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INVENTORYING, MAPPING AND MONITORING OF BIORESOURCES USING GIS AND REMOTE SENSING

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Abstract

The role of bioresources in meeting a region's requirement of fuel, food, fodder and timber has increased the interest for quantifying the amount of biomass available in a region. The issue of land use is of paramount importance to environmental issues on all spatial scales. Changes in land cover and land use have affected bioresource availability and biodiversity at species, genetic and ecosystem levels. Biodiversity and biological resources are vital to the very foundation of sustainable development of a region. Recent land use changes have led to species loss, and the loss of ecosystem has affected essential ecological functions. Biodiversity has direct (medicines, food, fuel, fiber, etc.), indirect (regulating air and water quality, soil fertility, economic values) as well as ethical, aesthetic and cultural values. Current effort is focused on developing bioresource inventory for Kolar district using Geographical Information System (GIS), Global Positioning System (GPS) and remotely sensed data. The range of areas that GIS, GPS and remote sensing can aid is vast including inventorying, mapping and monitoring of natural resources. This enables estimates, for the whole region, to a high degree of reliability and provides a spatial representation useful in coupling with spatial land use change data.

Vegetation indices were computed for qualitative and quantitative assessment of land cover using remote spectral measurements. The different-scale mapping of land use pattern in Kolar district is being implemented to know the area covered under each land use i.e., agriculture, forest, plantation, built up area, water bodies, and wasteland. Tree vegetation of Kolar and Chikballapur has been studied in detail and tree inventory was prepared for species level mapping. Bioresource inventorying is done considering the village as sampling unit and based on the stratified random sampling survey approach. Mapping of village wise tree species was carried out using GPS and village survey maps and these were converted to vector layers using GIS. Standing biomass estimates for Kolar and Chikballapur were done from field estimates of diameter and height of trees in sampled quadrants. Ecological parameters like *standing biomass and diversity indices were computed to understand the vegetation composition in meeting the requirement.*

Land cover analyses using slope based vegetation index show that in Kolar district, 47.41% land cover is under vegetation and 52.59% is under non-vegetation. Similarly, computation of distance based vegetation index, which is appropriate for semi arid region shows that 45.93% is under vegetation and 54.07% is without vegetation. Land use analyses using maximum likelihood classifier indicate that 42.33% is wasteland (barren land), 46.69% is agricultural land, etc. A total of 116 tree species were found distributed in 39 families in Kolar taluk. In most of the villages the plantation trees like Eucalyptus constitute more than 65% and among naturally occurring trees, species like Pongamia pinnata is more prevalent. Compared to Kolar Taluk, Chikballapur has relatively higher species diversity and hence the total biomass density is not distributed among a few species. Spectral response pattern of selected fuelwood species is determined using IRS 1C panchromatic data (of spatial resolution 5.8 m). Mapping of Prosopis juliflora – a fuelwood species was done in Gauribidanur taluk (with an accuracy of 88%) using field data (collected in villages of Kolar taluk using GPS) covering parameters such as density, age of the plantation, etc. However, linkages between landscape metrics and human activity have yet to be demonstrated empirically over the large spatial extents appropriate to remote sensing. The detailed investigations of resource availability and the demand aided in assessment of the region's bioresource status and also helped identify the areas to be conserved / preserved from further degradation.

Keywords: Bioenergy, Inventorying, Land cover, land use, Remote sensing, GIS.

INTRODUCTION

Biomass energy is an important energy source for a majority of the world's inhabitants. The United Nations estimate of global biomass energy consumption was about 6.7% of the world's energy consumption in 1990. Biomass energy continues to be a major source of energy and fuel in developing countries (Klass 1998). In order to meet the growing demand for energy, it is imperative to focus on efficient production and uses of biomass energy to meet both traditional (as a heat supplier) and modern fuel (electricity and liquid fuel) requirements. This production of biomass in all its forms for fuel, food, and fodder demands environmentally sustainable land use and integrated planning approach (Ramachandra et al. 2000). Its relatively easy access and simple end-use technologies explain this widespread use despite poor efficiencies. With this massive utilization of existing bioresources, there is a need for critical evaluation and assessment of the remaining bioresources at micro-level. India with its not so huge landmass of 320 million hectares, when compared to its one billion human population, which directly or indirectly depends on its bioresources, inventorying of bioresources for sustainable management and conservation has emerged as an important scientific challenge in recent years.

Sustainable energy management requires a detailed planning from National, to State, to District, to Taluk and village levels. Decisions by policy makers regarding the management and use of bioenergy require accurate and precise information on the state and patterns and rate of change of the resource. Broad-based bioenergy development programmes that aim for the efficient, economical and sustainable supply and utilisation of bioenergy, can be viable energy policy and strategy options for many regions. Formulating broad-based energy development programmes involves integrated analyses of supply and demand for bioenergy. Defining policies and strategies would require the incorporation of bioenergy assessment and analysis in energy planning and other relevant sectoral planning exercises such as forestry and agriculture (Ramachandra et al., 2000).

A regional database on bioresources is needed to support the information requirements of the regional energy planning for sustainable development, including estimates for tree volume/biomass by broad type categories and administrative boundaries (http://ces.iisc.ernet.in/energy/HC270799/Frames/ErgWelcome.html).

Information on forest volume and biomass is important for developing regional perspectives on bioenergy supply and for computing carbon cycling and climate change analyses. Inadequate and inaccurate bioresource data has posed serious problem in decentralised area-based energy planning. To meet these needs, reliable estimates on the state and change of biomass for all regions over the long term must be made. In this context, emerging technologies such as GIS and remote sensing could be used effectively to carryout inventorying of resources over spatial and temporal scales.

A pilot study was carried out in Kolar district, Karnataka State, India through a detailed field investigation in selected villages of Kolar and Chikballapur taluks. This involved remote sensing data analyses, field survey involving villagewise inventorying of the tree diversity and mapping of resources using GPS (Global positioning system) and GIS (Geographic information system). Various diversity indices and standing biomass of trees were computed to analyse the species meeting the energy requirement.

