MAPPING AGROFORESTRY AND TREES OUTSIDE FOREST

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CAFRI

The Central Agroforestry Research Institute (CAFRI) http://cafri.res.in/ is a national institute and India's only dedicated research institution on Agroforestry under the umbrella of the Indian Council of Agricultural Research (ICAR). It promotes and works on improving quality of life of rural people through the integration of perennials in agriculture landscapes for economic, environmental and social benefits.

ICAR

The Indian Council of Agricultural Research (ICAR) https://icar.org.in/ is the research wing of the Ministry of Agriculture & Farmers Welfare, Government of India. It promotes harnessing the power of science and innovation for food security, food safety and farmer's prosperity as well as enhancing the natural resources base to promote inclusive growth and sustainable development.

ICRAF

The World Agroforestry (International Centre for Research in Agroforestry, ICRAF) http://www.worldagroforestry.org/ is a centre of scientific excellence that harnesses the benefits of trees for people and the environment. Leveraging the world's largest repository of agroforestry science and information, ICRAF develops knowledge practices, from farmers' fields to the global sphere, to ensure food security and environmental sustainability. ICRAF is the only institution that does globally significant agroforestry research in and for all of the developing tropics. The knowledge produced by ICRAF enables governments, development agencies and farmers to utilise the power of trees to make farming and livelihoods more environmentally, socially and economically sustainable at scale.

ICRAF is a member of the CGIAR consortium (www.cgiar.org) with its headquarters located at Nairobi, Kenya. ICRAF operates in more than 30 countries through its six regional and sub-regional offices located across Africa, Asia, and Latin America.

CGIAR

The Consultative Group on International Agricultural Research (CGIAR) https://www.cgiar.org/ a consortium integrates and coordinates the research of its 15 Member Centres to increase the effectiveness and relevance of their work, and to enhance the impact of the research by setting common objectives and planning concerted action.

त्रिलोचन महापात्र, पीएच.डी.
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FOREWORD

Population of India is expected to touch more than 1500 million by 2030; and land under agriculture is decreasing at the rate of 0.03 million hectares per year (30,000 hectares). Besides this intensive agriculture is putting immense pressure on land to produce more food leading to accelerate the process of soil degradation. Over use of chemical fertilizers and pesticides, and adverse effect on livestock population due to shrinking fodder production are other concerns. Ever increasing challenge of climate change and threats posed by extreme weather further compound the vulnerability of small holders' livelihoods and in turn food security. Agroforestry is recognized by more than 140 countries as one of the most effective tools to mitigate and to adopt to adverse effects of climate change; support restoration and arrest degradation of soil; ensure livelihood, food, nutrition, energy, fodder, and increased income for farmers; and adopt to mitigate for climate change. India has been on the forefront of agroforestry research and development. Implementation of a National Agroforestry Policy, a Sub-Mission on Agroforestry, and a National Bamboo Mission clearly demonstrate the commitment and the will of the Government of India to mainstream and implement agroforestry at large scale.

Indian Council of Agricultural Research (ICAR) and its international partners like World Agroforestry (ICRAF) have recognized that agroforestry practices occupy considerable area in the country and at global level. Therefore, accurate mapping and estimation of extent of agroforestry area in the country is of utmost importance for planners and policy makers. For this purpose, geo-spatial technologies like GIS, GPS and satellite remote sensing has crucial role to play. Scientific methodologies for mapping agroforestry using medium, high resolution and hyperspectral remote sensing data have been developed and refined through long-term research at ICAR- Central Agroforestry Research Institute, Jhansi. At global level ICRAF also standardized the mapping techniques for agroforestry. This publication compiles harmonized terminology, definitions, and techniques used to map Tree outside Forest/Agroforestry; geospatial methodology to map a particular agroforestry tree species.

The publication "***Mapping Agroforestry and Trees outside Forest***" is a joint effort of ICAR and ICRAF, attempted to address the challenge of mapping agroforestry. The information provided is easy to understand and implement by promoters of agroforestry. I compliment ICAR-CAFRI and ICRAF for bringing out this compilation. This would certainly be a ready reckoner for researchers, planners, policy makers, practitioners, and other stakeholders.

(T. MOHAPATRA)

Dated the 25th February, 2020
New Delhi

Preface

In India, agroforestry has been practised since time immemorial. Presently, it occupies a sizable area outside the forest area in the country. The Design and Diagnostic Survey envisages that innumerable agroforestry practices are prevalent in different parts of the country. However, authentic and realistic figures on the extent of the agroforestry area are not available. It has been realised that for a quick, reliable and accurate estimate of an area under agroforestry in the country, frontier technologies like GIS, GPS and satellite remote sensing can play an important role. Nevertheless, geospatial technologies have to be used in a judicious way. Further application of GIS and remote sensing in agroforestry requires the development of a sound methodology. ICAR-Central Agroforestry Research Institute, Jhansi started working on mapping agroforestry in 2007, which got momentum when ICRAF joined in on this aspect in 2014.

ICAR-CAFRI developed and tested the methodologies for both medium and high-resolution remote sensing data. Through these methodologies, very encouraging and accurate results were obtained. ICRAF provided the experiences/techniques from other countries and a global perspective. The efforts of ICAR-CAFRI and ICRAF got recognised with the recommendation of the Expert Committee constituted by the MoEFCC to develop a strategy to increase green/tree cover outside recorded forest areas (Trees Outside Forest, TOF) that ICAR-CAFRI, FSI, NRSC, and ICRAF should work using the consortium model for mapping the distribution pattern of tree species in different regions of the country. The MoEFCC also recommended CAFRI to prepare agroforestry maps for every five-year cycle and committed itself, as far as possible, to providing species-wise maps by using spectral signature data of common agroforestry species available in their Digital Library, provided they receive dedicated funding and resources (MoEFCC 2018).

The authors from ICAR, CAFRI and ICRAF, have attempted to bring out a compilation of scientific information in the form of a technical book: *Mapping Agroforestry & Trees Outside Forest.* This technical bulletin is an attempt towards understanding and addressing various issues in mapping agroforestry, possible approaches and methods developed, and assessing the future scope of geospatial technology in agroforestry research. This book will certainly be a ready reckoner for researchers and planners, covering important aspects of the extent of the area under TOF/agroforestry. We congratulate the authors for this endeavour and wish them very good luck for the future.

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Acronyms Used in the Book

AI	Artificial Intelligence
ANR	Assisted Natural Regeneration
AOI	Area of Interest
AR	Artificial Regeneration
ASPS	Agri-silvipasture System
CAFRI	Central Agroforestry Research Institute
CAZRI	Central Arid Zone Research Institute
CCP	Cloud Computing Platforms
CGIAR	Consultative Group on International Agricultural Research
CIR	Colour Infrared
CNFA	Culturable Non-Forest Area
CSE	Centre for Science and Environment
DaaS	Data-as-a-Service
DARE	Department of Agricultural Research and Education
DBH	Diameter at breast height
DBMS	Database Management System
DEM	Digital Elevation Model
DIP	Digital Image Processing
DN	Digital Number
DoAC	Department of Agriculture and Cooperation
DSM	Digital Surface Model
DTM	Digital Terrain Model
EOS	Earth Observation System
EROS	Earth Resources Observation Systems
FAO	Food and Agriculture Organization (United Nations)
FCC	False Colour Composites
FMU	Forest Management Unit
FRA	Forest Resource Assessment
FSI	Forest Survey of India
GCP	Ground Control Point
GEE	Google Earth Engine
GIS	Geographic Information System
GNDVI	Green Normalised Difference Vegetation Index
GOI	Government of India
GPS	Global Positioning System
IARI	Indian Agricultural Research Institute

ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRAF	International Centre for Research in Agroforestry (World Agroforestry)
ICTs	Information and Communication Technologies
IIT	Indian Institute of Technology
IKONOS	IKONOS: one of the first commercial satellites to serve imagery to the public
IoE	Internet of Everything
IoT	Internet of Things
IRS	Indian Remote Sensing Satellite
ISFR	India State of Forest Report
ISRO	Indian Space Research Organization
ITC	Indian Tobacco Company
IUFRO	International Union of Forest Research Organizations
KEFRI	Kenya Forest Research Institute
LDSF	Land Degradation Surveillance Framework
LISS	Linear Imaging Self Scanning Sensor
LMU	Land Management Unit
LULC	Land uses/land covers
ML	Machine Learning
MLC	Maximum Likelihood Classifier
MoAFW	Ministry of Agriculture & Farmers' Welfare, GOI
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEFCC	Ministry of Environment, Forest & Climate Change, GOI
NARS	National Agricultural Research Systems
NASA	National Aeronautics and Space Administration
NCCF	Network for Certification and Conservation of Forests
NDVI	Normalised Difference Vegetation Index
NGA	National Geospatial-Intelligence Agency
NR	Natural Regeneration
NRSC	National Remote Sensing Centre
OA	Open-Access
OBIA	Object-Based Image Analysis
R2V	Raster to Vector Conversion
RDVI	Renormalized Difference Vegetation Index
RED	Reducing Emissions from (gross) Deforestation
REDD	Reducing Emissions from Deforestation and Forest Degradation
RF	Reserved Forests
ROC	Raster Object Creator

ROO	Raster Object Operator
RPP	Raster Pixel Processor
RS	Remote Sensing
SaaS	Software-as-a-Service
SARP	South Asia Regional Programme (ICRAF)
SARVI	Soil Atmospherically Resistant Vegetation Index
SFP	Single Feature Probability
SOI	Survey of India
SPOT	Système probatoire d'observation de la Terre (France)
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave Infrared
TIN	Triangular Irregular Networks
TOA	Top of Atmospheric reflectance
TOF	Trees Outside Forest
UN-CBD	United Nations Convention on Biological Diversity
UN-CCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard
VI	Vegetation Index
VOC	Vector Clean up Operator
VOO	Vector Object Operators
VOP	Vector Object Processor
WAC	World Agroforestry Centre

Introduction

Mapping the Extents of Agroforestry using Geo-informatics

Agroforestry is a collective name for land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land-management unit. The integration can be either in a spatial mixture or in a temporal sequence. There are normally both ecological and economic interactions between the woody and non-woody components in agroforestry. In recent years, there has been a shift in the focus of agroforestry research from the plot or field scale to the landscape scale, which has uncovered the multiple benefits that trees provide in agricultural landscapes. But the spatial distribution and extent of agroforestry was not well understood earlier due to the complexity involved in accurately mapping agroforestry and Trees Outside Forest (TOF) in mixed tree/crop/livestock systems. As per ISFR 2019, all trees growing outside recorded forest areas irrespective of patch size are referred as Trees Outside Forest.

A major problem in estimating the area under agroforestry is the lack of procedures for delineating the area influenced by trees in a mixed stand of trees and crops. Besides, simultaneous agroforestry where the tree and the crop components grow at the same time and in close enough proximity for interactions to occur is more complex. As 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 trees are planted at a wide distance between rows (windbreak) or around agricultural fields (boundary planting). In such cases, the influence of trees extends over a larger area than is easily perceivable. In addition, there is a general lack of systematically collected ground reference information for the development of predictive models for the extent of agroforestry area, as well as for the validation of these estimates.

Using geospatial technologies to estimate agroforestry area is an option. The high-resolution satellite or aerial imagery may be used to detect individual trees and has been applied for estimating the extents of Trees Outside Forest at the local scale. However, these imageries are very costly and often lack the spatial coverage necessary for assessments of agroforestry at regional to national scales. Also, part of the challenge in mapping agroforestry is that it is not sufficient to be able to detect trees, but one needs integrated methods that capture both the trees and the land-use systems (WAC, ICRAF 2015).

India's landmark National Agroforestry Policy 2014 (http://agricoop.gov.in/sites/default/files/National_agroforestry_policy_2014.pdf) has recommended developing a sound database and information system on agroforestry for planning, implementation and monitoring. However, unlike for forest and agriculture areas, exact estimates for the area under agroforestry are not available. The major problem in estimating it lies in the different modes in which agroforestry is practised. The area under agroforestry in India, according to one estimate, is at 25.32 m ha or 8.2 percent of the total geographical area of the country (Dhyani et al. 2013). However, these estimates are not based on revenue records or actual measurements. Dhyani (2014) had pointed out that the assessment of FSI (2011) for forest cover (69.20 m ha) was overestimated and tree cover (9.08 m ha) was underestimated, as they included a large area of agroforestry, mainly agri-silviculture, block plantations, orchards on crop lands, homestead, scattered trees on farms and so on in the forest area. The actual area under forest in both the classes will be less than these estimates.

An accurate assessment of the area under agroforestry can be done with the help of geospatial technologies as manual (traditional) methods of mapping are expensive and take a relatively long time. Use of geospatial technologies to estimate agroforestry area was initiated in 2007 by the Central Agroforestry Research Institute (CAFRI), Jhansi, using medium-resolution data with a methodology in which areas under agroforestry, forest and plantation are separately identified. In 2014, ICRAF's South Asia Regional Programme (SARP) joined in to develop new approaches for mapping complex agroforestry systems, building on a wide body of research in agroforestry by ICRAF and its partners in ICAR.

A Brainstorming Session was organised by ICAR-ICRAF on using geoinformatics for agroforestry mapping on July 17, 2014, wherein resource persons from ICAR, Department of Agriculture Cooperation (DoAC), Central Agroforestry Research Institute (CAFRI) Jhansi, Central Arid Zone Research Institute (CAZRI) Jodhpur, IARI, IIT-Kharagpur, Forest Survey of India, Indian Space Research Organization (ISRO), and ICARDA participated.

ICRAF-SARP is promoting to mutual learning between National Agricultural Research Systems (NARS) and ICRAF's central geospatial laboratories in Kenya through international training and study visits on geospatial technologies and collaborative research. The main objectives of the initiative are to: build an archive of calibrated imagery for detecting trees on farms for India; estimate and map the extents of agroforestry in India at multiple spatial resolutions (~30 m to ~500 m); strengthen capacity within ICAR and other Indian partner institutions on the mapping of agroforestry at landscapes level; and, eventually, use the technology in the South Asia region.

The publication presents harmonised terminologies, definitions and techniques to be used to map Trees Outside Forest (TOF) and agroforestry and is an attempt towards understanding and addressing various issues in mapping agroforestry, possible approaches and methods developed as well as the future scope of geospatial technology in agroforestry research.

Part-I

Harmonised Terminology and Definitions*

1.1 Agroforestry, Forest, Trees Outside Forest

Aboveground Biomass

This term encompasses all living biomass of trees that is located above the ground. It includes the stem, stump, branches, bark, seeds and foliage. Some standards, such as the VCS, also distinguish between tree and non-tree biomass.

Afforestation

According to the FAO's Forest Resource Assessment (FAO 2012), forested land area can increase through two processes: afforestation (planting or seeding of trees on land that was not previously forested) or natural expansion (expansion of forest on land previously not classified as forest).

Agroforestry

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately integrated on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. World Agroforestry defines agroforestry as the practice and science of the interface and interactions between agriculture and forestry, involving farmers, livestock, trees and forests at multiple scales.

