Forest Studies Using Optical and Microwave Remote Sensing Data

THE THESIS SUBMITTED TO

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

BOTANY

BY

MUDALIAR ASHWINI NATARAJ

GUIDED BY

DR. (MRS.) SANDHYA KIRAN GARGE

DEPARTMENT OF BOTANY

FACULTY OF SCIENCE

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA

VADODARA-390 002

GUJARAT

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CERTIFICATE

This is to certify that the thesis entitled "**Forest Studies Using Optical and Microwave Remote Sensing Data**" is submitted by Ms. Ashwini N. Mudaliar in partial fulfillment of the requirement for the award of degree of Doctor of Philosophy in Botany, to The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat is a record of the candidate's own work and due acknowledgement has been made in the text to all other materials used. The matter embodied in this thesis is original and has not been submitted for the award of any other degree.

Mudaliar Ashwini N
(Candidate)

Date:
Place: Vadodara

I certify that the above statement is correct.

Dr. (Mrs.) Sandhya Kiran Garge
(Guide)

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List of Abbreviations

a	Alpha (α º)
A	Anisotrophy
ASAR	Advanced Synthetic Aperture Radar
σ°	backscattering coefficient
BA	Basal area
B	Brillouin
CC	Crown cover
CC	Tree Canopy cover
CDM	Clean Development Mechanism
dB	decibel
DBH	Diameter at Breast Height
DI	Diversity Index
DN	Digital Number
EMR	Electromagnetic Radiation
ENVISAT	Environment Satellite
EO	Earth Observation
ETM	Enhanced Thematic Mapper
FSI	Forest Survey of India
GIS	Geographical Information System
H	Entropy
$\overline{H}$	Shannon-Wiener
ha	hectares
HH	Horizontal Horizontal
HV	Horizontal Vertical
IHS	Intensity Hue Saturation
IRS	Indian Remote Sensing
LAI	Leaf Area Index
LISS	Linear Imaging Self Scanner
M ha	Million Hectares

m	meter
Ma	Margalef
MI	McIntosh
MLR	Multiple linear regression model
MSS	Multispectral Scanner
NDMI	Normalized Differential Moisture Index
NDVI	Normalized Differential Vegetation Index
OR	Out of Range
RADAR	Radio Detection and Ranging
RADARSAT	Radar Satellite
RVI	Radar Vegetation Index
RWC	Relative leaf water content
S.E	Standard Error
SAR	Synthetic Aperture Radar
SFR	State of Forest Report
sq.km	square kilometer
TH	Total tree Height
TM	Thematic Mapper
VH	Vertical Horizontal
VV	Vertical Vertical
WR	Within Range

INTRODUCTION

1.0. Forest Resource:

Forest - A forest is a naturally occurring biological community dominated by trees. Biologists define *community* as a group of interacting species. In natural forest communities, man has not planted the trees, and all the life stages of the trees are present: seeds, seedlings, mature trees, injured trees, infected trees, dead standing trees, and dead and down trees. Defining what constitutes a forest is not easy. According to the CDM (Clean Development Mechanism) of the Kyoto Protocol, a "forest" is an area of more than 0.5–1.0 ha with a minimum "tree" crown cover of 10–30%, with "tree" defined as a plant with the capability of growing to be more than 2–5 m tall (UNFCCC 2002, Sasaki and Putz, 2009). Forest also includes young natural stands and all plantations, which have yet to reach a crown density of 10-30 per cent or tree height of 2-5 meters.

Forests cover slightly less than one-third of the total land area of the Asia and the Pacific region. The world's total forest (**Plate 1**) area is just over four billion hectares or 31 percent of the total land area. They are the largest carbon pool and act as both carbon source and sink according to their management. In India, Forest comprises of 21.0 % (**Plate 2**) of the geographic area (i.e. 69.1 M ha) (FSI, 2009) and forestry represents the second major land use in the country after agriculture and it has been estimated that nearly 41% of the country's forest cover has been degraded to some degree (MoEF, 2002).

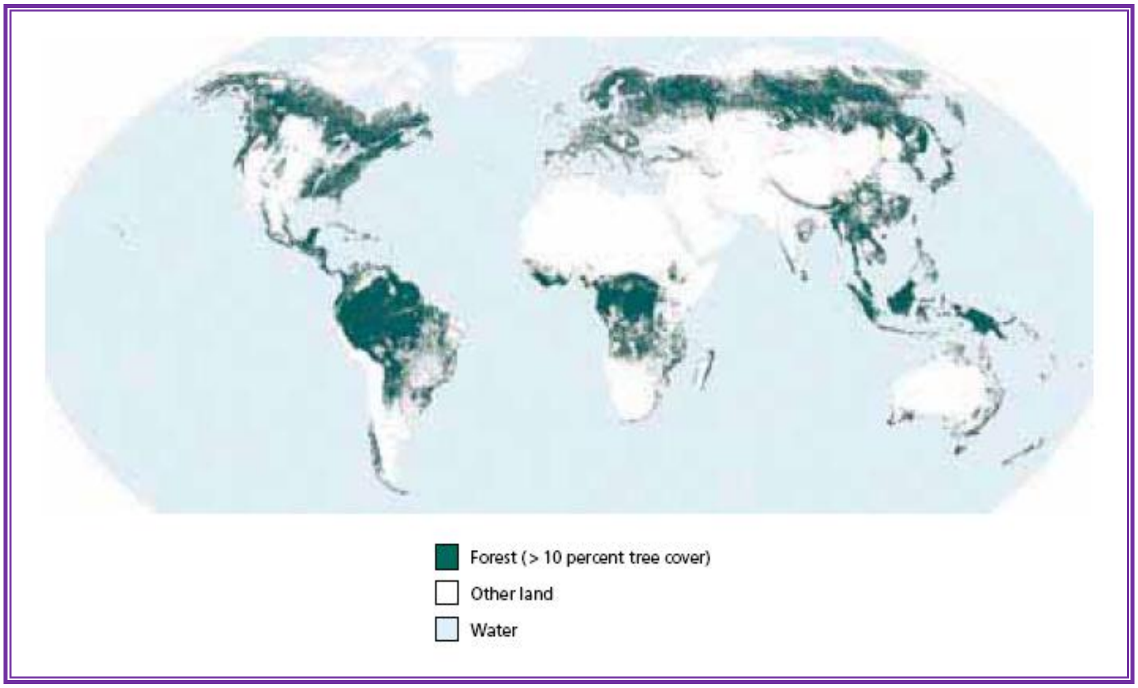
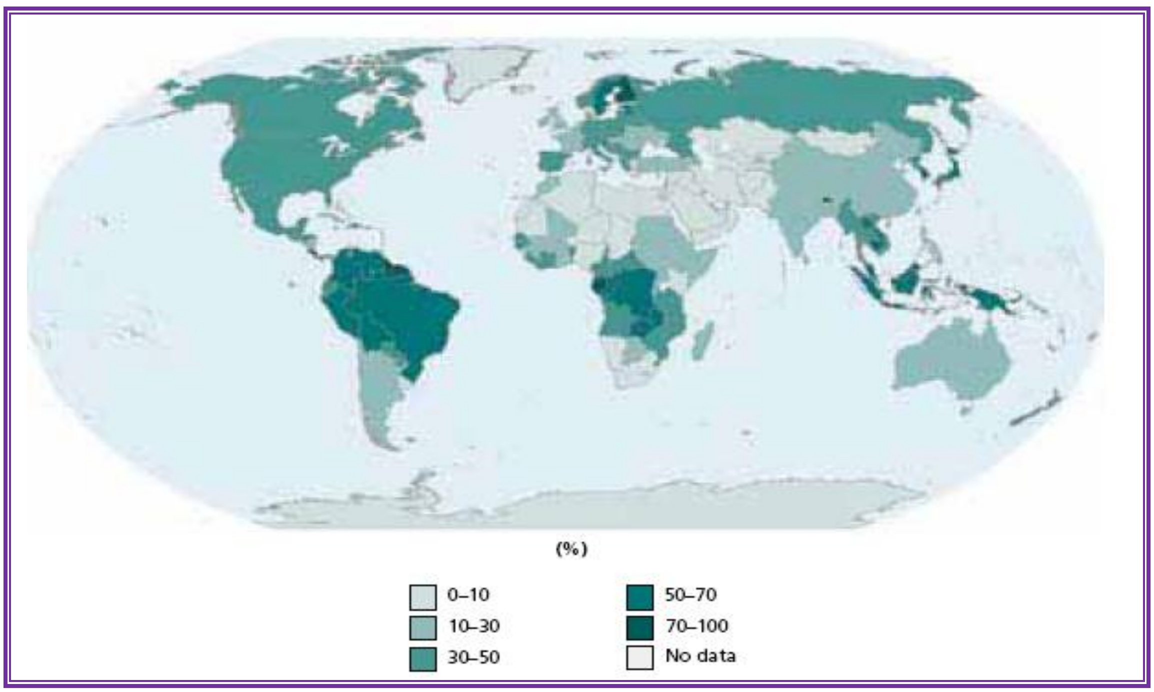


Plate 1: The world's forests



Source: FAO report, 2010

Plate 2: Forest area as a percentage of total land area by country, 2010

1.1. Present vital problems and emerging issues:

Forests play an important role in the conservation of environmental quality by preserving soil and water resources and biological diversity. The shrinking natural resource base, rapidly increasing human and livestock populations, and poverty are all responsible for the tremendous degradation and pressure on existing forest resources (Kumar et al., 2000). Degradation also occurs because forest subjected to a variety of disturbances that are themselves strongly influenced by climate. Disturbances such as fire, drought, landslides, species invasions, insect, and disease outbreaks, and climatic events such as hurricanes, windstorms, and ice storms influence the composition, structure and functions of forests (Dale et al., 2001). In addition climate change not only affects forests' susceptibility to disturbances, but also the frequency, intensity, duration and timing of such disturbances. It also brings changes in disturbance dynamics, in addition to the direct impacts on trees. This can have devastating effects and can increase forests' susceptibility to other disturbances. All of these impacts on trees and forests inevitably, have widespread effects on the forest sector. As observed in recent years global forest area is declining. The forest cover is taken over by other land cover. These forests are under tremendous pressure and are continuously declining. The degradation of tropical forest is proceeding at an unprecedented rate that is destroying the biodiversity and natural resource of the region. India is also facing the similar problem of deforestation due to increase pressure on the forest to meet biomass demand. This generates a need to monitor and quantitatively measure the changes occurring in the forest area. Considering the above facts in the present work the forest status of Dediapada region has been assessed, measured and monitored

1.2. Measuring a forest:

Measurement of things is a fundamental part of any scientifically based discipline. The measurement of trees and forests is fundamental to the practice of forestry and forest science throughout the world. Measurements are used to understand how forests grow and develop? To determine how much they contain the products man wants from them, and to ensure that they are managed appropriately. Many of the things which one need to know about trees or forests are that they are difficult to measure directly. For example, it is not easy to determine the amount of wood in the stem of a tree standing in a forest, simply because the tree is so tall and large. To deal with such problems, techniques have been developed to estimate those difficult things from simple measurements, which can be taken from the ground. This measurement obtained from the ground survey are known as the forest inventory.

1.3. Forest Inventory:

Inventory of trees involves collection of data and its analysis to establish the current condition and to generate baseline information of forest (Mc Lean, 2002; Nowak et al., 2002, Christensen *et al*., 1996). It may be defined as the systematic collection, evaluation, and presentation of specific information about forest areas. Generally, detailed observations are made only of a small part of the area and reliable techniques are applied to extrapolate from these limited observations of the whole area of interest. Such inventories are done similarly in earlier times using different tree inventories.

1.4. History of Forest Inventories:

The main method used in inventories in the 19th century was complete enumeration, but it was soon noted that there was a possibility to reduce costs by using representative samples. Sampling-based methods were used in forestry a century before the mathematical foundations of sampling techniques were described (Doig, 1976, Honer and Hegyi, 1990, Gregoire, 1992, Van Hooser et al., 1992, Schreuder et al., 1993, Frayer and Furnival, 1999). According to Loetsch et al. (1973), visual estimation was used until the 1940's in Germany, where learning this method was part of a good training program for a forester in those days. Visual estimation was often used, as it was cheap and fast. In North America, for instance, these inventory surveys were carried out at the beginning of the 20th century by "timber lookers," whose years of field experience allowed them to develop the ability to assess timber volumes by eye without the benefit of any measurements. In the Nordic countries, especially in Finland, these visual estimates are still used for acquiring data for management planning at the stand level. In early inventories visual estimates were combined with statistical estimates in order to reduce bias (Ilvessalo, 1923). Statistical knowledge was gradually introduced into the forestry literature between 1900 and 1920, primarily in Scandinavia where the first small-scale forest inventories using systematic strip sampling had been carried out in Sweden in the 1830's by Israel af Ström (**Israel af Ström** (1778-1856) was a Swedish forest researcher and founder of Sweden's National Forestry Institute). An auxiliary purpose in conducting an inventory was that of developing a map showing the distribution of timber, forest types, access, and topographic detail. The method of cruising with continuous strips of fixed width covering a known percentage of the land area was the most popular in the 1930s because it served both purposes, inventory and mapping. The most important scientific work in this field in Finland was the inventory carried out in Sahalahti and Kuhmalahti by Werner Cajanus in 1912 (Seppälä 1985). Ilvessalo carried out the first four National Forest Inventories between 1921 and 1963 (1927, 1942, 1956, 1962). National inventories in the other Nordic countries started at almost the same time. Since these first inventories were systematic, estimators for the variance in systematic sampling have been intensively developed in these countries. Tree inventories are the primary methods for determining the composition of trees.

India started the regular program for forest inventory with the use of the remote sensing technology way back in early 1980s. Forest Survey of India (FSI) has conducted national assessments of forest resources since 1965 as it was mandated for this activity. The National Forest Policy of India, since 1952 has set a goal of bringing one-third area of the country under forest cover. The policy goal has given direction to the efforts of conservation, afforestation, and tree planting outside the traditional forest areas. Realizing the need for a closer and scientific monitoring of forest cover, the use of remote sensing was introduced. The first report on forest cover monitoring was published as “State of Forest Report” (SFR, 1987). Since then, biennial monitoring of the country’s forest cover is being done regularly. India is among the few countries in the world to start such a unique system of monitoring of forest cover at National level.

In recent years, the need of assessing forest structure along with monitoring of forest cover has become essential for the forest management.

Forest structure is an integrated composite of individual tree structure, quantity, and arrangement in the landscape in both the horizontal and vertical dimensions and it should be studied from both these dimensions. The understanding of such structure along with different parameters such as tree size, stem density, growth is a prerequisite. Tree inventory, which involves the generation of comprehensive measurement of population of trees through ground surveys (Kenney and Puric-Mladenovic, 2002) is needed for the forest management. Tree inventory during a forest survey is basically carried out in three steps. First step is to understand the species composition of the forest, second is to observe the different phenological pattern in all the trees of forest and third is to, recognize the trees present in that composition and examine the different tree structures including the Diameter at Breast Height (DBH), Total tree Height (TH), Tree Canopy cover (CC), and the tree Basal area (BA).

Forest Inventory can be attempted in two ways either through conventional (ground survey) or through non-conventional method (Optical and Microwave remote sensing data).

1.5. Conventional /Ground Survey method:

It involves identification of the composition and phenology of the species present in an area. It also involves assessment of tree damage and different structural variables like DBH, basal area, total tree height, and the crown cover essential for understanding the tree health. Such assessment is done through primary analysis.

1.5.1. Primary Analysis

1.5.1.1. Species Composition- Understanding of species is essential for identification of native vegetation (or even weed species) as it is an indicative of site characteristics.

1.5.1.2. Phenology- It is the study of the timing of periodic biological events in the animal and plant world as influenced by the environment (Schwartz, 2003).

Records of long-term phenological observations on trees, such as the dates of leaf unfolding, flowering, leaf discoloration and leaf fall, provide historical information to indicate how plants have responded to variations in climatic conditions. Plant phenological studies are fundamental in understanding of forest as a resource base for other dependent populations or communities.

1.5.1.3. **Tree damage -**Tree damage involves the evaluation of Physical damage of the trees that occurs during pest outbreak or any other reason, affecting the overall tree health of the forest.

1.5.2. Tree structure

1.5.2.1. **DBH-** is the Diameter at Breast Height (DBH). DBH is an important predictive variable. (Leboeuf et al., 2007) It alone explains more than 95% variation in biomass (Gibbs et al., 2007). The actual location of DBH varies slightly around some countries. In continental Europe, Australia, U.K, Canada, and some former members of the British Commonwealth DBH of a tree is taken at 1.3 m above ground. According to the policy developed by USA, New Zealand, India, and South Africa and for other countries the DBH of a tree is measured at a height of 1.4 m (or 4' 6") above ground (Russell and Honkala, 1990)

1.5.2.2. **Crown Cover** is the percentage of the ground covered by a vertical projection of the outermost perimeter of the crowns in a stand (Spurr, 1960). Only the crowns that form part of the upper canopy level (dominant / codominant stratum) are used to determine closure in uneven-aged or stands with multiple canopy layers.

1.5.2.3. **Height-** In forestry, tree height is defined as the vertical distance from ground level to the highest green point on the tree (which will be referred to here as the tip of the tree). (West, 2009) The height of trees is important to forestry particularly because it is a part of the calculation of the total amount of wood contained within it and an important measure used in forestry to assess site productive capacity.

1.5.2.4. **Basal Area (BA)** is defined as the cross-sectional area of a stem of a tree at its breast height assuming cylindrical stem (Helms, 1998). This is an indicator of growing stock and biomass production in a forest area.

Along with the assessment of above forest parameters, ecological diversity is also one of the guiding principles for forestry management and planning. This diversity is often quantified with measurable indices, such as Shannon–Weaver index, Margalef,
Mc Intosh and Brillouin Index.

1.5.3. Secondary analysis

1.5.3.1. **Shannon-Wiener Diversity index-** which takes into account the number of individuals as well as number of taxa. It is commonly used to characterize species diversity in a community. It accounts both abundance and evenness of the species present.

1.5.3.2. **Margalef Index-** This index denoted as D was given by Margalef in 1957. The higher the index the greater is the diversity. It has no limit value and it shows a variation depending upon the number of species. Thus, it's used for comparison between the sites.

1.5.3.3. **McIntosh Index-** It was suggested by McIntosh in 1967. The values ranged between 0 – 1. When the values are getting closer to 1, it indicates organisms in a community are homogeneously distributed.

1.5.3.4. **Brillouin index:** This index measures the diversity of a collection, as opposed to the Shannon index, which measures a sample. Pielou (1975) recommended this index in all situations where the sampling is carried out in non-random, or where the full composition of the community is known. The value obtained rarely exceeds 4.5 and both the Brillouin and Shannon Indices tend to give similar comparative measurements.

1.6. Non-Conventional /RS-GIS Method of forest Inventory:

1.6.1. **Remote sensing in forest Inventory-** This method takes advantage of the fact that vegetation canopy structure through their inventory has significant impact on Earth Observation (EO) signal in both optical and microwave range of EMR. This fact has already been proved by various workers (Ross, 1981; Imhoff, 1995; Knyazikhin *et al*., 1998a, b; Panferov *et al*., 2001; Widlowski *et* *al*., 2004). These structural characteristics of a forest and the correlative relationships with canopy reflectance support the utility of remote sensing as a useful tool for assessing forest condition and forest disturbances, which are often patchily distributed across a landscape both spatially and temporally. Thus, such non-conventional techniques are cost-effective, precise providing near real-time data for larger area at an instant *i.e.* when compared to field survey methods, which are labor intensive, and costly, resulting in low sample coverage and frequency. Forest assessment using optical remote sensing till date has been attempted by several workers (Howard, 1991; Solberg, 1999; Robert, 2005; Pearson, 2007). It has been used for timely information regarding their stocking levels, health, and species diversity which is required for effective treatment decisions. Assessment of forest structure by optical remote sensing becomes difficult during cloud cover, when the terrain is not flat and the measurements are to be made in both vertical and horizontal directions. Microwave remote sensing data solve this difficulty as it is not affected by cloud cover and terrain. It has the ability to penetrate into the forest canopy due to its longer wavelength. Different wavelengths of microwave data help in understanding different forest features because the backscatter strength from the canopy is a function of different tree features as explained and shown below (Figure 1**)**.

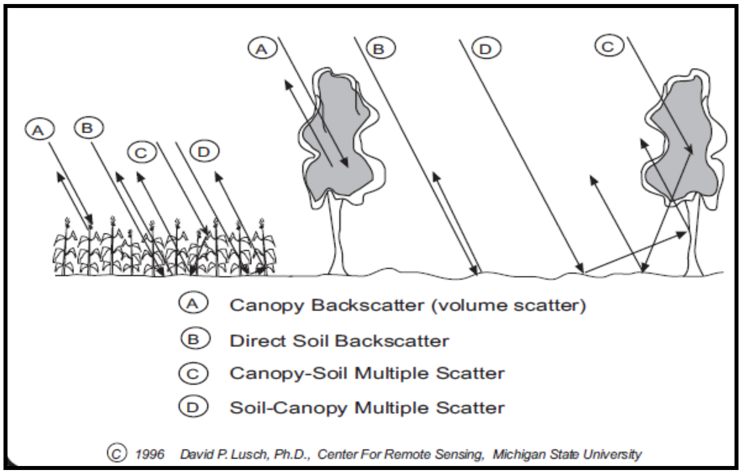


Figure 1: Types of canopy Backscatter

1.6.2. GIS in Forest Inventory:

The voluminous information on forest parameters is required to be updated, monitored, and assessed continuously. This can be done easily with Geographic Information Systems (GIS), which are computer-based methodologies conceived for spatial data collection, storage, retrieval, transformation, display and analysis (Kitanidis, 1996). The forest variable data can be integrated to produce a resource map, which can be compiled, manipulated, modeled, and analyzed using different statistical algorithm present in the system. e.g., Geostatistical methods using auxiliary data provide a variety of spatial estimation procedures, which are known as Kriging. Prediction accuracy can also be increased by incorporating large volumes of auxiliary data (i.e. Remote sensing data) for forest research with the help of Kriging, co-Kriging etc (Meng, 2006) .

In the present study, potential of both conventional and non-conventional methods has been exploited to understand the species composition, phenological status of forest trees, levels of tree damage to the forest area and for the assessment of different tree structural parameters essential for forest inventory. To recognize the levels of damage of forest tree, these trees can be further analyzed to understand their biochemical and biophysical parameters. These parameter forms an indicator to detect the tree health status.

2.0. Estimation of Biochemical and Biophysical parameters of Forest:

Changes in forest and forest ecosystem are also due to continuous and long-term succession. Discontinuous, occasional, and sudden natural or human-induced disturbances also contribute towards the changes in the forest (Wulder and Franklin, 2007). Different biotic and abiotic factors such as extreme weather conditions, pathogens like fungi or insects and anthropogenic pollution (Wild et al., 1996; Tausz et al., 1999) results into the decline of the forest. Decline in forest is therefore called as complex disease. To take protective measures against this disease bio-indicator parameter should be utilized as given by Ulrich 1991. Such indicators help in deducing information about the different physiological processes that is performed in living systems, to enable responses about plant vitality.

These indicators may be observed visually and through biochemical and biophysical parameters. The visual parameters can be like the foliage loss, leaf discoloration, necrosis, etc. A biochemical parameter can be understood through different photosynthetic components like chlorophyll, nitrogen, antioxidant, and phenolic etc and biophysical through relative water content, leaf area index and Biomass. The biochemical and biophysical parameters provide necessary supplementary information about plant vitality that may lead to an early risk assessment.

In the case of understanding, the forest health status, biochemical parameter like chlorophyll and biophysical parameters such as water, LAI, and biomass becomes significant because these parameters comprises the spectral feature of the plant and can be picked up through satellite images for understanding forest functionality.

Understanding of biochemical parameter through conventional and biophysical parameters through both conventional and non-conventional techniques will help in identifying the tree health status in the forest. It is also necessary for any forester or forest manger to monitor the forest cover.

3.0. Forest cover:

Tropical forests, although covering less than 10% of the land areas, represent the largest terrestrial reservoir of biological diversity, from the gene to the habitat level. For example, more than 50% of known plant species grow in the tropical forests. Forests are an important natural resource base, requiring action for their informed utilization, management and protection at spatial scales from the local to the global. In India according to the State of Forest Report 2003, forest cover is 67.83 M ha covering 20.64% of the geographic area. In the last two years, Gujarat has lost close to 100 square kilometers (sq. km) of forest area due to human activity. This is a 13 per cent of the national loss (728 sq. km) of forest area (Sulaimani, 2008). The FSI report also emphasized that the loss of green cover is due to human activity. In other words, increasing population pressures are taking a toll on the state's forest cover.

Utilization of satellite imagery can substantially improve the knowledge on changes in forest area as a result of deforestation, afforestation and natural forest expansion. Remote sensing data in combination with additional data sources has been recognized as an important source of information for detecting forest cover and its changes.

3.1. Optical remote sensing in forest mapping

In non-conventional method, the data of optical remote sensing satellites such as LISS-III, LISS-IV and Landsat-ETM$^+$ are used due to its resolution, both radiometric and spatial. Optical remote sensing methods have successfully been utilized in the inventory of forest species. The incorporation of ancillary data with remotely sensed data for digital data analysis in determining forest species distribution have further increased the classification accuracy. One of the most common applications of remote sensing in forestry is the production of thematic maps, depicting tree species or stand age, by means of image classification.

The only disadvantage of the optical data is that it is cloud affected. It is important to establish forest cover map in the cloud covered areas for continuous monitoring of these areas. Ulaby et al. (1982) suggested that, in order to achieve high correct classification rates, it is necessary to have uninterrupted (cloud free) coverage of the area under investigation for successive passes of the satellite.

3.2. Microwave Remote Sensing in forest mapping

Tropical forest cover and its depletion due to natural and anthropogenic factors have been studied previously using various remote sensing data. Generally high or coarse optical data are used to assess forest cover. Forest cover classification using optical data mainly depends on weather conditions and it is very difficult to get cloud-free optical data in the rainy season. Nonetheless, the utility of optical data is highly affected by atmospheric conditions. Synthetic Aperture Radar (SAR) provides an alternative to obtain the information. Microwave data in this context give a continual data, which gives the opportunity for continuous monitoring of forest. One more advantage can be attributed to microwave data is that its surface interaction is found to be different from the optical sensors, thus providing unique information about ground features. Due to the active nature of radar, whether or not the sensor detects any surface response it is a function of incident angles, landscape geometry, material dielectric constant, and surface roughness, which collectively constitute the amount of energy returned to the sensor (i.e. backscatter). Along with single polarization datasets, dual or fully polarimetric SAR images have been used. Disturbances in forested areas can be detected or mapped through fully polarimetric SAR.

Polarimetric SAR data can be utilized to detect or map disturbances in forest areas. VanZyl (1998), aimed at using a priori knowledge of a specific class of scattering properties to classify multi-polarization imagery without training areas. Radar Vegetation Index (RVI), was introduced which generally has a similar background of rating methods of reflective bands in optical datasets such as the NDVI. The RVI employed cross-polarized backscattering cross section in comparison with total backscatter in order to characterize designated objects. Woody vegetation, which retains a strong cross polarization component, has high RVI value. Nonetheless, this technique was confirmed to have faster saturation than other polarimetric features; hence, the application has been limited.

3.2.1. Polarimetric decomposition:

Polarimetric Decomposition techniques provide a new insight on polarimetric SAR data analysis. They offer a thorough and meaningful way to exploit fully polarimetric datasets. Various decomposition techniques have been presented; however, many researchers have favored the model based (for example Freeman-Durden decomposition algorithm) and eigen-based (such as Cloude-Pottier algorithms). The purpose of this study is to evaluate polarimetric SAR to assess different levels of forest stress with the help of the Cloude-Pottier decomposition theorem.

Cloude (1986) introduced the use of the characteristic decomposition of target covariance and coherency matrix for incoherent target decomposition. Cloude's decomposition was found to be unique and, in the monostatic case, breaks the average covariance matrix up to the weighted sum of three covariance matrices representing three different single scatterers. Cloude applied his decomposition on the target coherency matrix on the basis formed by the Pauli spin matrices. The classification technique used here is based upon polarimetric decomposition classification parameters: Entropy (H), Anisotropy (A) and Alpha (a). This classification procedure is based on decomposition theorem. The H/A/a set of parameters is derived from an eigen value decomposition of the coherency matrix. The entropy provides information on the scattering degree of randomness. The alpha parameter indicates the nature of the scattering: single or double bounce reflection or scattering over anisotropic media. The anisotropy provides information on the relative importance of secondary mechanisms.

Utilizing the above advantages of individual datasets in optical and microwave region the present study was undertaken to monitor and map the forest area of Dediapada Taluka. The combination of these data was further used to understand the explicit of both these data sets by fusion techniques.

4.0. Fusion of satellite data for further classification:

Data fusion is a process dealing with data information from multiple sources to achieve refined/improved information for decision-making (Hall, 1992). On the other hand, image fusion is the combination of two or more different images to form a new image by using a certain algorithm (Genderen and Pohl, 1994). Data fusion takes the advantage of the strengths of a particular data for improvement of visual interpretation and quantitative analysis. Due to the availability of multiple types of sensors, more and more data have become available for scientific researches. Such type of voluminous data for specific variable when gathered from different sources and combined can aid in extracting most useful information regarding the variable. (Figure-2)

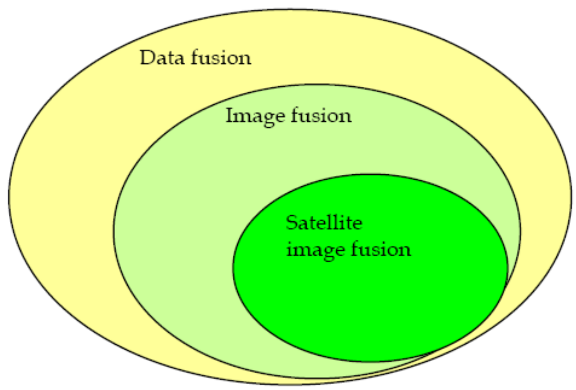


Figure 2 Illustration of relationship of data fusion and image fusion

Generally, the visible and infrared wavelength systems are recognized as being superior to radar data, due to their multispectral information content (Brisco and Brown, 1999). Based on this, strong argument for the utility of sensor fusion multispectral systems are based, where the fusion is carried out using of several individual bandwidths. The problem involved in such type of fusion is the sensitivity of optical and infrared wavelength to differential scattering and absorption caused by chlorophyll, green leaf area, and leaf structure, and leaving some vegetation types that cannot be separated, due to the similarity of their spectral responses (Raghavswamy et al., 1996). Microwave data on the other hand responds differently to varied terrain and dielectric factors such as plant canopy roughness and structure, plant moisture content, and sub-canopy conditions. As such, a combined sensor analysis could contribute to information regarding both the leaf composition and the surface geometry, thereby greatly increasing the potential information content (Henderson et al., 2002).

There are distinct advantages of fusing radar with optical data, as the end product has the advantage of textural information from radar image, and spectral information from the optical and infrared bands. Hence, by fusing multiple datasets, an analyst has a single and more informative image (Pal et al., 2007). With its origin in military applications, image fusion has provided a framework to the civil sector which helps to integrate different sensor platforms for a variety of uses. One of the reasons for this increase in multisensory fusion is due to the complementary information about the various different datasets (Chavez et al., 1991). It is crucial for the scientific community to harness this potential useful technique, as it will immensely improve the geographical knowledge and application for remote regions across the world. To achieve an accurate classification of ground, an image of a suitable resolution of the forest to be acquired first, and then the characteristics of each small segment of the image must be classified accurately. Therefore, the present study has been undertaken involving different Fusion Techniques for accurate classification.

5.0. Need of the study:

This study addresses the status of one of the forest's most visible resources: the trees. Many of the world's ecosystems depend on trees for vital functions, such as sustaining soil structure and fertility and preventing soil erosion and floods. Trees provide human society with sources for industrial products, construction materials, food, and fuel-wood. The forest ecosystems can be optimally managed if timely information on their structure and function is available. There is a requirement of quantitative information on forest health, and how it varies in space and time. Therefore, Forest study is essential in order to monitor the forest.

6.0. Objectives

- To collect different information on tree attributes such as crown cover, tree height, DBH.
- To estimate biochemical parameter such as chlorophyll content and biophysical characteristics such as biomass, leaf area index (LAI), leaf Relative water content (LRWC) and vegetation indices
- To conduct forest mapping with the help of optical and microwave remote sensing to understand changes going in forest.

STUDY AREA

Study area

7.0. Description of the Study Area

7.1. Geographical area:

The Shoolpaneshwar forests in south Gujarat are remnants of some of the finest forests in the Gujarat. The Dediapada forests are part of the Shoolpaneshwar forest. They are home to a variety of natural resources and a diversity of flora and fauna. This place is situated in Narmada district, Gujarat, India, its geographical coordinates are **73°41'6" E, 21° 45' 43"N** and its original name (with diacritics) is Dediapad.

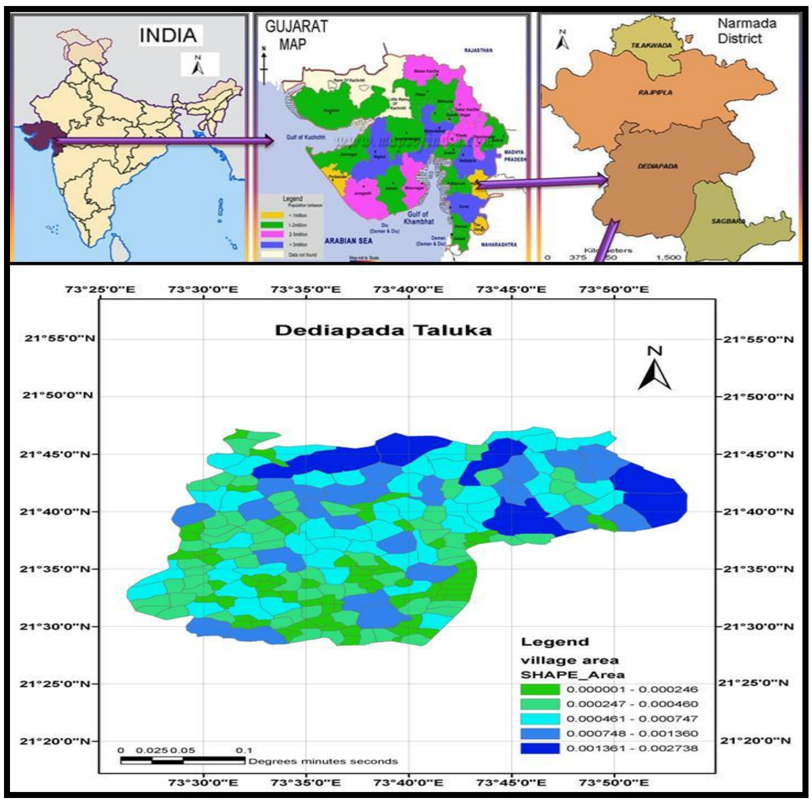


Plate -3: Study Area –Dediapada Taluka of Narmada District

7.2. History:

Rajpipla forests were managed by the erstwhile Rajpipla State up to independence. The present Dediapada Taluka was part of this State. The forests were managed on scientific lines and regular working plans were prepared. Most part of the sanctuary, which was the part of the Rajpipla State, was left unworked except for small amount of work plans prepared for yield.

After independence, the forests were managed by the Forest Department of the erstwhile Bombay state. After reorganization of states and formation of Gujarat state, Rajpipla

Division came under the Surat conservancy. In 1972 the division was bifurcated and the areas of the present sanctuary came under Rajpipla East Division. The sanctuary was established in 1982, when it was known as ***Dumkhal Sloth Bear Sanctuary.*** In later Notifications made in 1987 and 1989, the area of the sanctuary was enlarged and after final notification, it came to be known as ***Shoolpaneshwar Wildlife Sanctuary.*** **(Plate-4)**

Plate 4:**Shoolpaneshwar Sanctuary -Dhumkal Range**

The Dediapada forest, consisting the Shoolpaneshwar sanctuary has 75% of the area under bamboo, which is a big fire hazard during the summer season. Fire and repeated fires causes extensive damage to the area, besides affecting regeneration and disturbing the wildlife. The areas of the Sanctuary, especially those falling on Maharashtra border, are prone to illicit cutting for commercial purposes. Intensive patrolling of these areas is required as they are hilly and rugged. Inside the Sanctuary, the locals for house construction and other requirements resort to the cutting. With the population going up, the illicit cutting for domestic requirement also took up a big toll on the forests.

7.3. Resources:

As per the Champion & Seth’s classification, the sanctuary has two distinct forest types viz. Southern Tropical Moist Deciduous Forest, sub type slightly moist teak forests 3B/C1C and Southern Tropical Dry Deciduous Forests, sub type dry teak forests 5A/C1B. The area is generally hilly and rugged with precipitous slopes at most of the places. Dhaman mal hill near Piplod is the highest point in the sanctuary at 880.87 meters.