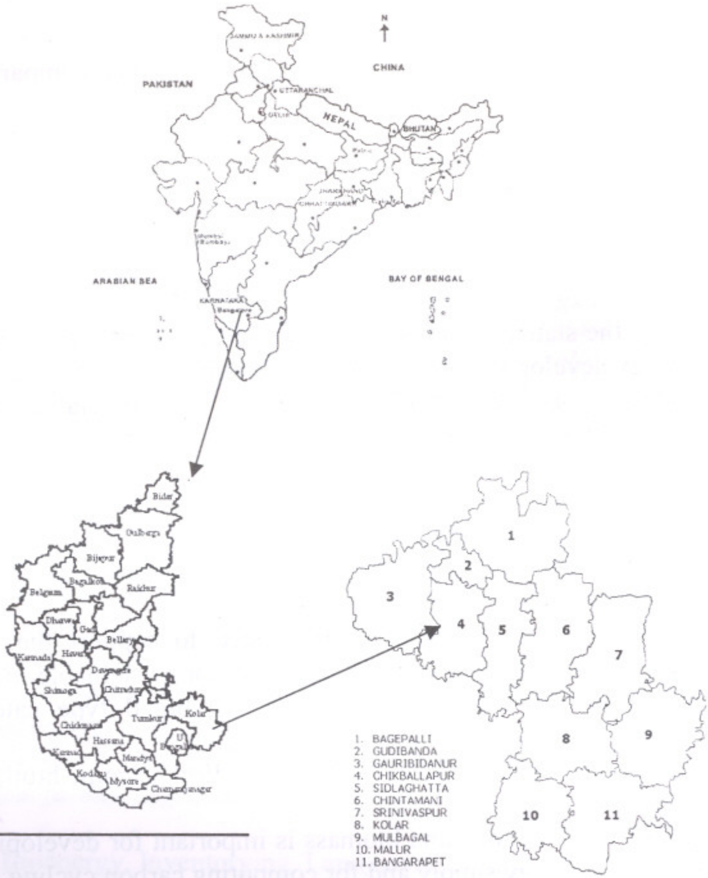

Figure 1. Study area

OBJECTIVES

The proposed bioresource inventorying involves qualitative and quantitative evaluations of the potential through:

- Land cover and Land use analyses,
- Analyses of spatial distribution of bio resource,
- Estimation of standing woody biomass,
- Inventorying of tree species diversity,
- Tree diversity analysis through computation of various ecological indices in selected villages of Kolar and Chikballapur Taluk,
- Mapping of selected fuelwood species, and
- Talukwise bioresource status assessment.

STUDY AREA: KOLAR DISTRICT

Kolar District is located in the southern plains of Karnataka State, India. It lies between 77° 21' to 78° 35' east longitude and 12° 46' to 13° 58' north latitude and extends over an area of 8,225 Sq. km.

DATA USED

- Spatial (village, taluk, district maps) and non-spatial data (demography, population, etc.),
- Survey of India toposheets of scale 1: 250,000 and 1: 50,000 were digitised to generate vector layers of road network, administrative boundaries, contours, drainage network, etc.
- Village revenue maps – digitised to map resources at village level,
- Village wise vector layer showing all trees (species wise) was prepared through an extensive field survey using GPS (Global Positioning System),
- Remotely sensed data of 23.5 m (IRS-LISS-III) and 5.8 m spatial resolution (IRS-PAN) having a cloud cover less than 2 percent - for land cover and land use analyses. The data sets used for the analysis were procured from NRSA, Hydrabad for the month of March 1998. Kolar district is covered in three scenes. Multi-spectral LISS III imagery scenes of IRS-1C were used in the analysis.
- Path 100 Row 63 (covering Bagepalli taluk of Kolar district).
- Path 100 Row 64 (covering maximum no. of taluks of Kolar district).
- Path 101 Row 64 (covering parts of Mulbagal and Bangarpet taluks).

METHODOLOGY

Analyses of remote sensing data involved:

- Restoration of the image in its correct geometric position,
- Training sites selection and field data collection,
- Visual interpretation of satellite images to delineate various geomorphic units and land cover classes,
- Field verification of interpreted units, and
- Classification of images based on field data: supervised classification.

LAND USE ANALYSIS

Based on the information that could be obtained from LISS III MSS imagery (Figure.2) of 23.5 m spatial resolution, six major land use categories were identified as built-up, agriculture, plantation, natural forests, wasteland, and water body. The land use map for Kolar district (talukwise) was prepared based on the interpretation of IRS-1C satellite imageries. This involved:

- False color composite generation,
- Training sites, Ground truth collection (field data collection),
- Signature generation for classification, (Figure.3)
- Extraction of statistics,
- Demarcation of boundaries, and
- Villages, taluk and district boundaries and road network were digitized from SOI toposheets.

MAPPING AND INVENTORY OF TREE DIVERSITY IN SELECTED VILLAGES

This is done through stratified random sampling (selection of villages) and pixel level mapping, taking the village as a sampling unit. Villages were selected so as to represent the entire taluk / district. The pilot surveys were undertaken to ascertain the sample size – the number of villages needed to be surveyed in order to obtain a reliable picture of bioresources in the region and their growing stock (wood volume in case of trees). The necessary distribution of villages to be surveyed in different taluks was worked out by proportional allocation based on the non-forest area of taluk.

Detailed mapping of trees growing in an entire village were mapped using GPS (Global Positioning System). When the study area or the population being investigated is small, census survey was carried out wherein all the scattered trees in both cultivated and non-cultivated fields were considered. The survey counts and measures all trees with a GBH (Girth at Breast Height) of 30 cm and above in the selected villages. All those having a GBH of 30 cm and above were considered as trees, except for highly fast growing plantation trees like Eucalyptus with minimum GBH of 15 cm were considered. Each tree was marked on the survey map along with the following attribute data:

1. Zone number (Survey map was divided into different number of zones).
2. Geo-coordinates or Latitude-Longitude of each tree using GPS.

3. Species type.
4. Height and Girth of each tree.
5. Crop type in adjacent fields.
6. Season and Soil wherever possible.

In the case of homogenous plantations covering large area, 10 x 10 m quadrant was laid and the total number of trees in it was counted, which was later extrapolated to its spatial extent. These quadrants were chosen depending on the density of trees in the plantation and the age of the trees in the stand. Later, this information was converted into digital format using GIS (a vector map of respective village using GIS with attribute database). Vector layers of the villages were generated and each and every tree was marked on the village layer and the corresponding tree information was recorded in the database. The data was later analysed for the following ecological parameters:

$$\text{Individual species density} = \frac{\text{Number of species A}}{\text{Area sampled}} \qquad \ldots (4)$$

$$\text{Relative species density} = \frac{\text{Density of species A x 100}}{\text{Total density of all species}} \qquad \ldots (5)$$

$$\text{Dominance} = \frac{\text{Total cover or basal area of species A}}{\text{Area sampled}} \qquad \ldots (6)$$

$$\text{Relative dominance} = \frac{\text{Dominance for species A x 100}}{\text{Total dominance for all species}} \qquad \ldots (7)$$

$$\text{Standing woody biomass} = 0.0790 + 0.4149\, D^2H \qquad \ldots (8)$$

where D = Diameter at breast height and H = Stand height

$$\text{Tree density} = \frac{\text{Number of trees}}{\text{Total area}} \qquad \ldots (9)$$

DIVERSITY

Species richness can be described as the number of species in a sample per unit area. Indices can be generated to bring them to similar scale. The simplest species richness index is based on the total number of species and the total number of individuals in the sample or the habitat. Higher the value greater is the species richness.

