Chapter 25

Role of Geospatial Technologies to Estimate Extent of Agroforestry Area in India: An Initiative

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Agroforestry is a traditional and ancient land use practice in India, having the deliberate integration of trees in crop and livestock operations. There are innumerable examples of traditional land use practices involving combined production of trees and agriculture species on the same piece of land in many parts of the world. In India, the organized research on agroforestry began in 1983 with the launch of an All India Co-ordinated Research Project on Agroforestry (AICRPAF) by ICAR. The diagnostic survey and appraisal revealed that there are remunerable agroforestry practices prevalent in different agro-ecological zones of India occupying sizeable areas. The most, if not all, agroforestry systems have the potential to sequester carbon. With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric C could be captured and stored in plant biomass and in soils. The geospatial technologies have shown great potential in natural resource management through out the world, especially in developed countries in the fields like forest cover mapping, agricultural planning, watershed management, land use planning, etc. However, spatial technologies like Geographical Information System (GIS), Remote Sensing (RS) and Geographical Positioning System (GPS) have yet to be implemented extensively in this field. The geospatial technologies have the potential in the utilization of aggregate agroforestry information for variety of research and application purposes. In India the agroforestry land use occupy large areas but use of these technologies to estimate area has been initiated at National Research Centre for Agroforestry (NRCAF), Jhansi in year 2007. The area under agroforestry systems has been estimated/mapped in two districts *viz.*, Yamunanagar (Haryana) and Saharanpur (Uttar Pradesh), where intensive commercial agroforestry was predominant. Besides, the methodology developed under this study is being replicated for mapping and estimating agroforestry area in other parts of the country under National Initiative on Climate Resilient Agriculture (NICRA) project.

Keywords: *GIS, Geo-spatial technologies, Mapping, Remote sensing.*

1. Introduction

Several forms of agroforestry are common throughout the country that contributes to satisfy the daily need of local communities and produce raw material for the wood based-industry. Pathak and Solanki (2002) gave an account of prominent agroforestry systems in different agro-climatic regions of India. Agrisilviculture and agrihorticulture systems in western and eastern Himalyan regions; Agrihorti-silviculture system in upper and trans-Gangetic plains; agrisilviculture and silvipastoral systems in southern plateau and Hilly regions are some of the systems. The National Commission on Farmers (2006) in its reports has envisaged potential of agroforestry for environmental, food and livelihood securities, alleviation of poverty and mitigation of adverse effects of pollution and health hazards. The role of agroforestry in carbon storage and tapping atmospheric CO_2 in the form of standing biomass (above and below ground) is yet to be quantified for different agro-climates. However, the potential of agroforestry for resource conservation, rehabilitation of degraded lands, and improvement of environmental quality has been clearly demonstrated (Dhyani *et al.*, 2005) and also potential for agroforestry exists in fallow lands (NRCAF, 2007).

The growing awareness of importance and potential of agroforestry has resulted in an invaluable proliferation of site specific case studies (Unruh and Lefebvre, 1995). In India the diagnostic survey and appraisal of agroforestry practices in the country revealed that there are enumerable practices in different agro-ecological zones (Pathak *et al.*, 2000). These systems/practices occupy sizeable areas. Though an effort has been made by Dhyani *et al.* (2006) to estimate the agroforestry area in the country, however, these estimates are not the true reflection as they are not based on ground truthing. Some estimates of area and production of wood for the tree cover outside forests are available (FSI, 2011), but these estimates include trees on canalside, roadside, and in urban areas thus does not representing true agroforestry area. The accurate assessment of the area under agroforestry systems in different agro-climatic regions of India can be done with the help of geospatial technologies. Nair *et al.* (2009) estimated globally 823 M ha area under agroforestry and Silvo-pastoral systems, of these 307 M ha is under agroforestry. However these estimates come from taking the FAO estimate of agricultural land multiplied by an estimate of 20 per cent covered by agroforestry.

But this value of 20 per cent is not based on objectively measured data. Zomer *et al.* (2009) find agroforestry widespread with almost half of the world's agricultural lands have at least 10 per cent tree cover. Manual (traditional) methods of mapping take a relatively long time and high cost.

The integrated use of spatial technologies like, Geographical Information System (GIS), Remote Sensing (RS) and Geographical Positioning System (GPS) have the potential to over come the above constraints. GIS enables the storage, management and analysis of large quantities of spatially distributed data (De Mers, 1997). 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. Remote sensing techniques have been utilized successfully in certain areas of application, including forestry, watershed management, agriculture and related fields, especially in developed countries where agriculture patterns are well defined and methodologies developed. In agroforestry, however, these technologies have yet to be used extensively (Ellis *et al.*, 2000).

