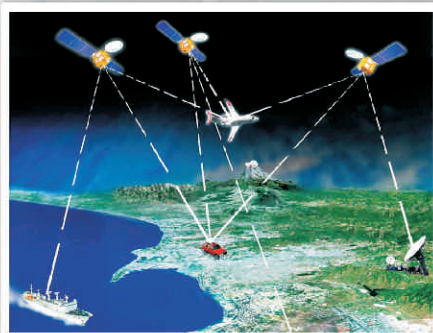
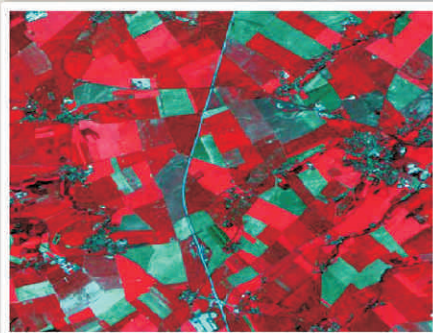
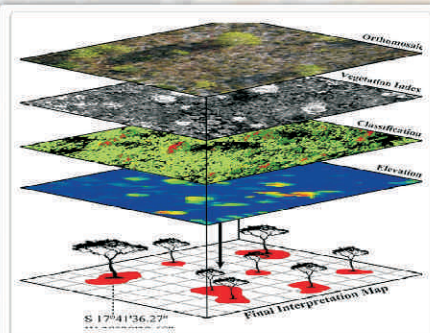
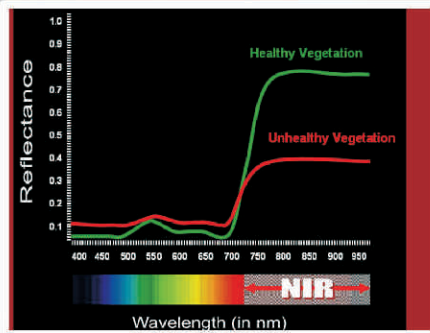




Agroforestry Mapping in India through Geospatial Technology Present Status & Way Forward



R.H. RIZVI • RAM NEWAJ • A.K. HANDA • K.B. SRIDHAR • ANIL KUMAR



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ICAR-Central Agroforestry Research Institute
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Foreword



In India, agroforestry is practiced since time immemorial. But systematic and scientific research on agroforestry started with All India Coordinated Research on Agroforestry (AICRPAF) in 1983. Design and Diagnostic Survey envisages that innumerable agroforestry practices are prevalent in India. Agri-silviculture, agri-horticulture, silvi-pasture, agri-horti-pasture are some of them. These agroforestry practices occupy considerable area in the country. But authentic and realistic figures on agroforestry area are not available. For reliable and accurate estimate of area under agroforestry in the country, frontier technologies like GIS, GPS and Satellite Remote Sensing can play an important role. These geo-spatial technologies has to be used in judicious way. Further application of GIS and remote sensing in agroforestry requires development of sound methodology.

ICAR-Central Agroforestry Research Institute, Jhansi started work on mapping agroforestry in 2007 with case studies of Yamunanagar and Saharanpur districts. Then CAFRI has been given the task of mapping agroforestry in the whole country under NICRA project. ICAR-CAFRI developed and tested the methodologies for both medium and high resolution remote sensing data. By these methodologies very encouraging and accurate results were obtained. This technical bulletin on “Agroforestry Mapping in India through Geospatial Technology: Present status & Way Forward” is a very timely and thoughtful compilation. This technical bulletin is an attempt towards understanding various issues in mapping agroforestry, possible approaches and methods developed, future scope of geospatial technology in agroforestry research. Species level identification & mapping, trees signature generation, biomass/ carbon estimation are also discussed in length.

I congratulates the authors for bringing out this compilation of scientific information in the form of technical bulletin. This would certainly be ready reckoner for researchers and planners on an important aspect of agroforestry status in India. I congratulates all the authors for this endeavor and wish them very good luck for future.

(Anil Kumar)

Director (A)

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Preface

Accurate mapping and estimation of extent of agroforestry area in the country is of utmost importance for planners. For this purpose, geo-spatial technologies like GIS, GPS and satellite remote sensing has crucial role to play. These technologies have successful applications in forestry, agriculture, geology, etc. but so far limited in agroforestry research. With the availability of high- resolution/hyperspectral remote sensing data, now species level mapping can be possible. But this needs systematic approach to be evolved and adopted. Integrated use of GIS, GPS and satellite remote sensing technologies may prove promising for agroforestry and tree species mapping on farmlands. As a result of 12 years research at ICAR- Central Agroforestry Research Institute, Jhansi, scientific methodologies for mapping agroforestry using medium, high resolution and hyperspectral remote sensing data have been developed and refined. This technical bulletin compiles all the research aspects of agroforestry like mapping trees/ tree species on farmlands, generation of spectral signatures, and assessment of carbon sequestration with the help of geo-spatial technologies.

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Agroforestry Mapping in India through Geospatial Technologies: Present Status & Way Forward

I. An Introduction to Geospatial Technologies

1. Geographic Information System

GIS is a generic term denoting the use of computers to create and depict digital representations of the earth's surface. Geographic Information System (GIS) offers capabilities of integrating multisector, multilevel and multi-period database. GIS is a computerized database system for capture, storage, retrieval, analysis, and display of spatial data. It is a general-purpose technology for handling geographic data in digital form, and satisfying the following specific needs, among others:

- (i) The ability to preprocess data from large stores into a form suitable for analysis, including operation such as reformatting, change of projection resampling, and generalization.
- (ii) Direct support for analysis and modeling, so that form of analysis, calibration of models, forecasting, and prediction are all handled through instructions to the GIS.
- (iii) Post processing of results including such operation as reformatting tabulation, report generation, and mapping.

Another major function of GIS capability is the study of environmental surroundings and the monitoring of environmental parameters (Burrough *et al.*, 1988). Although analytical models have been linked to GIS for spatial measurement and resource assessment, the cross fertilization between the modules of modeling measurement and automated mapping allows the GIS user to monitor the environment and the earth systems.

2. Remote Sensing

Remote sensing of earth's environment comprises measuring and recording of electromagnetic energy reflected from or emitted by the planet's surface and atmosphere from a vantage point above the surface, and relating of such measurements to the nature and distribution of surface materials and atmospheric condition. Sensors mounted on aircraft or satellite platform measure the amounts of energy reflected from or emitted by the earth's surface. These measurements are made at a large number of points distributed either along a one- dimensional profile on the ground below the platform or over a two – dimensional area on either side of the ground track of the platform. The sensors scan the ground below the satellite or aircraft platform and as the platform moves forward, an image of the earth's surface is built up.

Broadly, there are two types of sensing systems to record the information about any target. They are **active sensing system** and **passive sensing system**. An active sensing system generates and uses its own energy to illuminate the target and



records the reflected energy which carries the information content or entropy. Synthetic aperture radar (SAR) is one of the best examples of active sensing systems. These sensing systems operate in the microwave region of electromagnetic spectrum and include radiation with wavelengths longer than 1 mm. These systems do not rely on the detection of solar or terrestrial emissions as the solar irradiance in microwave region is negligible. The second type of remote sensing systems are passive systems mainly depending on the solar radiation operates in visible and infrared region of electromagnetic spectrum. The nature and properties of the target materials can be inferred from incident electromagnetic energy that is reflected, scattered or emitted by these materials on the earth's surface and recorded by the passive sensor (for example, a camera without flash). The remote sensing system that uses electromagnetic energy can be termed as electromagnetic remote sensing

The reflectance characteristic of earth's surface features may be quantified by measuring the portion of incident energy that is reflected. It is a dimensionless quantity. The quantities described above are very often used to refer to particular narrow wavebands rather than to the whole spectrum. The terms are then preceded by the word spectral as in spectral radiance for a given waveband is the radiant flux density in the waveband per unit solid angle per unit wavelength (Curran, 1988). The sun's light is the form of electromagnetic radiation most familiar to human beings. The light as reflected by physical objects travels in a straight line to the observer's eye. On reaching the retina, it generates electrical signals which are transmitted to the brain by the optic nerve. These signals are used by the brain to construct an image of the viewer's surroundings. This is the process of vision and it is closely analogous to the process of remote sensing; indeed, vision itself is a form of remote sensing. The set of all electromagnetic waves is called the electromagnetic spectrum, which includes the range from the long radio waves, through the microwave and infrared wavelengths to visible light waves and beyond them to the ultraviolet and to the short wave X- and gamma rays.

3. Electromagnetic Spectrum

In brief, the electromagnetic spectrum is the continuum of energy that ranges from meters to Nano-meters in wave length, travels at the speed of light, and propagates through a vacuum like the outer space (Sabins 1986) All matter radiates a range of electromagnetic energy, with the peak intensity shifting toward progressively shorter wave lengths at an increasing temperature of the matter. In general, the wavelengths and frequencies vary from shorter wave length high frequency cosmic waves to long wavelengths low frequency radio waves. The wave lengths of greatest interest in remote sensing are visible and near-infrared radiation in the wave band 0.4-3 micrometers, infrared radiation in the wave band 3-14 micrometers and microwave radiation in the wave band 5-500mm.

Every object on the surface of the earth has its unique spectral reflectance. Figure 1 shows the average spectral reflectance curves for three typical earth's features: vegetation, soil and water. The spectral reflectance curves for vigorous vegetation



manifests the (peak-and valley) configuration. The valleys in the visible portion of the spectrum are indicative of pigments in plant leaves. Dips in reflectance that can be seen at wavelengths of 0.65 μm , 1.4 μm and 1.9 μm , are attributable to absorption of water by leaves. The soil curve shows a more regular variation of reflectance. Factors that evidently affect soil reflectance are moisture content, soil texture, surface roughness, and presence of organic matter. The term spectral signature can also be used for spectral reflectance curves. Spectral signature is a set of characteristics by which a material or an object may be identified on any satellite image or photograph within the given range of wavelengths. Sometimes, spectral signature are used to denote the spectral response of the target.

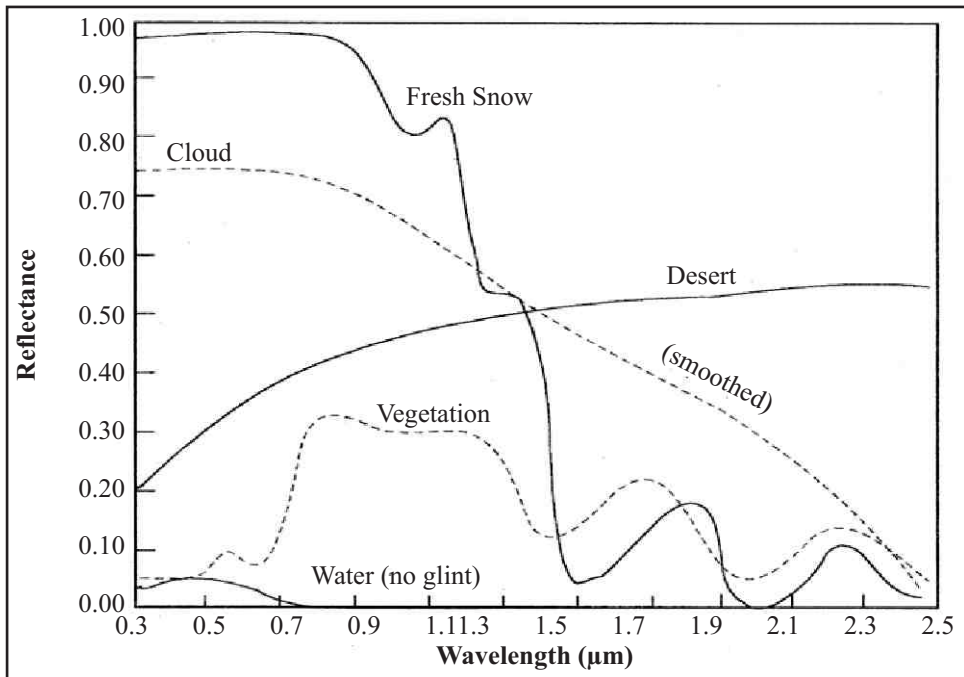


Fig. 1. Spectral reflectance curves (signatures) for different land features

Geo-spatial technologies like, Geographical Information System (GIS), Remote Sensing (RS) and Geographical Positioning System (GPS) have found applications in almost all areas. Natural resources management, biodiversity assessment, watershed planning, disaster management, forest cover mapping, crop acreage estimation, etc. are few of them. Satellite images are used to identify what is growing, while GIS component is used to assess area, categorize it and locate its position on earth's surface to provide complete record of the site. The integration of satellite remote sensing data into GIS is one of those great ideas which have made valuable contribution in other fields but need to be utilized in this area. Furthermore, remote sensing is often the most cost effective source of information for updating a GIS and it is a valuable source of current land use land cover data. In agroforestry, these technologies may be used for mapping agroforestry area, estimation of carbon



sequestration, identification of potential areas for suitable agroforestry interventions and more importantly in developing GIS based decision support system.

II. Remote Sensing Data and Methods for Mapping Agroforestry

1. Types of Remote Sensing Data

Remote sensing data is classified according to spatial resolution and spectral resolution. Various types of remote sensing data is now available for Indian and Foreign satellites. These satellite provides data from three types of sensors: panchromatic (PAN), multispectral (MSS) and hyperspectral. Spatial resolution of remote sensing data varies from coarse resolution of 250 m (MODIS), medium resolution of 30 m (LANDSAT), high resolution of 10 m (Sentinel-2) to very high resolution upto 2.5 m (Quick Bird, World View). Number of spectral bands also varies from 3 to 12 bands in visible, near infrared (NIR) and short-wave infrared (SWIR) spectral region. As far as Indian Remote Sensing satellites are concerned, Resourcesat-2 satellite images of different resolutions are available for the users (Table 1). Among them, medium resolution images like AWiFS (56m), LISS-3 (23.5m), and high resolution LISS-4 (5.8m), Cartosat-1 (2.5m) and Cartosat-2 (1m). Besides these, Cartosat Digital Elevation Model, Synthetic Aperture Radar microwave data of RISAT-1 and OCM data (360 m) are also available for the users. Remote sensing data of Indian satellite can be obtained from National Remote Sensing Centre (NRSC), Hyderabad.

With the help of medium resolution data like AWiFS and LISS III, land features like water bodies, agricultural crops and natural forests can be easily identified and mapped. But in case of agroforestry where scattered trees, boundary and agri-silviculture/block plantations exist, only agrisilviculture/ block plantations can be captured by these medium resolution data. Other systems like scattered trees and boundary plantations cannot be identified accurately. Agroforestry can be mapped with the help of high resolution data like LISS-4 (5.8 m), Cartosat-1 (2.5 m) and Cartosat-2 (1 m) with reasonably good accuracy. But Cartosat data is Panchromatic, so if LISS IV data is merged with Cartosat-1 data, we can get multispectral data of high resolution (2.5 m). Sentinels- 2A & 2B data can also be useful in mapping agroforestry, which is provided in 12 spectral bands (Table 2). These data are freely available and can be downloaded from <https://scihub.copernicus.eu/>.