$$\text{Species richness} = S\text{-}1 / \text{LogN} \quad \ldots (10)$$

Where S = Number of species and N = Number of individuals

$$\text{Simpson diversity indices (Ds)} = 1\text{-} (\Sigma\ Pi^{2)} \text{ or } 1 / \Sigma\ (ni/N)^2 \quad \ldots (11)$$

Where ni =Number of individual in each species and N=Total number of individuals.

$$\text{Simpson dominance (D)} = \Sigma\ (ni/N)^2 \quad \ldots (12)$$

Where ni = Number of individual in each species and N = Total number of individuals.

$$\text{Shannon's diversity indices } (\overline{H}) = -\ \Sigma\ (ni / N) \log (ni / N) \text{ or } -\ \Sigma\ Pi \log Pi \quad \ldots (13)$$

Where ni = Number of individual in each species, N = Total number of individuals and Pi = ni/N.

$$\text{Pielou's evenness indices (e)} = \overline{H} / \log S \quad \ldots (14)$$

Where, $\overline{H}$ = Shannon index and S = Number of species

Mapping of *Prosopis juliflora*

Mapping of *Prosopis juliflora* using GPS was done in Iraghasandra and Huthur villages of Kolar taluk. The study was done in two phases. In the first phase all the areas with *Prosopis juliflora* were identified and marked as quadrants. Then the imageries of the particular quadrants were studied to get the spectral pattern. In the second phase, sub quadrant was taken within the quadrant with thick patches (density of trees, age of the plantation – juvenile and adult, etc.). With the results of second phase the spectral pattern was still narrowed down based on the density (spatial spread of trees in a quadrant) and age of the trees.

Sampling units were selected such that they included variability in ***Prosopis juliflora*** cover. The selected sites were visited with imagery, toposheet, taluk maps, village maps and GPS. Details like the age of the tree, its girth, type of soil and associated tree species, if any were noted. To know the density of the patch, quadrants of 10m x 10m were laid and numbers of trees coming under each type of distribution pattern were noted along with the GPS value. Overlaying this field data with the remote sensing data corresponding to the same region helps in identifying the spectral response pattern of the species.

STATUS OF BIO RESOURCE AVAILABILITY AND DEMAND FOR KOLAR

Bioenergy status assessment is based on compilation and computation of bioresource supply for the energy generation. This is based primarily on land use statistics and yield of various crops (agriculture and horticulture), plantation and forest biomass productivities. The taluk wise area of the dominant crops cultivated was collected from the state agriculture department for the last 6 years (1995-2000). Area under cultivation was not variety specific for a crop at the taluk level. The proportion of the area under high yielding variety and the traditional variety of a crop at the district level was used to segregate the area by variety at the taluk level. The yield of a crop was obtained by averaging the yields of the previous six years. The area under the horticulture plantations of coconut, areca and cashew at the taluk level were obtained from the State horticulture department for the previous four years. The average yield figures of the district were used to compute the production at the taluk level. The biomass productivity of the different types of forests was collected through primary field surveys in selected plots and from Karnataka forest department. The forest area by type, given division wise in the forest records was used to compute the forest type at the taluk level. The area of plantations raised by the forest department under various schemes was obtained from the State forest department. The biomass that could be obtained for fuelwood purposes was calculated assuming that 30% were adult plantations. The fuel wood demand is in the range of 1.3 to 2.5 kg/person/day. The ratio of productivity and fuel wood demand (considering both higher and lower values) is computed to get an idea of level of bioresource availability in Kolar district. Ratio greater than one indicates the presence of surplus bioresource, while a value less than one characterises a bioresource deficient zone.

RESULTS AND DISCUSSIONS

Land Cover Analysis

NDVI has the ability to minimise topographic effects while producing a linear measurement scale and is ideally suited for the localities rich with vegetation.

Compared to this, TSAVI is intended to minimize the effects of soil background on the vegetation signal and is used for the regions with sparsely spread vegetation. Table 1 gives the land cover analysis of Kolar district considering different vegetation indices.

Table – I Land cover analysis of Kolar district with different VI aspect

Kolar	Case-1	Area in, ha		Area in, %	
		Non-vegetation	Vegetation	Non-vegetation	Vegetation
NDVI	0.0	431292	388834	52.59	45.41
TSAVI	-9.0	457687	388834	54.07	45.93

NDVI computation (figure 4) reveals that, 47.41% land is under vegetation and 52.59% is under non-vegetation in Kolar district. Land cover analysis using TSAVI as illustrated in figure 5, shows that area under vegetation is 45.93% and non-vegetation accounts to 54.07%.

Land Use Analysis

A Land use analysis was carried out for Kolar district using multi-spectral data (IRS 1C LISS). Both supervised and unsupervised classification techniques were attempted. The accuracy of Supervised classification is 86% and that of unsupervised classification is 45%. The maximum likelihood classifier is found to be appropriate (based on confusion matrix analysis). Among the supervised classification techniques, hard classifiers were tried using Minimum Distance to mean with Standard Distance, Parallelepiped and Maximum Likelihood Classification approach and results are illustrated in figures 6, 7 and 8 respectively.

The land use classification for Kolar district using MLC shows that 46.69% of the total area is under various types of agriculture. This is followed by wasteland (42.33%), which is barren unproductive land. Remaining land use types are built up (4.62%), plantation (3.07%), natural forest (2.77%) and water bodies (0.53%). Table 2 lists the talukwise land use pattern, computed using hard classifiers of supervised classification techniques. Determination of the level of error was done through computation of contingency and error matrix and is listed in tables 3, 4 and 5 for Maximum Likelihood, Minimum Distance to mean and Parallelepiped classifier respectively. This analysis demonstrates that the maximum likelihood classifier has least errors (due to commission and omission).

Table - II Talukwise land use pattern computed using hard classifiers of supervised classification techniques