Agroforestry is defined as a land-use system which integrate trees and shrubs on farmlands and rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability. It is a dynamic and ecologically based natural resource management system that, through integration of woody perennials on farms and in the agricultural landscape, diversifies and sustains production and builds social institutions. (National Agroforestry Policy, India 2014 http://agricoop.gov.in/ sites/ default/ files/National_agroforestry_policy_2014.pdf).

Some common terms related to agroforestry:

a) Agri-silviculture

Agri-silviculture is a production technique which combines the growing of agricultural crops with simultaneously raised and protected tree crops.

(*Sources are listed at the end)

b) ***Silvopasture***

Silvopasture is an agroforestry practice that integrates livestock, forage production, and trees on the same land management unit.

c) ***Agri-silvipasture***

Agri-silvipasture (ASPS) is a collective name for land-use systems, implying the combination or deliberate association of a woody component (trees or shrubs) with cattle in the same unit land.

d) ***Block Agroforest (Block Formations)***

Agroforests or agroforest formations with minimum area of 0.1 ha having one edge longer than 10 m.

e) ***Non-Block Agroforest (Non-Block Formations)***

Tree growing in linear, isolated & scatter, bund, tank bund, homesteads, etc. fall under the non-block agroforestry category. The linear formations can be single or multiple row and with maximum width of 10 m.

Alley Cropping

An agroforestry intercropping system in which species of shrubs or trees are planted at spacing relatively close within row, and wide between row, to leave room for herbaceous cropping in between, that is, in the 'alleys'. Synonym: hedgerow intercropping.

Biomass

This is a renewable energy source from living or recently living plant and animal materials, which can be used as fuel, fodder, timber, etc.

Belowground Biomass

Belowground biomass is one of seven key agriculture, forestry, and land-use carbon pools. It includes all living biomass of live roots. Fine roots of less than 2 mm diameter are often excluded because these cannot be distinguished empirically from soil organic matter or litter.

Block Plantation

Tree plantations with closed spacing in compact blocks of more than 0.1 ha on lands outside recorded forest areas.

Buffer Zone

An area around a forest, national park, or any other conserved place that provides the local community with products that they would otherwise take from the forest, or that provides an opportunity to produce alternative products.

Bush Fallow

The natural vegetation that arises when land is left uncultivated for some time. Composed of small trees, shrubs, grasses (and sedges) and herbaceous plants.

Bush fallow may be grazed or browsed, and firewood collected from it before it is returned to cultivation. Related terms: enriched fallow, shifting cultivation.

Canopy

The cover of branches and foliage formed by the crowns of trees above tree bole.

Canopy Density

Percent area of land covered by the canopy of trees. It is expressed as a decimal coefficient, taking closed canopy as unity.

Community Forestry

Forestry developed in areas marginal to agriculture, involving members of many communities being landless or small-scale farmers, often characterised by ecological and cultural diversity and the employment of traditional technologies. Communal land development is basic to this type of forestry. Related term: social forestry.

Crown Area

The area of vertical projection of a tree crown on the ground.

Culturable Non-Forest Area (CNFA)

The net geographical area, lying outside recorded forest and forest cover, which can support tree vegetation (thus excluding areas under wetlands, riverbeds, perennial snow-covered mountains, etc.). CNFA is the area over which the sample data on tree cover is aggregated for the assessment of tree cover.

Fallow

Allowing crop land to lie idle, either tilled or untilled, during the whole or greater portion of a growing season. Tillage is usually practiced to control weeds and encourage the storage of moisture in the soil.

Land rested from deliberate cropping, not necessarily without cultivation or grazing but without sowing.

State of land left without a crop or weed growth for extended period, often to accumulate moisture. Related term: bush fallow.

Farm Forestry

The practice of cultivating and managing trees in compact blocks on agricultural lands. Growing trees on farmland for timber, poles, fuelwood purpose. This may be done in small woodlots or as boundary plantings.

Forest Garden

A land-use form on private lands outside the village in which planted trees and sometimes additional perennial crops occur.

Forest

In Indian context the word forest must be understood according to its dictionary meaning. This description covers all statutorily recognised forests, whether designated as reserved, protected or otherwise for the purpose of section 2(i) of the Forest Conservation Act. The term forest land, occurring in section 2 will not only include 'forest' as understood in the dictionary sense, but also any area recorded as forest in the government record irrespective of the ownership.

The forest definition agreed on by UNFCCC in the context of the Kyoto protocol has three significant parts, only the first of which has received a lot of attention:

- Forest refers to a country-specific choice of a threshold canopy cover (10–30 percent) and tree height (2–5 m);
- These thresholds are applied through 'expert judgment' based on the potential to be reached in situ, not necessarily to the current vegetation; and
- Temporarily unstocked areas (without 'temporarily' being defined) remain forest as long as a state forest entity thinks they will, can or should return to tree cover conditions.

Rules 2 and 3 were added to restrict the concept of reforestation and afforestation and allow forest management practices including clear-felling followed by replanting within the forest domain. They make direct observation of forest difficult.

Forest definitions adopted by major international environmental and forestry organisations

1. United Nations Food and Agriculture Organization (FAO; 2000): Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 ha. The trees should be able to reach a minimum height of 5 m at maturity in situ. May consist either of closed forest formations where trees of various storey and undergrowth cover a high proportion of the ground; or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes, but which are expected to revert to forest.
2. United Nations Framework Convention on Climate Change (UNFCCC; 2002): A minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30 percent with trees with the potential to reach a minimum height of 2–5 m at maturity in situ. A forest may consist either of closed forest formations where trees of various storey and undergrowth

cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown cover of 10–30 percent or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.

3. United Nations Convention on Biological Diversity (UN-CBD; 2010): A land area of more than 0.5 ha, with a tree canopy cover of more than 10 percent, which is not primarily under agriculture or other specific non-forest land use. In the case of young forest or regions where tree growth is climatically suppressed, the trees should be capable of reaching a height of 5 m in situ, and of meeting the canopy cover requirement.
4. United Nations Convention to Combat Desertification (UN-CCD; 2000): Dense canopy with multi-layered structure including large trees in the upper story.
5. International Union of Forest Research Organizations (IUFRO; 1994): A land area with a minimum 10 percent tree crown coverage (or equivalent stocking level), or formerly having such tree cover and that is being naturally or artificially regenerated or that is being afforested.

Note: Kindly also refer to the Ministry of Environment, Forest and Climate Change's letter no. F. No. 11-98/2019-FC dated 14.11.19 addressed to the State Forest Departments, wherein the Ministry has issued guidelines for defining Dictionary meaning of Forest as contained in the order dated 12.12.1996 of Hon'ble Supreme Court (Copy Attached as Annexure III).

Forest Area

The area recorded as a forest in the Government records. It is also referred to as 'recorded forest area'.

Forest Blank

A patch within a forest which bears few or no trees.

Forest Cover

All lands, more than 1 ha in area, with a tree canopy density of more than 10 percent irrespective of ownership and legal status. Such lands may not necessarily be a recorded forest area. It may include plantations on farmlands, orchards, bamboo and palm.

Forest Inventory

The measurement of certain parameters of forests to assess the growing stock and other characteristics of forests.

Forest Management Unit (FMU)

A spatial forest area or areas with clearly defined boundaries managed to a set of explicit long-term management objectives which are expressed in a management plan. (Source: FSC Glossary of Terms).

Forest Restoration

The purpose of forest restoration is to restore a degraded forest to its original state – that is, to re-establish the presumed structure, productivity and species diversity of the forest originally present at a site.

Forest Type

A unit of vegetation, which possesses broad characteristics in physiognomy and structure sufficiently pronounced to permit of its differentiation from other such units. (Source: Champion and Seth, 1968).

Green Manure

A crop that is grown for soil protection, biological nitrogen reduction, or organic matter and ploughed, disked or hoed into the soil. Any crop grown for the purpose of being turned under while green, or soon after maturity, for soil improvement.

Growing Stock

The sum (by no. or volume) of all the trees growing/living in the forest or a specified part of it.

Hill District

A district with more than 50 percent of its geographic area under 'hill talukas' based on criteria adopted by the Planning Commission for Hill Area and Western Ghats Development Programme.

Home Garden

A land-use form on private lands surrounding individual houses with a definite fence, in which different tree species are cultivated together with annual and perennial crops; often with the inclusion of small livestock. There are many forms of such gardens varying in how intensively they are cultivated and their location with regard to the home, for example, 'village forest gardens', 'compound gardens', 'kitchen gardens'.

Intercropping

The cultivation of two or more crops simultaneously on the same field, with or without a row arrangement ('row intercropping' or 'mixed intercropping') or growing of two or more crops on the same field with the planting of the second crop after the first one has already completed development. Also called relay cropping. Related terms: mixed cropping, multiple cropping.

Land Cover

Broad land-use classes interpreted from satellite data. It includes very dense forest, moderately dense forest, open forest, scrub and non-forest.

Landscape

A geographical mosaic composed of interacting ecosystems resulting from the influence of geological, topographical, soil, climatic, biotic and human interactions in a given area. (Source: International Union for Conservation of Nature, Glossary of Definitions).

Land Management Unit (LMU)

A clearly demarcated area of land or a group of land parcels where trees, agriculture, animals, pastures, etc. are practised and managed according to set objectives and land use.

Live Fence

A way of establishing a boundary by planting a line of trees and/or shrubs at relatively close spacing and by fixing wires to them. If animals are to be kept in or out, more uprights (dead sticks) can be tied to the wires. Also called a 'living fence'. Related terms: hedge, hedgerow.

Mangroves

Salt tolerant evergreen forest ecosystem found mainly in tropical and sub-tropical coastal and/or inter-tidal regions.

Mangrove Cover

Area covered under mangrove vegetation as interpreted from remote sensing data. It is included in the forest cover.

Moderately Dense Forest

All lands with forest cover having a canopy density between 40-70 percent of the total forest area.

Net Change (in Forest Cover)

The sum of positive and negative changes in forest cover over two assessment periods for a given area.

Non-Forest Land

Any land without forest cover like agricultural land.

Open Forest

Lands with forest cover having a canopy density between 10-40 percent of the total forest area.

Physiographic Zone

A physiographic zone constitutes geographical areas that exhibit broad similarities in factors responsible for the growth of tree vegetation. Physiographic zones have been used as strata for assessing forest/tree cover in the country.

Protected Forest

An area notified under the provisions of the Indian Forest Act or other State Forest Acts, having limited degree of protection. In protected forest all activities are permitted unless prohibited.

Recorded Forest Area (RFA)

Same as 'forest area' i.e. geographic areas recorded as forests in Government records.

Reforestation

As defined by the FRA, reforestation (re-establishment of forest through planting trees or deliberate seeding on land already classified as forest) does not increase forest area, as it occurs on lands already defined as forest.

Regeneration

The act of establishing or enriching vegetation on barren or degraded land/forest naturally or artificially.

a) ***Artificial Regeneration (AF)***
Establishing or enriching forests by artificial methods through seeds or vegetative prorogation.

b) ***Assisted Natural Regeneration (ANR)***
Regenerating secondary forest by protecting and nurturing the mother trees and their wildlings inherently present in the area. It aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances.

c) ***Natural Regeneration (NR)***
Regeneration of a forest by natural seeding, seed dispersal, coppicing, suckering, etc. without any human intervention.

Restoration or Rehabilitation

Forest restoration emphasises historical fidelity and recovery of native species composition (ecological integrity), whereas forest rehabilitation emphasises functional aspects of recovery and can involve non-native species.

RED

Reducing Emissions from (gross) Deforestation (RED): only changes from forest to non-forest land cover types are included and details very much depend on the operational definition of forest.

REDD

Reducing Emissions from Deforestation and Forest Degradation and role of conservation, sustainable management of forests and enhancement of forest carbon stocks (Source: UNFCCC).

REDD = RED plus (forest) degradation, or the shifts to lower C-stock densities within the forest; details very much depend on the operational definition of forest.

REDD+

REDD+ = RED plus restocking within and towards forest; in some versions REDD+ will also include peatlands, regardless of their forest status; details still depend on the operational definition of forest.

REDD++

REDD++ = REALU = RED plus all transitions in land cover that affect C storage, whether peatland or mineral soil, trees outside forest, agroforest, plantations or natural forest. It does not depend on the operational definition of forest.

Reserved Forests (RF)

An area so constituted under the provisions of the Indian Forest Act or other State Forest Acts, having full degree of protection. In reserved forests, all activities are prohibited unless permitted.

Scrubland

Degraded forest lands having a canopy density of less than 10 percent.

Sequential Cropping

A pattern of multi-cropping in which one crop follows another on the same land without any break (continuous cropping = continuous land occupancy) or with a break (intermittent cropping = intermittent land occupancy).

Growing more than one crop on the same piece of land with each seasonal crop component being grown during a different time of the year. Related term: simultaneous cropping.

Shelterbelt

An extended windbreak of living trees and shrubs established and maintained for the protection of farmlands over an area larger than a single farm.

Shifting Cultivation

Found mainly in the tropics, especially in humid and sub humid regions. There are different kinds; for example, where a settlement is permanent, but certain fields are fallowed and cropped alternately ('rotational agriculture'). In others, whole settlements move and clear new land once the old one is no longer productive. Also called 'swidden' (Old English for a 'burnt clearing'), used more to designate the social group, or 'slash-and-burn', so-called because of the operations undergone. Related term: slash-and-burn system.

Silvopastoral System

Any agroforestry system that include trees or shrubs with pastures and/or animals. Related term: forest grazing.

Slash-and-burn System

A kind of shifting cultivation in high rainfall areas where the cropping period is followed by a fallow period during which grass, herb, bush or tree growth occurs.

A pattern of agriculture in which existing vegetation is cut, stacked and burned to provide space and nutrients for cropping; also called 'swidden' cultivation and shifting cultivation.

Strip Cropping

Growing two or more crops simultaneously in different bands wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically. Related term: zonal agroforestry system.

Growing crops in a systematic arrangement of strips or bands to serve as vegetative barriers to wind and water erosion. Related terms: windstrip, barrier hedge.

The practice of growing crops in narrow bands along the contour in an attempt to reduce runoff, thereby preventing erosion or conserving moisture.

Sustainable Development

The management and conservation of the natural base and the orientation of technological and institutional change, in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. It conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically feasible and socially acceptable.

Taungya System

Method of raising forest trees in combination with (seasonal) agricultural crops. Used in the early stages of establishing a forest plantation, it not only provides some food but also lessens the establishment costs.

Tree

A large woody perennial plant having a single well-defined stem (bole or trunk) and a more or less definite crown. It also includes bamboos, palms, fruit trees, etc. and excludes non-perennial non-woody species like banana and tall shrubs or climbers. For the purpose of assessing growing stock and tree cover, only those trees having a diameter at breast height (dbh) of 10 cm or more are measured.

Tree Cover

Comprises tree patches outside the recorded forest area exclusive of forest cover and less than the minimum mappable area (1 ha). Such small patches comprised of block, linear and scattered trees are not delineated as forest cover during interpretations of satellite data. The areas of scattered trees are computed by notional numbers.

Tree Farming

Any agroforestry practice that incorporates trees into farmland. Related term: farm forestry.

