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)

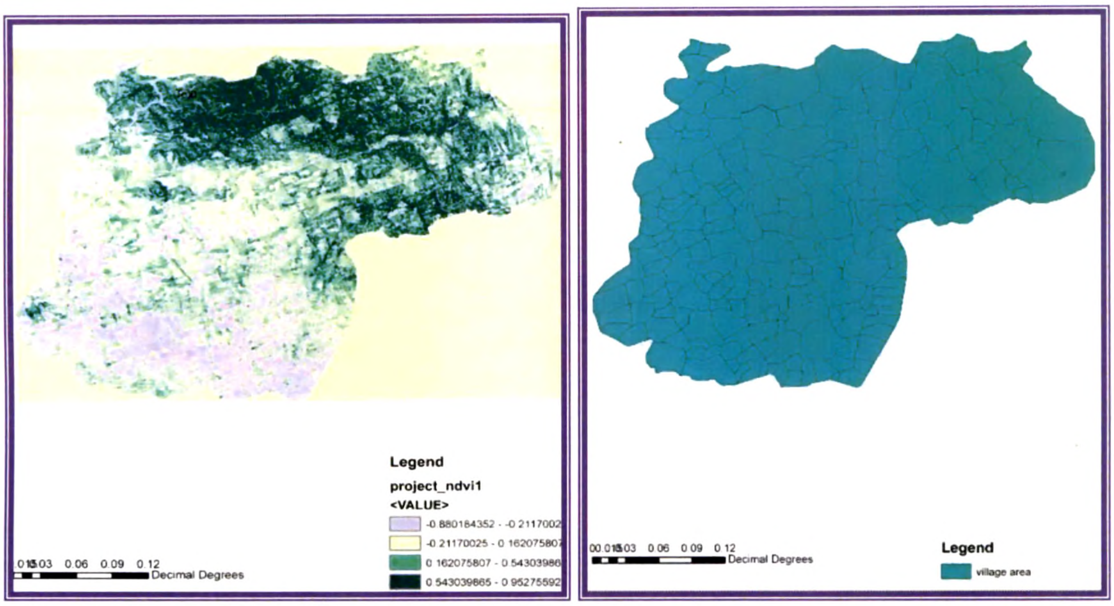
Table 3 A comparative evaluation of different diversity indices

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

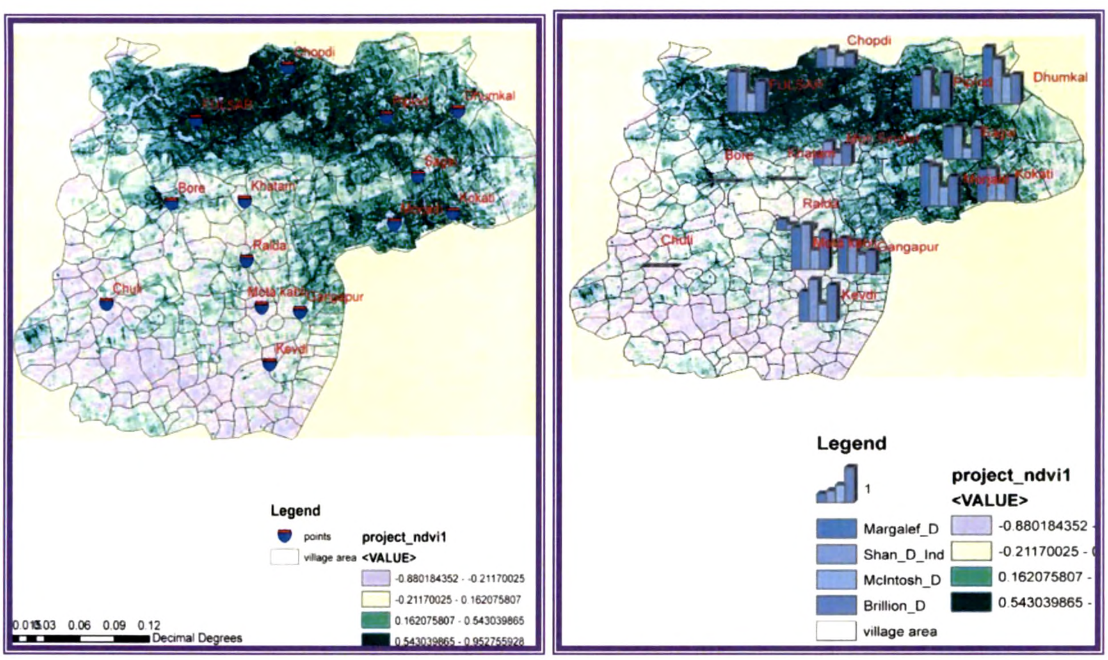
10.3. Non-conventional method:

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

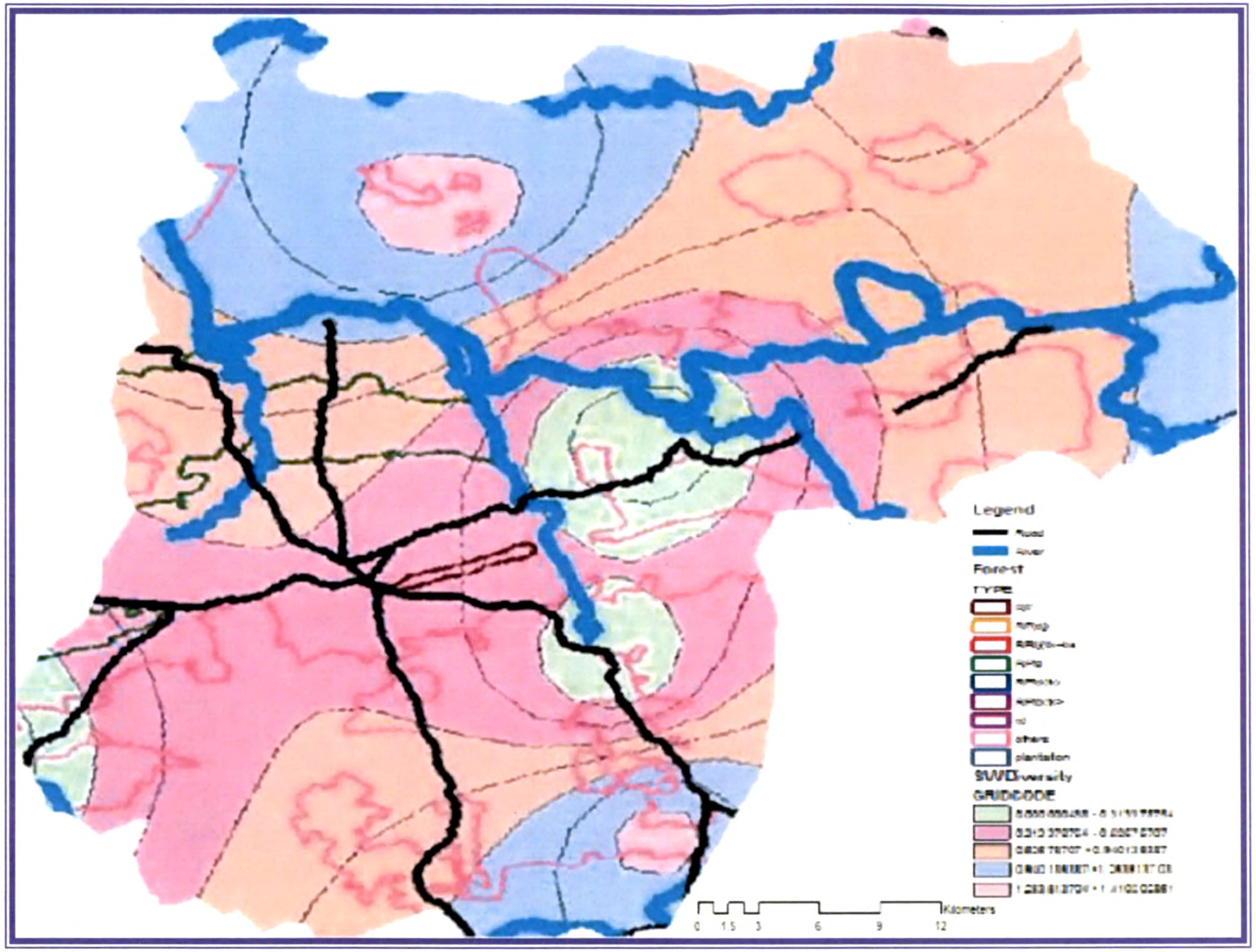


Plate 10 Showing the different Forest Type along with Shannon diversity Map

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.

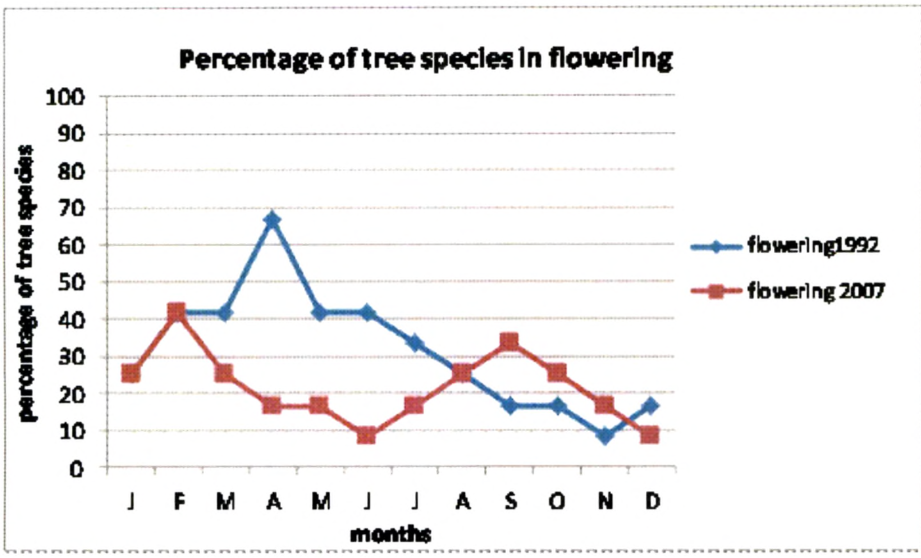


Figure 3Percentage of tree species in flowering

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)

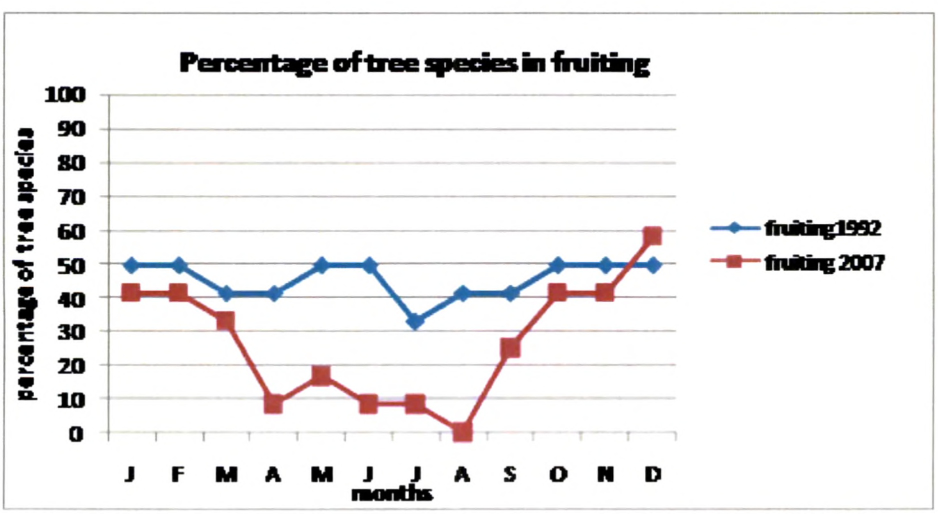


Figure 4 Percentage of tree species in fruiting

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)

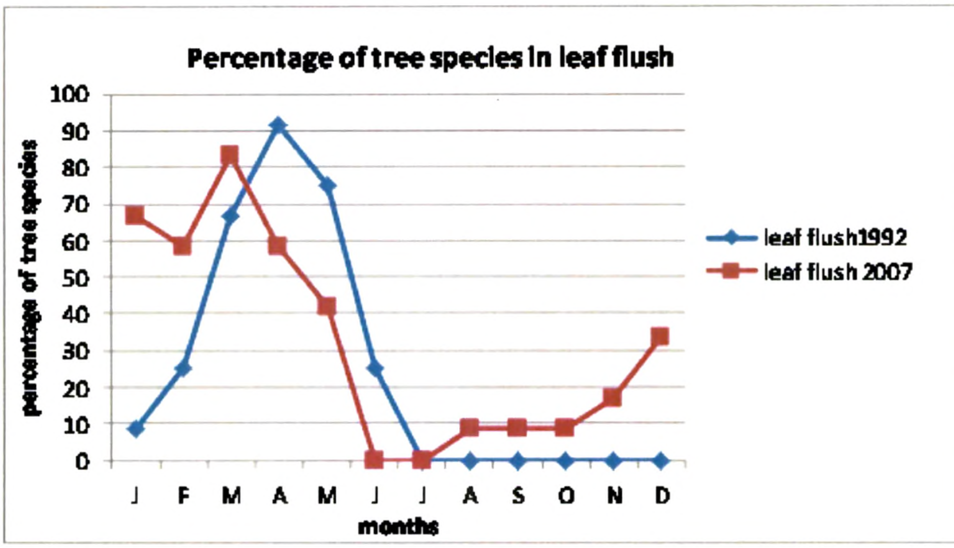


Figure 5 Percentage of tree species in leaf flush

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)

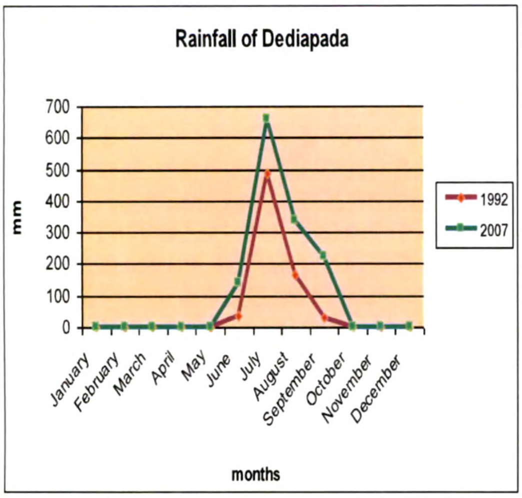


Figure 6 Rainfall-Dediapada (1992 & 2007)

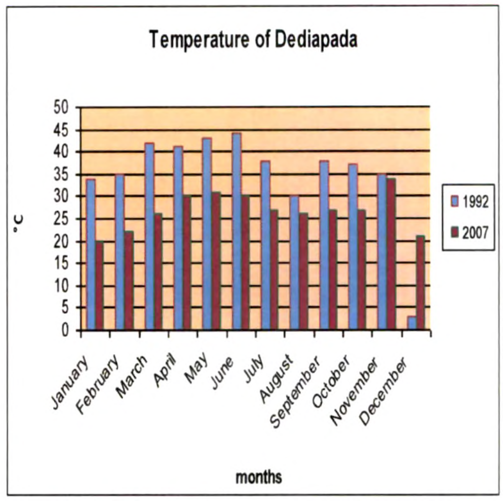


Figure 7 Temperature-Dediapada (1992 & 2007)

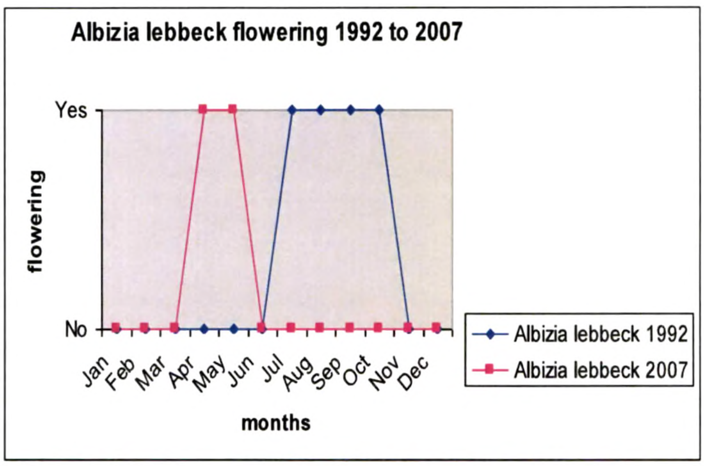
The shifting in phenological events (i.e. Flowering, fruiting, and leaf flush) leading to shortening of one phenological event led to the prolongation of another event. This irregularity in different stages of phenology can be attributed to the erratic fluctuation in rainfall and temperature. Temperature 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.