Taluk	Classification	Land Use (in Square meters)					
		Built-up	Agriculture	Plantation	Vegetation	Wasteland	Water body
Bagepalli	MLC	78262804.13	302588384.22	1651144.70	9057743.61	541044633.93	6725094.10
	MD	197282460.03	187350723.53	10110740.97	18524531.14	518766297.88	5271437.77
	PP	38474041.20	268174124.49	4306903.33	7854163.60	538452877.87	7575299.44
Bangarpet	MLC	23041005.91	495746035.85	37288933.52	50561786.92	258311141.99	9124814.46
	MD	86186051.62	364528384.74	63534144.40	59640244.51	290638489.91	6931266.42
	PP	14392952.46	472912111.84	50437192.46	34026355.17	266714625.81	8295082.44
Chikballapur	MLC	18005322.63	314445680.54	15463977.50	30601668.60	252458918.04	8664962.22
	MD	68892983.10	218220378.43	21892002.63	52315997.99	265471436.04	5316007.79
	PP	8881584.62	287586892.22	19711946.06	21899340.19	243340176.46	8921927.44
Chintamani	MLC	50742715.68	428909576.98	4982603.90	1047592.91	409684258.45	2988682.90
	MD	189550111.02	259256721.81	14016911.10	1669906.76	426382022.20	2625701.66
	PP	27133534.28	372297880.98	5641034.46	884280.20	441382403.02	2056264.28
Gauribidanur	MLC	51583721.51	325848721.98	715004.56	5231485.11	511821016.37	2923661.26
	MD	150951857.33	321993882.16	6376718.75	12071946.18	492198637.65	1867409.35
	PP	27672182.58	293412756.61	2106929.37	4550480.90	488970795.11	3304522.83
Gudibanda	MLC	8027095.65	62343210.76	108935.68	1028417.05	154356824.40	1537999.60
	MD	36721859.56	39201568.19	792752.75	2445370.69	147124998.39	1201630.15
	PP	4666221.15	52757146.41	357523.95	1019764.32	149579786.59	1398839.88
Kolar	MLC	25776587.87	406980304.50	17404056.86	14502390.75	330176813.85	3233435.06
	MD	15506940.06	370732758.85	18461269.35	11695388.73	332738444.70	683380.05
	PP	110718832.39	270901258.81	33736673.93	14238253:05	362243868.82	3321440.05
Malur	MLC	10757792.59	414674734.63	47107322.38	3530337.50	168509131.07	4283196.80
	MD	57079115.24	306079266.78	61392673.10	5435025.63	212283396.45	3610331.80
	PP	6020066.01	387386229.89	43952748.00	3031489.45	170837615.61	3558470.41

Taluk	Classification	Land Use (in Square meters)					
		Built-up	Agriculture	Plantation	Vegetation	Wasteland	Water body
Mulbagal	MLC	49806214.31	428676044.85	15265975.01	6357961.39	321250676.10	4720204.34
	MD	127094725.52	288112540.16	37163698.60	10750179.30	355982083.95	3901247.44
	PP	27223962.00	434019165.04	18844297.09	6451208.05	322122794.85	3402116.53
Sidlaghatta	MLC	33953924.25	320396089.23	35154341.46	4731491.65	276296233.88	2080268.38
	MD	16436714.57	297588833.45	31396192.16	4227795.71	283117866.21	667424.68
	PP	105191712.28	232040829.34	45965870.79	4996632.01	280822423.72	1886702.89
Srinivasapur	MLC	32942688.59	480395727.21	32523586.22	57454985.92	262807237.48	3117927.99
	MD	96941424.12	334239550.74	61920875.18	60754865.83	310817444.29	1909639.34
	PP	17159532.57	455789848.03	37239331.86	44182722.83	293733979.05	3057375.66

Table - III Contingency (Error) matrix for Maximum Likelihood classification

Land Cover	Built-up	Agriculture	Plantation	Vegetation	Waste land	Water body	Total	Errors of Commission
Built-up	2608	27	0	0	248	8	2891	0.0979
Agriculture	3	24350	64	25	123	2	24567	0.0088
Plantation	0	88	1988	45	0	0	2121	0.0627
Vegetation	0	89	0	7040	4	0	7133	0.013
Wasteland	4	654	0	8	34724	15	35405	0.0192
Water body	8	0	0	0	277	3775	4060	0.0702
Total	2623	25208	2052	7118	35376	3800	76177	
Errors of Omission	0.0057	0.034	0.0312	0.011	0.0184	0.0066		0.0222

SPECIES LEVEL MAPPING: SPECTRAL SIGNATURE ANALYSIS

The vector layer of a particular species is overlaid to its corresponding raster layer and spectral value is found out. Frequency distribution and histogram analyses of spectral values were done. Frequency distribution of spectral values helped in delineating the reasons for variations. The range where the highest peak occurs corresponds to a spectral value of adult species. Average value of the selected range was taken as spectral value of that species and its standard deviation gives the range of spectral signature from its average value. Average plus standard deviation corresponded to juvenile plants. Spectral value depends on type of species, its girth, height and density. Considering these parameters, training sites for each type of species were mapped. Then their corresponding spectral signature is found out by overlaying field data with remote sensing data. Table 6 shows the spectral response patterns of various tree species dominant in the villages of Kolar taluk.

Table - IV Contingency (Error) matrix for Minimum Distance to Mean classification

Land Cover	Built-up	Agriculture	Plantation	Vegetation	Wasteland	Water body	Total	Errors of Commission
Built-up	2187	103	0	0	1867	73	4230	0.483
Agriculture	2	20522	714	78	942	0	22258	0.078
Plantation	0	968	1335	51	0	0	2354	0.4329
Vegetation	0	47	3	6803	491	0	7344	0.0737
Wasteland	411	3568	0	186	31640	18	35823	0.1168
Water body	23	0	0	0	436	3709	4168	0.1101
Total	2623	25208	2052	7118	35376	3800	76177	
Errors of Omission	0.1662	0.1859	0.3494	0.0443	0.1056	0.0239		0.131

Table - V Contingency (Error) matrix for Parallelepiped classification

Land Cover	Built-up	Agriculture	Plantation	Vegetation	Wasteland	Water body	Total	Errors of Commission
Built-up	1938	5	0	0	312	0	2255	0.1406
Agriculture	67	19672	197	149	147	0	20232	0.0277
Plantation	0	224	1654	0	0	0	1878	0.1193
Vegetation	0	16	0	6289	47	0	6352	0.0099
Wasteland	221	3758	201	400	32661	7	37248	0.1231
Water body	279	0	0	0	693	3657	4629	0.21
Total	2623	25208	2052	7118	35376	3800	76177	
Errors of Omission	0.2612	0.2196	0.194	0.1165	0.0767	0.0376		0.1353

Table - VI Spectral response patterns of various tree species dominant in the villages of Kolar taluk

Tree / Species Village	Eucaly ptus	Prosopis Juliflora	Mangi-fera indica	Ponga-mia Pinnate	Acacia nilotica	Acaciaau riculofor mis	Tamarin dus indica
Huttoor	83-92	98-105		76– 80	76-88		93-100
Ganeshpura	95-115		90–105	98–104			94-102
Ramasandra	86–102		92–106		97-107		
Kondasandra			90–107			90-100	93-101
Kaparasiddana halli	92-110					98-114	
Nandikamana halli	88-102		87–96	87– 96		99-107	
Iragasandra	98-118		92–112	92–104			88-110
Antaragange	92–102						
Sangondahalli	94–101						

Based on these spectral signatures (field investigations involving detailed mapping), classification for Chikballapur and Kolar taluk was done. Table 7 shows the details about area covered under each vegetation.

