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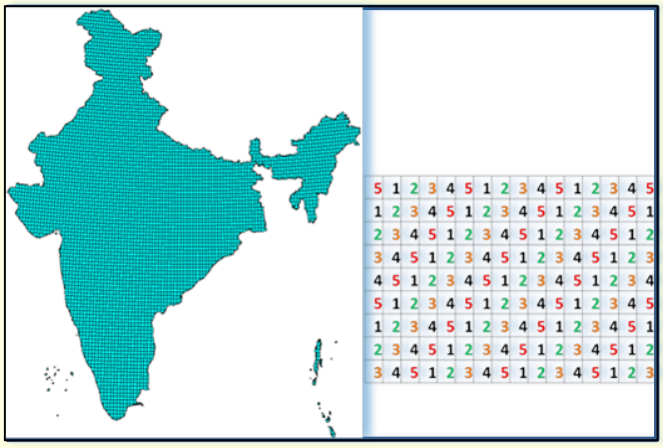
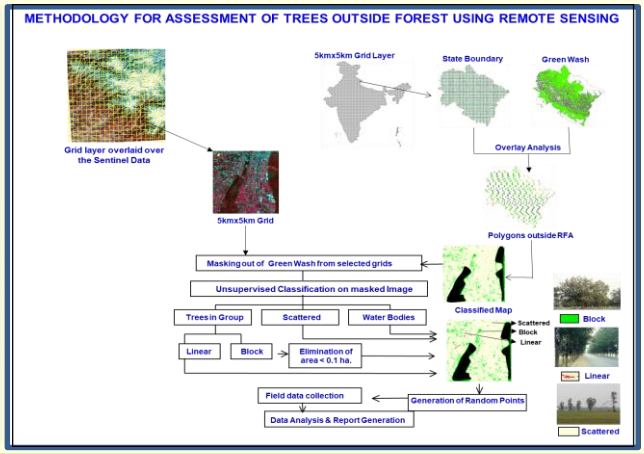
Trees Outside Forest Resources in India





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Trees Outside Forest Resources in India

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Trees Outside Forest Resources in India

Abstract

Trees Outside Forest (TOF) which are defined as 'trees growing outsides forests' play a vital role in the social-economic life of rural India and generate valuable ecosystem services in urban and rural parts of the country. Timber and panel products of TOF origin have emerged as the major alternative to timber from forests and thus TOF have significantly obviated pressure from forests.

Trees Outside Forest (TOF) are found in diverse formations in the rural and urban landscapes in the country like small woodlots, block plantations, trees along linear features such as roads, canals, bunds, etc. and scattered trees on farmlands, agricultural lands, homesteads, community lands and urban areas. TOF play a significant role in livelihood of rural and urban people of the country both economically and ecologically. They also act as important source for timber and fuel wood and contribute in carbon sequestration and conservation of biodiversity, provides habitat for wildlife and help in microclimate stabilization etc. They make a critical contribution to sustainable agriculture, food security and rural household economies.

The present report focuses on TOF resources in India, evolution of assessment methodology and important outcomes of TOF assessment done by FSI. The methodology followed from 1991 to 2001, was confined to only at State or group of districts. The study area was stratified according to agro-ecological zones (AEZ) and village was taken as sampling unit for the inventory of rural areas, whereas for urban TOF, UFS (Urban Frame Survey) blocks maps of National Sample Survey Organization (NSSO) were taken as sampling unit. This methodology was modified in 2001 and was continued till 2016. Under this methodology, the country was stratified into 14 physiographic zones based on the similar vegetation type, climate, soil etc and 60 districts spread over the entire country representing all the physiographic zones were selected for the detailed inventory of TOF in a cycle of 2 years. For inventory of TOF (Rural), high-resolution satellite data was used to stratify TOF resources of the selected districts into three strata, namely block, linear and scattered. For urban TOF, UFS block based of NSSO was used. From the year 2016 the methodology of TOF assessment has been further revised and country has been stratified into uniform grids of size 5kmx5km. The cycle for the TOF inventory in the new design has been kept at 10 years. All TOF grids are marked with numbers 1 to 10 in sequential manner. Grids of a particular number are taken for inventory in a particular year. Both TOF (Rural) and TOF (Urban) inventory are carried out in the selected grids.

In a first ever attempt, extent of TOF in the country has been presented in the ISFR- 2019. The extent of TOF in the country has been assessed 29.38 m ha which is 8.94% of the total geographical area of the country. *Mangifera indica, Azadirachta indica, Acacia Arabica and Cocos nucifera* are the major species found in TOF in rural areas which are contributing most to the total growing stock, whereas, *Cocos nucifera, Areca catechu, Mangifera indica and Azadirachta indica* are the major TOF species in the urban areas of the country. The scattered and block plantations contribute more than 90% of the TOF volume of the entire country.

Trees Outside Forest Resources in India

1. Introduction

Trees Outside Forest (TOF), are defined as 'trees growing outside the forest'. In India, trees growing outside the recorded forest areas (RFA) are termed as TOF. Trees Outside Forest (TOF), are found in diverse formations in the rural and urban landscapes in the country like small woodlots, block plantations, trees along linear features such as roads, canals, bunds, etc and scattered trees on farmlands, agricultural lands, homesteads, community lands and urban areas. TOF play a significant role in livelihood of rural and urban people of the country. They also act as important source of timber and fuel wood, contribute in carbon sequestration and conservation of biodiversity, provide habitat for wildlife, stabilize microclimate etc. They make critical contribution to the sustainable agriculture, food security and rural household economies. They supply many products and services similar to forests. They protect crops and the soil against water and wind erosion, thus combating drought and desertification and protecting water resources. TOF in India have emerged as the major source of wood-based industries including plywood and wood panel industries. TOF resources are important not only from the national perspective but are also part of the strategies for combating ecological problems globally.

In the 1990s, FAO recognised that TOF are typically splinted among the components of agroforestry, urban and rural forestry and other disciplines. An expert meeting held in Finland in 1996, recommended that FAO should address the need for hard data on TOF. As a result, a thematic study on TOF was included in the Global Forest Resource Assessment (FRA) 2000. Along with several publications on the subset, the FAO Forestry Department included TOF in the National Forest Monitoring and Assessment (NFMA) Programme and other country level reporting efforts.