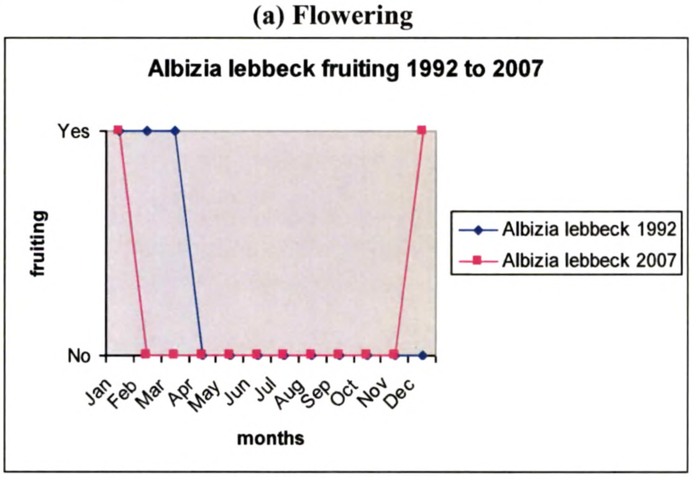
In case of *Albizzia lebbeck,* (figure 8) the changes in different phenophase i.e. flowering, fruiting and leaf flush was notable. The flowering and fruiting phase which were long phase in 1992 shortened in 2007, they also got preponed.

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.

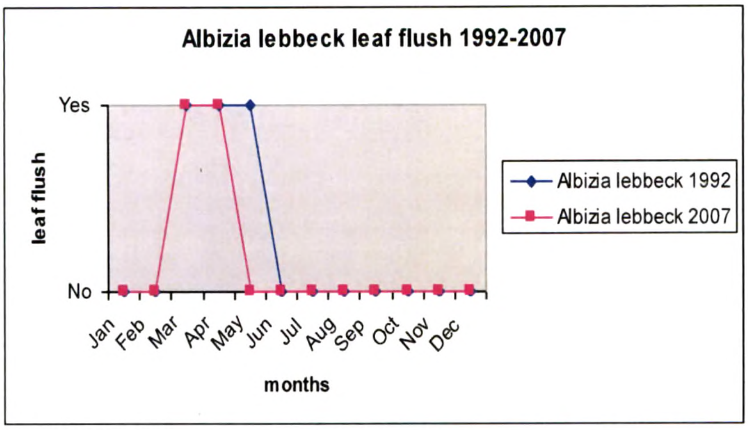
Similar cases were seen in Europe, since the early 1960s where the average growing season has lengthened by 10.8 days. In western Canada, *Populus tremuloides* showed a 26-day shift to earlier blooming over the last century (Beaubien and Freeland, 2000).



(a) Flowering

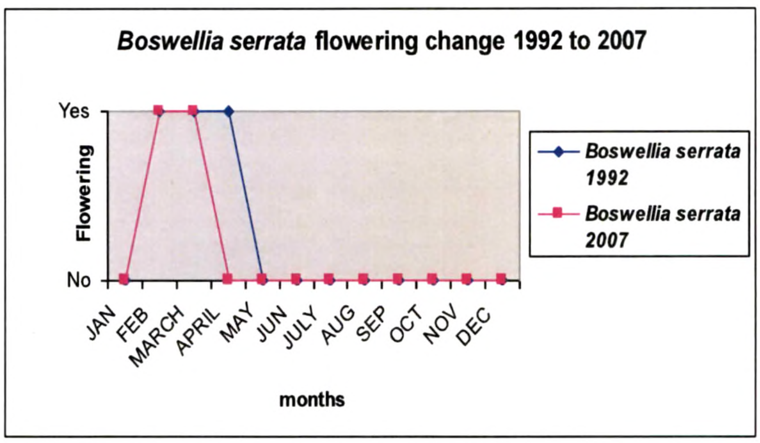


(b) Fruiting

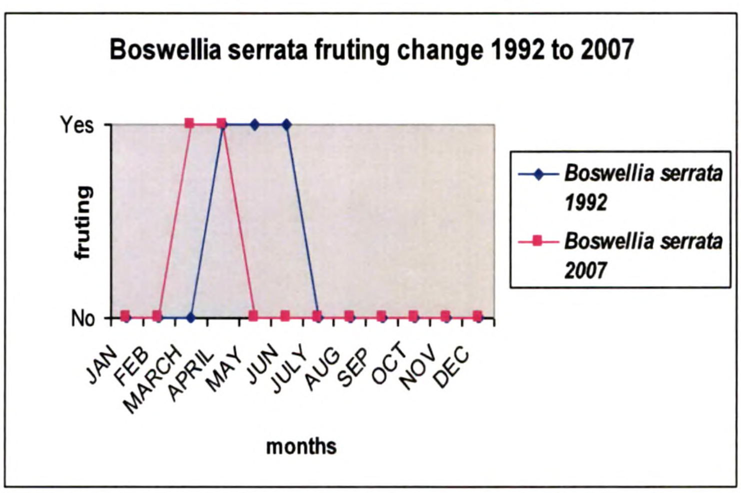


(c) Leaf flush

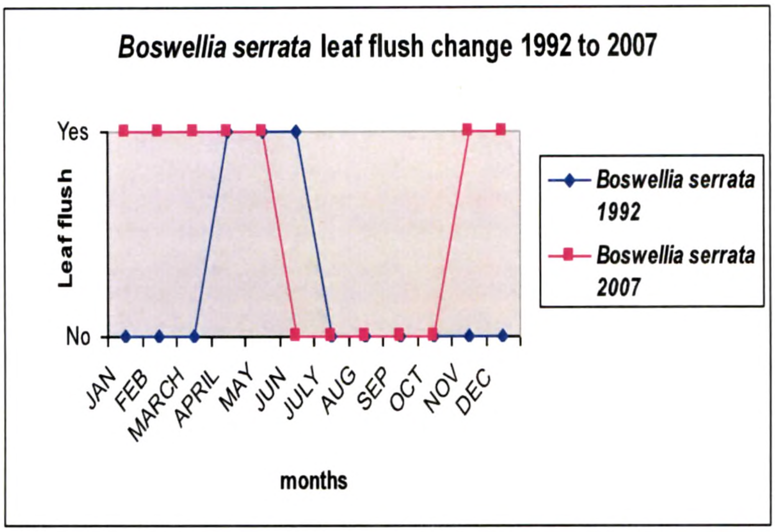
Figure 8 - Phenology of Albizia lebbeck during 1992-2007



(a) Flowering

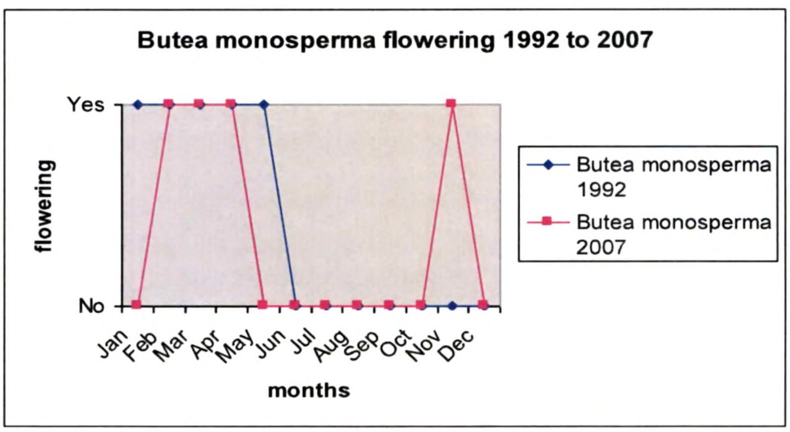


(b) Fruiting

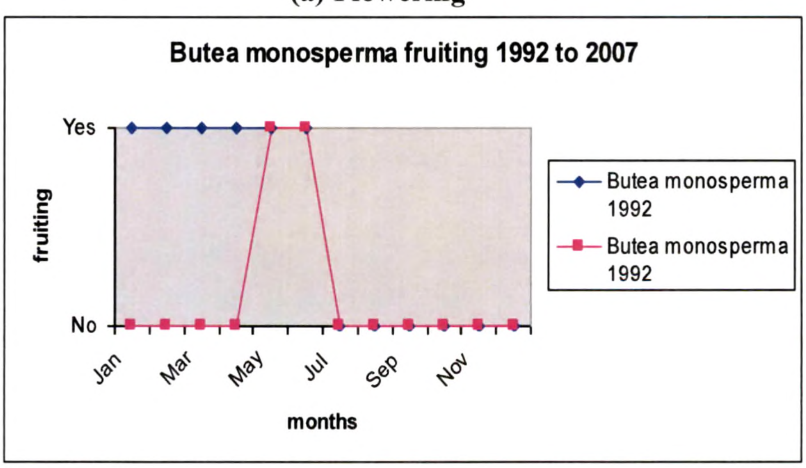


(c) Leaf flush

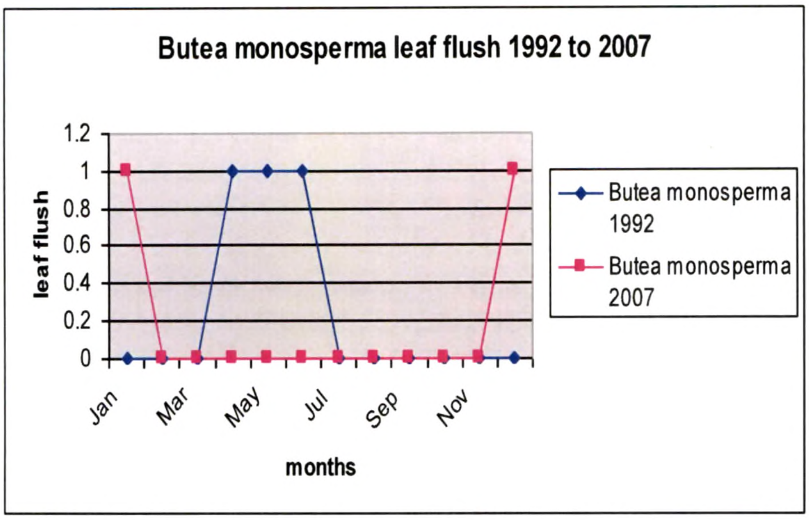
Figure 9- Phenology of Boswellia serrata during 1992-2007



(a) Flowering

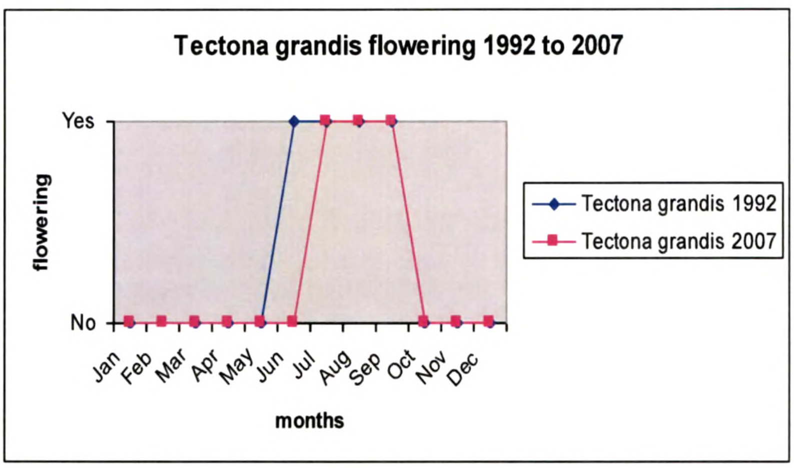


(b) Fruiting

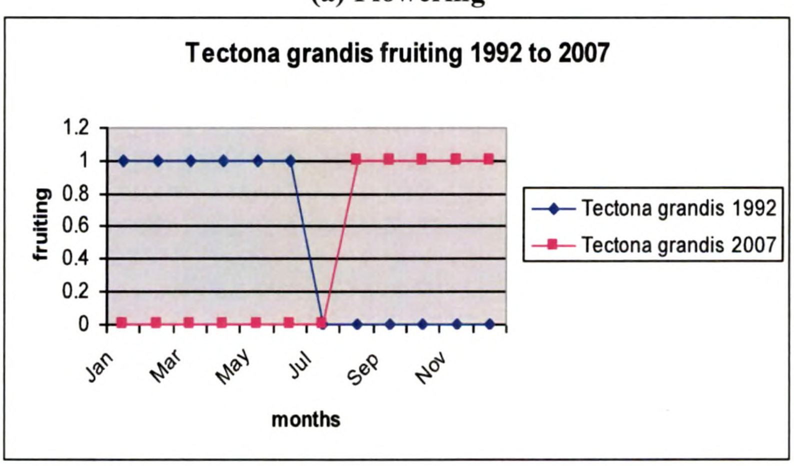


(c) Leaf flush

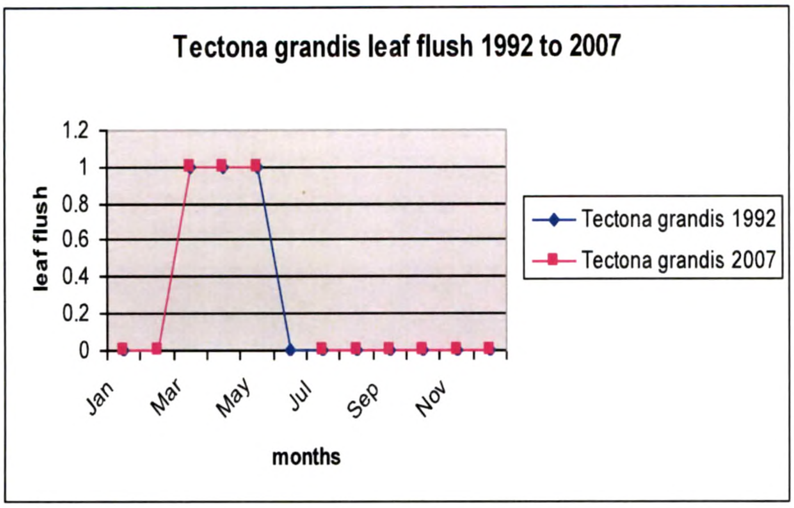
Figure 10: Phenology of Butea monosperma during 1992-2007