Table - VII Area covered under each vegetation in Chikballapur and Kolar

Taluks	Area in Hectares					
	Eucalyptus	Forest	Ragi	Mulberry	Mix agri	Barren
Chikballapur	7585.00	7208.65	8609.29	4734.13	9874:40	9840.12
Kolar	9083.60	3622.84	17422.75	7698.76	16627.23	16876.18

Mapping of *Prosopis juliflora* was done in Iraghasandra and Huthur villages of Kolar taluk where the growth was more due to the favorable edaphic factor. With the identification of spectral response pattern for the species (considering density and age), mapping was done for the entire Kolar taluk as well as for the neighbouring Gauribidanur taluk (figure 9) with the help of merged remote sensing data (LISS III MSS and PAN) in Kolar district. Figure 10 depicts fused image of MSS and PAN data (spatial resolution of 5.8 m and spectral resolution of G, R and NIR). The map of Prosopis juliflora was verified (field visit) using GPS. Polygons chosen for verification are given in figure 11. The accuracy of mapping is 88% as 44 polygons out of 50 mapped polygons correlated with the species.

TREE SPECIES INVENTORY

Woody flora of Kolar and Chikballapur taluks include nearly 180 tree species distributed among 49 families. The number of species is a conservative estimate because it does not include undetermined species in genera that are on the list. Families with more than 10 species include Fabaceae, Bignoniaceae, Moraceae, and Rubiaceae. Genera with 3 or more species include Acacia (7), Albizzia (3), Cassia (5), Dalbergia (4), Diospyros (4), Ficus (8), Syzygium (3), and Terminalia (6).

Kolar Taluk

A total of 116 tree species were found distributed in 39 families. Species like *Cassia siamea, Tamarindus indicus, Pongamia pinnata, Melia azadirach, Syzigium cumini, Acacia nilotica, Eucalyptus sp*., etc., are distributed in more than 30 study areas. Eucalyptus species have the highest number of individuals with 34,83,417 trees followed by *Acacia auriculiformis* with 2,92,991 trees, *Azadirachta indica* having 1,53,855 trees and *Acacia leucophloea* with 1,38,546 trees). Highest tree density is found in reserve forests and monoculture plantations dominated villages like Singireddy halli (3420 trees/ha), Ganeshpura (2751 trees/ha), Thondala-1 (2663 trees/ha), and Thondala-2 (2530 trees/ha).

Estimates of tree standing biomass

Total of 26 villages were surveyed in Kolar taluk (figure 12) and the results show that village Antaraganga including the reserve forest (RF) has highest Standing biomass of 555 ton/ha followed by Thirumalakoppa with 458 t/ha and Thondala-1 reserve forest with 454 t/ha. Iragasandra-2 has the lowest with 3.4 t/ha. The average SB of Kolar Taluk is 116.53 t/ha. SB for some of the reserve forests (table 8) shows that Thondala reserve forest has highest standing biomass whereas the Kaparasiddanahalli reserve forest has the least due to relatively smaller basal area of trees which are harvested regularly. There are other reserve forests like the Muduvadi RF, where including the non-reserve forest trees, the standing biomass is only 138 t/ha. This may be due to highly degraded status of the forests, sparse eucalyptus plantation with very low basal area. Table 9 shows the computation of various parameters like species total, tree total, standing biomass (SB) in tons/ha, and species density for different villages.

Table - VIII Standing biomass (SB) of Kolar Taluk

Sl.no	Reserve forests	Total area (ha)	SB (t/ha)
1	Antaraganga	51.09	554.864
2	Kaparasiddanahalli	76	233.27
3.	Singireddyhalli	178	316.73
4.	Thondala-1	15	454.45
5.	Thondala-2	226	381.992
6.	Thondala-3	170	77.53

Table - IX Village wise computation of various parameters

Village id	Village	Area	Sp. Total	Tree Total	SB (tons/ha)	Sp. density
1	Antaraganga	51.09	38	22180	555	0.7437
2	Balagere	267.26	50	82651	45	0.1871
3	Basavanatha	121.80	34	35262	25	0.2791
4	Belahalli	124.83	40	21557	18	0.3204
5	Byrasandra	93.99	39	187125	192	0.4149
6	Ganeshpura	89.05	16	245028	221	0.1797
7	Haralakunte-1	304.02	33	65640	23	0.1085
8	Haralakunte-2	171.20	44	142369	60	0.2570
9	Hutoor-1	242.00	23	184608	144	0.0950
10	Hutoor-2	246.00	46	53389	32	0.1869
11	Iragasandra-1	219.00	41	101866	50	0.1867
12	Iragasandra-2	55.96	4	1996	3	0.0715
13	Iragasandra	221.00	27	75504	41	0.1222
14	Kalkeri	131.00	39	29160	26	0.2969
15	Kallandur-1	291.00	37	163015	57	0.1270
16	Kallandur-2	179.00	48	133544	83	0.2681
17	Kaparasiddanahalli	76.00	41	144216	23	0.5408
18	Karadubandahosahalli-1	241.00	32	15959	8	0.1326
19	Karadubandahosahalli-2	145.00	10	70426	45	0.0690
20	Karadubandahosahli-3	208.00	19	21993	12	0.0914
21	Kondasandra	240.00	37	70884	53	0.1539
22	Kooteri-1	236.00	46	49690	22	0.1950
23	Kooteri-2	347.00	49	203540	114	0.1413
24	Koratamallandahalli	121.00	37	30720	30	0.3047
25	Muduvadi-1	296.00	41	12117	6	0.1386
26	Muduvadi-2	281.00	32	340426	132	0.1139
27	Nandikamanahalli	83.00	23	37175	95	0.2771

Village id	Village	Area	Sp. Total	Tree Total	SB (tons/ha)	Sp. density
28	Ramasandra	96.00	29	85127	134	0.3015
29	Sangondahalli	169.75	34	1947	4	0.2003
30	Shapur	160.00	42	140138	85	0.2630
31	Singireddihalli	178.00	21	609057	317	0.1179
32	Thokalaghatta	201.00	39	28644	17	0.1938
33	Thondala-1	15.00	7	39600	454	0.4708
34	Thondala-2	226.00	11	572569	382	0.0486
35	Thirumalakoppa-1	147.00	26	250659	458	0.1765
36	Thirumalakoppa-2	170.00	36	309822	380	0.2116
37	Vibhuthipura	29.00	24	356	5	0.8387
38	Thondala-3	170.00	39	93393	78	0.2298

BIOMASS DISTRIBUTION AMONG DIFFERENT SPECIES

In most of the villages plantation trees like Eucalyptus constitute more than 65% while the plantation trees like *Acacia nilotica, Acacia auriculiformis, Tamarindus indica,* etc., comprises the rest leaving very less for other species. Thus, relatively few species appear to determine the physiognomy in these villages. However, in villages like Singireddyhalli, Hutoor, etc., there may be two or more species, which share the total standing biomass.