Based on the recommendations of National Commission on Agriculture (NCA, 1976), Government of India launched social forestry programme in the late seventies on a large scale. Extensive tree plantations on non-forest lands were raised by the State Forest Departments under social forestry schemes. Along with this many people particularly farmers took up agro forestry and farm forestry on their lands in several regions of the country for higher economic returns from their agricultural lands. In this way, considerable area was brought under tree plantations over the years. Planned development of this segment of forest resource is imperative to ensure sustained supply of essential forest products and environmental services.

TOF occur in a variety of shapes and sizes, which may range from single tree to large plantations and orchards. Further, TOF may consist of strip plantations along roads, railways and canals, linear array of trees on farm boundaries, man-made or naturally occurring tree clusters in the rural areas, patches of plantations on the community lands, farmlands etc.

Local population, having lived in harmony with and aware of the vast potential of off-forest trees, protect these resources, whether they have actually planted them or not. Trees outside forest are often known to serve as source of food and contribute to a balanced diet, and provide the ingredients for various remedies. In many parts of the world a significant amount of timber and service wood comes from TOF. Agro forestry systems and orchards are also well-known sources of fuel wood and timber (Bhattarai, 2000). We are also well aware of the many ways in which Trees Outside Forest are used in construction and crafts, and their useful role in providing shade and marking the boundaries of fields and other areas, not to mention the cultural and religious aspects. There is mounting evidence of their impact on soil and water conservation, and their essential role in anti-desertification (Carucci,R, 2000), climate control, and maintaining biological diversity and ecosystem balance. Yet, Trees Outside Forest remain a sort of overlooked and hidden treasure. We are still unable to accurately assess the resource itself and the contribution of its products to household incomes.

The priority assessment challenge is to ascertain the status and dynamics of tree resources outside the forest (FAO: FRA 2000, 1998). Classifying the challenges of assessing off-forest trees by territorial scale highlights the sheer size of the resource and the need to assess it in light of the clear link with such current major concerns as food security, the need for forest products, sustainable management, carbon sequestration and the conservation of biological diversity. Another assessment problem is to select realistic objectives that can satisfy all the stakeholders. This is a crucial stage in forest resource assessment and is even more crucial for Trees Outside Forest, which are complex for their spatial distribution, highly diversified in terms of use and function, and highly sensitive to interaction with people. While these characteristics indicate what a rich and complex resource this is, they also show how hard it is to establish a qualitative and quantitative reading on it.

Periodically updated spatial database to facilitate analysis of spatial distribution and dynamism of change would be the key information requirement for planning and management of TOF. At present, information in this regard is almost non-existent. At the best, one can get an estimate of forest plantations created by Forest Departments, which is based on the recorded area of plantations over the years and does not reveal factual status of the plantations. It is understandable that conventional method based on ground survey would be highly tedious, time consuming, expensive and therefore impracticable.

Significance of TOF may be summarized as:

- they make critical contribution to sustainable agriculture, food security and diversification of household economies
- they supply many products (including wood for fuel and construction, fruits, barks and food products) and services (e.g. biodiversity, habitat for wildlife, microclimate stabilisation)

- they protect crops and the soil against water and wind erosion, thus combating drought and desertification and protecting water resources
- an important source of carbon sequestration
- major source of wood for wood based industries
- they provide shade and mark property boundaries
- rich in significance from a cultural and social perspective

Remote sensing based vegetation mapping has emerged as standard practice world over. These days, satellite data in wide range of spectral, spatial, radiometric, and temporal resolutions are available from various Remote Sensing Agencies of several countries. Along with this, there has been rapid advancement in development of digital image processing software. In this scenario, desired mapping of natural resources with the reasonable accuracy is possible. It is only required that the suitable methodologies for the remote sensing application for meeting the objectives of mapping and assessment are developed and standardized.

Trees Outside Forest have been defined differently by different countries and international agencies. In India, TOF is defined as all trees found outside the recorded forest, in line with the FAO's definition of TOF as trees available on lands which is not defined as 'forests' or 'other wooded land'.

In agroforestry sector, comprehensive classification schemes elaborated by eminent agriculturists (Nair 1987; Sinclair 1999), yet there is only a broad classification system exists that embraces all TOF. A key question is whether TOF constitute an area, (i.e. having geometrical identity) or whether the resource must be described in other ways, such as growing stock per unit of area on non-forest land. Both options are valid and allow map representations of the resource that are useful for different purposes.

In classifying TOF, the lands where TOF are found, both land cover (biophysical: how much of the land is covered by tree crowns) and land use (socio-economic) should be taken into consideration. The various classification of TOF resources as per the land use and geometrical formation are given in Table 1.

Table 1: Various Classification of TOF

As per Land Use	**As per Geometrical Formation**
• *Trees with Settlements:* ✓ Urban ✓ Rural • *Trees with Agricultural Lands:* ✓ Agroforestry • *Trees along Manmade or Natural Features:* ✓ Beside Railways ✓ Beside Roads ✓ Beside Canals / Rivers	• *Isolated and scattered trees* ✓ Trees exist in scattered form • *Zonal Trees:* ✓ Trees in lines ✓ Trees in blocks

In the context of the background given above, the report on TOF presents information on the objectives of TOF assessment, methodology of assessment followed by FSI, various output obtained from inventory of TOF including growing stock, carbon stock, extent of TOF, species distribution in rural and urban area etc.

The main objectives of TOF inventory done by FSI are as follows:

- to assess the extent of plantations raised outside the recorded forest areas under various forestry schemes.
- to estimate the total number of trees in TOF
- to estimate the volume of standing trees outside the forest area.
- to estimate carbon sequestered in TOF
- to estimate potential yield of timber from TOF
- to estimate the contribution of TOF in tree cover
- to estimate the extent of TOF

2. Assessment of TOF: A review of practices

Since there exists a large amount of wood resources outside the conventional forests, accurate information about tree resources is a pre-requisite for their proper management. Vast volumes of data, collected by means of forest survey and inventory, are required for scientific management of forests. These data are also used for policy and planning purposes at the national, regional, State or local levels.

Any inventory of natural resources is a costly process and therefore it requires an objective justification, which usually embraces the economic, social and ecological role of the resource. The TOF resources in general are independent of forest resources, and are an integral part of the non-forest landscape having ecological as well as economic implications. Therefore, they should be taken into consideration in large-area for natural resource planning, carbon and growing stock estimation and therefore, accounting of TOF resources is extremely essential on regular basis.

Most countries in the world are having policies for the (sustainable) management of forest resources. However, little attention has yet been given to the dynamics of TOF, although its information on TOF is crucial for developing management options to maintain tree cover and plan wood production.