Table 1. Sensor details of Indian Remote Sensing Satellite (Resourcesat-2)

Sensor	Type	Bands	Resolution (m)	Revisit (days)	Swath (km)
LISS-3	Multispectral	Green, Red, NIR, SWIR	23.5	24	140
LISS-4	Multispectral	Green, Red, NIR	5.8	5	23
	PAN	Red	5.8	5	70
AWiFS	Multispectral	Green, Red, NIR, SWIR	55	5	740



Table 2. Sensor details of Sentinel-2 bands and their spatial resolutions

Sentinel-2 Bands	Central Wavelength (μm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

2. Suitable Methods and RS Data for Mapping Agroforestry

2.1. Pixel & Sub-pixel based methods

Generally remote sensing data is analyzed for different land uses land covers (LULC) and images are classified by unsupervised and supervised methods. In unsupervised methods (K-means, ISO data), images are automatically classified into the number of classes specified by user. In this method, pixels are grouped according to their spectral values (DN or NDVI). On the other hand, in supervised classification methods like maximum likelihood, minimum distance to mean, etc. user gives training samples of land features. Then spectral signatures are generated and images are classified into those land features. But for supervised classification prior knowledge of possible land features is essential. Accuracy of land use/ land cover classification depends upon the spatial resolution of remote sensing data used. If the high resolution image is used say Cartosat-1 (2.5 m resolution) or LISS IV (5.8 m resolution); different vegetation like grass, crops and trees can be identified and delineated. But the cost and time will be much high if the study area is large say state or country and also administrative approval is required for procuring high resolution data like Quick Bird.

In case of high resolution data, single pixel will have spectral reflectance from single feature, so there are less chances of mixing of features within a pixel. Whereas in case of medium resolution data like LISS III (23.5 m resolution), LANDSAT (30 m resolution) single pixel can consist of two or more features or land covers such as crop, soil and trees. If high resolution LISS IV data is used where pixel size is 5.8 m, it may cover single tree with some crop or fallow area.

So it will represent agroforestry and agroforestry area obtained using high resolution data will be more accurate than when medium resolution data is used. When trees are planted on the field bunds/ boundary, even pixel based methods using LISS IV data may give wrong figures. In this case only those trees which have large canopy will be captured and trees having small canopy will be left out.

Another type of error that is usually occurred in agroforestry mapping is the intermingling of sugarcane crop with agroforestry. Reason for this is the similarity between signatures of sugarcane crop and young plantations (Figure 2). Soft classifiers like Fuzzy, though detects more than one features within pixel, cannot separate sugarcane with young plantations. Therefore, agroforestry mapping requires thoughtful and systematic approach as well as skill. Whether we use LISS III or LISS IV data, new plantations on farmlands are unable to be identified by any of pixel based classification methods. So the area estimates so obtained will not include such plantations and lead to wrong estimation.

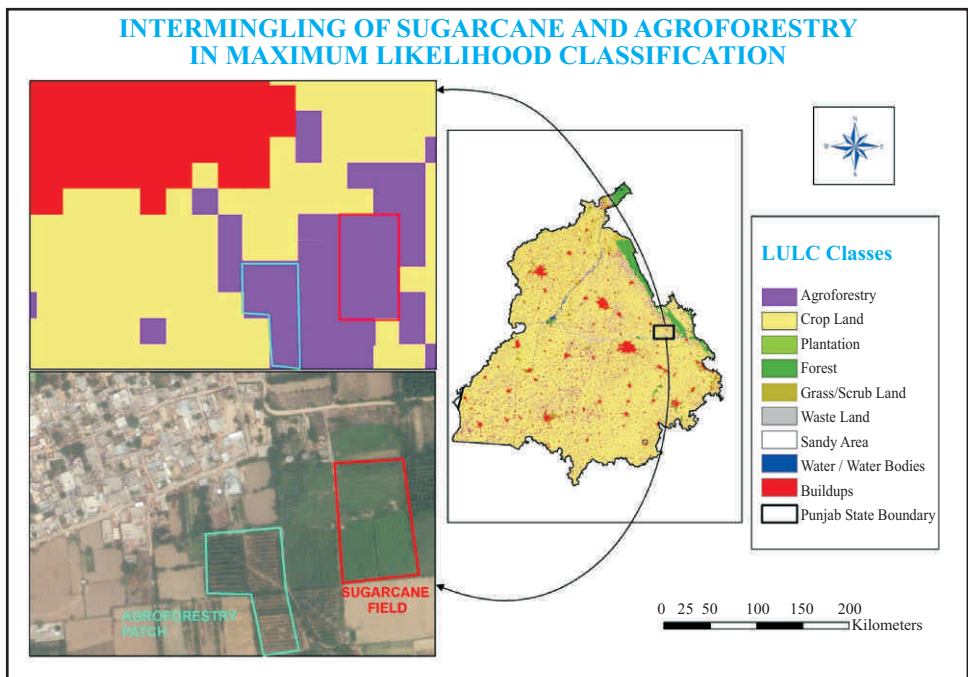


Fig. 2. Intermingling of sugarcane and agroforestry in maximum likelihood classifier

An alternative approach is to use a mixed pixel method or spectral mixture analysis (SMA). This method recognizes that a single pixel is typically made up of a number of varied spectral types (e.g. soil, vegetation, water). In effect, SMA is a technique used to measure the percentage of spectra for each land cover type in a single pixel. SMA has been successfully used to classify forest types (Settle and Drake, 1993), Alder trees (Oki *et al.*, 2002), Coconut land cover (Palaniswami *et al.*, 2006), Urban landscape (Lu and Weng, 2004). In SMA process, ground based data is especially useful with respect to increasing the accuracy of such classifications. Sub-pixel method of classification is another proven method, which has been used with



medium resolution data for mapping agroforestry (Rizvi *et al.* 2016, Rizvi *et al.* 2017). Agroforestry area has been mapped using sub-pixel classifier in some districts of Punjab, Gujarat and Maharashtra (Figures 3, 4a & 4b).

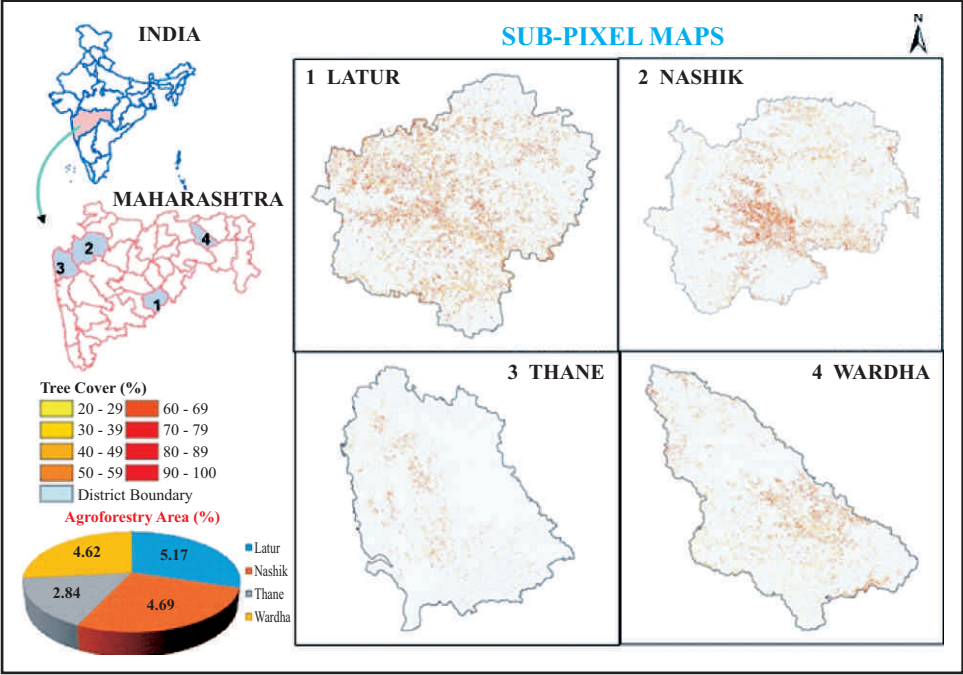


Fig. 3. Distribution of agroforestry area in selected districts of Maharashtra

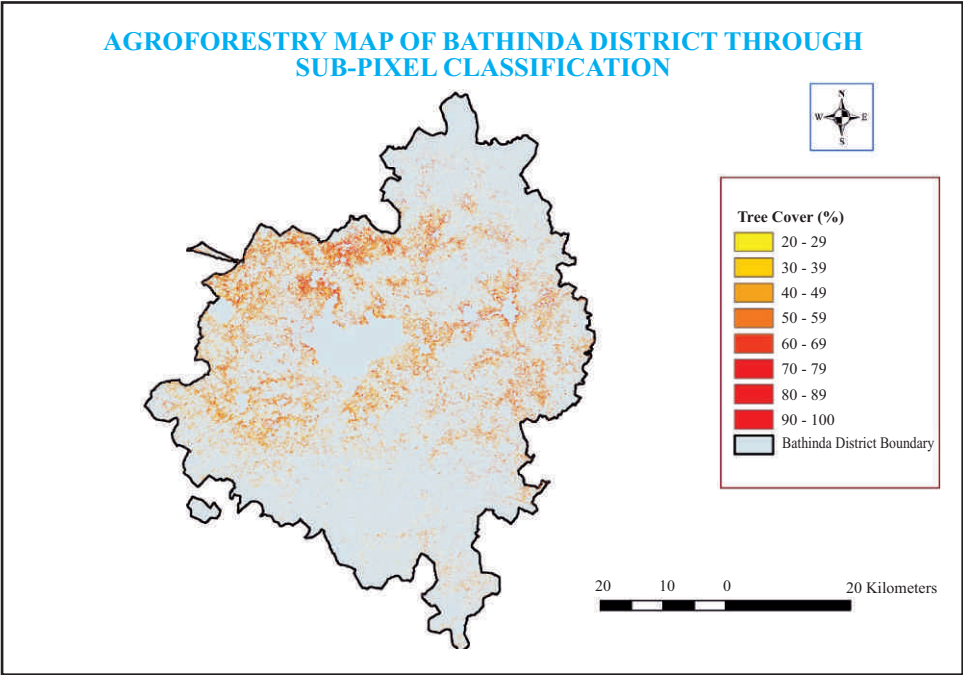


Fig. 4a. Agroforestry area mapped by sub-pixel method in Bathinda district

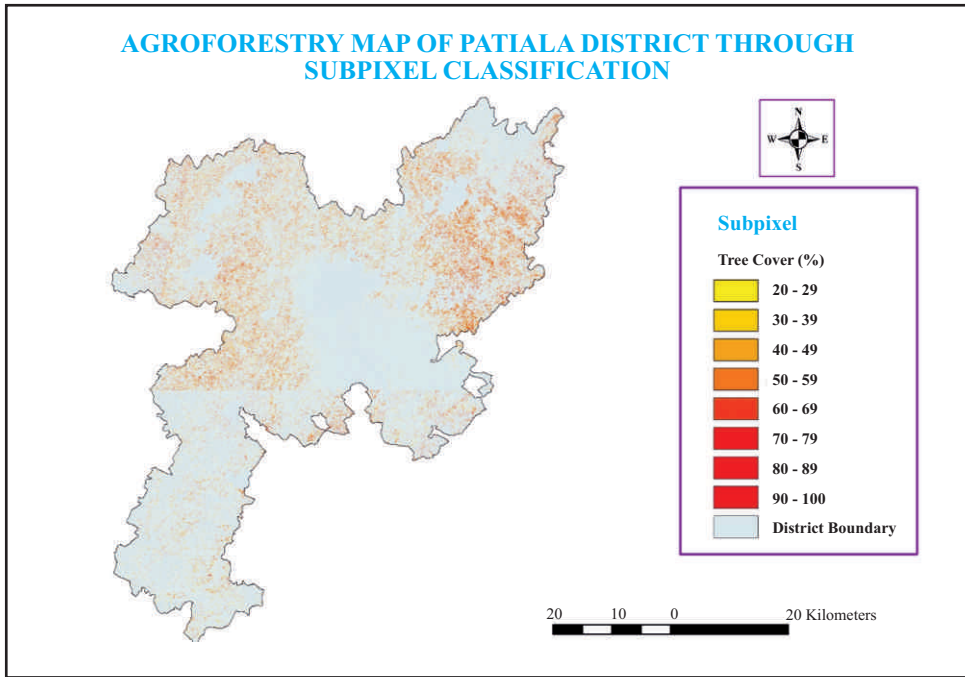


Fig. 4b. Agroforestry area mapped by sub-pixel method in Patiala district

2.2 Object Oriented Classification Method

Object oriented classification method is a useful and promising method of classifying objects from high resolution satellite images. This approach considers not only identification of land cover on a pixel but also organizes such pixels into groups (segments) that corresponds to real world objects. Object oriented image analysis approach combines spectral information and spectral information contrary to traditional methods relying on spectral information only. The method segments the pixel into objects according to the colour/ tone, texture, etc. of the image and classify by treating each object as a whole. Utilizing characteristic information like size, shape, orientation, shadow, etc. of an object in addition to using spectral information, Object oriented image analysis becomes a powerful image classification approach.

IMAGINE Objective in ERDAS 2010 and higher versions is one of the software solution to Object oriented classification and feature extraction available in the market. IMAGINE Objective tool employs feature models, which work on objects produced by image segmentation and various other pixel based algorithms which after being vectorized can be processed by geometric and textural parameters (Lack and Bleisch, 2010). With object-oriented analysis, it is possible to get better results from remote sensing information. That information may be immediately integrated into GIS allowing direct realization of vector maps (Barrile and Bilotta, 2008).



2.3. Steps involved in Object Based Image Analysis (OBIA)

Imagine Objective was used to map TOF by employing different feature detection and extraction methods. Constructing a feature model using different process nodes and cues for image interpretation.

➤ **Raster Pixel Processor (RPP):**

(Using NDVI)

For this pixel and object based classification NDVI and Bayesian network was chosen. Defining the training areas for trees as well as for background pixels. These training areas are submitted to compute pixel cue matrix to train the pixel classifier. NDVI pixel cue uses red and infrared band and computes the measure of vegetation vigor, where higher values (near 1.0) represent healthy vegetation.

(Using SFP)

For this pixel and object based classification, single feature probability (SFP) and Bayesian network was chosen. SFP using pixel cue that computes the probability matrix (between 0 & 1) to each pixel of the input image based on its pixel value and the training samples.

(Using NDVI + SFP)

Spectral information of NDVI were used as inputs for generation of SFP layers with the help of sample training pixels. The definition of training areas for agroforestry as well as for background pixels is of central importance in the classification process.

The output of this layer (Pixel probability layer) identifies the object of interest i.e. trees.

- **Raster Object Creator (ROC):** In this step function 'Threshold/Clump' was applied on a pixel probability layer. It keeps only those pixels which have probability greater than or equal to threshold value and it converts the remaining pixels in (0, 1).