Among naturally occurring trees, species like *Pongamia pinnata* dominates (in most of the taluks), as it is highly adaptive in most of the drier regions and commonly found along streams, field bunds, and small grooves. If both natural and plantation trees are considered, Eucalyptus sp. dominates in most since it is planted extensively by the farmers as it is one of the major sources of income and fuel wood for both household and small industries. This is followed by *Cassia siamea*, which is mostly planted for afforestation programs. Some are also regenerating by themselves in many villages along water channels and other moist places. *Syzigium cumini* and *S.operculatum* mostly are found along streams in most of the villages and also in open areas. Figures 13, 14, and 15 illustrate vegetation cover map, PAN image, and spectral curve of Irigasandra village respectively. Villagewise tree density and standing biomass for Kolar taluk is given in table 10.

Table - X Villagewise tree density and standing biomass (SB)

Sl.no	Village	Area (ha)	Tree sp.	Tree density	Predominant trees SB, t/ha	SB, t/ha
1	Ganeshpura	89.05	Eucalyptus	2751	219.65	221
2	Huttor-1	242	Acacia nilotica	762	79.43	144.31
3	Kaparasiddanahalli	76	Eucalyptus	1902	226.13	233.27
4	Hararalakunte-2	171.19	Eucalyptus	831	58.70	60.08
5	Koratamallandahalli	121	Eucalyptus	253	22.30	30.07

Diversity

The highest species density of 0.8386 is seen in Vibhuthipura village wherein 24 species are found in an area of 29 ha. The lowest is seen in Thondala-2 with 0.0486. 11 species are found in 226 ha. However, the highest species number of 50 species is found in village Balagere in a total of area of 267.26 ha and 82651 trees while the lowest is found in Iragasandra-2 with only 4 species in 55.96 ha of area and 1996 trees. Table 11 shows diversity in reserve forests/plantations of Kolar taluk.

Table - XI Diversity in reserve forests/plantations of Kolar taluk

Sl.no	Reserve forest plantation	Total species	Total trees	Shannon value
1	Ganeshpura	16	245028	0.0139
2	Kaparasiddanahalli	41	144216	0.05573
3	Singireddyhalli	21	609057	0.7716
4	Thondala-1	7	39600	0.45521
5	Thondala-2	11	572569	0.5488
6	Thondala-3	39	93393	0.1008

Highest species richness of 10.032 is found in village Sangondahalli and the lowest in Thondala-3 with a richness of only 0.0004 due to high dominance by Eucalyptus plantation. The highest Simpson diversity of 0.81894 is found in Vibhuthipura, which shows high evenness of 24 species in an area of 29 hectare. Lowest Simpson diversity of 0.00139 is found in Karadubandehosahalli-2 with 10 species in area of 145 hectares. Kolar taluk is highly dominated by monoculture plantation species and hence in many places like Karadubandehosahalli-2, Simpson dominance value is 0.9986, which is very high due to dominance by Eucalyptus plantations.

Many of the other reserve forests of Kolar taluk show a very low Shannon value indicating their poor species diversity. This may be due to the loss of many species by extravagant exploitation like illegal logging, huge fuel wood collection for local population and mass monoculture plantation of exotic species like Eucalyptus. The highest evenness can be seen in village Vibhutipura with evenness value of 0.6857. It has 24 species with 356 trees.

Chikballapur Taluk

A total of 18 villages were surveyed in Chikballapur taluk (figure 16). Among these, Maralakunte plantation has the highest standing biomass of 287.92 t/ha. It has an area of 105.670 ha and a tree density of 2691.78 and total trees of 2,84,462. Reserve forests like the Narasimhadevara betta range though harbor good natural dry deciduous forests have standing biomass, which are not optimum to that area. For example, Kethenahalli plantation, which has good forest cover, has trees whose average height ranges from 10-50 m and rarely have more than this value. Places like Nandhi hills also have natural forests whose basal areas are very less and hence the total biomass. However, eucalyptus plantation (old plantations) has slightly higher standing biomass of 188.83 t/ha. Table 12 gives villagewise tree density and standing biomass.

Table - XII Villagewise tree density and standing biomass (SB)

Sl. no	Reserve forests + plantations	Area	Tree density	SB, t/ha
1	Gollahalli	247	1330.02	135.5
2	Jakkalamadugu	207	986.58	96.04
3	Kadadibbur	182	1440.10	141.33
4	Madhurenahalli	652	566.68	70.69
5	Mudigondavobanadinne	87.20	656.98	103.35
6	Nandhi plantations	1050	974.4	188.8
7	Kethenahalli	1511.20	945.01	119.941

As compared to Kolar Taluk, Chikballapur enjoys relatively more number of species diversity and hence the total biomass density may not be distributed among a few species, but a large number of species. Table 13 shows the various parameters computed for Chikballapur Taluk. In Gollahalli plantation, species like *Firmiana colerata, Dalbergia lanceolaria,* and *Terminalia paniculata* account for more than half of the total biomass. Similarly in Kethenahalli the total biomass of tree species like *Anogeissus latifolia, Pongamia pinnata, Premna tomentosa, Eucalyptus sp., Lagerstroemia parviflora, Shorea talura* comprise 65% of total biomass. The highest tree density per hectare is found in Nallakadirenahalli-2 with 2400.02 and the lowest in Kethenahalli having 1.468 trees.