Besides these technical justifications, a number of International agreements and commitments (e.g. the Forest Principles of Agenda 21, the Convention on Biological Diversity and the Framework Convention on Climate Change) emphasize that an appropriate database is a prerequisite for sound management of the world's natural resources. While these agreements and commitments generally refer to forest only, although, the principles of sustainable management of natural resources apply to TOF, also in the landscape approach.

To assess TOF resources, various initiatives have been undertaken world over, following different methodology. In Costa Rica, Hidalgo, D.M. and Kleinn, C. (Hidalgo, D.M. *et al*. 2002) has advocated two-stage sampling by pre-selecting sites and followed by sample plots on the ground as secondary units. In their opinion pre-stratification based on the segmentation and fusion of Landsat image with IRS image would be ideal. This methodology was tested on silvopastoral system in Costa Rica.

Holmgren (Holmgren, P. *et al.* 1994) in Kenya and Belouard in France (Beloured, T. 2002) have used systematic two-stage sampling. In the first stage they selected systematically aerial photographs covering the study area and in the second stage they chose number of sample points at the ground to enumerate trees and other physical and technical use of the area.

Glen (Glen, 2002) commented that the main lessons learned from the two projects, namely, Sudan Reforestation & Anti-desertification and Resource Assessment & Development projects between 1987 and 1993, is that satellite imagery without good ground verification can produce misleading results, and that there is a need for ground plots to supply details on volume, stem/ha, species, site conditions and land use.

In 2009, World Agroforestry Centre (till 2002 it was known as ICRAF) came out with a report 'Trees on Farm: Analysis of Global Extent and Geographical patterns of Agroforestry' based on study using remote sensing data. The remotely sensed data was analysed to assess the extent of tree green cover in agricultural land. The study has mapped 'tree canopy cover' at the global level in which tree canopy cover is depicted from zero per cent to 100 per cent. The study found high tree cover (> 45 per cent) in the more humid regions such as southeast Asia, Central America, eastern South America and coastal west Africa. The moderate level of 10 per cent to 30 per cent tree cover was found in the agricultural areas in south Asia, sub-humid Africa, central and western Europe, Amazonian South America, and mid-western North America. The agricultural areas with relatively low (<10 per cent) tree cover was found in eastern China, northwestern India and the Punjab, west Asia, the southern border of the Sahara, the northern prairies of North America and the southwest of Australia. It is obvious from above that the tree canopy cover follows a pattern influenced by precipitation regimes. This rule is not observed in the areas where population density or human activities are higher namely, China and India.

Dhyani *et al.* 2013, on the basis of secondary data, has estimated that the current area under agroforestry in India, is 25.32 million ha which, is 8.2 per cent of the total geographical area of the country. They have mentioned that there is a scope of increasing the area under agroforestry in future by another 28.0 million hectares. The obvious choice of inclusion of land for agroforestry is from fallows, cultivable fallows, pastures, groves and rehabilitation of problem soils. Thus, a total of 53.32 million hectares, representing about 17.5 per cent of the total reported geographical area of the country, could potentially be brought under agroforestry by the year 2050.

3. Methodology of Assessment followed by FSI

Inventory of TOF resources and their actual contribution to timber and fuelwood supplies was not known at the National level till 1991. In some States, wood balance studies were undertaken as an important component of the social forestry projects during the 1980s. At that time, data on TOF at national or State level did not exist. The production of wood from TOF was either estimated in an approximate manner or ignored. FSI started inventory of TOF in 1991 to assess the number of trees and their volume in TOF. Since then inventory of TOF is one of the important activity of FSI. The methodology of assessment has improved significantly over the years keeping pace with data requirements and change in technology. The evolution of the methodology in TOF assessment by FSI has been described in the following sub sections.

In India FSI assesses forest cover of the country in biennial cycle. Forest cover includes all patches of tree formations which are of size 1 ha or more, it does not discriminate whether the tree patch is within the recorded forest area or outsides. Therefore forest cover map of the country also includes TOF which occur in tree patch size of 1 ha or more. Apart from this there is significantly large extent of TOF resource which occurs in the patch size less than 1 ha or in the scattered form. This segment of TOF resource is assessed by FSI through sampling techniques following stratified random sampling design and is assessed as tree cover in terms of extent, growing stock etc. The methodology in detail is given in the following sections. Thus in the FSI's assessment framework, TOF has two components.

(a) TOF as map in the forest cover i.e. patches ≥ 1 ha
(b) TOF assessed through sampling techniques i.e. patches less than 1 ha and scattered trees, which is termed as tree cover and not mapped.

The following Venn diagram shown in figure 1 depicts the relationship between RFA, Forest Cover, TOF & Tree Cover.

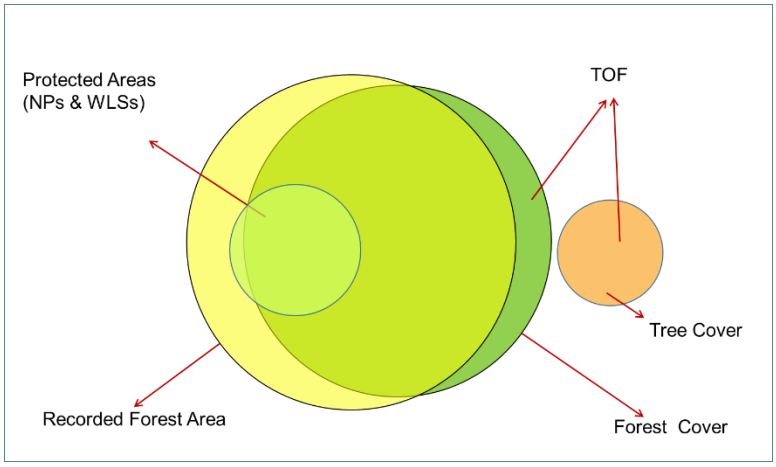

Figure 1: Concept of TOF and Tree Cover

3.1 Methodology followed from 1991 to 2001

The inventory of TOF started by FSI in 1991 was confined to the States or group of districts. Multistage stratified sampling design was used for the selection of samples. Separate methodology was followed for inventory of rural and urban TOF. As per the sampling design, the study area was stratified according to agro-ecological zones (AEZ). Districts, the basic planning and administrative units, which have significant influences on TOF and their resources, are considered for further stratification of these AEZs. The villages within these stratified areas are the sampling units selected, through stratified random sampling. The number of sample villages to be surveyed were decided by conducting a pilot study in 20-25 randomly selected villages with 10 to 15 percent permissible error, at 95 percent probability level. A complete inventory is conducted for all the trees of 10 cm DBH (Diameter Breast Height) and above in the randomly selected villages. For the inventory of TOF in urban areas, UFS (Urban Frame Survey) blocks maps of National Sample Survey Organization (NSSO) were taken as sampling unit. The number of sample blocks in the district was determined through a pilot study in randomly selected blocks with 10 to 15 percent permissible error, at 95 percent probability level. The randomly selected blocks in selected district were used for conducting a complete enumeration of the trees of 10 cm DBH and above.

