A GEO-SPATIAL APPROACH TO ASSESS TREE OUTSIDE FORESTS (TOF) IN HARYANA STATE, INDIA

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Abstract

Mapping and monitoring the Trees outside Forests (ToF) is gaining significance in the scientific community as they provide critical ecosystem services such as protecting soil and water resources, wildlife habitat, energy efficiency etc. Also, quantifying ToF can provide useful information on emissions estimation in the Agriculture, Forests, and Other Land Use (AFOLU) category of the Intergovernmental Panel for Climate Change (IPCC). Despite the importance of quantifying ToF, very few studies have attempted to quantify them in India's natural resource inventory programs. In this study, we focus on Haryana state, India, to map ToF using very high-resolution (VHR) Indian Remote Sensing (IRS) satellite data. Haryana's landscape is highly interspersed with croplands and ToF, thus providing a challenging environment to test VHR satellite data's ability to quantify the diversified landscape structure. We specifically used Cartosat-1 panchromatic (2.5m) and Multispectral LISS IV (5.8m) datasets to quantify the vegetation and build a much-needed database on ToF. We used a novel classification scheme based on the geometry, i.e., point, polygon, or polygon formations, to quantify ToF at 1:10,000 scale. Our results suggest ToF with the point, area, and linear block formations of about 2,774,531, 20.51, and 128.83 sq. km, respectively, accounting for ~3.38% of the total study area . Our study highlights the usefulness of VHR satellite data and fused imagery to quantify ToF in highly diverse landscapes, with the case study in Haryana State, India. The results will help address vital ecosystem services from ToF, including greenhouse gas emissions quantification from the AFOLU category.

Keywords: multispectral, panchromatic, classification, image interpretation, ToF.

1. INTRODUCTION

Forests, a complex ecosystem, supports a myriad of life forms buffering the Earth have been realized as the salvager in international political scenario providing for its essential role in combating greenhouse gases, conserving biodiversity, storing carbon and reduction of global temperature. About 90% of biomass is constituted by terrestrial plants (Pan et al. 2013) accounting for terrestrial gross primary production of 48.5% (Beer et al. 2010). However, the advancements and developmental activities, and growing modernization and urbanization due to the outgrowing population and its associated repercussions have caused a reduction in forests and its ecological devastation overruling the concept of sustainable development. The degradation of the ecosystems resulting from human interference requires a frisk without ceasing remediation which could be rendered by only better management practices. The pragmatic approach to conservation requires sustainable consumption of natural resources so as judicious and equitable exploitation by the present generation does not jeopardize the rights of forthcoming generations. The sound resource management principles are to be adopted taking advantage of modern scientific technology to enhance management practices. One of the management practices would be extensive tree growth outside forest areas for providing fuel, fodder and timber to the local people, which will also help mitigate the ecological imbalance to some extent. The customized landscapes (livestock production, crop growth) within communities put challenges of various kinds for plant species to adapt to the modified environments (Forman, 1995; Warkentin et al., 1995; Verboom and Huitema, 1997; Daily et al., 2001). The transformation of the extensive land area into sources that provide food and shelter has caused the reduction in land committed to biodiversity conservation, adversely affecting the landscapes and life of various biological species associated with them in due course of time.

In several rural landscapes of the world, including India, the scattered trees add significant aesthetic value to the croplands, including ecosystem services (Hodgkins et al., 1999; Ozolins et al., 2001; Arnold, 2005; Kull et al., 2013) but their role is undervalued (Reid and Landsberg, 1999). However, their contribution is vital to promoting sustainable agriculture, and maintaining rural households' food and livelihood security. The scattered trees help in protecting soil and crops against wind and water erosion. They also help protect against climatic factors such as droughts and floods (Plieninger *et al.*, 2004; Lumsden and Bennett 2005; Manning *et al*., 2006). The artistic and scenic beauty of scattered trees has caught many researchers' attention, and their importance for recreational uses is reckoned (Herzog, 2000). In addition to aesthetic value, the scattered trees can aid in carbon sequestration (Nowak, 2002) even in the urban environments regulating the micro-climate (Bowler *et al.*, 2010) and pollution control (Jim and Chen, 2009). The potential to sequester carbon by ToF, particularly agro-forestry, can thus be considered high, the dense canopy covers adding an advantage (IPCC, 2000).