7.4. Geology:

Geologically the area has formations of Eocene time with bagh beds being the most representative. The Deccan trap, dikes and alluvium deposits are the other formations.

The soils in this area vary in color, texture, depth and stoniness depending upon the rock and topography. The reddish brown loamy soil, yellowish brown loamy soil, sandy loam, fine murram and black cotton soil are some of the soils found in the sanctuary area.

7.5. Climate:

There are three main seasons - Monsoon, which extends from June to October, winter from November to February and summer from March to June. The area receives an annual rainfall of 100 to 125cms. The summers are hot while the winters are pleasant.

7.6. Flora and Fauna:

Flora: The two Forest types found in the area are not distinctly reflected on topography. The moist teak forests are found in Fulsar, Piplod, and Sagai ranges of the sanctuary. The composition of teak is usually 25% of the total crop. The dry teak forests also occur in the same locality within a short distance but mostly on poor soils, hill ridges and areas subjected to biotic interference. Under storey consisting of *Dendrocalamus strictus*, is a characteristic feature of this area. Ground cover consists of evergreen to semi evergreen species and occurrence of woody climbers is common feature. This area can be categorized into different strata. The top Strata is occupied by the trees , which consist of *Tectona grandis, Terminalia cranulata, Dalbergia Sissoo, Anogeissus latifolia,Lannea coromandelica, Garuga pinnata, Mitragyna parvifolia, Lagerstroemia parviflora, Diospyros melanoxylon, Soymido febrifaga, Terminallia bellerica, Madhuca indica* and rest other species.(Plate -5,6,7)

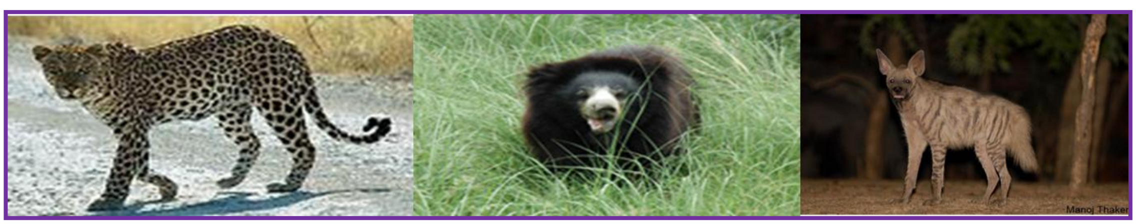
Plate 5: Photograph showing Teak forest

Plate 6: Photograph showing Butea forest

Plate 7: Butea monosperma flowers

Fauna: The forest area has a large bird population with more than 200 species of birds found therein, which includes some of the rare and endangered birds as well. Besides, there is a large number of raptors population which are at the apex of this pyramid.

The mammals which are found in this sanctuary includes leopard, sloth bear hyena (plate-8a), fox, jackal, cats, mongoose besides herbivores like sambar, four horned antelope, wild boar, hares, porcupines and monkeys. The Narmada River harbors a lot of crocodiles. Sometimes even the casual bath in the river is dangerous. Among the reptile species; python, snakes like cobra are also often seen. The chital population has become extinct and a need for a breeding program for the same is felt. The flying squirrel and the giant squirrel are some of the other species, which are found in the area



(a) Leopard **(b) Sloth Bear** **(c) Hyena**

Plate 8a: Wildlife of Dediapada forest

7.7. Non Wood Forest Product (N.W.F. P.)

Ninety percent of the non-wood forest products (NWFP) production in Rajpipla comes from the sanctuary area highlighting the degree of dependence on the sanctuary. The term non-wood forest products cover all forest products other than timber, small wood and firewood. Thus N.W.F.P specifically includes grasses, fruit, leaves, barks, gums, etc.

besides, plants of medicinal importance. Apart from their monetary value, forest products, are of enormous value to the tribes residing in Shoolpaneshwar sanctuary. However, of the various NWFPs only a few have high economic value viz. *Madhuca indica* flower, *Madhuca* seeds and *Diospyros melanoxylon* leaves. These three contribute 95% of total revenue. Apart from the collection, as per the rights and privileges, the local tribes are entitled to collect the NWFPs for their benefit use. A majority of NWFP production comes from the rich forested areas that are also the best habitat for wildlife. These areas are Geechad, Chopdi, Namgir, Kalwat, Piplod, etc. Thus the area of NWFP production overlaps with areas of rich bio-diversity requiring broad conservation and management strategy.

7.8. Tourism:

In these beautiful forest range Ninai waterfalls (plate-8b) and Shoolpaneshwar wildlife sanctuary are present. They become the excellent trekking and camping options, especially after the monsoon season, when the area is more lush.

Plate 8b: Ninai Waterfalls

MATERIALS
&
METHODOLOGY

8.0. Data used

8.1. Reference Maps:

The Survey of India (SOI), topographical maps at 1:50,000 scales was used as a reference map for the base map preparation. Besides, SOI Toposheet, maps provided by forest department was used for digitizing district boundary as well as village boundaries.

8.1.1. Satellite Data:

8.1.1.1. Optical Data

Table A-Displaying optical data

Sr. No	Data used	Path/ Row	Date of data acquisition	Wavelength width in µm/ band	Spatial resolution (m)	Swath (km)
1	Landsat-TM	148/045	19th October 1990	0.45-0.52 (blue) 0.52-0.60 (green) 0.63-0.69 (red) 0.76-0.90 (NIR) 1.55-1.75 (SWIR) 10.4-12.5 (thermal IR) 2.08-2.35 (SWIR)	30m (120m -thermal)	185 km
2	Landasat ETM+	148/045	11th November, 2001	0.45-0.515 (blue) 0.525-0.605 (green) 0.63-0.690 (red) 0.75-0.90 (NIR) 1.55-1.75 (SWIR) 10.40-12.5 (thermal IR) 2.09-2.35 (SWIR) 0.52-0.90 (pan)	30m (60m- thermal, 15m pan)	183 km
3	IRS- 1C, 1D LISS III	99/ (54,55) 100/ (54,55)	16-November 1997, November 2005	0.52-0.59 (green) 0.62-0.68 (red) 0.77-0.86 (NIR) 1.55-1.70 (MIR)	23.5	141

8.1.1.1.1. Landsat-TM Data:

The Thematic Mapper (TM) is an advanced, multispectral scanning, Earth resources sensor designed to achieve higher image resolution, sharper spectral separation, improved geometric fidelity and greater radiometric accuracy and resolution than the MSS sensor. TM data are sensed in seven spectral bands simultaneously. Band 6 senses thermal (heat) infrared radiation. Landsat can only acquire night scenes in band 6. A TM scene has an Instantaneous Field Of View (IFOV) of 30 square meters in bands 1-5 and 7 while band 6 has an IFOV of 120 square meters on the ground**.**

8.1.1.1.2. Landasat ETM$^+$:

The Enhanced Thematic Mapper Plus (ETM+) instrument is a fixed "whisk-broom", eight-band, multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth's surface. It detects spectrally filtered radiation in VNIR, SWIR, LWIR, and panchromatic bands from the sun-lit Earth in a 183 km wide swath when orbiting at an altitude of 705 km. An ETM+ scene has an Instantaneous Field Of View (IFOV) of 30 meters in bands 1-5 and 7 while band 6 has an IFOV of 60 meters on the ground and the band 8, an IFOV of 15 meters.

8.1.1.1.3. IRS LISS III:

LISS - III camera provides multispectral data in 4 bands. The spatial resolution for visible (two bands) and near infrared (one band) is 23.5 meters with a ground swath of 141 kms. The fourth band (short wave infrared band) has a spatial resolution of 70.5 meters with a ground swath of 148 kms. The repetitivity of LISS - III is 24 days.

8.1.1.2. Microwave data:

Table B Displaying Microwave data

Sr. No	Product	Date	Beam	Band	Polarization
1	**ENVISAT ASAR-ASA-APP**			**C**	**VV/HH**
2	**RADARSAT-2**	**February 2011** **April 2011** **June 2011**	**FQ4** **HH** **VV** **HV** **VH**	**C**	**VV,HV,VH, HH**

8.1.1.2.1. ENVISAT Advanced Synthetic Aperture Radar (ASAR):

The ASAR is an advanced version of the synthetic aperture radar from the ERS-1 and 2 missions. It operates at 5.331GHz and incorporates a number of imaging modes that provide a variety of resolutions, polarizations and swath widths. Generally, the swath width is 100 km with the exception of wave mode (5 km) and the wide swath width and global monitoring (400 km) products.

8.1.1.2.2. ASAR Alternating Polarization Precision Image:

ASAR data product is generated from Level 0 data, collected when the instrument is in Alternating Polarization Mode (7 possible swaths). The product contains two

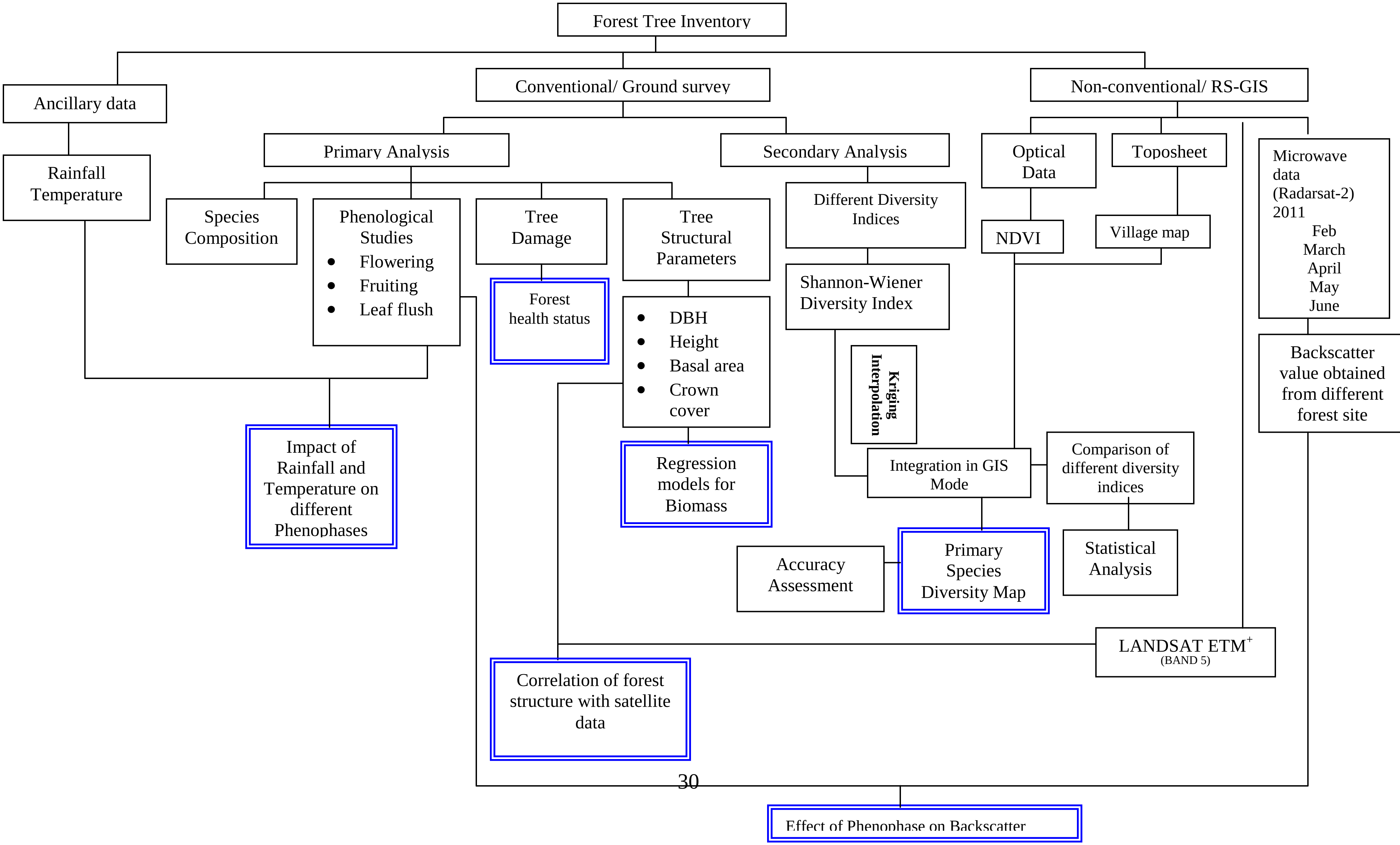
CO-registered images corresponding to one of the three polarization combination submodes (HH and VV, HH and HV, VV and VH). The distinct features are as follows:

- Coverage-100 km along-track, 56-100 km across-track
- Geometric resolution -Approximately 30m ground range * 30m azimuth
- Radiometric resolution - Product ENL > 1.8
- Pixel spacing **-12.5m * 12.5m**

8.1.1.2.3. RADARSAT-2:

RADARSAT-2, launched in 2007, is a SAR satellite developed by the Canadian Space Agency and MacDonald, Dettwiler, and Associates, Ltd. (MDA). The satellite advancements include 3 meter high-resolution imaging, flexibility in polarization selection, left and right-looking imaging options, and superior data storage. In addition to RADARSAT-1, beam modes, RADARSAT-2 offers Ultra- Fine, Multi-Look Fine, Fine Quad-Pol, and Standard Quad-Pol beam modes. Quadrate-polarization means that four images are acquired simultaneously; two co-polarized images (HH and VV) and two cross polarized images (HV and VH).

Flow-chart 1--Forest Inventory



9.0. Ground survey:

The ground survey involved detailed reconnaissance of the forest area to understand the species composition, phenological status of the forest, levels of damage to the forest area and assessment of different tree structural parameters.

Information comparison and need of each feature is essential for tree inventory and it has been brought out separately.

9.1. Primary analysis:

Primary analysis consisted of understanding the tree diversity, phenological status and evaluating the tree structural parameter.

9.1.1. Tree composition:

Tree composition was assessed to understand the Tree diversity composition of Dediapada Taluka.

9.1.2. Phenology:

The Phenological observations of tree species were carried out at ground level. Phenology chart was prepared based on the Frequency of flowering, fruiting and Leaf flush of each tree species in a particular month this was carried out by frequent field visit for year 2007. In addition to these the previous records of Phenology for the year 1992 (Sabnis and Amin,1992) was taken and comparison for both the year was carried out.

9.1.3. Tree structural parameter:

Assessment of Tree structural has been carried out in five different villages of Dediapada Taluka. For tree species, belt transect (20 m X 10m) was laid down in three replicates at each site.

1. **DBH-** DBH of trees was measured using diameter tape at a height of 1.4 m (or 4' 6")

from the ground level and correspondingly the basal area was calculated**.**

2. **Average crown spread** was measured as per the method given by Banks *et al*. (1999). In each transect all the stems having 30 cm and above girth were considered as trees (Pande, 2006).

3. **Basal area (BA)** of individual tree and Total Basal Area (TBA) of different tree species in the forest were calculated as follows:

$$BA\ (cm^2) = (GBH/2\pi)^2 \times \pi$$

$$TBA\ (in\ m^2\ per\ ha) = \sum BA/10{,}000$$

4. Tree Height:

Tree height was calculated using a Blume Leiss clinometer. This instrument uses the principle of Trigonometry illustrated in Illustration 1. One measurement is made at the tree top, another at the stem base. The two angles a1 and a2 are read, and the distance of the observer from the tree, *D*, is measured. The tree height is then determined from these three known variables accordingly the formula for tree height is as given below:

H=AB =BC+CA

Where, BC = $D \tan \alpha_1$, and CA=$D \tan \alpha_2$, and so,

AB=$D (\tan \alpha_1 + \tan \alpha_2)$.

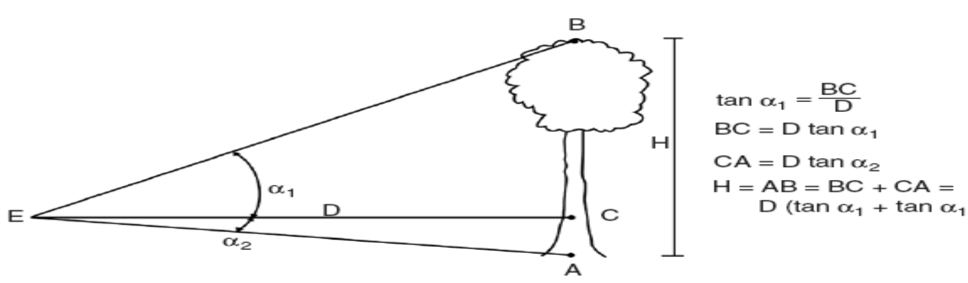


Illustration 1: Height measurements: trigonometric principle

9.2. Secondary analysis:

Field data were subjected to various ecological methods for assessment of the species diversity. Different indices were used to show the species compositional package. Different indices studied are listed as below:

9.2.1. Shannon-Wiener Diversity Index -Shannon in 1948

$$H' = -\Sigma [(ni / N) \times (\ln ni / N)]$$

H': Shannon Diversity Index, ni : Number of individuals belonging to i species,

N : Total number of individuals

9.2.2. Margalef Index-Margalef 1957

$$d = (S-1) / \ln N$$

d : Margalef Diversity Index

S : Total number of species

N : Total number of individuals

9.2.3. McIntosh Index- It was suggested by McIntosh in 1967.

$$Mc = [N - \sqrt{(\sum n_i^2)}] / [N - \sqrt{N}]$$

Mc : McIntosh Diversity Index

ni : Number of individuals belonging to i species

N : Total number of individual

9.2.4. Brillouin index -Pielou 1975.

The Brillouin index, HB, is calculated using:

$$HB = \frac{\ln N! - \sum_{i=1}^{s} \ln n_i!}{N}$$

N is the total number of individuals in the sample, ni is the number of individuals belonging to the i^{th} species and s the species number

9.3. Non-Conventional:

Non conventional techniques like remote sensing (RS)and Geographical information system (GIS) were used to assess the species diversity, Phenology and tree structural parameters.

9.3.1. Species diversity assessment:

IRS_P3 LISS-III of Nov-2005 data, Normalized Differential Vegetation Index (NDVI) Map was generated using ERDAS-9.1. Different maps viz, NDVI, and Village (generated from the cadastral map) were converted into digital format with help of ArcGIS-9.1. The information on tree diversity collected from the ground was then integrated with spatial information in gis mode to generated diversity map. The geostatistical Kriging interpolation technique was generated for the Shannon Index. Accuracy of the Kriging interpolation technique was then carried out to validate the result.

9.3.2. Phenological assessment:

Backscatter values from Radarsat-2 were retrieved using Next ESA SAR Toolbox (NEST) 4A software for the period of five months (February to June). Backscatter values were also plotted for quad-pol for five months**.**

9.3.3. Regression analysis:

Relationships between DBH, Total Height and Canopy Cover of the following trees, viz. *Tectona grandis* Linn. *Butea monosperma* (Lam.) Taub., *Dalbergia sissoo* Roxb. ex DC. *Madhuca longifolia* (J.Konig) J.F.Macbr., and *Terminalia crenulata* Roth were carried out.

9.3.4. Tree structural parameter prediction with non-conventional method

DBH, Total height, crown cover and basal area was correlated and regressed with NDVI

9.4. RS & GIS Analysis:

9.4.1. Base Map preparation:

Reference topographical maps procured from SOI were mosaiced to prepare the base map for the entire Taluka. For which the map sheets were projected and tiled after digital trimming of the map boundaries. This process enabled the contiguous representation of the topographical area and the corresponding map extent.

9.4.2. Village Map Generation:

The SOI maps were also used for the generation of the village map for the study area.

9.4.3. Importing Satellite Data:

The digital data of IRS LISS III, Landsat-TM, Landsat-ETM$^+$ was initially loaded into the computer hard disk in a band sequential format (BSQ), using ERDAS imagine 9.1 Image processing software. Prerequisite information such as number of pixels, rows, columns and bands was filled up while importing the data.

9.4.4. Geo-referencing: The data was geo-referenced using Geographic WGS 94 Projection

9.4.5. Sub-setting:

Using the subset utility of the ERDAS 9.1 Image software module, the exact area under the study was extracted.

9.5. Microwave data processing

Microwave data was imported in NEST 4.A environment and was subjected to other data processing techniques.

9.5.1. Need for speckle filtering

Unlike optical remote sensing images, characterized by very neat and uniform features, SAR images are affected by speckle. Speckle confers to SAR images a granular pattern with random spatial variations.

9.5.2. Filter used: Gamma filter was selected for the present study.

Gamma Map filter: This filter was first proposed by Kuan et al., 1987. The scene reflectivity was assumed to be Gaussian distributed. However, this is not quite realistic since it implicitly assumes a negative reflectivity. Lopes et al., 1990 modified the Kuan map filter by assuming a gamma distributed scene and setting up two thresholds. A prior knowledge of the probability density function of the scene is required to apply the MAP (Maximum a posteriori) approach to speckle reduction. With the assumption of a gamma distributed scene, the Gamma MAP filter is derived in the following form:

$$R = \text{Mean for } \left(SD/Mean\right) \leq \left(\sqrt{1/NLOOK}\right)$$

$$R = R_f \text{ for } \left(SD/Mean\right) < \left(\sqrt{1/NLOOK}\right) < \sqrt{\sqrt{\left(SD/Mean\right)}}$$

$$R = C_p \text{ for } \left(SD/Mean\right) \geq \sqrt{\sqrt{\left(SD/Mean\right)}}$$

where: Rf = (B*Mean + SQRT(D))/(2*A);

Mean = mean value of intensity within window;

Cp = center pixel in filter window

$$B = \left(1+\left(\sqrt{1/NLOOK}\right)^2\right) / \left(\left(SD/Mean\right)^2 - \left(\sqrt{1/NLOOK}\right)^2\right) - NLOOK - 1$$

D = Mean*Mean*B*B + 4*A*NLOOK*Mean* Cp. Once the Gamma filter was generated using Erdas imagine, the backscatter values generated from filtered data were then correlated with different phenological stages and biomass levels.

9.5.3. Geo-referencing of microwave data

The ENVISAT-ASAR and Radarsat-2 data were geo-referenced with Geographic WGS-84

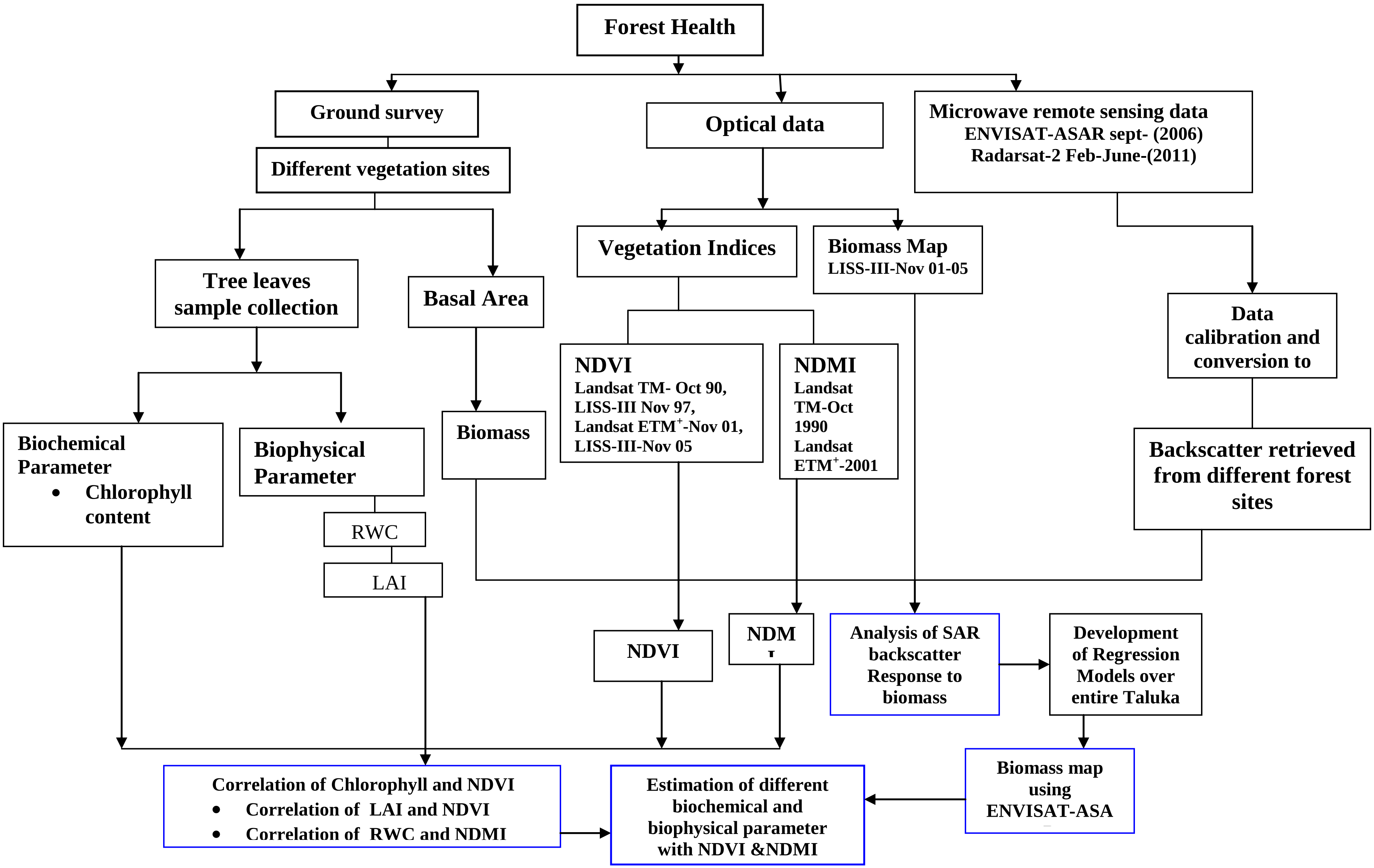
9.5.4. Sigma Nought (σ^o)

Backscattering coefficient is the conventional measure of the strength of radar signals reflected by a distributed scatterer, usually expressed in dB. It is a normalized dimensionless number, comparing the strength observed from the target to that expected from an area of one square meter. Sigma nought is defined with respect to the nominally horizontal plane, and in general has a significant variation with incidence angle, wavelength, and polarization, as well as with the properties of the scattering surface itself (ESA, 2005). The calibrated value can be transformed into dB units by applying 10*log10.

9.5.4.1. Retrieval of backscatter values for vegetation analysis

A 7X7 window was taken and backscatter values for different vegetation types were derived from this window.

Flow chart 2-Forest health using biochemical and biophysical parameter



9.6. Estimation of Biochemical and Biophysical parameters

9.6.1. Conventional techniques

9.6.1.1. Estimation of chlorophyll content:

Total chlorophyll content was measured by following the method of Arnon (1949). The Arnon's equation converted absorbance measurements to mg Chl g^{-1} leaf tissue.

Chl_a (mg/g) = [(12.7 × A663) - (2.6 × A645)] × ml acetone / mg leaf tissue

Chl_b (mg/g) = [(22.9 × A645) - (4.68 × A663)] × ml acetone / mg leaf tissue

Total Chl = $Chl_a + Chl_b$

9.6.1.2. Estimation of Leaf area Index:

The leaf area index (LAI) is the ratio of leaf area per plant to the land area occupied by the plant and was calculated by using the formula as suggested by Sestak *et al.* (1971).

$$LAI = \frac{\text{Leaf area per plant (m}^2\text{)}}{\text{Land area occupied by a plant (m}^2\text{)}}$$

9.6.1.3. Estimation of Relative water content (RWC):

The RWC stated by Slatyer in 1967, expressed the percentage of water content in leaf tissue at a given time and specifically when the tissue are fully turgid.

$$RWC = \frac{FW - DW}{TW - DW},$$

Where, FW is the field weight, DW the oven dry weight, and TW the turgid weight.

9.6.2. Correlation of conventionally derived parameters with spatially derived indices.

9.6.2.1. Normalized difference vegetation index:

NDVI= (NIR-Red)/ (NIR+Red)

9.6.2.2. Normalized Difference Moisture Index

NDMI was derived from Landsat spectral bands 4 and 5 and was calculated using the following equation:

NDMI = [*NIR – SWIR] / [NIR+SWIR]*

9.6.2.3. Correlation of Biochemical and Biophysical parameter with Non-Conventional Data

Biochemical parameter such as chlorophyll content and Biophysical parameters such as LAI was correlated with NDVI. RWC was correlated with NDMI

9.6.3. Secondary Analysis:

Based on the forest Inventory, Biomass analysis was carried out. Basal area per hectare is an indicator of a growing stock of the forest, the approximate size of trees and standing biomass. The Biomass was calculated using the following regression equation given by Ravindranath, 1995.

Above ground Biomass (AGB)

AGB (t/ha) = -1.689 + 8.32 X BA

Where,

SE of coefficient = 1.689

R^2 = 0.5

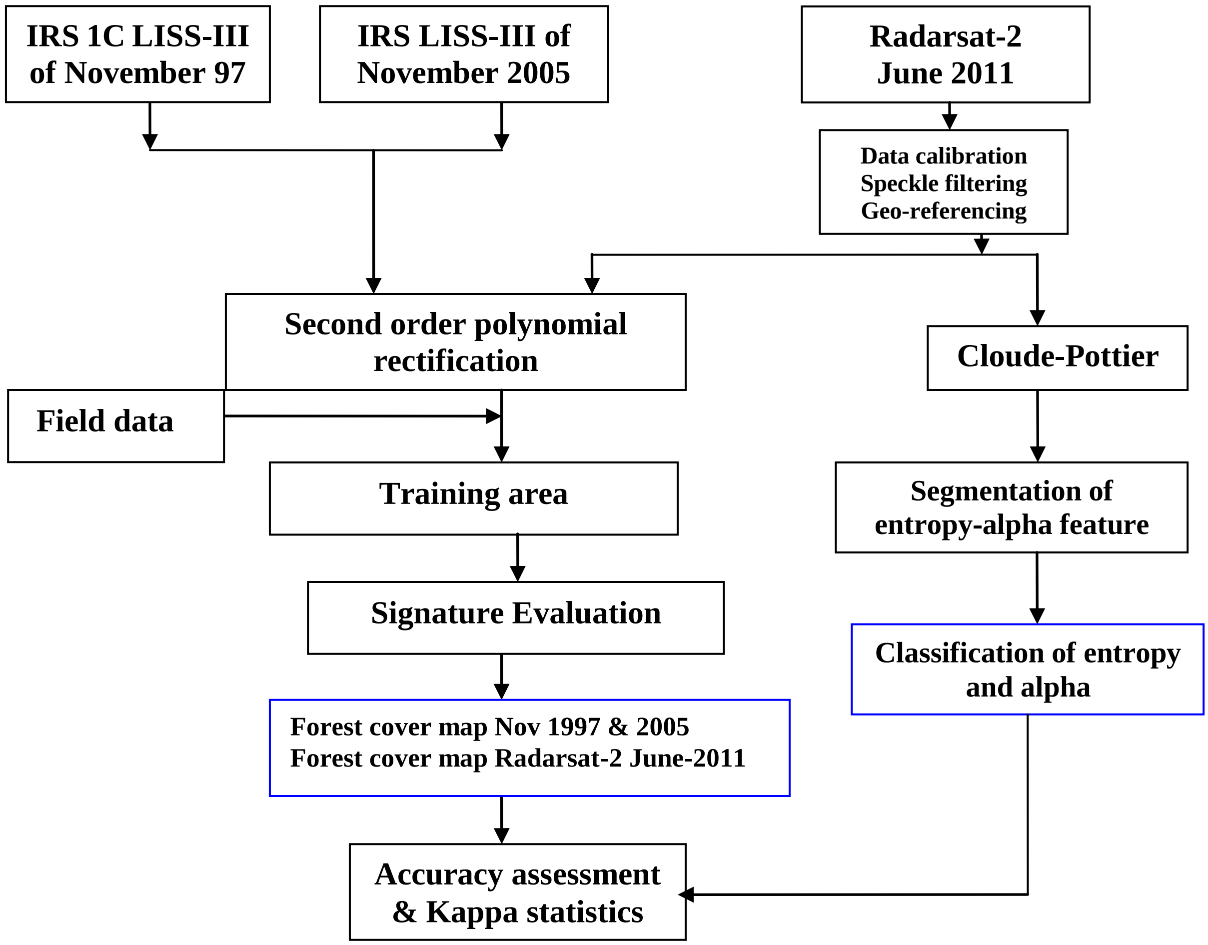
BA = Basal Area in m^2/ha

9.6.4. Biomass from Optical Data

Above ground biomass through ground data was correlated to derive the regression equation. This equation was used to develop the biomass map from optical data.

9.6.5. Biomass from Microwave Data

Similarly the AGB was used to correlate the backscatter values obtained from ENVISAT ASAR was used to derive the regression equation. The ENVISAT-ASAR map was then generated using regression equation.



Flow chart 3Forest cover mapping using remote sensing

9.7. Techniques used for Image classification:

9.7.1. Supervised Classification for optical and microwave data

In the present study both optical and microwave data were subjected to supervised classification. This type of classification requires some knowledge about the scene, such as specific vegetative species, ground truth (field data), or data from aerial photographs or maps used to identify objects in the scene. The classification was carried using the following steps:

a) Firstly, satellite data and accompanying metadata was acquired. Information regarding platform, projection, resolution, coverage, and, importantly, meteorological logical conditions before and during data acquisition was looked for.

b) Secondly, the surface types to be mapped were chosen. Ground truth data with positional accuracy (GPS) was collected. These data were then used to develop the training classes for the discriminant analysis. Care was taken that the time of ground truth data collections to coincide with the date of data acquisition.

c) Thirdly, post-processing techniques such as corrections, image mosaics, and enhancements were performed for the image. Pixels were selected in the image that were representative (and homogenous) of the object. The Global Positioning System (GPS) data were collected, and were used for geo-referencing. The image training sites are defined by outlining the GPS polygons. The training class contained the sum of points (pixels) or polygons (clusters of pixels). The spectral histogram to inspect the homogeneity of the training classes for each spectral band was viewed. Each class was assigned a specific color. Lastly, using a discriminate analysis routine remaining pixels were extracted into the designed classes. The classified image was subjected to accuracy assessment and was performed by using predefined ground-truth values.

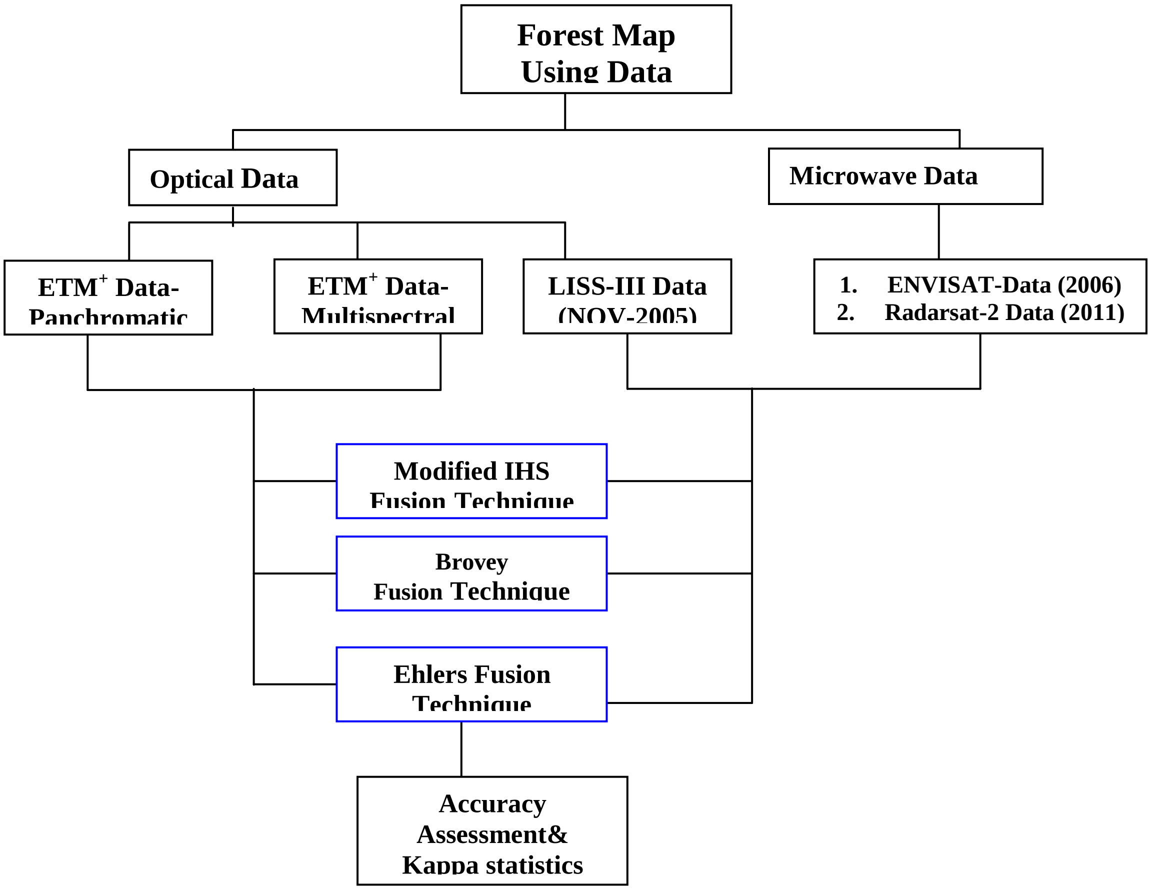
9.7.2. Cloude-Pottier Decomposition

The microwave data were also classified using Cloude-Pottier decomposition. According to this theory, a target coherence matrix [T] was constructed using measurements of radar polarimetry. The coherency matrix mentioned as kp is constructed from a scattering vector in the base of Pauli that reflect geometrical properties. Usually elements of kp, are described as target vectors. It consists of horizontal or vertical components with combinations of transmitted and received SAR signals. Here, notation <…> denoted an ensemble averaging over specific neighborhood. The Cloude-Pottier theory decomposed the complex coherence matrix [T] into a set of eigenvalues (k) and eigenvectors <e>using below equation:

$$[T] = \sum_{j=1}^{3} \lambda_j \underline{e}_j \underline{e}_j^T$$

where, $\underline{e}_j = \left[\cos\alpha \quad \sin\alpha\cos\beta e^{i\delta} \quad \sin\alpha\sin\beta e^{i\gamma}\right]$

The α angle represents the types of scattering. The Beta angle (β) denotes object orientation about the line of sight. Phase difference between HH+VV and HH-VV is represented by the angle δ, while the phase difference between HH+VV and HV is represented by γ.