The trees in the TOF (Figure 2) area were classified into 9 categories for the purpose of data recording, processing and analysis. These categories were as follows:

1. Farm forestry: trees along farms and in small patches up to 0.1 ha in area.
2. Woodlot: naturally growing and planted trees on community land (e.g. parks, gardens, institutional plantation).
3. Block plantation: patches covering areas of more than 0.1 ha and not considered in the above categories.
4. Roadside windbreaks: trees planted along roadsides.
5. Pond side plantation: trees planted in and around water bodies.
6. Railway windbreaks: trees planted along railway lines.
7. Canal side plantations: trees planted along canals.
8. Homestead: trees appearing in the house area and not covered in the first three categories above.
9. Others: trees not falling in any of the above categories.

Figure 2: Pictorial Representation of Various Forms of TOF

3.2 Methodology from 2001 to 2016

The methodology adopted during 1991 to 2001 was not suitable for generating national level estimates of growing stock and other parameters as the inventory was confined to only group of districts or State at different point of time. Therefore, to generate the national level estimates of TOF, the sampling design was modified in 2001. As per the modified design, the country was stratified into 14 physiographic zones based on the similarities in vegetation, climate, soil etc. 60 districts spread over the entire country representing all the physiographic zones were selected for the detailed inventory of TOF in a cycle of 2 years. Separate methodology was used for the inventory of rural and urban areas. The sampling frame for inventory of TOF (Rural) was created using the high resolution satellite data to stratify TOF resources of the selected districts into three strata, namely block, linear and scattered. Thereafter, simple random sampling was followed to select optimum number of sample points from each stratum. The optimum number of sample points and plot size in each stratum were determined with the help of the pilot study. Inventory was carried out in all the selected sample points in each stratum. Remote sensing based methodology used for inventory of rural area was not followed for urban areas because the geo-referenced boundaries of urban areas were not available. Moreover, it was not possible to layout plots of desired size in urban areas due to tree pattern and residential configuration. Therefore, a different sampling design, based on the UFS block maps of NSO, as was done earlier, was adopted for inventory of urban TOF.

3.3 Methodology from 2016 onwards

The district based methodology adopted in 2001 was again modified in 2016 to meet the data requirement at national and international levels. As per the modified design, FSI has switched over from district to grid based design. The country has been stratified into uniform grids of size 5kmx5km (Figure 3). This grid layer has been obtained from NRSC. The cycle for the TOF inventory in the new design has been kept at 10 years. All TOF grids are marked with numbers 1 to 10. Grids of a particular number are taken for inventory in a particular year. TOF grids consist of both TOF (Rural) and TOF (Urban). As generation of State level estimates is one of the main objectives of the new sampling design, the optimum sample size has been calculated at State level separately for rural and urban areas using past inventory data. For rural grids, remote sensing based methodology, as described earlier, was used for stratification of TOF resources into block, linear and scattered stratum and inventory is carried out in each selected grids. Similarly, for the urban inventory, UFS block maps of town falling in the selected grids are used for inventory of TOF in urban areas. Sample Plots of FSI for TOF Assessment during 2016 to 2018 is shown in figure 4.