(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

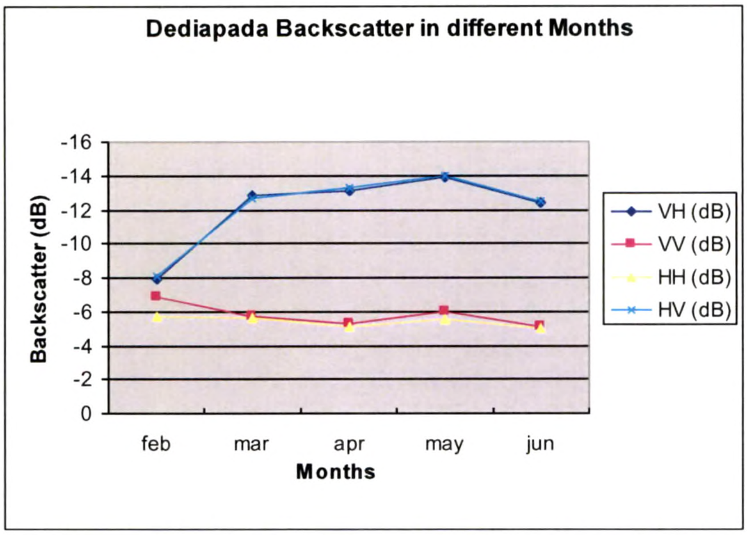


Figure 12 Dediapada Backscatter in Different Months

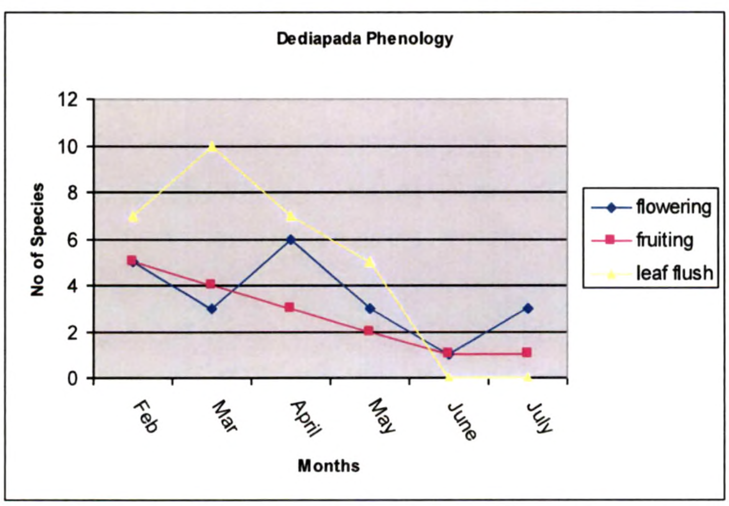


figure 13 Dediapada Phenology in Different Months

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

Locatio	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
Dhumk	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 k	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
Morjad	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.

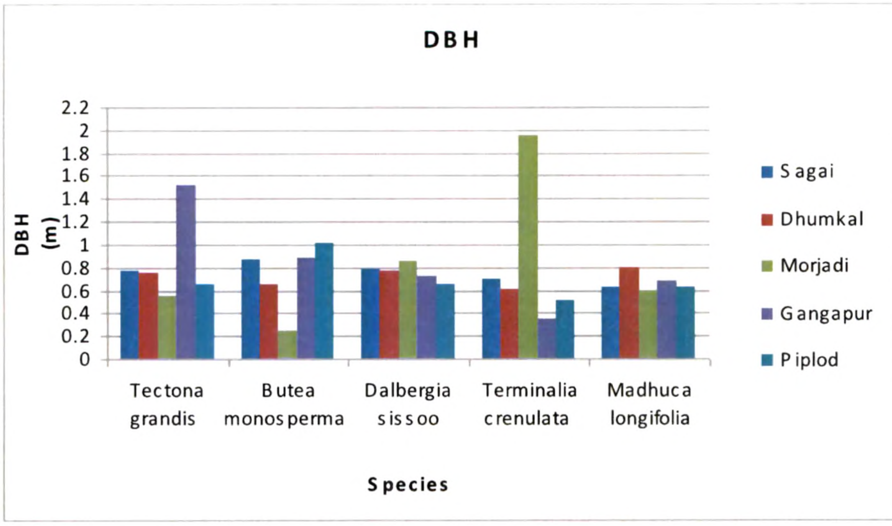


Figure 14 -DBH across different villages of Dediapada

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*.

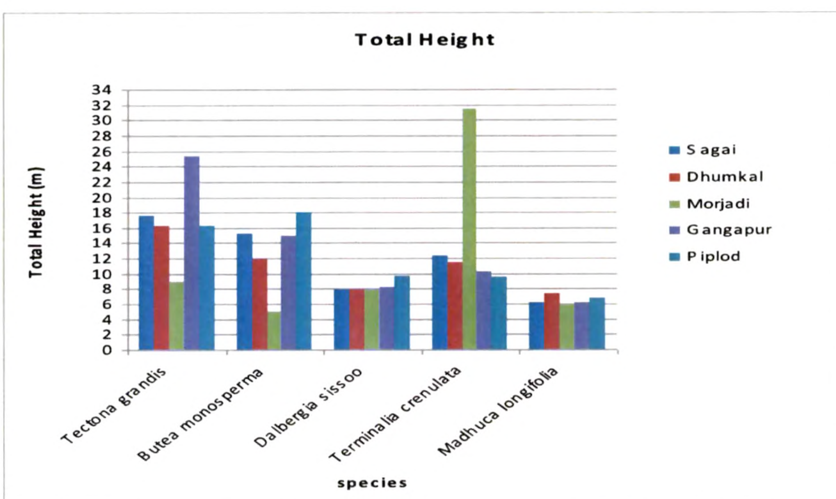


Figure 15 Total Height across different villages of Dediapada

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).

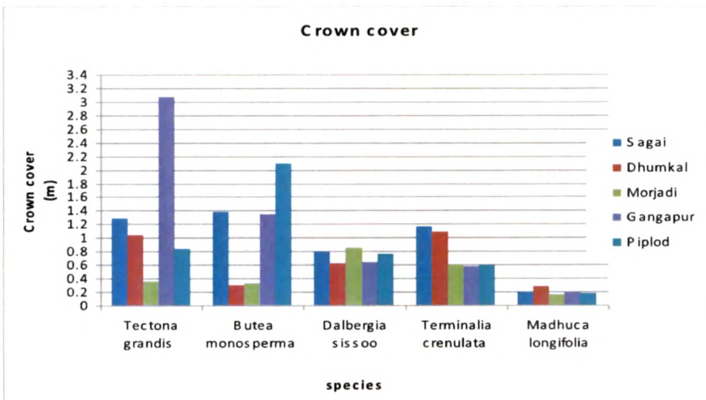


Figure 16 Crown cover across different villages of Dediapada

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.

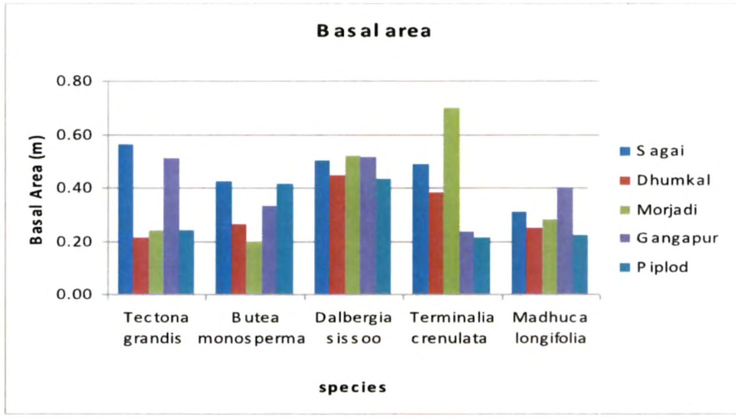


Figure 17 Basal Area across different villages of Dediapada

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.

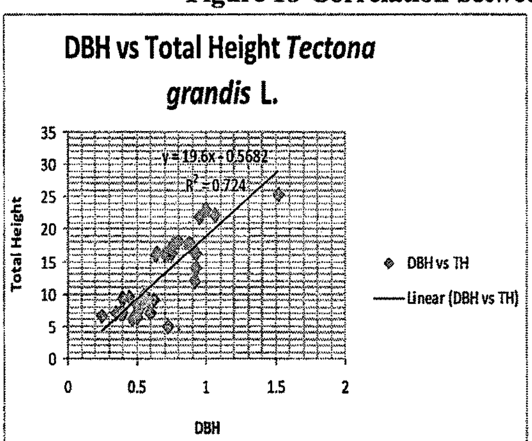
Table 6 Sample Means for DBH, Tree Height and Crown cover (S.E in Parentheses)

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)**

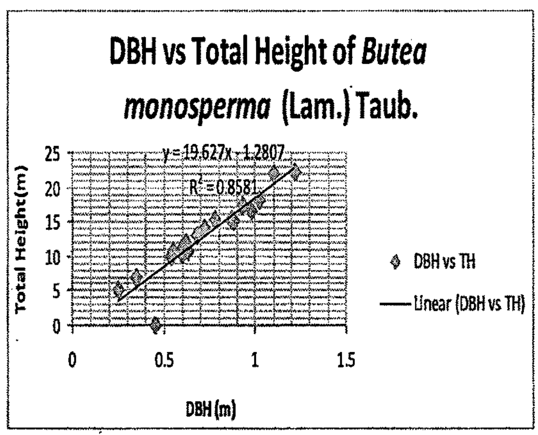
D.B.H = diameter ate breast height, S.E. = Standard error

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 differěnt 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.

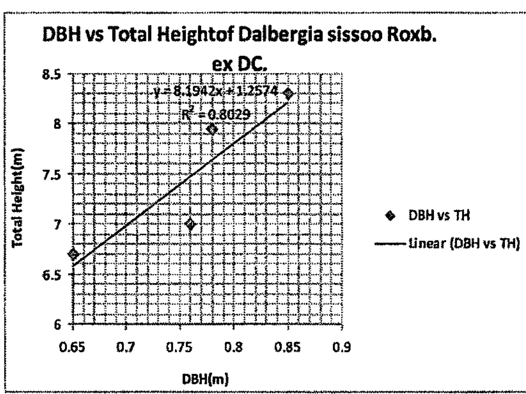
Figure 18-Correlation between DBH and Total Tree Height



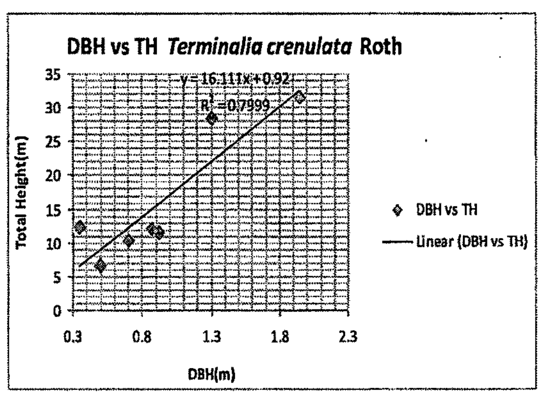
(a) **DBH vs. TH of *Tectona grandis* L.**



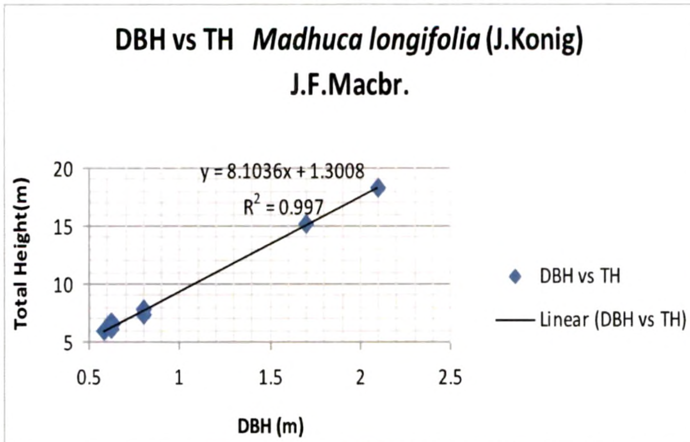
(b) **DBH vs. TH of *Butea monosperma* (Lam.) Taub.**



(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.*

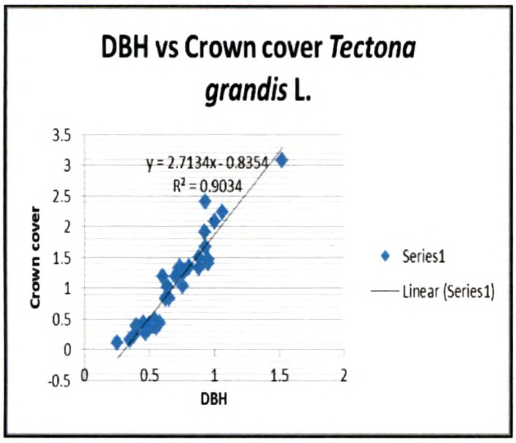
The prediction of DBH in *Madhuca indica* (figure 18) was found to be the best which is expressed by the linear regression equation with R^2= 0.99. In almost all the five species (figures 3) the correlation between the DBH and Total Height was found to be very high.

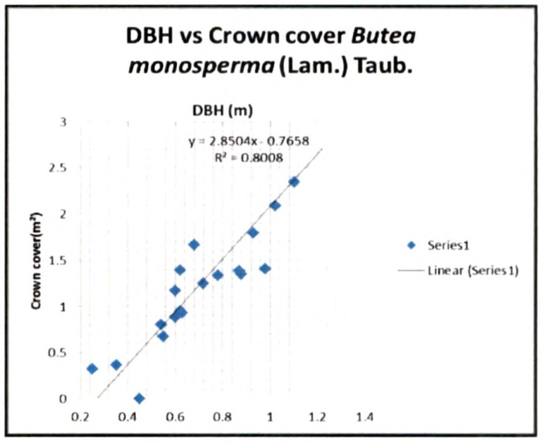
10.9. Correlation between DBH and Crown cover:

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.