It converts the pixel probability layer to raster object layer.

- **Raster Object Operator (ROO):** In this step probability filter and size filter are applied

Higher probability values are assigned to those pixels whose values are similar to the ones of pixels in the non-background training samples.

Lower probability values are assigned to those pixels whose values are either similar to the ones of pixels in the background training samples or significantly different from the values of pixels in the non-background training samples.



- **Raster to Vector Conversion (RVC):** In this step output of ROO is converted to vector object as polygon then produces a vector object layer.
- **Vector Object Operators (VOO):** In this step vector objects were 'smoothened' in shape.
- **Vector Object Processor (VOP):** In this step the object cues are computed on the tree polygons such as circularity, size and geometry.

III. Various Estimates of Agroforestry Area in India

1. Preliminary Estimates of Agroforestry Area

In India, the diagnostic survey and appraisal of agroforestry practices in the country revealed that there are enumerable practices in different agro-ecological zones. These systems/practices occupy sizeable areas and their accurate assessment is not yet done. Although different estimates at country level are available, but they are not realistic as they are not based on ground verification. Dhyani *et al.* (2013) estimated the agroforestry area as 25.32 million ha or 8.2 percent of the total geographical area of the country. As such on an average 14.2% of total cultivated land has agroforestry in one form or the other. However, these estimates are not the true reflection as they are not based on ground verification or revenue records. They have also projected the agroforestry area for year 2050 at 53.32 million ha. As per FSI (2013) estimates of green tree cover under agroforestry, 11.15 million area was found. For agroforestry, only rural TOF has been taken into consideration and tree green cover was estimated for 14 physiographic zones of India. Rizvi *et al.* (2014) gave preliminary estimates for extent of agroforestry area in India by using Bhuvan LULC data (<http://bhuvan-noeda.nrsc.gov.in/theme/thematic/theme.php>) for the year 2011-12. These estimates have been worked out by considering minimum 10 percent of agricultural land having agroforestry. According to this, there is about 14.46 million ha area under agroforestry when fallow lands are not included and potential area under agroforestry is estimated to be 17.45 million ha when fallow lands are included (Figure 5).

2. Agro-climatic Zone-wise Estimates of Agroforestry Area

Under National Innovations on Climate Resilient Agriculture (NICRA) project, agroforestry area has been estimated for different agro-climatic zones of India. So far 12 zones have been completed and total agroforestry in these zones was estimated to be 23.25 million ha which is about 8.69 percent of the total geographical area of these zones (Table 3). Highest agroforestry area of 15.47 percent was found in Upper Gangetic region, followed by 14.18 percent in West Coast Plains & Hill region and 13.56 percent in Gujarat Plains & Hill region. Thematic map showing agroforestry area in different agro-climatic zones of India is shown in figure 6.

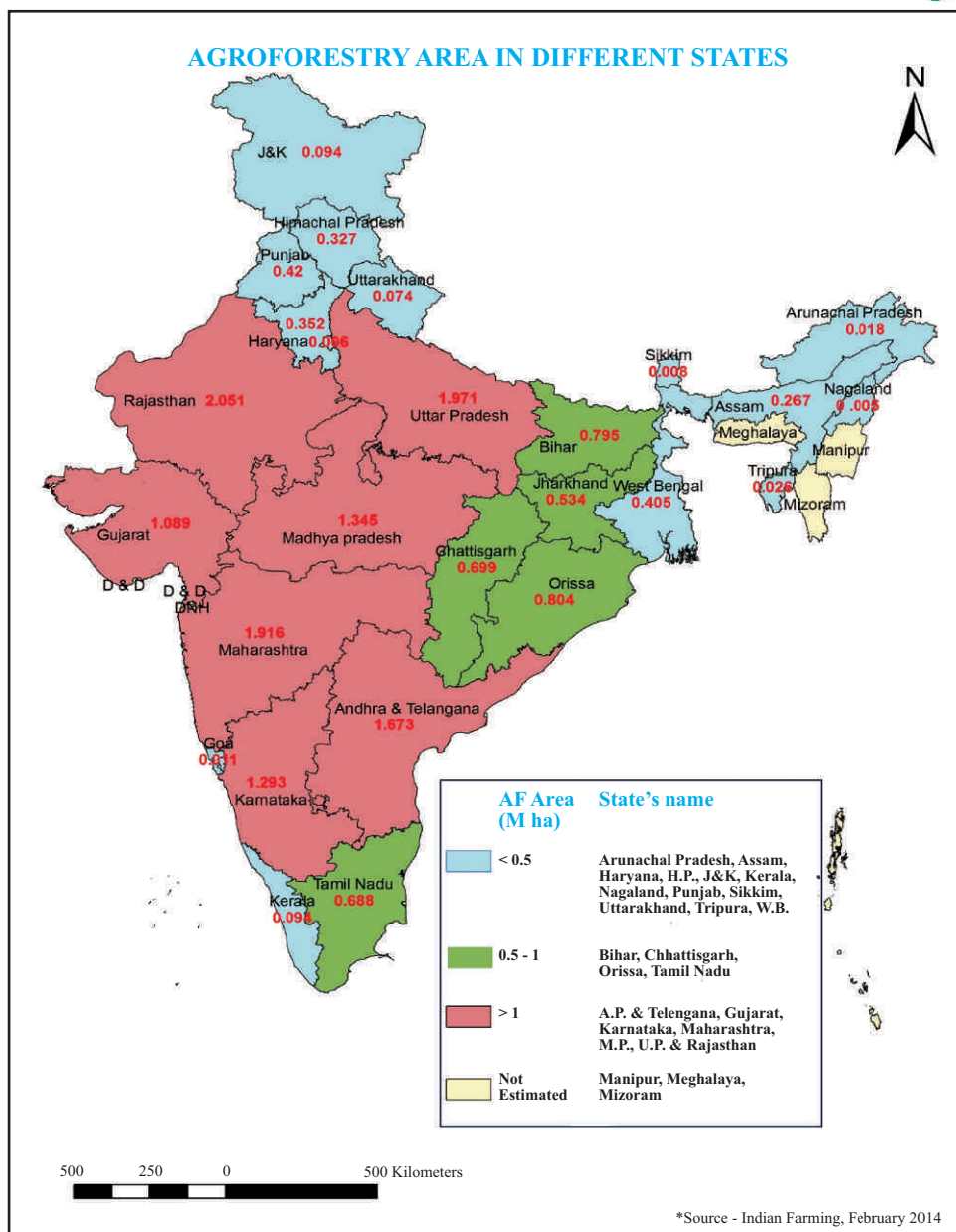


Fig. 5. Map showing state-wise estimated area under agroforestry

Table 3: Agro-climatic region-wise estimated area under agroforestry

ACZ No.	Agro-climatic Zones	Geographical Area (M ha)	Agroforestry Area (M ha)	Agroforestry Area (%)
3	Lower Gangetic Plains Region	6.733	0.802	11.91
4	Middle Gangetic Plains Region	16.570	1.304	7.87
5	Upper Gangetic Plains Region	14.441	2.234	15.47
6	Trans Gangetic Plains Region	11.603	1.143	9.85



7	Eastern Plateau & Hill Region	39.591	4.292	10.84
8	Central Plateau & Hill Region	37.843	1.926	5.09
9	Western Plateau & Hill Region	32.740	1.556	4.75
10	Southern Plateau & Hill Region	39.412	2.976	7.55
11	East Coast Plains & Hill Region	20.206	2.360	11.68
12	West Coast Plains & Hill Region	11.682	1.657	14.18
13	Gujarat Plains & Hill Region	18.977	2.570	13.56
14	Western Dry Region	17.871	0.431	2.41
Total		267.668	23.251	8.69

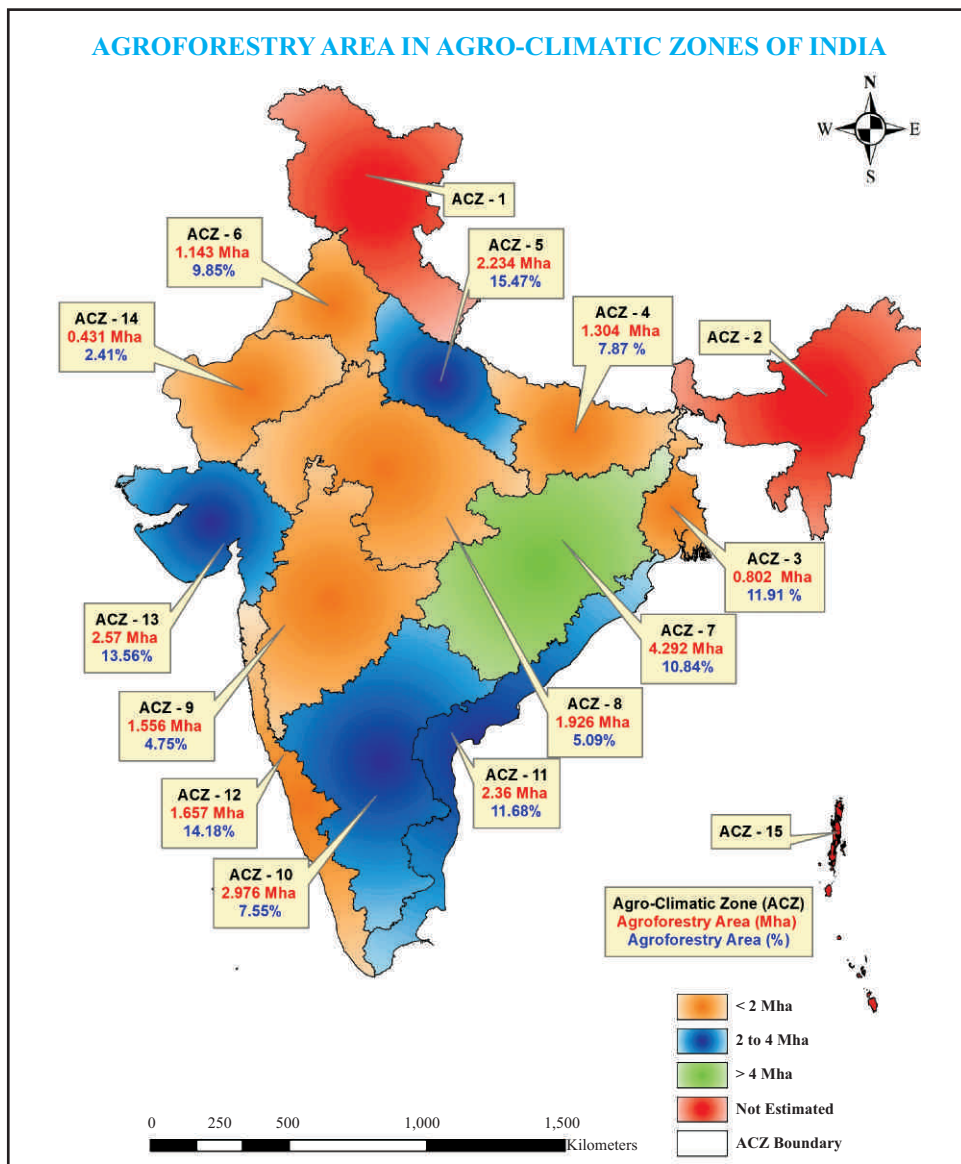


Fig. 6. Agro-climatic zone-wise estimated agroforestry area



Agroforestry Area in Selected Districts of Agro-climatic Zones

Total 13 and 9 districts were selected from agro-climatic zone-7 and zone-11, the two zones include parts of Jharkhand, Chattisgarh, Odisha, Madhya Pradesh, Andhra Pradesh, Maharashtra and Tamil Nadu states. Sub-pixel method was applied on LISS-3 whereas OBIA method was applied on LISS-4 data for mapping and estimating agroforestry area in these districts. Total agroforestry area in these 22 districts was estimated to be 1.58 million ha, which is 11.19 percent of their geographical area (Table 4). Agroforestry area varied from 4.71 to 28.10 percent in these districts with highest area of 0.233 million ha in Bilaspur district of Chhattisgarh. Map showing agroforestry area in selected districts of zone-7 and zone-11 are depicted in figures-7 & 8.

Table 4. Estimated agroforestry area in selected districts of agro-climatic zones- 7 & 11

Agro-climatic Zone	Selected district	Geographical Area (ha)	AF area (ha)	AF area (%)
Eastern Plateau & Hill Region (ACZ-7)	Shehdol	567653.00	67555.87	11.90
	Bilaspur	831378.24	233615.17	28.10
	Dhamtari	408496.72	26466.51	6.48
	Raigarh	705544.39	135413.08	19.19
	Bijapur	904734.54	50442.28	5.58
	Paschim Sighbhum	723632.49	46314.20	6.40
	Gumla	536878.02	60256.28	11.22
	Sundargarh	976192.1	86819.43	8.89
	Dhenkanal	445695.24	20983.76	4.71
	Balangir	657500.00	46588.80	7.09
	Koraput	836621.57	42978.55	5.14
	Bokaro	288525.14	24648.02	8.54
	Dumka	376378.85	52935.67	14.06
East Coast Plains & Hill Region (ACZ-11)	W. Godawari	772678.80	126156.00	16.33
	Vizianagram	616864.95	71220.07	11.55
	Prakasham	1761690.83	176253.90	10.00
	Puri	349670.41	32387.97	9.26
	Jajpur	291540.98	21613.98	7.41
	Shivganga	410159.08	53417.97	13.02
	Tiruannamalai	619210.5	78717.32	12.71
	Cuddalore	371827.96	62751.39	16.88
	Tiruneveli	681940.9	63813.51	9.36
Total/ Average		14134814.71	1581349.73	11.19