Tree Garden

A multi-storeyed agroforestry system in which a mixture of several fruit and other useful trees is cultivated (that is, for a mixture of products), sometimes with the inclusion of annual crops. Related terms: home garden, mixed garden, village forest garden.

Trees Outside Forest (TOF)

'All trees growing outside recorded forest areas, irrespective of patch size' are referred to as Trees Outside Forest (ISFR 2019). The recorded forest area means 'reserve', 'protected' or 'unclassified forest'. The trees growing in private lands in agroforestry, farm forestry, along the farm bunds and homesteads, and in orchards and in common and government non-forest lands in parks and gardens, along roads, canals and railway line in rural or urban areas constitute TOF. Trees Outside Forest can have their occurrence in the form of block, linear and scattered stratum.

Unclassed Forests

An area recorded as forest but not included in reserved or protected forest category. Ownership status of such forests varies from state to state.

Very Dense Forest

Lands with forest cover having a canopy density of 70 percent and above.

Windbreak

A group of trees or shrubs in any arrangement that will afford protection from high winds to animals or crops or both. When the arrangement is in a long line the group is called a shelterbelt. If an associated reason is to harvest timber at some future date it is sometimes called a 'timber belt'. Related term: wind strip.

Zero Tillage

Growing crops without any significant disturbance of the soil, and often by leaving the previous crop residues on the soil surface as a protective mulch. Related terms: minimum tillage, stubble mulching.

1.2 Geospatial Technology

Accuracy Assessment

Comparison of a classification to geographical data that is assumed to be true. Usually, the data assumed to be true are derived from ground truthing.

Accuracy Report

In a classification accuracy assessment, a list of the percentages of accuracy, which is computed from the error matrix.

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.

Algorithms

Mathematical formulas or statistical processes used to analyse data. These are used in software to process and analyse any input data.

Analogue

Things that aren't made up of numbers. A photo taken with a film camera would be an analogue picture. A photo taken by a digital camera would be defined in terms of zeros and ones and would be considered digital. Related term: digital.

Area of Interest (AOI)

A point, line, or polygon that is selected as a training sample or as the image area to be used in an operation. AOIs can be stored in separate .aoi files.

Artificial Intelligence (AI)

The ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalise, or learn from experience. Since the development of the digital computer in the 1940s, it has been demonstrated that computers can be programmed to carry out very complex tasks.

Atmospheric Correction

The atmosphere affects the spatial and spectral distribution of the electromagnetic radiation originating from the sun before it reaches the Earth's surface, and it also attenuates the subsequently reflected energy recorded by a satellite sensor.

Attribute

The tabular information associated with a raster or vector layer.

Backscattering

Energy, when hitting a target, can be scattered in many directions. The part of the energy that is scattered back in the exact direction where it came from, is 'backscattered'. Related term: reflection.

Band

A set of data file values for a specific portion of the electromagnetic spectrum of reflected light or emitted heat (red, green, blue, near-infrared, infrared, thermal, and so forth), or some other user-defined information created by combining or enhancing the original bands, or creating new bands from other sources. Sometimes called channel.

Base Map

A map portraying background reference information onto which other information is placed. Base maps usually show the location and extent of natural surface features and permanent human-made features.

Buffer Zone

A specific area around a feature that is isolated for or from further analysis. For example, buffer zones are often generated around streams in site assessment studies so that further analyses exclude these areas that are often unsuitable for development.

Cartographic Limit

The minimum mappable area of a feature, which can be presented on a map at a given scale.

Change Matrix

Presents classes of change in land use land cover for a given geographical region (district or state) during two assessment periods in a matrix form by showing the changes of area from one class to another, OR

Rate, degree or nature of change of forest/land resources for a particular site in a given time period. It could be as a result of present or past management activities and anthropogenic impacts in terms of diversity, species richness, relative abundance of species as well as the network of interactions among the different components in the ecosystem. (Source: NCCF FM Standard).

Class

A set of pixels in a GIS file that represents areas that share some condition. Classes are usually formed through the classification of a continuous raster layer.

Cloud Computing

A distributed computing system over a network used for storing data off-premises.

Cloud computing simply means storing or accessing data (programmes, files, data) over the internet instead of on a hard drive.

Composite Image

We can make a 'composite' image by selecting the most appropriate parts of other images. For instance, we could take only the cloud-free parts of many images to make a 'composite' image of all of India showing no clouds at all. It would not be a realistic scene, since we always have some clouds, but it would show all of India without allowing cloud cover to mask parts of it. Related words: combining, mosaic.

Continuous Data

A type of raster data that are quantitative (measuring a characteristic) and have related, continuous values, such as remotely sensed images collected from satellites such as Landsat, SPOT, GeoEye, WorldView, and so forth.

Contrast Stretch

The process of reassigning a range of values to another range, usually according to a linear function. Contrast stretching is often used in displaying continuous raster layers, since the range of data file values is usually much narrower than the range of brightness values on the display device.

Data-as-a-Service (DaaS)

Treats data as a product. It providers use the cloud to give on-demand access of data to customers. This allows companies to get high quality data quickly.

Dark Data

This is information that is gathered and processed by a business, but never put to real use. Instead, it sits in the dark waiting to be analysed. Companies tend to have a lot of this data laying around without even realising it.

Data Mining

Data miners explore large sets of data to find patterns and insights. This is a highly analytical process that emphasises making use of large datasets.

Data Science

The professional field that deals with turning data into value such as new insights or predictive models. It brings together expertise from fields including statistics, mathematics, computer science, communication as well as domain expertise such as business knowledge.

Database

An organised collection of data. It may include charts, schemas or tables. It may also be integrated into a Database Management System (DBMS), a software that allows data to be explored and analysed.

Descriptive Analytics
Condensing big numbers into smaller pieces of information.

Detection
If you are detecting something, you are trying to find if it is there. This could be done by using your senses or by using instruments. Once it is found, it has been detected. Related terms: sensing, discovery, detect.

Digital Analysis
If you have a digital satellite image, then it is useful to analyse it digitally. Special computer programmes called image analysis softwares are available for this. Such programmes can stretch and distort a digital image to make it fit on a map, they can enhance it to show some features more clearly, they can classify the image into categories which contain similar features, and much more. Related terms: image analysis, classification, enhancement.

Digital Data
Information that is made up of numbers is digital data. Telephone numbers are digital data, so are digital images from satellites. The opposite of digital is 'analogue'. Related terms: digitised, analogue.

Digital Elevation Model (DEM)
A 'bare-earth' raster grid referenced to a vertical datum.

Digital Image Processing (DIP)
Interpretation and classification of satellite remote sensing data using a computer and a DIP software.

Digital Surface Model (DSM)
Represents the mean sea level elevations of the reflective surfaces of trees, buildings and other features elevated above the 'bare-earth'.

Digital Terrain Model (DTM)
Synonymous with a DEM. This means that a DTM is simply an elevation surface representing the 'bare-earth' referenced to a common vertical datum.

Earth Observation
Looking down at the Earth from aircrafts or satellites using various sensors, which take images that are afterwards used to study what is happening on or near the Earth's surface. Related term: remote sensing.

Electromagnetic Spectrum
The continuum of energy that ranges from meters to nanometres in wavelengths, travels at the speed of light, and propagates through a vacuum like the outer space. 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.

Emit

Means the same as 'send out' or 'give off'. The sun emits radiation, some of which we can feel as heat and some of which we can see as light. The radar sensor in RADARSAT emits a radar beam. Related terms: transmit, radiation.

Enhancement

The process of making an image more interpretable for an application. Enhancement can make important features of raw, remotely sensed data more interpretable to the human eye. Anything that you do to an image to make it simpler, faster or more accurate to analyse and interpret by eye is a form of 'enhancement'. Special enhancement techniques can improve colour, brightness, contrast, sharpness, etc. Related words: visual interpretation.

Error Matrix (Confusion Matrix)

A means to quantitatively assess the accuracy of classification of interpreted satellite data. Under this, the reference data (ground check points) is compared with the corresponding results of the classification on the randomly selected locations on category-by-category basis. It is presented in the form of a square matrix.

False Colour Composites (FCC)

Allow us to visualise the wavelengths the human eye does not see (near the infrared range). Blue, green and red colours are falsely given to three bands of remote sensing image.

Geometric Correction

Images are accurately determined planimetrically (X, Y) and elevational (Z). In other words, the position of each feature in the image should represent its true and exact location on the Earth's surface and be provided in an appropriate geographical coordinate system.

Geographic Information System (GIS)

A generic term denoting the use of computers to create and depict digital representations of the Earth's surface. GIS is a computerised database system for capture, storage, retrieval, analysis, and display of spatial data. A larger concept than often believed, GIS is the hardware, software, data, personnel systems, etc., involved with geographical positions (latitude, longitude and altitude).

Google Earth Engine (GEE)

The most advanced cloud-based geospatial processing platform. The main components of Earth Engine are: Datasets, Compute power, APIs, Code Editor.

Global Positioning System (GPS)

Consists of broadcasting satellites, receiving hardware and software used to locate coordinates on or near the surface of the Earth.

Green Wash

The extent of wooded areas generally shown in light-green colour on the SOI toposheets.

Ground Control Point (GCP)

Specific pixel in image data for which the output map coordinates (or other output coordinates) are known. GCPs are used for computing a transformation matrix, for use in rectifying an image.

Ground Truthing

The acquisition of knowledge about the study area from fieldwork, analysis of aerial photography, personal experience, and so forth. Ground truth data are the most accurate (true) data available about the area of study.

Remote sensing analysts must be sure that their image analysis is accurate. This is done by field, where they go out to the actual places shown in the images and confirm that what they think they see on the image is actually true. Related terms: verification, calibration.

Hadoop

An open source software framework, works largely by storing files and processing data. It is also known for its large processing power, making it easy to run a multitude of tasks concurrently.

Hyperspectral

Hyperspectral remote sensing combines imaging and spectroscopy in a single system, which often includes large data sets in narrow, continuous spectral band and requires new processing methods.

Image

The picture that is a result of the sensing process. A remote sensing image can be displayed on a computer monitor or it can be made into a printed copy. Related term: imagery.

Image Analysis

This is the process of studying an image in order to explain, measure, map, count or monitor what is on the Earth's surface. Related terms: interpretation, classification.

Image Classification

Assigning pixels in the image to different categories or classes of interest.

Image Co-registration

The rationale of co-registration is to ensure that the images become spatially aligned so that any feature in one image overlaps as well as possible its footprint in any other image in the series.

Image Interpretation

Image interpretation is defined as the extraction of qualitative and quantitative information in the form of a map, about the shape, location, structure, function, quality, condition, relationship of and between objects, etc. by using human knowledge or experience.

Imaging System

Imaging systems are devices used for the purpose of measuring position, momentum, energy, or mass of charged particles. It is used for observation or image capture in a variety of applications including inspection, remote sensing or machine vision. Imaging Systems typically consist of a camera, imaging lens, along with an illumination source.

Internet of Everything (IoE)

Combines products, people and processes to generate even more connectivity.

Internet of Things (IoT)

Generally described as the way products are able 'talk' to each other. It is a network of objects (for example, your phone, wearable or car) embedded with network connectivity.

Landsat

Owned and launched by the United States, this is a series of remote sensing satellites that use the visible and infrared parts of the spectrum to record images of the Earth's surface. Landsat 1 to Landsat 8 are the satellites in this series.

Layer Stacking

A process for combining multiple images into a single image. In other words, all images/bands should have the same spatial resolution to be able to perform layer stacking.

Line-of-Sight

When two objects (such as a satellite and a receiving station) have nothing in between them, then they are in 'line-of-sight' of each other. When a satellite is on the other side of the Earth from a receiving station, the Earth is in between them, so the satellite and the receiving station are not in 'line-of sight' of each other. Related terms: visibility, data reception.

Machine Learning

The use of algorithms to allow a computer to analyse data for the purpose of 'learning' what action to take when a specific pattern or event occurs.

Masking

Process in which certain image parts are marked for exclusion from further analysis.

Monitoring

Keeping track of how things are changing over time. For example, with remote sensing images taken over different periods of time, one can monitor the result of logging in a forest or how well crops are growing or how much a glacier has melted or how far a plume of sediment travels in a lake, etc. Related terms: change detection, multi-temporal analysis.

Mosaic

A big image made by combining smaller images into one.

Multispectral

A data product in which the data are binned into as few as two, or as many as approximately fifteen.

Neural Network

Artificial Neural Networks are models inspired by the real-life biology of the brain. These are used to estimate mathematical functions and facilitate different kinds of learning algorithms. Deep Learning is a similar term, and is generally seen as a modern buzzword, rebranding the Neural Network paradigm for the modern day.

Normalised Difference Vegetation Index (NDVI)

The formula for NDVI is IR-R/IR+R, where IR stands for the infrared portion of the electromagnetic spectrum, and R stands for the red portion of the electromagnetic spectrum. NDVI is an index mainly used for finding vegetation on an imagery.

Object-Based (Object-Oriented) Image Classification

Object-Based Image Classification groups pixels into representative shapes and sizes. Object-Oriented Image Analysis combines spectral information and spectral information contrary to traditional methods relying on spectral information only. It segments the pixel into objects according to the colour/tone, texture, etc. of the image and classifies it by treating each object.

Orbit

The path traced by a satellite as it passes around a planet.

Orthorectification

A form of rectification that corrects for terrain displacement and can be used if a DEM of the study area is available.

Pan Sharpening

Shorthand for "Panchromatic sharpening". Pan sharpening is a technique that merges high-resolution panchromatic data with medium-resolution multispectral data to create a multispectral image with higher-resolution.

Parallel Data Analysis

Breaking up an analytical problem into smaller components and running algorithms on each of those components at the same time. Parallel data analysis can occur within the same system or across multiple systems.

Passive Sensing System

Mainly depends on the solar radiation originating from the visible and infrared region of electromagnetic spectrum.

Pixel

The smallest unit in a digital image, it is short form of 'picture element'.

Platform

What carries a sensor - usually a satellite or an airplane.

Polygon

A closed multi-sided figure representing an area on a map.

Predictive Analytics

Studying recent and historical data, analysts are now able to make predictions about the future. Finally, having a solid prediction for the future, analysts can prescribe a course of action.

Radar Shadow

Just as with a flashlight, a radar sensor 'illuminates' a scene, and if an object blocks the beam, a shadow area develops behind it. Such shadows can be seen in a radar image. Radar shadows are pure black - they contain absolutely no information. Related term: radar beam.

RADARSAT

The first Canadian remote sensing satellite, it uses radar technology to capture images of the Earth's surface. Related terms: satellite, radar.

Radiometric Resolution

Its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution.

Raster

A regular grid of cells covering a fixed area on satellite images.

Raster Data Structure

A database containing all mapped, spatial information in the form of regular grid cells.

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.

Receiving Station

At a receiving station, antennas collect the signals sent by an orbiting satellite. Electronic devices process the signals and the data are stored. Usually the station also converts the data into usable digital and printed images/forms. Related terms: satellite, reception, downlink.

Reflection

Occurs when radiation (light, radar signals, etc.) bounces off a target. It is very important in remote sensing that how reflection happens, how much is reflected and how the radiation is changed in the process of reflection, because it tells us much about the target that caused the reflection.