Flow chart 4 Forest Map Using Data Fusion

9.8. Data fusion Technique

In the present study optical and microwave data were fused using different data fusion techniques such as Ehlers, Modified IHS, and Brovey.

9.8.1. Ehlers Fusion Technique

In this technique the IHS transform was applied to the multispectral image.(Illustration 2) Since the IHS transform is limited to three input bands (RGB), the process is extended to include more than three bands by using multiple IHS transforms until the total number of bands is exhausted. Fourier transform is then used to enhance the spatial information. With the fast Fourier transform (FFT), the intensity channel from the IHS transform is filtered using a low pass (LP) filter and the panchromatic image (P) is filtered with an opposing high pass (HP) filter. These images are converted back into the spatial domain using an inverse fast Fourier transform (FFT^{-1}) process and added together to generate a fused intensity channel with low frequency information from the coarse spatial resolution image (via the Intensity channel) and high frequency information from the high resolution panchromatic image. An inverse IHS transformation (IHS^{-1}) is performed to produce the final fused image that contains the spatial information supplied by the panchromatic image with the spectral resolution of the multispectral image. Again, since the IHS transform is limited to using three bands, the process is extended by using multiple IHS transforms until the total number of bands are derived.

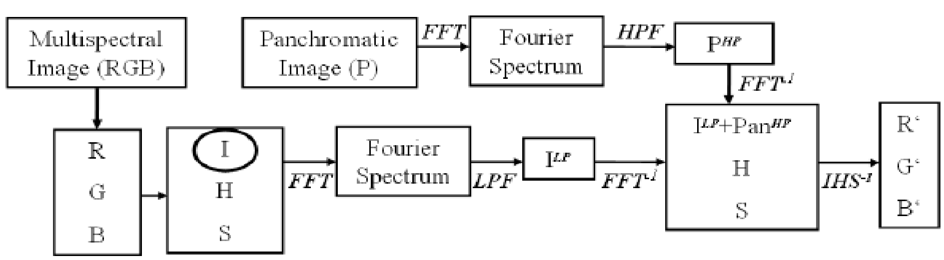


***Illustration* 2: Basic overview of the Ehlers Fusion process**

9.8.2. The Modified IHS (intensity, hue, saturation) Transformation:

This process involved the conversion of three input multispectral bands from red-green-blue (RGB) space to intensity-hue-saturation (IHS) space. The higher resolution panchromatic band was substituted for the intensity channel and the IHS transform was converted back into RGB space maintaining the panchromatic bands spatial structure.

9.8.3. Brovey Transform:

This process used a ratio algorithm to combine the multispectral and panchromatic images. The technique normalized each of the multispectral bands used and multiplied these with the higher resolution panchromatic band. When these band layers were stacked, the resultant higher resolution image was synthesized.

RESULT

10.0. Tree inventory

Tree inventory of Dediapada forest generated interesting facts related to following forest attributes 1) Species composition studies gave an idea of species diversity. 2) Phenology studies showed correlation between phenophases of different forest tree species with season 3) Tree damage assessment gave an idea of the health condition of trees in different villages of Dediapada forest. 4) Tree structural parameters such as the DBH, Height, Basal Area, and the Crown cover through ground survey exhibited interrelationship between various structures.

10.1. Species composition:

The floristic composition of the forest exhibited the presence of thirty-six species, which were recorded from the samples laid in fourteen different villages of the study area (Table-1). *Tectona grandis* Linn. f., *Butea monosperma* (Lam.) Taub**.**, *Dalbergia sissoo* Roxb ex DC, *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr., *Lannea coromandelica* (Houtt.)Merrill., and *Terminalia crenulata* Roth. were found to be dominant. Fabaceae was found to be the dominant Family among the different tree species.

Table 1: Tree species observed in various plots of the study area

Sr. No	Ground vegetation			
	Botanical name	Common name	Vernacular name	Family
1.	*Acacia auriculiformis* A.Cunn. ex Benth.	Ear leaf Acacia	Bengali Bavad	Mimosaceae
2.	*Acacia catechu* (L.) Willd., Oliv.	Catechu	Khair	Fabaceae
3.	*Aegle marmelos* (L.) Corr.Serr.	Stone apple	Bili	Rutaceae
4.	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr.	Axle wood	Dhavda	Combretaceae
5.	*Azadirachta indica A. Juss*	Neem tree	Limdo	Meliaceae
6.	*Borassus flabellifer* Linn.	Palmyra Palm	Tad	
7.	*Boswellia serrata* Roxb.	Indian Frankincense	Gugal	Burseraceae
8.	*Bridelia retusa* (L.) A.Juss	Spinous Kino Tree	Asan	Euphorbiaceae

9.	*Butea monosperma* (Lam.) Taub.	Flame of the Forest	Khakhro	Fabaceae
10.	*Casearia elliptica* Willd	Toothed Leaf Chilla	Munjaal	Samydaceae
11.	*Cassia fistula L.*	Golden Shower	Garmado	Caesalpiniaceae
12.	*Cassia siamea* Lam	Siamese Senna	Kashid	Caesalpiniaceae
13.	*Dalbergia sissoo* Roxb ex DC.	South Indian Redwood	Sisam	Fabaceae
14.	*Delonix regia Rafin.*	Flamboyant Flame tree	Gulmohar	Caesalpiniaceae
15.	*Diospyros melanoxylon* Roxb.	Coromandel Ebony	Timsu	Ebenaceae
16.	*Emblica officinalis Gaerta.*	Indian gooseberry	Amla	Euphorbiaceae
17.	*Eucalyptus globulus* Labill.	*Blue-Gum tree*	*Nilgiri*	*Myrtaceae*
18.	*Ficus religiosa* L.	Sacred Fig	Pipdo	Moraceae
19.	*Garuga pinnata Roxb.*	Grey Downy Balsam	Kakad	Burseraceae
20.	*Gmelia arborea Roxb.*	Candahar tree	Sivan	Verbenaceae
21.	*Grewia tiliaefolia Vahl.*	Dhaman	Dhaman	Tiliaceae
22.	*Holarrhena antidysenterica* (Linn.) Wall.	Easter tree	Kudi	Apocynaceae
23.	*Holoptelea integrifolia* (Roxb.) Planchon	Indian-elm	Kanjo	Ulmaceae
24.	*Lannea coromandelica* (Houtt.)Merrill.	Indian Ash Tree	Modad	Anacardiaceae
25.	*Madhuca indica* J. F. Gmel. Synonym= *Madhuca longifolia* (J.Konig) J.F.Macbr.	Mahua tree	Mahudo	Sapotaceae
26.	*Mitragyna parvifolia* (Roxb.) Korth.	Kaim	Kalam	Rubiaceae
27.	*Morinda tomentosa* Heyne	Indian Mulberry	Al	Rubiaceae
28.	*Phoenix sylvestris* (L.) Roxb.	Wild Date Palm	Khajuri	Arecaceae
29.	*Pongamia pinnata* (L.) Pierre	Pongam tree	Karjan	Fabaceae
30.	*Pterocarpus marsupium* Roxb.	Indian Kino Tree	Biyo	Fabaceae
31.	*Soymido febrifuga* (Roxb.)	Indian Red-Wood	Rayan	Meliaceae
32.	*Tectona grandis* Linn. f.	Teak tree	Sag	Verbenaceae
33.	*Terminalia bellirica* (Gaertn.) Roxb	Belleric Myrobalan	Behdo	Combretaceae
34.	*Terminalia crenulata* Roth.	Indian Laurel	Sadad	Combretaceae
35.	*Wrightia tomentosa* Roem. & Schult.	Woolly Dyeing Rosebay	Dudhlo	Apocynaceae
36.	*Ziziphus jujube* (Lam.) Gaertn. non-Mill.	Indian Jujube	Bor	Rhamnaceae

10.2. Species diversity through conventional and Non-conventional technique:

The assessment of forest biodiversity has recently become a priority area for forest research. Several measures of species diversity among communities have been recommended to assess biodiversity through environmental gradients (Whittaker, 1972). Although tropical ecologists have put forward a number of hypotheses to explain this species diversity, however testing these hypotheses has been hampered by the lack of field studies with sufficiently large long-term data sets. The understanding of the diversity of Dediapada Forest was done by evaluating and comparing different diversity indices (Table 2). Diversity indices generated, gave the idea of species distribution pattern of this forest community. Evaluation of these indices is potentially an enormous task, and any methods that can be adopted to reduce the amount of time spent collecting data are therefore of interest. Remote sensing represents such method although it has been under-utilized in studies of forest biodiversity (Stoms & Estes, 1993). In the present study, utility of satellite data along with GIS tool has aided significantly in understanding and extrapolating the diversity information on a larger scale.

Table 2: Exhibiting diversity Indices in different Villages of Dediapada Region

Name of village	Shannon-Wiener Diversity Index	Margalef Diversity Index	McIntosh Diversity Index	Brillouin Diversity Index
FULSAR	1.41	1.94	0.58	1.02
FULSAR	1.15	1.16	0.53	0.88
Chopdi	0.56	0.48	0.32	0.41
Piplod	1.14	0.95	0.39	1.04
Mathasar	1.090	0.83	0.59	0.85
Sagai	0.97	0.93	0.32	0.88
Dhumkal	1.32	1.67	0.79	0.86
Gangapur	0.95	1.02	0.55	0.66
Mota kabli	1.31	1.22	0.56	1.11
Khatam	0	0	0	0
Morjadi	1.16	1.25	0.55	0.86
Kevdi	1.23	0.88	0.51	1.07
Chuli	0	0	0	0
Ralda	0.16	0.30	0.04	0.12
Kokati	0.93	0.91	0.51	0.69

Four different types of diversity indices Shannon-Wiener (H) DI, Margalef (Ma) DI, McIntosh (MI) DI, and Brillouin (B) DI, (Plate-9) calculated for different locations in fourteen different villages indicates the H values to be on higher side. Different indices exhibited different range.

10.2.1. Shannon index -depicts the abundance and evenness of the species, in the present forest it ranged from 0- 1.4. Higher Shannon value was present in the areas such the Fulsar, Dhumkal and Mota Kabli. Chuli and Khatam showed the lower Shannon diversity index indicating presence of a single species.

10.2.2. Margalef index:

It is calculated from the total number of species present and the abundance or total number of individuals. Higher the index, greater is the diversity. It has no limit value and it shows a variation depending upon the number of species. Thus, it's used for comparison between the sites (Kocataş, 1992). For the present study, it ranged between 0-1.94. Regions such as Fulsar, Piplod, Morjadi, and Mota Kabli showed a high value of Margalef Index.

10.2.3. McIntosh Index:

The values of this index ranged between 0 – 1. When the value is getting closer to 1, it means that the organisms in a community are homogeneously distributed (McIntosh, 1967). Dhumkal, Fulsar and Mathasar had high values indicating that the tree species in these villages were homogeneously distributed.

10.2.4. Brillouin Index:

The result of Brillouin Index is similar to Shannon. It measures the diversity of a collection, as opposed to the Shannon index, which measure a sample. This index is recommended where non-random sampling or the full composition is known. The value ranged between 0 to 1.1. Mota Kabli, Kevdi and Piplod showed the highest diversity value. (Table-2)

The results when subjected to statistical analysis exhibited that, all the species diversity indices showed a significant degree of negative Kurtosis and Skewness. (Table-3)

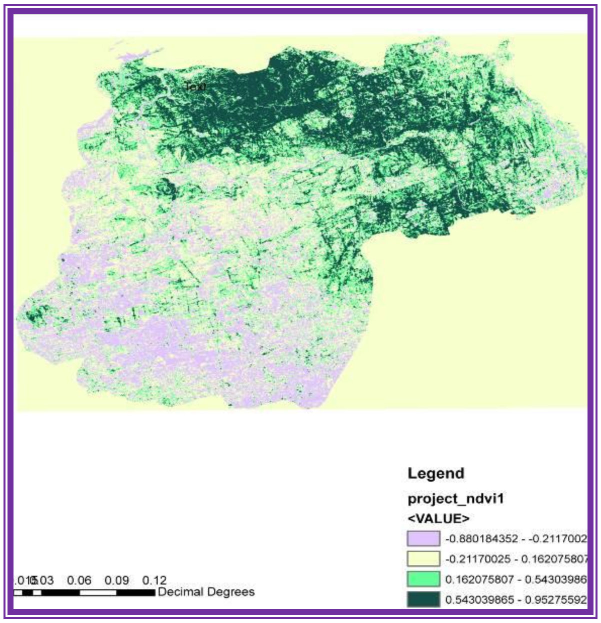
Table 3 A comparative evaluation of different diversity indices

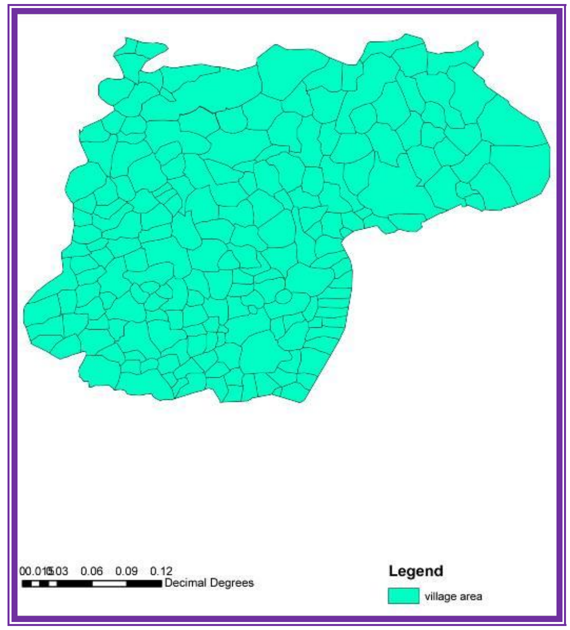
Diversity indices	Mean	Standard deviation	Coeff of variation	Skewness	Kurtosis
Shannon-Wiener DI	0.89	0.48	53.79	-0.97	-0.51
Margalef DI	0.90	0.54	60.23	-0.047	-0.35
McIntosh DI	0.42	0.23	56.86	-0.69	-0.52
Brillouin DI	0.70	0.38	54.94	-0.87	-0.64

10.3. Non-conventional method:

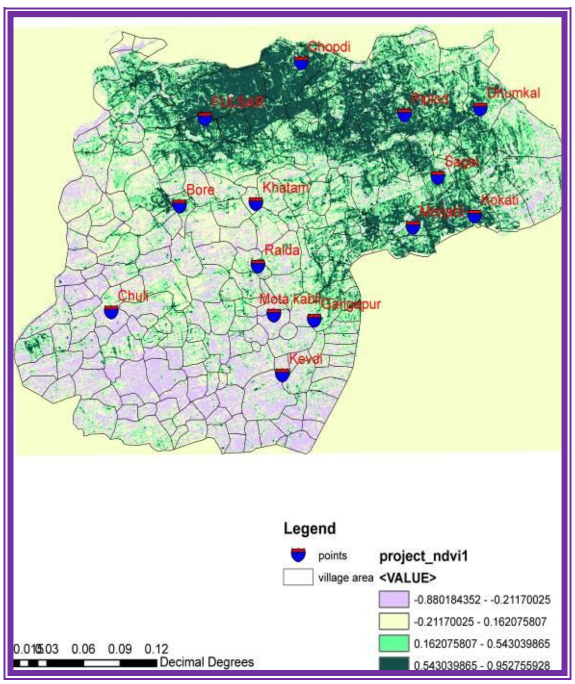
The use of satellite image data for floristic Inventory and Species Diversity is a very basic step towards conservation. Non-conventional technique such as remote sensing is found to be effective in estimating the presence or absence of Vegetation. GIS helps in displaying the location of different species. Integration spatial and non-spatial information helps in generating floristic and diversity map. Prediction of different Indices and understanding of presence and absence of vegetation becomes simpler when both remote sensing and GIS tools are used.

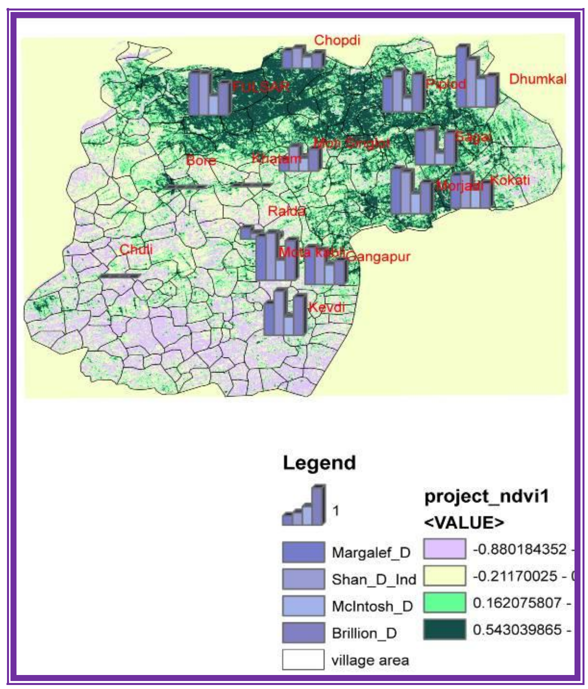
With the help of IRPS_P3 LISS-III data (Plate-9a), Normalized Differential Vegetation Index (NDVI) Map was generated. Different maps viz, NDVI, and Village (Plate-9b) were converted into digital format. The indices data generated from the ground were then integrated with these maps(Plate-9c, 9d). The Kriging interpolation technique generated Kriging map (plate-10) for the Shannon Index. Accuracy of the Kriging interpolation technique was then carried out to validate the result. This extrapolation was about 65- 75% accurate at 85% confidence level (Table 4).





a) NDVI MAP + b) Village Map





c) Selected Sites Integrated **d) Different Diversity Indices with NDVI and GIS**

Plate 9 - Displaying the NDVI, village and the integrated map with selected sites

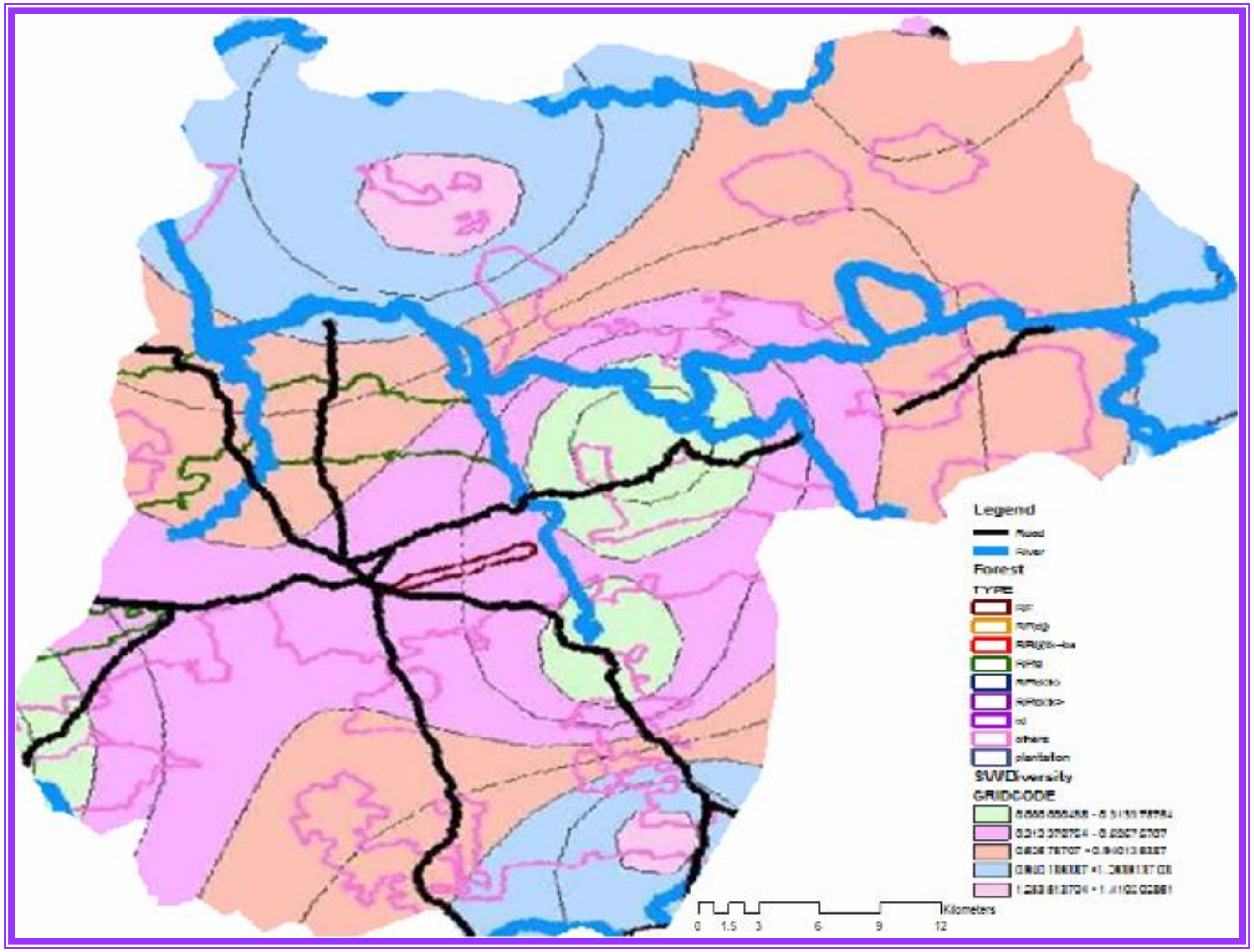


Plate 10 Showing the different Forest Type along with Shannon diversity Map

Table 4: Accuracy verification for Shannon Index-64.28 percentage

Sr no	**Village name**	**Range of diversity**	**Accuracy Within Range (WR) / Out of Range (OR)**
1.	**Dabka**	0.94-1.25	WR
2.	**Singal Gaban**	0.94-1.25	WR
3.	**Khapar**	0.94-1.25	OR
4.	**Vaghumar**	0.94-1.25	OR
5.	**Gichad**	0.31-0.62	OR
6.	**Pansar**	0.31-0.62	OR
7.	**Bore**	0.31-0.62	OR
8.	**Dhanor**	0.62-0.94	WR
9.	**Tilipada**	0.31-0.62	WR
10.	**Khunbar**	0.0438-0.31	WR
11.	**Kanjal**	0.94-1.25	WR
12.	**Pangam**	0.62-0.94	WR
13.	**Chikda**	0.94-1.25	WR
14.	**Namgir**	0.94-1.25	WR

10.4. Phenology:

Alternation of phenophases in the course of a year proceeds consistently, rhythmically, but their dates differ every year. Phenology of different tree species from 1992 and 2007 were analyzed. These observations were then compared with the rainfall and temperature data. Shifting in phenophase can be seen in almost all the tree species of Dediapada forest.

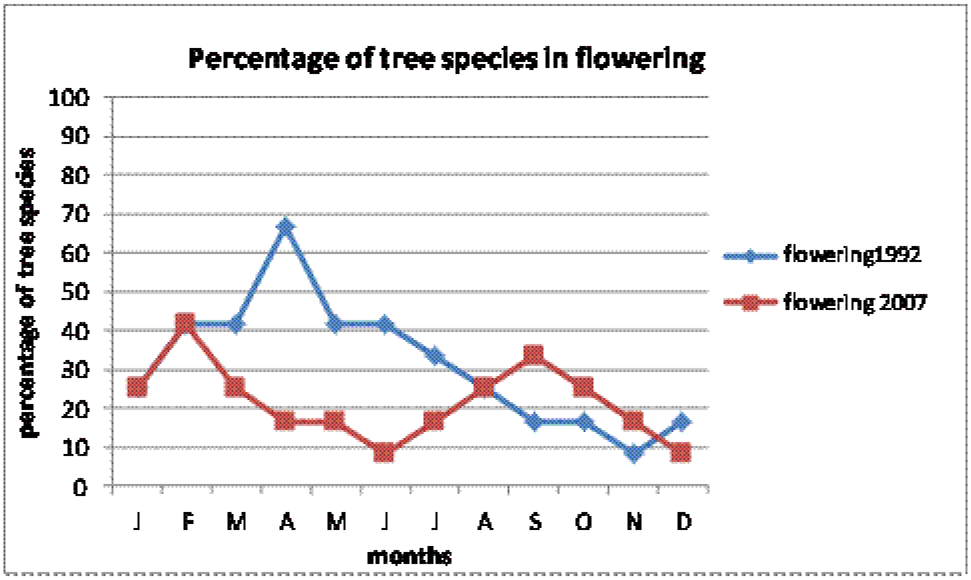


Figure 3Percentage of tree species in flowering

The number of tree species that were in flowering stage in January remained same in the year 1992 and 2007. In the year 1992, April month showed 65% of tree species in flowering stage whereas, in 2007 it was just 25%. In 1992 September 35% of tree species were in flowering condition, whereas in 2007 only 15% went in flowering stage. (Figure-3)

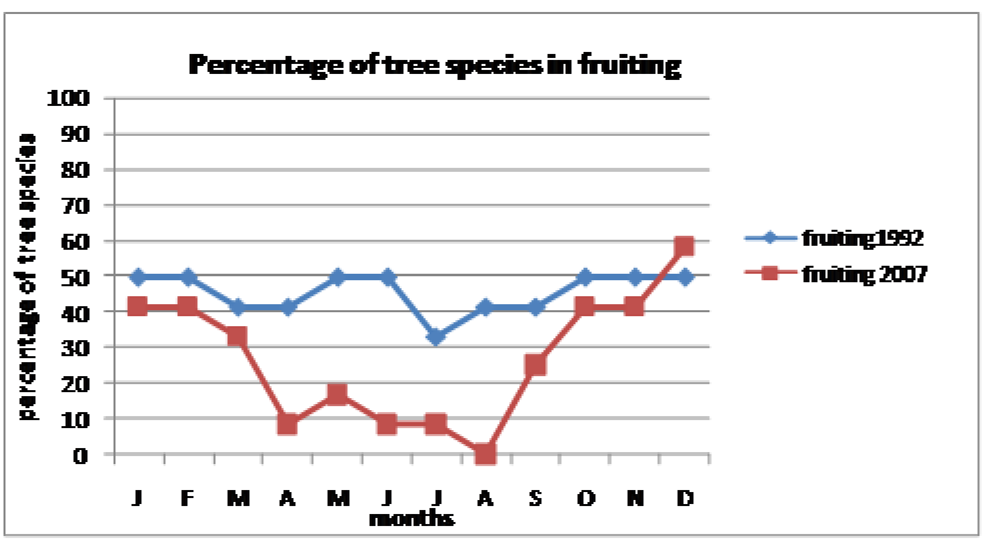


Figure 4 Percentage of tree species in fruiting

The number of tree species that were in the fruiting stage in January was around 40 % and 50 % in 1992 and 2007 respectively. In the year 1992, April month showed 40 % of tree species in the fruiting stage whereas, in 2007 the same month showed only 10% of tree species in flowering. In 1992, September 40 % of tree species were in fruiting condition, whereas in 2007 only 25% went on fruiting stage. (Figure-4)

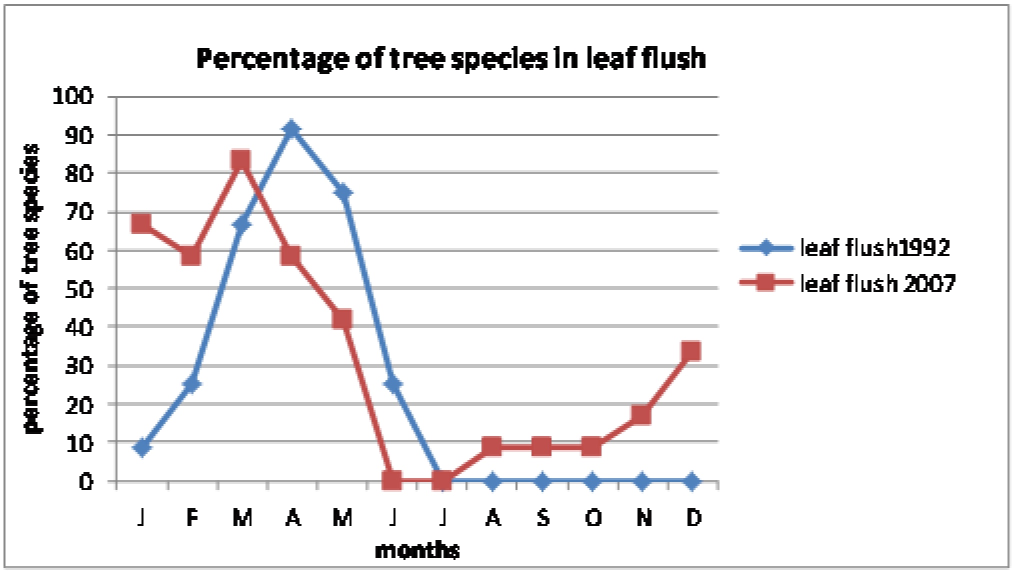
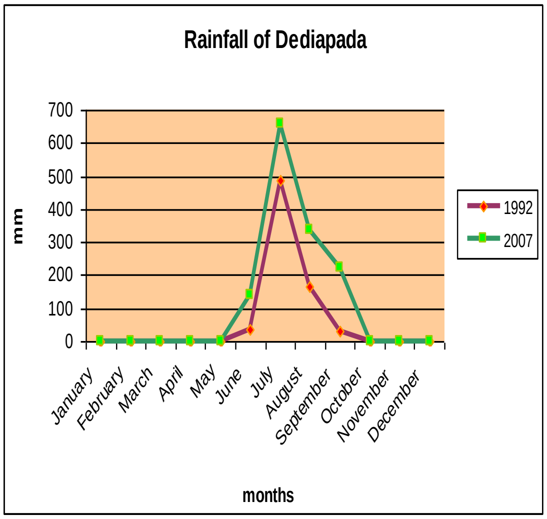


Figure 5 Percentage of tree species in leaf flush

The number of tree species that were in the leaf flush stage in January was around 70 % and 10 % in 1992 and 2007 respectively. In the year 1992, April month showed 90 % of tree species in leaf flush stage whereas, in 2007 the same month showed 60 % of tree species in leaf flush. In 1992 September, none of the tree species were in leaf flush condition, whereas in 2007 only 10 % went on leaf flush stage. (Figure-5)



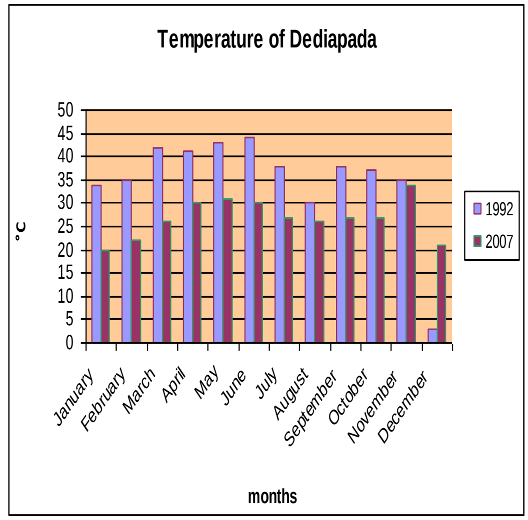


Figure 6 Rainfall-Dediapada (1992 & 2007) **Figure 7 Temperature-Dediapada (1992 & 2007)**

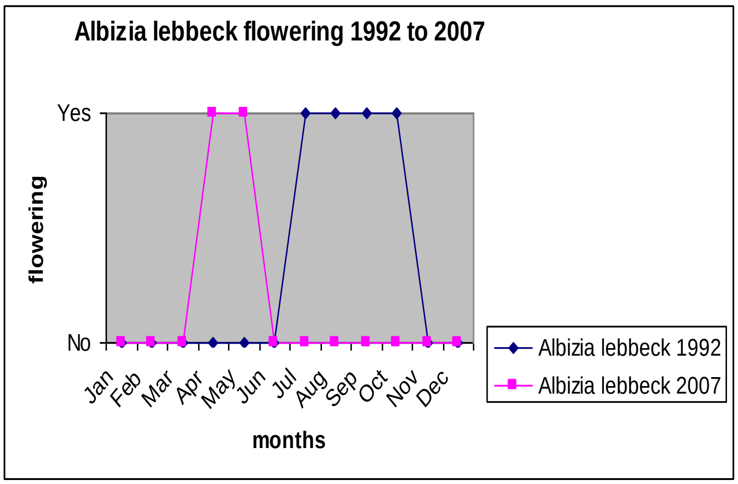
The shifting in phenological events (i.e. Flowering, fruiting, and leaf flush) leading to shortening of one phenological event led to the prolongation of another event. This irregularity in different stages of phenology can be attributed to the erratic fluctuation in rainfall and temperature. Temperature and rainfall (figure 6 & 7) play major role in flowering fruiting and leaf flush, any increase or decrease in these two parameters will lead in fluctuation in phenological event.

For further analysis of this fluctuation in different phenophase in the year 1997 and 2007, four dominant tree species were assessed for different phenophase.

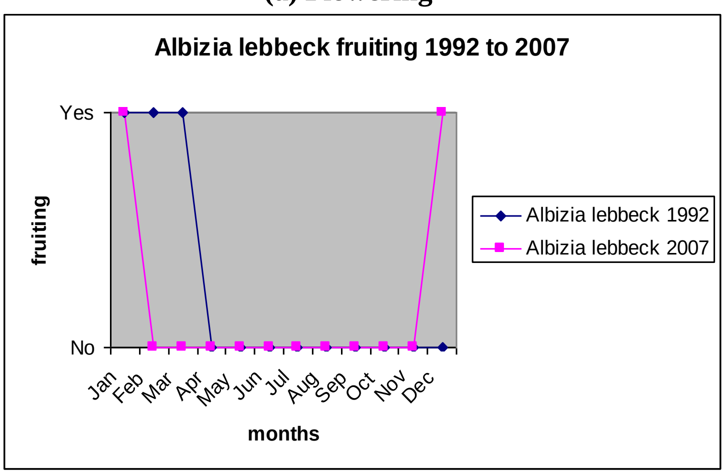
In case of *Albizzia lebbeck*, (figure 8) the changes in different phenophase i.e. flowering, fruiting and leaf flush was notable. The flowering and fruiting phase which were long phase in 1992 shortened in 2007, they also got preponed.

In *Boswellia serrata* (figure 10) change was not similar to *Albizzia* and *Butea*. There was not much shift in fruiting phenological events such as the flowering, fruiting and the leaf flush was preponed similar case was observed in case of where, in the case of *Butea monosperma* (figure 10), shifting was very high. Two peaks were observed in the flowering season. In case of *Tectona grandis* (figure 11*)* there was a slight delay in flowering season, whereas the fruiting season was totally reversed as to the previous year.

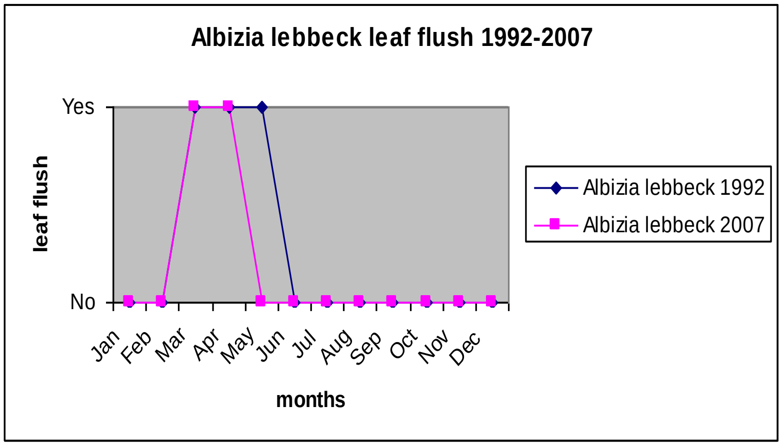
Similar cases were seen in Europe, since the early 1960s where the average growing season has lengthened by 10.8 days. In western Canada, *Populus tremuloides* showed a 26-day shift to earlier blooming over the last century (Beaubien and Freeland, 2000).