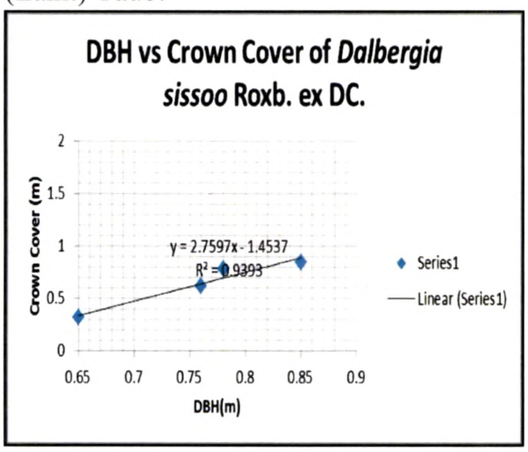
In case of *Dalbergia sisoo* (figure-19c) the linear regression (Table-7) was found to be highly correlated with R^2= 0.93. The other four species (Figure-19) also showed a linear regression with R^2>0.5. The coefficients of determination (R^2) for these graphs were all above 0.5, meaning that they are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

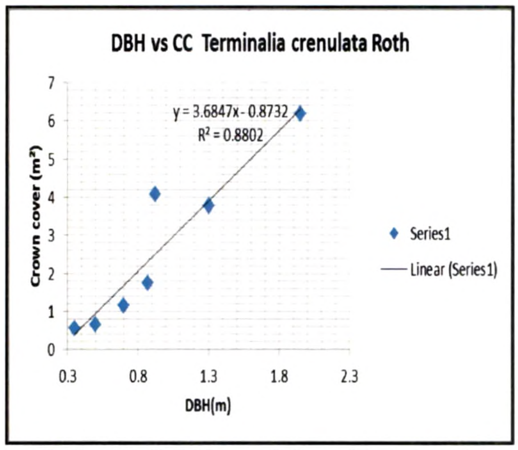
Figure 19 - Correlation between DBH and Crown cover



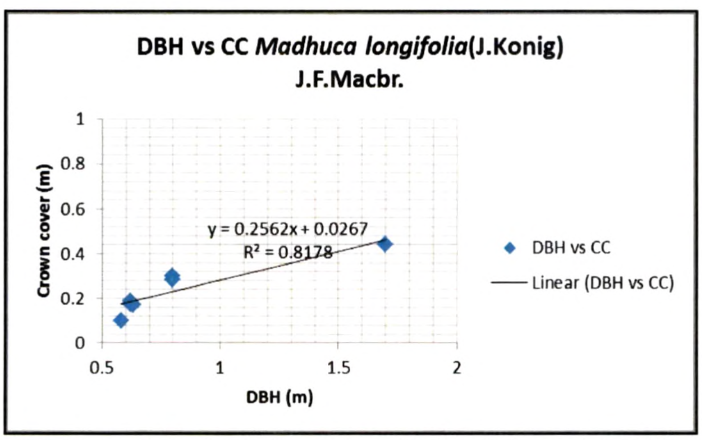


(a) DBH vs. CC of *Tectona grandis* L. (b) DBH vs. CC of *Butea monosperma* (Lam.) Taub.





(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*

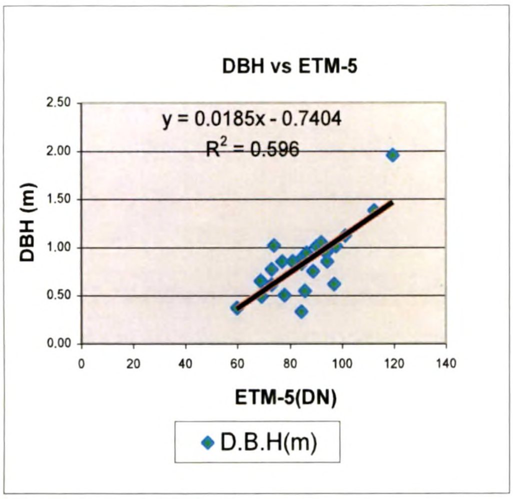
Table 7-Correlation and the Regression analysis between DBH, Total Tree Height and Crown Cover

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

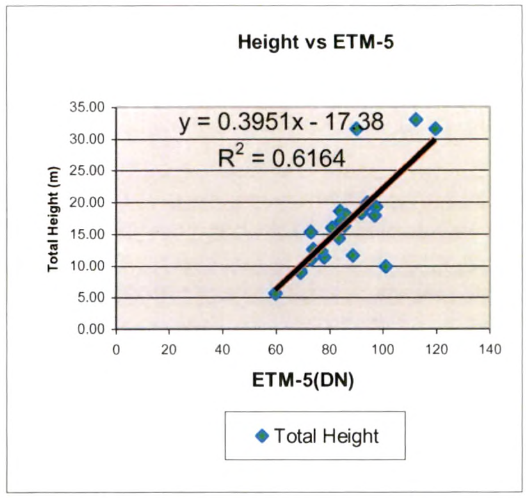
Estimation of different forest structural parameters such as DBH, height, and crown cover in a large area using remotely sensed data has considerable significance for sustainable management and utilization of natural resources.

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.

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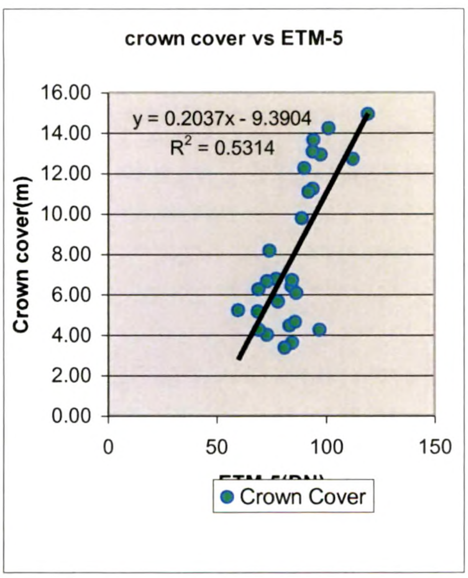
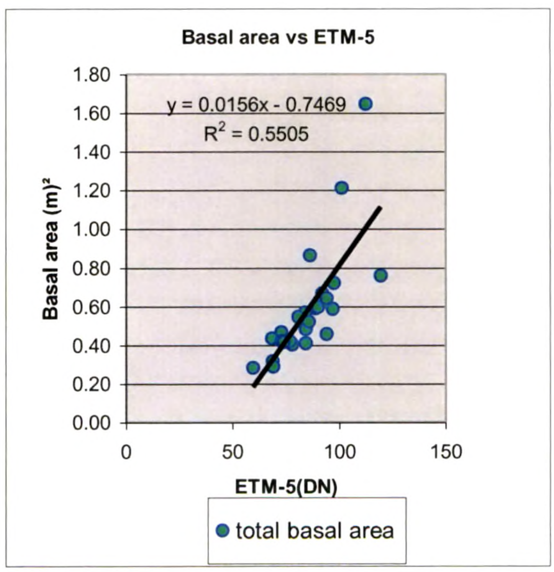


(c) Crown cover



(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:

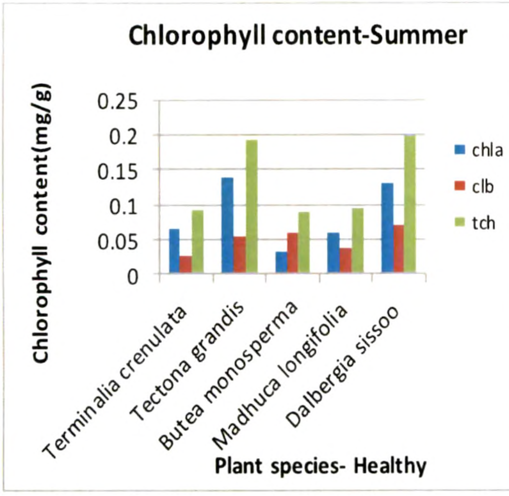
The biochemical parameter estimated through conventional method and biophysical parameters derived from the conventional and non-conventional techniques gave the idea of the health status of the Dediapada forest.

11.1. Conventional technique:

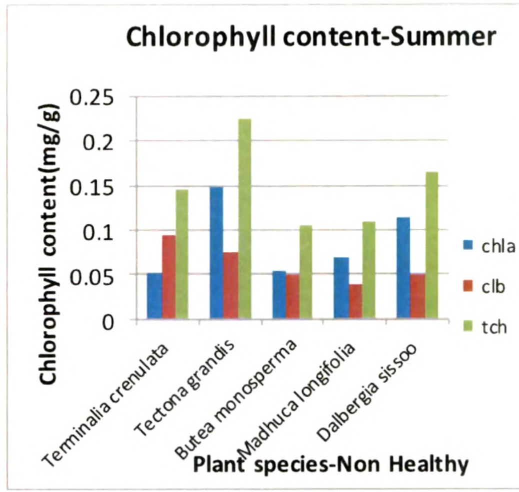
11.1.1. Chlorophyll content:

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).

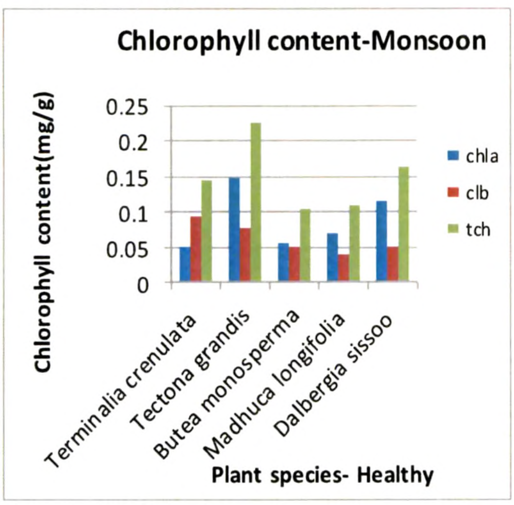
Figure 21 -Chlorophyll content in five different species in various seasons



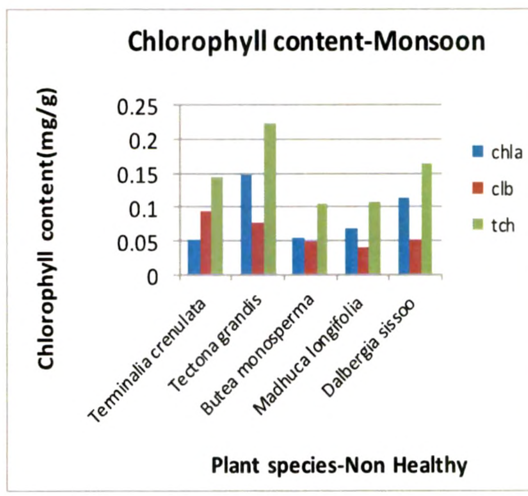
(a) Summer-Healthy



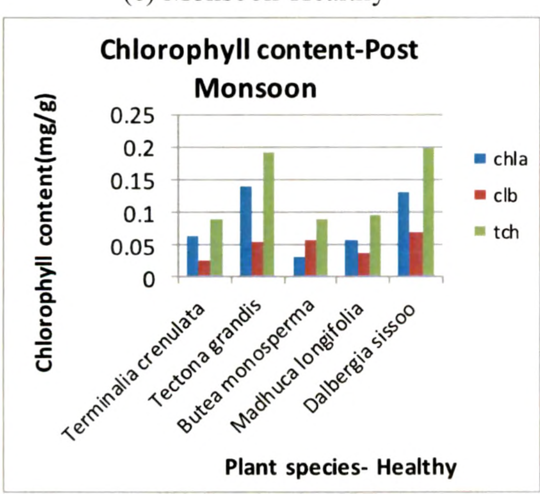
(b) Summer-Non-Healthy



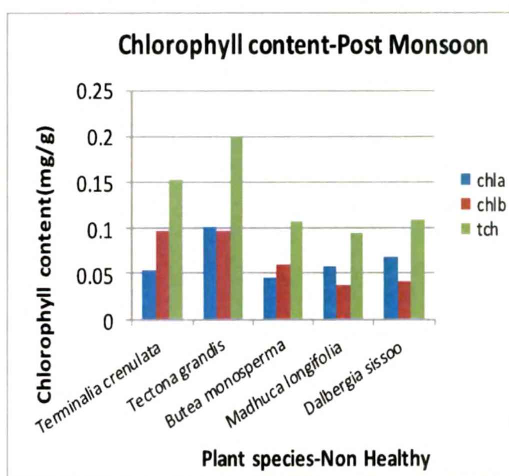
(c) Monsoon-Healthy



(d) Monsoon-Non-Healthy



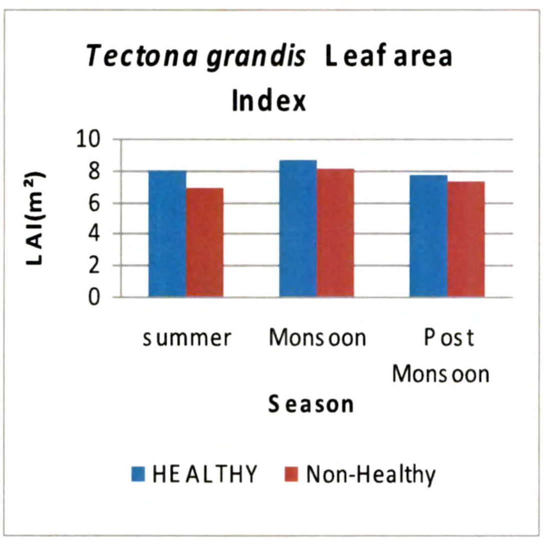
(e) Post Monsoon -Healthy



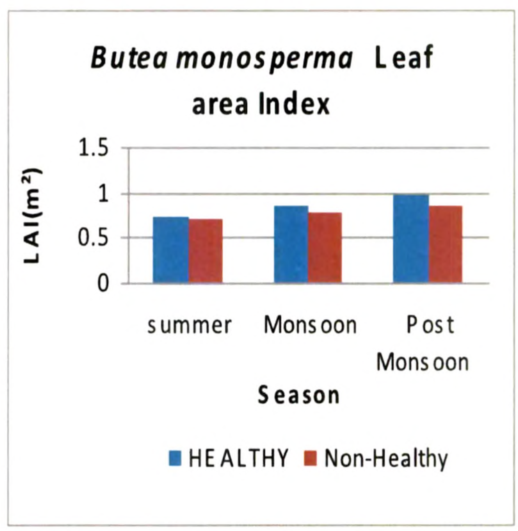
(f) Post Monsoon-Non-Healthy

11.1.2. Leaf area Index:

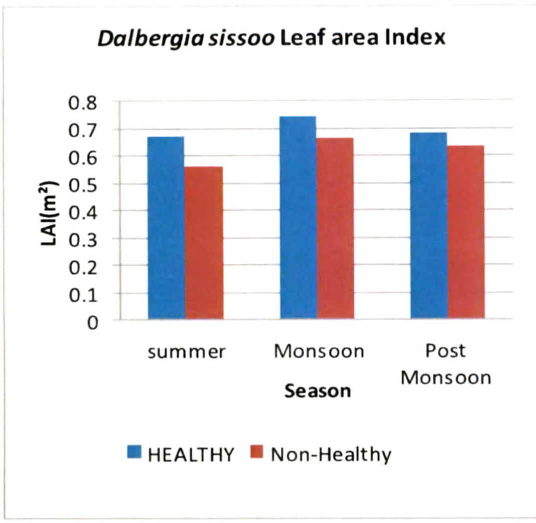
Different species when analyzed for their Leaf area Index in their healthy and non-healthy state exhibited seasonal fluctuation *Figure 22 (a-f)*. LAI in *Terminalia crenulata* varied in both healthy and non-healthy condition during different seasons. Maximum LAI expanded to 8.6 m^2 in healthy trees 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.