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. Sensors mounted on aircrafts or satellite platforms measure the amounts of energy reflected from or emitted by the Earth's surface.

Resolution

Spatial resolution describes how clearly you can see detail in a picture. Consider the focusing done by a camera. If the picture is blurry and you can't see small objects, the resolution is poor (low resolution). If the picture is sharp and you can see small objects, the resolution is good (high resolution). Resolution is also used in describing colour detail (how similar colours are) and even time detail (how close in time things happen). Related terms: detail, image analysis.

Software-as-a-Service (SaaS)

Enables vendors to host an application and make it available via the internet. Yes, that's cloud servicing. SaaS providers provide services over the cloud rather than hard copies.

Satellite

A satellite is a natural or manmade object continuously orbiting above the Earth or another planet or star. A remote sensing satellite carries one or more instruments for recording images of the Earth, which are transmitted to a receiving station using radio waves. Related terms: platform, receiving station, orbit.

Scaled Map

A georeferenced map that is accurately arranged and referenced to represent distances and locations. A scaled map usually has a legend that includes a scale, such as 1 inch = 1000 feet. The scale is often expressed as a ratio like 1:12,000 where 1 inch on the map equals 12,000 inches on the ground.

Scanner

While a camera would take a picture of an area at once, a scanner is a device that examines an area point by point until the entire area has been imaged. These points become the pixels in a digital remote sensing image.

Scanning

The transfer of analogue data, such as photographs, maps, or another viewable image, into a digital (raster) format.

Sensor

Device that records a remote sensing image, much like a camera. Related terms: scanner, platform.

Shuttle Radar Topography Mission (SRTM)

International research effort that obtained elevation data from 56°S to 60°N on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. It is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

Spark

An open-source computing framework originally developed at University of California, Berkeley. Spark was later donated to Apache Software. Spark is mostly used for machine-learning and interactive analytics.

Spatial Modelling

An analytical process conducted in conjunction with a geographical information system (GIS) in order to describe basic processes and properties for a given set of spatial features.

Spatial Resolution

The minimum area on Earth's surface that can be captured by a satellite sensor as being separate from its surroundings and is represented by a 'pixel'. The range of wavelengths of the electromagnetic spectrum that a satellite imaging system can detect. It refers to the width and number of spectral bands, the narrower the bands, the greater the spectral resolution.

Spectral Signature

A characteristic shape to a spectrum which can be used as an unambiguous indicator of some chemical constituent (or vegetative component) of the area being studied.

Subpixel Classification

Subpixel approaches aim to address the mixed pixel problem that arises when coarse spatial resolution images are used for mapping small agricultural fields in heterogeneous landscapes.

Supervised Classification

Is generally done on the basis of representative training samples for each land cover classes.

Supervised Learning

Learning process designed to form a mapping from one set of variables (data) to another set of variables (information classes).

Targets

The features being studied in a remote sensing image. Related terms: backscatter, reflection.

Temporal Resolution

The amount of time needed to revisit and acquire data for the exact location.

Thematic Maps

Maps generally on 1:50,000 scale, showing forest types, major species composition, and other land uses land covers prepared by the interpretation of aerial photographs and verified by ground truthing.

Transmit

Energy that passes through an object or material is 'transmitted'. This is in contrast to energy that may be reflected or absorbed. A window (which is not too dirty) allows light to transmit through and thus we are able to see through glass. Related terms: reflect, absorb, backscatter.

Triangular Irregular Networks (TIN)

TINs are a form of vector-based digital geographic data and are constructed by triangulating a set of vertices (points).

Unsupervised Classification

In unsupervised classification, pixels are grouped into 'clusters' based on their properties.

Unsupervised Learning

Exploration of the data space to discover the scientific laws underlying the data distribution.

Vector

The representation of spatial data by points, lines and polygons.

Vector Data Structure

A means of coding and storing point, line and areal information in the form of units of data expressing magnitude, direction and connectivity.

Vector Object Operators (VOO)

In this step, vector objects were 'smoothened' into shape.

Vector Object Processor (VOP)

In this step, the object cues are computed on the tree polygons such as circularity, size and geometry.

Visual Interpretation

A manual method of interpreting satellite remote sensing data normally by magnifying glass and light table.

Part-II

Techniques/Methodologies Used to Map TOF/Agroforestry

2.1 Methodologies Developed by CAFRI

ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi has developed different methodologies for medium-resolution (>10 m spatial resolution) and high-resolution (<10 m spatial resolution) remote sensing satellite data, which are discussed below:

a) Methodology for Medium-Resolution Data

For mapping and estimating area under agroforestry using medium-resolution remote sensing data, a methodology has been proposed (Figure 1). First, land use land cover (LULC) classification on LISS III data (23.5 m spatial resolution) is to be done by the maximum likelihood method. Agricultural land including cropland and fallow land is then extracted from this classified image for masking equivalent area from False Colour Composite (FCC). Since pixel-based methods account for a 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, the subpixel method of classification was applied on agricultural land because agroforestry exists on agricultural land only. The advantage of using a subpixel classifier is that this method not only overcomes the problem of the intermingling of sugarcane with young plantations, but it also gives outcomes in the form of percent tree cover within a pixel. This tree cover (20-100 percent) accounts for all types of agroforestry systems, viz., scattered trees, boundary plantations, agri-silviculture/ agri-horticulture and block plantations on farmlands (Figure 2).

Applying the subpixel classifier on extracted agricultural area using the generated signatures, the 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.

Figure 1: Flowchart showing methodology for agroforestry mapping

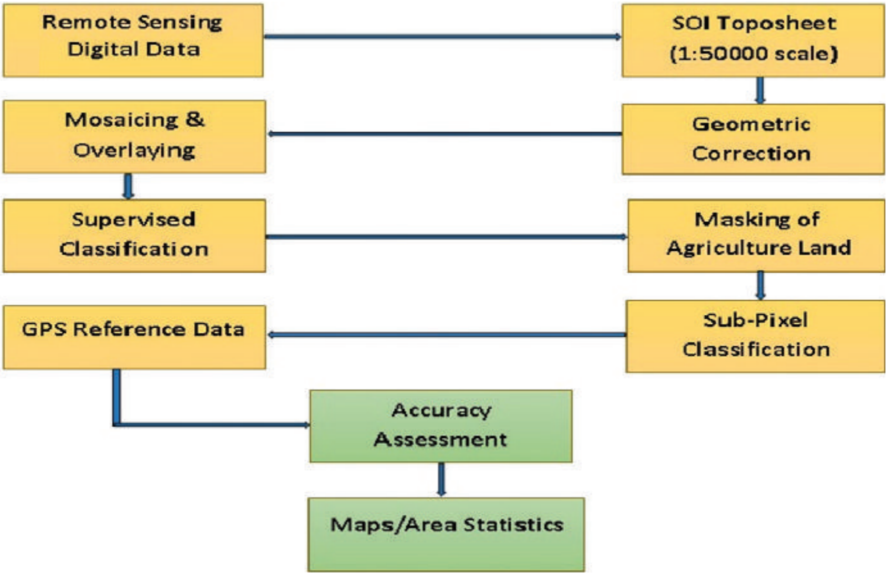
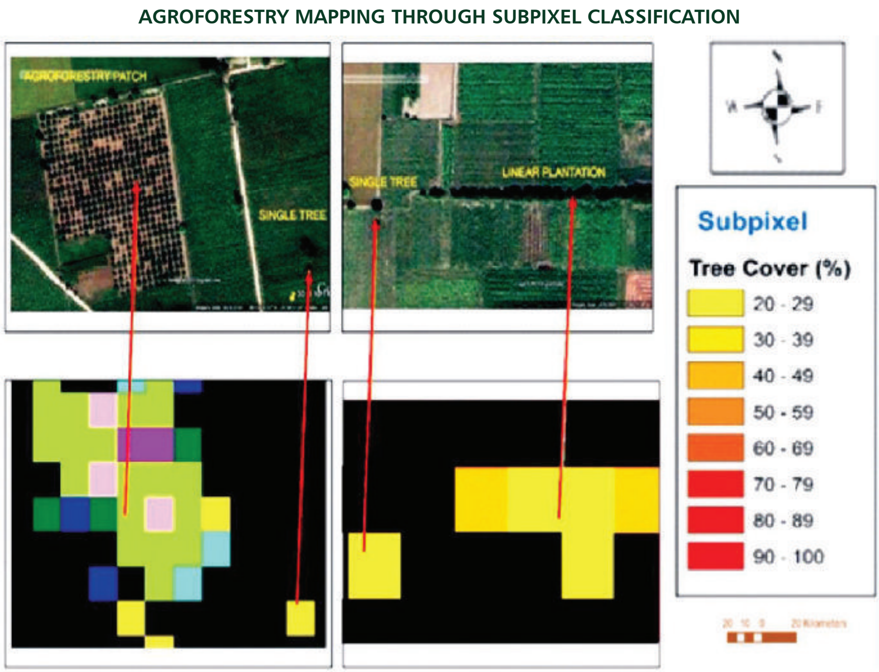


Figure 2: Single tree, linear and block plantations identified through subpixel classifier



The pixels of the first three categories, which includes scattered trees, boundary plantations as well as block plantations, will represent agroforestry in the real sense.

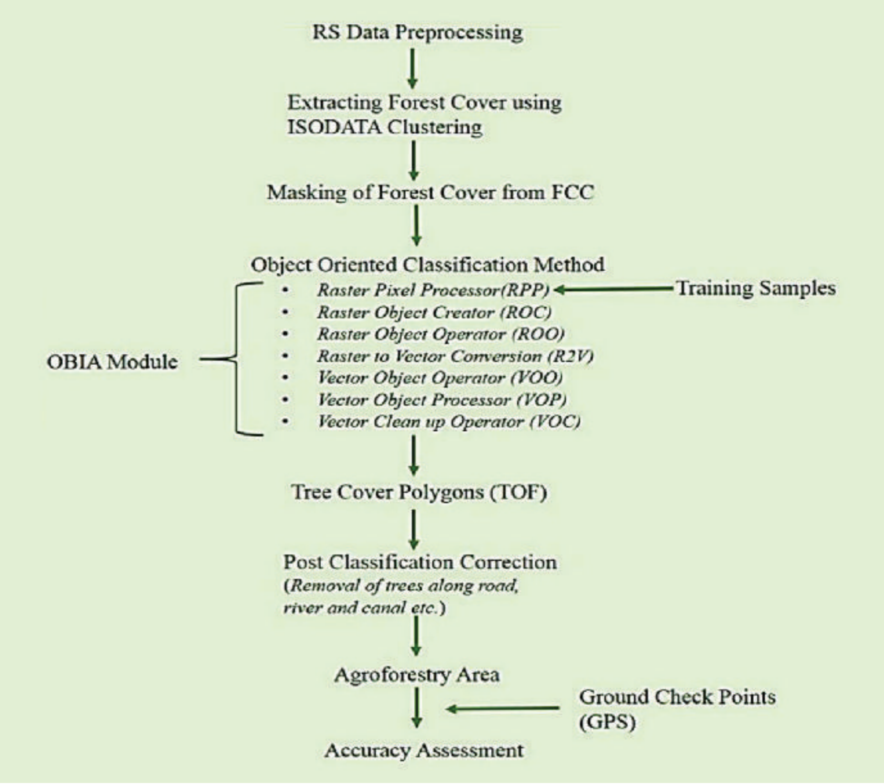
b) Methodology for High-Resolution Data

In case of high-resolution remote sensing data like LISS-IV (5.8 m spatial resolution) or Cartosat-1 (2.5 m spatial resolution), trees on farmlands can be easily captured as compared to medium-resolution data. ICAR-CAFRI, Jhansi has developed a methodology for mapping trees on farmlands (i.e. agroforestry) using an object-oriented classification technique applied on LISS-IV data. The 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 organises such pixels into groups (segments) that correspond to real world objects. The object-oriented image analysis approach combines spectral information and contrary to traditional methods relying on spectral information only. It segments the pixel into objects according to the colour/tone, texture, etc. of the image and classifies it by treating each object as a whole. Utilising 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.

The flowchart of the methodology adopted (Figure 3) and various steps involved in this methodology are given below:

1. Multispectral high-resolution LISS-IV data (spatial resolution - 5.8 m) were procured from NRSC, Hyderabad.
2. Pre-processing of scenes including layer stacking, mosaicking and sub-setting the LISS-IV bands (green, red & NIR) with district boundary shape file.
3. Unsupervised classification method (k-means/ISODATA) was applied for getting different land uses and land covers including forest cover.
4. Extracting the forest cover area from the FCC image with the help of the classified image of the district.
5. OBIA Module - Applying Single Feature Probability (SFP) with the help of training samples, background pixels (crop, bare soil, etc.) on the FCC image. Thereafter, threshold and pixel probability are fixed for the target feature (trees), output will consist of Trees Outside Forest (TOF) in the form of polygons.
6. Post-classification correction was applied on TOF to remove trees along roads, canals, within urban areas, etc. to get the agroforestry area.
7. Accuracy of agroforestry area so obtained is determined with the help of ground check points (GCPs) and final map is prepared.

Figure 3: OBIA methodology for mapping tree cover and agroforestry



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

c) Mapping Agroforestry using Object-Based Image Analysis (OBIA) Approach

Case Study of Koraput District of Odisha

The Koraput district of Odisha was taken as case study for mapping agroforestry using the Object-Based Image Analysis (OBIA) technique for which LISS-4 data have been used. In case of maximum likelihood classifier (MLC), the area under agroforestry was estimated to be 31795.28 ha (3.80 percent). The overall accuracy of LULC comes out to be 80.8 percent with a kappa coefficient of 0.783 in this case. While using OBIA (on agricultural land), the agroforestry area was estimated to be 42978.55 ha (5.14 percent).