Table - XIII Various parameters computed for Chikballapur Taluk

Village id	Village	Area	Sp. number	Tree no.	SB	Sp. density	Tree Density
1	Bannikuppe	31	3	72218	222.5	0.10	2304.9
2	Bannikuppe trees	147	41	1163	1.6	0.28	7.9
3	Gollahalli Pln	247	39	328625	135.6	0.16	1330.0
4	Gollahalli trees	228	51	662	0.7	0.22	2.9
5	Haristhala-1	237	54	1719	1.8	0.23	7.2
6	Haristhala-2	12	24	484	6.1	2.05	41.3
7	Jakkalamadevu Pln	207	22	204108	96.0	0.11	986.6
8	Jakkalamadevu trees	61	51	1965	6.7	0.83	32.0
9	Jathavarahosahalli Pln	98	36	563	2.7	0.37	5.8
10	Jathavarahosahalli trees	3	2	8590	276.3	0.59	2543.7
11	Kadadibburu Pln	182	11	262027	141.3	0.06	1440.1
12	Kadadibburu trees	175	51	1307	1.3	0.29	7.5
13	Kammathanahalli Pln	5	2	205	14.0	0.41	42.5
14	Kammathanahalli trees	419	31	816	0.8	0.07	1.9
15	Kanajenahalli Pln	5	2	9262	160.8	0.37	1707.9
16	Kanajenahalli trees	279	38	550	0.6	0.14	2.0
17	Kethenahalli Pln	1511	68	1428106	119.9	0.04	945.0
18	Kethenahalli trees	361	21	531	0.4	0.06	1.5
19	Madhurenahalli Pln	652	23	369600	70.7	0.04	566.7
20	Madhurenahalli trees	433	42	1324	0.7	0.10	3.1
21	Maralakunte Pln	106	5	284462	287.9	0.05	2692.0
22	Maralakunte trees	147	43	933	2.0	0.29	6.3
23	Mudigondvobanadinne Pln	87	23	57293	103.3	0.26	657.0
24	Nallakadirenahalli-1Pln	11	1	29650	243.3	0.90	2687.4
25	Nallakadirenahalli-1trees	31	32	632	3.0	1.02	20.1
26	Nallakadirenahalli-2 Pln	23	6	55839	223.5	0.26	2400.0
27	Nallakadirenahalli-2trees	248	51	1037	0.6	0.21	4.2
28	Nandi Pln	1050	82	1023610	188.8	0.08	974.4
29	Nandi trees	85	56	1428	25.3	0.66	16.9
30	Sambaragidadakavalu Pln	767	32	785676	105.6	0.04	1025.0
31	Sambaragidadakavalu trees	15	4	226	1.8	0.27	15.1
32	Sulthanpete Pln	36	7	58623	148.9	0.20	1643.5
33	Sulthanpete trees	230	55	1571	2.1	0.24	6.8
34	Yalagadahalli Pln	54	15	86088	185.2	0.28	1600.7
35	Yalagadahalli trees	857	68	8852	2.3	0.08	10.33

Distribution of tree species

As this Taluk consists of relatively good patches of dry deciduous forest patches, a large number of forest species makeup the total species pool, though forests in villages like Haristala have been totally cleared or planted monoculture with trees. Hence, there are very few villages dominated by single species. However Pongamia pinnata and Eucalyptus are versatile in their distribution. Vegetation cover map, PAN image, and spectral response of eucalyptus tree in Bannikupe village are illustrated in figure 17, 18, and 19 respectively.

Table 14 shows the species dominance in Chikballapur taluk. Trees like *Anogeissus latifolia* are however slightly dominant in villages like Jakkalamadugu, Kethenahalli, and Nandhi forests but don't have higher standing biomass due to their lower basal area. Nandhi forest and Kethenahalli reserve forests have a very rich combination of species and total tree individuals with former having total tree species count of 82, followed by Kethenahalli dry deciduous forests with 68 tree species. Nandhi forests due to its varied climate, topography and large area, provides habitat for a large number of species, which comes under Narasimhadevarabetta forest range. Also these two have the largest number of trees, Kethenahalli reserve forest having 14,28,106 trees in an area of 1511.20 hectares with 68 species, followed by Nandhi forests harboring 10,23,610 trees with 82 species in an area of 1,050 hectares. Gollahalli-trees have a high species richness of 17.725 with 51 species among 662 trees followed by Nandhi-trees with species richness of 16.885 having 56 species in 1428 trees. Distribution of individuals in different tree species is shown in table 15.

Table - XIV Dominant species in Chikballapur

Sl. No	Species	No. of villages
1	Pongamia pinnata	15
2	Eucalyptus	14
3	Albizzia amara	4
4	Anogeissus latifolia	2

Table - XV Distribution of individuals in different tree species

Sl. No	Village/forests	Diversity parameters	Results	Status
1	Gollahalli-trees	Num.species richness	17.725	Highest
2	Kanajenahalli forests	Num.species richness	0.2520	Lowest
3	Nandhi forests	Shannon-wiener	1.46	Highest
4	Kethenahalli forests	Shannon-wiener	1.45	High
5	Kanajenahalli forests	Shannon-wiener	0.0157	Lowest
6	Bannikuppe forests	Simpson dominance	0.9883	Highest
7	Kethenahalli forest	Simpson dominance	0.0542	Lowest
8	Kethenahalli forest	Simpson diversity	0.9457	Highest
9	Bannikuppe forest	Simpson diversity	0.0116	Lowest
10	Nallakadirenahalli-2	Pielov's evenness	0.9368	Highest
11	Maralakunte forests	Pielov's evenness	0.033	Lowest

Results show that the Nandhi plantation has highest Shannon value of 1.46 followed by Kethenahalli with 1.45 and Gollahalli 1.28. The value of Shannon diversity index usually ranges between 1.5 - 3.5 and rarely surpasses 4.5, because 10^5 species will be needed to produce a value of $\overline{H} > 5.0$. Higher the $\overline{H}$ value greater is the diversity and also the evenness. Hence, due to more evenness in species distribution Nandhi forest has good Shannon value (table 15). In case of plantation reserve forests Singireddyhalli that has seen government afforestation program has slightly better diversity compared to other planted forests. The plot of species diversity versus area (species area curve) show that except in villages like Maralakunte plantation, Kadadibbur and Kanajenahalli, the tree diversity increases with an increase in sampled area and reaches a plateau or slightly decreases from 1000 ha onwards.

STATUS OF BIORESOURCE IN KOLAR DISTRICT

The availability to demand ratio ranges from 0.33 (considering fuel wood demand as 2.5 kg/person/day) to 0.64 (fuel wood demand as 1.3 kg/person/day). The ratio being less than one indicates that there is bio resource scarcity. The computation of bioenergy availability, demand and talukwise bioresource status listed in table 16, shows that Chikballapur Taluk has higher value of 0.42 and Chintamani Taluk has the least of 0.12.

Table - XIV Talukwise bioresource status

Taluk Name	Resource/Demand
Bagepalli	0.1490
Bangarpet	0.1518
Chikballapur	0.4220
Chintamani	0.1200
Gauribidanur	0.1550
Gudibanda	0.1590
Kolar	0.3259
Malur	0.2122
Mulbagal	0.1840
Sidlaghatta	0.1730
Srinivasapur	0.3858

CONCLUSIONS

Land cover analyses show that Kolar District has a vegetative cover (Forest, Agriculture and Plantation) of 47.41% and non-vegetative cover of 52.59%. Talukwise land use analyses show that among 11 taluks, Bangarpet has maximum forest cover of 10.46 %, followed by Srinivasapur (6.61%), Chikballapur (4.78%) and Gauribidanur with 0.58%. Area under plantation ranges from 8.81% (Bangarpet) to 0.08% (Gauribidanur). Area under agriculture ranges from 63.91% (Malur) to 32.21% (Bagepalli). Wasteland in the district is about 42.33 % and talukwise it ranges from 25.97% (Malur) to 56.99% (Gauribidanur) to 57.60% (Bagepalli).