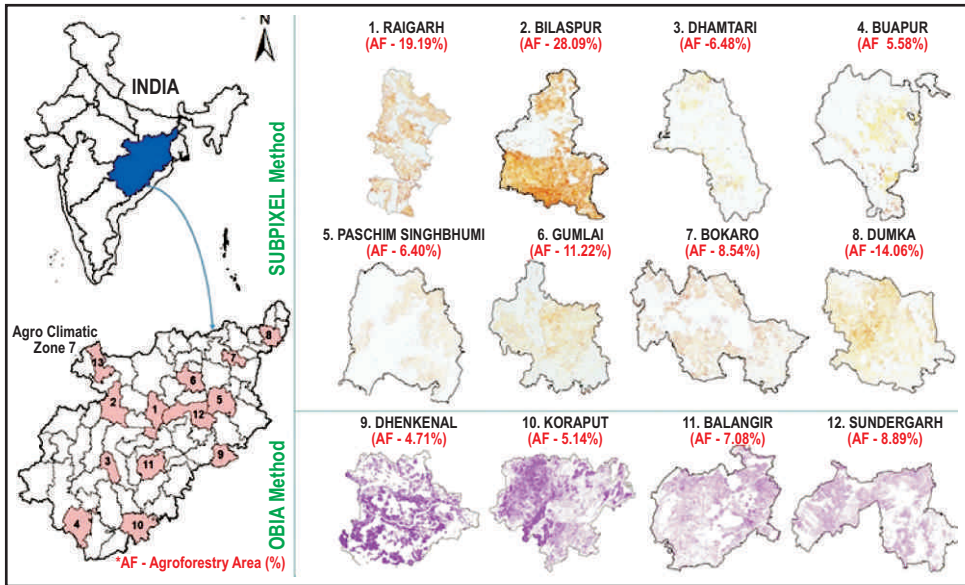


Fig. 7. Agroforestry area in selected districts of agro-climatic zone-7

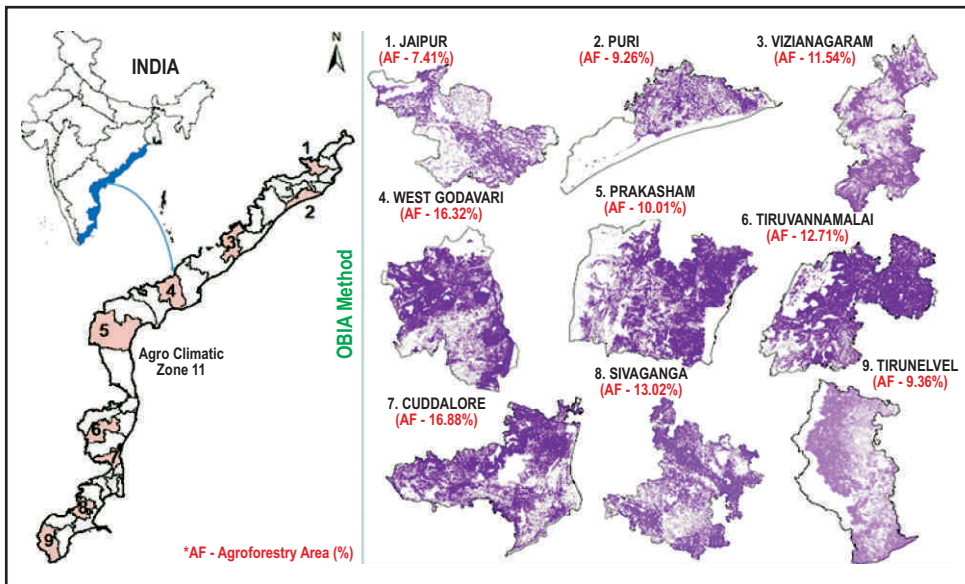


Fig. 8. Agroforestry area in selected districts of agro-climatic zone-11

IV. Methodology Developed by CAFRI for Mapping Agroforestry

A major problem in estimating area under agroforestry is lack of procedures for delineating the area influenced by trees in a mixed stand of trees and crops. In simultaneous systems the entire area occupied by multi-strata systems such as home gardens, shaded perennial systems and intensive tree-intercropping situations can be listed as agroforestry. The problem is more difficult in the case of practices such as windbreaks and boundary planting where although trees are planted at wide



distance between rows (windbreak) or around agricultural fields (boundary planting) because the influence of trees extend over a larger than easily perceivable extent of areas. Different methodologies have been developed for mapping agroforestry. In some, pixel based methods were used with high resolution remote sensing data whereas in others medium resolution data was used. Forest Survey of India (FSI) has used tree inventory and remote sensing technology for mapping trees outside forest, but bund plantations which is a part of agroforestry have not been included.

1. Methodology for Medium Resolution Data

For mapping and estimating area under agroforestry using medium resolution remote sensing data, Central Agroforestry Research Institute, Jhansi (U.P.) has developed a methodology (Figure 9). First, land use land cover classification (LULC) on LISS III data is to be done by supervised method. Agricultural land including cropland and fallow land is then extracted from this classified image for masking equivalent area from False Colour Composite. Since pixel based methods account for single major feature occurring in a pixel, even if more than one features/ land covers are present. Besides, some wrong classification may happen with pixel based methods. Therefore, sub-pixel method of classification was applied on agricultural land because agroforestry exist on agricultural land only. Advantage of using sub-pixel classifier is that this method not only overcomes the problem of intermingling of sugarcane with young plantations, but also gives outcome in the form of per cent tree cover within pixel. This tree cover (20 to 100%) accounts for all types of agroforestry systems *viz.* scattered trees, boundary plantations and block plantations on farmlands (Figure 10).

Applying sub-pixel classifier on extracted agricultural area using the generated signatures, resultant image will consist of pixels of five categories i) pixels covering trees plus cropland, ii) pixels covering fallow land plus trees, iii) pixels covering trees only, iv) pixels covering cropland only and v) pixels covering fallow land only. Pixels of first three categories which includes scattered trees, boundary plantations as well as block plantations will represent agroforestry in real sense.

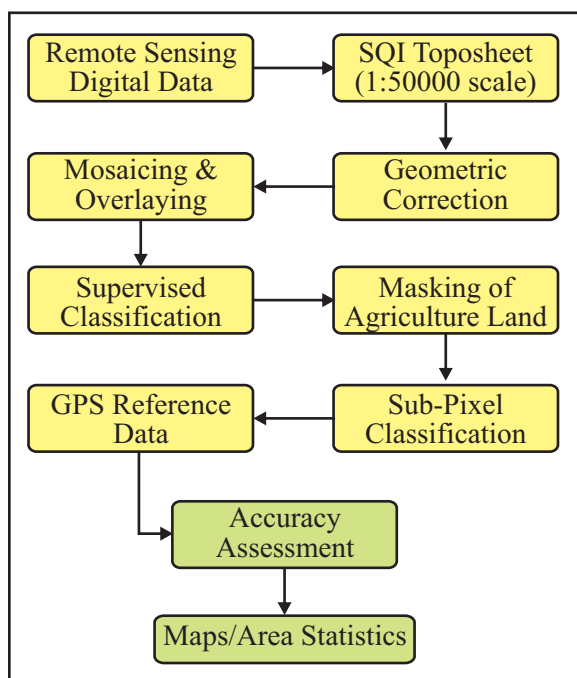


Fig. 9. Flowchart showing methodology for agroforestry mapping

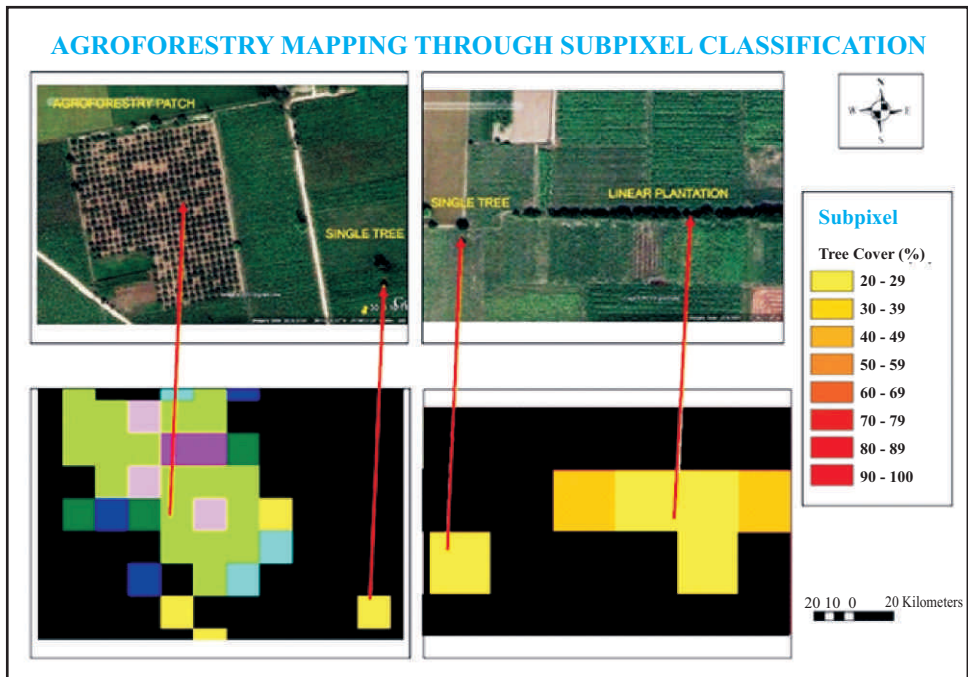


Fig. 10. Single tree, linear and block plantations identified through sub-pixel classifier

2. Methodology for High Resolution Data

In case of high resolution remote sensing data like LISS-4 (5.8 m) or Cartosat-1 (2.5m) data, trees on farmlands can be easily captured as compared to medium resolution data. ICAR-CAFRI, Jhansi has developed methodology for mapping trees on farmlands i.e. agroforestry using object-oriented classification technique applied on LISS-4 data. Flowchart of methodology adopted is shown in figure 11. Various steps involved in this methodology are given below:

Approach Followed:

- Step 1: *High Resolution LISS-4 data (spatial resolution- 5.8 m) were procured from NRSC, Hyderabad.*
- Step 2: *Pre-processing of scenes includes layer stacking, mosaicking and sub setting the LISS-4 bands (green, red & NIR) with district boundary shape file.*
- Step 3: *Unsupervised classification method (k-means/ ISODATA) was applied for getting different land uses and land covers including forest cover.*
- Step 4: *Extract the forest cover area from the FCC image with the help of classified image of the district.*
- Step 5: *Applying object based image analysis (OBIA) method on district area excluding forest cover, output will include only trees out sided forest (TOF) in the form of polygons.*



Step 6: *Post classification correction was applied on TOF to remove trees along roads, canals, within urban areas, etc. to finally get agroforestry area.*

Step 7: *Accuracy of agroforestry area so obtained is determined with the help of ground check points (GPS) and final map is prepared.*

The above methodology was tested on many districts and results were compared with that of pixel based methods. The results obtained by this methodology were quite encouraging for delineation of scattered trees, linear patterns and block plantations with reasonable good accuracy. A case study of Koraput district in Odisha is given in the next section.

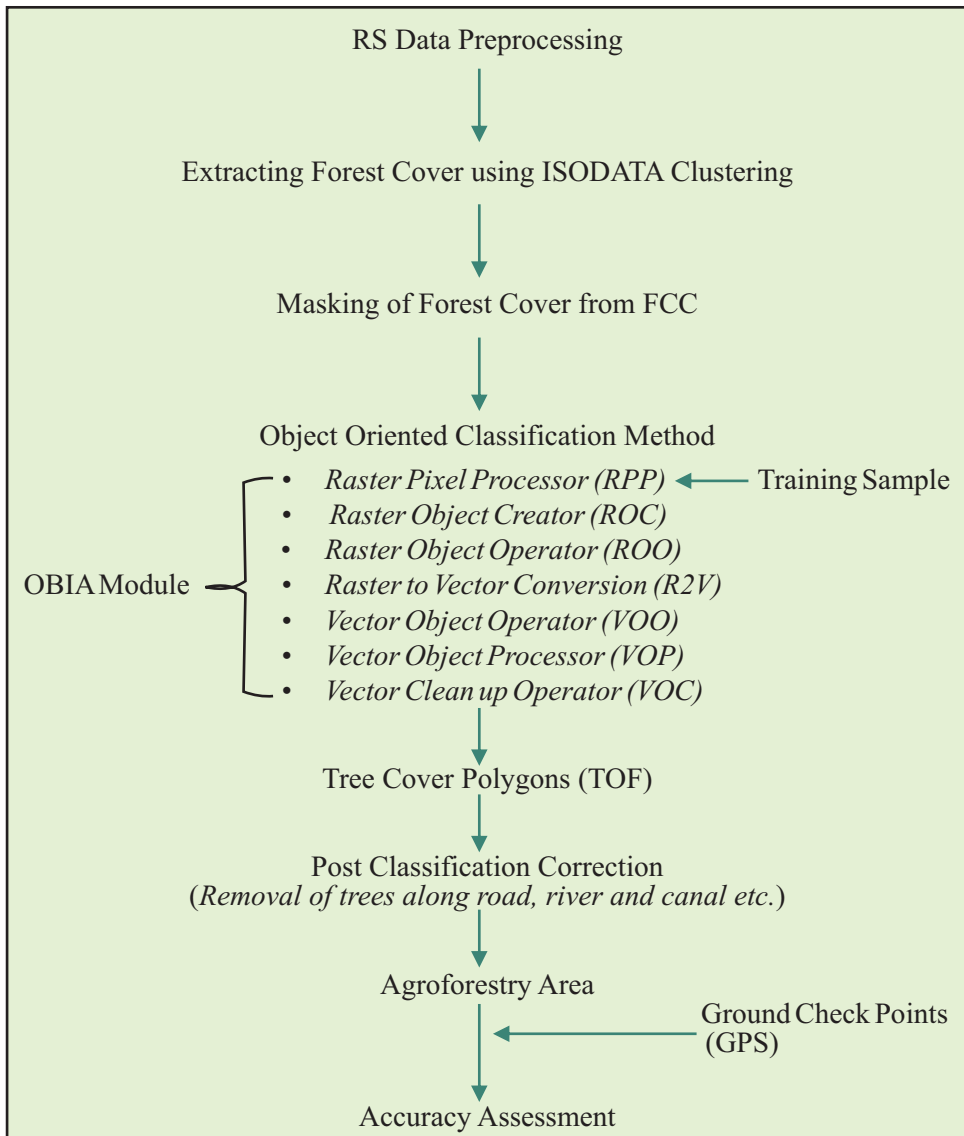


Fig. 11. OBIA methodology for mapping tree cover and agroforestry



3. Mapping Agroforestry using OBIA Approach

Case Study of Koraput district of Odisha

Koraput district of Odisha was taken as case study for mapping agroforestry using Object Based Image Analysis (OBIA) technique for which LISS-4 data has been used. In case of maximum likelihood classifier (MLC), area under agroforestry was estimated to be 31795.28 ha (3.80%). The overall accuracy of LULC comes out to be 80.8% with kappa coefficient of 0.783 in this case. While using OBIA (on agricultural land) agroforestry area was estimated to be 42978.55 ha (5.14%) (Table 5). Very good accuracy of 91.2% was achieved in agroforestry class by OBIA classification. The results obtained by MLC and OBIA methods were compared in case of agroforestry (Figure 12). In case of supervised classification, those pixels are fully captured where trees exist, whereas OBIA captures trees according to their crown shapes. This lead to accurate estimation of area under trees in scattered, in linear and also in patch form (Figure 13). Therefore, OBIA could be an appropriate method for mapping all types of agroforestry (scattered trees, boundary and block plantations) existing on farmlands. Agroforestry area in Koraput district obtained by OBIA technique is given in figure 14.