(a) Flowering

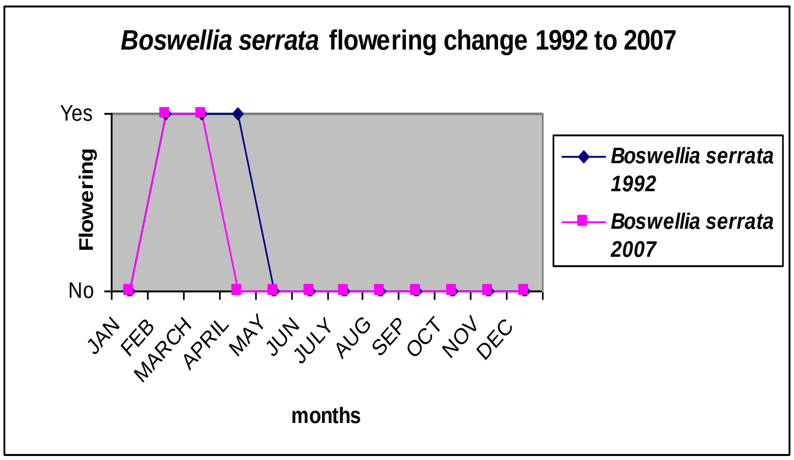


(b) Fruiting

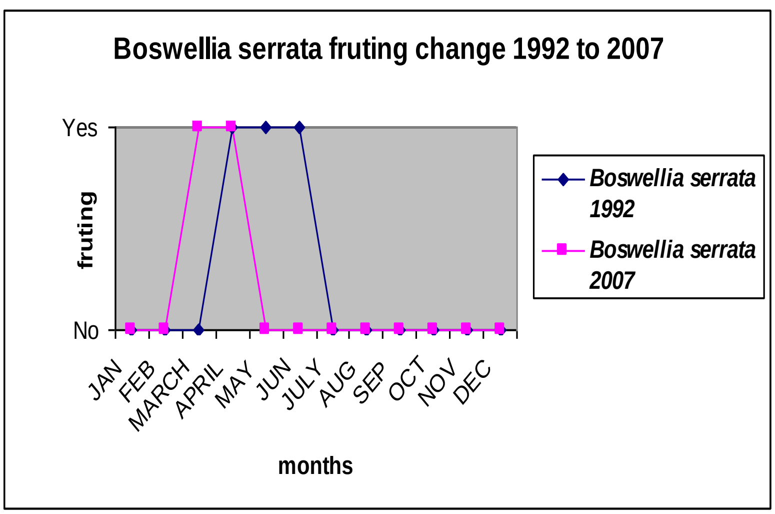


(c) Leaf flush

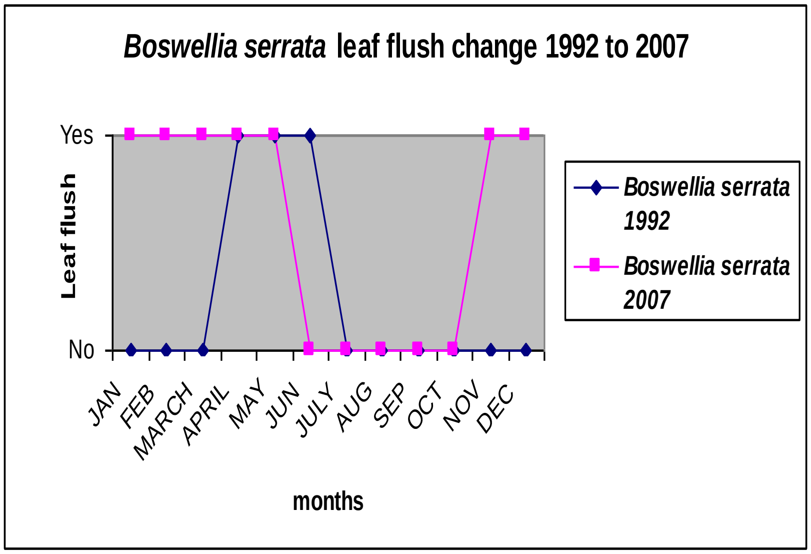
Figure 8 - Phenology of Albizia lebbeck during 1992-2007



(a) Flowering

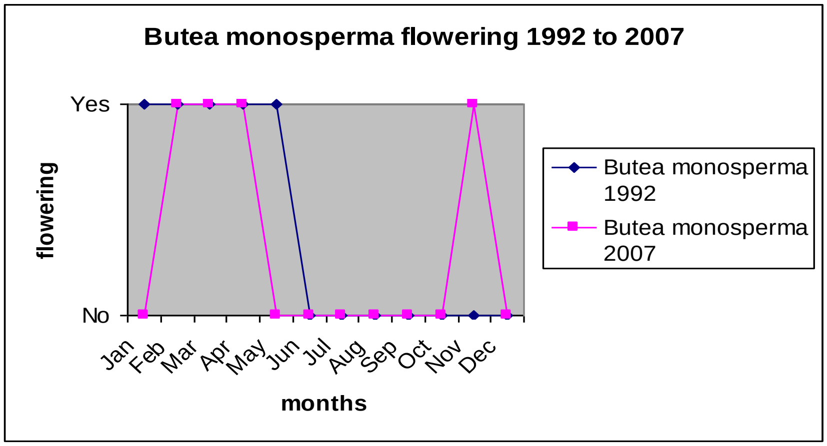


(b) Fruiting

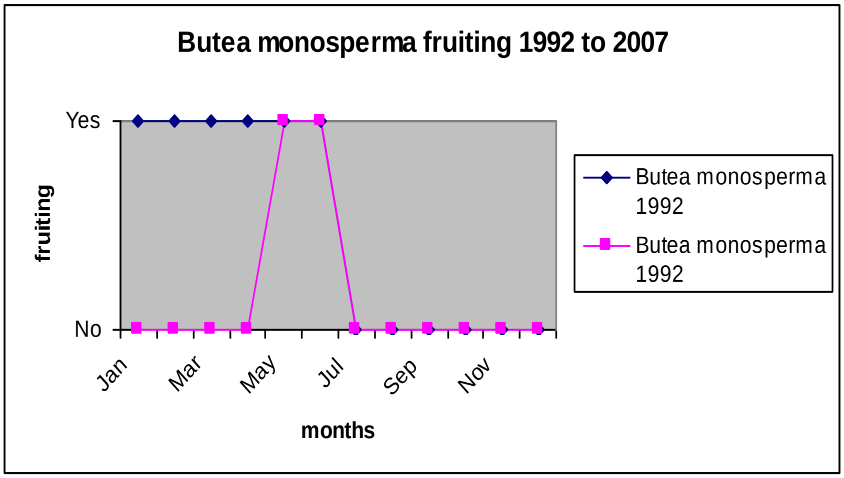


(c) Leaf flush

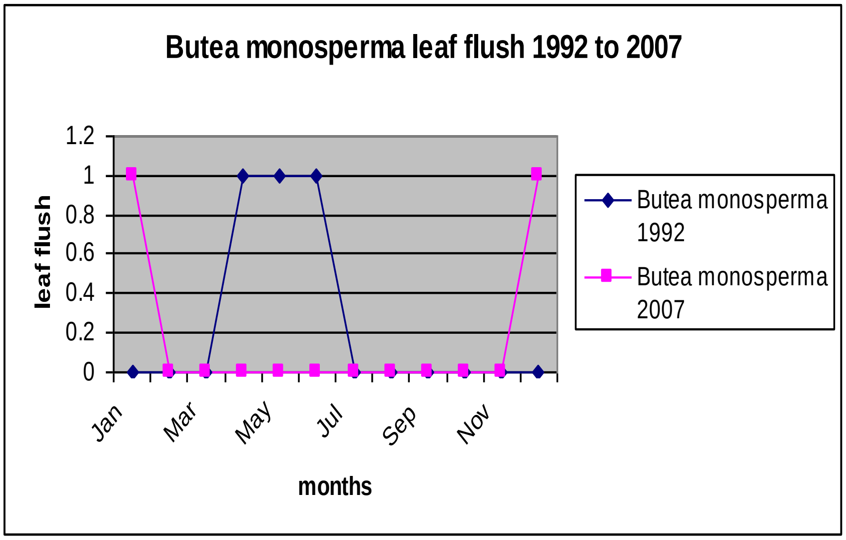
Figure 9- Phenology of Boswellia serrata during 1992-2007



(a) Flowering

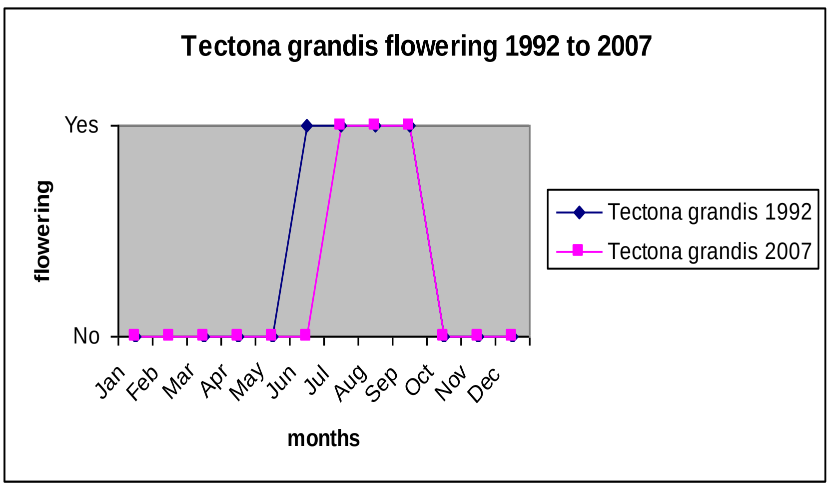


(b) Fruiting

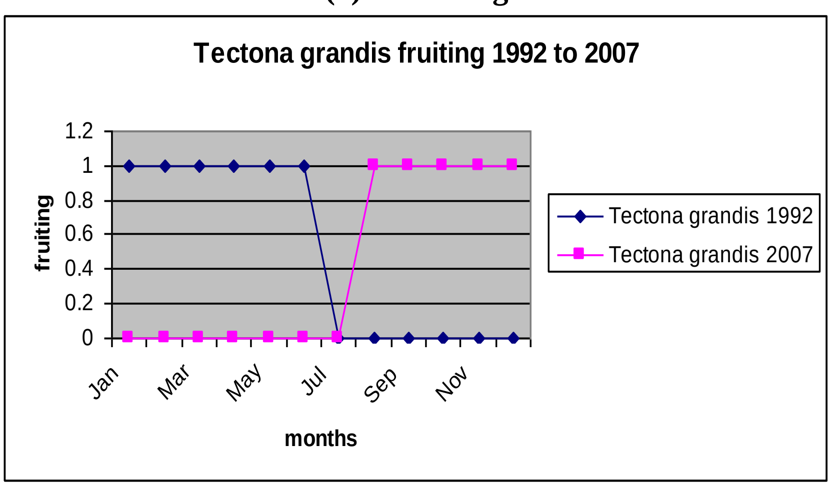


(c) Leaf flush

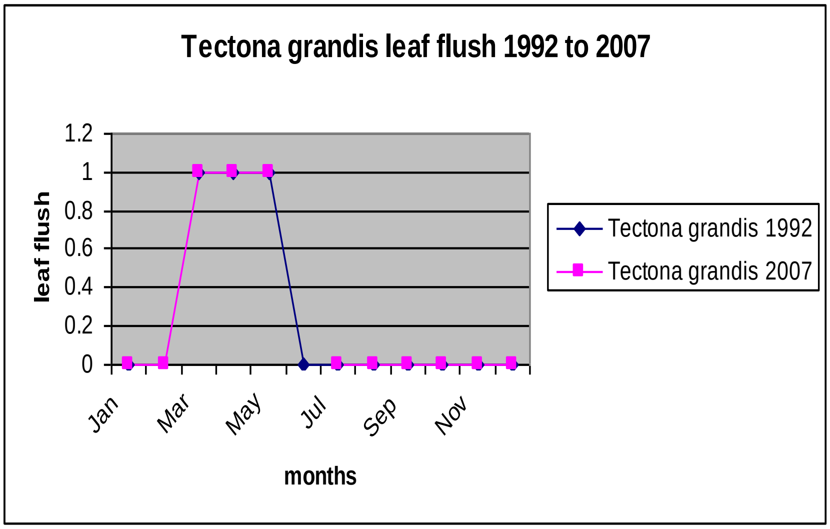
Figure 10: Phenology of Butea monosperma during 1992-2007



(a) Flowering



(b) Fruiting



(c) Leaf flush

Figure 11 Phenology of Tectona grandis during 1992-2007

Because of the sensitivity of vegetation phenology to climate variation in general, and temperature changes in particular, it was important to understand how climate forcing affects vegetation phenology and correlate these factors with the phenological event.

Backscatter from the vegetation during the growth period is different from the normal vegetative stage. This aspect of backscatter has been utilized in the present study to understand the relationship between the backscatter and phenology of tree species.

10.5. Impact of phenology on Backscatter obtained from Microwave data:

Temporal signatures of Dediapada forest, were plotted for the observation period of five months in all four (VH, HH, VV and HV) polarization channel. The corresponding status of phenology was also shown in the corresponding Figures

During February, very few species were in flowering condition (figure13) and maximum number of tree species were on fruiting stage, wherein the backscatter value in all the four bands fluctuated between -6 to -8 dB. In the month of March when many of the species are undergoing leaf flush, correspondingly the backscatter in HH and VV were around -5.0 dB (Figure12). Flowering was in peak during the April month, where the VV and HH polarization were in between -5.5 to 6.0 dB.

In the month of June when few species were either in flowering, fruiting or leaf flush the backscatter (VV and HH polarization) value was found to in between -5.5 to -6.0 dB

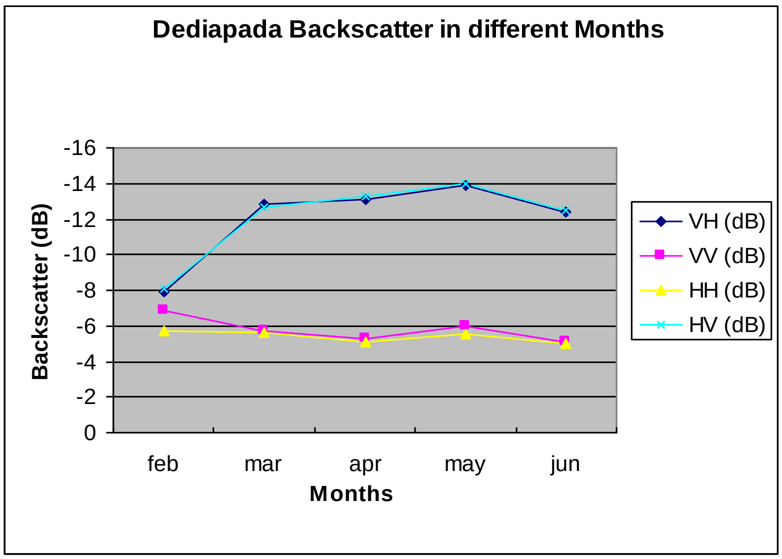


Figure 12 Dediapada Backscatter in Different Months

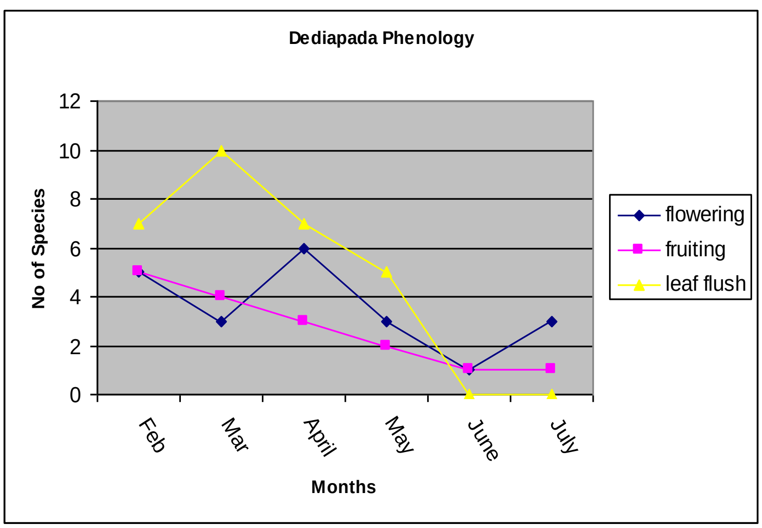


figure 13 Dediapada Phenology in Different Months

Tree health is also one of the important criteria in forest studies. Tree damage assessment will further help in understanding the forest health status.

10.6. Tree Damage – Many environmental and biological factors affects growth and success of trees. Visual inspections of leaves, branches, stems, and roots reveal indication of stress on trees. (Alexander and Palmer 1999). Tree condition can also be used as a predictor of the probability of future disease or insect infestations, as trees which are in poor condition either have the latent disease or insect infestations, or have a higher susceptibility to them. Health condition of five different dominant species viz *Tectona grandis, Butea monosperma, Dalbergia sissoo, Terminalia crenulata and Madhuca indica* were understood after detailed study on damage assessment in fourteen different villages. The occurrence of these species varied in the areas of seventy plots, laid in fourteen villages, showed the presence or absence of one or another species. Based on the health rating (table-5) the overall conditions of these five species ranged between best to poor. This indicated that all tree species faced only minor and no apparent problems. *T. grandis* were observed in 45 different plots distributed in nine different villages; similarly, *Butea*, *Dalbergia*, *Madhuca*, and *Terminalia* were observed in the plots of six, four, two, and four villages respectively. Health assessment of *T.grandis* exhibited the best condition only in Gangapur while in other villages it exhibited poor branch attachment, insect infection or exposed roots. *Butea monosperma* next dominant species was not found to be in best condition. Health condition ranged from good to medium. Similarly, the health of *Dalbergia* trees also ranged between good to medium. Minor damages in the form of poor branch attachment were observed in tree species of Dhumkal and Kokati. The health condition of remaining two species i.e. *Terminalia* and *Madhuca* ranged between medium to poor. *Madhuca* trees health were moderately affected in Sagai and Piplod, and *Terminalia* trees were found to be affected in Fulsar, Chopdi and Mathasar. Health conditioned got deteriorated in these species because of the level of damage that occurred due to poor branch attachment, leaf damage, insect infection, tree cavity and exposed root. Healthy trees were those having best conditions. No damage was observed in these trees. All the Tree structural parameters were in their healthy state. Such best healthy state was observed only in *Tectona*. The other trees which were in good health condition were *Butea* and *Terminalia*. These trees showed no branch dieback, leaf density, leaf color, and other tree parameters were normal except for only minor stem and root damage. There was a total absence of fungal rot and decay. Trees, which were moderate healthy, its branches were either dead or broken. Stem and root damage in these trees was up to twenty percent of the circumference. Trees having poor health condition showed dieback of two or more large upper limbs. The foliage was sparse, small, and off-color (Plate-11). Stem and root damage covered up to 50 percent of the circumference. Rot and decay causing fungi were also present in these trees.

Plate-11 Tree damage assessment carried out in Dediapada Taluka

Diseased Teak Tree Trunk

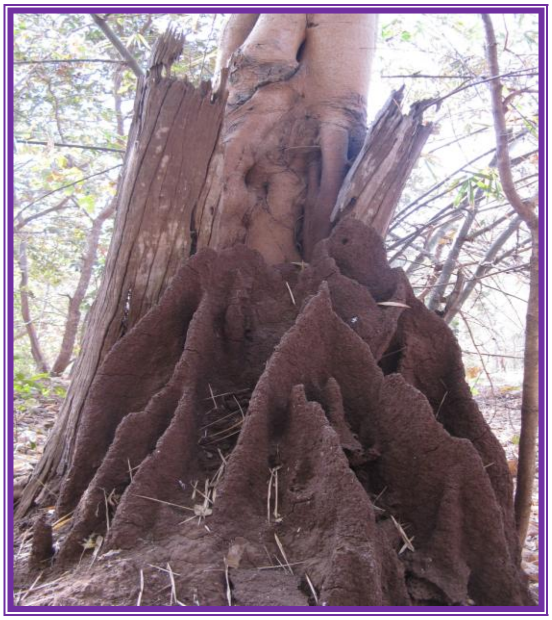
Leaves showing necrosis in Teak

Fallen Tree

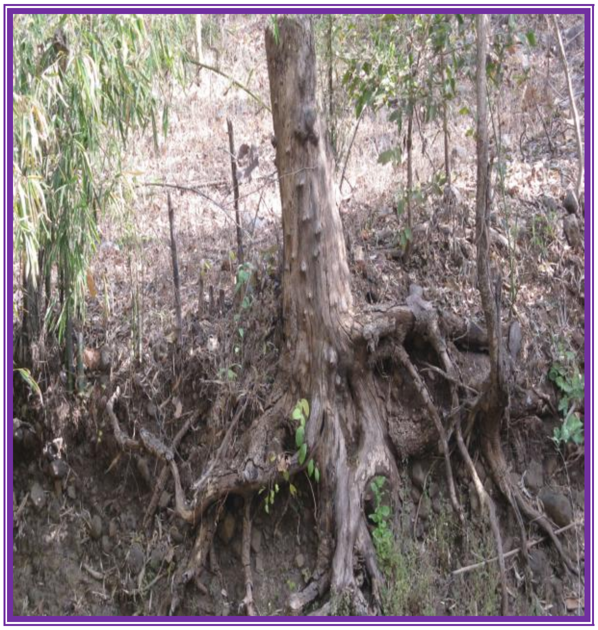
Bended Tree as seen in Teak forest

Slender tree trunk of teak

Lean trees as seen in Teak forest



Infected teak tree



Exposed root Tree

Table 5 Tree condition in Dediapada Taluka

Locatio	lat	long	Species name	Unbalanced crown	weak/ yellowing foliage	Defoliation	dead/ broken branches	poor branch attachment	lean	basal/ trunk scars	insect infection	rot/ cavity	cracks	girdling roots	exposed surface roots	Total points out of	Rating
Fulsar	21.707	73.6	*Azadirachta indica* A. Juss	√	x	x	x	x	x	√	x	x	√	x	x	3	medium
			Azadirachta indica A. Juss	√	x	x	x	√	x	√	x	x	x	x	x	3	medium
			Azadirachta indica A. Juss	√	x	x	x	x	x	x	x	x	√	x	x	2	good
			Grewia tiliaefolia Vahl.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Cassia fistula L.	x	√	x	x	x	x	√	√	√	√	x	x	5	poor
			Terminalia crenulata Roth.	√	x	x	x	x	x	x	√	x	√	x	x	3	medium
			Dendrocalamus strictus (Roxb.) Nees	√	x	x	√	√	x	x	x	x	√	x	x	3	medium
			Casearia elliptica Willd	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Terminalia crenulata Roth.	√	x	x	x	x	x	√	x	x	x	x	x	2	good
			Diospyros melanoxylon Roxb.	x	x	x	√	√	x	√	x	x	√	x	x	4	poor
			Morinda tomentosa Heyne	√	x	x	x	x	x	x	x	√	x	x	x	2	good
			Bridelia retusa (L.) A.Juss	√	x	x	√	√	x	√	√	√	x	x	x	6	poor
			Terminalia crenulata Roth.	√	x	x	x	x	x	√	√	√	x	x	x	4	poor
Chopdi	21.763	73.7	*Terminalia crenulata* Roth.	√	x	x	√	x	x	√	√	√	x	x	x	5	poor
			Tectona grandis Linn. f.	√	x	x	x	x	x	√	x	x	√	x	x	3	medium
Piplod	21.725	73.8	*Diospyros melanoxylon* Roxb.	√	x	x	√	√	x	√	x	√	√	x	x	6	poor
			Wrightia tomentosa Roem. & Schult.	√	x	x	x	x	x	x	√	x	x	x	x	2	good
			Ziziphus jujube (Lam.) Gaertn. non-Mill.	x	x	x	√	x	x	x	√	x	x	x	x	2	good
			Tectona grandis Linn. f.	√	x	x	x	x	x	√	x	x	x	x	x	2	good
			Madhuca indica J. F. Gmel.	x	x	x	x	√	x	√	x	x	√	x	x	3	medium
Mathasa	21.79	73.8	*Butea monosperma* (Lam.) Taub.	√	x	x	x	x	x	√	x	x	√	x	x	3	medium
			Terminalia crenulata Roth.	√	√	√	x	x	√	x	√	√	x	x	x	6	poor
			Tectona grandis Linn. f.	√	x	x	x	x	x	√	x	√	x	x	x	3	medium

(cont)

Rating legend

Range- 0,Ranking-5-best	Range- 1-2,Ranking-4-good	Range- 3-4,Ranking-3-medium	Range- 5-6,Ranking-2-poor

Locatioı	lat	long	Species name	Unbalanced crown	weak/ yellowing foliage	Defoliation	dead/ broken branches	poor branch ttachment	lean	basal/ trunk scars	insect infection	rot/ cavity	cracks	girdling roots	exposed surface roots	Total points out of 12	Rating
Sagai ra	21.67	74	*Butea monosperma* (Lam.) Taub.	√	x	x	x	x	x	x	x	√	√	x	x	3	medium
			Terminalia crenulata Roth.	√	x	√	x	x	x	x	√	x	√	x	x	4	poor
			Tectona grandis Linn. f.	√	x	x	x	√	x	x	√	√	x	x	x	4	poor
			Dalbergia sissoo Roxb ex DC.	√	x	√	x	√	√	√	x	x	√	x	x	6	poor
			Madhuca indica J. F. Gmel.	√	x	√	x	x	x	x	√	x	x	x	x	3	medium
Dhumka	21.73	74	*Tectona grandis* Linn. f.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Acacia catechu (L.) Willd., Oliv.	x	x	x	x	x	x	√	x	x	x	x	x	1	good
			Dalbergia sissoo Roxb ex DC.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Butea monosperma (Lam.) Taub.	√	x	x	x	x	x	√	x	x	√	x	x	3	medium
Mota ka	21.6	74	*Tectona grandis* Linn. f.	√	x	x	x	x	x	√	√	√	x	x	x	2	good
			Eucalyptus globulus Labill.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Eucalyptus globulus Labill.	√	√	x	x	x	x	√	√	x	√	x	x	3	medium
			Eucalyptus globulus Labill.	√	x	x	x	x	x	x	x	x	√	x	x	2	good
			Butea monosperma (Lam.) Taub.	√	√	x	x	x	x	x	x	x	x	x	x	2	good
Khatam	21.66	74	*Tectona grandis* Linn. f.	√	x	x	x	x	√	√	x	x	x	x	x	3	medium
Gangap	21.58	74	*Tectona grandis* Linn. f.	√	x	x	x	x	x	√	x	x	x	x	x	2	good
			Tectona grandis Linn. f.	x	x	x	x	x	x	x	x	x	x	x	x	0	best
			Butea monosperma (Lam.) Taub.	√	x	x	x	x	x	√	x	x	x	x	x	2	good
			Ficus religiosa L.	x	x	x	x	x	x	x	x	x	x	x	x	0	best
			Eucalyptus globulus Labill.	√	x	x	x	x	x	√	√	√	x	x	x	2	good
			Tectona grandis Linn. f.	√	x	x	x	x	x	x	x	x	√	√	x	3	medium
			Butea monosperma (Lam.) Taub.	√	x	x	x	x	x	√	x	x	x	x	x	2	good
Morjadi	21.64	74	*Dalbergia sissoo* Roxb ex DC.	√	x	x	x	√	x	√	x	x	√	x	x	4	poor
			Tectona grandis Linn. f.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Eucalyptus globulus Labill.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
			Butea monosperma (Lam.) Taub.	x	x	x	x	√	x	√	√	√	x	x	x	4	medium
kevdi	21.53	74	*Cassia fistula* L.	√	x	x	x	x	x	x	√	x	x	x	x	2	good
			Cassia siamea Lam	√	x	x	x	x	x	√	x	x	√	x	x	3	medium
			Delonix regia Rafin.	√	x	x	x	x	x	x	√	x	√	x	√	4	medium
			Eucalyptus globulus Labill.	√	x	x	x	x	x	x	√	x	x	x	x	2	good
Chuli	21.58	74	*Borassus flabellifer* Linn.	√	x	x	x	x	x	x	x	x	x	x	x	1	good
Ralda	21.61	74	*Butea monosperma* (Lam.) Taub.	x	x	x	x	x	x	√	x	x	x	x	x	1	good
			Pongamia pinnata (L.) Pierre	√	√	x	x	x	x	x	x	x	√	x	x	2	good
Kokati	21.65	74	Dendrocalamus strictus (Roxb.) Nees	x	x	x	x	x	x	√	√	√	x	x	√	4	poor
			Dalbergia sissoo Roxb ex DC.	√	x	x	x	x	x	x	x	x	√	x	x	2	good
			Cassia fistula L.	√	x	x	x	x	x	√	√	√	√	x	x	5	poor

10.7. Forest Structural parameters

Forest structure is the above ground organization of plant materials (Spurr and Barnes, 1980), these structures of a given forest is dependent on light, water and nutrients at a particular location (Kozlowski *et al*., 1991). Accordingly, the assessment of forest structure permits insights into the environmental factor, such as productivity. Understanding of the forest structure aids in monitoring and predicting the important biophysical processes. (Running et al., 1994). Changes in forest structure may also provide for forest inventory information related to forest vigor, harvests, burns, stocking level, disease and insect infestations (Gillis and Leckie, 1996).

The tree evaluation carried out in five different villages each with five replicates of Dediapada Taluka gave the insight of the forest nature. Five different dominant species such as *Tectona grandis*, *B. monosperma*, *Dalbergia sissoo, T. crenulata* and *Madhuca longifolia* were chosen to assess the tree structural parameter.

10.7.1. DBH- The Different tree species assessed for the Diameter at Breast Height (DBH) in different villages of Dediapada ranged from 0.25 m to 1.95m. (Figure 14) In Morjadi three of the species i.e. *Tectona grandis*, *Butea monosperma* and *Madhuca indica* exhibited lower DBH values and two higher values i.e. *Dalbergia sissoo* and *Terminalia crenualata*. Piplod exhibited lowest value of *D.sissoo* and higher value of DBH in *B.monosperma. M.indica* and *T.grandis* exhibited highest value in Dhumkal and Gangapur.

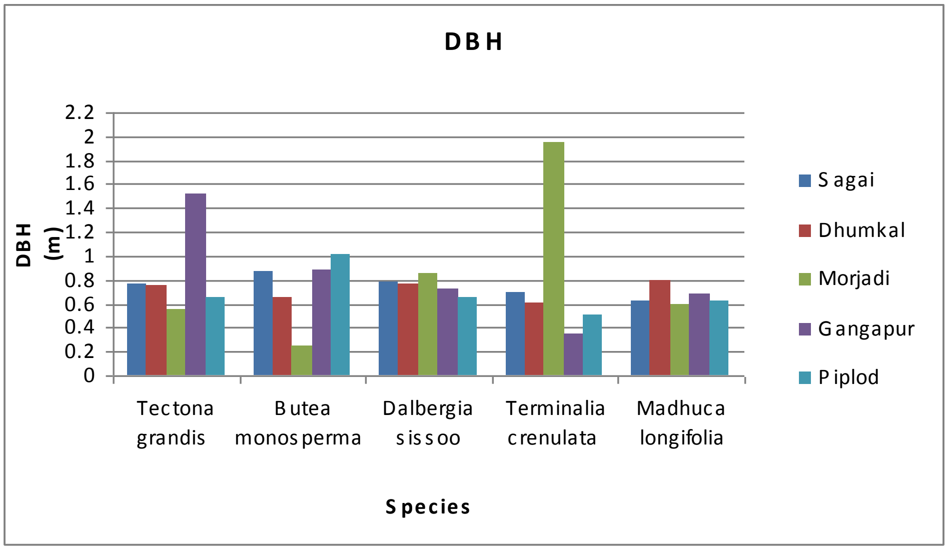


Figure 14 -DBH across different villages of Dediapada

10.7.2. Total Height

The Different tree species assessed for the Total tree Height (TH) in different villages of Dediapada ranged from 4.65 m to 33 m. (Figure 15). Piplod exhibited highest total tree height value in *B.monosperma* and *D.sissoo* and lowest in T.crenulata. In Morjadi four of the species i.e. *Tectona grandis*, *Butea monosperma*, D.sissoo and *Madhuca indica* exhibited lower TH values and one higher values i.e. *Terminalia crenualata*.

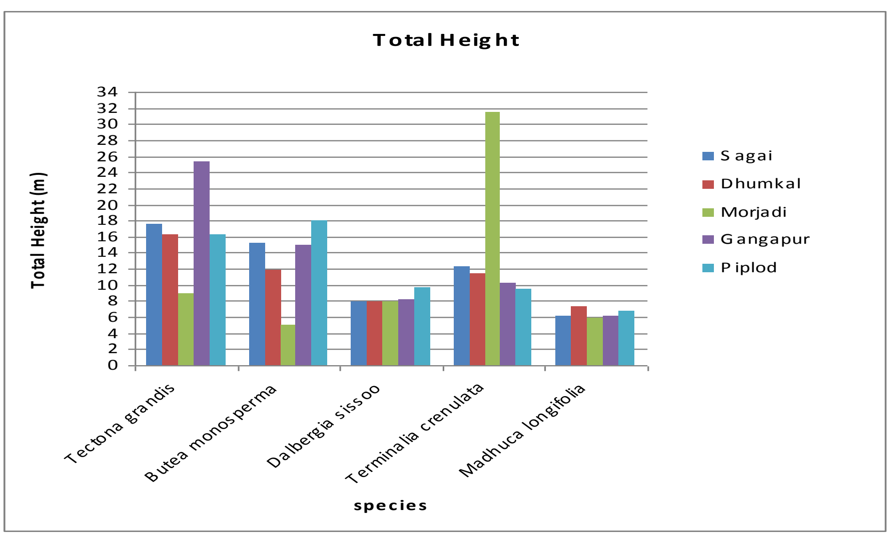


Figure 15 Total Height across different villages of Dediapada

10.7.3. Crown cover: The crown cover spread in five different villages evaluated ranged from 0.15m to 3.07 m. *T.grandis* Crown cover (CC) was seen largest (3.07m) in case of Gangapur village *B. monosperma* also showed larger CC with 2.08m. *M.indica* showed small CC in Morjadi (figure 16).

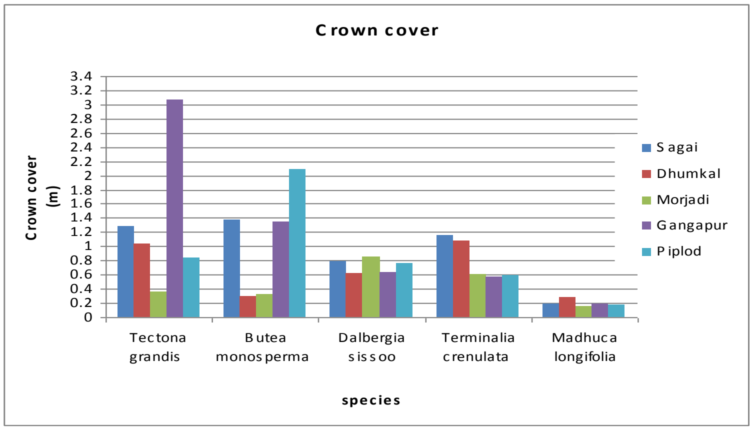


Figure 16 Crown cover across different villages of Dediapada

10.7.4. Basal area: The Different tree species assessed for the Basal Area (BA) in fourteen different villages of Dediapada ranged from 0.2 m to 0.7 m. (Figure 17) Basal area of *T.crenulata* tree species was found to be largest in the Dediapada. In Sagai the *Tectona grandis* showed its largest basal area. *B.monosperma* showed the smaller basal area in the Morjadi.

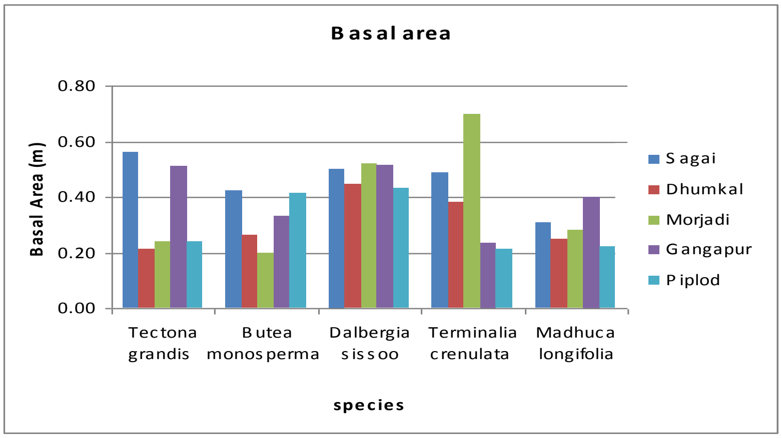


Figure 17 Basal Area across different villages of Dediapada

10.8. Relationship between DBH, Total Tree Height, and Crown Cover

For each of the five tree species sampled, mean of the DBH, tree height and crown cover measurements were calculated. The standard error for all the sample means were also computed and the results are given in Table 6.