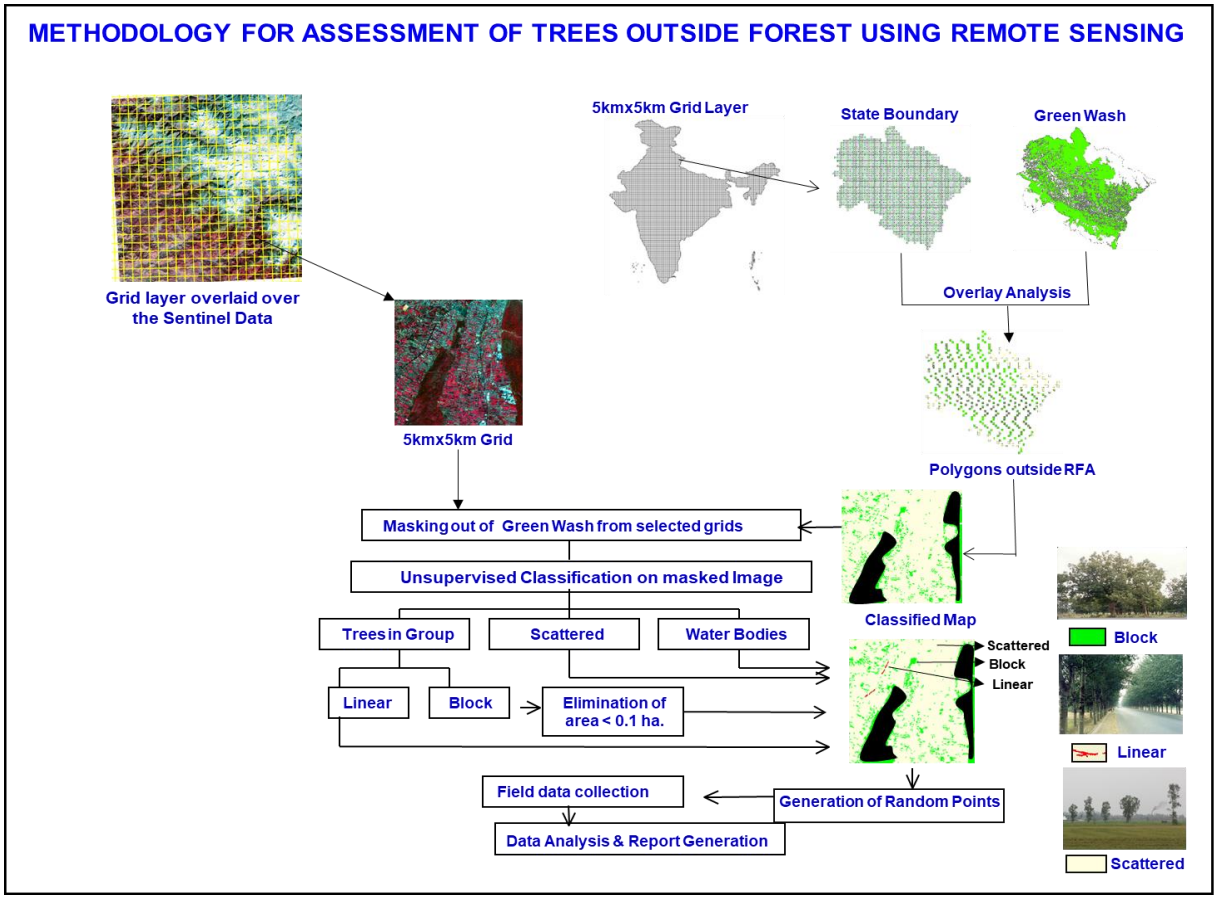

Figure 3: Schematic Diagram of Methodology of TOF Assessment

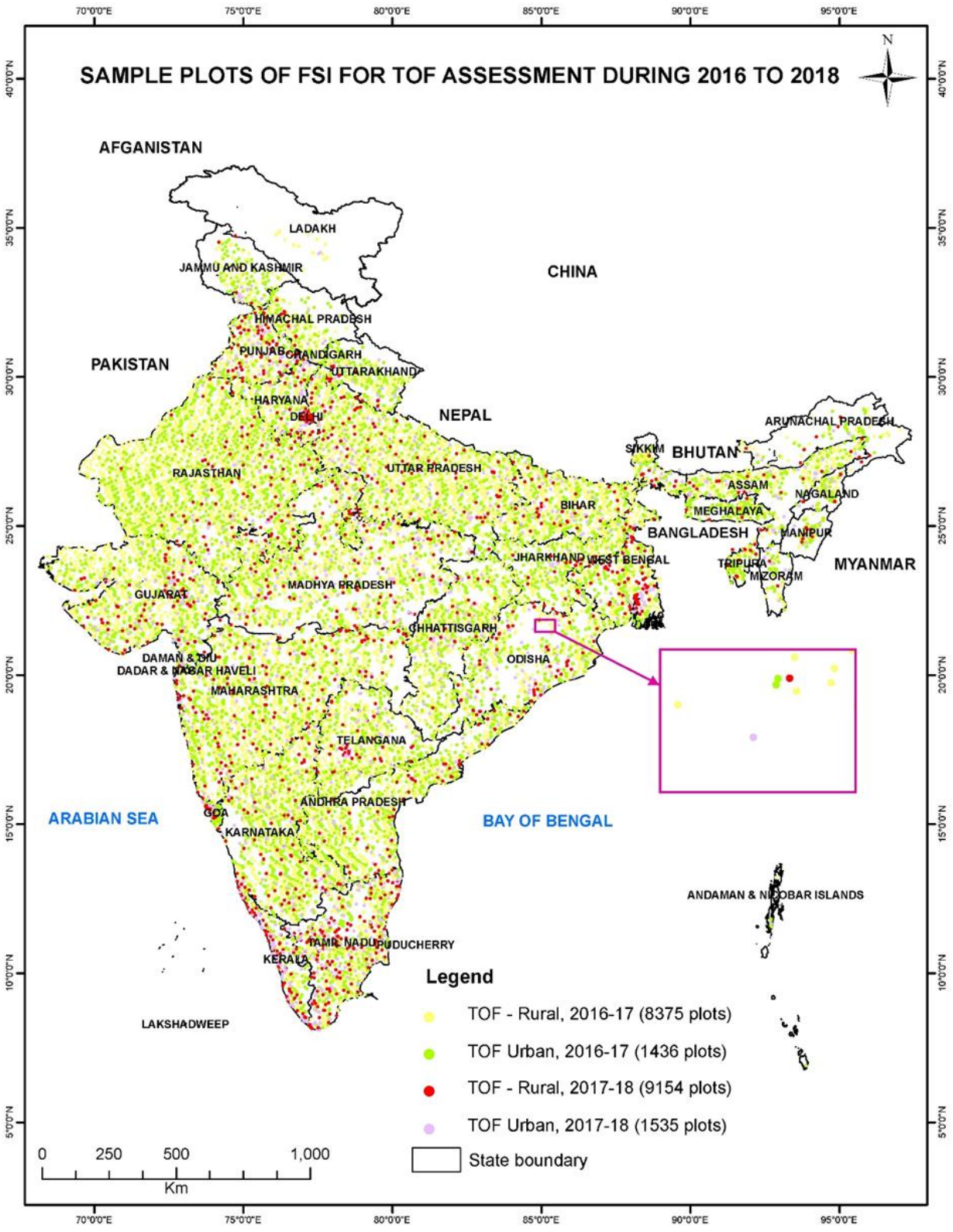

Figure 4: Sample Plots of FSI for TOF Assessment during 2016 to 2018

4. TOF Resource in the Country as per the latest assessment

The regular assessment of TOF gives many important information about TOF, which may be useful for better understanding of TOF resources in the country and their better planning & management. Some of the important outcome of TOF assessment are given as follows**:**

4.1 Extent of TOF

FSI carries out wall-to-wall mapping of forest cover of the country using satellite data on a biennial basis. The forest cover includes all areas outside the recorded forest areas, which are more than 1 ha in extent with a tree canopy density of 10 percent and more irrespective of the land use and legal status. Forest Cover outside the recorded forest area (RFA) is derived using boundaries of RFAs. There are States where RFA boundaries are not available in digital format, in such States, Green Wash shown on SOI toposheets have been used as a substitute to the RFA boundaries. Tree cover, on the other hand, is defined as all tree patches of size less than 1 ha occurring outside the recorded forest areas. Tree cover includes trees in all formations including scattered trees. TOF and tree cover appear as similar terms but they are two different entities, though closely related to each other. TOF refers to all trees growing outside RFA irrespective of patch size which could also be larger than 1 ha. Thus tree cover becomes a subset of TOF. Tree cover is estimated using high resolution satellite imagery along with sample plot data. Thus, trees included in the tree cover constitute only a part of TOF. Extent of TOF therefore may be estimated as the sum of extent of forest cover outside the RFAs and tree cover.