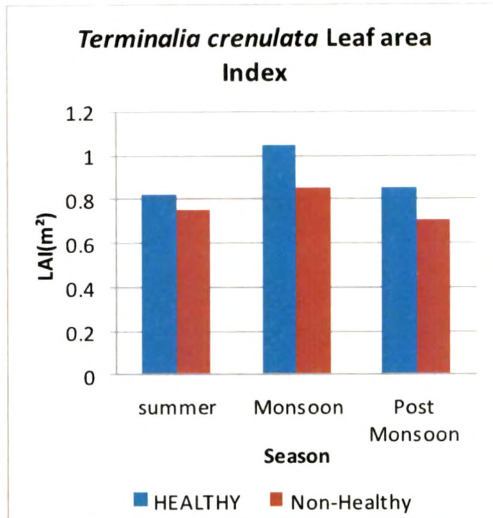
(a) Leaf area Index of *Tectona grandis*



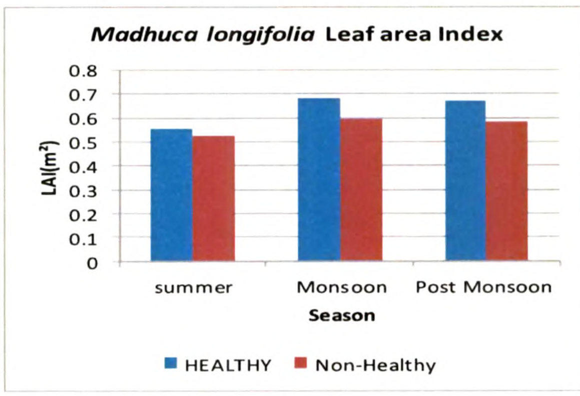
(b) Leaf area Index of *Butea monosperma*



c) Leaf area Index of *Dalbergia sissoo*



d) Leaf area Index of *Terminalia crenulata*



e) Leaf area Index of *Madhuca longifolia*

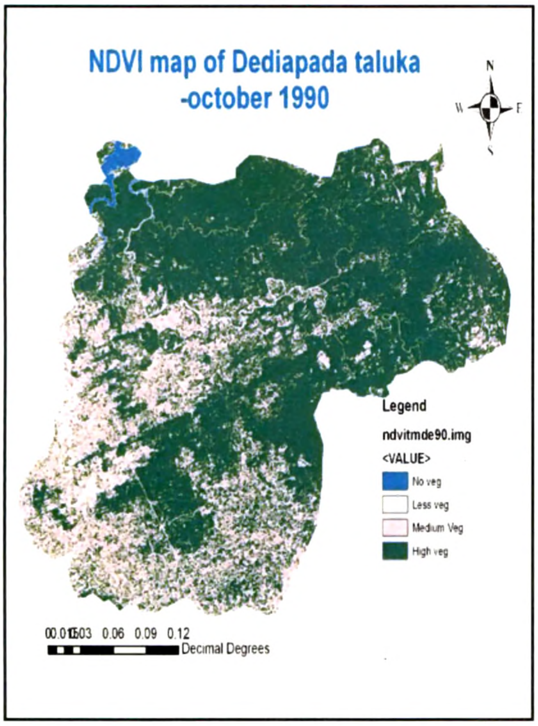
Figure 22 LAI in five different species in various seasons

11.2. Non-Conventional Technique

11.2.1. Normalized Difference Vegetation Index:

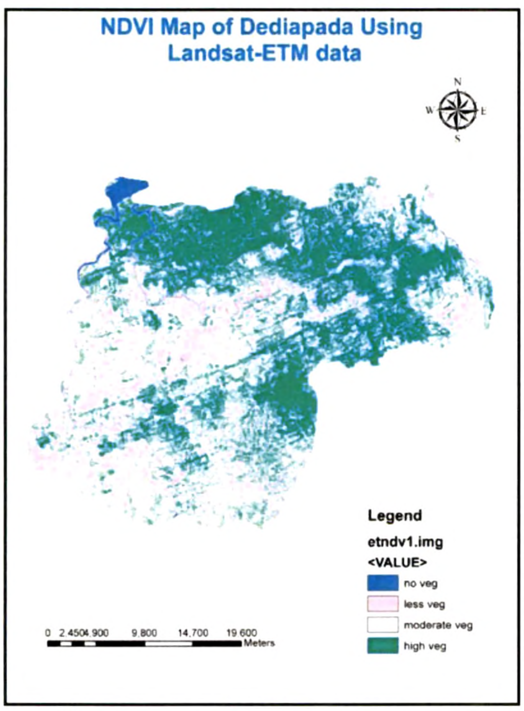
Satellite derived NDVI was used to measure and monitor plant growth, vegetation cover, and health status. Index values can range from -1.0 to 1.0, but vegetation values typically ranged between 0.1 and 0.7. Higher index values are associated with higher levels of healthy vegetation cover, whereas clouds 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

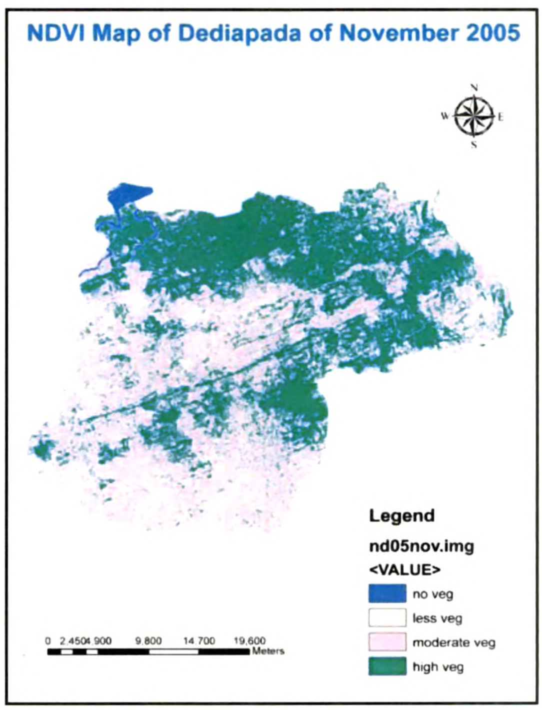


a) Landsat TM-1990

b) LISS-III-1997



c) Landsat ETM-2001



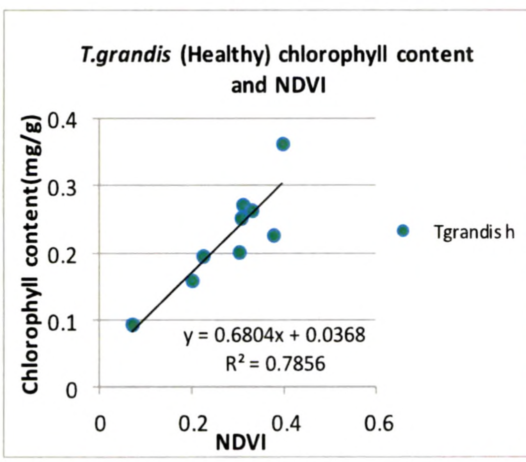
d) LISS-III-2005

11.3. Correlation of Biochemical and Biophysical parameter with NDVI:

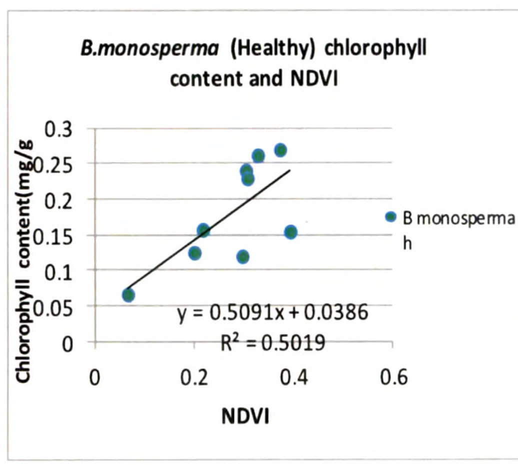
An attempt was made to correlate the conventionally derived biochemical and biophysical parameters with the non conventional satellite based parameter i.e. NDVI. This attempt was possible for only two species i.e. *T.grandis and B.monosperma* as they were present in the pure homogenous patch of forest 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*

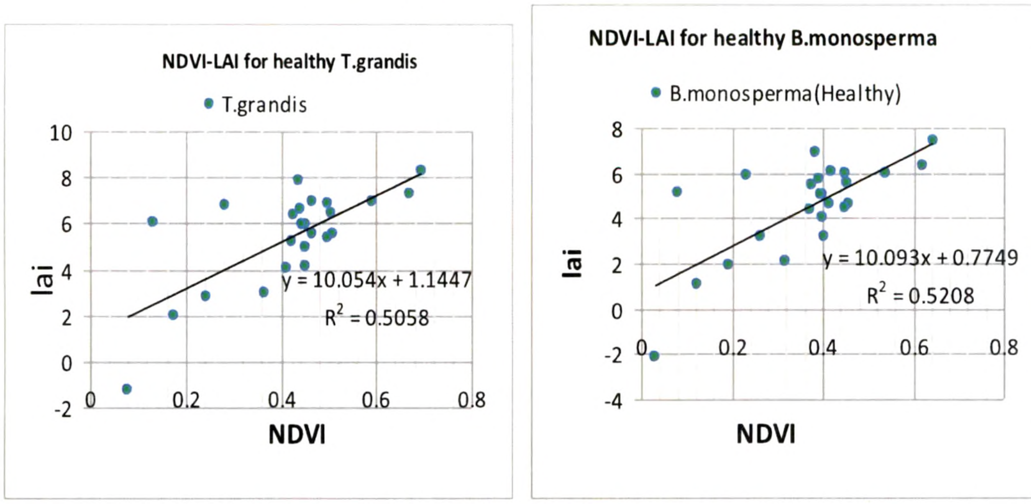


(b)- *B.monosperma Healthy*

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



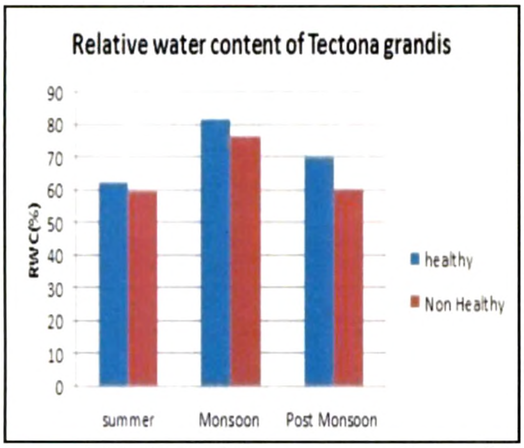
(a)- *Tectona grandis Healthy* (b) *B.monosperma Healthy*

11.4. Relative Leaf Water content

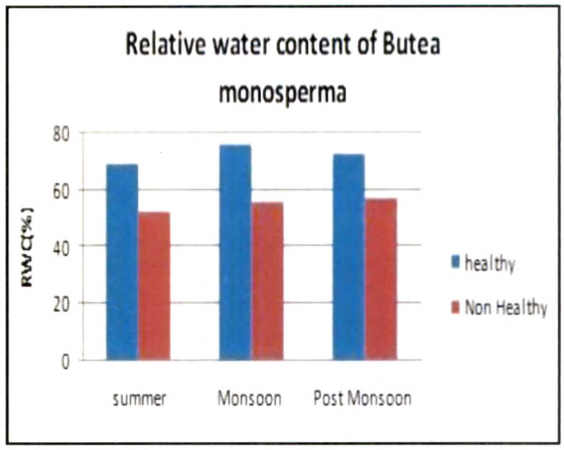
11.4.1. Conventional technique:

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).

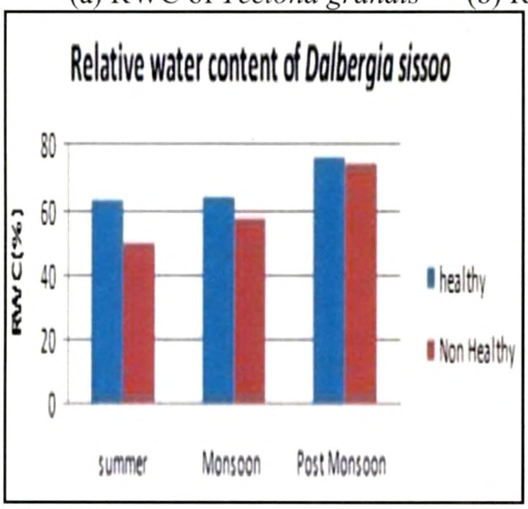
Figure 25 Relative Water content in five different species



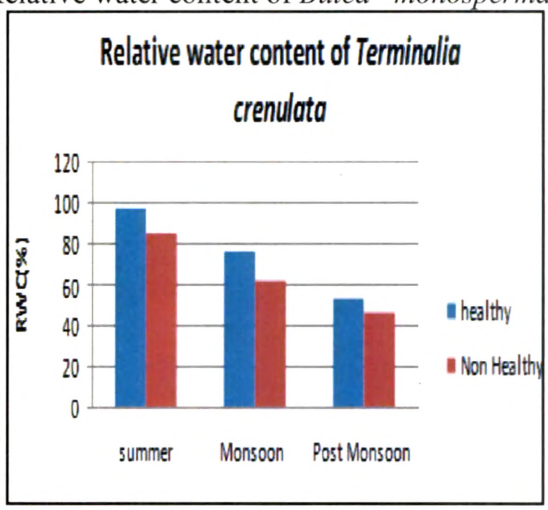
(a) RWC of *Tectona grandis*



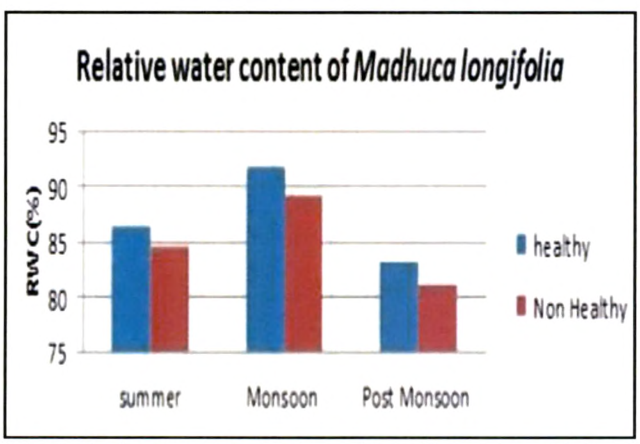
(b) Relative water content of *Butea monosperma*