The reservoir of knowledge concerning ToF representing case studies of different countries have been reviewed and documented (Bellefontaine *et al.*, 2002) signaling comprehensive management at local, regional and global scale. The enumeration of trees outside forest employing application of remote sensing provides accurate information of wood resources presence which is a pre-requisite for their proper management. FSI, 2011 defines ToF in India as all those trees, which has attained 10 cm or more diameter at breast height (dbh) and area coverage of 0.5 hectare on land, which is not notified as forests. However, FAO defines ToF as trees available on lands which is not defined as 'forests' or 'other wooded land'. ToF resources with noteworthy positive assistance to biodiversity conservation have also reduced pressure on forests (NBSAP, 2014) consequently leading to enhanced carbon absorption and species diversification (Singh *et al*., 2009, Thompson, *et al*., 2009) meeting the imperative goal of Reducing Emission from Deforestation and Forest Degradation (REDD+) mechanism. The non-competence of ToF with other land uses while providing additional space for carbon sequestration can be appraised as mitigation strategy to irresistible climate change (Schoeneberger, 2009; Plieninger, 2011; Schoeneberger *et al.*, 2012). The species *Albizzia lebbek, Ficus gibbosa, Terminalia arjuna,* and *Madhuca latifolia* were found tolerant to abate air pollution (Agarwal and Tiwari, 1997) which when planted along linear features (roads, canals, railway lines) could serve in mitigating air pollution and even adding to aesthetic value. The aboveground vegetation biomass stocks and its associated changes can be quantified by employing suitable remote sensing methods (IPCC GPG, 2004). The fragmentation of landscape can be limited to facilitate the dispersal of species by managing the development of green infrastructures and corridors which connect urban and rural territories (Benedict and McMahon 2006; Clergeau and Blanc 2013).

Forest Survey of India (FSI), an organization under the Ministry of Environment, Forests and Climate Change (MOEFCC) Government of India is engaged in assessing the ToF wealth of the country since 1991 on a scale of 1:50,000. However in trying to improve upon the methodology of ToF assessment which has so far been based on field inventory methods, use of IRS LISS III and PAN data is being used in recent times. The fused image obtained from LISS III and PAN is also being made use of in editing and refinement of classified images of LISS III and PAN (Rawat et al., 2003).In the recent past, the field of remote sensing technology has made a quantum jump both in terms of spatial and radiometric resolution enhancement. Current remote sensing systems offer unique opportunities for detecting patterns at the surface of the earth, and for analyzing data about the underlying processes at a variety of spatial scales, ranging from kilometres to centimetres. Analysis and computing environments now allow data transformation from a diverse and multivariate form to a usable state. Parallel improvements in the forestry specific sector have significantly aided information synthesis and development (Wulder and Franklin, 2003). Also, the geographic information systems (GIS) provide opportunities to create multi-scale representations by incorporating and linking digital maps at different scales and developing statistical and mathematical functions to deal with the scale variations. In this study, we use VHR remotely sensed data to map scattered trees among farmlands, plantations, linear features (canals, railway lines, roads and farm bunds), and troops representing horticulture scrubs, farm forest and miscellaneous plantations. We focused on two different objectives: a). Identification and mapping of various ToF categories (point, linear and block) in Haryana State, India on a scale of 1:10,000; b). Establishment of area statistics for maintenance and updating of records on the existing database on vegetation cover of the study area

2. STUDY AREA

The State of Haryana is situated between 27.0 29' to 30.0 56' N latitude to 74.0 27' to 77.0 36' E longitudes (Fig.1) with a total geographical area of 44,212 sq km. Nearly eighty percent of the total area is under agriculture and the rest under forests (0.86%), not available for cultivation (14.94%), permanent pasture and other grazing lands (0.57%), culturable wasteland (0.39%), fallow land (0.51%), etc. (Ministry of Agriculture and Farmers Welfare, 2020). The State's cropping intensity is more than 150 percent, significantly higher than the national average of 136%. The landscape is diverse, varying from hills in the northern region, alluvial plains in the central part and dunes in the South. The major part of the State is under Indo- Gangetic alluvial plains. The State's climate is subtropical, semi-arid to sub-humid, subcontinental, and monsoon type. Forests are scattered over the rugged Shiwalik Hills in the North, Aravalli Hills in the South, dunes in the South-West, other wastelands, water-logged, saline and alkaline soils in the Central part of the State. Against the National Forest Policy (1988) of maintaining forest cover over one-third of the area, only 3.52% of the State's total geographical area is forested.