Very good accuracy of 91.2 percent was achieved in the agroforestry class by OBIA classification. The results obtained by MLC and OBIA methods were compared in the case of agroforestry (Figure 4). In the case of supervised classification, those pixels are fully captured where trees exist, whereas OBIA captures trees according to their crown shapes. This led to an accurate estimation of the area under trees in scattered, in linear and in patch form (Figure 5). Therefore, OBIA could be an appropriate method for mapping

Figure 4: Agroforestry mapping by Maximum Likelihood and OBIA techniques

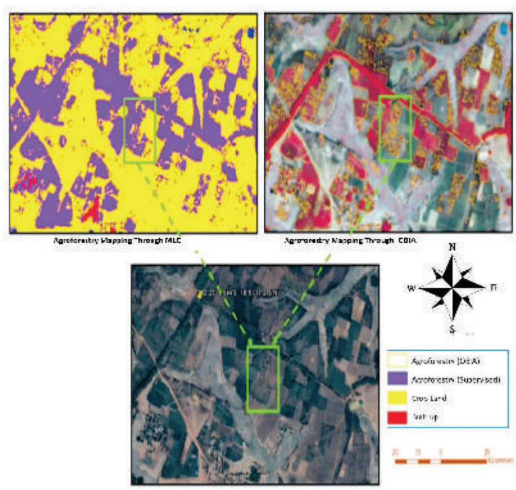


Figure 5: Agroforestry mapping by Maximum Likelihood and OBIA techniques

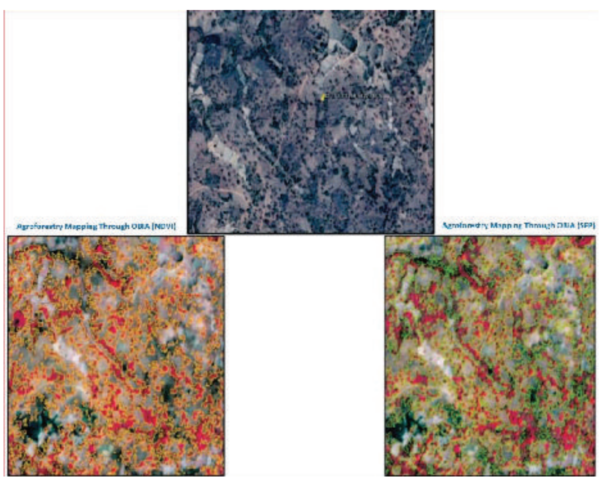
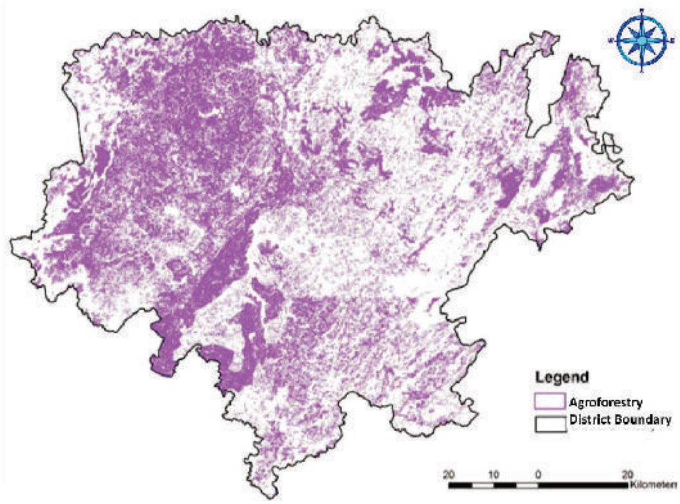


Figure 6: Agroforestry area in Koraput district mapped by OBIA method



all types of agroforestry (scattered trees, boundary and block plantations) existing on farmlands. The agroforestry area in the Koraput district obtained by the OBIA technique is given in Figure 6.

d) Mapping Species on Farmlands: Possible Approaches

Importance of Spectral Signatures for Mapping Species

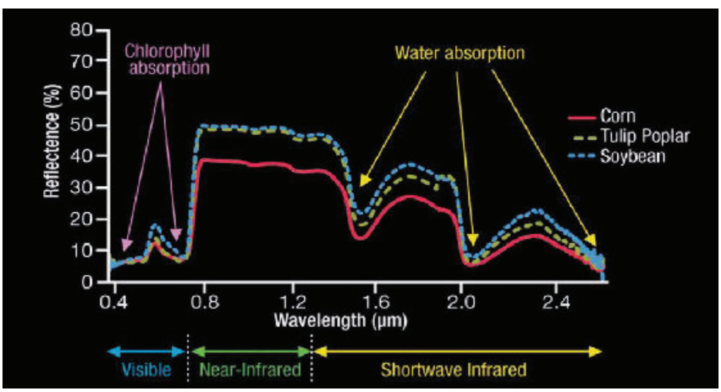
Recent advances in hyperspectral sensors offer considerable potential for discrimination of Earth surface materials. It is because the electromagnetic spectrum is divided into hundreds of discrete, contiguous spectral bands, enough to read the spectral signature of the material in the image. As compared 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 (Table 1). 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 onboard the EO-1 satellite with 242 bands and the FTHSI sensor from the US Airforce Research Lab onboard the Mightysat- II satellite with 256 bands. Using hyperspectral data, spectrally similar materials can be distinguished, and subpixel information can be extracted.

Table 1: 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 for 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 spectral library of spectral signatures for major agroforestry tree species. Under this project four agroforestry species, viz., Aonla, Mango, Eucalyptus and Poplar were selected, and spectral signatures were developed using hyperspectral/high-resolution remote sensing data (Figure 7).

Figure 7: Comparison of signatures of different vegetation on hyperspectral scale



2.2 Methodology Developed by FSI

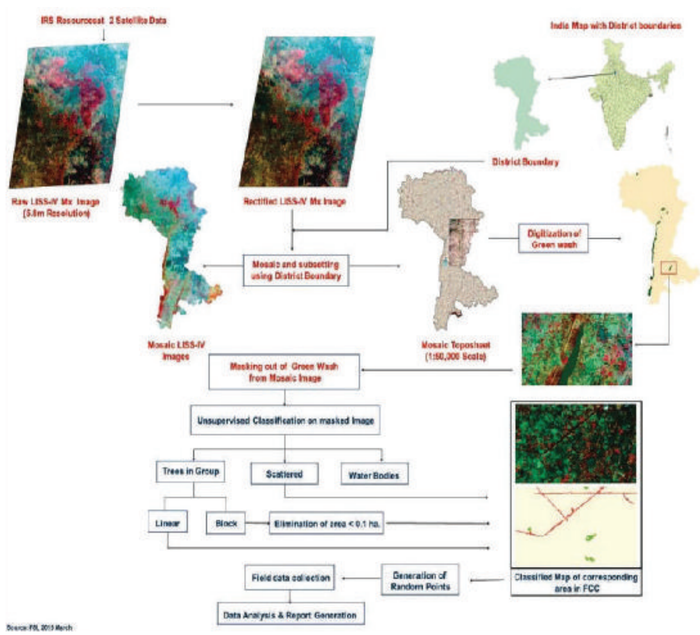
a) FSI Methodology

Separate methodologies are followed by Forest Survey of India for mapping TOF (Rural) and TOF (Urban) in 60 randomly selected districts both in rural and urban areas (FSI, 2015).

TOF (Rural): The sampling framework for inventory of TOF (Rural) using high-resolution satellite data to stratify TOF resources of the selected districts into three strata namely block, linear, and scattered (Figure 8). IRS Resource sat-II LISS-IV Mx data (spatial resolution - 5.8 m) for the desirable period are acquired from NRSC, Hyderabad for the selected districts. Thereafter, the images are geometrically rectified with the help of SoI toposheets on a 1:50,000 scale. Since the area of interest is TOF, the recorded forest area of the district is masked out. The image is then classified into vegetation, snow cover, alpine pasture, water bodies and riverbeds. The classified image is visually analysed for editing and refinement. Since the area less than 0.1 ha is not qualified to be included into block, thus such pixels are clumped and clusters of pixels less than 0.1 ha are eliminated. The final classified map is generated having three

Figure 8: FSI methodology for mapping TOF (Rural) using remote sensing (Source: FSI, 2015)

METHODOLOGY FOR ASSESSMENT OF TREES OUTSIDE FOREST USING REMOTE SENSING TECHNIQUE



classes in TOF areas, namely block, linear and scattered, which are treated as strata for the TOF inventory. From the classified TOF map, the area under each stratum is calculated.

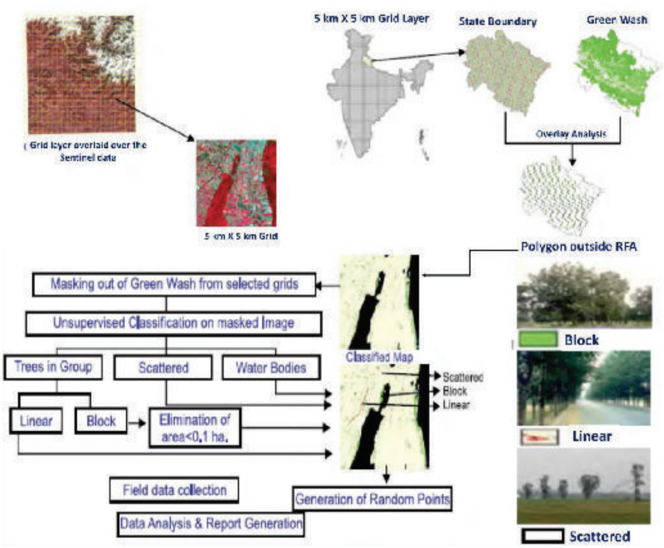
For the purpose of agroforestry, only the rural TOF inventory is taken into consideration. High-resolution satellite data are used for the stratification of Culturable Non-Forest Area (CNFA) into three strata, viz., block, linear and scattered. Out of the three strata, only the block and scattered strata are considered, while linear stratum and other private forest stratum are excluded as they do not fall within the definition of agroforestry.

b) FSI New Methodology for TOF

According to ISFR (2019), FSI has now switched over to a grid-based approach, in which the whole country is divided into 5 km x 5 km grids. The Sentinel data is downloaded and geo-rectified with the help of the Survey of India open series map topo-sheets on a 1:50,000 scale. The multispectral remote sensing data of Sentinel-2 with spatial resolution of 10 m is used for classification of the selected grids. The image is classified into settlement, water bodies, tree patches, agriculture and other classes. The classified image is visually analysed for editing and refinement. Since the minimum mappable area is 0.1 ha, pixels are clumped and clusters of pixels having areas of less than 0.1 ha are eliminated. After editing the classified image, the final classified map is

Figure 9: FSI methodology for mapping TOF using remote sensing (Source: FSI, 2019)

METHODOLOGY FOR ASSESSMENT OF TREES OUTSIDE FOREST USING REMOTE SENSING



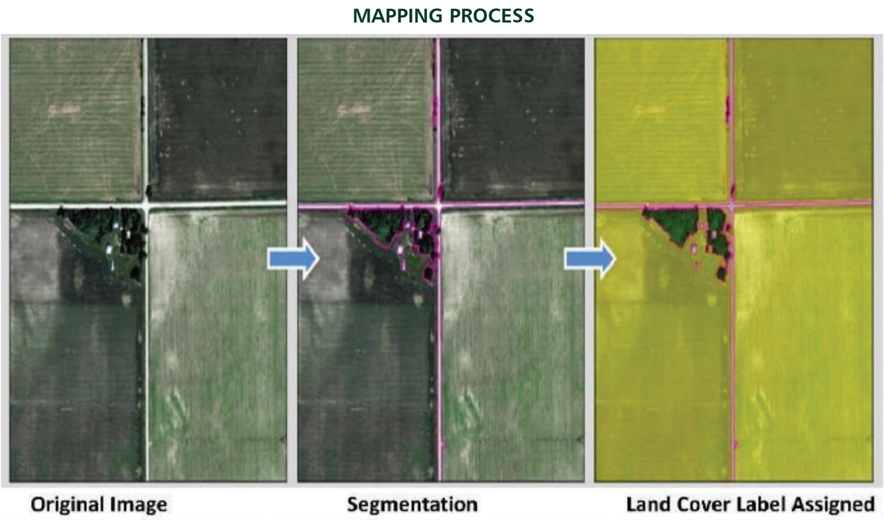
generated with three classes in TOF areas, namely block, linear and scattered, from which the area under each category is calculated. The schematic diagram of the methodology for TOF using remote sensing is depicted in figure 9. As per the current estimates, 29.38 million ha area is under TOF in the country.

2.3 Methodology Developed by USDA

The mapping process (Figure 10) was developed by the US Department of Agriculture, Forest Service, National Agroforestry Centre. First, the pixels in a high-resolution aerial image (above, left) are grouped into similar areas, a process called image segmentation (above, centre). Next, we 'train' a computer to recognise different types of land cover (e.g., trees, water, roads, etc.) using a sample of image segments that we manually label as one of these categories. Finally, a computer algorithm assigns a land cover label to all the image segments based on the training information provided. Explore the output land cover map on the right by sliding the spyglass over the aerial photo. Click on the spyglass and hold the left mouse button down to move it around. Inside the spyglass you will see the land cover categories that were mapped using the process explained above. The land cover categories are shown in the legend. (https://usfs.maps.arcgis.com/apps/MapJournal/index.html?appid=4d1fbe2200cf432bb2cc2c1584f6f9f6)..

(https://usfs.maps.arcgis.com/apps/MapJournal/index.html?appid=4d1fbe2200cf432bb2cc2c1584f6f9f6).

Figure 10: Mapping Process USDA



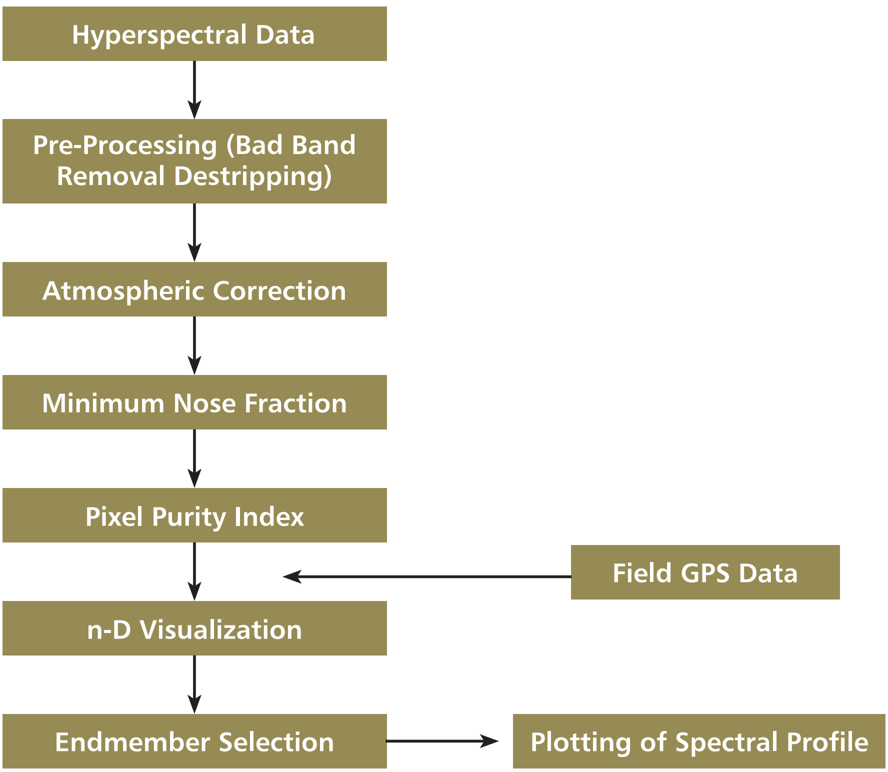
Part-III

Examples of Mapping from India, Asia and Kenya, Africa

3.1 Mapping of Poplar (*Populus deltoides*) Species in India

For Poplar species, spectral signatures have been generated using EO-1 Hyperion data for three periods (May, Sept., and Dec.). Those data were downloaded from the USGS website and then processed and analysed using the ENVI 5.3 software. A methodology has been developed for the generation of spectral signatures from the hyperspectral data. It involves various steps like pre-processing, atmospheric

Figure 11: Methodology for generation of spectral signatures



correction, MNF transformation, pixel purity index, n-D visualization, endmember selection, etc. (Figure 11).