(c) Relative water content of *Dalbergia sissoo*



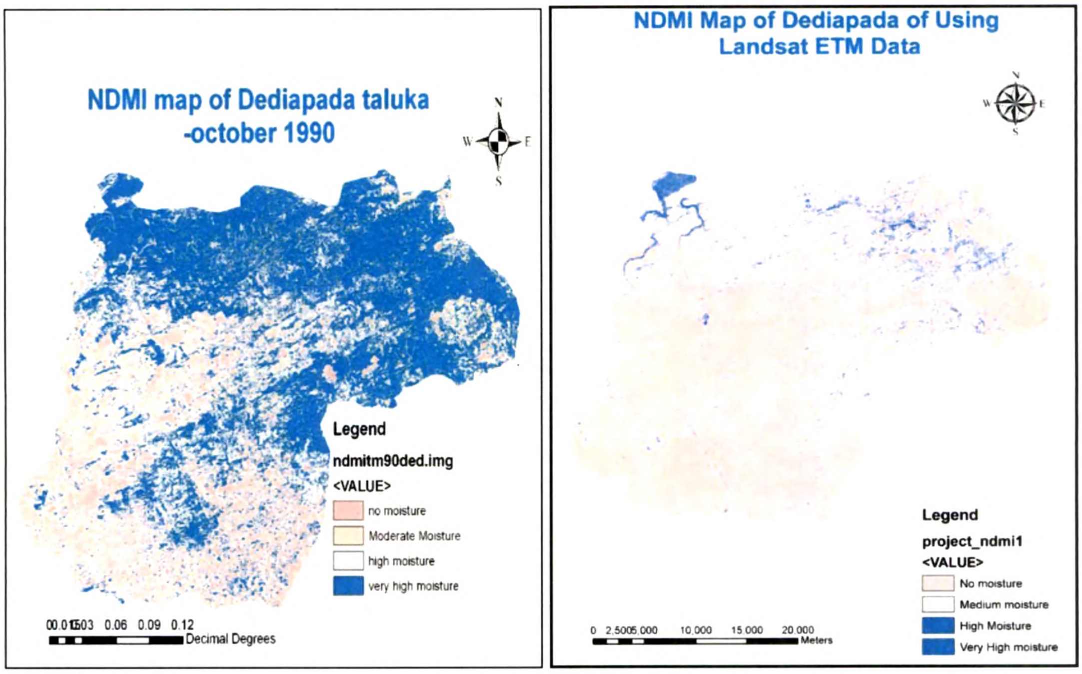
(d) Relative water content of *Terminalia crenulata*



(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)



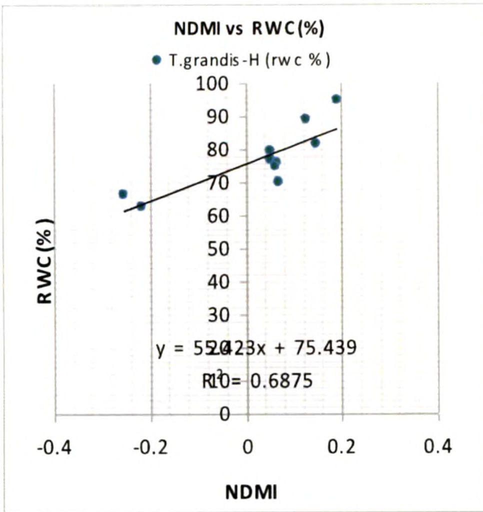
a) Landsat TM-1990 b) Landsat ETM^{+}-2001

Plate 13 Estimation of NDMI from satellite data

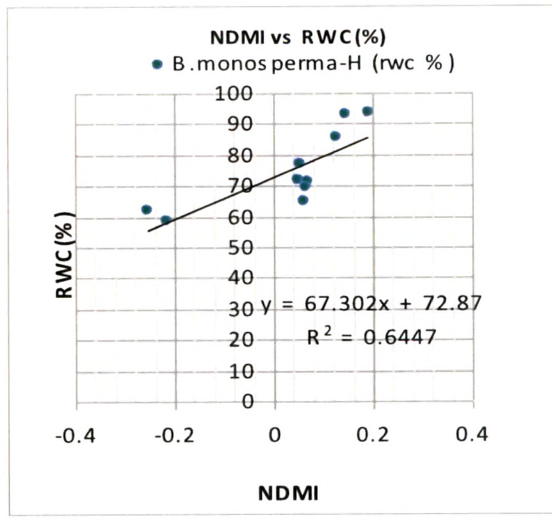
T.grandis and *B.monosperma* are the dominant and important tree species found in Dediapada forest. These two species had a purely homogenous patch in the forest area, so there was ease in analyzing RWC with the NDMI

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.

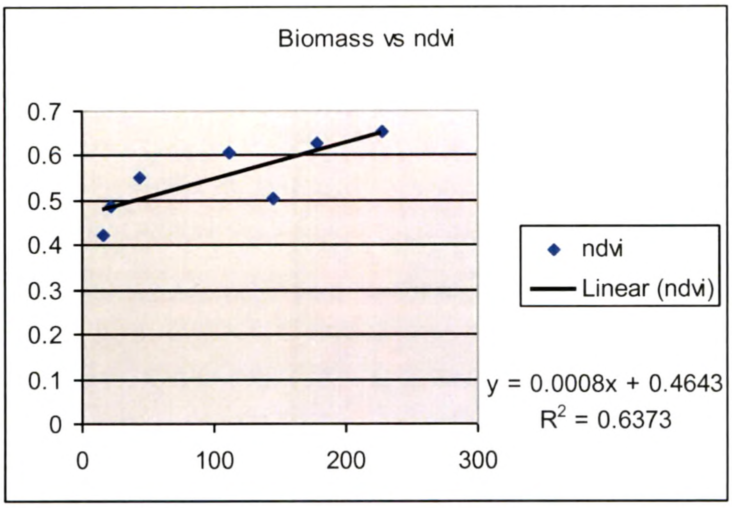
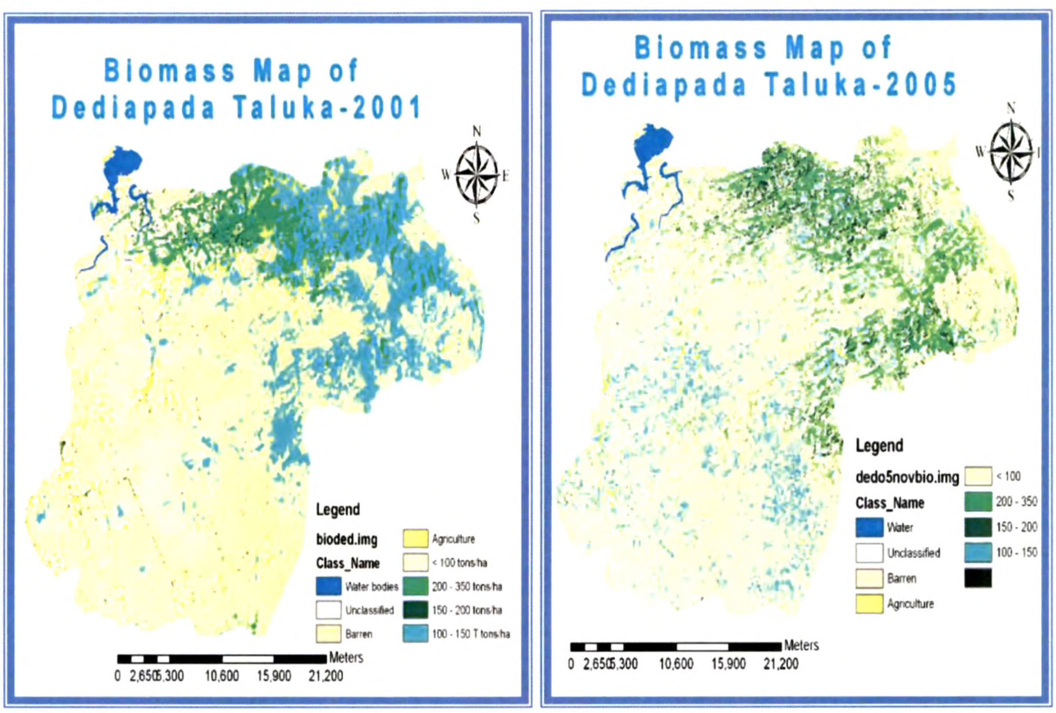


Figure 27 Biomass correlation with NDVI



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

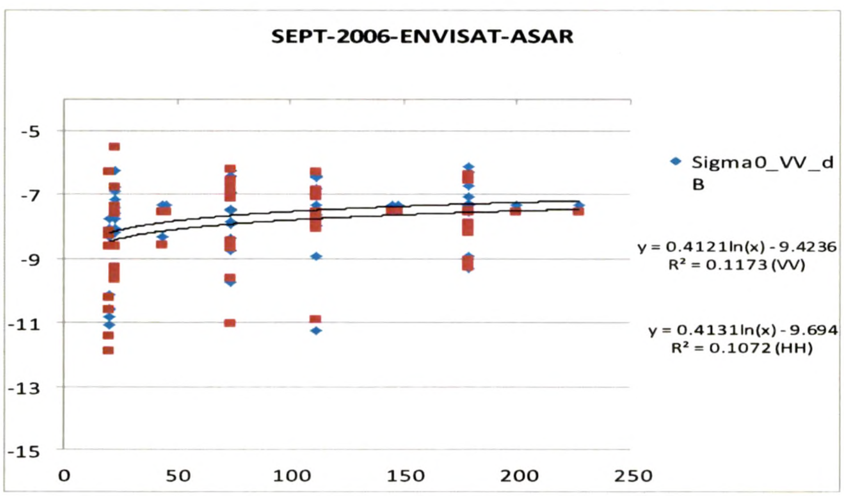
In case of ENVISAT-ASAR, in low biomass (0-50 t/h) the backscatter ranged between -11.0 to -6.2 dB in VV polarization, for HH polarization it ranged between -12.8 to -5.5 dB (fig-28). The backscatter value (for 50-150 t/ha) ranged between -11.2 dB to 6.2 and -11.0 to 6.19 dB for VV and HH polarization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

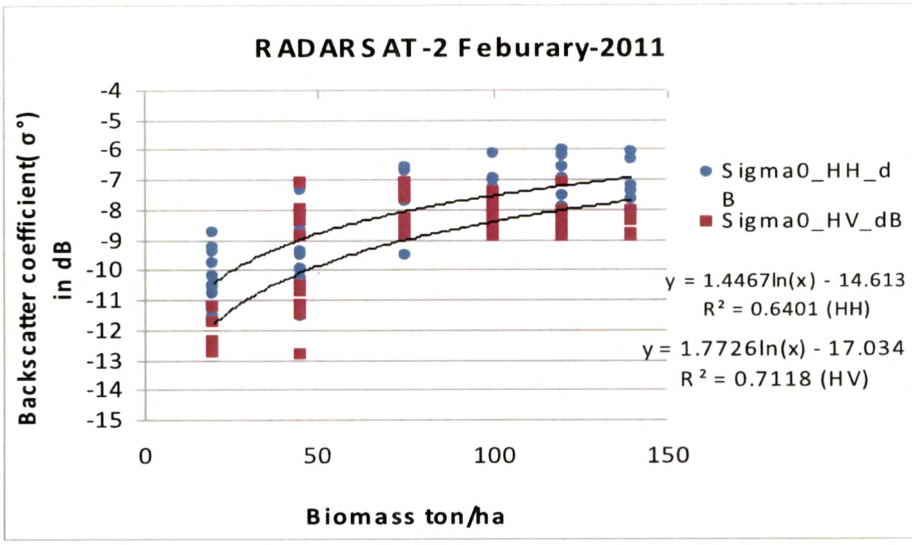


Figure 29 -Biomass vs Backscatter- February-2011

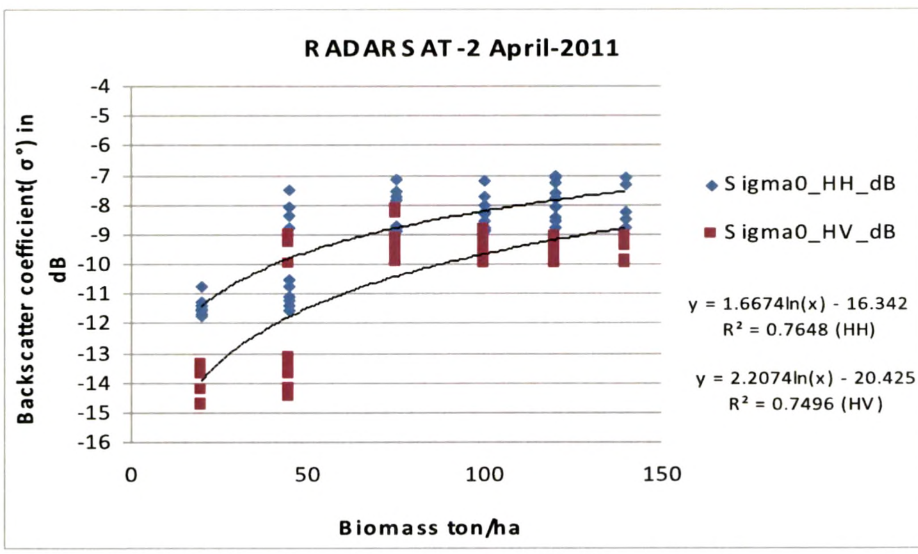


Figure 30 -Biomass vs Backscatter- April-2011

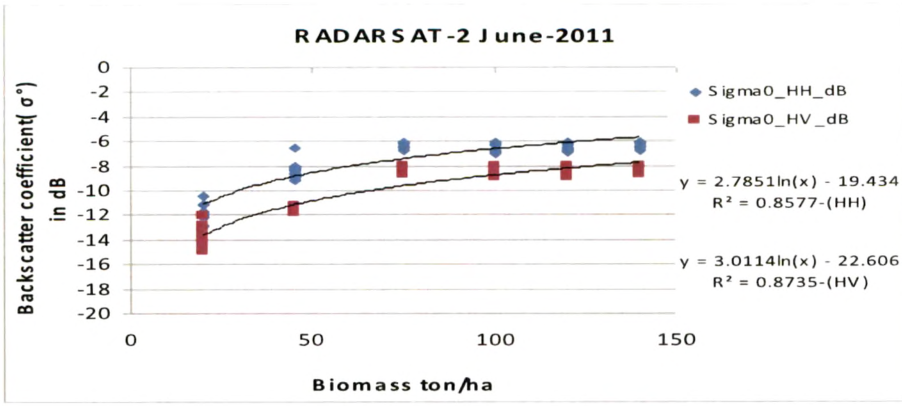


Figure 31 -Biomass vs Backscatter- June-2011

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).