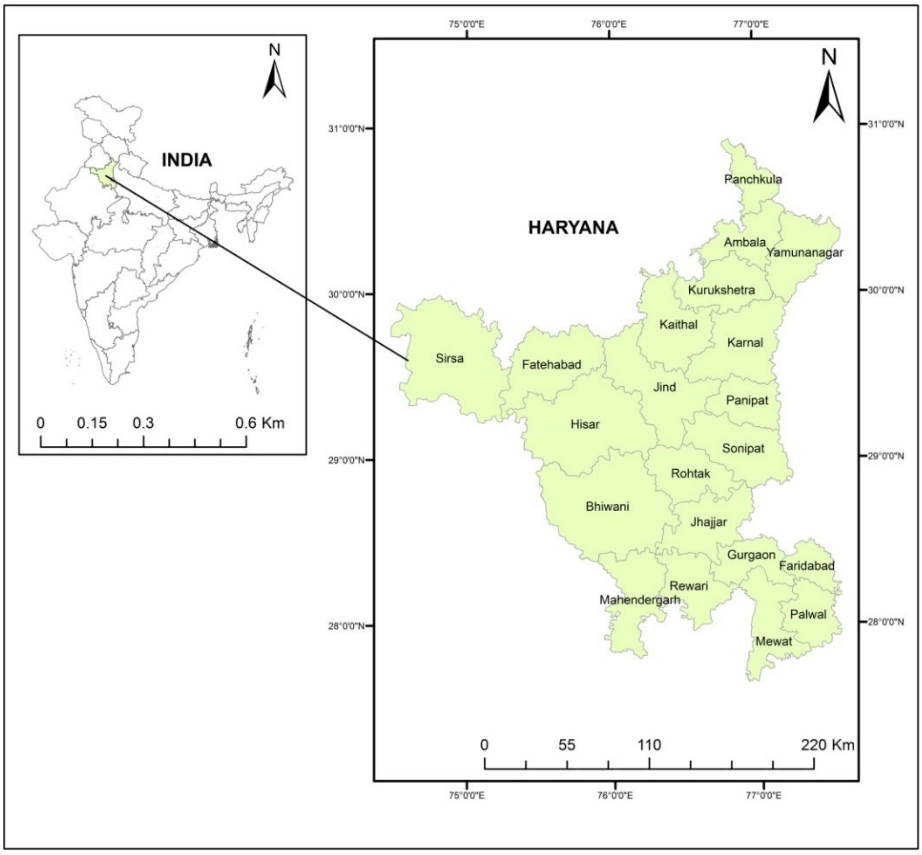

Fig.1. Study area location map.

The forests in Haryana are classified as Reserved Forests (RF), Protected Forests (PF), Areas closed U/S 38 of Indian Forest Act (IFA, 1927) and Areas closed U/S 4 & 5 of Punjab Land Preservation Act (PLPA, 1900). Large natural forest areas are confined to the Shiwalik ranges in Panchkula and Yamunanagar districts; relatively small forest patches are scattered in the districts of Yamunanagar, Kaithal, Ambala, Jind and Hisar. The majority of forests in the State belong to the sub-tropical dry deciduous category. In contrast, sub–tropical thorny Forests are found only in the Aravalli hills in the State's southern parts. Due to large scale plantation initiated by the Haryana Forest Department (HFD) on non-forest lands, i.e.,

community lands, institutional lands, private wastelands etc. as well as adoption of tree farming by farmers on their holdings, the total forest and tree cover of the state has become 6.8%. The total forest area in the State, as per the Haryana forest department's records based on interpretation of satellite data of October-December 2015(SFR, 2017), is 1588 sq km, which is 3.59% of the State. The State's tree cover estimated is 1,559 sq km, which is 3.53% of the State (SFR, 2019). The growing stock of trees outside forests is 15.49 million cubic meters (SFR, 2017).

3. MATERIALS AND METHODOLOGY

3.1. Datasets Used:

For identification, delineation and mapping of various tree resources outside the legal forest classes, the multi temporal, geo-rectified fused product of Resourcesat-1 LISS – IV and IRS Cartosat 1 PAN data (Table 1) of rabi (winter season crops), kharif (summer season crops) and zaid (summer season crops that require significant warm dry weather) were used. In the preparation of ToF maps, the ancillary data in the form of topographic maps, existing land use land cover data, wasteland data, district and any other published relevant material were used as reference data. Survey of India topographic maps were used for identification of base features and for planning ground data collection. Legacy data on salt wastelands and biodiversity/forest data generated on different scales were used as a reference data during delineation of various ToF categories.

Table 1. Specifications of satellite data used

Specifications	LISS-IV	Cartosat-1
Spatial Resolution	5.8 m	2.5 m
Sensor Type	Multispectral	PAN
No. of spectral Bands	3	1
Launch Date	2003	2005

3.2. Approach

The collected scenes of satellite sensors (Cartosat 1 and LISS-IV) were subjected to image fusion. Improved Brovey transform, a method of image fusion was adopted to generate the fused product for analysis on the single image. The VHR characteristics of Cartosat-1 at 2.5 m and multispectral LISS IV data at 5.8m enabled us to generate a more robust fused product (Fig. 2) using the Brovey transform (Chavez et al., 1991).