The spectral reflectance pattern for Poplar in three periods appears different in different spectral ranges: visible (400-700 nm), near-infrared (700-1100 nm) and short-wave infrared (100-1800 nm). In the month of May, when trees are full of new flesh, the spectral reflectance of the NIR range is high (Figure 12), which is not the case in the month of September (Figure 13). Again, in the month of December, when trees have no leaves, the spectral reflectance in visible, with NIR and SWIR showing low values (Figure 14). Spectral signatures of Poplar plantations of different ages generated from Sentinel-2A data shows variation in both visible and near-infrared regions (Figure 15). This clearly indicated that seasonal or phenological behaviours of trees have a significant effect on spectral signatures. Therefore, having a library of spectral signatures for different seasons would help in the accurate mapping of poplar tree species.

Figure 12: Spectral signature of Poplar in the month of May

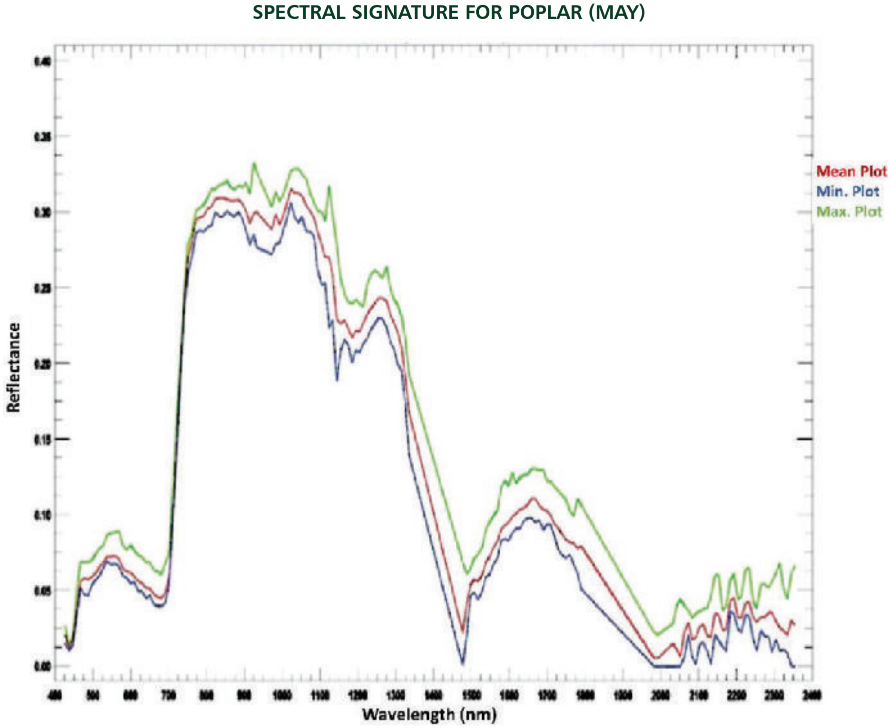


Figure 13: Spectral signature of Poplar in the month of September

SPECTRAL SIGNATURE FOR POPLAR (SEPTEMBER)

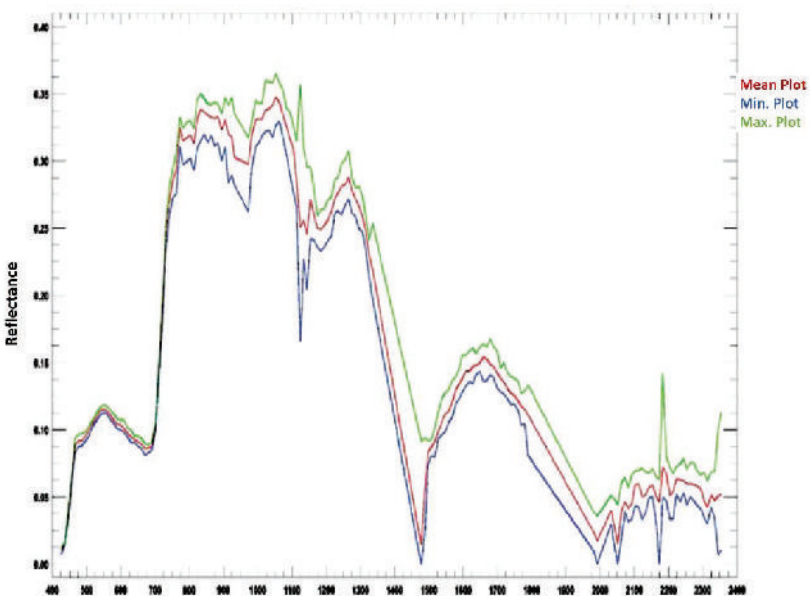


Figure 14: Spectral signature of Poplar in the month of December

SPECTRAL SIGNATURE FOR POPLAR (DECEMBER)

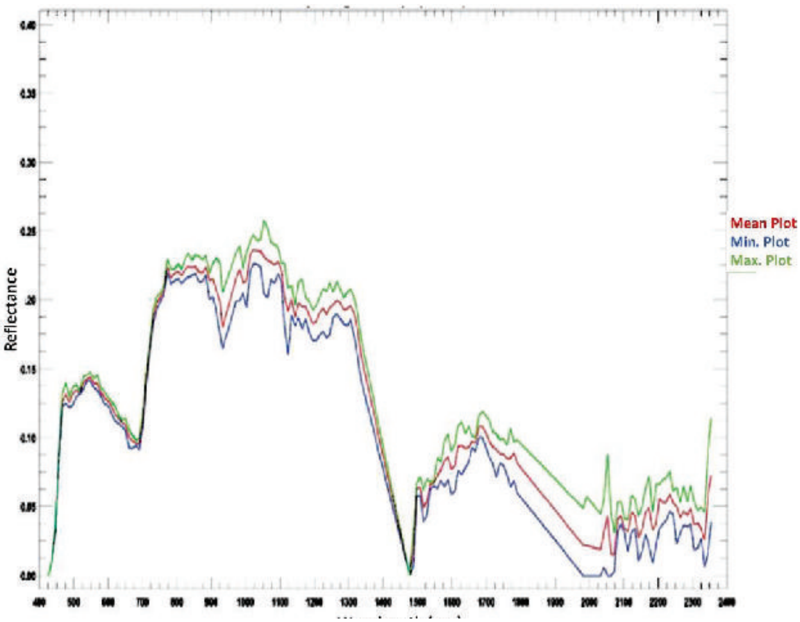
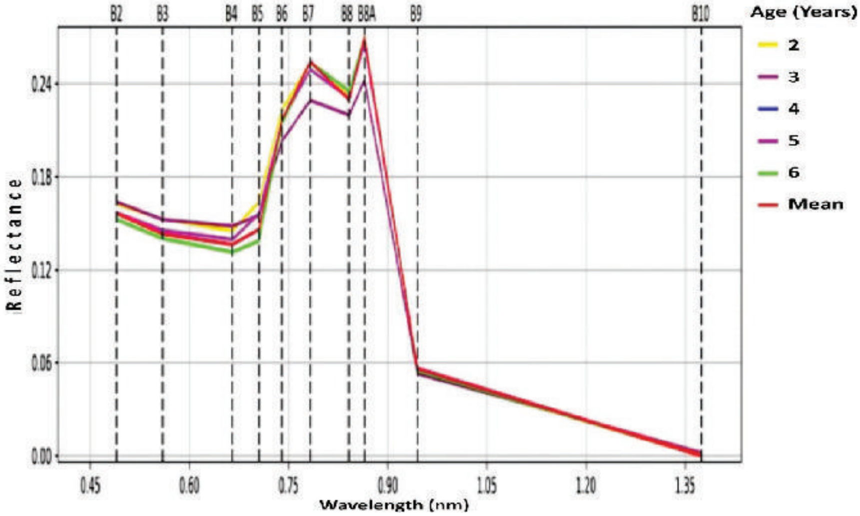


Figure 15: Spectral reflectance patterns for Poplar plantations of different ages



3.1.1 Mapping Poplar Species Using Vegetation Indices

Geometrically corrected Landsat 8 images having a spatial resolution of 30 m for January, May and October 2017 were searched using the OLI sensor in the US Geological Survey. Landsat scene 8 of path 147 and row 39 for Yamunanagar district has been downloaded from the USGS website (http://earthexplorer.usgs.gov). Pre-processing of this scene includes layer stacking of six bands (blue, green, red, NIR, SWIR1 and SWIR2) and sub-setting of the district boundary. These data were visually and digitally interpreted using the ERDAS 2014 and ArcGIS 10.4.1 softwares.

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

pX = MpQcal + Ap

Where,

pX = TOA planetary reflectance, without correction for solar angle

Qcal = 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 the red and NIR bands of Landsat images but NDVI may be insufficient in explaining tree species. Meanwhile, the Landsat programme 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), and Soil Atmospherically Resistant Vegetation Index (SARVI) were generated using reflectance of red, green, blue and NIR bands (Figure 16). The formulae of different vegetation indices are given below:

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

GNDVI = (NIR- Green) / (NIR+ Green)

RDVI = (NIR- Red) / SQRT (NIR+ Red)

TNDVI = SQRT ((NIR- Red) / (NIR+ Red)) + 0.5

SARVI = (NIR-RB) * (1+L) / (NIR+RB+L)

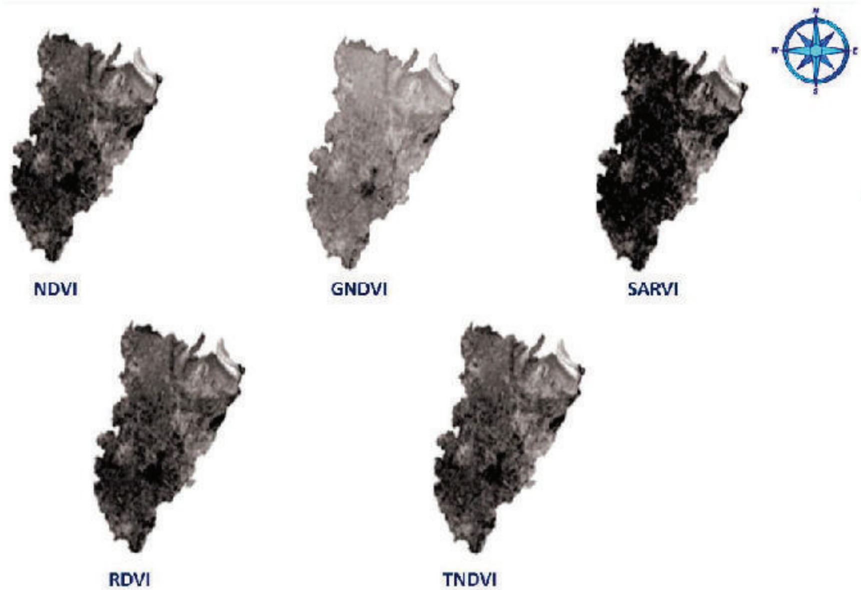
Where, RB = Red-Gamma*(Blue-Red)

L = 0.5 (vegetation cover correction factor)

Gamma = 1 (aerosol content stabilization factor)

The temporal Landsat-8 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 the plant canopy also change. 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, the principle component image and ground check points. It was observed that satellite data of May (new flesh) season gives the exact spectral information of the Poplar species, while January (leaf fall) and October (old flesh) season gives the ground reflection more than tree canopy (Figure 17). Investigations of RDVI, GNDVI and TNDVI revealed that they are not precise enough, while NDVI and SARVI can be used for identification of Poplar species. Finally, the reflectance values of NDVI and SARVI were calculated for Poplar species (Figure 18). The NDVI values were classified into two classes: for Poplar species (0.191 < NDVI < = 0.310) and for other LULC classes (NDVI < = 0.191 & NDVI > 0.310). The SARVI image were classified for poplar (0.485 < SARVI < = 0.693) and for other LULC classes (SARVI < = 0.485 & SARVI > 0.693). The area covered by Poplar species using NDVI is 13.98 percent (24109.2 ha) and, using SARVI, it is 13.79 percent (23783.85 ha). The estimated area was found to be almost same but, in this study, we prefer SARVI because it gives better separability and approximation of tree species (Figure 19). The spectral variables

Figure 16: Different vegetation indices generated for Yamunanagar district



Generated Vegetation indies

Figure 17: Differentiation and identification of Poplar area by vegetation indices

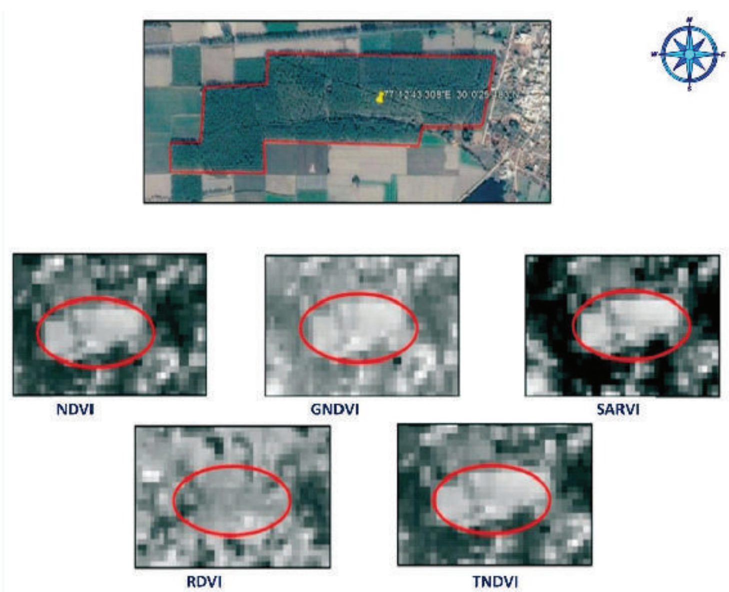


Figure 18: Temporal variation in NDVI and SARVI indices for Poplar plantation

TEMPORAL VARIATION IN NDI AND SARVI INDICES FOR POPLAR TREE IN YAMUNANAGAR DISTRICT

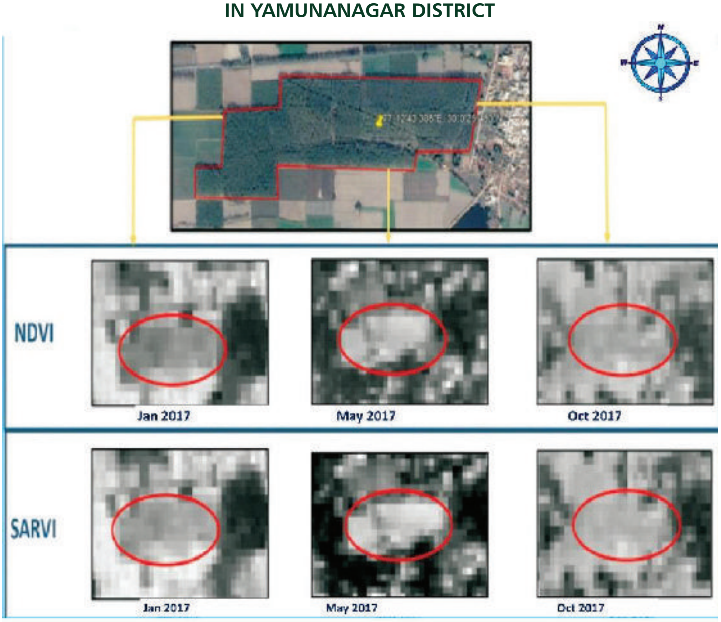
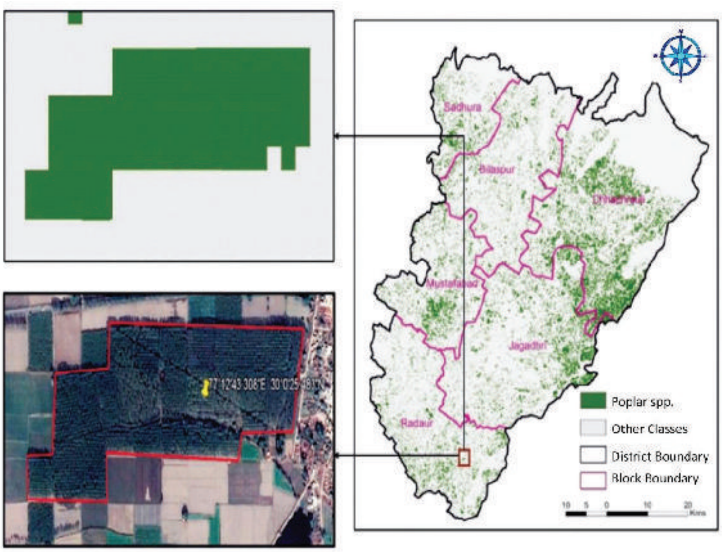


Figure 19: Poplar area mapped in Yamunanagar district using SARVI index

DISTRIBUTION OF POPLAR AREA IN YAMUNANAGAR DISTRICT (2017)



of NDVI and SARVI can be considered useful for identification of Poplar spp. during the peak of the growing season. The area obtained using NDVI and SARVI was similar but the SARVI proved to be better for the approximation of tree species identification than NDVI.