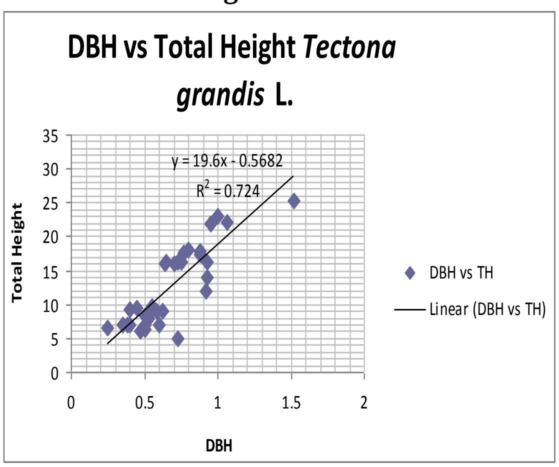
Table 6 Sample Means for DBH, Tree Height and Crown cover (S.E in Parentheses)

Village	D.B.H (m) ±S. E	Total Height (m) ±S. E	Crown Cover (m^2) ±S. E
Tectona grandis	**0.85 (0.17)**	**16.8 (2.5)**	**1.32 (0.4)**
Butea monosperma	**0.73 (0.13)**	**13.0 (2.2)**	**1.09 (0.3)**
Dalbergia sissoo	**0.75 (0.03)**	**8.3 (0.3)**	**0.7 (0.04)**
Terminalia crenulata	**0.82 (0.28)**	**15.01(4.1)**	**0.79 (0.13)**
Madhuca longifolia	**0.66 (0.03)**	**6.42(0.2)**	**0.2 (0.02)**

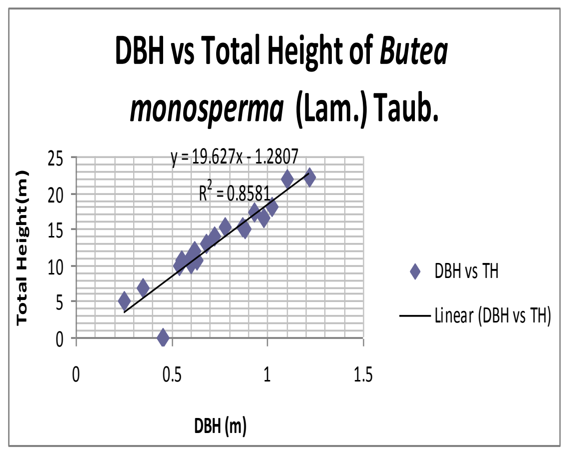
D.B.H = diameter ate breast height, S.E. = Standard error

Variation and flexibility in terms of shape and size of tree crown, height and trunk diameters of different tree species are a common phenomena. (Givnish, 2002; Kuppers, 1989). This variation is mainly controlled by a specific inherited developmental tendency which in various condition gets modified either due to environmental or any other factors related to the habitat in which the tree grows. The understanding of different forest structural parameters not only helps in understanding the relationship between different tree variable but also convert this relationship into the distinct regression equation which can be useful for understanding these features without tree harvesting. In the present study, the relationship between tree height (TH) and diameter at breast (DBH) appeared to be a linear one, in all the five tree species studied. That is taller trees have larger trunks while shorter ones have smaller trunks. In almost all the five species (figures 20 a-e) the correlation between the DBH and Total Height was found to be very high.

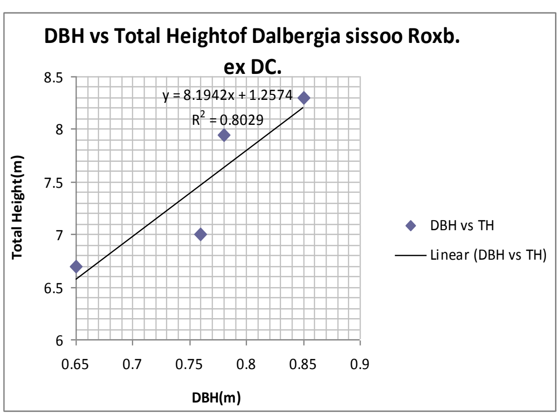
Figure 18-Correlation between DBH and Total Tree Height



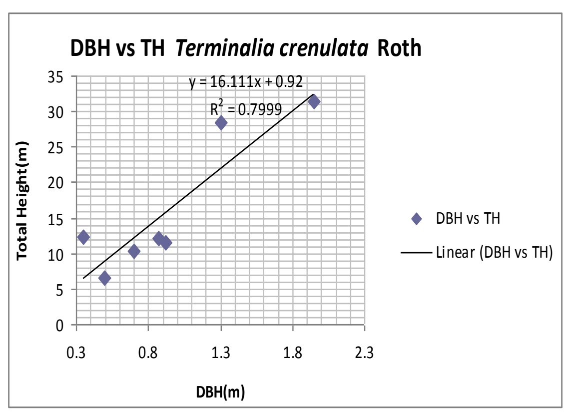
(a) DBH vs. TH of *Tectona grandis* L.



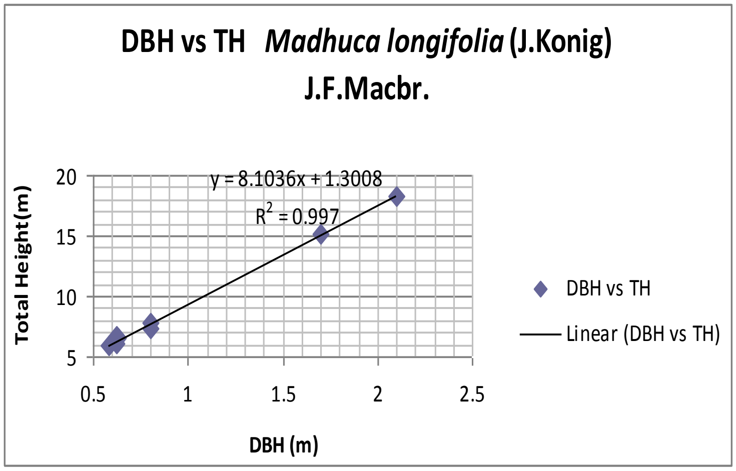
(b) DBH vs. TH of *Butea monosperma* (Lam.) Taub.



(c) DBH vs. TH of *Dalbergia sissoo* Roxb. ex DC.



(d) DBH vs. TH of *Terminalia crenulata* Roth



(e) DBH vs. TH of Madhuca longifolia *(J.Konig) J.F.Macbr.*

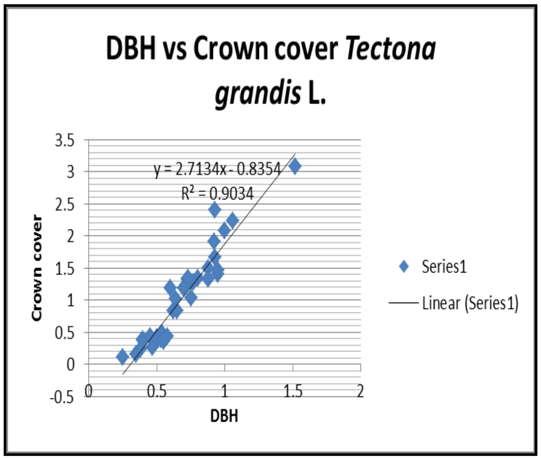
The prediction of DBH in *Madhuca indica* (figure 18) was found to be the best which is expressed by the linear regression equation with R^2= 0.99. In almost all the five species (figures 3) the correlation between the DBH and Total Height was found to be very high.

10.9. Correlation between DBH and Crown cover:

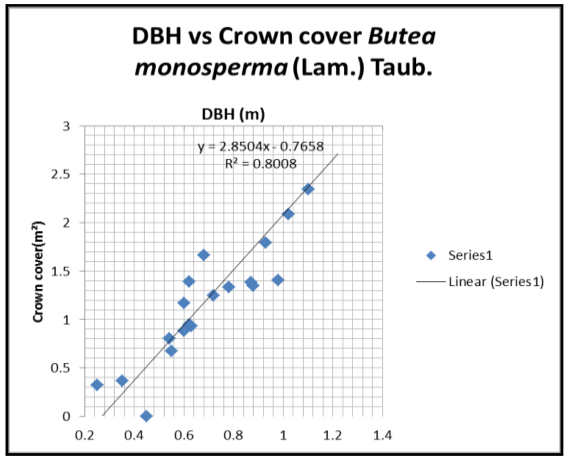
Diameter at breast height (DBH) and crown width are important tree characteristics and an accurate prediction of tree dimensions has become prominent as analysis techniques, models, and other statistical tool allow a rapid evaluation of extensive volumes of data. For DBH-crown diameter relationship, the DBH was taken as the independent variable, while the crown diameter was taken as the dependent variable.

In case of *Dalbergia sisoo* (figure-19c) the linear regression (Table-7) was found to be highly correlated with R^2= 0.93. The other four species (Figure-19) also showed a linear regression with R^2>0.5. The coefficients of determination (R^2) for these graphs were all above 0.5, meaning that they are statistically significant models and can be used for the future biophysical property determination.

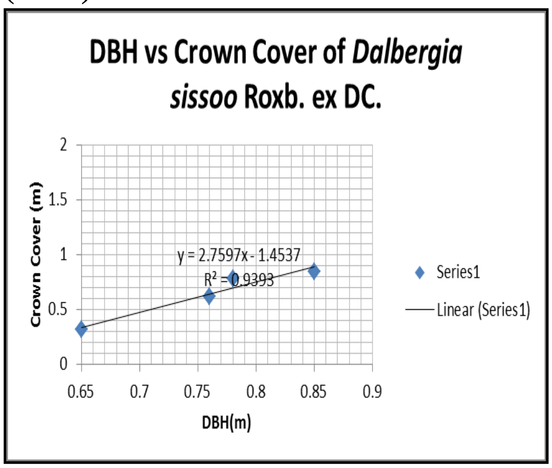
Figure 19 - Correlation between DBH and Crown cover



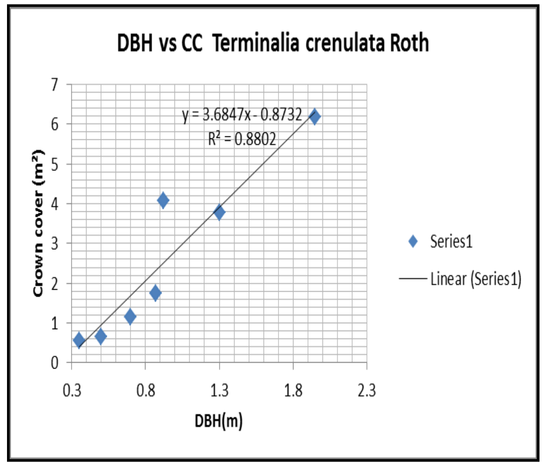
(a) DBH vs. CC of *Tectona grandis* L.



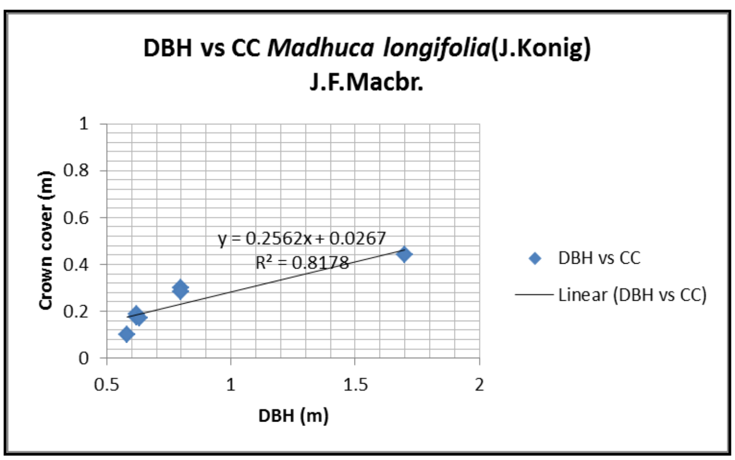
(b) DBH vs. CC of *Butea monosperma* (Lam.) Taub.



(c) DBH vs. CC of *Dalbergia sissoo* Roxb. ex DC.



(d) DBH vs. CC of *Terminalia crenulata* Roth



(e) DBH vs. CC of Madhuca longifolia *(J.Konig) J.F.Macbr*

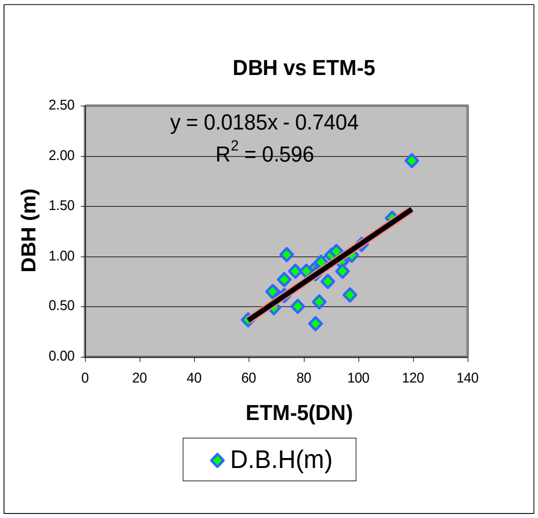
Table 7-Correlation and the Regression analysis between DBH, Total Tree Height and Crown Cover

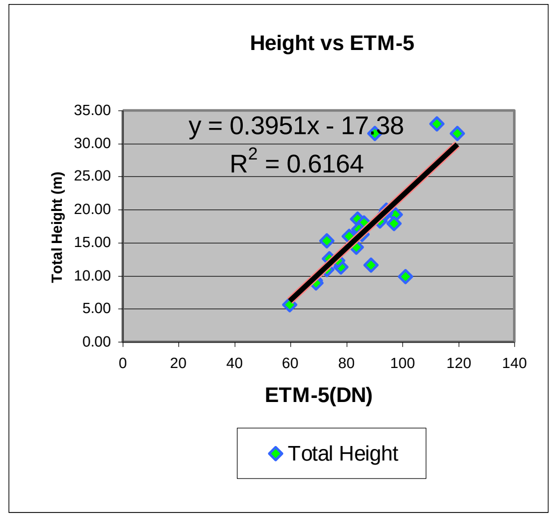
Sr. No	Tree Species	Regression Equation for DBH and Total Tree Height	Regression Equation for DBH and Crown cover
1.	***Tectona grandis*** **Linn.**	**y = 19.6x - 0.5682 R2 = 0.724**	**y = 2.7134x - 0.8354 R^2 = 0.9034**
2.	***Butea monosperma*** **(Lam.) Taub.**	**y = 19.627x - 1.2807 R2 = 0.8581**	**y = 2.8504x - 0.7658 R^2 = 0.8008**
3.	**Dalbergia sissoo Roxb. ex DC.**	**y = 8.1942x + 1.2574 R2 = 0.8029**	**y = 2.7597x - 1.4537 R^2 = 0.9393**
4.	***Terminalia crenulata*** **Roth**	**y = 16.111x + 0.92 R2 = 0.7999**	**y = 3.6847x - 0.8732 R^2 = 0.8802**
5.	***Madhuca indica*** **J. F. Gmel**	**y = 8.1036x + 1.3008 R2 = 0.997**	**y = 0.2562x + 0.0267 R^2 = 0.8178**

Estimation of different forest structural parameters such as DBH, height, and crown cover in a large area using remotely sensed data has considerable significance for sustainable management and utilization of natural resources.

10.10. Predicting Forest structure using Remote sensing data:

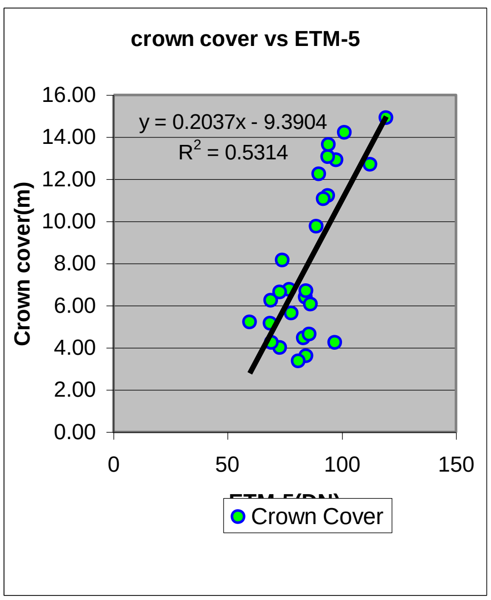
Spatial data helps in predicting different tree structures. In the present study the results have shown that there was a positive correlation between band 5 and the tree parameters such as the DBH, height basal area and the crown cover. A better understanding of forest stand parameters and remote-sensing spectral relationships are a prerequisite for effectively using appropriate image bands for developing forest structural parameter estimation models. Band 5 of Landsat ETM Data was utilized to establish the relationship between this band and different tree structures.



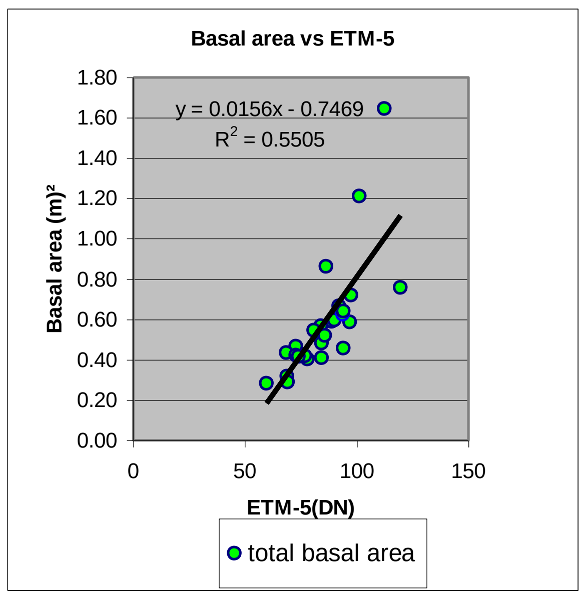


(a) Scatter plots and the result of regressing regressing DBH of a 30 m X 30 m ground plot
.

(b) Scatter plots and the result of Height of a 30 m X 30 m ground plot.



(c) Crown cover



(d) Basal area

Figure 20 Scatter plots and the result of regressing DBH, height, crown cover and Basal area of a 30 m X 30 m ground plot.

Figure 20 (a-d) gives the result of a linear correlation between DN(s) and DBH, height crown cover and basal area. It is seen that the DN(s) in T.M. Band 5 has a higher correlation with the height (r^2=0. 6) than the DBH (r^2=0. 59)

11.0. Estimation of biochemical and biophysical parameters of forest:

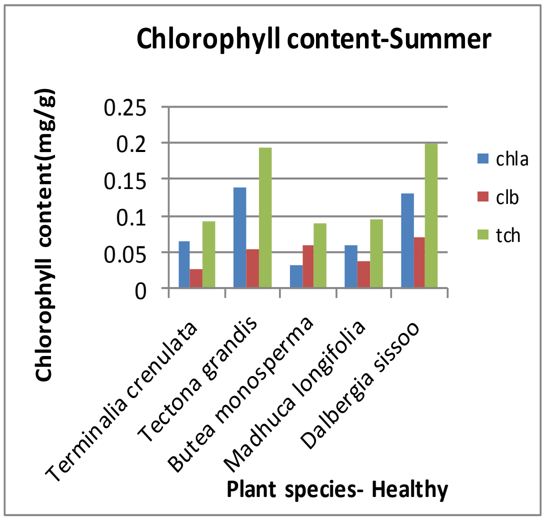
The biochemical parameter estimated through conventional method and biophysical parameters derived from the conventional and non-conventional techniques gave the idea of the health status of the Dediapada forest.

11.1. Conventional technique:

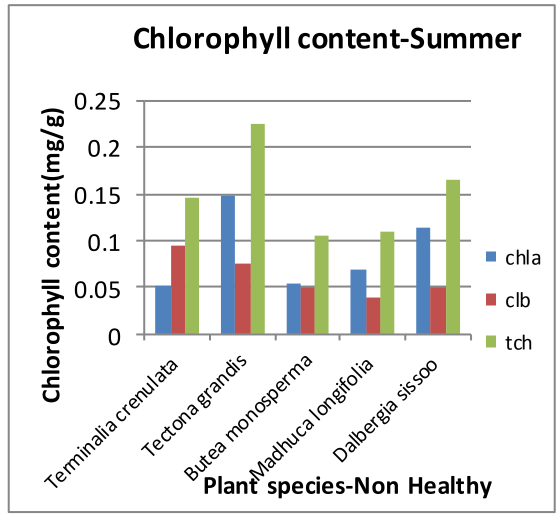
11.1.1. Chlorophyll content:

Fluctuation in chlorophyll content was observed in almost all the five tree species both in healthy and non-healthy condition *Figure 21 (a-f).* Maximum chlorophyll content was observed in healthy trees of *Tectona grandis* (0.26 mg/g) and minimum in healthy trees of *Terminalia crenulata.* (0.09mg/g) Seasonal variation in the chlorophyll content occurred in almost all tree species, but the distinct seasonal variation was observed in *Tectona grandis* and *Madhuca longifolia.* In stress condition all the tree species exhibited decrease in chlorophyll content. Maximum reduction of 0.11 mg/g of chlorophyll content was seen in non-healthy trees of *T.crenulata,* in summer. Similar results were reported in other tree species, where the chlorophyll level either decreased or remained unchanged during stress (Kpyoarissis *et al*., 1995).

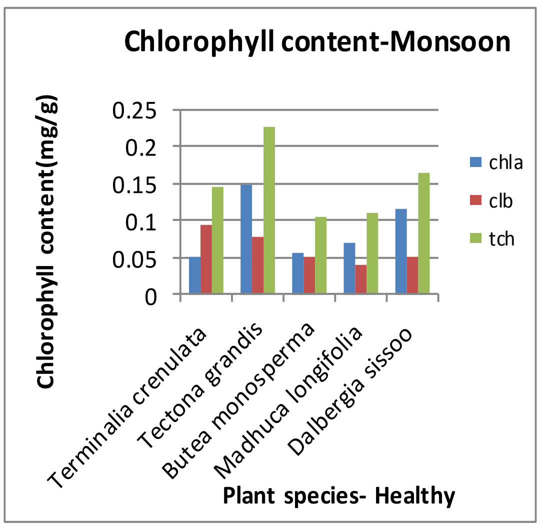
Figure 21 -Chlorophyll content in five different species in various seasons



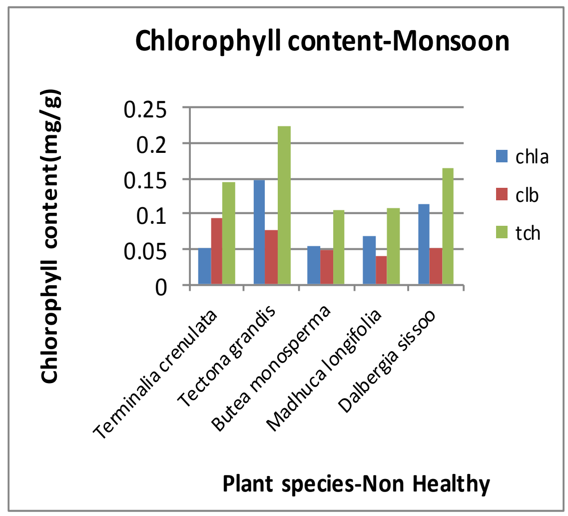
(a) Summer-Healthy



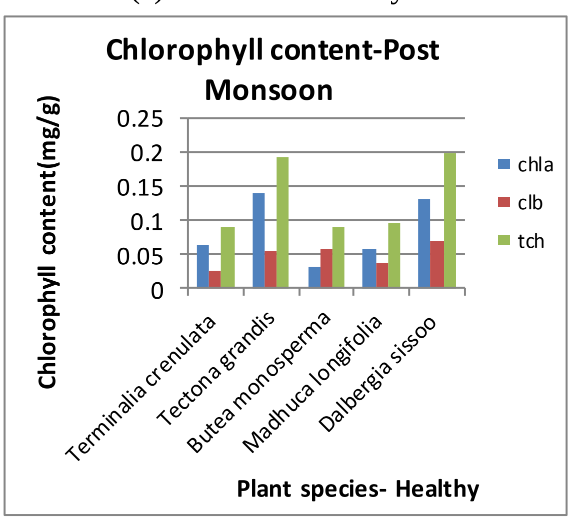
(b) Summer-Non-Healthy



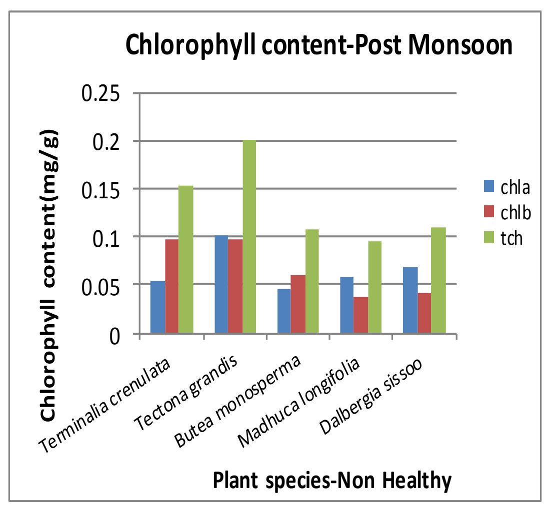
(c) Monsoon-Healthy



(d) Monsoon-Non-Healthy



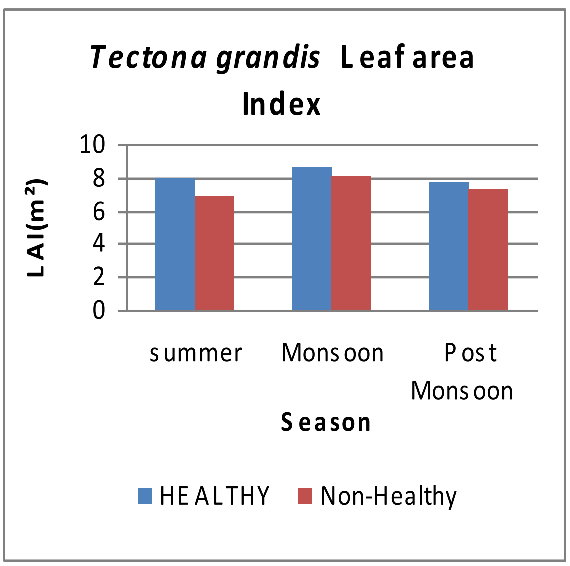
(e) Post Monsoon -Healthy



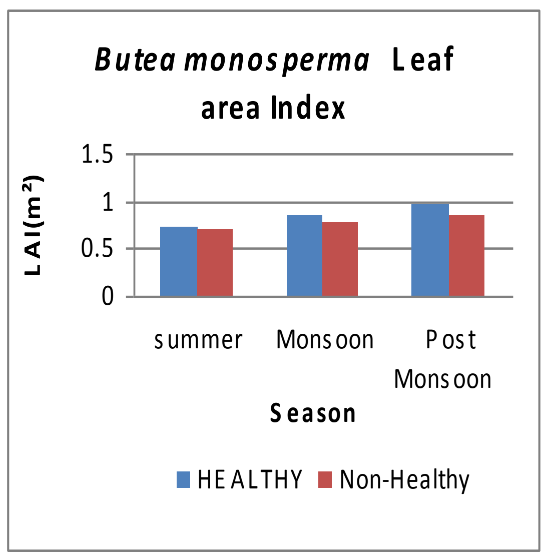
(f) Post Monsoon-Non-Healthy

11.1.2. Leaf area Index:

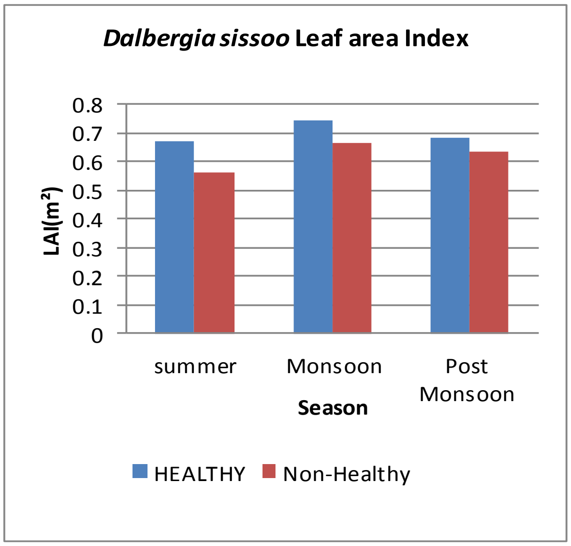
Different species when analyzed for their Leaf area Index in their healthy and non-healthy state exhibited seasonal fluctuation *Figure 22 (a-f)*. LAI in *Terminalia crenulata* varied in both healthy and non-healthy condition during different seasons. Maximum LAI expanded to 8.6 m^2 in healthy trees of *Tectona grandis* in monsoon season. Minimum LAI was noted in *Madhuca longifolia* (0.55 m^2) in summer. Stress reduces the LAI as noted in this area, a similar result was observed by Rao *et al* 2008, where the average leaf area decreased with increased stress. Maximum decrease of 0.19 m^2 in the leaf area was observed in non-healthy trees of *T.crenulata* during monsoon season.



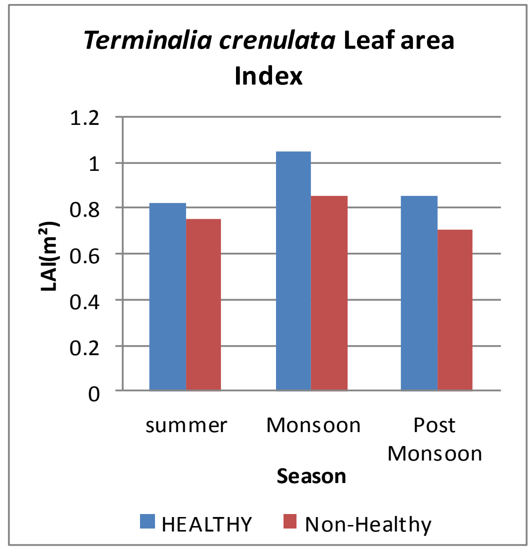
(a) Leaf area Index of *Tectona grandis*



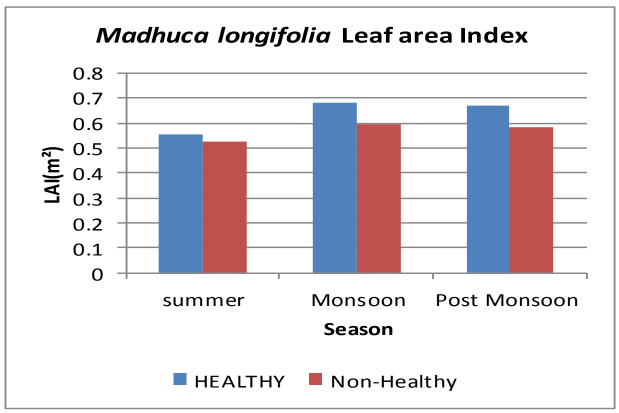
(b) Leaf area Index of *Butea monosperma*



c) Leaf area Index of *Dalbergia sissoo*



d) Leaf area Index of *Terminalia crenulata*



e) Leaf area Index of *Madhuca longifolia*

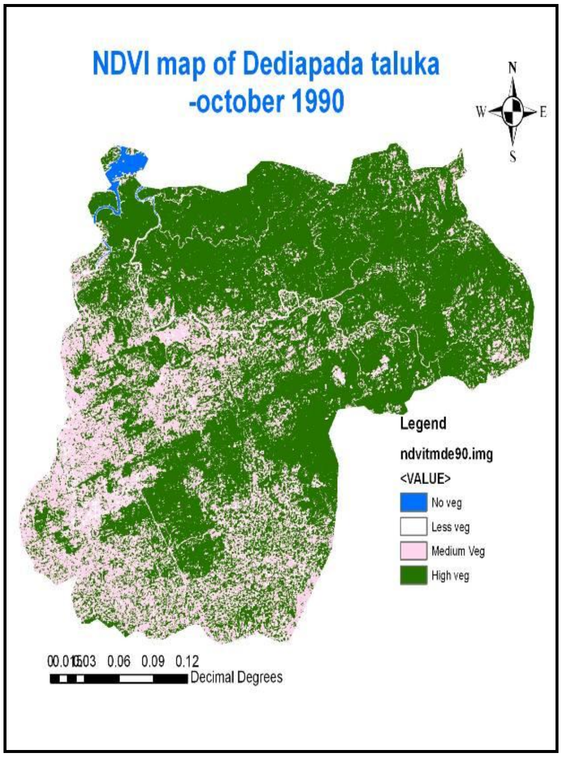
Figure 22 LAI in five different species in various seasons

11.2. Non-Conventional Technique

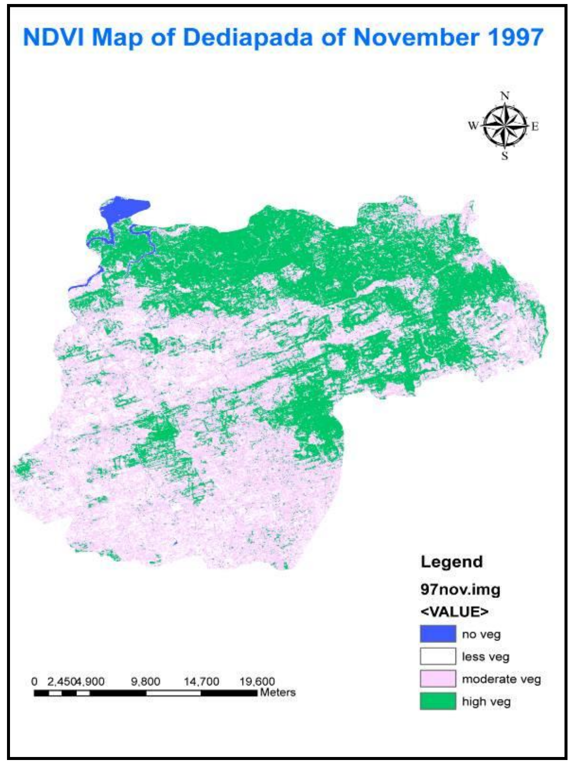
11.2.1. Normalized Difference Vegetation Index:

Satellite derived NDVI was used to measure and monitor plant growth, vegetation cover, and health status. Index values can range from -1.0 to 1.0, but vegetation values typically ranged between 0.1 and 0.7. Higher index values are associated with higher levels of healthy vegetation cover, whereas clouds and water will cause index values near zero, making it appear that the vegetation is less green (Plate-12a-d).