The applications of spatial technologies enable the storage, management and analysis of large quantities of spatially distributed data. These data are associated with their respective geographic features. For example in agroforestry the type of tree species and associated crops would be related with a sampling site, represented by a point. Data on existing agroforestry systems and area dwell in might be associated with fields or experimental plots, represented on a map by polygons. The power of GIS lies in its ability to analyze relationship between features and associated data (Samson, 1995). 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. Computer based Decision Support Tools (DST) help to integrate information to facilitate the decision making process that directs development, acceptance, adaptation and management aspects in agroforestry. Computer based DSTs include databases, geographic information systems (GIS), models, knowledge-base or expert systems and hybrid decision support systems (Ellis *et al.*, 2004).

2. Geospatial Technologies and Agroforestry Research

An initial effort to use computers to manage agroforestry data began in the late 1980s with Agroforestry System Inventory Database (AFSI) developed by the International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya, now the World Agroforestry Centre (Nair, 1987; Oduol *et al.*, 1988). Multipurpose Tree and Shrub (MPTS) database version 1.0 contained information for 1093 species including site specific requirements (*e.g.* soils), morphological and phonological descriptions, management characteristics and environmental responses (Shroder and Jaenicke, 1994). In India the agroforestry database (*Agroforestry BASE*) has been developed containing information on various aspects of agroforestry under four independent module/database namely MPTs, economic analysis and agroforestry intervention/innovations (Ajit *et al.*, 2003). On regional scale similar applications were fashioned for Zimbabwe, identifying areas within a country climatically suitable for particular tree species (Booth *et al.*, 1990). In a spatial database approach suitable areas for agroforestry were estimated in sub-Saharan Africa (Unruh and Lefebvre, 1995) and suitable areas of *Annona cherimola* agroforestry system were determined in Southern Ecuador (Bydekerke *et al.*, 1998). The role of GIS in the characterization and monitoring of agroforestry parks was also highlighted by Bernard and Depommier (1997). Paquette and Domon (1997) did spatial analysis of census and geomorphologic data in GIS environment to explore dynamics of agroforestry in 19th century Canadian landscape.

In temperate alley cropping spatial analysis using ground penetrating radar (GPR) to evaluate root biomass and distribution and soil nutrient crop-tree interactions was done by Jose *et al.* (2001). Zomer *et al.* (2007) in his study used a simple water balance approach, combined with the results of a remote ensing analysis of tree cover in the study area, to estimate the impacts of poplar agroforestry on hydrological cycles at the farm to regional scale. Bentrup and Leininger (2002) did suitability assessment using GIS to determine the best locations for growing agroforestry specialty products. Suitability assessment matches potential products with ideal growing conditions.Acosta and Reyes (2002) developed a geographic information system for identification of areas suitable for development of silvopastoral systems in the region of Jimaguyu in the provenance of Camaguey in Cuba. The Southeastern Agroforestry Decision Support System (SEADSS) developed by the Centre for Subtropical Agroforestry (CSTAF) at University of Florida brings on-line GIS capabilities directly to the extension agents and land owners. It offers county soils, land use and other spatial data for selecting suitable tree and shrub species in a specified location (Ellis *et al.*, 2005). An assessment of the current status of the West African agroforestry parklands was launched in 2002 by ICRAF. The GIS tool was used to find out links between tree biodiversity and land use among peasant farmers in three adjacent village territories in these parklands (Rouxel *et al.*, 2005). A geospatial analysis of remote sensing derived global datasets investigated the correspondence and relationship of tree cover, population density and climatic conditions within agricultural land at 1 km resolution. There are limitations in this analysis that one cannot expect results for an individual pixel (1 km x 1 km) to be close to reality. Also at landscape scale, the correlation between tree cover and per cent crown cover is probably quite good within broad agroforestry systems and climate zones but this will not be true globally (Zomer *et al.*, 2009).