Table 5. Agroforestry area obtained by MLC & OBIA methods in Koraput district

LULC Classes	MLC		OBIA	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Agroforestry	31795.28	3.80	42978.55	5.14
Crop land	322367.25	38.53	.....	.....
Plantation	3167.41	0.38	.....	.....
Forest	261348.25	31.24	.....	.....
Degraded forest	24930.94	2.98	.....	.....
Waste land	151472.64	18.11	.....	.....
Sandy area	269.69	0.03	.....	.....
Water body	33182.19	3.97	.....	.....
Built ups	8087.92	0.97	.....	.....
Geographical Area (ha)	836621.57			

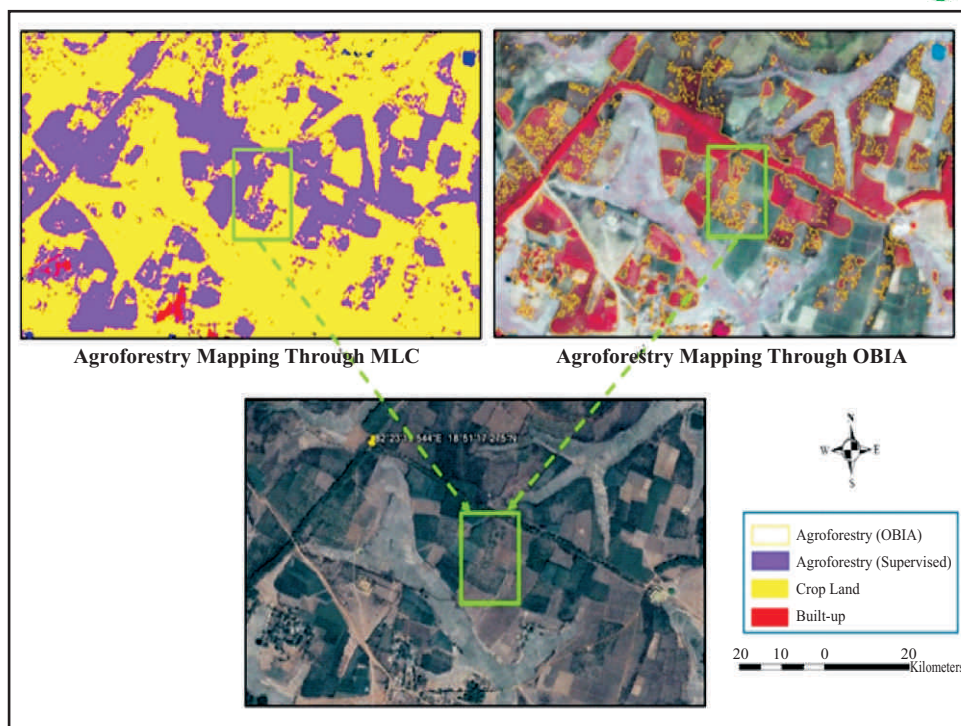


Fig. 12. Agroforestry mapping by maximum likelihood and OBIA techniques

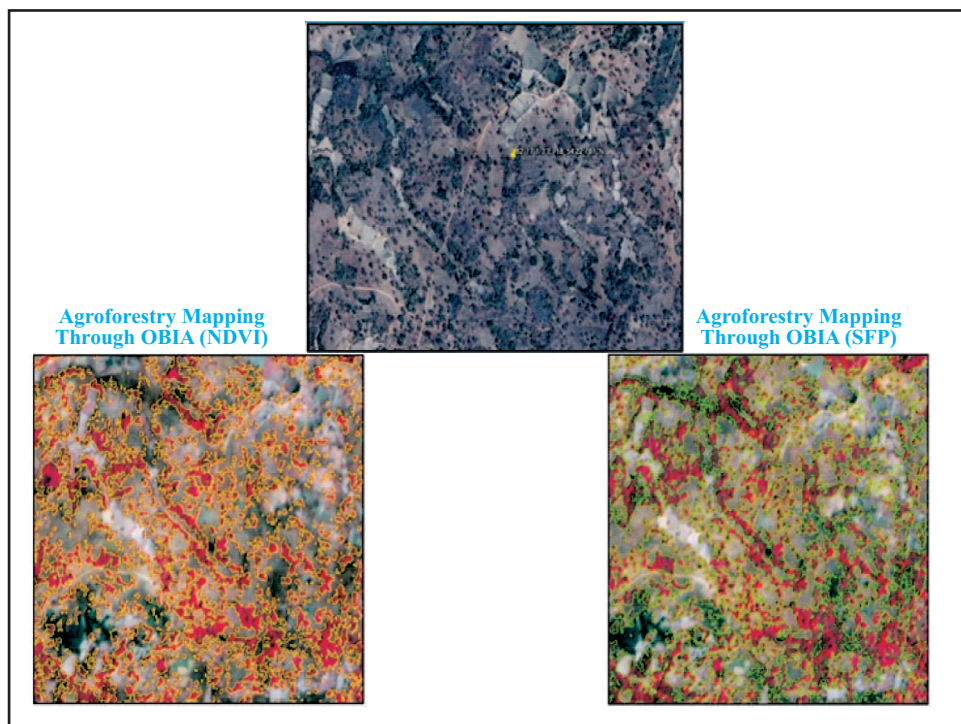


Fig. 13. Agroforestry mapping by maximum likelihood and OBIA techniques

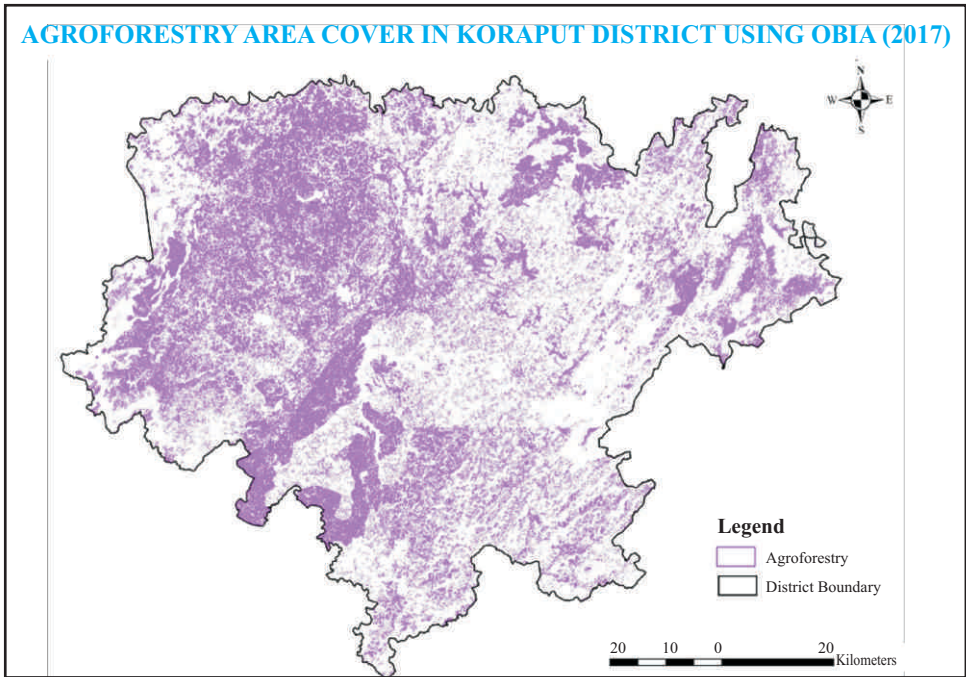


Fig. 14. Agroforestry area in Koraput district mapped by OBIA method

V. Mapping Species on Farmlands: Possible Approaches

1. Importance of Spectral Signatures for Mapping Species

Recent advances in hyperspectral sensors offer considerable potential for discrimination of earth surface materials. It is because the electromagnetic spectrum is divided into hundreds of discrete, contiguous spectral bands, sufficient to read the spectral signature of the material in the image. Hyperspectral imaging systems acquire images in over one hundred contiguous spectral bands. While multispectral imagery is useful to discriminate land surface features and landscape patterns, hyperspectral imagery allows for identification and characterization of materials (Table 6). As compared to Multi-spectral sensors, Hyperspectral sensors collect reflectance from objects simultaneously in hundreds of narrow adjacent spectral bands. Thus due to their high spectral resolution, they are more efficient in discriminating soils, minerals, vegetation and man-made materials (Figure 15).

Hyperspectral images provide ample spectral information to identify and distinguish spectrally unique materials. Vegetation Scientists are using hyperspectral imagery to identify plant species, study plant canopy chemistry and detect vegetation stress; which is not possible with multi-spectral data. Most hyperspectral sensors are airborne, with two exceptions, the Hyperion sensor from NASA, USA on board the EO-1 satellite with 242 bands and the FTHSI sensor from the US Airforce Research Lab on-board the Mightysat- II satellite with 256 bands. Using hyperspectral data, spectrally similar materials can be distinguished and sub-pixel information can be extracted.



Table 6. Comparison of multispectral and hyperspectral data

Characteristics	Multispectral data	Hyperspectral data
No. of spectral bands	3 - 8	100 - 256
Spectral range	400 - 1300 nm	350 - 2500 nm
Bandwidth	Broad	Narrow, discrete
Applications	Land/ Forest cover mapping, crop area estimation, etc.	Species identification, vegetation stress detection, plant canopy chemistry, mineral mapping, etc.

Well-developed scientific application areas include geology and mineral exploration; forestry; marine, coastal zone, inland waters and wetlands; agriculture; ecology; urban; snow and ice; and atmosphere. The high spectral resolution of a hyperspectral imagery allows for detection, identification and quantification of surface materials, as well as inferring biological and chemical processes. For all of these applications, ground truth signatures collected in the field and indexed in spectral libraries are critical for many methods of analysis. While image processing packages often include basic spectral libraries, application distinct libraries containing spectra of the specific materials occurring in the target field area greatly improves the accuracy of generated interpretations.

In particular, spectra of vegetation are influenced by such a wide range of environmental conditions that it makes it difficult to adequately represent this variability without the collection of site specific field spectra. With this aim, an ICAR-Extramural project was initiated at CAFRI, Jhansi in 2016 to develop a digital library of spectral signatures for major agroforestry tree species. Under this project four agroforestry species *viz.* Aonla, Mango, Eucalyptus, Poplar were selected and spectral signatures were developed using hyperspectral/ high resolution remote sensing data.

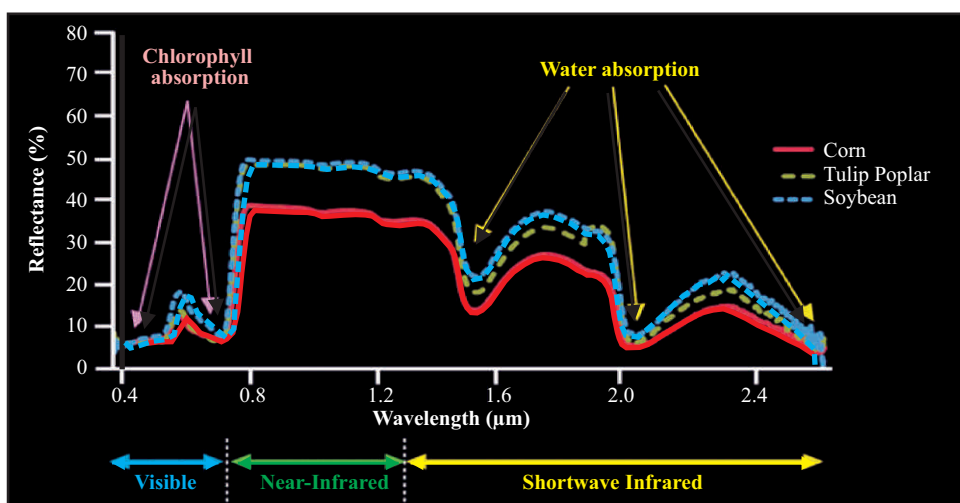


Fig. 15. Comparison of signatures of different vegetation on hyperspectral scale

2. Mapping of Mango (*Mangifera indica*) species

EO-1 Hyperion hyperspectral data for Lucknow and Unnao area has been downloaded from USGS website (<http://earthexplorer.usgs.gov>). USGS Hyperion product (L1R) contains 242 bands, of which 44 bands (1-7, 58-76, and 225-242) are uncalibrated bands. Also there exist spectral overlapping between visible to near infra-red (VNIR) and short wave infra-red (SWIR) spectral range for bands 56-57 and 77-78. Therefore, out of the 198 calibrated bands, there are 196 unique spectral channels.

Downloaded data was pre-processed using ENVI software ver. 5.3 for poor band removals, de-striping, atmospheric correction, etc. Minimum Noise Fraction (MNF) transformation was also done for improving the quality of image which would help in better features identification. Pure pixels (endmember) of mango have been identified by pixel purity index (PPI) and n-D visualization techniques. Spectral signatures using Hyperion data for three periods March, May and November have been generated for mango species. It can be observed from the signature plots that spectral reflectance is higher in NIR spectral region (700-1300 nm) than visible region (400-700 nm). An erratic pattern was observed in spectral reflectance beyond 2000 nm in all three periods and sudden drop was also observed in the values just after 1300 and 1800 nm.

For the month of March, large variation is seen in mean spectral reflectance (0.17-0.27) in NIR region; whereas for May, spectral reflectance is almost same (0.33-0.35). This is due to the fact that in March, flowers are there on the Mango tree, which are not green. But in May, Mango tree is covered with both fruits and leaves, which are green in colour. This has led to high spectral reflectance in the month of May (Figure 16). Again in the month of November, mean spectral reflectance has large variation (0.26-0.38) in NIR region. This is because at that time, tree has both fresh and old leaves and fresh leaves were brown in colour.