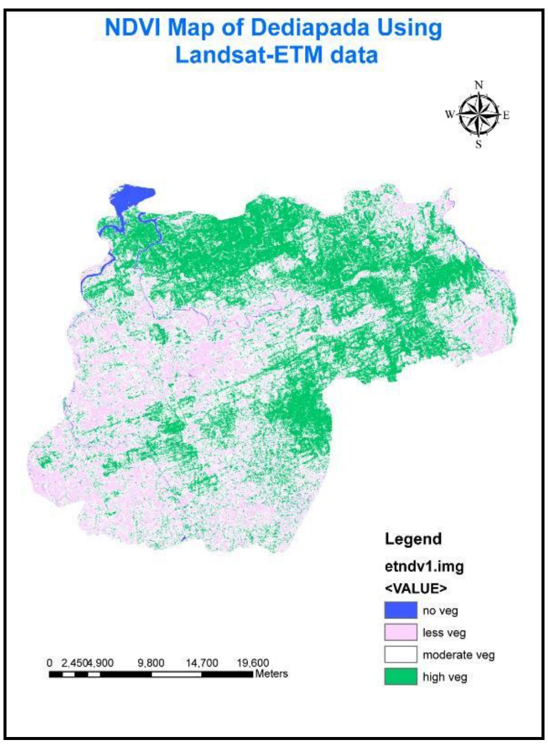
Plate 14 Displaying the NDVI (1990-2005) of Dediapada Taluka



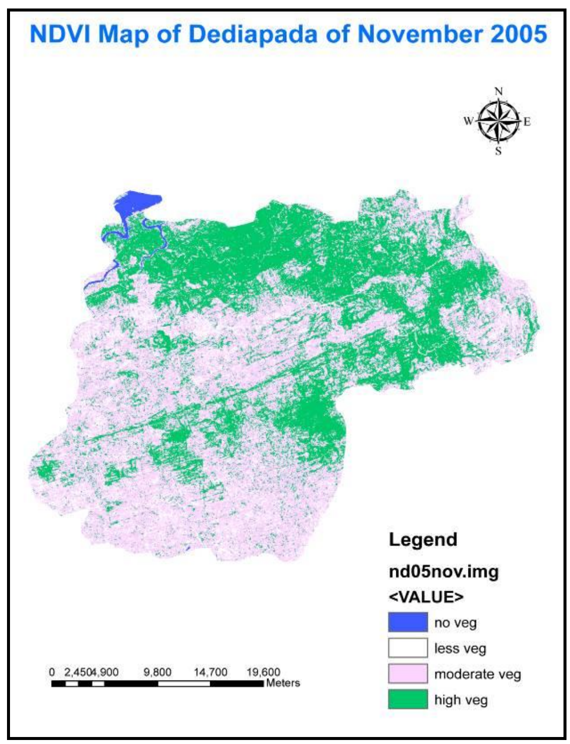
a) Landsat TM-1990



b) LISS-III-1997



c) Landsat ETM-2001



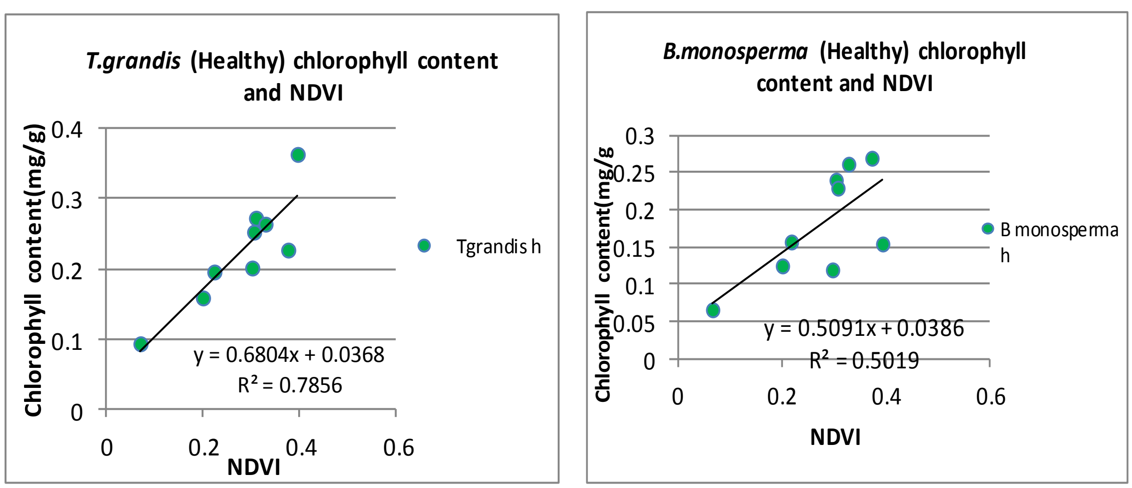
d) LISS-III-2005

11.3. Correlation of Biochemical and Biophysical parameter with NDVI:

An attempt was made to correlate the conventionally derived biochemical and biophysical parameters with the non conventional satellite based parameter i.e. NDVI. This attempt was possible for only two species i.e. *T.grandis and B.monosperma* as they were present in the pure homogenous patch of forest and could be extracted from the pure pixel of NDVI, other species were heterogeneously distributed therefore none taken for consideration.

11.3.1. Chlorophyll-NDVI The biochemical feature i.e. chlorophyll content when correlated with NDVI exhibited a positive correlation with the healthy species with r^2 =0. 7 Figure 23 (a-b).

Figure 23-Chlorophyll content correlation with NDVI

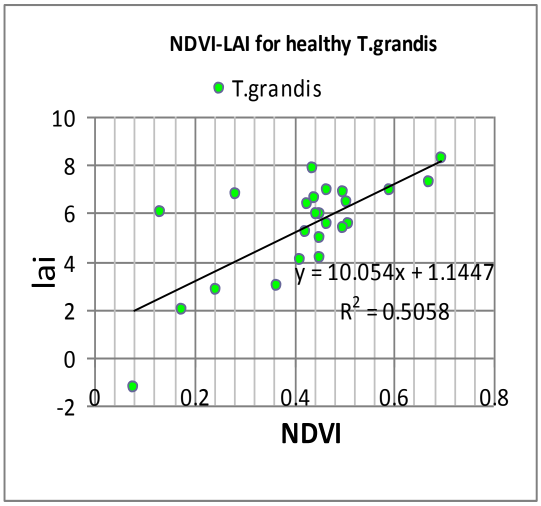


(a)- *Tectona grandis Healthy* (b)- *B.monosperma Healthy*

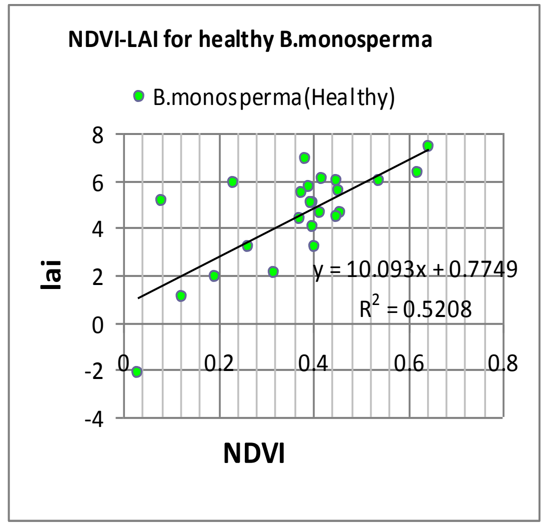
11.3.2. LAI-NDVI

NDVI stated to have correlation with the greenness of the tree. Therefore, in the present study correlation analysis for the LAI and NDVI was carried out in homogenous patches of Two tree species of *T.grandis* and *B.monosperma*. The healthy tree species for both *T.grandis* and *B.monosperma* showed good correlation with NDVI with r^2=0.50 and 0.52 respectively as shown in Figure 24.

Figure 24 correlation between LAI and NDVI



(a)- *Tectona grandis Healthy*



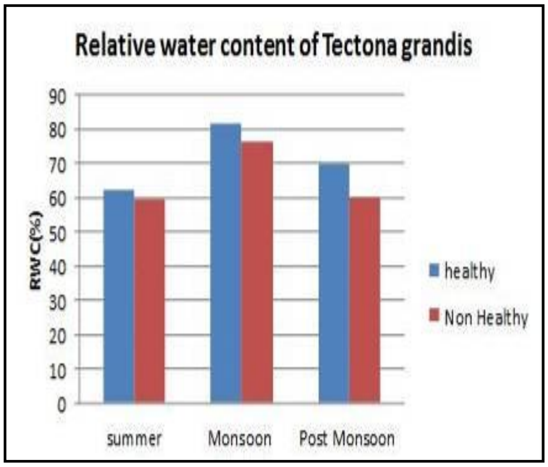
(b) *B.monosperma Healthy*

11.4. Relative Leaf Water content

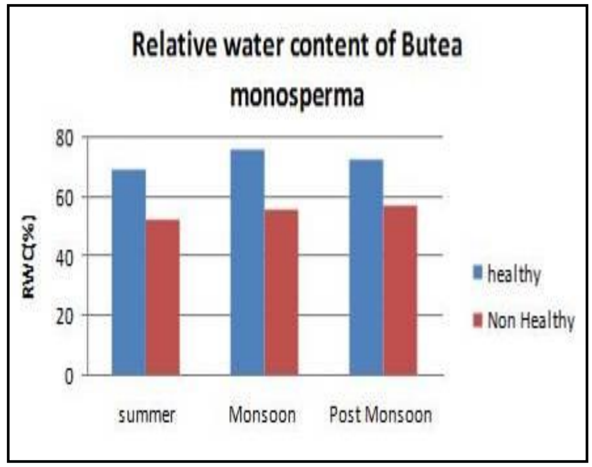
11.4.1. Conventional technique:

Fluctuation in relative leaf water content (RWC) were observed in almost all the five species examined in healthy and non-healthy condition *figure 25.* The maximum RWC was observed in healthy trees of *Terminalia crenulata* (97.2%). and minimum in healthy trees of *Tectona grandis* (62.1%) *and Dalbergia sissoo* (62.1%) in summer and monsoon season respectively. RWC in all the tree species showed seasonal variation but the distinct seasonal variation were observed in *Terminalia crenulata* and *Madhuca longifolia.* Maximum reduction of 20% in RWC can be seen during stress condition *i.e.* in non-healthy trees of *Butea monosperma,* in the monsoon season. Similar results were observed in *Araucaria*, where the leaves when subjected to stress showed decline in relative water content (Yamasaki and Dillenburg, 1999).

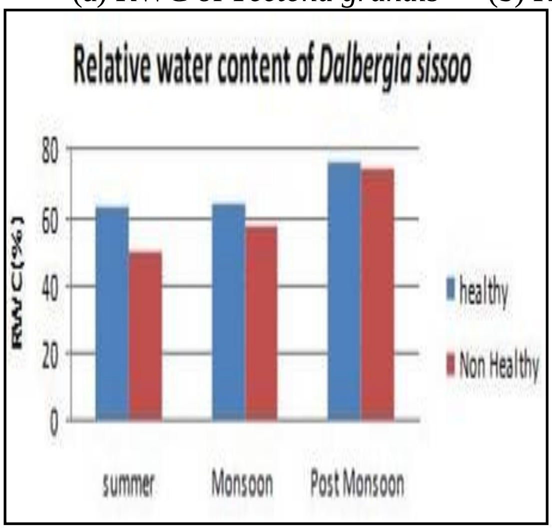
Figure 25 Relative Water content in five different species



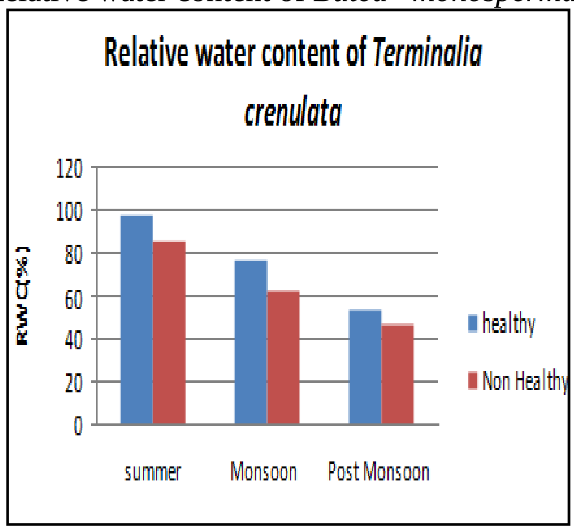
(a) RWC of *Tectona grandis*



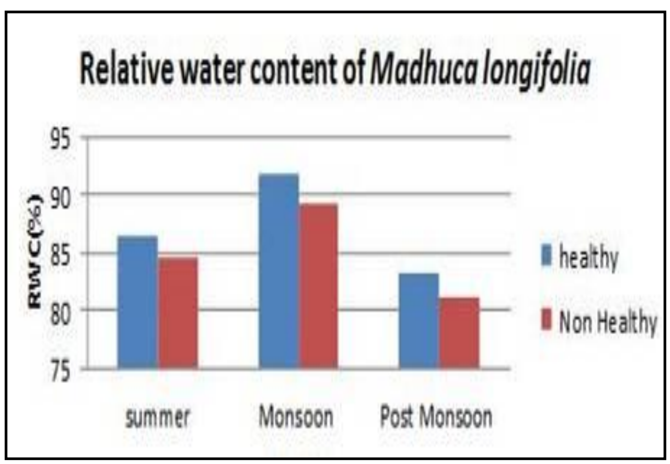
(b) Relative water content of *Butea monosperma*



(c) Relative water content of *Dalbergia sissoo*



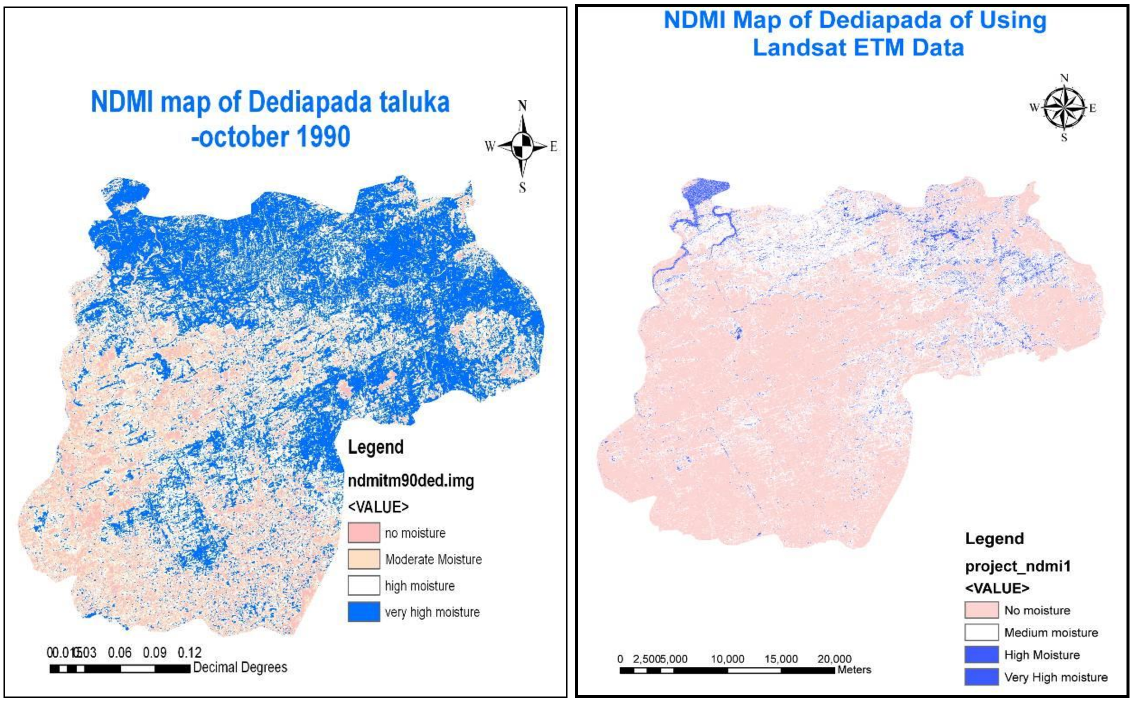
(d) Relative water content of *Terminalia crenulata*



(e) Relative water content of *Madhuca longifolia*

11.5. NDMI-Normalized Differential Moisture Index:

Satellite derived NDMI were found to be high in vegetation areas and low in the non vegetated area. This aspect of NDMI was further used to analyze the relationship between the leaf water content and the NDMI. (Plate 13)



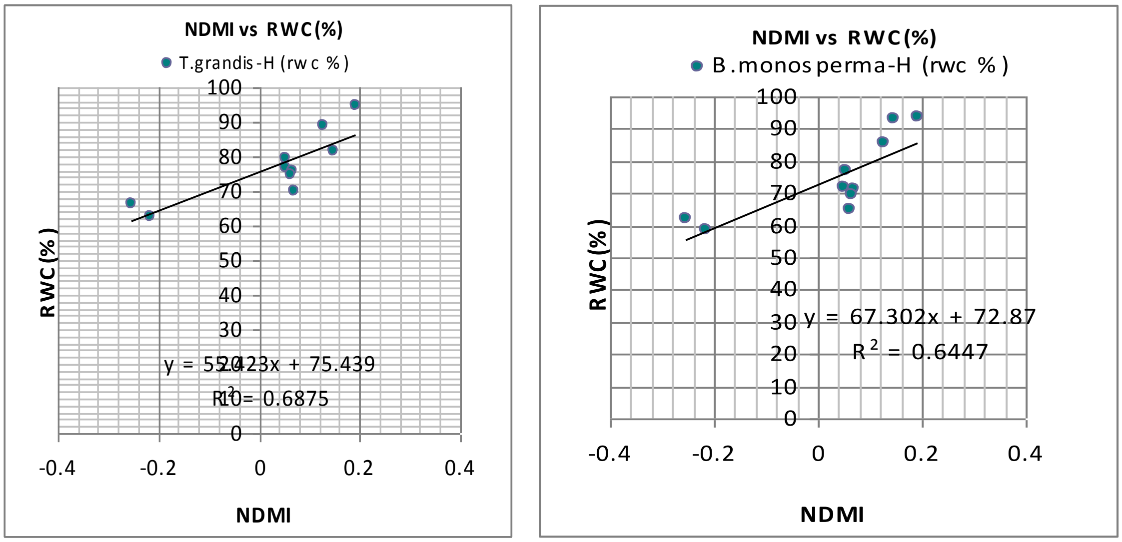
a) Landsat TM-1990 b) Landsat ETM$^+$-2001

Plate 13 Estimation of NDMI from satellite data

T.grandis and *B.monosperma* are the dominant and important tree species found in Dediapada forest. These two species had a purely homogenous patch in the forest area, so there was ease in analyzing RWC with the NDMI

The healthy tree species for both *T.grandis* and *B.monosperma* showed good correlation with NDMI and poor correlation with non-healthy tree species as shown in Figure 26. The R^2 of 0.68 and 0.64 was seen for the healthy trees of *T.grandis* and *B.monosperma* repectively.

Figure 26 correlation of NDMI with RWC



a)T.grandis-Healthy b) *B.monosperma -Healthy*

11.6. Biomass with help of Conventional technique

Biomass values were calculated for fourteen different villages of Dediapada Taluka. With the help of ground survey the biomass values were calculated using Ravindranath equation for biomass (Table 8). It was seen that Sagai had the highest biomass in the Dediapada taluka and the least was seen in Kokati. This indicated that Sagai had presence of good vegetation status, when compared to other villages.

Table 8- Biomass obtained from Ground survey for fourteen different villages

Location	Total basal area m2/ha	Woody biomass t/ha
Fulsar	**13.6157**	**111.594**
Chopdi	**5.39411**	**43.19**
Piplod	**17.7424**	**145.928**
Mathasar	**21.6943**	**178.807**
Sagai	**27.5314**	**227.373**
Dhumkal	**2.83479**	**21.8965**
Mota kabli	**15.2147**	**124.897**
Gangapur	**9.00451**	**73.2285**
Morjadi	**5.56661**	**44.6252**
Kevdi	**9.74841**	**79.4178**
Chuli	**26.5393**	**219.118**
Ralda	**4.19971**	**33.2526**
Kokati	**2.15564**	**16.2459**
Khatam	**17.9703**	**147.824**

11.6.1. Generation of Biomass map through Non-conventional of Dediapada Taluka

Remote sensing measures the amount of microwave, optical or infrared radiation that is reflected or scattered by the imaged area in the direction of the sensor. This amount is related to biomass levels of the vegetation in the image resolution cell at certain electromagnetic wavelengths. Generally, biomass is estimated via a direct relationship between spectral response and field estimates of biomass.

Biomass data was regressed with NDVI values and regression equation was derived. A positive correlation (r^2=0. 63) was obtained when the ground biomass values were correlated with satellite derived NDVI data (Figure-27). A regression equation was derived from this analysis which was further used to prepare biomass map from optical data. The biomass map was categorized into six different classes i.e. water, barren, 200 - 350 tons/ha, 150 - 200 tons/ha, 100 - 150 T tons/ha and < 100 tons/ha.

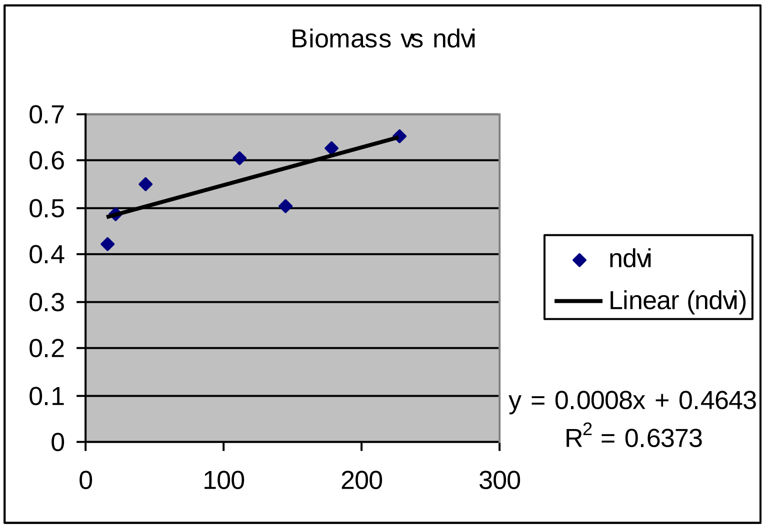
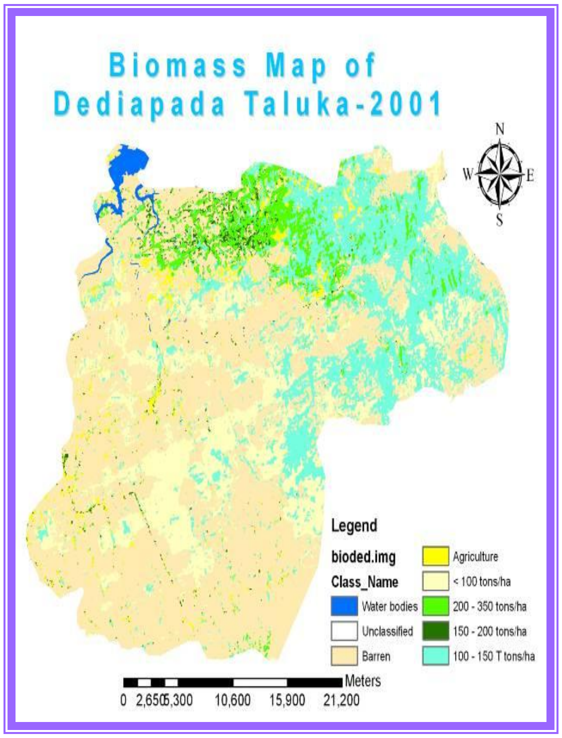
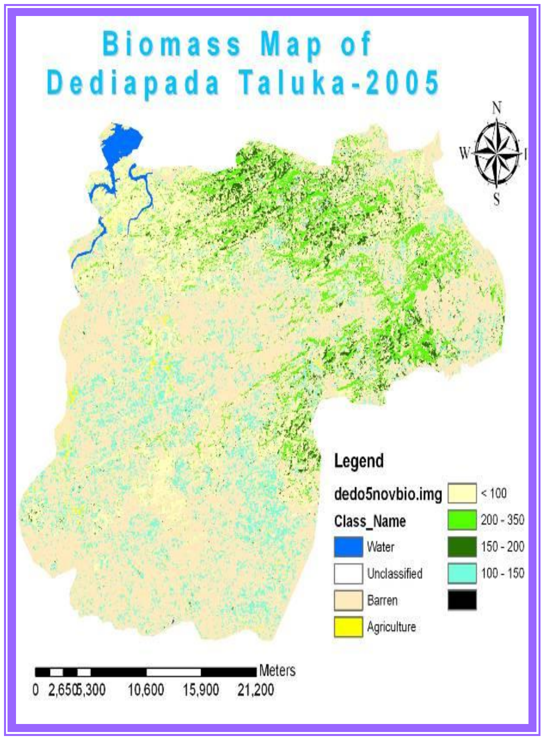


Figure 27 Biomass correlation with NDVI





2001 2005

Plate 14 showing the biomass map for year 2001 and 2005

Table 9 Showing the changes in the area of Biomass values from 2001-2005

Class name	2001 (sq.km)	2005 (sq.km)	Change in forest Biomass (%)
200 - 350 tons/ha	72.07	81.10	0.874409
150 - 200 tons/ha	10.29	36.73	2.55827
100 - 150 T tons/ha	201.09	113.99	-8.42693
< 100 tons/ha	175.30	223.03	4.618344
Barren	564.03	567.60	0.346074
Water bodies	10.77	11.08	0.029833
Total	1033.54	1033.53	

In the year 2005, there was a steady rise in the areas with biomass levels i.e., 350-200 tons/ha, less than 100 tons/ha, barren and water bodies by 0.8%, 2.5 %, 4.6%, 0.3 % and 0.02 % respectively. A reduction of 8.4 % was observed in the areas having 100-150 tons/ha biomass level.

11.6.2. Biomass Estimation Using Microwave Data

Correlation of backscatter values with biomass values were carried out in Dediapada Taluka in different season. Forest biomass values are interrelated with the amount of water existing in the canopy, and are expected to be correlated with radar backscatter. They have different interactions with the various tree components at different wavelengths. SAR images are at varying wavelengths, therefore, all contain some information on the total aboveground biomass, even though each wavelength senses different portions of a tree. The total dynamic range of the backscatter is taken for zero biomass (lower value) and maximum or totally saturated backscatter for biomass equals to infinity.

11.6.3. ENVISAT-ASAR

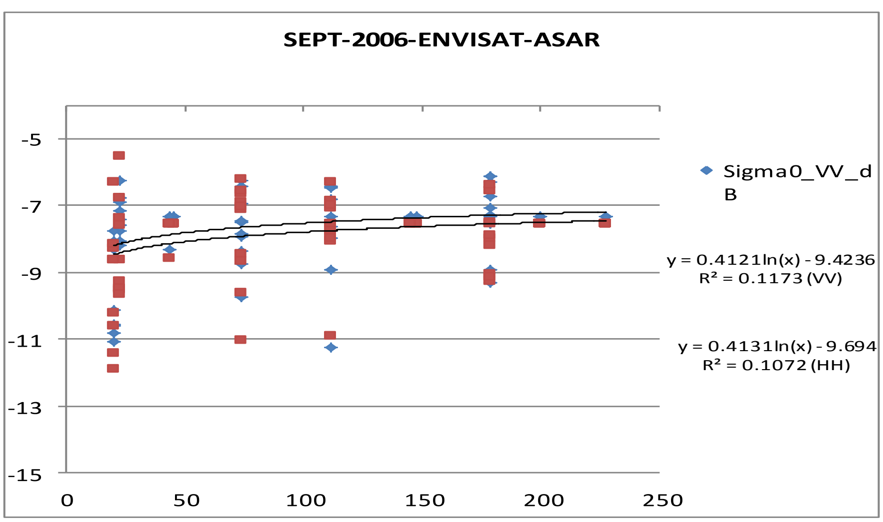
In case of ENVISAT-ASAR, in low biomass (0-50 t/h) the backscatter ranged between -11.0 to -6.2 dB in VV polarization, for HH polarization it ranged between -12.8 to -5.5 dB (fig-28). The backscatter value (for 50-150 t/ha) ranged between -11.2 dB to 6.2 and -11.0 to 6.19 dB for VV and HH polarization respectively.

Biomass values obtained from the ground were further regressed with backscatter value of ENVISAT-ASAR image to generate the Multiple linear regression equation y= 295.68006+14.80254484VV+ 9.168553883 HH. This was further used to generate the biomass map.

11.7. RADARSAT-2

For the present study area in 100-150 T/ha biomass class, backscatter values of HH and HV were lying between -11.5 to -16.8 dB in February (fig 29), -11.0 to -18.4 dB in March, -7 to -11 dB in April (fig30), and it was between -10.9 to -20 dB during June (fig 31). The low biomass σ° nought for the polarization, fluctuated between -10.4 to -20.8 dB during the five seasons. The area with no biomass showed the σ° nought ranging between -10.6 to -33dB. The backscatter of non-forested areas are less than that of forested areas. These variations are probably due to differences in surface and near-surface moisture contents.

Figure 28 Relationship between Radar backscatter and Biomass for HH, HV, VV, and VH Polarizations of C-band. (ENVISAT(a), RADARSAT-2(b,c,d))



(a) Biomass vs Backscatter- September-2006

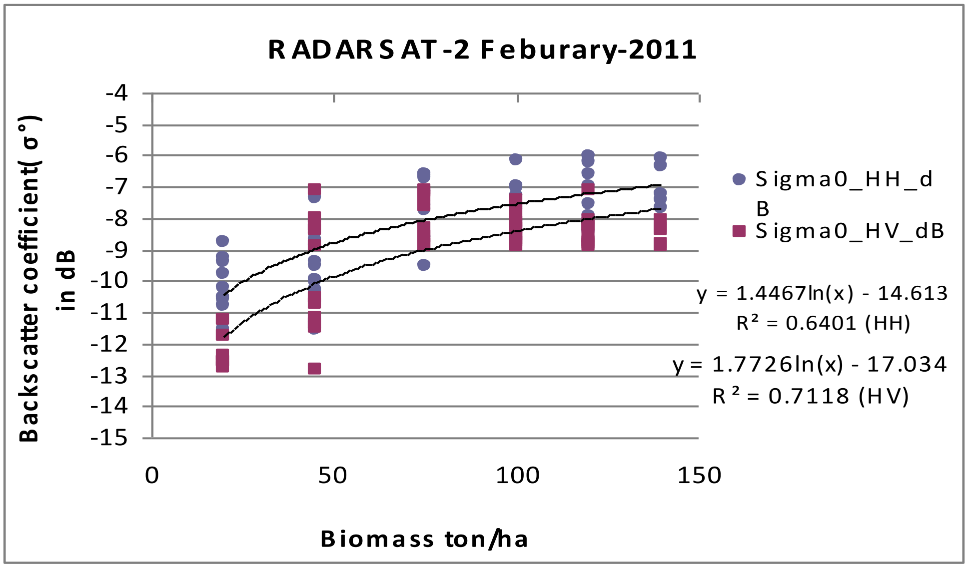


Figure 29 -Biomass vs Backscatter- February-2011

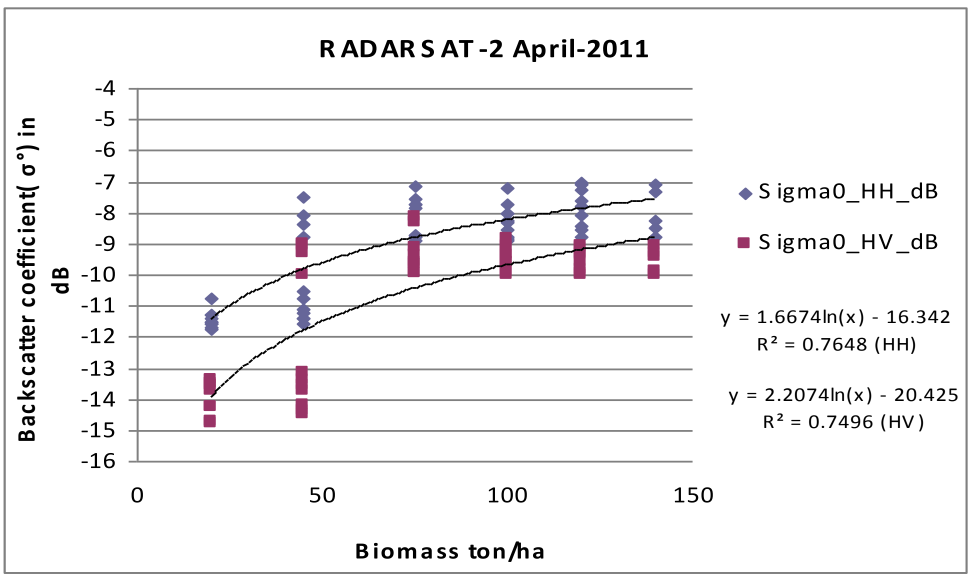


Figure 30 -Biomass vs Backscatter- April-2011

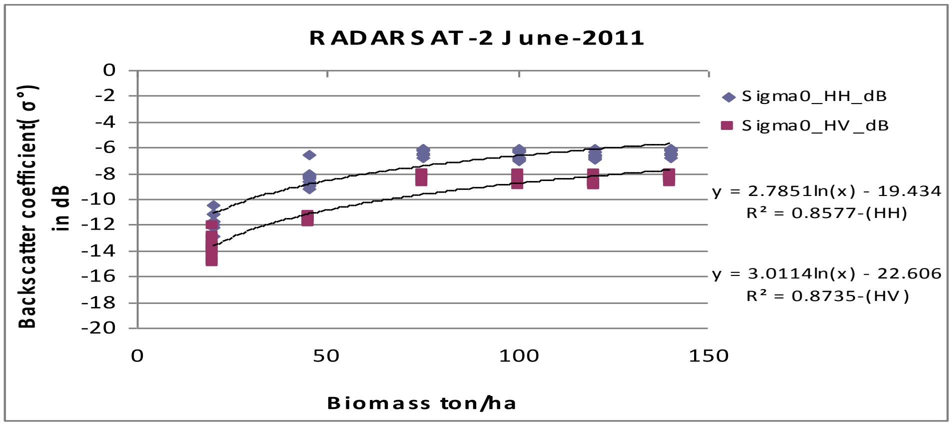


Figure 31 -Biomass vs Backscatter- June-2011

As observed from Fig 28-31. , for all the bands, backscattering coefficients are more or less constant after biomass region of ~ 300 (ton/ha).

11.8. ENVISAT-ASAR based Biomass Map

The Multiple linear regression (MLR) y= 295.68006+14.80254484$_{VV}$+ 9.168553883 $_{HH}$ generated when applied to ENVISAT-ASAR data generated Biomass Map (plate-15).

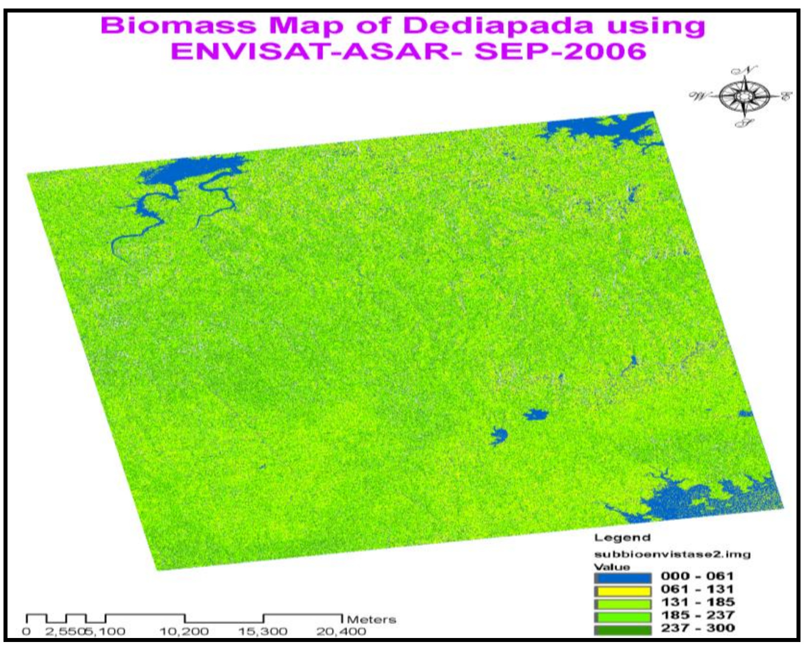
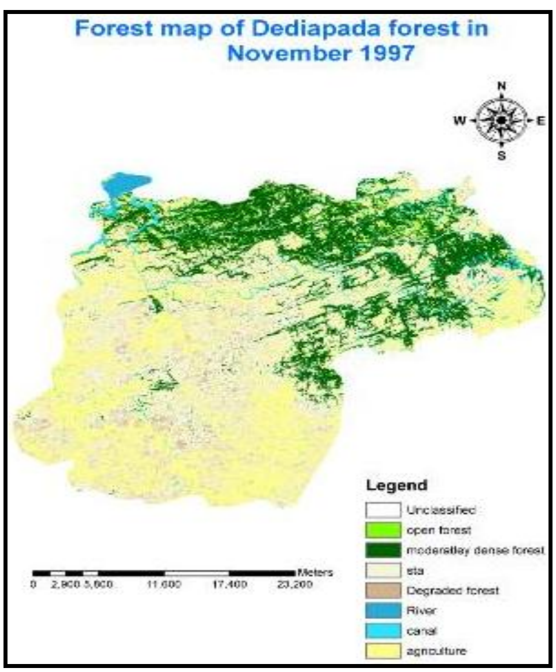


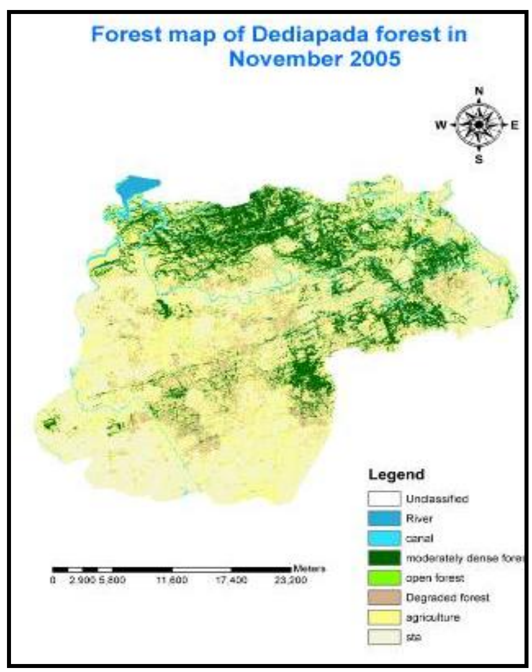
Plate 15 ENVISAT-ASAR based Biomass Map

The map was exhibited five different categories of areas with different biomass levels i.e. 0-61 t/ha, 61-131 t/ha, 131-185 t/ha, 185-237 t/ha, 237-300 t/ha. More categorization could not be achieved, as backscatter values were saturated at high biomass level i.e above 300 t/ha. This explains the fact that the microwave data proves its potential in understanding the distribution of biomass only upto certain level, but its advantage is such categorization can be achieved throughout the year.