The result of the extent of TOF across different States / UTs of the country has been given in Table 2. The total extent of TOF at the country level is 8.94 % of the total geographical area of the country. The Union Territory of Lakshadweep is having maximum extent of TOF (91.3 %). Among the States, Kerala (37.17 %) and Goa (36.05 %) have maximum TOF area, as percentage to their geographical area. In absolute terms Maharashtra has the maximum area under TOF, followed by Odisha and Karnataka.

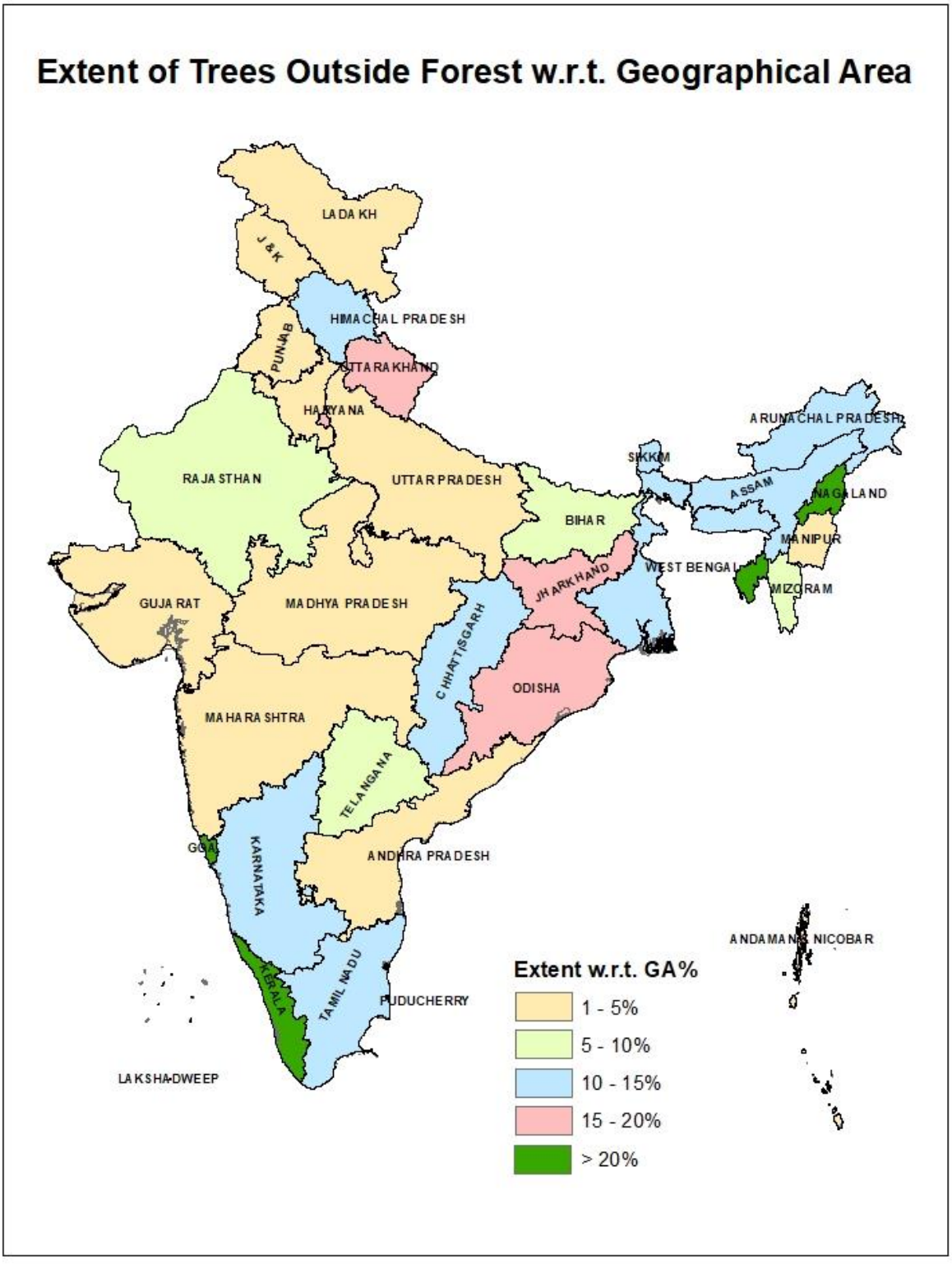

Figure 5: Extent of Trees Outside Forest as Percentage of GA

Table 2: Extent of Trees Outside Forest (ISFR 2019)

State/UTs	TGA (sq km)	Tree cover 2019 (sq km) (A)	Forest cover outside RFA 2019 (sq km) (B)	Extent of TOF 2019 (sq km) (A+B)	% of Geographical Area of the State/UT
Andhra Pradesh	162968	3,914	5,018	8,932	5.48
Arunachal Pradesh	83743	848	7,967	8,815	10.53
Assam	78438	1,408	8,183	9,591	12.23
Bihar	94163	2,003	2,537	4,540	4.82
Chhatisgarh	135192	4,248	13,195	17,443	12.90
Delhi	1483	129	136.37	265	17.92
Goa	3702	272	1,063	1,335	36.05
Gujarat	196244	6,912	5,072	11,984	6.11
Haryana	44212	1,565	1,229	2,794	6.32
Himachal Pradesh	55673	829	4,796	5,625	10.10
J&K and Ladakh*	222236	7,944	11,390	19,334	8.70
Jharkhand	79716	2,657	11,402	14,059	17.64
Karnataka	191791	6,257	16,104	22,361	11.66
Kerala	38852	2,936	11,507	14,443	37.17
Madhya Pradesh	308252	8,339	12,730	21,069	6.83
Maharashtra	307713	10,806	16,139	26,945	8.76
Manipur	22327	173	1,829	2,002	8.96
Meghalaya	22429	710	2,275	2,985	13.31
Mizoram	21081	441	270	711	3.37
Nagaland	16579	362	3,759	4,121	24.86
Odisha	155707	4,648	18,810	23,458	15.06
Punjab	50362	1,592	1,065	2,657	5.28
Rajasthan	342239	8,112	4,348	12,460	3.64
Sikkim	7096	36	996	1,032	14.54
Tamil Nadu	130060	4,830	8,775	13,605	10.46
Telengana	112077	2,514	2,313	4,827	4.31
Tripura	10486	231	2,275	2,506	23.90
Uttar Pradesh	240928	7,342	5,611	12,953	5.38
Uttarakhand	53483	841	7,513	8,354	15.62
West Bengal	88752	2,006	9,825	11,831	13.33
Andaman & Nicobar Islands	8249	41	521	562	6.81
Chandigarh	114	25	13.76	39	34.41
Dadra & Nagar Haveli	491	28	47	75	15.32
Daman & Diu	111	5	20.49	25	22.52
Lakshadweep	30	0.29	27.10	27	91.30
Pondicherry	490	23	51.41	74	15.15
Total	**3287469**	**95027**	**198813**	**293840**	**8.94**