3. Initiative for Agroforestry Mapping in India

In India, use of GIS-RS-GPS has also widened from natural resource management to habitat analysis. Though the agroforestry land use occupy large areas in our country, but use of these technologies to estimate area has been initiated in year 2007. A Department of Science and Technology, Govt. of India sponsored project entitled '*Spatial and Temporal analysis of agroforestry intervention in North–western India using GIS and Remote Sensing*' was taken up. Two districts namely Yamunanagar (Haryana) and Saharanpur (U.P.) were selected and area under agroforestry systems mainly Poplar and Eucalyptus based systems was assessed. For mapping and estimating area under agroforestry in the two districts, IRS-P6 LISS III data (spatial resolution of

23.5 m) was used and both unsupervised and supervised methods of classification were applied. The methodology adopted under this study is depicted in Figure 25.1 and 25.2.

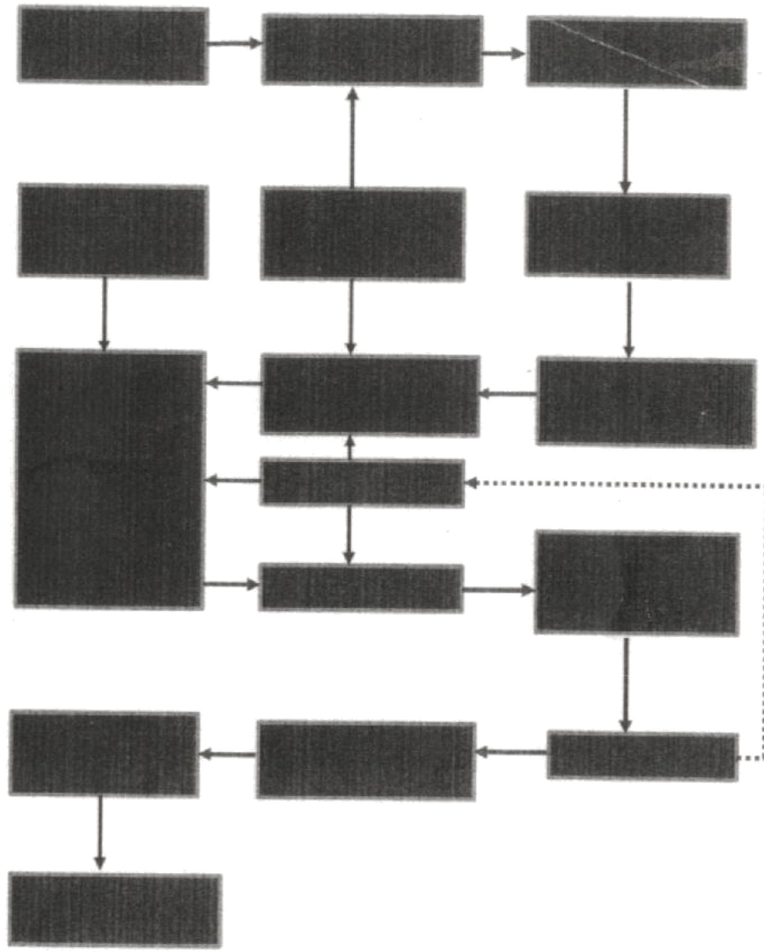

Figure 25.1: Flow Chart Showing Methodology for Mapping of Agroforestry.