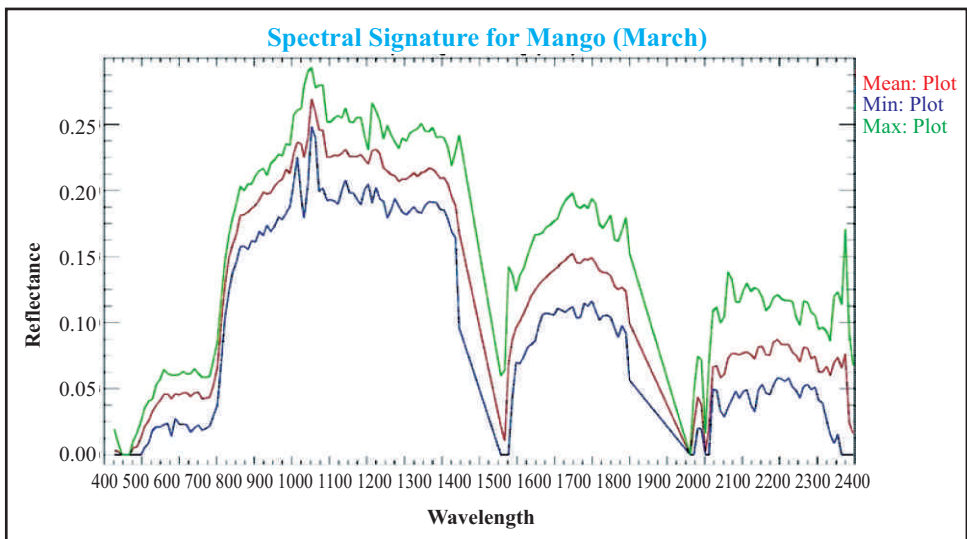


Fig. 16. Spectral signature of *Mangifera indica* in the month of March

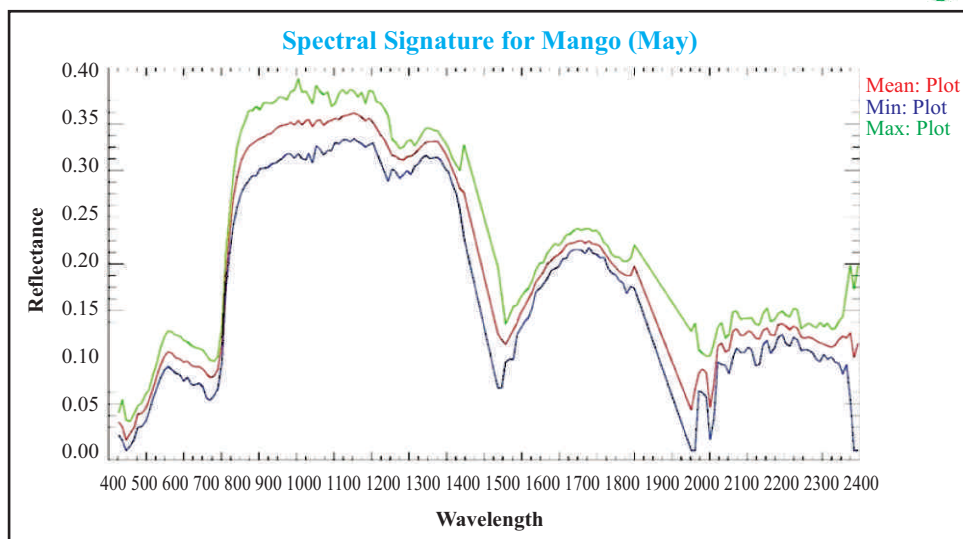


Fig. 17. Spectral signature of *Mangifera indica* in the month of May

Hyperion data for the period May was classified using developed spectral signature of mango using Spectral Angle Mapper (SAM), a spectral matching technique. The result of SAM classification is an image showing best match at each pixel for Mango species. Spectral Angle Mapper actually computes spectral angle between pixel spectrum and target spectrum. Three different spectral angles (0.06, 0.07 and 0.08 radians) were used in SAM classifier. The classified images were checked for accuracy with the help of GPS points collected on mango during field survey. Reasonably good accuracy of 87 percent was found in Mango classification using SAM and hyper-spectral signature. Such library of spectral signatures developed for mango species in different seasons will work as target spectra for classification of remote sensing data for this species.

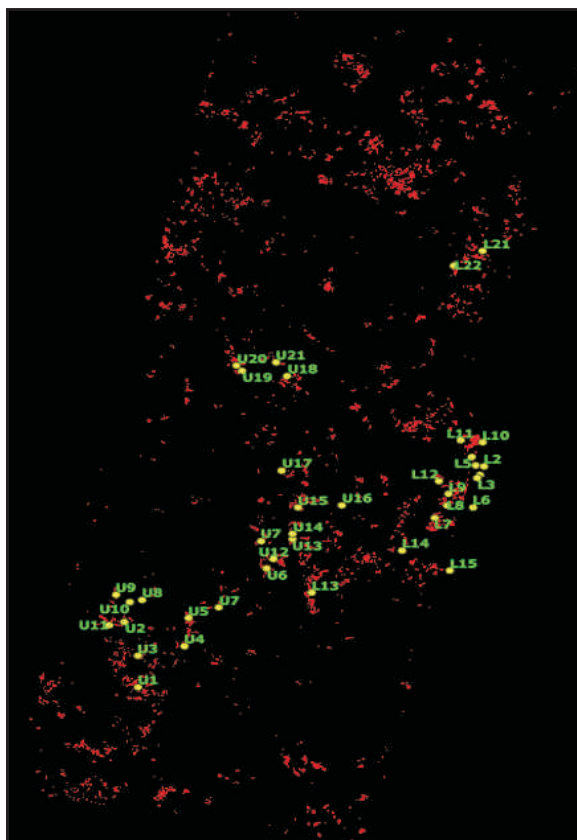


Fig. 18. Mapping of Mango species in Unnao and Lucknow

3. Mapping of Sapota (*Manilkara zapota*) species using sub-pixel

In Junagarh district, fruit as well as timber species were found under agroforestry, Sapota (*Manilkara zapota*) and Mango (*Mangifera indica*) were the dominant species among them. For species level classification, agroforestry area already obtained by sub-pixel classifier was again used and reclassified for Sapota and other species based agroforestry systems. Total 195 GPS points were collected for *Manilkara zapota* trees from the farmers' fields in Vanthalli and Una blocks of Junagarh district. Some of these points were used for making MOI (material of interest) which generated signatures for Sapota species and remaining points were used for finding classification accuracy. Area under Sapota based agroforestry come out to be 9966.76 ha (1.13%) of the total area under agroforestry (Figure 19). The accuracy of this classification come out to be 87.2 per cent for Sapota species. Remaining 11.25 per cent area was under other agroforestry systems like *Mangifera indica*, *Emblca officinalis*, *Zizyphus mauritiana* based agri-horticulture systems.

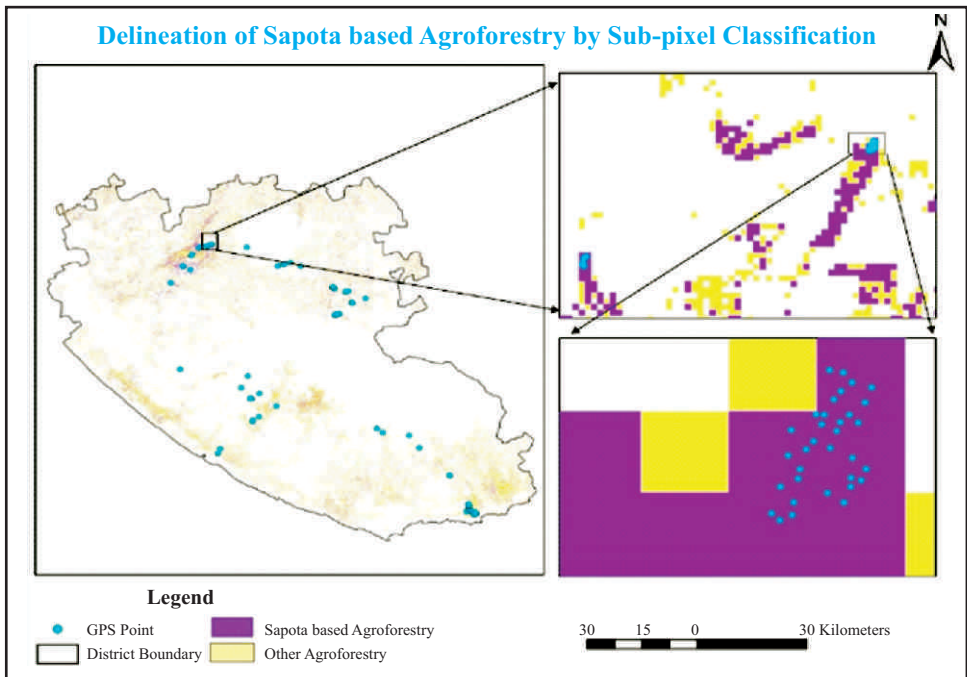


Fig. 19. Sapota based agroforestry in Juagarh delineated by sub-pixel classifier

4. Mapping of Poplar (*Populus deltoides*) species

For Poplar species, spectral signatures have been generated using EO-1 Hyperion hyperspectral data for three periods (May, Sept. and Dec.). That data was downloaded from USGS website, processed and analyzed in ENVI 5.3 software. Methodology has been developed for generation of spectral signatures from hyperspectral data. It involves various steps like pre-processing, atmospheric correction, MNF transformation, pixel purity index, n-D visualization, endmember selection, etc. (Figure 20).



Spectral reflectance pattern for Poplar in three periods appear different in different spectral ranges: visible (400-700 nm), near-infra red (700-1100 nm) and short-wave infra-red (100-1800 nm). In the month of May, when tree is full of new flesh, the spectral reflectance in NIR range is high (Figure 21), which is not in the month of Sept. (Figure 22). Again in the month of Dec. when tree has no leaves, spectral reflectance in visible, NIR and SWIR is showing low values (Figure 23). Spectral signatures of Poplar plantations of different ages generated from Sentinel-2A data shows variation in both visible and near-infra red regions (Figure 24). This clearly indicated that seasonal or phenological behavior of tree has significant effect on spectral signatures. Therefore by having library of spectral signatures for different seasons would help in accurate mapping of a particular tree species.