Estimation of area under important agroforestry tree species (Poplar) through remote sensing and GIS in India and develop, validate and pilot the protocol for large scale agroforestry species detection and mapping.

During the review meeting of ICAR-CGIAR in January 2018, it was decided to initiate a nation-wide mapping of agroforestry species. The activity of mapping and the estimation of the area under Poplar species in India using remote sensing and GIS was carried out in collaboration by ICAR-CAFRI and ICRAF in 2019 using different resolution satellite data products.

3.1.2 Methodology

The mapping and area estimation exercise was carried out using three different resolution satellite data sets. The Poplar mapping and area estimation was carried out at state and district levels (Table 2). At the state level, Sentinal-2 satellite data (spatial resolution 10 m) available in 12 different spectral bands was used after the Top of Atmospheric (ToA) correction to get the reflectance values for each pixel. At the district level, high-resolution LISS-4 data (spatial resolution 5.8 m) was used for pre-processing, which included layer stacking, mosaicking and clipping of the district area (Figure 20). Forest cover was then masked and remaining areas for the state and the district was analysed using the ERDAS Imagine software. For identification of the Poplar species, the object-oriented classification technique was applied to LISS-IV data and a knowledge classifier was used for the Sentinel 2 satellite data. In order to find out the optimum resolution of satellite data, another set of satellite data SKYSAT (Planet) with a resolution of 1 m was used in the pilot site in the Yamunanagar district of Utter Pradesh. The Poplar mapping and area estimation was carried out on SKYSAT data using image segmentation techniques. Finally, the accuracy was assessed through ground truthing (Figure 21) and area statistics were calculated for the state, district and pilot sites.

3.1.3 Results

The estimated area under the Poplar species is 2,76,000 ha (5.63 percent) in Punjab state, whereas it is 2,05,000 ha (4.66 percent) in Haryana state with a reasonably good accuracy of 85.2 percent (Figure 22). The district-wise distribution of the Poplar and other species is given in figure 23. The comparison of Poplar mapping using different resolution satellite data, viz., 10, 5.8 and 1 m has different levels of accuracy (Table 3). However, the study suggests the mapping of agroforestry species is possible using 10 meter to 1 meter resolution satellite data. The finer the resolution, the higher the cost, time and computing requirement. The study suggests that, for state level mapping, 10 m resolution satellites provide good results, whereas for district level mapping, 5.8 m resolution data can provide desirable results. If the purpose of the study is the identification of high-value species, then it is necessary to use very fine resolution satellite data (i.e. 1 m).

Table 2: Study Area

S.N.	State	Districts
1.	Punjab	Ludhiana, Hoshiarpur, Roopnagar, SKS Nagar
2.	Haryana	Yamunanagar, Kurukshetra, Karnal
3.	Uttrakhand	Udhamsingh Nagar, Haridwar
4.	UP	Saharanpur, Baghpat Bijnor, Muzaffarnagar, Shamli
5.	Bihar	Vaishali

Figure 20: Methodology used for mapping Poplar using LISS-IV data

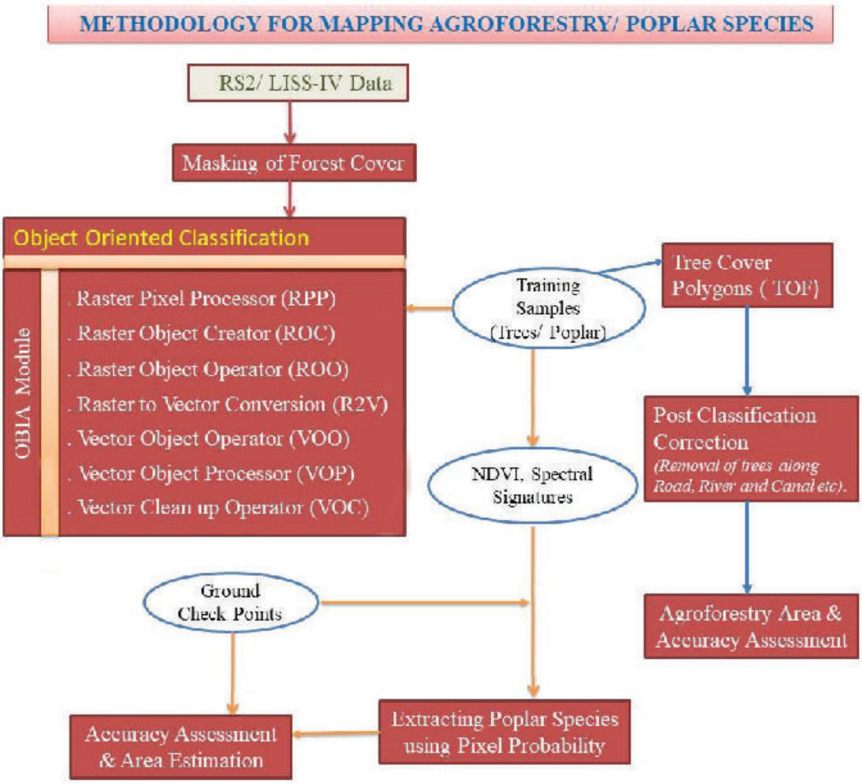


Figure 21: Ground data collection in Punjab State, India

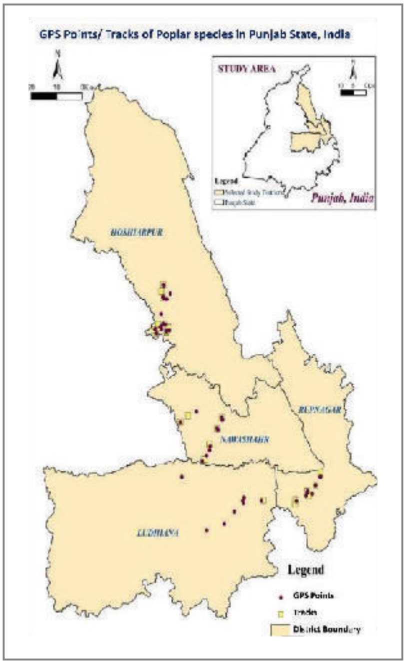


Figure 22: Poplar map and area in Punjab and Haryana states

POPLAR SPECIES IN PUNJAB STATE **POPLAR SPECIES IN HARYANA STATE**

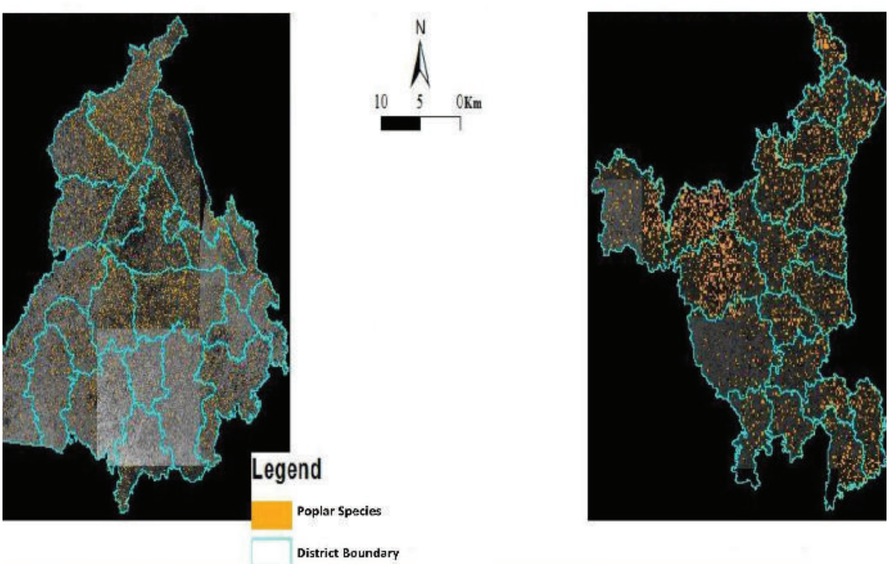


Figure 23: District-wise area of Poplar and agroforestry in Panjab and Haryana

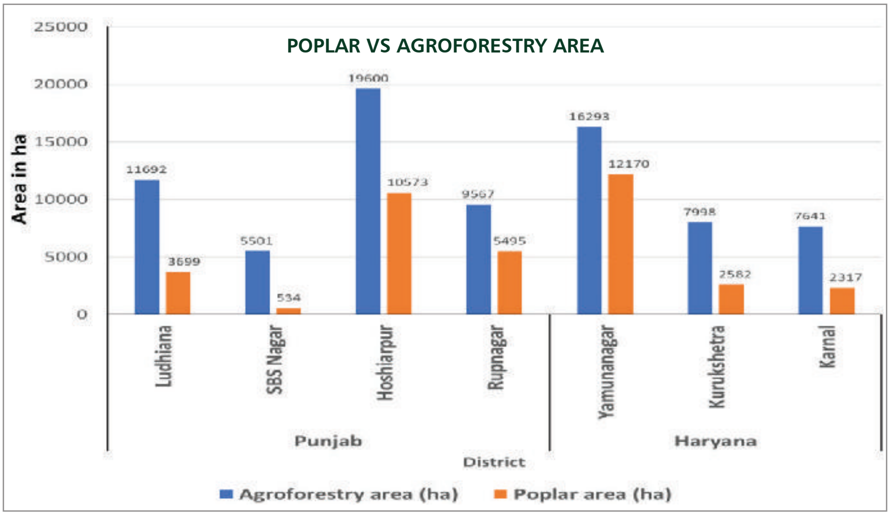


Table 3. Comparative Analysis of Satellite Data Resolution on Mapping Agroforestry

Sensors	Sentinel-2 (ESA)	LISS-IV(ISRO)	SKYSAT(Planet)
Spatial resolution (pixel, m)	10 m	5.8 m	1 m
Temporal resolution (days)	5	5	On demand
Data volume	Medium	High	Very high
Cost of data in rupees per tile	Free	Rs 12,000	Rs 70,000
Ease of collection and processing	Medium	High	Very high
Processing time (working hours/km^2)	24	40	60
Overall Accuracy (%)	85.2	90.1	94.2

3.2 Mapping of Croton *(Croton megalocarpus)* Species in Kenya

In Kenya, since 2015, the Biofuel Programme has been partnering with the EFK Group Ltd., a small social enterprise that produces liquid biofuel (straight vegetable oil), organic fertilizers, poultry feed and biochar, among others, through an integrated manufacturing process based entirely on the nut of the Croton tree (Croton megalocarpus) (Figure 24). This is an abundant, indigenous species found all across central and western Kenya, as well as in other East African

Figure 24: Croton trees close to Mt. Kenya (left); and from left to right: croton nuts, husks, seeds, seedcake, organic fertiliser produced from seedcake, and croton SVO (right)

countries. It is traditionally planted on boundaries and marginal lands to provide firewood and shade. Until recently, its nut had no commercial value (since it is not edible) and, in fact, largely remains a wasted natural resource. Croton's potential for multiple uses has long been researched, though, by ICRAF, and its value for energy production has even been recognised by the Government of Kenya. Nonetheless, it was only more recently that the species started attracting international interest in and private capital and professional management for the development of its value chain.

Since its founding in 2012, EFK has been sourcing croton nuts from rural communities, who harvest them mostly from farmlands in several counties in central Kenya. The nuts are then processed at the company's factory in Nanyuki, Laikipia County. The extracted oil is sold to local (agro) industries, who use it for many purposes, including both biofuel applications (e.g. SVO to run off-grid generators, water pumps and other agricultural machinery), as well as others, such as painting, leather tanning and cosmetics. Similarly to the Indian and Brazilian experiences, the leftovers from oil extraction are also valuable in this case. The husks are processed into certified organic fertilizers and biochar, while the seedcake is sold for commercial and other poultry producers to be incorporated as a rich source of raw protein for animal feed.

Based on this business model, the Biofuel Programme has contributed to assessing the sustainability of the croton value chain in Kenya and addressing research gaps to support its upscaling, while maximising its positive impact on livelihoods of the rural poor. In particular, ICRAF conducted an initial value chain analysis, which was then complemented by a thorough baseline survey with a representative sample (200 households across 50 villages in 4 counties) of the 5,000 collectors (predominantly subsistence farmers) currently engaged in the croton chain.

In order to facilitate the scaling up of croton production, both through the planting of new trees and through the identification of existing ones, the programme has also invested in modelling and mapping technologies, building on ICRAF's expertise in geographic information systems (GIS). In particular, the whole country was mapped according to three key criteria (precipitation, temperature and altitude) determining the suitability for croton trees to grow in a given area. Based on these preliminary results, a field survey was then conducted in collaboration with the Kenya Forest Research Institute (KEFRI) for collection of ground-truth data on the species. This involved the design of a mobile app to record the actual occurrence of croton in randomly selected points, focused mainly on the Kenyan highlands, including both high and low suitable areas as indicated by the preliminary map (Figure 25). The interactive maps and data set generated are available at the Landscape Portal maintained by ICRAF (Figure 26). Initial results indicate the presence of *Croton megalocarpus* in about 36 percent of the randomly generated plots surveyed. While the majority of these fall, as expected, in areas suggested as highly suitable for the species, its occurrence was also detected in places thought to be less suitable, such as in drier parts of Laikipia County. All these data are now being treated for the development of a spatial-statistical model capable of predicting the incidence of croton trees in any given plot in the country.