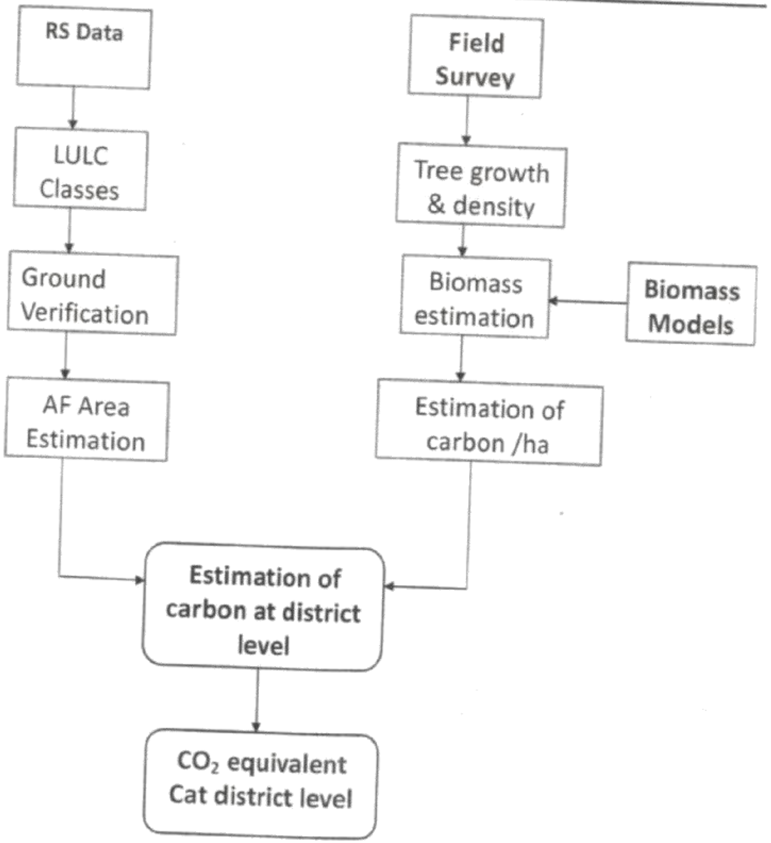

Figure 25.2: Methodology for Estimating Carbon Sequestration at District Level.

3.1 Methodology for AF Mapping

Mapping and estimation of area under agroforestry at district level using remote sensing data includes the following approach:

1. Tree patches on agricultural' fields which are identified through medium resolution satellite data (LISS III) are classified into agroforestry. This will include block plantations, trees within fields and orchards.
2. Scattered trees on farmlands and boundary plantation are classified using single pixel identification technique. All other plantations like road side, canal side, trees in urban areas are grouped into single class *i.e.* plantation.

3. Classified remote sensing data was subjected to correction for removing the pixels falling in urban areas, near the roads and canals. Pixels obtained for tree patches and scattered trees on farmlands are overlaid into single image and area under agroforestry is mapped and estimated.

Rizvi *et al.* (2009) reported that estimated area under both the agroforestry systems in Yamunanagar district was about 18.4 per cent in year 2007. In case of Saharanpur district, Rizvi *et al.* (2011) reported an estimated area of 11.3 per cent under agroforestry systems (Table 25.1 and Figures 25.3a–d). It was also reported that there was a decline in area under agroforestry from 1998 to 2007 in both these districts.

Table 25.1: Land Use and Land Cover in Saharanpur and Yamunanagar Districts without Forest (2007)

Land Uses/Land Covers	*Yamunanagar*		*Saharanpur*	
	Area (in ha)	*Area (Per cent)#*	*Area (in ha)*	*Area (Per cent)#*
Agroforestry	31914.77	18.4	40746.06	11.3
Cropland	80981.92	46.8	140631.00	38.8
Water/water bodies	1470.20	0.8	8889.34	2.5
Builtups/Sand	20805.15	12.0	25158.60	6.9
Fallow/wasteland	8257.03	4.8	43772.30	12.1
Plantation	12605.93	7.3	71539.20	19.8
Total Area	**156035.00**		**330736.50**	

#: Percentage of total geographical area.

Figure 25.3a: Eucalyptus Boundary Plantation as Seen on FCC of Saharanpur District.

Figure 25.3b: Poplar Block Plantation as Seen on FCC of Yamunanagar District.

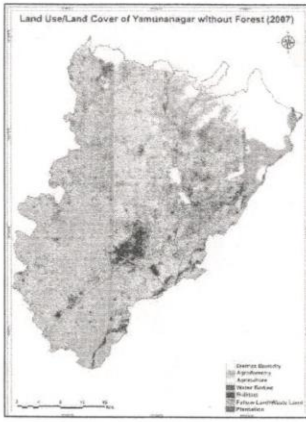

Figure 25.3c: Land Use and Land Cover of Yamunanagar District without Forest (2007).

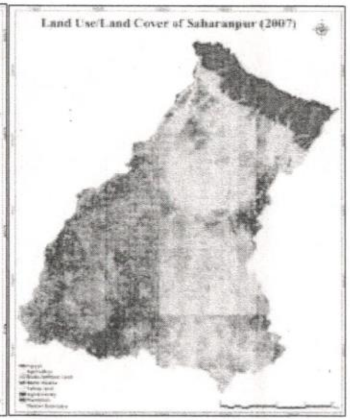

Figure 25.3d: Land Use and Land Cover of Saharanpur District (2007).

