsutus*	70
10.	Manjakadambu	*Haldina cordifolia*	71
11.	Venga	*Pterocarpus marsupium*	73
12.	Teak	*Tectona grandis*	75
13.	Vellapine	*Vaterica indica*	76
14.	Konna	*Cassia fistula*	89
15.	Njaval	*Eugenia jambolana*	93
16.	Unnam	*Grewia tiliifolia*	121
17.	Kanala	*Melicope lunuankenda*	132
18.	Marotty	*Hydnocarpus kurzii*	138
19.	Uravu	*Persea macrantha*	150
20.	Tanni	*Terminalia bellirica*	151
21.	Teambavu	*Terminalia elliptica*	158
22.	Pezhu	*Careya arborea*	184
23.	Vatta	*Macaranga peltata*	192
24.	Venteak	*Lagerstroemia lanceolata*	221

25.	Kadamaram	*Xylia xylocarpa*	230
26.	Nedunar	*Polyarthia fragrans*	267
27.	Puvam	*Schleichera oleosa*	303
28.	Chorapine	*Myristica attenuata*	717

Table 2: Total number of trees in the Nagarampara Reserve of Kottayam Division (Idukki district)

Sl No	Name of species	Botanical Name	Total
1.	Karimthakara	*Albizia lebbeck*	3
2.	Ambazham	*Spondias pinnata*	5
3.	Vayana	*Cinnamomum verum*	5
4.	Pambara kumbil	*Trewia polycarpa*	7
5.	Perumthodi	*Sterculia alata*	7
6.	Uthy	*Lennea grandis*	9
7.	Char	*Holigarna aarnotiana*	10
8.	Ezhilampala	*Alstonia scholaris*	10
9.	Marotty	*Hydnocarpus kurzii*	11
10.	Vetty	*Aporosa cardiosperma*	12
11.	Plavu	*Artocarpus heterophyllus*	12
12.	Bhadraksham	*Elaeocarpus serratus*	14
13.	Pambara kumbil	*Trewia nudifloflora*	18
14.	Chorapime	*Myristica attenuata*	18
15.	Erul	*Xylia xylocarpa*	20
16.	Njaval	*Syzygium cumini*	21
17.	Nelli	*Phyllanthus emblica*	23
18.	Elavu	*Bombax ceiba*	24
19.	Akhil	*Aquilaria malaccensis*	24
20.	Muruku	*Erythrina stricta*	26
21.	Kulamavu	*Machilus macrantha*	26
22.	Chandana Veppu	*Cedrela toona*	28
23.	Vatta	*Macranga peltata*	38
24.	Teak	*Tectona grandis*	51
25.	Eetty	*Dalberigia latifolia*	69

26.	Pezhu	*Careya arborea*	87
27.	Unnam	*Grewia tilliafolia*	97
28.	Maruthy	*Terminalia nudiflora*	101
29.	Punna	*Calophyllum inophyllum*	120
30.	Tembav	*Terminalia elliptica*	502

Table 3: Total number of trees in the Karikattoor Reserve Forest of Kottayam Division (Idukki district)

Sl. No	Species	Botanical name	Total
1.	Konna	*Cassia fistula*	2
2.	Manjakadambu	*Adina cordifolia*	2
3.	Uthi	*Lannea coromandelica*	2
4.	Kanjiram	*Strychnos nux-vomica*	3
5.	Teak	*Tectona grandis*	3
6.	Eayalvazha	*Albizia lebbeck*	3
7.	Manimaruthi	*Lagerstroemia speciosa*	3
8.	Vatta	*Macaranga peltata*	5
9.	Pezhu	*Careya arborea*	6
10.	Charu	*Buchanania lanzan*	6
11.	Kanala	*Melicope lunuankenda*	7
12.	Pala	*Alstonia scholaris*	11
13.	Elavu	*Bombax ceiba*	11
14.	Venga	*Petrocarpus marsupium*	14
15.	Uravu	*Machilus macrantha*	14
16.	Karingazha	*Stereospermum personatum*	15
17.	Thembavu	*Terminalia alata*	15
18.	Malampunna	*Calophyllum elatum*	15
19.	Anjili	*Artocarpus hirsutus*	17
20.	Tanni	*Terminelia bellirica*	21
21.	Venteak	*Lagarstroemia lanceolata*	36
22.	Vettti	*Aprosa lindleyana*	76
23.	Maruthi or Vellamaruth	*Terminalia paniculata*	91

Table 4: Total number of trees in the Alappara Reserve Forest of Kottayam Division (Idukki district)

Sl. No	Species	Botanical name	Total
1.	Potta vaka	*Albizia chinensis*	7
2.	Therakam	*Ficus exasperata*	8
3.	Myla	*Vitex altissima*	14
4.	Kanala	*Melicope lunu- ankenda*	15
5.	Uravu	*Persea macranta*	19
6.	Elavu	*Bombax ceiba*	21
7.	Unnam	*Grewia tilifolia*	21
8.	Kalayam	*Lannea coromandelica*	23
9.	Neervetty	*Aporosa acuminata*	25
10.	Cheru	*Holigarna aarnotiana*	26
11.	Konna	*Cassia fistula*	28
12.	Vayana	*Neolitsea zeylanica*	29
13.	Pezhu	*Careya arborea*	31
14.	Mulluvenga	*Bridelia retusa*	41
15.	Vatta	*Macaranga peltata*	42
16.	Karingara	*Steriospermum personatum*	43
17.	Thanni	*Terminelia bellirica*	50
18.	Anjili	*Artocarpus hirsutus*	56
19.	Puvam	*Schleichera oleosa*	61
20.	Malam Punna	*Calophyllum elatum*	74
21.	Kadamaram	*Xylia xylocarpa*	116
22.	Venteak	*Lagerstroemia lanceolata*	126
23.	Thembavu	*Terminalia alata*	197
24.	Vengai	*Pterocarpus marsupium*	206
25.	Maruthi	*Terminalia paniculata*	559