** includes J&K and Ladakh area outside LOC that is under illegal occupation of Pakistan and China*

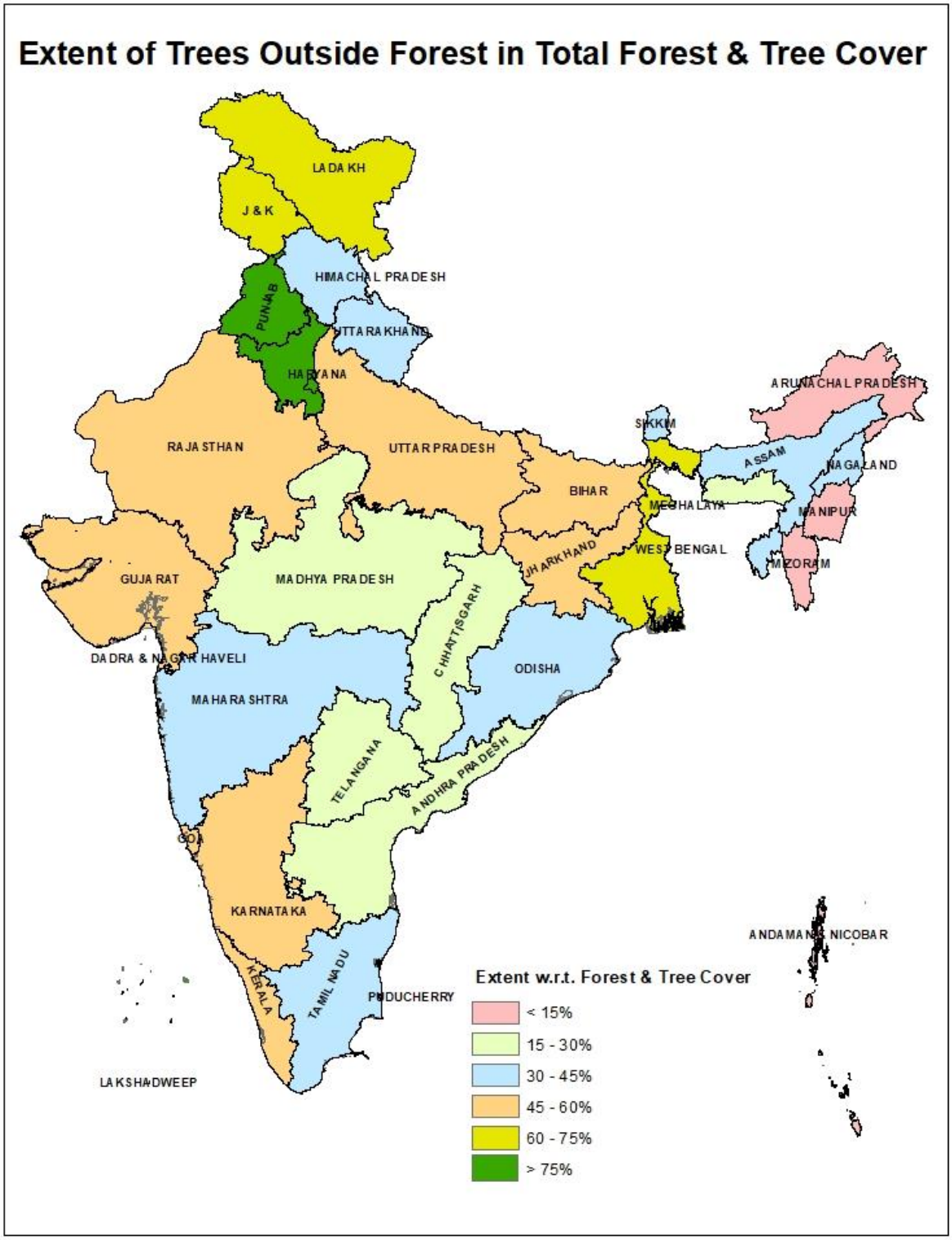

Figure 6: Extent of Trees Outside Forest as Percentage of Forest & Tree Cover

Figure 5 presents that maximum States are having TOF ranges of 5-10 percent and with respect to 'Total Geographical Area' of the country, whereas, Figure 6 depicts that tree cover is most in the State of Punjab due to the dominance in agriculture based land use and respective agroforestry plantations.

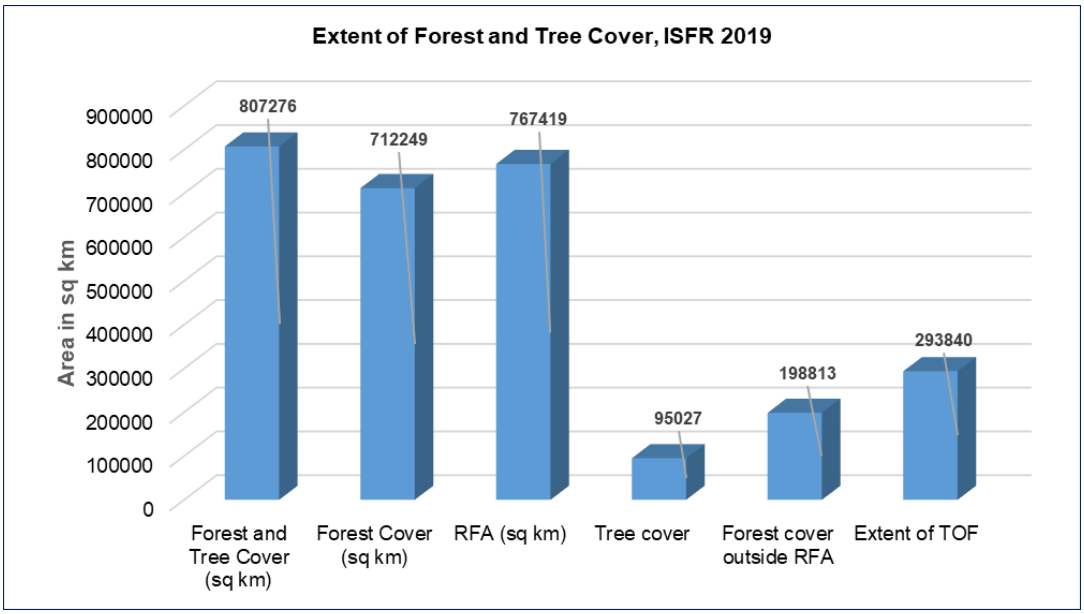

Figure 7: Extent of Forest and Tree Cover in India (ISFR 2019)

Figure 7 indicates that the area contribution of 'Tree Cover' (95027 sq.km) is considerable in 'TOF' (293840 sq.km).