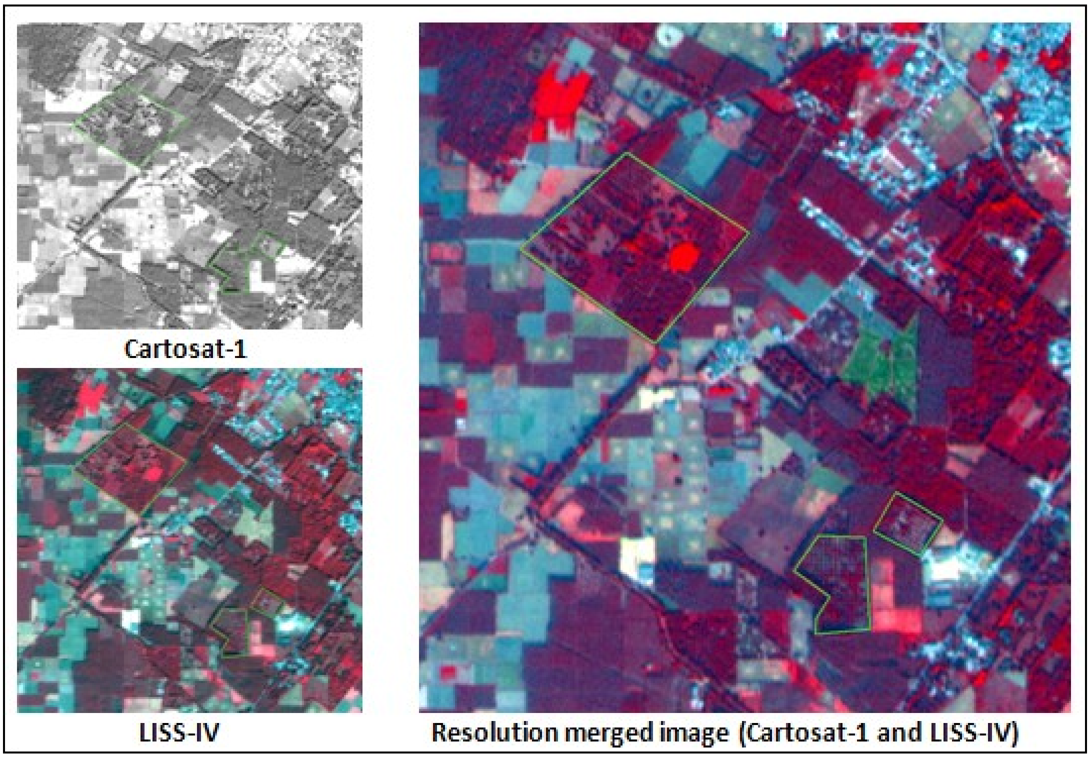

Fig.2. Cartosat-1 (panchromatic) with 2.5m and LISS-IV (RGB) with 5.8m native resolution images (on the left) and the merged product with 2.5m (on the right) is shown in the figure. The fused product showed a relatively higher contrast in vegetation than the native resolution images, as depicted in the green polygons. Also, the parcel edges were much distinct in the fused product.

Essentially, the Brovey transformation is a sharpening technique useful to increase the contrast in the image. It uses a ratio algorithm based on the chromaticity transform to fuse two different images (Chavez et al., 1991). Using the Brovey transform, the multispectral colored image can be fused with the very high-resolution PAN data. Each band in the multispectral color image is multiplied by a ratio of PAN sharpened bands divided by the sum of the color bands to get a fused image as (Vrabel, 1996, Karathanassi et al., 2007),

$$F1 = \frac{LR1}{LR1 + LR2 + LR3} HR \quad (1)$$

$$F2 = \frac{LR2}{LR1 + LR2 + LR3} HR \quad (2)$$

$$F3 = \frac{LR3}{LR1 + LR2 + LR3} HR \quad (3)$$

In the above equations, the Fi is the fused pan−sharpened bands, LRi is the low spatial resolution original bands (Resourcesat-1 LISS-IV in our case) and HR is the high spatial resolution image band (IRS Cartosat-1 PAN data) to be fused with the low spatial resolution bands. All the coarser-resolution data are preliminarily re-sampled to the finer scale, the final fused product with the finer scale. As a result of the Brovey transform, the image contrast increases in the low and high ends of a histogram, i.e., improvement in contrast in shadows, water, and high reflectance areas such as urban features (Vrabel, 1996; Karathanassi et al., 2007). Using the Brovey transformed images, we mapped ToF. The mapping of ToF across the entire Haryana State involved identifying very fine features on the transformed satellite images. For the same, we preferred manual digitization techniques rather than automated ones. A team of researchers was trained on the digitization process and image interpretation specific to ToF features based on the interpretation keys such as tone, texture, size, pattern, association, etc

Ground truth/ field verification, an important component in mapping and its validation exercise was carried out to note the field details and necessary corrections were incorporated.