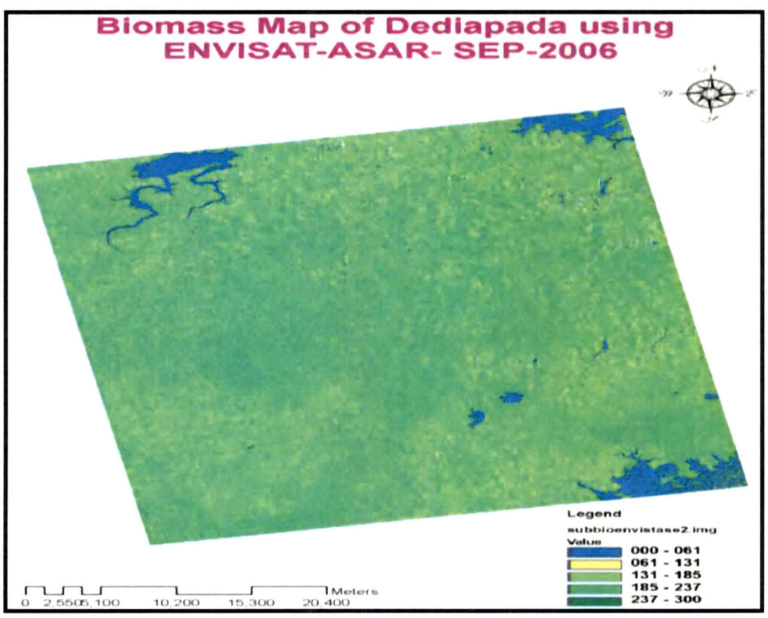
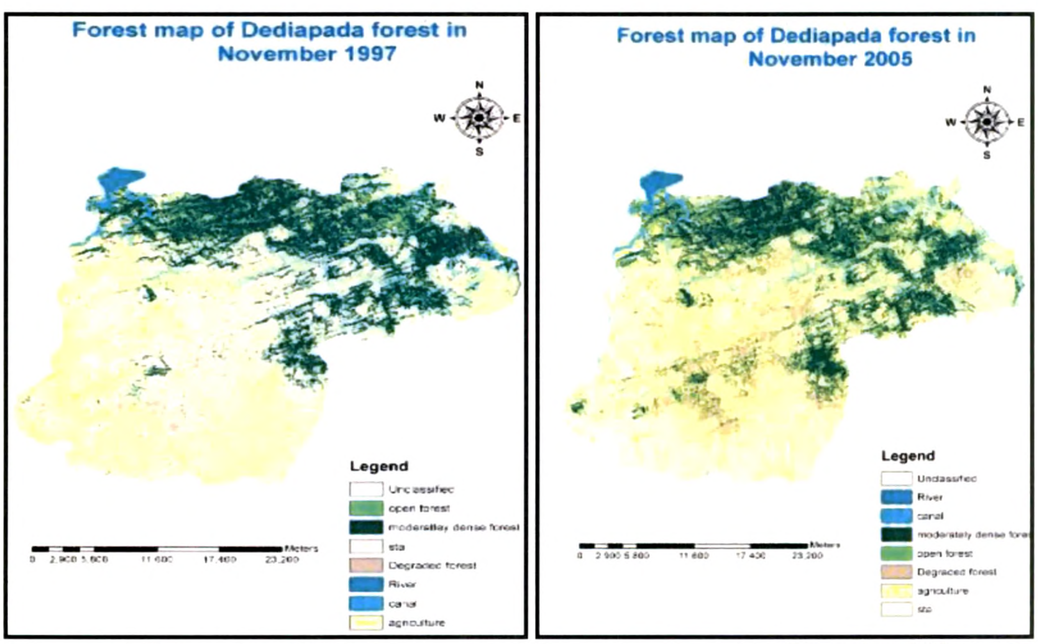


Plate 15 ENVISAT-ASAR based Biomass Map

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**

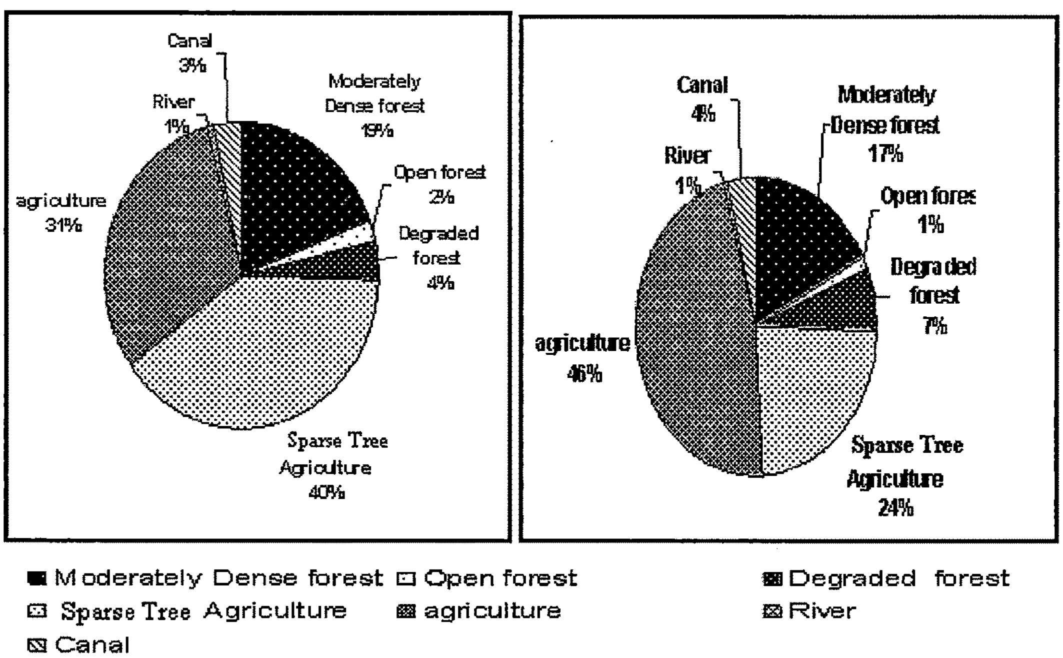


Figure 32 Chart depicting the area statistics for the year 1997 and 2005.

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.

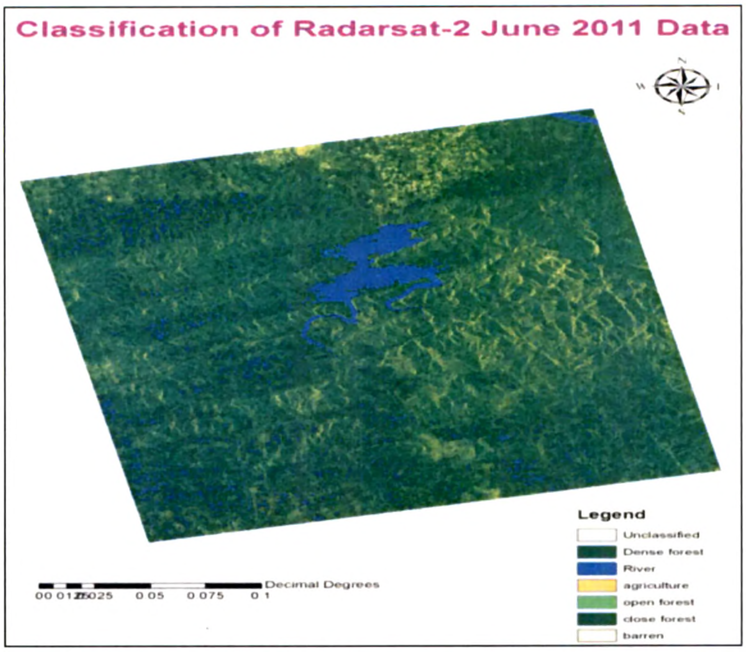


Plate 17 Classification of Radarsat-2-2011

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.

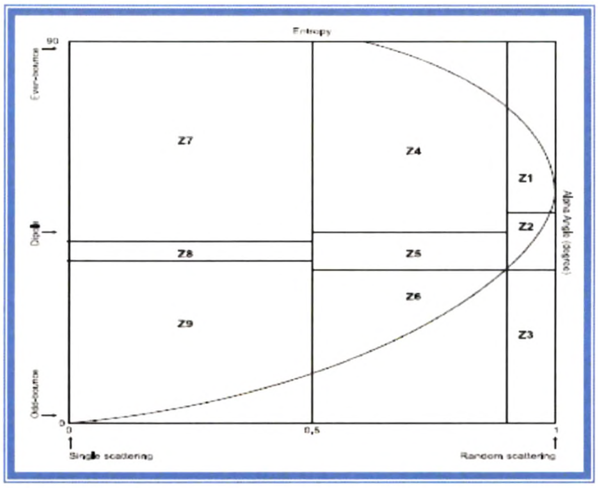


Figure 33 Segmentation of entropy-alpha feature space

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.

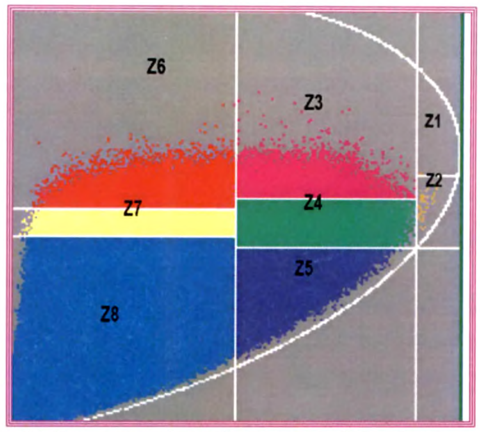


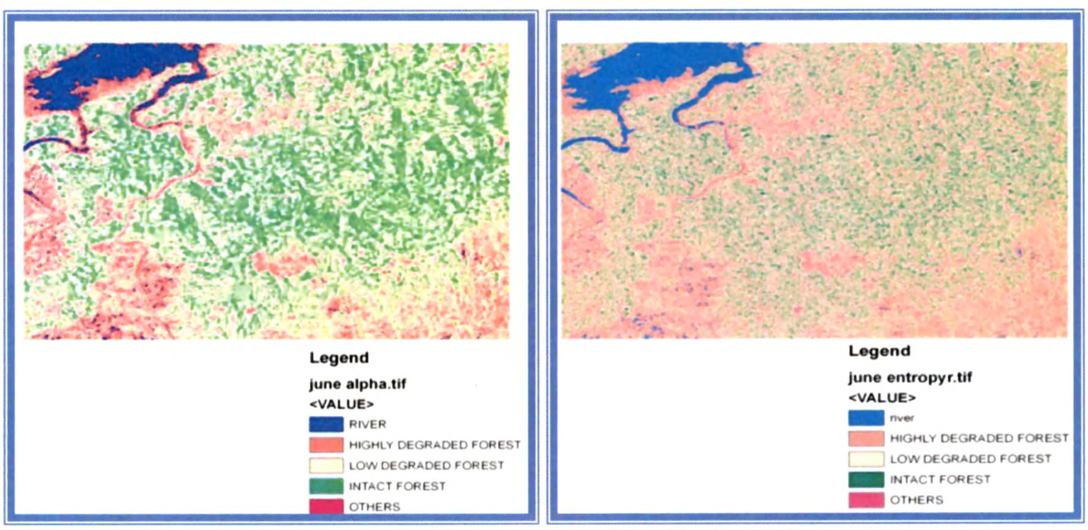
Figure 34 Segmentation of entropy-alpha feature space

Table 12 characteristic of forest cover classess

Wavelength	Class	Cluster Center		Zone
		Alpha(α °)	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°.

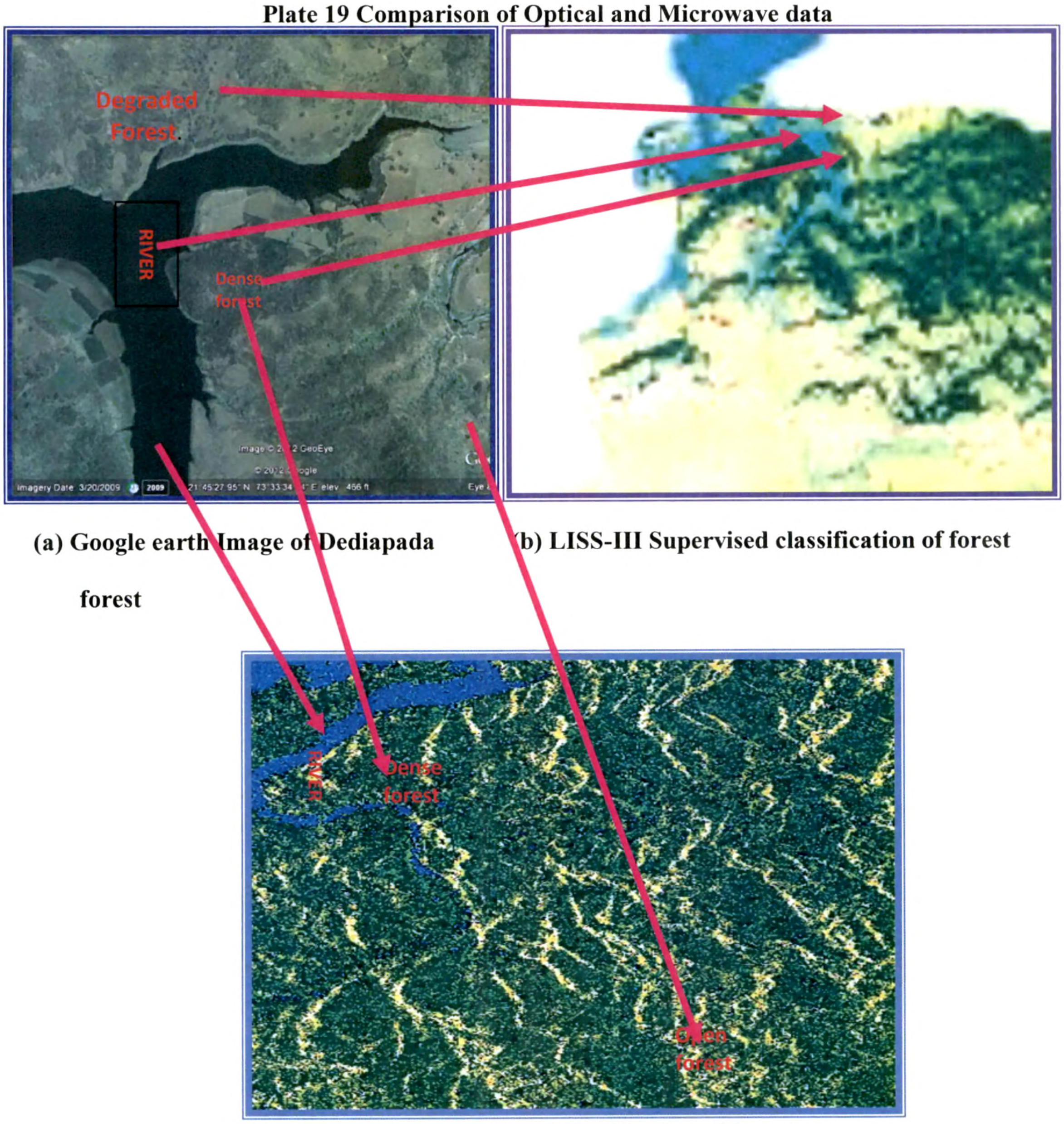


June Radarsat 2 data –ALPHA **June Radarsat 2 data –Entropy**

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.