Kolar has an average standing biomass of 116.53 and it is unevenly distributed. Many villages are dominated by monocultures like Eucalyptus plantation and other plantations like *Acacia auriculiformis, Acacia nilotica, Tamarindus indica, Mangifera indica* and relatively few other trees. Hence, large part of SB is human induced and not from naturally grown trees. However, this has a serious disadvantage since this system does not promote diversity, which is a vital necessity for a healthy ecosystem. This can be seen in reserve forests like Thondala, Singireddy plantation, and many others. Reserve forests like Antaraganga have high SB with high Shannon value due to large number of native tree species with monoculture plantation. Majority of smaller forests of Kolar district is fully degraded with low standing biomass and diversity like Karadubadehosaḥalli, Muduvadi, and few others. Reserve forests of Chikballapur like Narasimhadevarabetta, Nandhi etc, though having large number of trees, their SB are not so high due to the relatively lower basal area of trees, with girth usually not more than 30-50 cm GBH. Human activities like logging, charcoal making and manmade forest fire add to the decrease in SB.

Large numbers of villages have a very low diversity and high dominance due to sparse forest area and wide cultivation of monoculture plantation. Few villages like Vibhuthipura and Singireddyhalli have slightly good Shannon value compared to other villages, though largely planted. They mainly consist of reserve forests planted with large numbers of native species and as a result there is increase in diversity. The original forests have long been degraded and what remain now are few patches of secondary forests, scrub vegetation and plantations. Chikballapur taluk has retained some good patches of forests due its relatively higher rainfall and lesser aridity. Nandhi forest alone harbors 82 species of trees showing the species richness of the area. Some of the valleys like Narasimhadevarabetta range exhibit very large species heterogeneity not only in valley bottoms but also along the slopes enhancing their conservation value. There are many more forests around Nandhi and other places of Chikballapur, which if conserved properly and restored to their original state, large number of resources including firewood and timber can be utilized, and can prove to be of immense value for the dry and arid district.

Assessment of bioresource status considering the availability of resource and the demand, shows that all the taluks situated in Kolar district are facing bioresource scarcity. This is mainly due to mismanagement of resources, neglect of appropriate conservation, over exploitation and grazing.

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Figure 2.FCC Image of Kolar

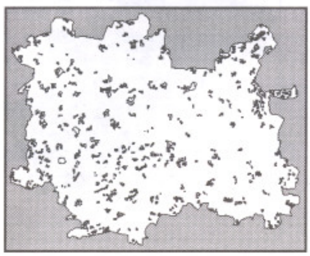

Figure 3. Training site

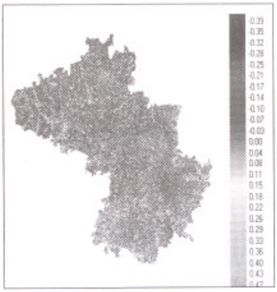

Figure 4. NDVI Iimage

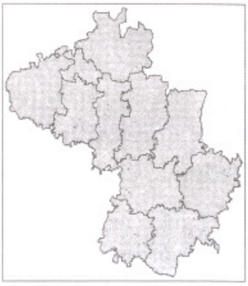

Figure 5.TSAVI Image

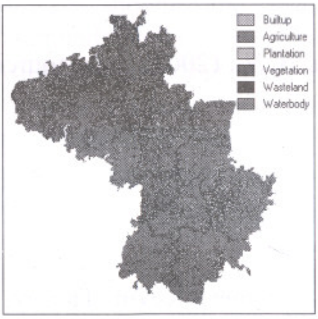

Figure 6. Minimum distance of mean with Standard distance classified image

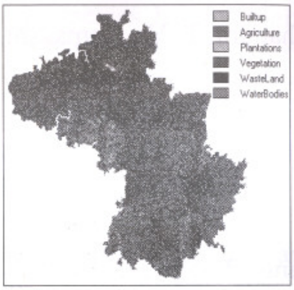

Figure 7.Parallelepiped classified Image

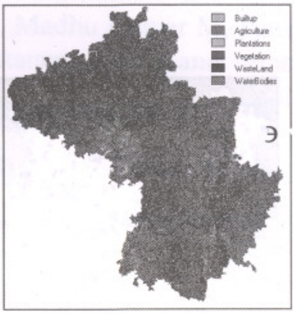

Figure 8. Maximum Likelihood Image

Figure 9. PAN image

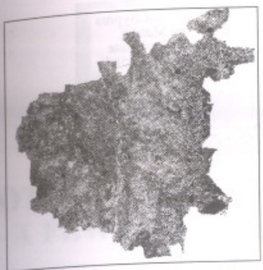

Figure 10. LISS III and PAN Image

Figure 11. Verification sites of prosopis juliflora

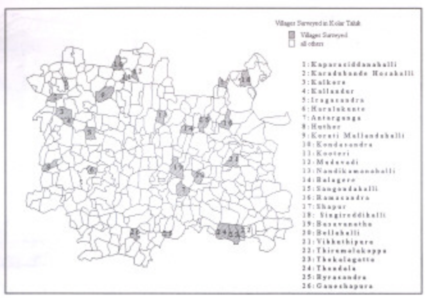

Figure 12. Villages surveyed in Kolar Taluk

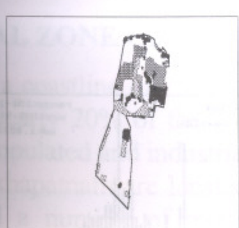

Figure 13. Vegetation cover map

Figure 14. PAN Iimage

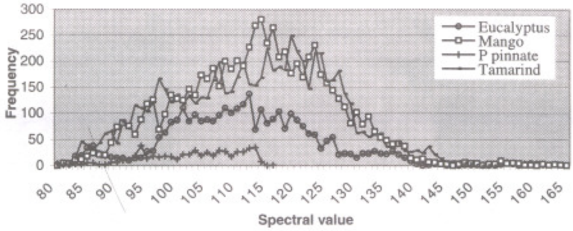

Figure 15. Spectral response curve of Irrigation village

Figure 16. Villages surveyed in Chikballpur village

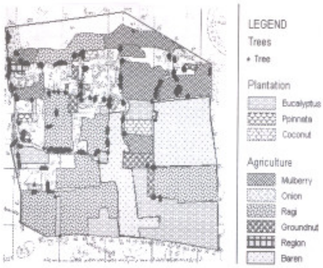

Figure 17. Vegetation cover map of Bannikupe village

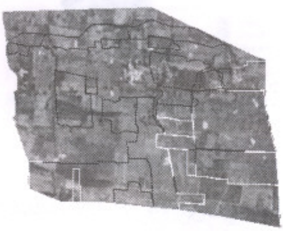

Figure 18. PAN Image of Bannikupe village

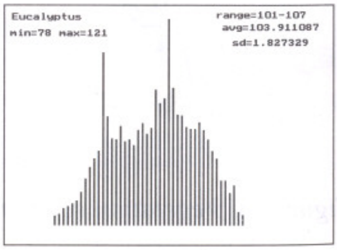

Figure 19. Spectral response curve of eucalyptus tree in Bannikupe village