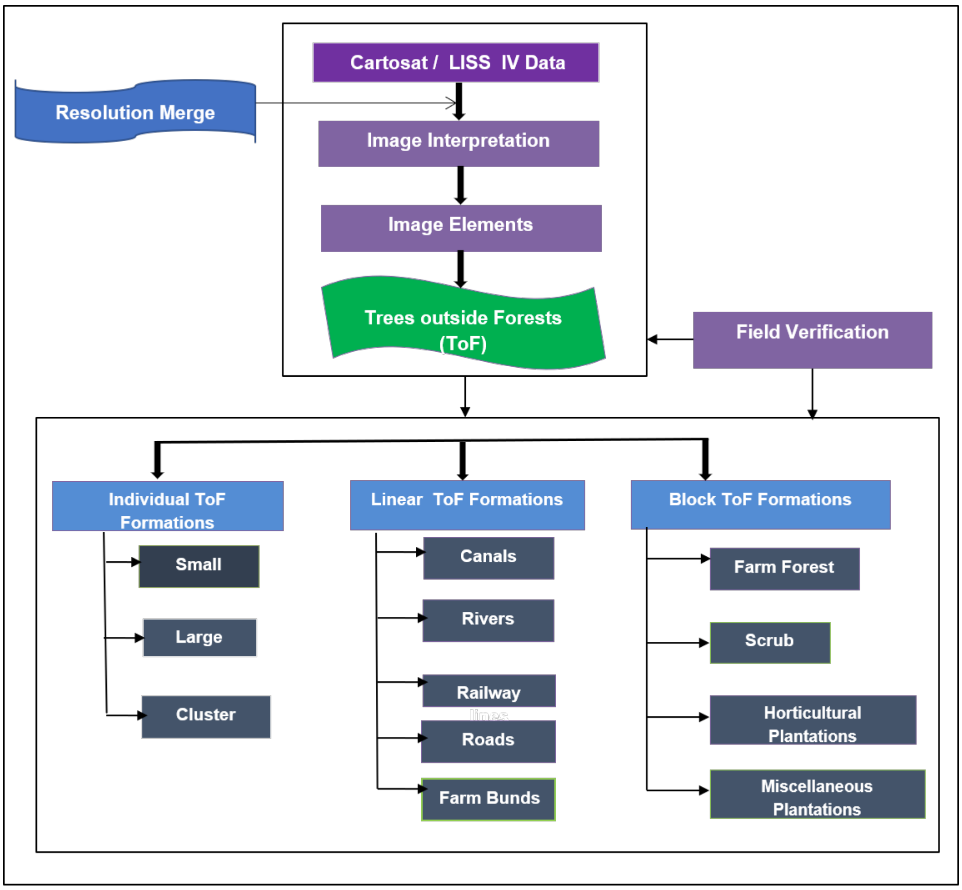

Fig.3. Flowchart representing the methodology adopted.

Illustrations depicting the image elements harnessed for delineating TOF were provided in Table 2 for the state of Haryana for clarity on contexts. Each of the ToF formations interpreted shows distinct image elements in terms of tree crown density and their alignment with the feature considered. Formulation of detailed categories is a critical step in interpreting the VHR data of the fused image radiometry. The tree crown density instances have been addressed as stocking levels since it conveys contrasting information, which is also apparent on the fused image. The case of well and under-stocked characteristics is illustrated since it can carry an element of subjectivity. Well stocked farm bund planted and canal bunds could be clearly delineated in the fused images. Shadows and lit crowns showed much contrast in the fused image enabling easy recognition and delineation. Also, the contrast between stocking levels in horticultural plantations is also apparent. The spacing between horticultural trees and crown sizes of the constituent trees enabled clear distinction from on-farm forest plantations. Scrub areas in the study area were associated with the eroded lands and on the image, they are characterized by the irregular size of the objects, and a distinct texture thus could be delineated. Various ToF categories identified in Haryana's state using the fused product of LISS–IV and Cartosat-1 at 1:10,000 scale are shown in Table 3.Ground truth/ field verification is an important component in mapping. Thus, the verification and validation exercise was carried out to infer various ToF formations (point, area, and linear features) and the necessary corrections were incorporated into the images. This exercise's resultant output was in the vector format, which supports the complex GIS analysis and has a smaller file size. The flowchart of the methodology is shown in Fig. 3.

Table 2. Identification criterion for selected Tof Categories.