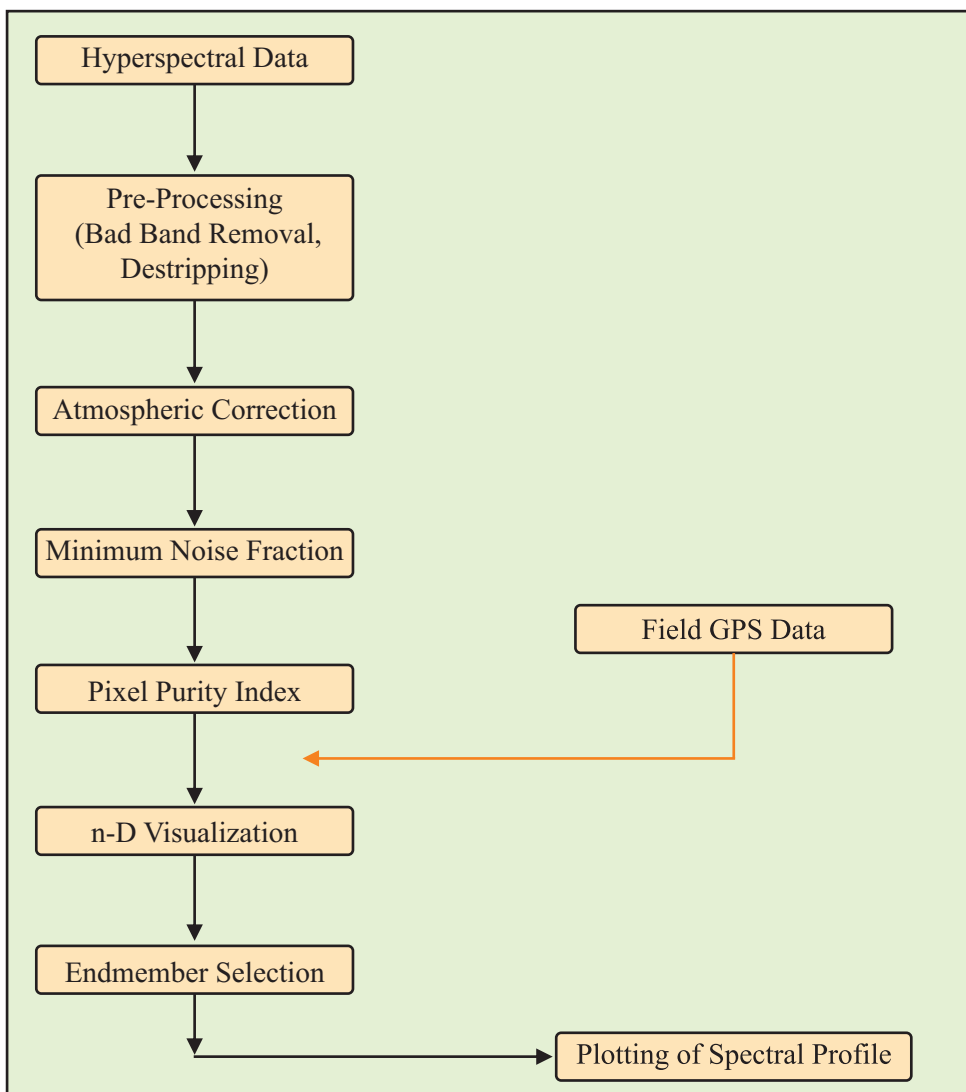


Fig. 20. Methodology for generation of spectral signatures

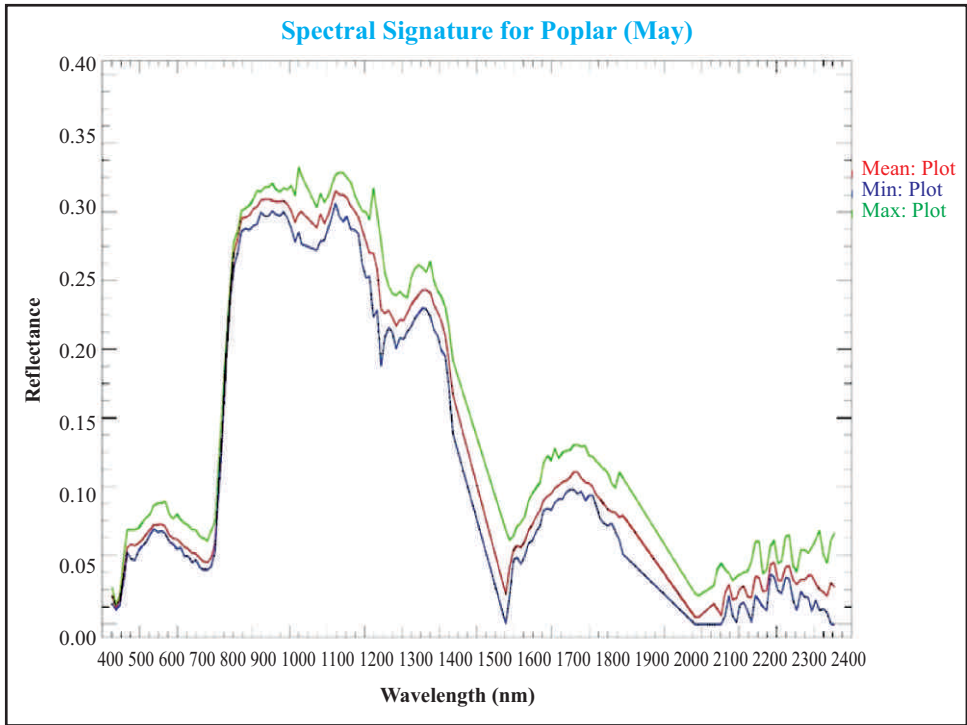


Fig. 21. Spectral signature of Poplar in the month of May

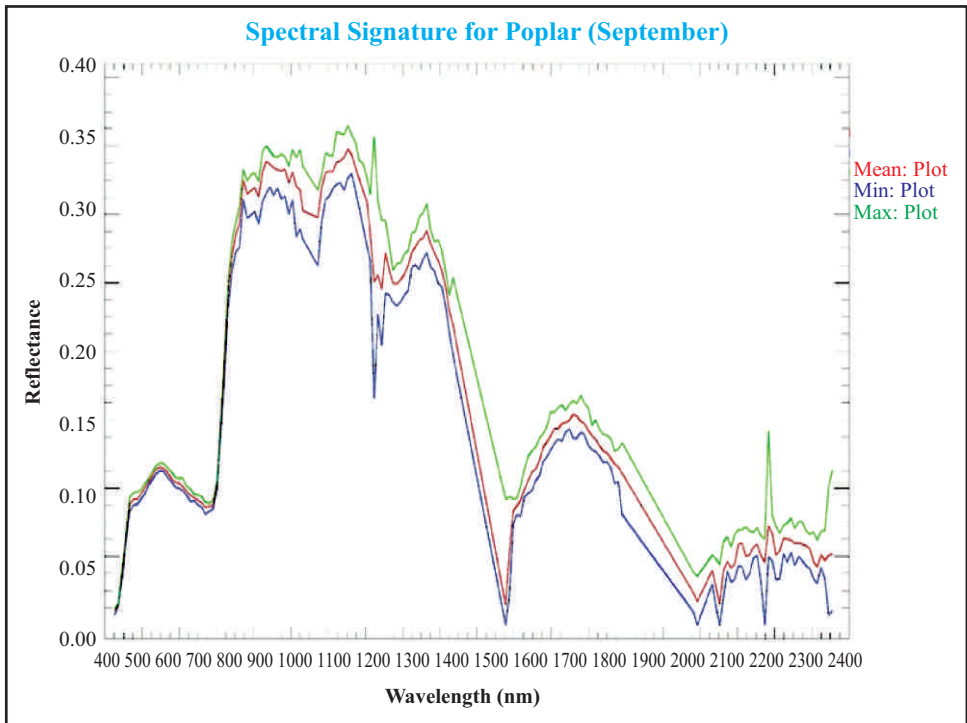


Fig. 22. Spectral signature of Poplar in the month of September

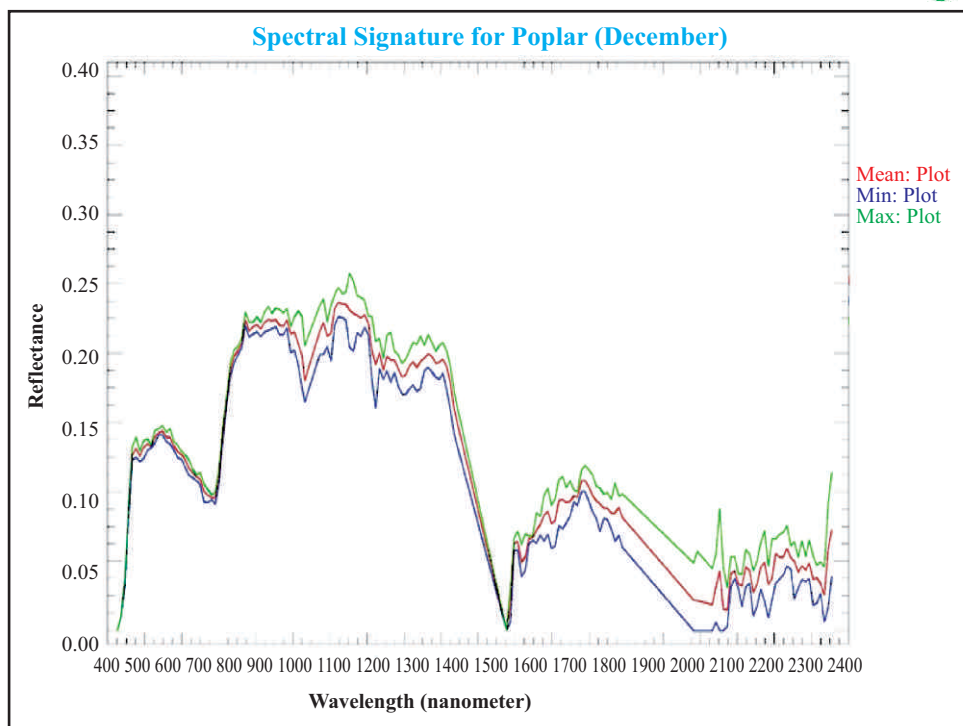


Fig. 23. Spectral signature of Poplar in the month of December

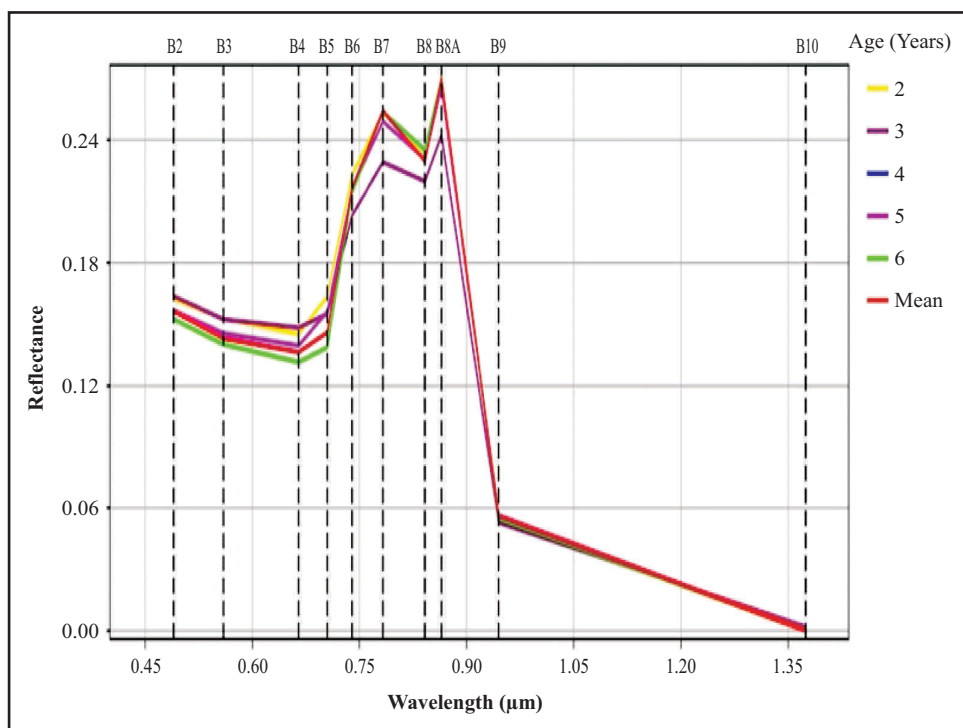


Fig. 24. Spectral reflectance patterns for Poplar plantations of different age



4.1 Mapping Poplar species using Vegetation Indices

Geometrically corrected Landsat 8 images having spatial resolution of 30 m for Jan., May and Oct., 2017 were searched by OLI sensor from the US Geological Survey. Landsat 8 scenes of path 147 and row 39 for Yamunanagar district has been downloaded from USGS website (<http://earthexplorer.usgs.gov>). Preprocessing of these images includes layer stacking of six bands (Blue, Green, Red, NIR, SWIR1 and SWIR2) and sub setting with district boundary. These data were visually and digitally interpreted using ERDAS 2014 and ArcGIS 10.4.1 software.

To extract the accurate Information from the satellite imagery the DN values were converted to the Top of Atmospheric reflectance (TOA). With the help of ERDAS model maker we generate a model to convert the DN values to the reflectance values using the formula:

$$pX = MpQ_{cal} + Ap$$

Where,

pX = TOA planetary reflectance, without correction for solar angle.

Q_{cal} = Quantized calibrated pixel value in DN

Mp = Band specific Multiplicative rescaling factor from the metadata

Ap = Band specific Additive rescaling factor from the metadata

The VI defines the spectral information from red and NIR bands of Landsat images as NDVI may not be sufficient in explaining tree species. Meanwhile, the Landsat program also collects the essential spectral information from the SWIR band which is related to plant properties. The five vegetation indices *viz.* NDVI, Green NDVI (GNDVI), Transformed NDVI (TNDVI), Renormalized Difference Vegetation Index (RDVI), Soil and Atmospherically Resistant Vegetation Index (SARVI) were generated using reflectance of red, green, blue and NIR bands (Figure 25). The formulae of different vegetation indices are given below:

$$NDVI = (NIR - Red) / (NIR + Red) \quad (1)$$

$$GNDVI = (NIR - Green) / (NIR + Green) \quad (2)$$

$$RDVI = (NIR - Red) / \sqrt{NIR + Red} \quad (3)$$

$$TNDVI = \sqrt{(NIR - Red) / (NIR + Red)} + 0.5 \quad (4)$$

$$SARVI = (NIR - RB) * (1 + L) / (NIR + RB + L) \quad (5)$$

Where, $RB = Red - \text{Gamma} * (Blue - Red)$

$L = 0.5$ (Vegetation cover correction factor)

$\text{Gamma} = 1$ (Aerosol content stabilization factor)

The temporal Landsat8 images (Jan., May and Oct.) represent the different phenological stages of Poplar. As the phenology of the leaves in plant canopy changes from one season to another, the reflectance properties of plant canopy also



changes. The phenological information and spectral variability were used to select the best suitable data for identifying the poplar species.

The satellite images of year 2017 were used to find the correlation between the vegetation indices, Principle Component image and ground check points. It was observed that satellite data of May (New flesh) season gives the exact spectral information of poplar species, while January (Leaf fall) and October (Old flesh) season gives the ground reflection more than tree canopy (Figure 26). Investigation of RDVI, GNDVI and TNDVI revealed that they are not precise enough, while NDVI and SARVI are good enough for identification of poplar species. Finally the reflectance values of NDVI and SARVI were calculated for poplar species (Figure 27).

The NDVI image was classified into two classes: for Poplar species ($0.191 < \text{NDVI} \leq 0.310$) and for other LULC classes ($\text{NDVI} \leq 0.191$ & $\text{NDVI} > 0.310$). The SARVI image were classified for poplar ($0.485 < \text{SARVI} \leq 0.693$) and for other LULC classes ($\text{SARVI} \leq 0.485$ & $\text{SARVI} > 0.693$). The area covered by poplar species using NDVI was 13.98% (24109.2 ha) and SARVI was 13.79% (23783.85 ha). The estimated area was found almost same but in this study we prefer the SARVI because it gives the better separability and good approximation of tree species (Figure 28). The spectral variables of NDVI and SARVI can be considered useful for identification of Poplar spp. during the max growing season. Area obtained using NDVI and SARVI was almost similar but the SARVI proved to be better approximation for tree species identification than NDVI.