Figure 25: Suitability map created for *Croton megalocarpus* in Kenya (0 = non suitable; 3 = highly suitable) (left); and screenshots of the mobile data-entry app developed to survey the presence/absence of the species. The application was developed using CyberTracker and was run on a Trimble GPS (right)

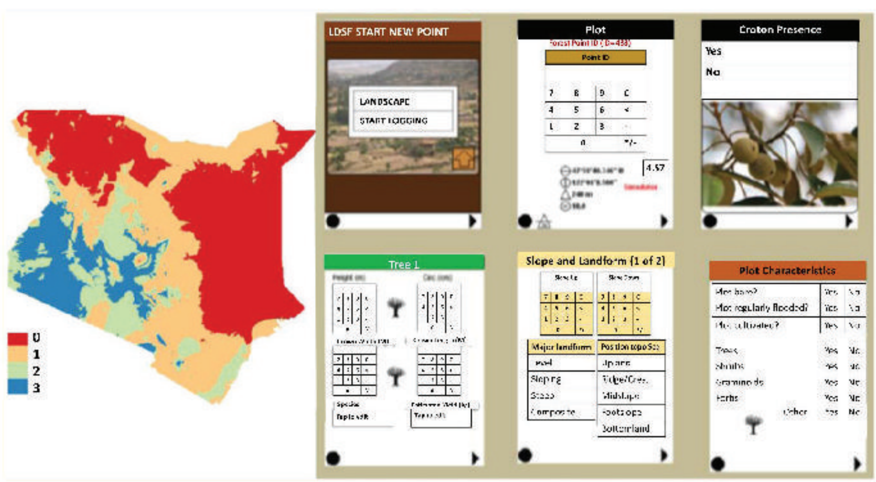
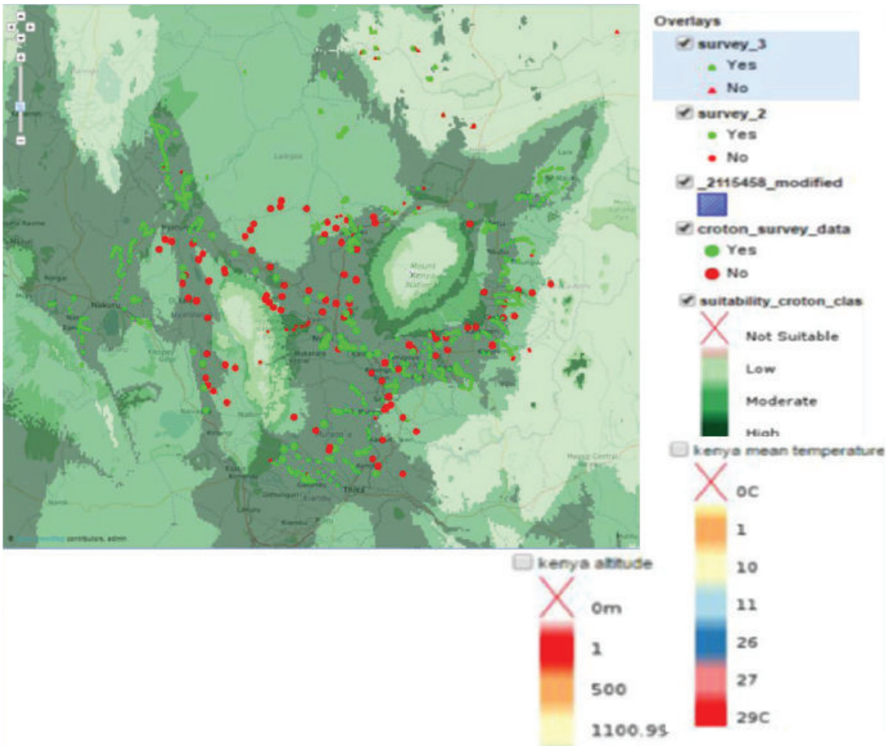


Figure 26: Interactive map of Kenya available at the Landscape Portal. Background colours indicate the suitability for growing croton (dark green = highly suitable), while dots denote plots where the tree is actually present (green) or absent (red)



Discussions were initiated to develop a close partnership with another IFAD-funded initiative – the Upper Tana Natural Resources Management Project (UTaNRMP). Potential synergies are significant, as Croton megalocarpus has already been identified by UTaNRMP as one of the preferred species for rehabilitation of degraded forest areas in 5 out of the 7 counties targeted by the project in the upper Tana catchment basin. Research results from the biofuels programme, such as the previously described baseline survey with croton collectors, are being shared with UTaNRMP's management, contributing to the project.

The Way Forward

Recent advances in Earth Observation System (EOS), Open-Access (OA), Artificial Intelligence (AI), Machine Learning (ML), Information, and Communication Technologies (ICTs), Cloud Computing Platforms (CCP) and Big-Data analytics are interoperable and much more useful than ever before. The valuable decision analytics that they provide at multiple scales and domains open tremendous opportunities. These technologies can be applied in this area in the following ways.

1. Build this around freely available remote sensing data (Landsat and Sentinel-2), including also radar imagery (Sentinel-1, etc.).
2. Build models based on ground truth data (i.e. field surveys). The LDSF data can also be used to train models.
3. Use machine-learning for predictive modelling of tree cover outside forests.
4. Develop a digital library of 'Tree Signatures' for major agroforestry species using high-resolution/hyperspectral remote sensing.
5. Mapping of area under major agroforestry species and estimation of growing stock at a large scale (state/ country/ region) using geospatial technologies.
6. Monitor changes in the agroforestry area using temporal remote sensing data.

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Dr T. Mohapatra, Secretary, DARE & Director General, ICAR; Dr K. Alagusundaram Ex, Deputy Director General (NRM), ICAR; Director, CAFRI & Project Coordinator, AICRP on Agroforestry.

Dr Tony Simons, Director General, World Agroforestry (ICRAF); Dr Graudal Lars, Dr Lars Holger Schmidt, Dr Ramni Jamnadass, Dr James Roshetko, Dr Betserai I. Nyoka, Dr Roeland Kindt, Jeanne Finestone, Susan Onyango and Robert Frederick Finlayson from ICRAF.

Dr Rajesh Kumar Deputy Director General (FI); Dr Prakash Lakhchaura Deputy Director (FI & Training); Dr Kamal Pandey. Deputy Director (Forest Inventory) Indian Statistical Service from Forest Survey of India.

Dr V. P. Singh, Ex-Senior Advisor for Policy and Impact, ICRAF, SARP, New Delhi; Shri Abhijit Ghose, Chairman, Expert Committee; Dr D. Pandey IFS; A K Bansal IFS; Jitender Sharma IFS, PCCF; Vinod Kumar IFS; A. K. Mohan IFS; Dr Vipin Choudhary and Pankaj Asthana, NAEB from MoEF&CC; Dr C.S. Jha, NRSC; A K Shrivastava IFS, NCCF; Dr Sachin Raj Jain, NCCF; Dr B.N. Mohanty, IPIRTI; R. B. Sinha IFS, JS; Dr P. Namita IFS, JS and Dr Dushyant Gehlot from DoACFW; Dr Suneel Pandey, ITC; Dr Ajay Kumar Saxena, CSE; Dr B. N. Mohanty, IPIRTI; Shruti Agrawal; Dr K. P. Mohapatra, Principal Scientist, ICAR RC NEH and Dr Sangram Chavan, Scientist, CAFRI and all other Experts who contributed time to time through attending meetings or electronically.

Representatives from Ministries of Agriculture & Farmers Welfare (MoAFW), Environment, Forests and Climate Change (MoEFCC), ICRAF, ICFRE, ICAR Institutes, SAUs, State Forest Departments, who participated and contributed inputs.

We acknowledge the financial support received from ICAR through ICAR-CGIAR funding program.

Annexes

Annexure - I

Expert Committee constituted by the MoEF&CC to develop strategy to increase green/tree cover outside recorded forest areas (Trees Outside Forest)

Major Recommendations (ToR-V) - RS&GIS

1. CAFRI, FSI, NRSC, and ICRAF should work in consortium mode, wherein NRSC will share high-resolution remote sensing data and FSI will share TOF inventory data to CAFRI to know the distribution pattern of tree species in different regions of country after geotagging. ICRAF will provide experience/techniques from other countries and a global perspective. (MoA&FW & MoEF&CC)

2. Methodological development is a continuum and needs to be undertaken because of the ongoing improvements in new data/information/technology and because of statistical advancement. Therefore, there should be a permanent collaboration of all the involved agencies. (CAFRI & FSI & NRSC)

3. CAFRI, will share agroforestry maps with NRSC to upload on the Bhuvan portal as well as to FSI, Dehradun. (CAFRI & NRSC)

4. Based on maps provided by CAFRI on a 1:50,000 scale, FSI will find out the extent of agroforestry on non-forest land using available geospatial digital RFA boundaries. (CAFRI & FSI)

5. Since FSI is undertaking inventory of TOF in the entire country on a grid-based system, the information obtained through field inventory can be provided to CAFRI for validation of agroforestry maps. Alternately, CAFRI can provide the agroforestry maps to FSI for a validation and accuracy assessment. (CAFRI & FSI)

6. Since FSI has the necessary software for FC, TC and Forest Inventory, data processing part will be done by FSI using ground data collected by their own staff as well as staff of CAFRI. (CAFRI & FSI)

7. Present infrastructure facilities at CAFRI appear inadequate for agroforestry mapping. They need upgrading, for which the latest softwares (Arc GIS, ERDAS, etc.) and hardware (computers and printers) are required. More technical manpower is also needed for such jobs. It is recommended that CAFRI should be provided INR 1.20 crores annually for at least 5 years continuously for wall-to-wall mapping of agroforestry for the entire country. This will enable it to monitor the coverage of agroforestry out of which INR 1 crore may be needed as a non-recurring expenditure. (MoA&FW)

8. CAFRI will prepare agroforestry maps in every five-year cycle and as far as possible will provide tree species-wise maps by using spectral signature data of common agroforestry species available in their digital library.

9. CAFRI can continue the agroforestry and species mapping only when dedicated funds and resources are made available in the form of a long-duration project. (MoA&FW & CAFRI)

10. By working in a collaborative mode, the duplication of efforts will be reduced, and the whole exercise will be more cost-effective. (CAFRI & FSI)

Expert Committee constituted to develop strategy to increase green tree cover outside forest 8/9 March 2018

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Annexure - II

Focused Group Meeting Notice of Expert Committee constituted by the MoEF&CC to develop strategy to increase green/tree cover outside recorded forest areas (Trees Outside Forest)

F. No. [illegible] 2018-FP
Government of India
Ministry of Environment, Forest & Climate Change
Forest Policy Division

Indira Paryavaran Bhawan,
Vayu Wing, 6th Floor,
Jor Bagh Road, Aliganj,
New Delhi - 110 003
Dated 19.02.2018

MEETING NOTICE

Sub: Expert Committee constituted to develop strategy to increase green cover/ tree cover outside recorded forest areas (Trees Outside Forests) reg.

The undersigned is directed to inform that the second meeting of the Expert Committee constituted to develop strategy to increase green cover/tree cover outside recorded forest areas (TOF) was held on 15th & 16th February, 2018 in the Ministry. During the meeting it was decided to hold a meeting for focused discussion on methodologies adopted by FSI, CAFRI and ICRAF to assess areas under TOF.

2. In this context, it is informed that a focused group meeting will be held on 8.03.2018 before the full body meeting of Expert Committee to be held on [illegible] 2018. Shri Vinod Kumar, IFS and other members from FSI, CAFRI and ICRAF are requested to kindly make it convenient to attend the meeting on 8.03.2018 from 11.00 AM to 4.00 PM at Indus Conference Hall, Jal Wing, Ground Floor, Indira Paryavaran Bhawan, Jor Bagh Road, New Delhi.

(Noyal Thomas)
Dy. Inspector General of Forests (Forest Policy)
[illegible]

Distribution:

To,
(E-mail enclosed)
1. The Chairman of the Committee
2. Shri Rajesh Kumar, DDG, FSI
3. Shri Vinod Kumar, [illegible], Govt. of Haryana
3. Director, CAFRI
4. Shri S.K. Dhyani, ICAR, New Delhi
5. Dr. [illegible], Director, ICRAF, New Delhi
6. Ms. Devashree Nayak, Scientist, ICRAF, New Delhi

Copy for information to:
5. PCCF & HoFF, Haryana.
7. DG, FSI, Dehradun.
8. PPS to DGF&SS/ PPS to ADG(WL)

Annexure - III

Ministry of Environment, Forest and Climate Change, Government of India's letter no. F. No. 11-98/2019-FC dated 14.11.19 addressed to the State Forest Departments, wherein the Ministry has issued guidelines for defining Dictionary meaning of Forest as contained in the order dated 12.12.1996 of Hon'ble Supreme Court

F. No. 11-98/2019-FC
Government of India
Ministry of Environment, Forest and Climate Change
(Forest Conservation Division)

Indira Paryavaran Bhawan,
Aliganj, Jorbagh Road,
New Delhi-110003
Dated: 14th November, 2019

To

The Principal Secretary (Forests),
All State/UT Governments

Sub: Defining "Dictionary meaning of Forest' as contained in the order dated 12.12.1996 of Hon'ble Supreme Court - regarding

Sir,

I am directed to refer to the matter mentioned in the subject above and to inform that issue was deliberated by the Forest Advisory Committee (FAC) in its meeting held on 26.09.2019. The FAC perused the directions contained in the Hon'ble Supreme Court's order dated 12.12.1996 with regard to the definition of forest. The action taken in compliance to order of Hon'ble Supreme Court by various State/UT Government was also noted. The FAC observed that there cannot be any uniform criteria to define forest which can be applicable to all forest types in all State/UTs. The FAC further observed that there is a matter related to this is *sub-judice* in the Hon'ble Supreme Court.

2. Based on the recommendation of the FAC with regards to the 'definition of forests', the Ministry has decided as follows:

(i) India is a vast country with varied geo-physical units and soil-climatic conditions that has given rise to a number of forest types. There are variations even within the forest types.

(ii) As far as developing criteria for 'deemed forests' is concerned, there cannot be any uniform criteria applicable to all forest types or all states. There has to be different criteria for different forest types or states.

(iii) It is not only that Hon'ble Supreme Court had directed states to identify their own forests, in fact the states, having well established forest departments, are in a better position, rather than MoEF&CC, to understand their own forests and needs, and should frame criteria for their forests.

(iv) While framing criteria, due diligence should be exercised taking into to account spirit of order of Supreme court, National Forest Policy, the rationale of having adequate forests, site quality of naturally occurring forest species etc for supporting a healthy environment.

(v) The criteria so finalised by a state, need not be subject to approval of MoEF&CC.

This issues with the approval of competent authority.

Yours faithfully,

(Sandeep Sharma)
Assistant Inspector General of Forests

Copy to:

1. The Principal Chief Conservator of Forests, All State/UT Governments
2. The Dy Director General of Forests (Central), All Regional Offices of the MoEF&CC
3. The Addl. PCCF & Nodal Officer (FCA), Office of the PCCF, All State/UIT Governments
4. Monitoring Cell, FC Division, MoEF, New Delhi
5. Guard File

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