S.No.	Attribute	Description
1.	Individual / Point ToF	Large crowns and small crowns were independently interpreted and pooled for statistics generation. Cluster of trees are assumed to contain a minimum of three trees presently for calculation of population (post inventory average for cluster would strengthen the estimate).
2.	Linear ToF	Linear formations of trees along the Road, Canal, Rail, River and Farm bunds were categorized as linear ToF. Stocking level of

		crowns (packed densely due to good crown formations and stocking) were considered for the generation of spatial information.
3.	Patch / Block ToF	Areas showing up tree clad in a densely packed manner, generally in a matrix (background) of cultivated / fallow with indicative roughness (rugosity) of the crown. Stocking level was also considered while interpretation.

4. RESULTS

The results show a substantial number of trees on agricultural landscapes and were demarked as point feature, polyline and polygons spread over the study area. Table 3 shows results obtained in number, area and length corresponding to the feature class along with their attributes. Specific details on the image interpretation and ToF formations, i.e., point, block and linear features, are discussed below.

Table 3: Extent of demarked ToF feature classes in Haryana state, India.

Sr. No.	ToF Category	Number (trees)	Area (ha)	% Total Ground Area (TGA)
1	Large Trees	2577400		
2	Small Trees	151911		
3	Cluster Trees	45220		
4	Farm Forests		18404.78	0.42
5	Horticulture Plantations		9480.84	0.21
6	Miscellaneous Plantations		80180.27	1.81
7	Scrub		20763.87	0.47
8	Canals		6080.19	0.13
9	Rivers		440.69	0.01
10	Roads		9691.75	0.21
11	Railway Line		646.38	0.015
12	Farm Bunds		3557.07	0.08
13	Bunds		94.43	0.002
	Grand Total	**2,774,531**	**149340.25**	**3.38**

4.1. Individual / Point Features

Under this category three types were identified, namely, Small Trees, Large Trees and Cluster of Trees. Figure 4 represents the identification benchmarks for point category of ToF where the presence on satellite image in the form of black dots of varying sizes help to distinguish them. A close perusal of the table 1 indicates that the large trees were found to be 2577400 in number, followed by small trees (151911) and a cluster of trees (45220).

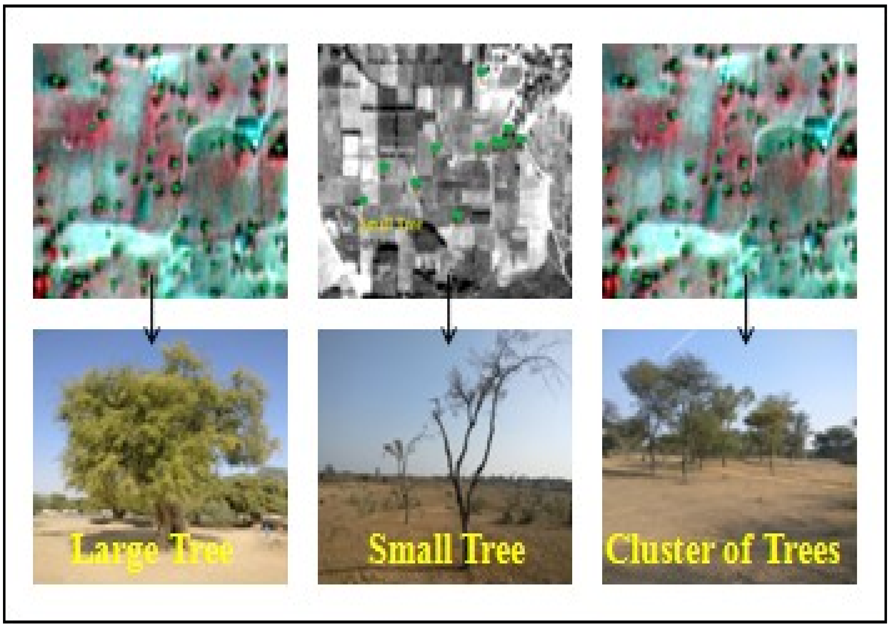

Fig.4. Fused Cartosat and LISS-III satellite product at 2.5m resolution with green points representing individual trees (point ToF). The corresponding field photographs of the individual trees are also shown in the figure.