Presently, under National Initiative of Climate Resilient Agriculture (NICRA) project, area under agroforestry systems in Indo-Gangetic plains is being assessed and estimated using same methodology discussed above. Four districts have been selected, Sultanpur district from Upper-Gangetic, Vaishali from Middle-Gangetic, North Dinajpur from Lower Gangetic and Ludhiana from Trans-Gangetic plains. The IRS P6/LISS IV data (spatial resolution of 5.8 m) of the four selected districts has been classified using ERDAS Imagine 11.0 software. Land uses and land covers including agroforestry of Sultanpur and North-Dinajpur districts were mapped and estimated (Table 25.2 and Figures 25.4a and b). According to this classification, area under agroforestry in Sultanpur and North-Dinajpur districts come out to be 3.43 and 4.41, per cent respectively. Land uses and land covers statistics of Vaishali and Ludhiana districts are given in Table 25.3 and Figures 25.5a and b. According to this, area under agroforestry in Vaishali and Ludhiana districts come out to be 11.26 and 14.87, per cent respectively.

Kumar *et al.* (2011) mapped trees outside forests (scattered trees, trees in groups, trees in simple lines, tree strip along waters) using merged data products of LISS IV and Cartosat-1 and found 11.09 per cent area under trees outside forest in Bilaspur block of Yamunanagar (Haryana). Bisen and Patel (2012) used object based classification on merged (LISS III and PAN) datasets for identification and mapping of agroforestry systems in Roorkee tehsil of Haridwar district. They found improvement in accuracy in delineation of pure crop and crop-hedge boundary plantation with high resolution multispectral data of Worldview-II.

Table 25.2: Land Uses and Land Covers in the Sultanpur and North-Dinajpur Districts

Sl.No.	Land Uses/Land Covers	Sultanpur		North Dinajpur	
		Area (ha)	Area (per cent)	Area (ha)	Area (per cent)
1.	Agroforestry	7977.58	3.43	13543.07	4.41
2.	Cropland	39706.70	17.08	109789.90	35.75
3.	Plantation	102690.00	44.18	67507.00	21.98
4.	Shrubs	31248.80	13.44	—	—
5.	Built ups	9159.07	3.94	9546.00	3.11
6.	Water bodies	3739.38	1.60	2739.00	0.89
7.	Forest	15048.50	6.47	551.78	0.18
8.	Fallow/bare land	8038.73	3.45	90672.00	29.53
	Total Geographical Area	232400.00		307059.00	

Table 25.3: Land Uses and Land Covers in the Vaishali and Ludhiana Districts

Sl.No.	Land Uses/Land Covers	Vaishali		Ludhiana	
		Area (ha)	Area (per cent)	Area (ha)	Area (per cent)
1.	Cropland	105762.00	51.94	201993.00	54.81
2.	Agroforestry	22926.00	11.26	54821.70	14.87
3.	Fallow/bare land	40329.40	19.80	6615.48	1.79
4.	Shrubs	–	—	5540.78	1.50
5.	Water Bodies	6284.01	3.08	6007.54	1.63
6.	Built ups	6479.50	3.18	33056.00	8.97
7.	Forest	8144.36	4.00	–	—
8.	Plantation	12136.73	5.96	34927.80	9.47
	Total Geographical Area	203600.00		368500.00	

Scattered trees on farmlands and trees in strips are difficult to identify with medium resolution satellite data like LISS III (23.5 m). For correct estimation of area under scattered trees, high resolution multispectral data either LISS IV (5.8 m) or merged LISS IV and Cartosat-1 datasets must be used. But this would involve enormous data processing and huge cost in case of country level agroforestry mapping.

4. Assessment of Carbon Sequestration in Agroforestry

For the assessment of carbon sequestration in agroforestry, two way approach is adopted (Figure 25.5). Firstly, the area under agroforestry in a district is estimated through remote sensing using the same methodology discussed above. Secondly, carbon sequestration by agroforestry systems per hectare (including biomass carbon + soil organic carbon) is estimated through a CO_2 FIX model. Finally carbon

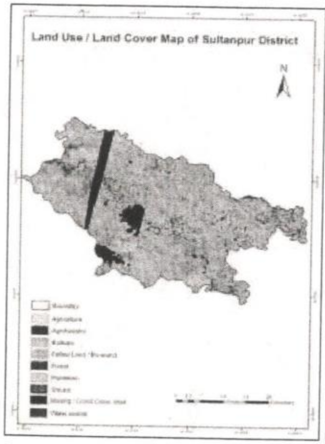

Figure 25.4a: Land Use and Land Cover Map of Sulatanpur District.