12.0. Forest cover mapping:

The present study carried out in the forest area of Dediapada Taluka in Narmada district of Gujarat have exhibited discrete changes in the forest area of this region. Forest cover map was generated for the year November 1997 and November 2005. The supervised classification carried out brought three distinct classes of forest area i.e. the close forest, the open forest and the degraded forest. The other non-forest classes consisted of river, canal, agricultural area and the Sparse Tree Agricultural area (STA).





a) November 1997 **b) November2005**

Plate 16 forest cover map for year 1997 and 2005

Table-10 Area in Percentage change from 1997-2005 under different forest covers

No	Class Names	Area % (1997-2005)	
		Net % change	Change
1	Moderately Dense forest	2.24	Decreased
2	Open forest	0.65	Decreased
3	Degraded forest	2.72	Increased
4	Sparse tree Agriculture	16.07	Decreased
5	agriculture	15.59	Increased
6	River	0.03	Decreased
7	Canal	0.47	Increased

November 1997 **November 2005**

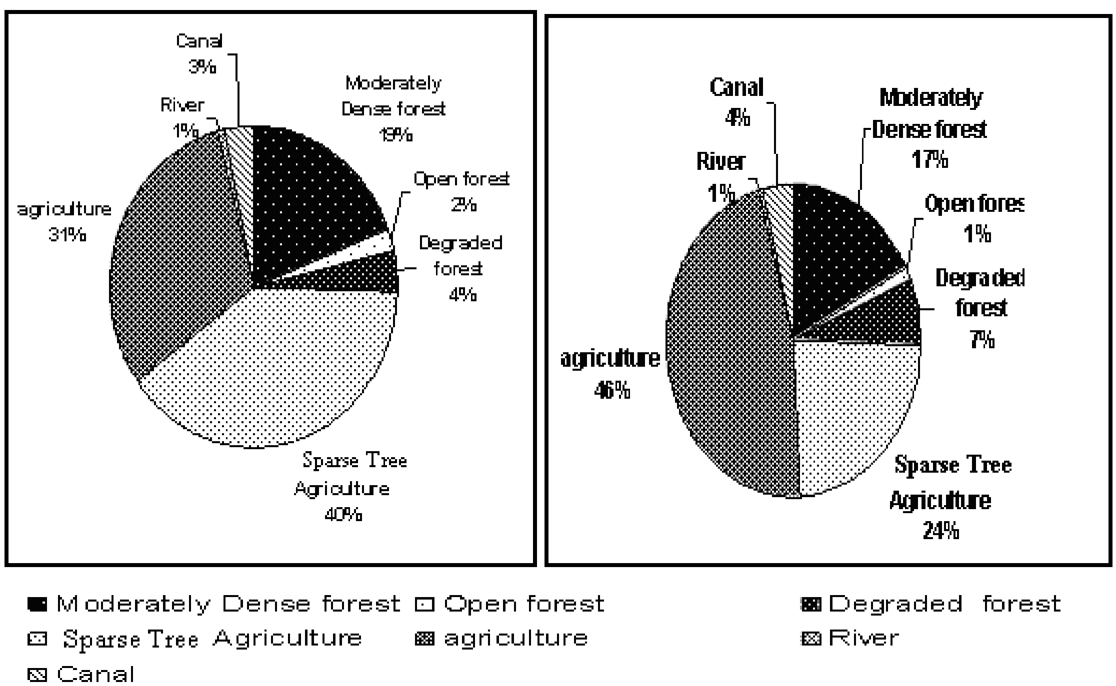


Figure 32 Chart depicting the area statistics for the year 1997 and 2005.

The current study on forest cover in these forests was determined in order to ascertain the causes of deforestation. A considerable decrease in forest area between 1997 to 2005 was observed (plate 16) with the forest map. Reduction in Moderately

Dense forest areas from Nov 97 to Nov 2005 by 2294.25 hectares i.e. loss of 2.24 % (fig-3) were observed. The open forest areas also decreased by 670.64 hectares during this period. A general increase in degraded land from Nov 97 to Nov 2005 by 2786.04 hectares, (Table-10) can be correlated with the fall in moderately dense forest. The period between 1997 and 2005 witnessed a decrease in the river area by 34.65 hectares; this is possibly due to changes occurring in river discharge because of a range of human activities, decrease in rainfall and climatic changes. Dams and man-made reservoirs dramatically also change the natural flow regime. A positive increase was seen in the canal areas during 2005 by 477.45 hectares. The agricultural land areas increased by 15.5 % from November 1997 (32406.89 ha) to November 2005 (48372.03 ha). The Sparse Tree Agricultural of the study area changed from 41042.92 to 24589.61 hectares.

12.1. Accuracy assessment:

The classified image of November 1997 and 2005 showed high accuracy. An accuracy of 92 % for November 1997 (Table-2) and 90 % for November 2005 was observed.

12.2. Kappa statistics:

Kappa statistics were found to be 0.89 and 0.87 in 1997 and 2005 respectively.

12.3. Classification of forest through microwave data

The Supervised classification of Radarsat-2 showed six different classes such as river, canal, dense forest, open forest, barren land, and agriculture. Accuracy assessment was found to be 85% and Kappa statistics was 0.83.

Dense forest, open forest and river were distinct others classes were not that distinct.

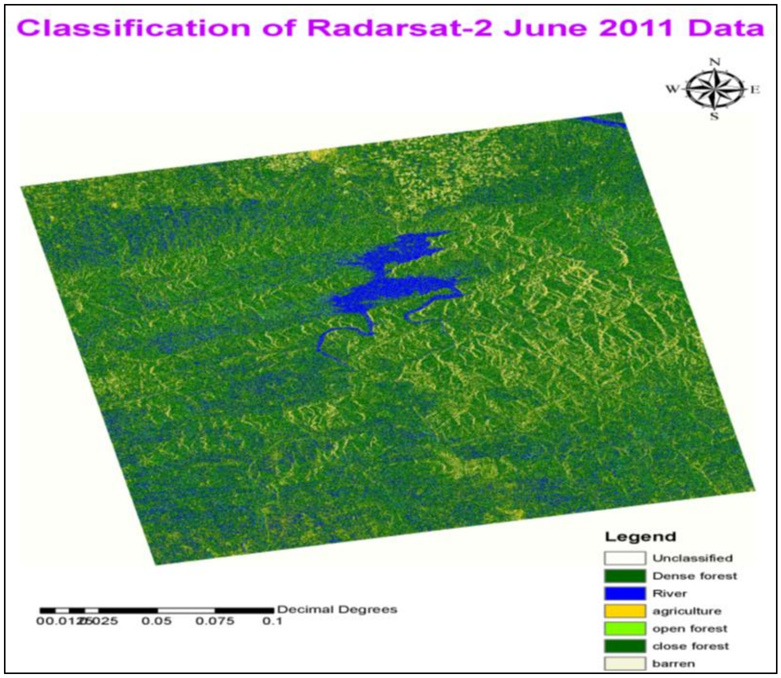


Plate 17 Classification of Radarsat-2-2011

The classification of an image is to identify the different spectral classes (similar image pixel values, which may be related to the various ground covered in a scene) present in it and their relation to some specific ground cover type. Since the supervised classification was unable to produce the desired output, alternative method i.e. polarimetric decomposition was utilized to classify microwave data.

12.4. Polarimetric decomposition

To understand the physical characteristics of a reflecting object, polarimetric radar analysis through decomposition technique was applied.

Polarimetric decomposition by means of a Cloude-Pottier algorithm was then performed, using the Polarimetric SAR Data Processing and Educational (PolSARpro) Tool software. As statistical ensemble is required, a 3 x 3 kernel was used in the derivation of the main polarimetric parameters i.e., Entropy (H), and Alpha angle. Descriptive statistics were then evaluated on selected regions of Dediapada Taluka. These regions represented three main land covers in the test site, namely the intact forest, low degradation and high degradation. The classes generated from this data were then verified using additional datasets including classified image of LISS-III Data 2005, and field visits.

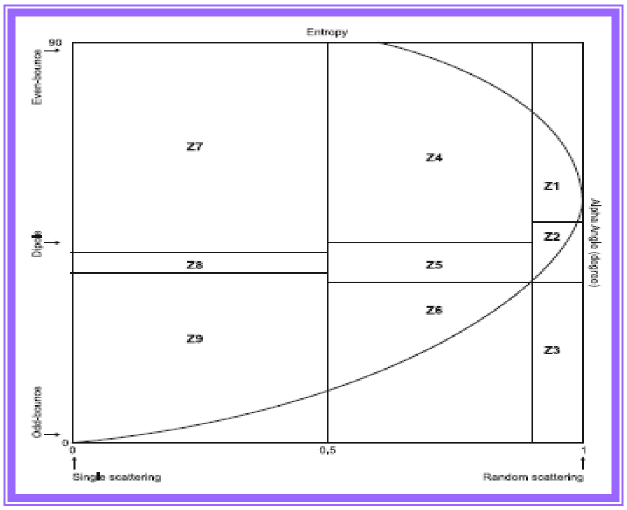


Figure 33 Segmentation of entropy-alpha feature space

Table 11 Interpretation of zones

Zone	Description	Examples
1.	High entropy vegetation scattering	Forest
2.	Non-feasible region	Unaccesible areas
3.	Medium entropy multiple scattering	Urban
4.	Medium entropy vegetation scattering	Low vegetation
5.	Medium entropy surface scattering	Low vegetation
6.	Low multiple scattering	Urban
7.	Low dipole scattering	Low vegetation
8.	Low surface scattering	Water, ice smooth bare surface

Entropy and mean Alpha angle are usually assessed using a special scatter diagram, as shown in Figure 33. To simplify the interpretation of scatter diagram, the feature space was then arbitrarily segmented into eight regions. A descriptive interpretation of each zones is presented in Table 11. The results of the Cloude-Pottier decomposition represented in Entropy-Alpha angle feature space is shown in plate-34.

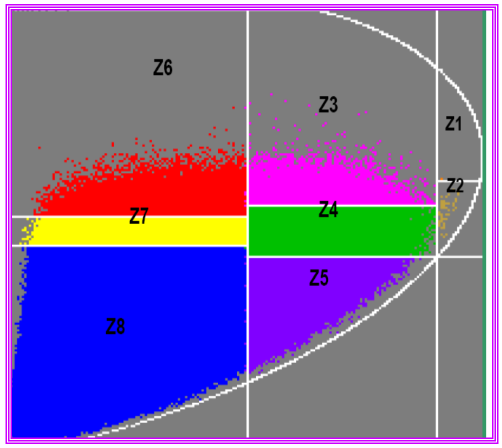


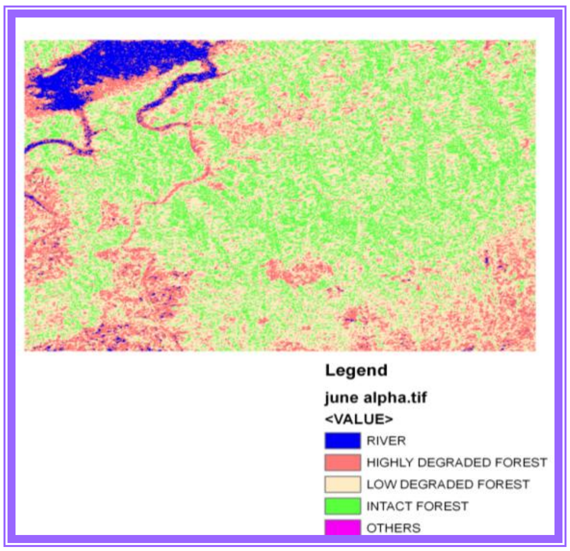
Figure 34 Segmentation of entropy-alpha feature space

Table 12 characteristic of forest cover classess

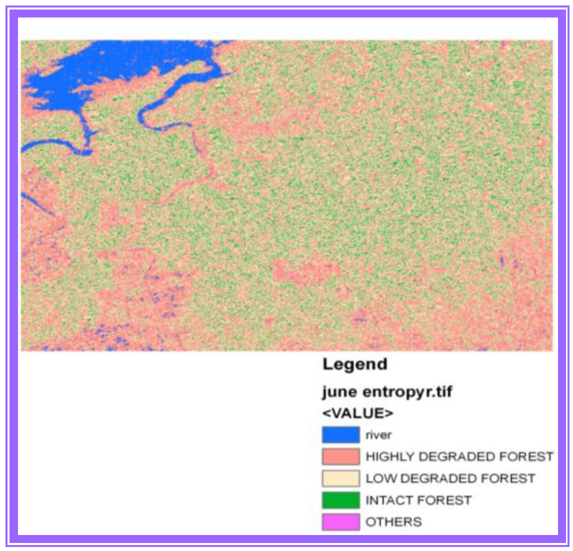
Wavelength	Class	Cluster Center		Zone
		Alpha(α º)	Entropy	
C	River	8.698344	0.064346	8
	High Degradation	40.93466	0.420527	8
	Low Degradation	49.40855	0.790106	4,7
	Intact Forest	50.9554	0.810826	3

Fairly good distribution of surface scatterers was observable in Entropy, making this parameter suitable for identifying different levels of disturbance. Intact forest class displayed a high value of Entropy, indicating dominance of a volume scattering mechanism. On the other hand, highly degraded forests showed very low Entropy. This indicated that a single deterministic scattering process dominated the present study area. Highly degraded areas were dominated by dead stands without leaves or branches, which was further confirmed by ground survey. Therefore, a random scattering mechanism due to canopy structure was less visible. In an intact forest, the results were fairly similar to a modelled scattering mechanism of Type III and IV (High entropy scattering) as identified by Cloude and Pottier. Type III can be interpreted as volume backscatter from a non-penetrable canopy and therefore, easily identifiable with high Entropy value (maximum of 0.95 from the model). This was similar to those observed for an intact forest using C-band (highest in this study was found to be 0.81). Type IV, included sub-canopy information (possibly surface) which contributed to the overall signal propagation. Although its cluster center can be categorized as medium Entropy, some scatterers within the high degradation class had similar characteristics to Cloude-Pottier Type V scattering (i.e., Dielectric Target Scattering).

Although the Alpha angle was found to be useful for explaining the scattering types, apparently the parameter did not provide a significant contribution to the interpretation. All scatterers tend to be clustered around α=44 i.e. between high and low degraded areas (Table 12), hence separation between cluster centers was difficult. Although unclear, the Alpha angle could be valuable for distinguishing healthy and degraded forest covers. Intact forests, which have thick vegetation layers with well-developed structures, clearly fit into the dipole region (around 50°), whereas the degraded forest remained at 40°.



June Radarsat 2 data –ALPHA

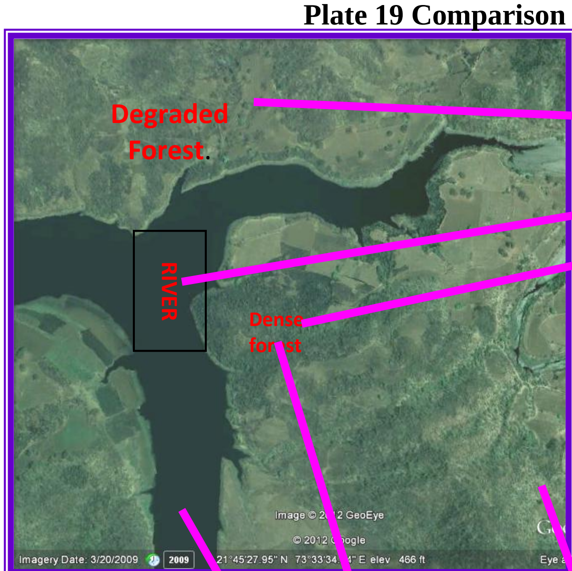


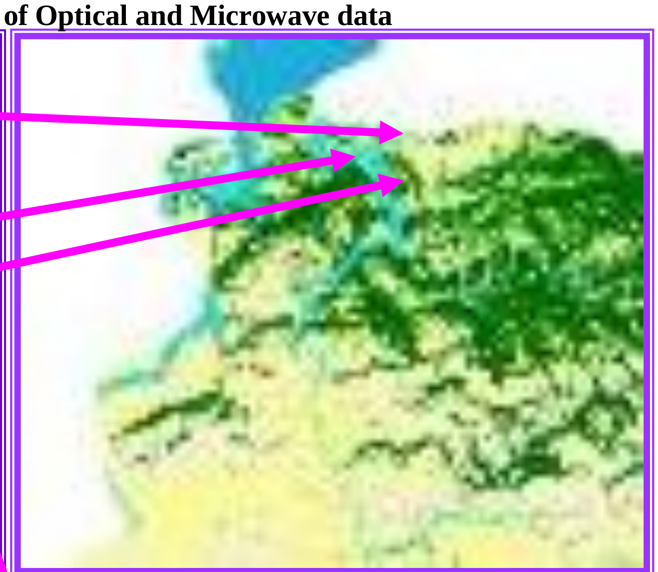
June Radarsat 2 data –Entropy

Plate 18 Classification of entropy and alpha

The June Radarsat-2 images were classified based on Alpha and Entropy scattering (plate-18). Five distinct classes were displayed namely River, highly degraded forest, low degraded forest, intact forest and others. The accuracy assessment for entropy was 89% and that for alpha 87%. The kappa statistics were found to be 0.87 and 0.86 for entropy and alpha respectively.

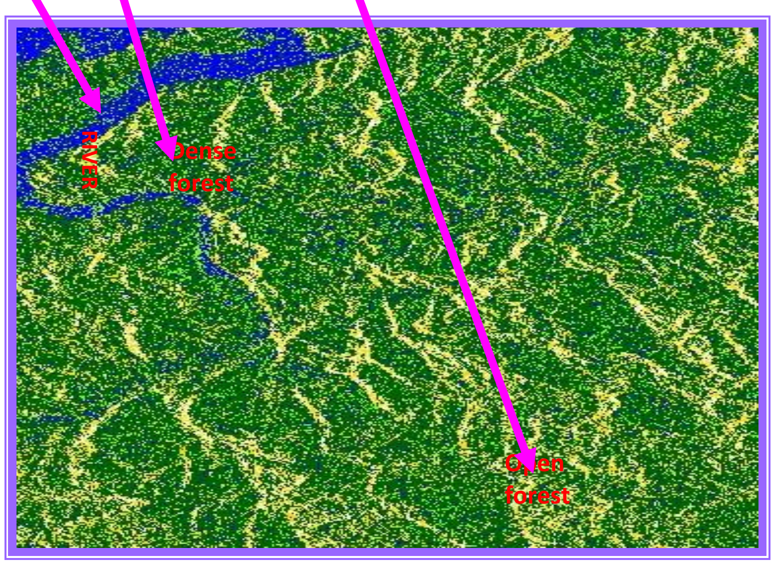
Plate 19 Comparison of Optical and Microwave data





(a) Google earth Image of Dediapada forest

(b) LISS-III Supervised classification of forest



(c) Radarsat-2 June-supervised classification of forest

Google earth image (Plate-19a) was compared with the supervised images of optical and microwave data (plate-19b). Due to the spectral properties of land features, delineation of different forest categories in optical data was found to be distinct, but in few sites, these classes were not that distinct, as observed for the open and degraded forest. Microwave data (plate-19c) proved to be beneficial in overcoming the limitation faced by the optical data. It utilized the backscatter value resulting from the different scattering mechanism of the tree structure and therefore, it could differentiate forest categories (i.e. degraded and open forest) more precisely than the optical data.

It was seen from the present study that both optical and microwave have their own unique properties. A fusion of both these datasets would provide a better forest classification.

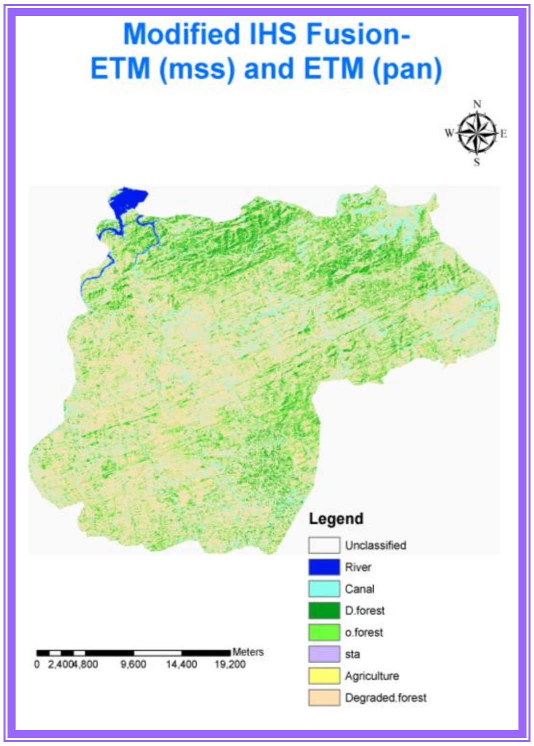
13.0. Data fusion:

The image fusion techniques was applied on various dataset such as the Landsat-ETM$^+$ panchromatic, IRS-LISS-III, ENVISAT-ASAR and Radarsat 2 data. Plate 20 shows an example of the fused data using three fusion algorithms, such as, Modified IHS, Brovey and Ehlers algorithms.

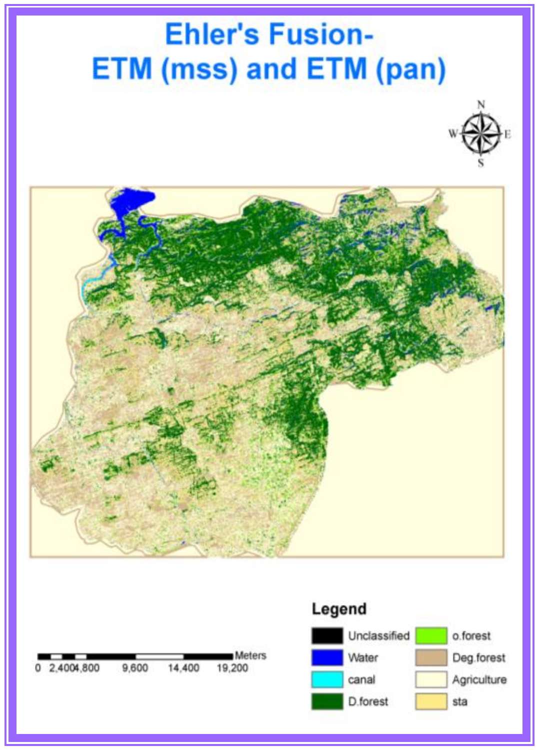
Table -13 Accuracy assessment and Kappa statistics

Data	**Landsat ETM (MSS+Panchromatics**			**LISS-III and Envisat-ASAR**			**LISS-III and Radarsat-2**		
Method	**MIHS**	**Ehler's**	**Brovey**	**MIHS**	**Ehler's**	**Brovey**	**MIHS**	**Ehler's**	**Brovey**
Accuracy(%)	93.3	93.3	96.6	90	90	94	92.6	92.6	96.5
Kappa statistics	0.90	0.87	0.94	0.85	0.85	0.92	0.89	0.88	0.93

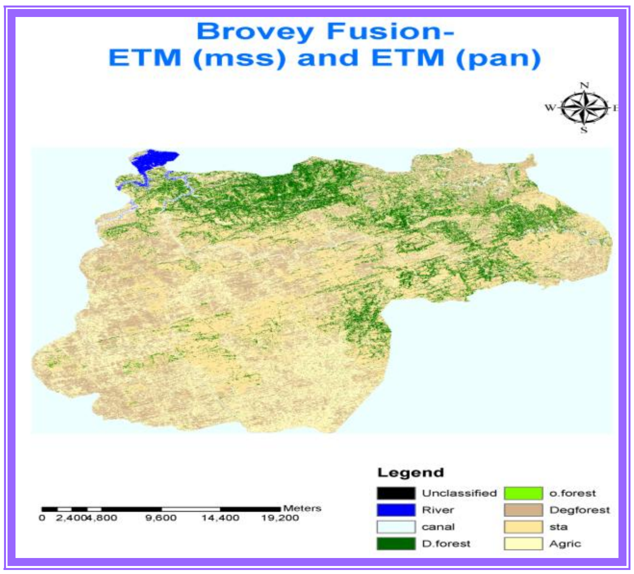
In the present study the Landsat ETM Multispectral image was fused with panchromatic data with the help of three main techniques such as the Modified IHS, Ehlers and Brovey Technique(plate-20 a-c). It was seen that the Bovery was the best technique with an accuracy of 96.7% (table 13). Ehlers showed mixing of classes in the open forest, while in Modified IHS open class was totally absent (plate-20 d-f).



(a) **Modified IHS**



(b) Ehler's

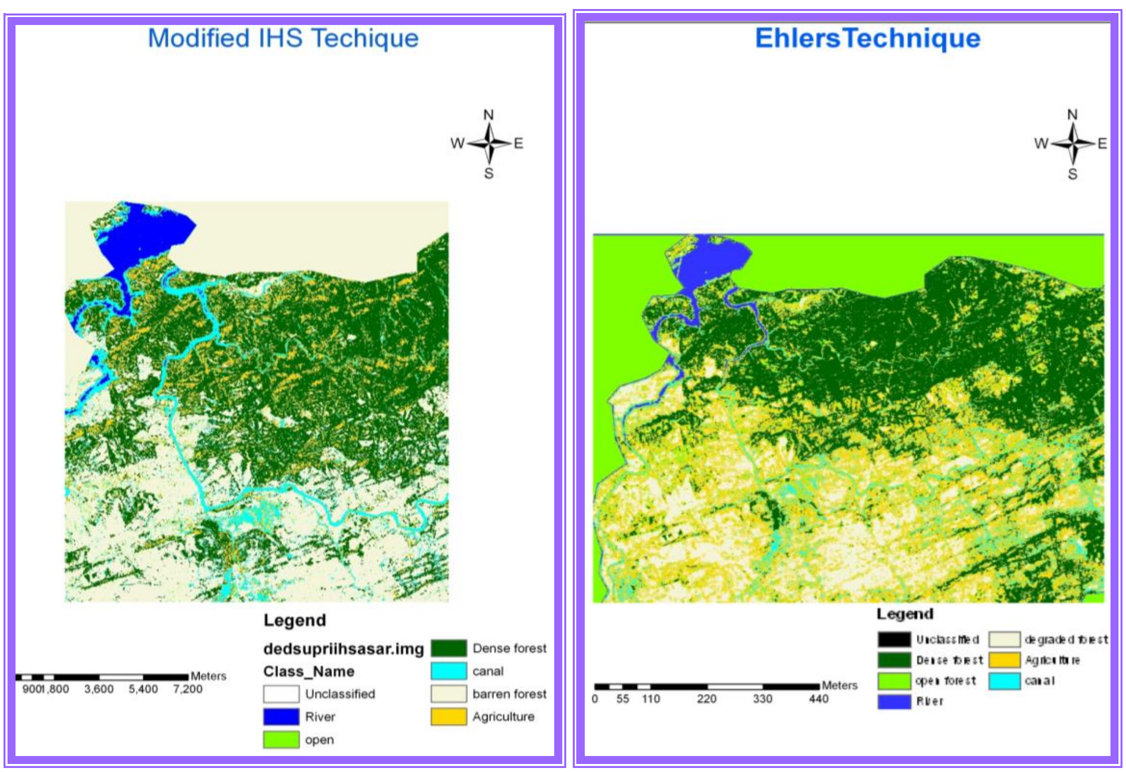


(b) Brovey

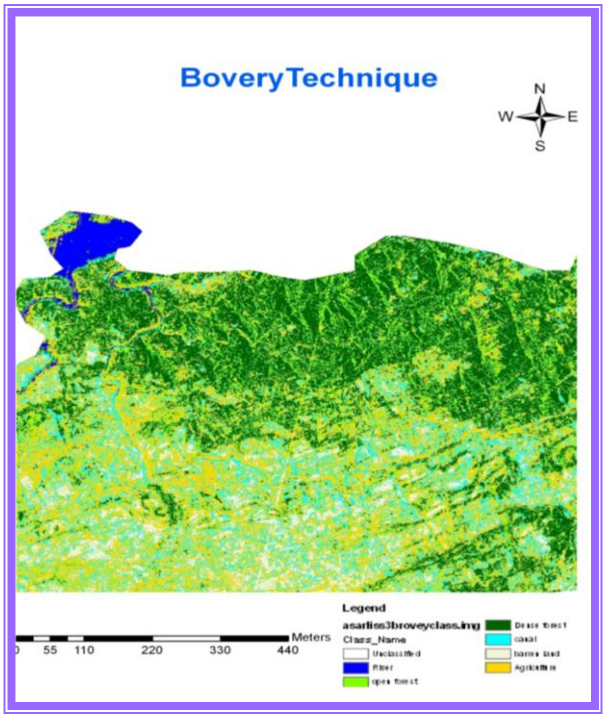
(d) **Modified IHS** **(e) Ehler's** **(f) Brovey**

Plate 20 Fusion techniques using Landsat ETM^{+}(MSS) and Landsat Panchromatic

In case of fusion between ENVISAT ASAR DATA and LISS-III data (Plate 21 a-c), Bovery was found to be best with 94% which was more than Ehlers and IHS Modified (90%). Ehlers showed mixing of classes in the river and dense forest, while in Modified IHS open class was totally absent (plate-21 d-f).

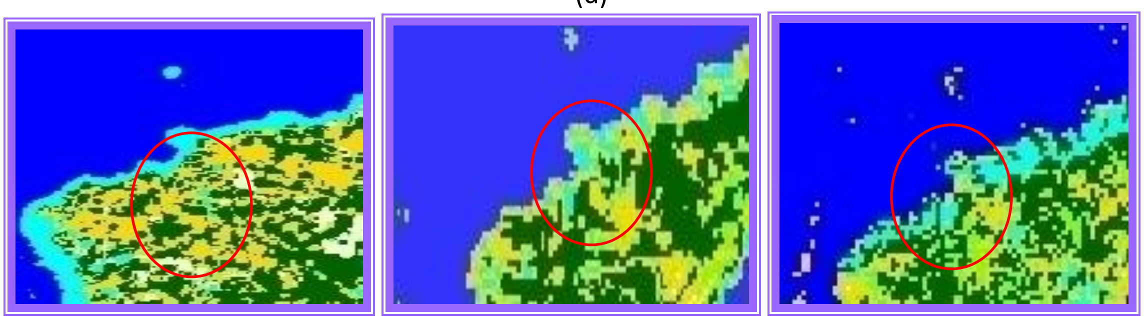


a) **Modified IHS** **(b) Ehler's**



(c) Brovey

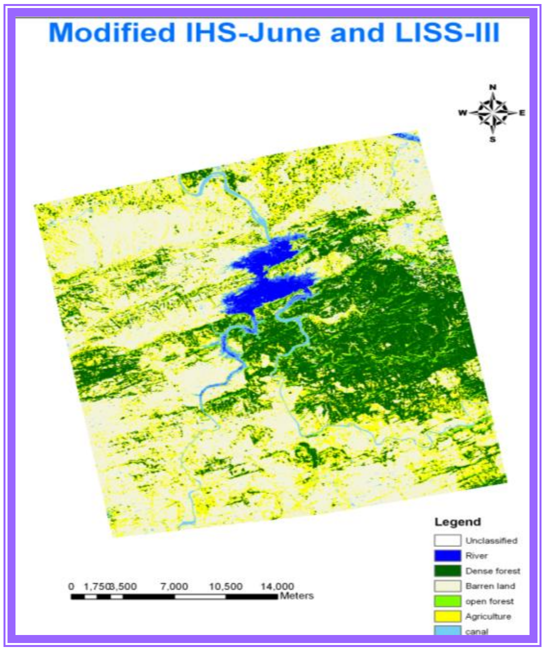
(d)

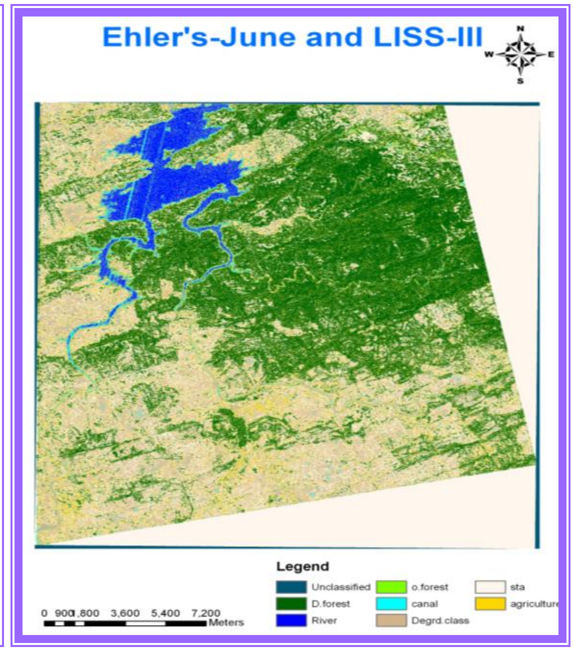


(d) Modified IHS **(e) Ehler's** **(f) Brovey**

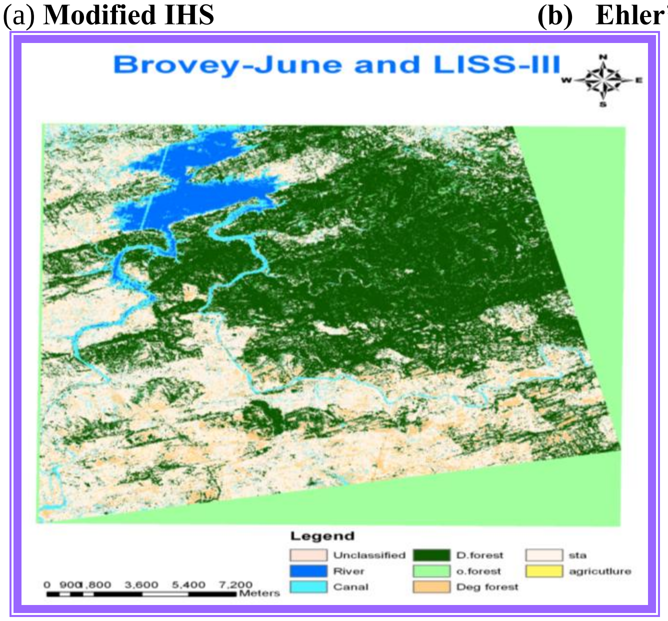
Plate 21 Fusion techniques using LISS-III (MSS) and ENIVISAT-ASAR

In case of fusion between Radarsat-2 data and LISS-III data, Bovery was found to be best with 96% which was more than Ehlers and IHS Modified (92%) (plate-22 a-c). Modified IHS showed mixing of classes in the river, agriculture and dense forest, while Ehlers in river and degraded forest was getting mixed (plate-22 d-f).

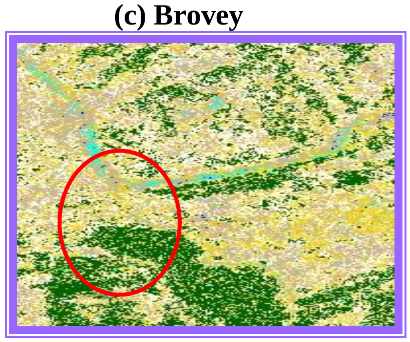


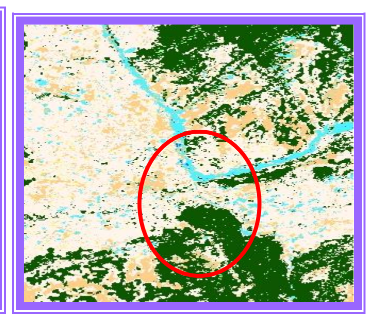


(a) **Modified IHS** **(b) Ehler’s**



(c) Brovey





d) Modified IHS **(e) Ehler’s** **(f) Brovey**

Plate 22 Fusion techniques using LISS-III (MSS) and Radarsat 2.

DISCUSSION

14.0. Discussions:

Forest resources have come under increasing pressure in recent years. Thus, their management and use, needs to be underpinned by information, and their properties at a number of levels. It is also essential to understand the accurate information on health status of forest and, in particular, where and how they have changed over a time (Franklin, 2001; Kleinn, et al, 2002). Today after completion of three decades since the launch of the first international satellite program designed for earth resources, monitoring forest assessment using satellite data provides three levels of information. Namely 1) the spatial extent of forest cover, which can be used to assess the spatial dynamics of forest cover 2) understanding of forest type and 3) retrieving of biophysical and biochemical properties of forests. Along with these components, it aids in forest tree inventory, phenology and tree damage assessment thereby understanding the forest as whole.

In the present work the information on forest on Dediapada forest, regarding various parameters like DBH, Height, site quality and tree damage, phenology and biomass, provided information about the state and dynamics of forests for strategic and management planning.