4.2. Block Features

The identified block ToFs in the study area mostly represent the farm forests, horticulture plantations, miscellaneous plantations and the scrubland. The well-stocked and under-stocked classification is done based on the vegetation vigor inferred from the fused satellite imagery. Their appearance in shape, tone, and texture on the imagery helped to delineate the block features (Figure 5). The details on the block features of ToF are as follows: a). Farm forests are the area with trees of commercial importance grown by local farmers to enhance their income. They are identified based on their location around agricultural fields in a specific pattern. b). Horticulture plantations (fruit crops) are found on the agricultural fields, sometimes along with crops and they appeared in a regular defined pattern on an image. They have a uniform pattern and a dark red tinge added to the canopy on the fused image. c). The miscellaneous plantations are areas having trees of forestry importance with a defined boundary wall. The sharp boundary exhibited by them and appearance in light red to red color in a contiguous pattern on the image aided in their identification. d). Scrubs emerge in the areas with shallow soils, generally with depleted nutrients and mostly tending to intermingle with the cropped areas. Thus, the open scrubs possess sparse vegetation with a thin soil cover. They are inclined to follow an irregular pattern; thus, they could be easily delineated on the image. e). Finally, the miscellaneous plantations occupied most of the ToF in the study area with ~80180.27 ha (1.81 % of the total ground area (TGA) of which 66931.60ha was under the well-stocked category and 13248.67 ha was the under-stocked category. The area under farm forests was ~18404.78 ha (0.42 % TGA), of which well-stocked farm forests were ~15984.26 ha and ~2420.52 ha was under the under-stocked farm forests. The horticultural plantations were ~9480.84 ha (0.21 % TGA), of which the well-stocked formations were ~5493.04 ha and the ~3987.80 ha were under the under-stocked ones were. The spatial extent of scrubland was ~20763.87 ha, which is about 0.47% of the TGA of the state (Table 3).

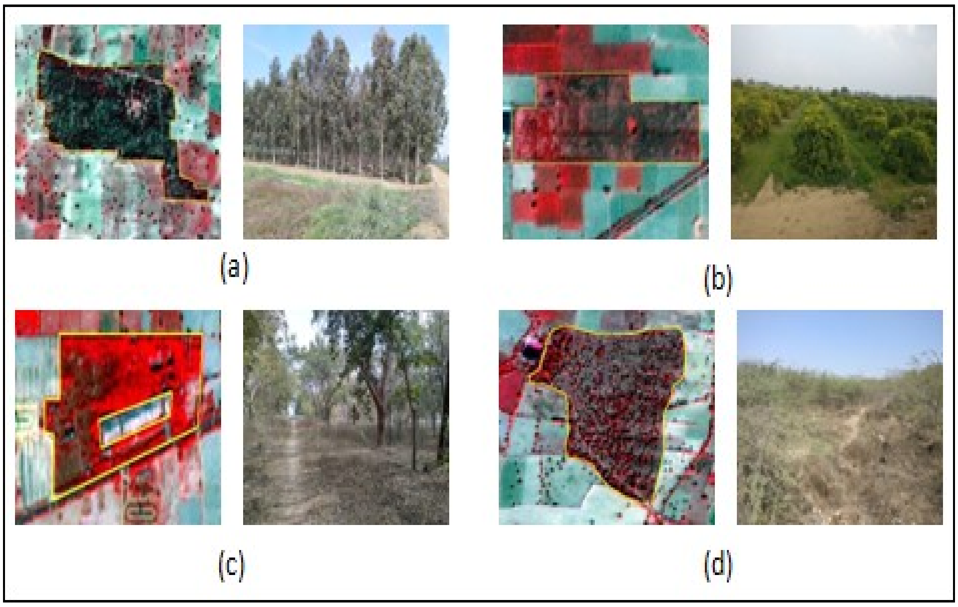

Fig.5. Fused Cartosat and LISS-III satellite product at 2.5m resolution with block ToF and corresponding field photographs (a). Farm forests (b). Horticulture (c). Miscellaneous plantations, and (d). Scrub

4.3. Linear Features

The linear formations of ToF were identified based on their contiguous pattern visible on the fused imagery. They are distinguished as emerged vegetation along the banks of canals, roads and the agricultural fields (farm bunds) (Figure 6). Their categorization is done based on their shape, tone, texture and association. The tree plantations under the canals were found to be 60.80 sq. km (0.14 % TGA), of which an area of 43. 44 sq. km was under the well-stocked category while an area of 17. 35 sq. km is under the stocked category. The plantations under well-stocked rivers were about 3.60 sq. km, while the under stocked category was 0.80 sq. km with an area of 4.40 sq. km (0.010 % TGA). The area under roads is ~ 96.91 sq. km (0.21 % TGA), of which 63.06 sq. km and 33.85 sq. km were under the well-stocked and under-stocked category, respectively. Plantations along the railway lines extended ~6.46 sq. km, of which 5.16 sq. km and 1.30 sq. km were under the well-stocked and under-stocked category. An area of about 35.57 sq. km (0.080 % TGA) of forest land was under farm bunds, of which 26.45 sq. km and 9.11 sq. km were under the well-stocked and under-stocked category, respectively, while an area of 0.94 sq. km (0.002 % TGA) is under the Bunds category.