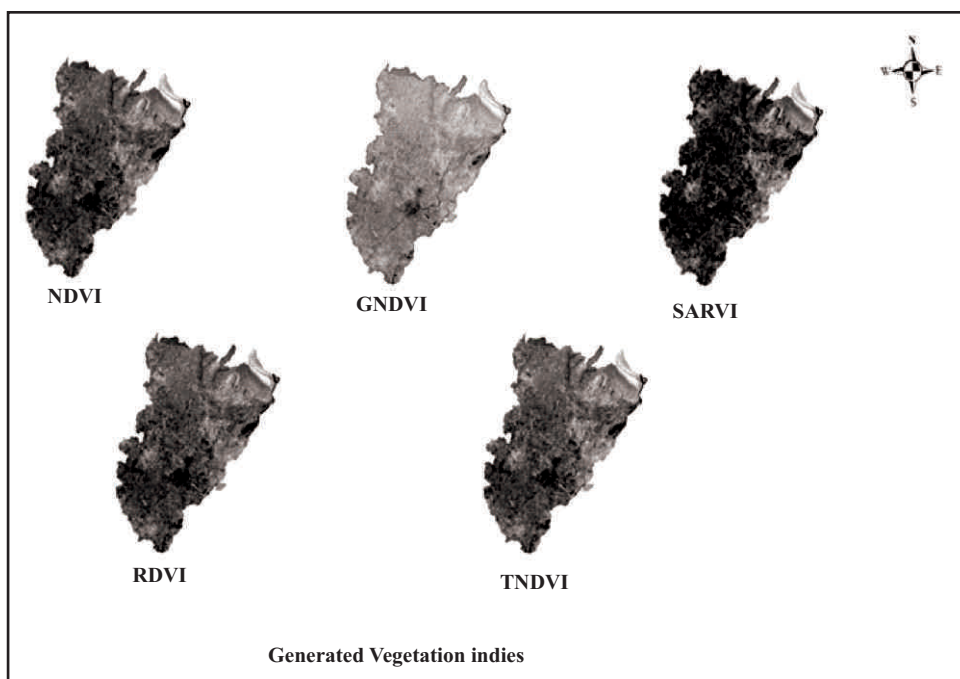


Fig. 25. Different vegetation indices generated for Yamunanagar district

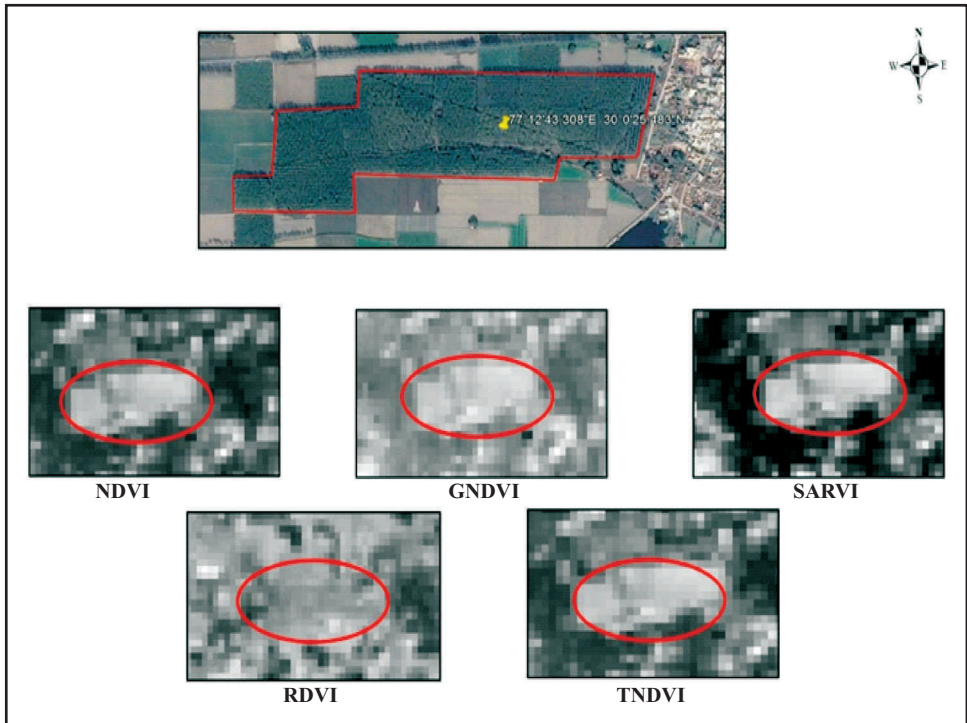


Fig. 26. Differentiation and identification of Poplar area by vegetation indices

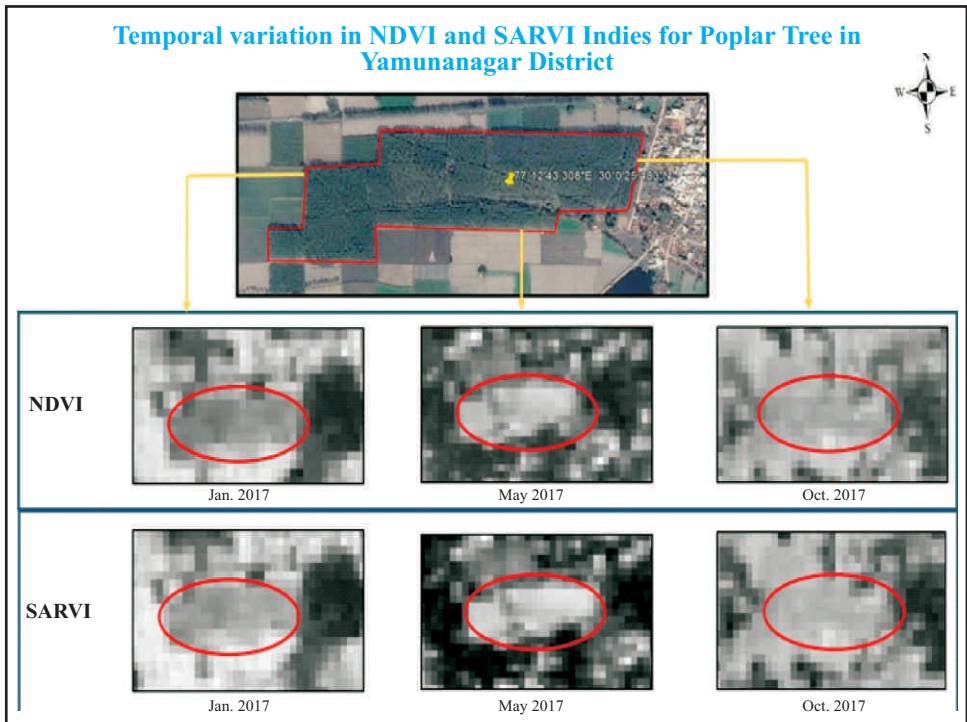


Fig. 27. Temporal variation in NDVI and SARVI indices for Poplar plantation

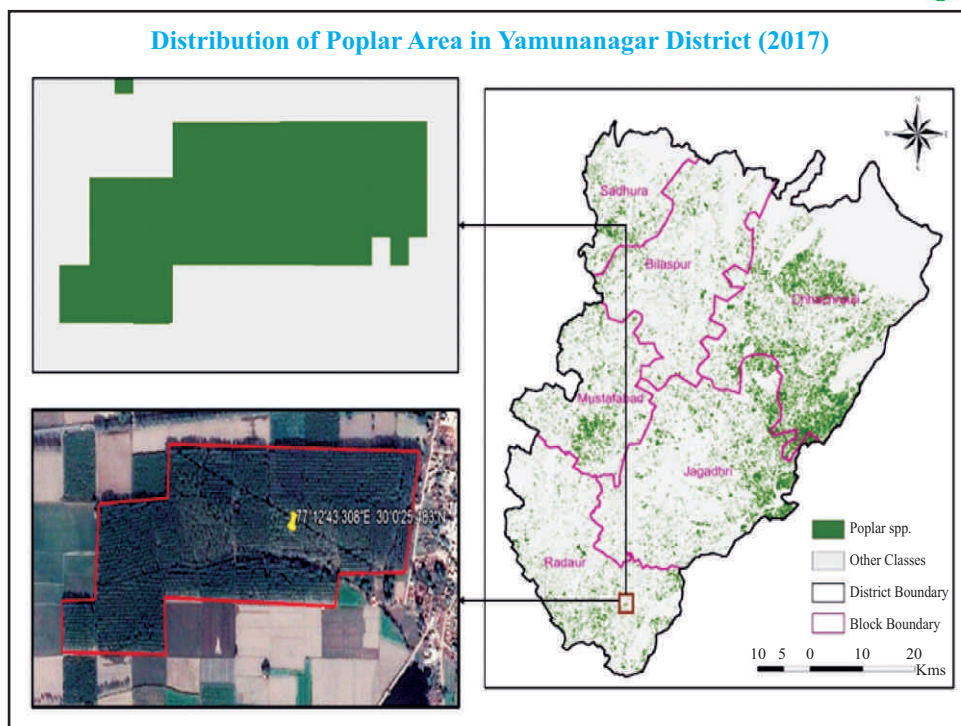


Fig. 28. Poplar area mapped in Yamunanagar district using SARVI index

5. Mapping Agroforestry Area in Different Elevations

Agroforestry area in hilly district “Tehri” of Uttarakhand has been mapped and estimated with the help of LISS-4 data and digital elevation model (DEM). The area under agroforestry was obtained by maximum likelihood classifier, which was categorized as per the elevation zones of Tehri district. Highest area under agroforestry was found in 1200-2000 m elevation i.e. 3707.36 ha followed by 288-1200 m elevation i.e. 2231.26 ha. Negligible area was found on high elevation zones of more than 2800 m (Figure 29). This is because very high elevation zones of more than 2800 m, area is not favorable for human settlements (Table 7). Further area under agroforestry obtained was classified into different classes such as area under *Grewia oppositifolia*, *Celtis australis*, *Quercus leucotrichophora* and remaining systems were grouped as other class. This classification was done by visual interpretation of agroforestry area based on texture and tone of the pixels and with the help of GPS points collected on different systems. Estimated area under *Grewia oppositifolia*, *Celtis australis* and *Quercus leucotrichophora* based agroforestry systems come out to be 2330.82, 1456.80 and 1129.10 ha, respectively. Area under other systems was estimated to be 2112.36 ha, which could not be verified from GPS points.

Table 7. Area under agroforestry in different elevation zones of Tehri district

Elevation zones (m)	Agroforestry area (ha)	Agroforestry area (%)
288 - 1,200	2231.26	0.61
1,200 - 2,000	3707.36	1.01
2,000 - 2,800	1038.65	0.29
2,800 - 6,471	52.11	0.016
Total	7029.06	1.93

Source: Vikrant *et al.* (2018)

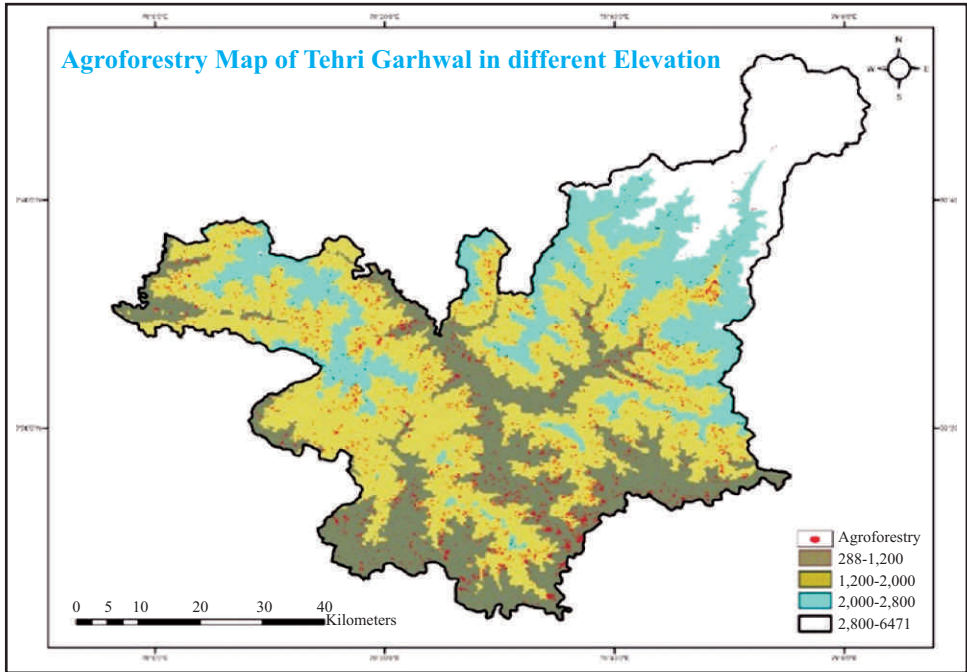


Fig. 29. Map showing agroforestry in different elevations of Tehri district

VI. Assessment of Carbon Stock under Agroforestry

Agroforestry plays a significant role in climate change mitigation through carbon sequestration. To know the carbon sequestration potential of agroforestry systems, an accurate estimate of area under agroforestry in the country is essential. Integrated use of geospatial technologies (GIS, GPS and Remote Sensing) can play an important role in accurate estimation of agroforestry area. Remote sensing together with field survey and modelling approach can be adopted for assessing carbon stock/ sequestration under agroforestry systems at district/ state/ region level. By following this approach (Figure 30), the carbon stock/ sequestration potential of agroforestry systems in many districts have been assessed in Gujarat, Karnataka, Maharashtra states (Tables- 8, 9 & 10). Total agroforestry area in four districts of Gujarat was estimated to be 0.196 million ha and carbon stock under agroforestry come out to be 2.907 Mt C. In Maharashtra, total agroforestry area in four districts



was estimated to be 0.168 million ha and carbon stock was 6.032 Mt C. In six districts of Karnataka, agroforestry area was estimated to be 0.53 million ha and carbon stock under agroforestry come out to be 0.111 Mt C.

Table 8. Estimated agroforestry area and carbon stock in some districts of Gujarat

S. No.	District	Total carbon stock, (Mt C)		AF Area	
		Baseline	Simulated	ha	%
1	Anand	0.247	0.292	26667.42	8.19
2	Dahod	0.745	0.919	45631.70	12.48
3	Junagarh	1.574	1.670	96606.09	10.95
4	Patan	0.332	0.370	51330.24	8.69
Total/ Average		2.907	3.251	196235.45	9.12

Mt C- million tonne carbon;

Source: Rizvi *et al.* (2016)

Table 9. Estimated area and carbon stock under agroforestry in some districts of Maharashtra

District	Carbon stock, (Mt C)	Agroforestry area	
		ha	%
Latur	1.022	37388.85	5.17
Nashik	2.803	73638.09	4.69
Thane	1.034	27540.06	2.84
Wardha	1.173	29187.19	4.62
Total/ Average	6.032	167754.19	4.31

Source: Rizvi *et al.* (2017)

Table 10: Estimated area and CSP under agroforestry in some districts of Karnataka

S. No.	District name	Agroforestry Area		Carbon stock (Mt C)
		ha	%	
1	Bagalkot	20377.99	3.09	4279.38
2	Bellary	25398.89	3.00	5333.77
3	Gulbarga	85641.85	7.78	17984.79
4	Mysore	29038.59	4.58	6098.10
5	Shimoga	80255.64	9.47	16853.68
6	Tumkur	289330.93	27.18	60759.50
Total		530043.89	10.29	111309.22

Source: Rizvi *et al.* (2018)

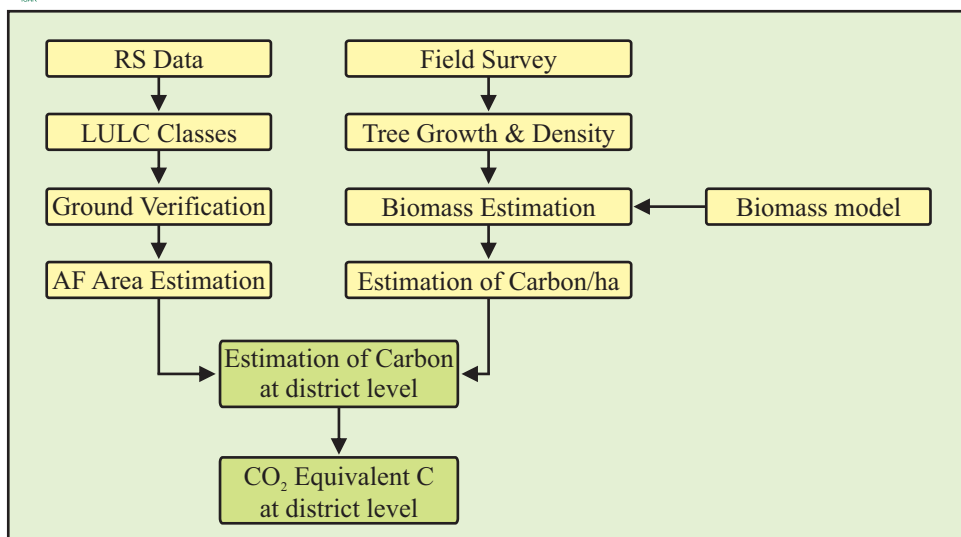


Fig. 30. Geospatial and modelling approach for assessment of carbon sequestration

VII. Summary & Way Forward

This bulletin highlighted the present status of geospatial technology applications in agroforestry and future scope. These include mapping of agroforestry area at district/ regional level, distribution of tree species on farmlands, assessment of carbon sequestration potential, etc. It also highlighted methodologies developed by ICAR-Central Agroforestry Research Institute, Jhansi for both medium and high resolution remote sensing data. These methodologies can be adopted for mapping and estimating agroforestry area at district level. Besides mapping agroforestry in general, extent of area under a particular tree species can also be assessed using high resolution remote sensing data.

Other important areas where geospatial technologies can play useful role are:

1. Land Suitability Analysis for Agroforestry Species
2. Monitoring of Agroforestry Plantations and Changes
3. Species Level Assessment of Carbon Sequestration

With the help of geospatial technologies, growth of plantations on farmlands can be monitored as well as potential areas can also be identified for suitable agroforestry interventions. With the help of these technologies, tree counts/ inventory of different age plantations can also be done. This would intern help in assessment of wood production from that particular species.

These technologies can play an important role in agroforestry research and development in India and also facilitate the decision support for planners.



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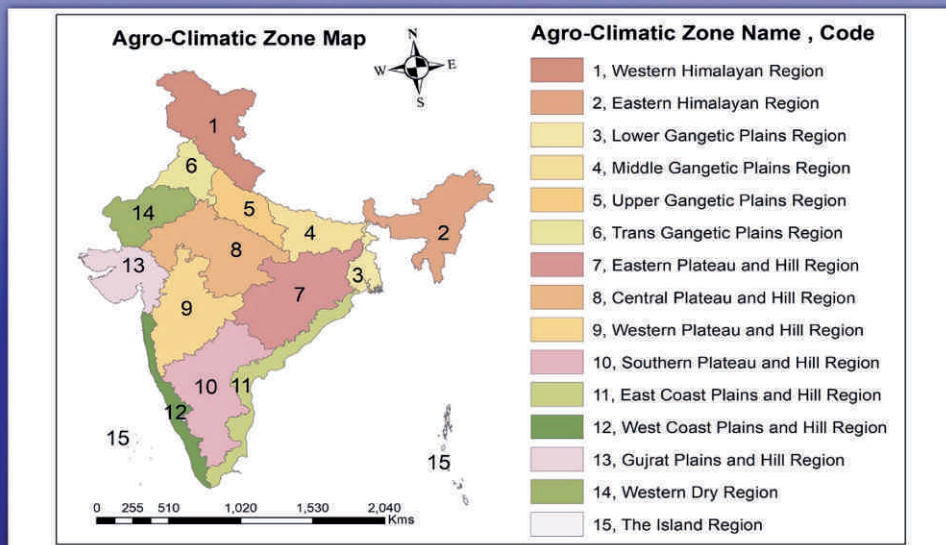


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