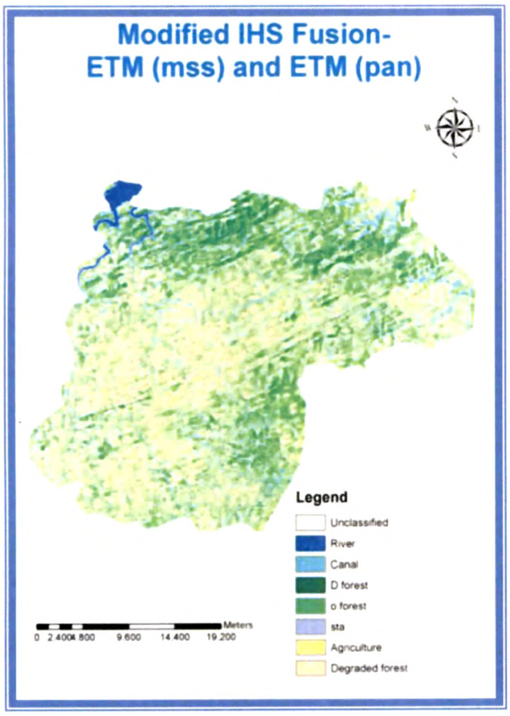
13.0. Data fusion:

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.

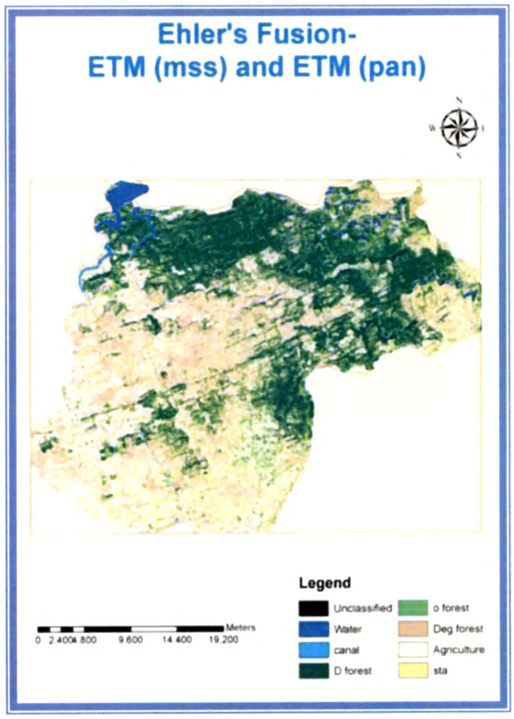
Table -13 Accuracy assessment and Kappa statistics

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

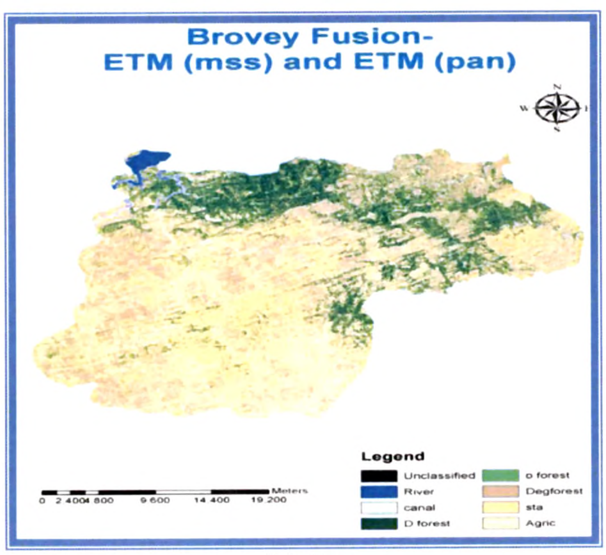
In the present study the Landsat ETM Multispectral image was fused with panchromatic data with the help of three main techniques such as the Modified IHS, Ehlers and Brovey Technique(plate-20 a-c). It was seen that the Bovery was the best technique with an accuracy of 96.7% (table 13). Ehlers showed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



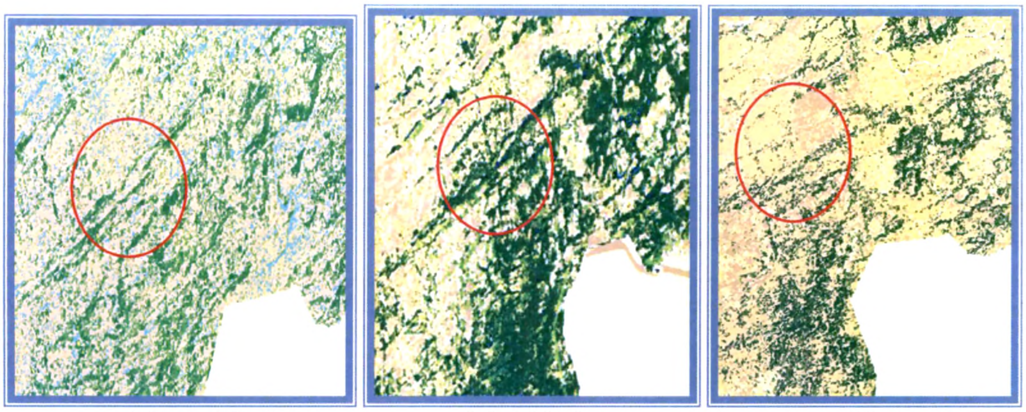
(a) **Modified IHS**



(b) Ehler's



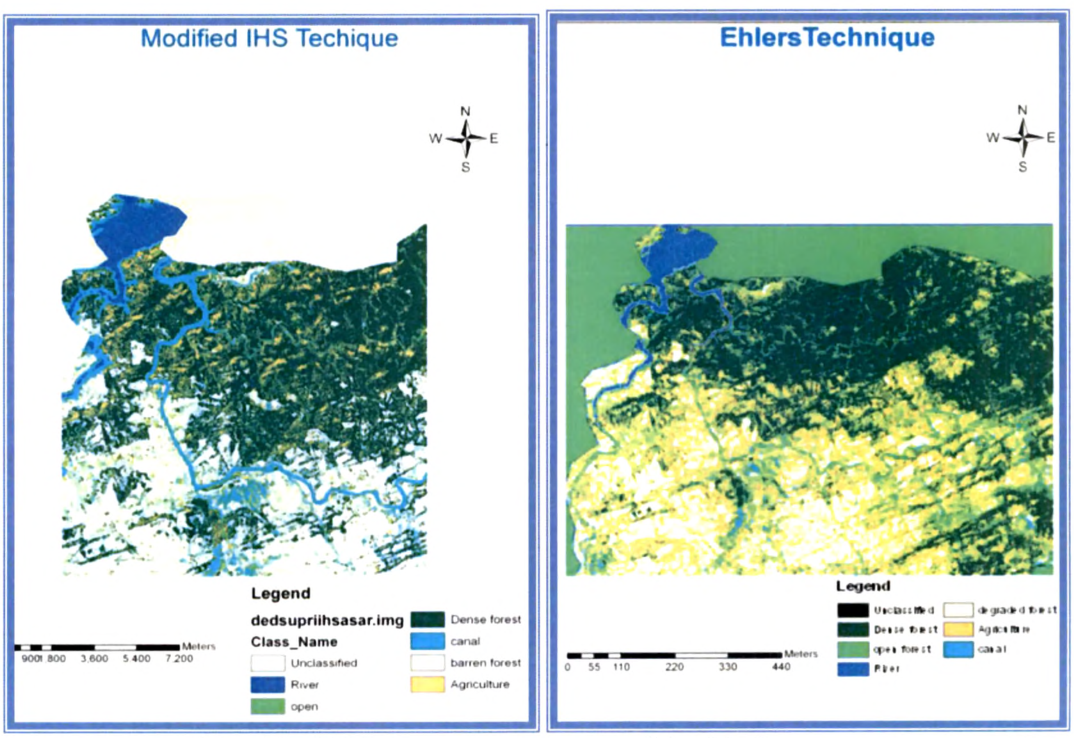
(b) Brovey



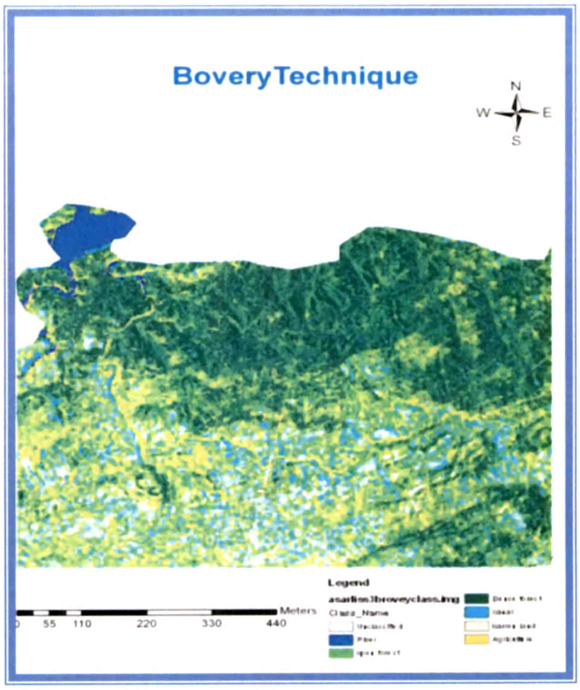
(d) **Modified IHS** (e) **Ehler's** (f) **Brovey**

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).



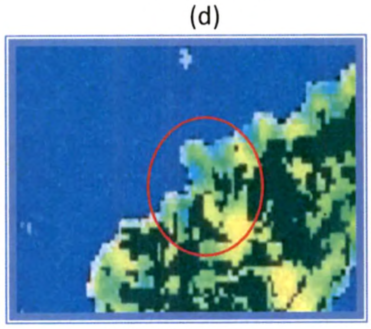
a) **Modified IHS** **(b) Ehler's**



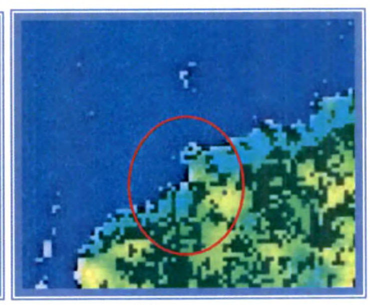
(c) Brovey

(d)

(d) Modified IHS



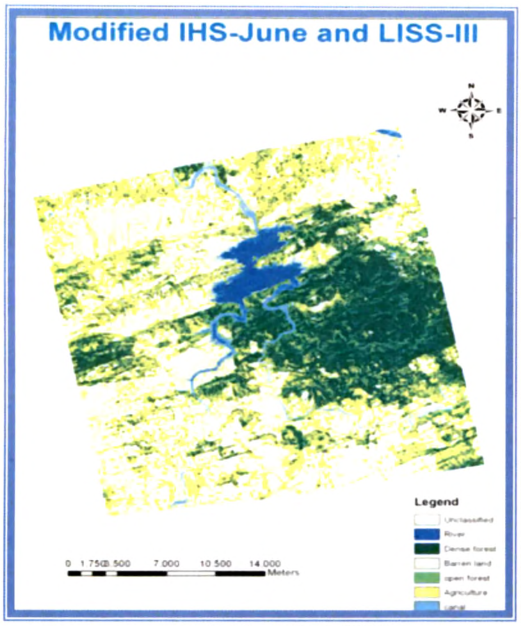
(e) Ehler's

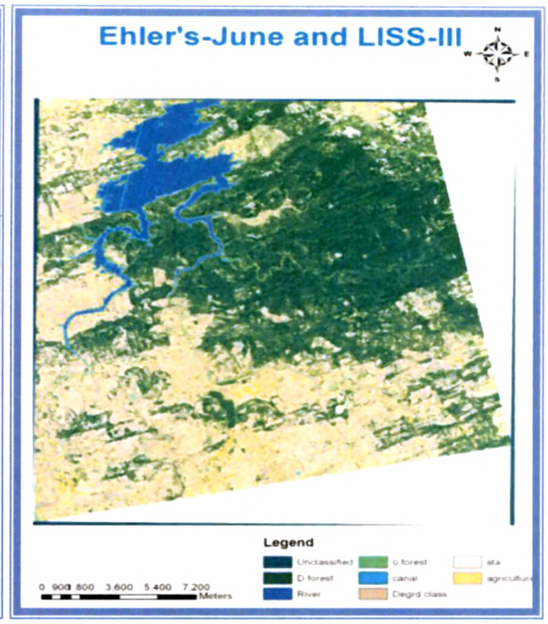


(f) Brovey

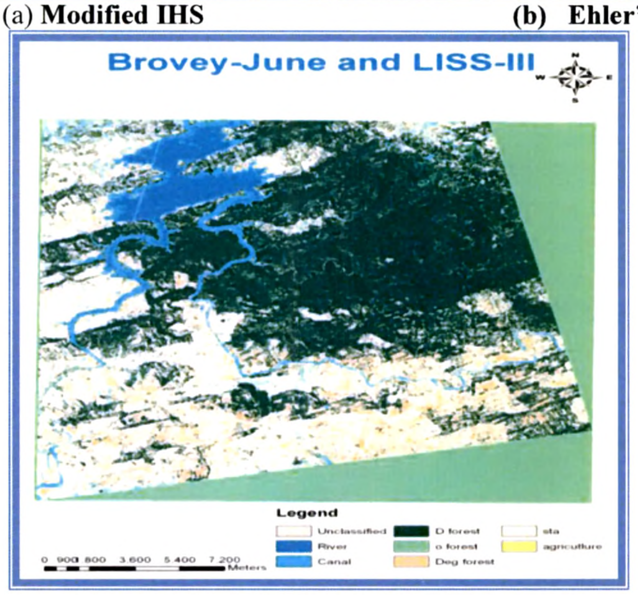
Plate 21 Fusion techniques using LISS-III (MSS) and ENIVISAT-ASAR

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).

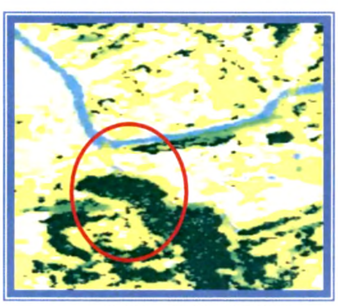


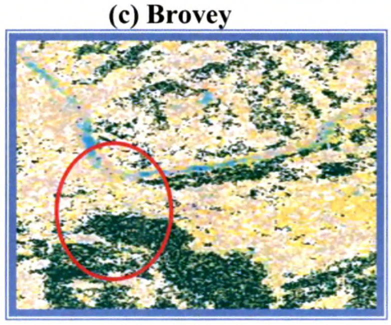


(a) **Modified IHS** **(b) Ehler's**



(c) Brovey





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

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