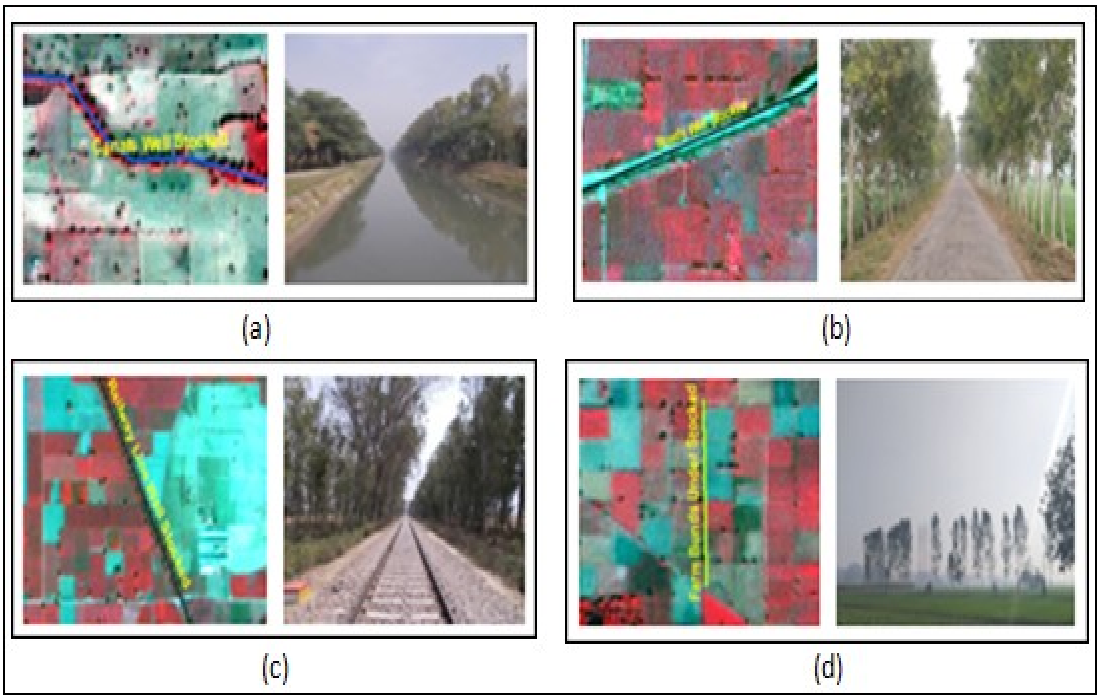

Fig.6. Fused Cartosat and LISS-III satellite product at 2.5m resolution with linear ToF and corresponding field photographs (a). Canals (b). Roads (c). Railway lines and (d). Farm bunds

5. Discussion

We have selected 100 random points well distributed in all the ToF formations in the study area based on image interpretation carried out on the fused product. We then conducted extensive fieldwork involving the Haryana forest department officials in all 22 districts of the state to verify the ToF enumerations mapped using the VHR data. The results suggested more than 95% accuracy in ToF formations. Some of the errors pertained to individual tree formations having a crown size of less than the minimum mapping unit. Also, the ToF block formations under the agro-forestry system, which are very dynamic in terms of growth and harvesting, were found missing sometimes on the ground, especially in Yamunanagar and Ambala districts. Nevertheless, these errors were minor and we strongly recommend using the VHR data for mapping ToF. The ToF outputs as vector files, will provide a baseline inventory for future mapping and monitoring efforts, including studies on the ecosystem services.

6. Conclusion:

ToF comprises an extensive and multi-use resource. They offer an array of ecosystem services like improved biodiversity, carbon sequestration, nutrient cycling, wildlife habitat, food, fuel, fiber and other acclaimed economic benefits. In this study, we used a fused satellite product derived from the panchromatic Cartosat-1 and multispectral LISS IV Indian Remote Sensing (IRS) datasets to map ToF in the Harayana State, India. Although tedious, the manual digitization was quite helpful in delineating various ToF formations. Of the different ToF, results suggested miscellaneous plantations occupying ~1.81 % of the total ground area (TGA) in the Haryana State, followed by farm forests (0.42 %), horticultural plantations (0.21 %) and scrub forests (0.47%). The tree plantations extending along the linear formations (rivers, canals, roads, farm bunds and bunds) occupied ~20510.51 ha. Using the fused, very high-resolution satellite data, we could map a cluster of trees, in addition to counting individual small and large trees. The resulting maps and the area estimates on the ToF will help local forest authorities address ecosystem services rendered by the ToF in the study area. The approach and image interpretation characteristics presented in the study can be replicated in other regions of India and elsewhere to map and monitor ToF using satellite data.

The extracted features were mapped at a scale of 1:10,000, providing more consistent information useful to quantify the ecosystem services rendered by the ToF. The large scale ToF mapping efforts from the current study will help local forest departments to undertake forest management and mitigation efforts in the concerned areas.

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