Tree inventory related to an understanding of different DBH, height crown cover and basal area have given a clear insight of the forest species of Dediapada forest. An effective plantation management requires such kind of information as it gives a clear idea of the divergence between actual and planted development. Although some DBH and height vs. age ground data models have been developed to forecast the plantation height and DBH, an implicit assumption of these models is that a plantation will grow exactly as forecasted whereas, during the planning period, the actual plantation growth may vary. Such kind of changes may be due to a number of factors like disease, fires, silvicultural treatments or competition from other invading species, etc. To understand precisely how such parameters are actually performing in terms of growth and yield, it is essential to provide a better method of monitoring these changes. Such correlation can be acquired both conventionally through a ground survey based and by non-conventional through remote sensing data. Both these techniques have yielded in understanding the significance of different parameters with each other

The variations of DBH were seen in the present study in five different villages. Higher values were exhibited by *Tectona* and *Madhuca,* suggesting their good health. This information is significant for understanding or acquiring the sustainable yield of that forest area and understanding the dynamics of the forest. (Lea et al, 1979; Day Jr., 1985; Conner and Day Jr., 1992). *Tectona grandis* and *Terminalia crenulata* in the Dediapada forest were found to be the tallest tree. The factors that play premium role on tree height growth are abundant, minor stress, and minimum competition for light. (King, 1991 and Waring and Schlesinger, 1985). The capacity of the tree to have a maximum height and the role of biophysical determinants of maximum height are poorly understood. Some models predict heights of up to 120m in the absence of mechanical damage (West et al, 1999, and Friend, 1993) but there are historical accounts of taller trees. Trees such as *Butea monosperma, Madhuca indica and Dalbergia sissoo* are medium height trees. Hypotheses suggest that tree height limitation focus on increasing water transport constraints in taller trees and the resulting reductions in leaf photosynthesis. The difference in tree height at various locations as seen in the present study suggest that for every species, the rate of height growth varies from place to place. Early foresters noticed that the maximum height a tree reaches, correlates with the speed at which it grew in height when it was young. The tree height increments is governed by two factors: the light reduction environment within the canopy, and a species- and site-specific empirical height function. The former property requires the definition of a (arbitrary) light reduction function within the canopy. This function describes the variation with age of the percentage of light reaching the ground from the top of the canopy and primarily controls the crown shape (Disney et al, 2006).

Reduction in Tree height can be attributed to stress or age as seen in *Butea* and *Madhuca*. Trees seem to have mechanisms that slow their growth as their age increases and prevent them from growing beyond a certain height. A similar case was seen in case of *Eucalyptus regans* in east of Melbourne, Australia, where the height of the tree increased by 2-3m every year, but at maturity the height of tree virtually ceased. (Ryan and Yoder 1997).

Crown cover and basal area interrelated to each other. The main functions of the crown of a tree is to display actively photosynthesizing leaves most efficiently to radiant energy and to provide for the renewal of the leaves and reduction in the value of crown cover leads to decline in tree growth. Large dense crowns like those of *Tectona* and *Butea* have been associated with vigorous growth rates, while trees with small, sparsely foliated crowns such as *Madhuca indica* are in a state of decline, showing little or no growth. Kramer (1966) showed that tree crowns affect growth and survival, while Hamilton (1969) illustrated the dependence of tree volume increment on crown dimensions.

T. crenulata had the maximum crown cover as seen in Mathasar indicating high growth rate, whereas, trees such as such as *T.grandis* and *D.sisoo* are either in their declining state or in young plantation.

Young plantation is typically manifested in smaller sized trees, lower height and DBH, and unfinished crown closure, compared to the older plantations. Tree height DBH and crown closure increase with age. As the tree crowns expand, they provide a greater light intercepting and reflecting face. Full interception occurs when the crown of all trees touches each other. It is commonly observed that an inverse relationship exists between tree canopy and their associated understorey ground coverage in terms of surface exposure.

The proportion of surface of exposed area to satellite sensored contributes to the canopy reflectance which is ultimately reflected in pixel value. Based on this concept it can be hypothesized that there can exist a quantitative relationship between different tree parameters like height DBH, tree canopy closure as measured on the ground and reflectance values as estimated from the satellite images. Consequently remotely sensed data can help in determining these parameters. In this study relationship between different tree parameters like DBH-height and DBH-crown cover has been retrieved developed both conventionally and non-conventionally. A relationship in the form of a regression equation has also been derived from these derived variables.

The development of simple and accurate height–diameter models, based on easily obtainable tree and stand characteristics, is a common precursor to using inventory and sample plot data to calculate volume and other stand attributes. A number of height–diameter equations have been developed using only DBH as the predictor variable for estimating total height (e.g., Curtis, 1967; Wykoff et al, 1982; Larsen and Hann, 1987; Wang and Hann, 1988; Huang, Titus et al,, 1992; Zhang, 1997; Peng, 1999; Fang and Bailey, 1998; Fekedulengn et al., 1999; Jayaraman and Zakrzewski, 2001; Robinson and Wykoff, 2004). A linear line was observed among all the species between DBH and tree height, indicating tree with broader tree trunk has a tall height. However, the relation between the diameter of a tree and its height varies among stands (Calama and Montero, 2004) and depends on the growing environment and stand, also the relationship between DBH and crown cover resulted in a simple linear regression. Linear regression was found in all the species between DBH and crown cover. In case of *Dalbergia sisoo* the linear regression was found to be highly correlated with R^2= 0.93. Four other species (Figure-4a-4e) also showed a linear regression with R^2>0.5. The coefficients of determination (R2) from these equations were found to be 0.5; meaning that they are statistically significant models and can be used for the future biophysical property determination. Similar studies were also carried out using different tree species (for example Bragg, 2001; Bechtold, 2003), and a strong relationship between DBH and crown diameter was noted. This relationship is of adaptive significance to the trees because the canopy size also contributes immensely to a trees total weight. Thus, huge trunks enable trees to support wide canopies (Horn, 1976).

A relationship between non-conventionally derived tree parameters and remotely sensed data has also been established in the present study. The correlation between the reflectance values in various Thematic Mapper (T.M.) bands and forest at different developmental stages is well known from the early plantation development stage (Coleman et al., 1990; Fiorella and Ripple, 1993) to the older forest stands (Poso et al., 1987; Cohen and Spies, 1992). Pierce et al. (1992) and Franklin et al. (1992) used T.M. data to separate different forest cover types. Gemmell (1995) investigated the utility of Landsat T.M. data to estimate coniferous timber volume for a mountainous mixed conifer species. Where both forest polygons and ground data were used to estimate timber volumes. It was reported that sampling T.M. imagery in small areas (0.25 ha) was unsuitable for specifying the relationship between T.M. data and the forest information.

Oldai , 2005 suggested that the visible region of the spectrum (0.4 to 0.7 µm; T.M. bands 1, 2, and 3) showed a narrower range of reflectance due to the higher absorption of the plant leaves, where the energy is required for photosynthesis, than the near and middle-infrared (T.M. bands 4, 5, and 7). This region of the spectrum may not be suitable for estimating canopy closure, DBH and height, using contrast reflectance between the overstory and the understory shrubs and herbs. A good correlation can be observed in the present research work when different structural parameter such as DBH, height, crown cover, and basal area were correlated and regressed with the Landsat ETM band 5 data.

Other than tree structural parameters, species diversity is also important component. Species diversity is subject to constant change and human induced modifications. The understanding of diversity, therefore becomes imperative for understanding (1) the number of species that occur in an area or sample, (2) the number of individual organisms that are present, and (3) the distribution of these organisms among the different species. This component was assessed conventionally and non conventionally. In the conventional methods four indices were analyzed such as Shannon-Wiener, Margalef, McIntosh and Brillouin.

Various indices put different weight on the importance of these components because they were originally developed to examine widely differing concepts, some of which do not apply directly to the problems of the study area (Huston, 1994). In the present work four different indices such as Shannon-Weiner, Margalef Mc-Intosh, and Brillouin were used to assess the diversity index of Dediapada forest.. Diversity indices generated gave the idea of species composition and its distribution in this forest community. Debate on the advantages and disadvantages of various diversity indices has continued over the last three decades (Hurlbert, 1971). The advantages of these indices over other indices are categorized in two, the first depends on information theory where diversity (or information) of a natural system is treated similar to information in a code or message (Zaghloul, 2008). Shannon-Wiener and Brillouin indices are classified under this category. The second category depends on the species dominance measures where it weighs towards abundance of the common species and so the total species richness is down weighted relative to evenness, McIntosh is included in this category. The Shannon-Wiener Index was applied to biological systems. It is the most preferred index among the other diversity indices. The index values are usually between 0.0 – 5.0. Index in this forest ranged between 0 to 1.5. The values above 3.0 indicate that the structure of the habitat is stable and balanced. In the present, the index was below 1.5 indicating the habitat to unstable and unbalanced. The values below 1.0 indicate that there is degradation of habitat structure as seen Chopdi, Chuli, Ralda and Khatam, the level of degradation is very high in these villages. Sagai and Gangapur are on the verge of degradation, with little input these forests can be revived back to their original state. The Margalef index has no limit value and it shows a variation depending upon the number of species. In the Dediapada forest, it ranged between 0 to 1.95. Thus, it can be used for comparison between the sites. This index shows variation depending on number of species, so that the number of individuals is less important for calculation. It has a different purpose of usage from other indices. However, it showed similar results with the other indices calculated in this study. The McIntosh in the present study indicated that tree species in these villages were homogeneously distributed. The Brillouin Index ranged between 0 to 1.1. It was sensitive to the abundance of rare species. (Hayat and Kudus, 2010) and exhibited the presence of unique species.

These species diversity indices showed a significant degree of negative Kurtosis and Skewness. Negative Skewness indicates a distribution with an asymmetric tail extending toward values that are more negative. Negative kurtosis indicates a relatively flat distribution. Negative kurtosis exhibits peakedness, which means very frequent small changes and less frequent, very large changes. Shannon-Weiner Index (H) was highly negatively skewed when compared to all other indices with its Kurtosis values to be slightly lesser than McIntosh (MI) and Brillouin (B). This indicated frequent and minor changes in this attribute when compared to other indices. The coefficient of variation (CV) for H was slightly lower than B. These CV for Margalef (Ma) and MI were still on the high side. In general, the better the variability of the index, the poor is its conformity with the total population or its statistical performance with regard to normality, therefore a compromise seems to lay in the middle of two indices, H & B, with variability around 54%. The present study has highlighted the H index most suitable for this area.

The assessment of forest biodiversity has recently become a priority area for forest research. Several measures of species diversity among communities have been recommended to assess biodiversity through environmental gradients. Although tropical ecologists have put forward a number of hypotheses to explain this species diversity, testing these hypotheses has been hampered by the lack of field studies with sufficiently large long-term data sets. Evaluation of this is potentially an enormous task, and any methods that can be adopted to reduce the amount of time spent collecting data are therefore of interest. Remote sensing represents such method although it has been under-utilized in studies of forest biodiversity. In the present study, utility of satellite data along with GIS tool has aided significantly in understanding and extrapolating the diversity information on a larger scale. The species diversity values, of this forest in Dediapada were overlaid on the NDVI and the village map provided the specific understanding of the diversity in these areas The Shannon index is based on the proportional abundances of species. It takes both evenness and species richness into account. No assumptions are made about the shape of the underlying species abundance, so it is referred to as a non-parametric index. Values of this index when were incorporated to generate species diversity map using the Kriging tool in GIS, aided in extrapolating the understanding of this index in other areas other than the sampling points. Spatially distributed data behave more like random variables, however, and regionalized variable theory provides a set of stochastic methods for analyzing them. Kriging is the method of interpolation deriving from the regionalized variable theory. It depends on expressing spatial variation of the property in terms of the variogram, and it minimizes the prediction errors, which are themselves, estimated. (Oliver and Webster, 1990) The accuracy and the statistical results together gave a precise idea regarding the distribution of the H index in the Dediapada forest. Inclusion of more ground truth points in the areas where the values were more skewed can help in increasing the accuracy of the results.

Another component of forest is the tree phenology. It is very important specifically in the recent years of climate change. Climate influences major vegetation types at the same time vegetative phenology acts as indicators of climate. The attempt to understand such relation in these studies has shown, that a high percentage of tree species showed shifting in flowering, fruiting, and leaf flush during a span of 16 years. The climatic component like rainfall and temperature are on the higher side when compared to 1992. This ensures the role of these two components in fluctuation in phenological stages.

Tropical trees are expected to respond variously to changes in rainfall and temperature because they differ widely with respect to adaptations to seasonal drought and cues for bud break of vegetative and flower buds (Singh and Kushwaha, 2005b). This component was also studied both conventionally and non-conventionally.

Conventionally shifting of phenology in the four trees such as *Albizzia lebbeck*, *Boswellia serrata* , *Butea monosperma* and *Tectona grandis* of Dediapada forest can be very well seen from the present work. Several studies have shown significant variation (advanced or delayed) in onset dates of flowering and fruiting responses in tree species as a result of climatic change. In 1971, Walter stated that the amount and the annual distribution of rainfall, forms an indicator in deciduous, semi-deciduous and evergreen tropical, because seasonal variation in tree water status constitutes a major determinant of tropical tree phenology. Severe water stress enhances the abscission of old leaves and prevents the expansion of new shoots and leaves. The leaf flush was found to be less in 2007 compared to 1992 which may be due to increase in duration and severity of the dry season that results in trees leafless for progressively longer periods. Inversely, the duration of deciduousness among trees in a landscape should be considered as an indicator of the duration of severe drought. Probably the climate change impact can be better assessed at the level of functional types based on the duration of deciduousness and the timing of onset of the reproductive phase (first-visible-flower). The need for functional types has been emphasized to evaluate and predict the nature of vegetation responses to future global change (Box, 1996).

Non-conventionally the phenology was assessed with microwave backscatter information. Radar backscatter sensitivity to canopy condition is a function of sensor frequency and polarization, as well as forest cover type and phenology. The Dediapada forest showed variation in backscatter with changes in the phenological pattern in different season. These results indicated that even a slight change in the flowering, fruiting or in leaf flush correspondingly, changes the backscatter value. When more number of tree species are in any of the phenophase then the backscatter also tends to increase mainly in the HH and VV polarization. Variations of the radar signal are mainly caused by changes of the dielectric properties of the scattering surface and by changes of the scattering mechanism as introduced by changes of surface roughness and contributions by volume scattering. The main reasons for these variations are changes of soil moisture and the growth of vegetation. Vegetative growth and increased surface soil moisture increased the backscatter from the surface. An increase in the backscatter signal therefore indicates growing conditions.

Satellite microwave remote sensing has been used for landscape- to global-scale assessments of a variety of biophysical parameters including soil moisture [e.g., Magagi and Kerr, 1997; Wagner et al., 1999a; Wagner and Scipal, 2000], and vegetation dynamics [e.g., Frison and Mougin, 1996; Hardin and Jackson, 2003]. Radar sensitivity to these parameters arises from the strong dependence of radar backscatter to surface dielectric properties, which are strongly dependent upon the liquid water content of the forest. Shorter microwave wavelengths such as the C-band of Radarsat-2 are particularly sensitive to the vegetation canopy structure and moisture. Because of the similar characteristic sizes of leaves and branches, which increases the radar backscatter response to these canopy constituents [Ulaby et al., 1982; Elachi, 1987] Thus, it can be said that the with increase in percentage of flowering, fruiting or leaf flush, backscatter value also increases.

Tree inventory which further aided in tree damage assessment is a major feature for understanding the forest health status, because the tree damage increase in the prescribed annual cut has a negative effect on sustainable forest management. A growing amount of salvage cutting operations requires that the focus be placed on the forest health status and the quantity of tree damage. The primary task for forest management should be, to locate stands of poorer health in order to maintain their vitality and naturalness at an optimal level by applying timely measures (Pernar et a. 2007b). It is essential to inspect and determine what factors may be affecting tree health or vigor, including pest infestation, disease infection, change in environmental conditions, construction impacts, and soil- or water-related problems; provide specific action steps to improve and invigorate tree health. In the present work, visual interpretation of tree health assessment was carried out. The assessment is based on tree characteristics, which serve as good indicators of overall tree health, twelve different parameters were assessed to understand the health status of individual tree. It was seen the *Tectona grandis* was found to be best in Gangapur because of good environmental condition. In some areas, health of *Tectona* was in medium to poor, which suggested that the trees must be in stress condition due to either disease infestation or poor physiology. *Butea monosperma* and *Dalbergia sissoo* also showed health status from medium to poor; their condition was the result of poor branch attachment, leaf diseases or cut stems and weak stem. These are mainly due to a certain amount of insect activity, disease, mortality, damages, and decay in normal and healthy forest system, leading to death of the individual and provide critical habitat for wildlife.

The second level of forest assessment with respect to biophysical and biochemical properties. These properties indicate resource quality and resource management information. The biophysical variables like leaf area index and biochemical content like chlorophyll affects forest function light interception and nutrition cycle (Bonan, 1993). They vary both spatially and temporally across forest areas and are difficult and expensive to measure. They are, however, the key spatial; variables required to drive forest ecosystem stimulation models at a range of spatial scales and so considerable effort has been expended in developing remote sensing techniques to map these variables over extensive forest areas (Running et al 1989, Song and woodcock,2002).

These parameters when derived conventionally and non-conventionally in this study exhibited a good correlation between the ground based and spatially derived variables. A seasonal variation observed in the chlorophyll content seems to be quite classical. Strong increase during the first phase of the growing season is followed by stability and a strong decrease in cut-back season. Sun leaves tend to always have larger chlorophyll concentration than shaded leaves. Indicating that the leaves position towards the sun have maximum chlorophyll content as oppose to those which are in shaded condition. Exception can occur in tree species where the influence of the growing season and environmental condition is more than the position of the sun. This can be seen in the present study, where the *Tectona grandis* and *Terminalia crenulata* had more chlorophyll content in the growing season. Leaf total chlorophyll content was more in Monsoon season as the conditions were favorable for the tree growth. Under stress-inducing conditions, reductions in total chlorophyll concentration (Chl; chlorophyll a + chlorophyll b), can occur . Stress decreased total chlorophyll content of the plant by increasing the activity of the chlorophyll degrading enzyme: cholorophyllase (Rao & Rao, 1981), inducing the destruction of the chloroplast structure and the instability of pigment protein complexes (Singh & Dubey, 1995).

The leaf area index also controls many biological and physiological properties in the plant. The leaf exposed to full sunlight may differ in growth from those growing in shade. Adaptation of plants can be associated with morphological, physiological and ultra-structural changes in leaves (Lichtenthaler 1985). Rao and Singh (1985) suggested that leaf structure undergoes ontogenic progression, which are at the same time sensitive to environmental changes, leading to large changes in leaf area. In the present study, reduction of leaf area was observed as the stress level increased during summer. Plant exposed to stress environment generally has the reduced leaf area. Leaf area may be reduced due to drought, through inhibiting leaf initiation (Kozlowski, 1982 and Ibrahim, 1995) or decreasing leaf size (Ibrahim et al., 1997, 1998) or accelerating leaf senescence and consequently leaf shedding (Begg, 1980) or more than one of them.

Non-conventional technique such as NDVI used to assess these parameters which have been worked by several workers. (Carlson and Ripley, 1997; Sembiring et al., 1998) Higher NDVI values indicated an increase in vegetation growth per unit area and vice versa. The positive values represent different types of vegetation classes, whereas near zero and negative values indicate non-vegetation classes, such as water, and barren land. Increasing positive NDVI values indicated increasing amounts of green vegetation. Thick and healthy vegetation has a low red-light reflectance and high near-infrared reflectance, and hence, high NDVI values. NDVI values near zero and decreasing negative values indicate non-vegetated features such as barren surfaces (rock and soil) and water. Basically, when the index is below 0, it is the detection of clouds when it is between 0 and 0.1 it represents rocks, senescent vegetation or soil; when it is between 0.1 and 0.4 it is indicative of sparse vegetation and when it is above 0.4 it implies the presence of high vegetation

Conventionally derived parameter such biophysical and biochemical parameters have proved to be useful in establishing the relationship between and non-conventionally derived biophysical parameter such as NDVI and NDMI. Basically forest parameter has no direct physical relationship with the remote sensed data signal, but they may be correlated through indirect relationships with LAI, biomass or canopy cover (Danson and Curran, 1993). For example, a large number of studies have found relationships between forest stand variables and a range of remote sensed data with mixed success. In the present study positive correlation has been derived between biophysical and biochemical parameters. In plants, there are mainly there are two main optical domains influencing the optical properties of vegetation, namely the visible region (400 to 700nm) which has a strong chlorophyll absorption and the near infrared region that has a strong reflectance (700 to 1000nm). The differential reflection of green vegetation in the visible and near infrared portions of the spectrum provides an innovative method for monitoring vegetation from space. However the NDVI is thought to be a suitable indicator of relative biomass and vegetation health (Boone et al. 2000).

The biomass that is the other important biophysical parameter. Optical remote sensing technologies, theoretically, have limited capability to predict forest biomass since the recorded spectral responses in the optical images are mainly related to the interaction between the sun radiance and forest stand canopies. Thus, the correlation between forest biomass and spectral responses or vegetation indices is usually poor, especially in the mature forests where spectral responses become saturated and lose sensitivity to trunk and branch biomass. However, the obtained correlation was found to be good for in the present study. The regression equation was used to generate biomass map. Changes in biomass can be easily interpreted from the generated map. It is seen that the areas where higher biomass values were present has increased in 2005, suggesting new plantation in that area. In the absence of encroachment and cutback, tree death, is the only way biomass can decrease in a plot and in such circumstances a negative rate cannot be used to assess changes in growth. (McMahon, 2010)

Limitations of optical data in biomass estimation can be overcome using attractive technology microwave remote sensing in frequent cloud cover. Previous workers have shown the ability of estimation of biomass using backscatter value.

The AGB estimation using C band data has achieved good results in vegetation covers with lower biomass. The main scattering component of the C band, are the leaves and small branches. For the present study the Microwave data such as the C-band of ENVISAT-ASAR and Radarsat-2 were utilized. This C band, which has an intermediate wavelength, shows greater penetration of the radiation into the canopy which enables further sources of scattering to be active and so there is some volumetric scattering. It can be said that in the present study canopy scattering and some volume scattering was present. As the typical sources of scattering at C band are secondary branches and leaves (Ranson and Sun 1994, Leckie and Ranson 1998), the penetration of crown thickness by the radiation is normally not exceeded (Le Toan et al. 1992). Recent studies indicate that the backscatter response to forest biomass depends on stand-to-stand differences in stand structure (tree height, diameter, and stocking density) and on species-related differences in growth form and branching pattern (Dobson et al., 1995; Imhoff, 1995). Lack of control over these variables is one cause of weak backscatter-biomass regressions and apparent “saturation” of the regression curves at low biomass levels. which can be seen in the present study area, where the backscattering occurs at a lower biomass value.

The important problem in using relationship between the backscatter in different polarization and biomass is the saturation level of different wavelengths and polarizations. The biomass map generated from Envisat ASAR data using the Multiple linear regression model also showed saturation at high biomass level. The saturation levels depend on the wavelengths (i.e. different bands, such as C, L, P), polarization (such as HV and VV), and the characteristics of vegetation stand structure and ground conditions.

Along with biomass other biophysical parameter is the relative water content which is a useful indicator of the state of water balance of a plant, essentially because it expresses the absolute amount of water, which the plant requires to reach artificial full saturation (González and González-Vilar, 2001). Unlike the vegetation stress indices, RWC does take into consideration the quantity of water in the plant. However, two different species may have the same RWC as is seen in *Tectona*, *Dalbergia* and *Butea*. The rate of RWC in plants with high resistance against water stress is higher than others. In other words, a plant having higher yields under stress should have high RWC. Under the water deficit, the cell membrane is subjected to changes such as an increase in penetrability and decrease in sustainability (Blokhina et al., 2003). Blackman et al., 1995 in his microscopic investigations of dehydrated cells revealed damages, including cleavage in the membrane and sedimentation of cytoplasm content. Water deficit can destroy the chlorophyll and prevent making it (Montagu and Woo, 1999; Nilsen and Orcutt, 1996). Mensah et al. 2006 found that subjecting Sesame plants to drought stress caused leaf chlorophyll was increased and then remained unchanged. The maximum reduction of 20% in RWC can be seen during stress condition *i.e*. in non-healthy trees of *Butea monosperma*, in the monsoon season. Overall, from the results of this study, it can be concluded that water stress (excess water and water deficit) significantly decreases leaf chlorophyll concentrations.

Correlation of RWC parameter with non-conventionally derived NDMI showed that retrieval of such parameter from satellite data can prove beneficial in deriving the plant moisture. NDMI contrasts the near-infrared (NIR) band 4, which is sensitive to the reflectance of leaf chlorophyll content to the mid-infrared (SWIR) band 5, which is sensitive to the absorbance of leaf moisture. Vegetation Moisture is related to forest health as seen in some areas of Dediapada Taluka. The lower level of moisture content as seen in the present study indicates trees under stress condition

Several remote sensing measures of vegetation moisture based on water absorption have been proposed, including indices based on near infrared (NIR) absorption (Gao, 1996) and shortwave infrared (SWIR) absorption (Hardisky et al., 1983; Ceccato et al., 2002). Sims and Gamon (2003) compared the abilities of water indices based on NIR and SWIR wavelengths to estimate the vegetation water content of common vegetation species in Southern California. They found an index based on a 1200 nm water absorption feature which was the best predictor of canopy water content and was less sensitive to atmospheric water vapor absorption. In the term NDMI the word “moisture” is conventional and is retained for lack of a better term (Cohen et al. 1995, Wilson and Sader 2002). A universally accepted term seems to be lacking because the biophysical interpretation of the indices that use the Middle infra-red (MIR) bands is more problematic than those that use near-infrared (NIR) and red bands. The MIR wavelengths are highly absorbed by leaf and soil water (Hunt and Rock 1989). Hunt et al. (1987) found that the reflectance of TM band 5 (SWIR) for dry leaves was almost equal to reflectance of TM band 4 (NIR), suggesting the difference between TM band 4 and 5 should equal the water absorbance for a fresh leaf. The lower level of moisture content as seen in the present study in the vegetation indicates trees under stress condition which is related to the relative water content. The stressed plants showed low RWC and NDMI were also low. Similarly healthy tree species showed good RWC and with high NDMI.

This relationship will help in Identifying healthy tree species from the NDMI map in homogenous pixel.

The biochemical and biophysical parameter proved to be useful in determining the tree health status. In addition to this disturbance and degradation should also be monitored which can be done through forest cover mapping.

This mapping can be achieved by optical and microwave data. Optical data of 1997 and 2005 showed serve reduction. Open forest also reduced during this period. Such studies have been carried out by several workers (Woodwell et al., 1987; Green and Sussman, 1990; Houghton et al., 2000, Rede, 2009). Depletion of forest cover in this area is mainly due to agriculture pratices. The adoption of improved varieties and the development in irrigation led to the encroachment of agriculture in the forest ecosystem. Increase of other classes are mainly due to the development of Narmada dam

To overcome some of the difficulties of optical sensors, SAR sensors are also used in mapping forest of this area.

The increase utility of this sensor is recommended by the studies that reported to well suited to forest cover, particularly, through the acquisition of multitemporal data sets (Suzuki and Shimada, 1992; de Groof et al., 1992; Kuntz and Siegert, 1999; Quegan et al., 2000; Rosenqvist et al., 2000; Balzter et al., 2002; Sgrenzaroli et al., 2002). The present dataset was acquired for June 2011 Radarsat-2. The supervised classification of microwave radarsat-2 data gave distinct separation of the class, river, dense forest, and the open forest. Due to different scattering mechanism of the trees in the forest and Radarsat-2 being C-band data, thereforesurface scattering can be seen. This is the reason why there is distinct classes of forest seen.

Forest mapping using Entropy and Alpha

This result is in agreement with previous research, which has suggested the use of, longer wavelength for forest applications. Using dual polarization data, Saatchi et al. 1997 showed that L-band HH and HV data were capable of separating three major forest cover classes in a Brazilian site. It has been seen from the result that decreasing Entropy is related to higher degradation level. Intact forest class has a high value of Entropy, indicating the dominance of a volume scattering mechanism. This characteristic has been observed in woody vegetation and details of the reports can be found elsewhere. On the other hand, highly degraded forests are shown to have very low Entropy. This indicates that a single deterministic scattering process dominates. This can be confirmed using classified satellite image showing that the area was dominated by dead stands without leaves or branches; therefore, a random scattering mechanism due to canopy structure was less visible. The forest floor in these regions was moist due to rainfall at this season, hence even-bounce scattering of ground-trunk interaction was responsible for this phenomenon.

The Alpha angle was found useful for explaining the scattering types. Although unclear, the Alpha angle could be valuable for distinguishing healthy and degraded forest covers. Intact forests, which have thick vegetation layers with well-developed structures, clearly fit into the dipole region (around 50°), whereas the degraded forest remained at 40°.

As opposed to using remotely sensed data from a single satellite sensor the synergy sensed data has shown to provide improve delineation of forest areas. Synergy proved to allow for the exploitation inclusion of forest and non forest collected by different sensors wherein attractive approach to combine optical and microwave data. The performance of, Modified IHS (MIHS), Ehler and Brovey techniques in different data combinations was analyzed statistically, visually and graphically. In the present work the classification of Dediapada was increased by applying a different fusion technique. Brovey was found to best technique in the present area in all the dataset (i.e. ETM^{+} {MSS & PAN}., Envisat-asar & LISS-III and Radarsat-2 with LISS-III) .The best was seen using the full Polarimetric data of Radarsat-2. MIHS technique has become a standard procedure in image analysis and is useful in color enhancement of highly correlated data. Finally, Brovey transformation was developed to visually increase the contrast on the data as well as for better representation of RGB images with a high degree of contrast. For the present area visually the color was enhanced in both these techniques where different classes were separated. Only in Ehler's technique degraded forest was separated from the dense forest and identification of these areas is distinct.

15.0. Conclusion

In the present work different aspects of forest have been highlighted, Forest studies require inventories which is labor intensive. They require advanced technologies to reduce cost time and to produce information at different levels as per requirement of forest planner and manager. This information includes different structural properties, estimates of existence and growth, diagnosis of the health status of forest and land use and the changes in forested areas. It also requires information regarding the diversity of the forest ecosystem. Hence, these areas have become a priority for forest research.

Several measures of species diversity have been recommended to assess biodiversity. Such evaluation of diversity is an enormous task, and any methods that can be adopted to reduce the amount of time spent collecting this data are therefore of interest. Remote sensing represents such method, which has been utilized in the studies of forest diversity assessment of Dediapada Taluka.

Further, a successful attempt was made to generate a detail information about tree structural parameters and their relationship with each other. This helps in generating the regression model, which can be used for further predication. In order to aid foresters, in action recovery program of forest, detail tree damage assessment was carried out which gave an idea of the health of five dominant tree species *Tectona grandis, Butea monosperma, Dalbergia sissoo, Terminalia crenulata, Madhuca indica*. The understanding of phenological changes in recent year of climate change gave a brief idea about the shift in phenological patterns in relation to the abiotic factor, temperature, and rainfall.

This study also demonstrated the utility of both optical and microwave remote sensing data in generating a huge amount of forest information related to biomass, forest condition, phenology along with the precise information on tree structural parameters. The use of polarimetric Radarsat -2 and ENVISAT-ASAR data are more practical for forest monitoring due to their mapping results specifically due to its all time weather acquisition capability, but fusion techniques seem to be better. The fusion Techniques such as Brovey, MIHS, and Ehler's have also proved their potential in forest classification accuracy.

Polarimetric decomposition can be used to study and interpret fully polarimetric data for forest applications. It is shown that the Cloude-Pottier decomposition offers a meaningful way to describe characteristics of land cover classes. In the case of forest degradation, the Entropy parameter was influential for discriminating different levels of forest disturbance. Healthy forests have high value of Entropy, indicating a strong contribution of a volume scattering mechanism. As the degree of disturbance increases, the Entropy declines. It shows a decrease of depolarizing agents (vegetation canopy) and increasing single scattering mechanism (in this case, double bounce process). The effect of stronger penetration of C-band on a canopy was indicated in understanding the health status of forest.

To be precise the study has brought out the utility of both optical and microwave remote sensing data in understanding the forest parameter of Dediapada Taluka.

Remote sensing data can effectively provide a synoptic view over the large areas and greatly increase efficiency and usefulness of limited conventional methods. So it can be used as a tool in AGB (aboveground biomass) estimation. Therefore, remote sensing based AGB estimation has increasingly attracted scientific interest. Biomass estimation using optical remote sensing data is usually realized by revealing the correlation between biomass and spectral responses and vegetation indices derived from multispectral images. Biomass map using ENVISAT-ASAR data was generated utilizing Multiple linear regression model.

The ENVISAT-ASAR and the Radarsat-2 data were used to derive backscatter information, which was used to determine for further characteristic of forest. The C-band showed the surface characteristic of forest. Phenology of tree species was also correlated with the backscatter. Microwave signatures of various forests show the influence of these parameters on radar signal strength. Estimation of these parameters requires a detailed knowledge of the ground survey along with microwave data. The vegetation index retrieved which is an indicator of forest health showed slight decrease in forest health; the vegetation water Index also supports this. The Vegetation indices were also correlated with different biochemical and biophysical parameters which helped us in knowing the health status of forest. It was seen that the trees in the protected areas were in much better condition than those that were presented in non-protected areas.

Optical remote sensing data and microwave remote sensing data are complementary to each other. The classification results indicated that the possibility of extracting more and accurate information from fused images and it proves to be of great benefit to forest management. It helps to reduce the effect of cloud cover and supply more information about multi-storied forest canopy and can therefore directly contribute to sustainable forest management. Hence, the fusion of these data would help in improving the classification accuracy.

Summary

Forest covers approximately a third of the planet's land area, and range from undisturbed primary forests to forests managed and used for a variety of purposes. Forests provide a number of goods and services, which are essential for civilizations and crucial for economic development. They offer access to water, agricultural productivity, energy, soil conservation, and flood control. Forests are also home to at least 80 per cent of terrestrial biodiversity, and are a major carbon sink for regulating global climate. These resources have a history of being exploited either adequately or abusively. Today efforts are made towards their use, and their value is periodically realized at both global and country levels. Applications related to the monitoring of forest management requires updated and accurate inventories summarizing knowledge of landuse changes related to forest, including the rates and patterns of deforestation and afforestation. This information must be more precise and detail at both regional and local scale for its utility and planning. Remote sensing can play a crucial role in providing information across these scales. It allows for the frequent measurement and monitoring of the world's forests on a continuous basis. Passive optical RS applications for forestry inventories are based on the sensitivity of optical radiation to the chlorophyllian content of the stands. However, several factors can interfere such as the optical properties of the soil background, illumination and viewing geometries and many on. Microwave signals, in contrast to optical wavelengths, are unaffected by atmospheric conditions, including clouds, because the wavelength of the radiation is several orders of magnitude larger than the atmospheric particles There has been growing interest in the capabilities of microwave remote sensing, particularly in the form of SAR instruments, for the estimation of forest biophysical

parameters. Microwave systems provide information on woody biomass and forest structure.

Keeping this in mind the present work was carried out using both optical and microwave remote sensing data. The highlights of the entire work are as follows:

- Species Diversity was estimated and different diversity indices were calculated. GIS Interpolation technique gave a good result in estimating the Shannon diversity index with an accuracy of 60%.
- Tree phenology was assessed using ground survey and correlation of tree phenology with backscatter was carried out. When phenology was analyzed for the past 16 years, shifts in the phenological events were observed for the most of the species. The phenophase exhibited variation with climatic variables, such as temperature. With the increase in temperature, flowering, fruiting and leaf flush in tree species also increased.
- DBH was estimated for different forest area of Dediapada Taluka. Out of five different species assessed for its DBH, it was seen that *Terminalia crenulata* had largest girth among the five species. The Total tree Height (TH) in fourteen different villages of Dediapada ranged from 4.65 m to 33m.
- The crown cover spread in fourteen different villages evaluated ranged from 0.03 m to 8.03 m. *Butea monosperma* had the maximum crown cover in the Dediapada Taluka
- Regression equation developed between DBH, tree height and crown cover revealed a close relationship amongst them. Thus, indirectly such parameters can be ascertained without removing or destructing the trees. It is a simple and practical method and easy to apply. The formulae are valid for the entity they represent and applicable to the areas under study. Therefore, it is worthwhile to develop equations on local or regional levels.

- In stressed tree species of Dediapada taluka, both biochemical and biophysical parameter i.e. chlorophyll and relative water content respectively, were found to be decreased. In case of *Dalbergia sisoo,* water content was found to be high during the stress condition.
- Vegetation indices i.e. NDVI and NDMI were analyzed for the Dediapada Taluka, The NDVI reflects the vegetation health status, a decreased in this index was observed in the present study for the year 1990-2005. Similarly, moisture content obtained from the NDMI was found to be decreased. Indicating the health status of tree species was decreased in the present study area.
- Biomass map from optical data was generated using regression equation developed from ground survey. Multi-temporal microwave data were found to be useful in analyzing biomass with backscatter value. The Multiple regression equation developed using the ENVISAT-ASAR data and ground survey data helped in preparing the biomass map.
- Different classification techniques were used. Optical data gave a good accuracy in forest classification, whereas microwave data highlighted the degraded forest areas more accurately.
- In the present study different fusion techniques such as the modified IHS, Ehler and the Brovey fusion technique were applied using microwave and optical data. The Brovey technique is found to be the best in forest classification with a good accuracy.

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