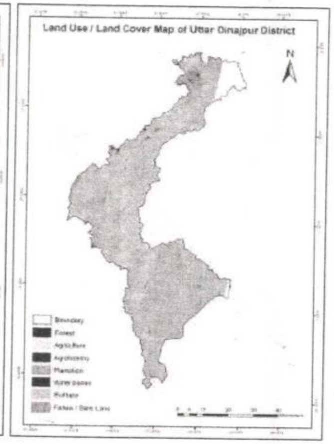

Figure 25.4b: Land Use and Land Cover Map of North-Dinajpur District.

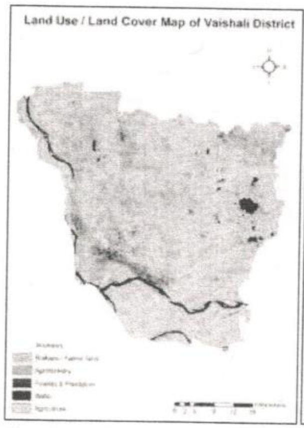

Figure 25.5a: Land Use and Land Cover Map of Vaishali District.

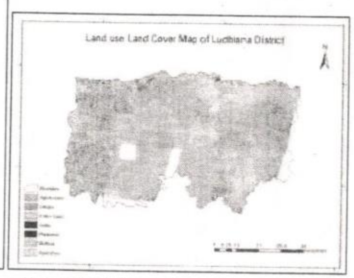

Figure 25.5b: Land Use and Land Cover Map of Ludhiana District.

sequestration by agroforestry systems in a particular district is obtained by multiplying the area under agroforestry with carbon sequestration per ha. Carbon sequestration potential of agroforestry systems in four districts of Indo-Gangetic plains namely Sultanpur (U.P.), Ludhiana (Punjab), Vaishali (Bihar) and North-Dinajpur (W. Bengal) has been assessed. The carbon sequestration of agroforestry in selected districts of Indo-Gangetic plains is about 18.10 t C ha^{-1}. Thus the total carbon sequestration potential of agroforestry in each district is about 0.44 t C (Ram Newaj *et al.*, 2012).

Ajit *et al.* (2013) used dynamic CO_2 FIX model v3.1 to assess the baseline (2011) carbon and to estimate the carbon sequestration potential (CSP) of agroforestry systems in three districts *viz.* Ludhiana (upper Indo-Gangetic plains (IGP) in Punjab), Sultanpur (middle IGP in Uttar Pradesh) and Uttar Dinajpur (lower IGP in W. Bengal). The CSP for existing AFS (for thirty years simulation) has been estimated to the tune of 0.111, 0.126 and 0.551 Mg C ha^{-1} yr^{-1} for Sultanpur, Dinajpur and Ludhiana districts, respectively. The preliminary estimates of area under AFS's were 2.06 per cent (3,256 ha), 2.08 per cent (6440 ha) and 12.69 per cent (38,860 ha) in Sultanpur, Dinajpur and Ludhiana districts, respectively.

5. Future Scope

Geospatial technologies can be applied in biomass/carbon estimation of established agroforestry systems using high resolution/hyper spectral remote sensing. The temporal pattern of spectral reflectance for agroforestry tree species over different ages and the effect of tree density/canopy cover on spectral pattern of established agroforestry systems can also be investigated. Development of Digital Library of Spectral Signatures for major Agroforestry Species/Systems would help in assessment of area under agroforestry in different Agro-climatic regions. It will be imperative to have Spatial Decision Support System (SDSS) for Agroforestry in India, which would help the planners and researchers in development of agroforestry based on agro-climatic situation of the area/region.

6. Conclusion

Application of GIS and RS technology in agroforestry is so far very limited in India. Although these technologies have great potential in agroforestry research and may be used for estimating system production (biomass/yield), assessment of carbon sequestration, identification of areas suitable for agroforestry intervention, etc. However, there are some constraints while applying these spatial technologies in this field on account of spatial, spectral, temporal, and radiometric resolutions. Besides the satellite limitations, errors in interpretation and classification may be caused due to cloud or shadow effects. Other constraints may be due to identification of boundary plantation with crops and intermingling of spectral signatures between young plantation and crops like sugarcane. There may be also the wrong assessment of areas under agroforestry system due to road side and canal side plantations. Hence, a systematic planning and judicious use of these technologies is essential in agroforestry research. However, with the commissioning of high resolution, hyper spectral and microwave remote sensing satellites, these constraints can be overcome.

Improved methods such as knowledge/expert classifier, mixed pixel analysis and object oriented classification would be better approach.

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