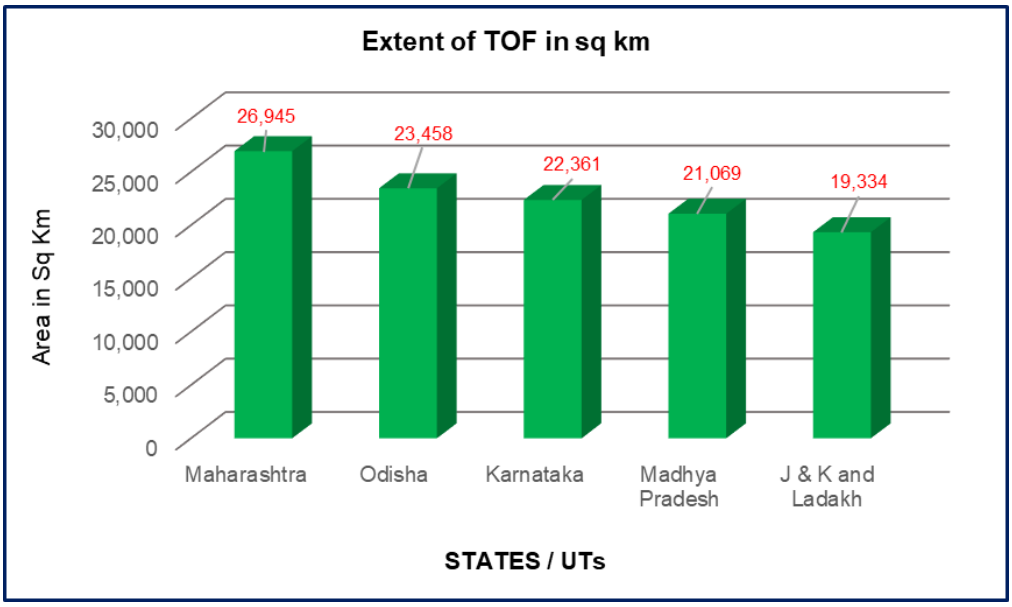

Figure 8: Top five States in extent of TOF (ISFR 2019)

The top 5 States / UTs in terms of extent of TOF are shown in figure 8.

4.2 Growing Stock of TOF

The information on number of trees and their growing stock are obtained from the inventory of TOF. FSI carries out inventory of TOF in rural and urban areas of the country at about 20,000 sample plots spread across the entire country in a cycle of 2 years. Various bio-physical parameters recorded from these plots give information on distribution of species in rural and urban areas of the country, their distribution in different diameter classes, their volume, tree cover etc.

Table 3 presents the growing stock per hectare in TOF in different States and UTs of the country in the year 2019. The average growing stock per hectare of TOF extent for the country has been estimated 55.89 cum. It is observed that Bihar is having the highest growing stock in TOF extent per hectare (89.12 cum /ha), followed by Telengana (85.87 cum/ha) and Arunachal Pradesh (85.17 cum /ha).

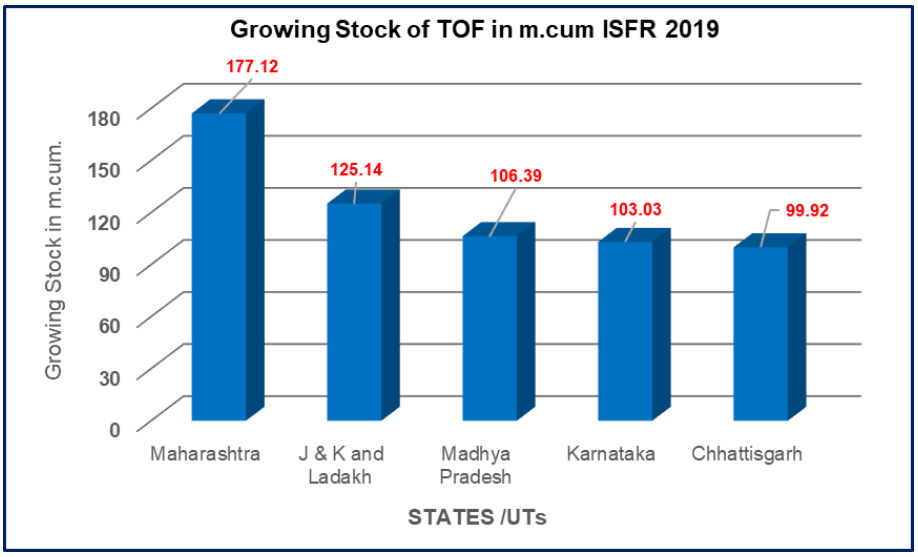

Figure 9: Top five States in Growing Stock of TOF

Figure 9 shows the top 5 States / UTs of the country which adds most towards the Growing Stock of TOF.

Table 3: Growing Stock of TOF (per ha) (ISFR 2019)

Sr. No.	State/UTs	Growing Stock of TOF (m.cum)	GS per ha in TOF Extent (in cum / ha)
1	Andhra Pradesh	67.68	75.77
2	Arunachal Pradesh	75.08	85.17
3	Assam	22.96	23.94
4	Bihar	40.46	89.12
5	Chhattisgarh	99.92	57.28
6	Delhi	1.69	63.77
7	Goa	4.03	30.19
8	Gujarat	82.6	68.93
9	Haryana	17.56	62.85
10	Himachal Pradesh	25.19	44.78
11	J&K and Ladakh*	125.14	64.73
12	Jharkhand	71.93	51.16
13	Karnataka	103.03	46.08
14	Kerala	55.26	38.26
15	Madhya Pradesh	106.39	50.50
16	Maharashtra	177.12	65.73
17	Manipur	6.07	30.32
18	Meghalaya	18.84	63.12
19	Mizoram**	44.11	-
20	Nagaland	13.72	33.29
21	Odisha	95.02	40.51
22	Punjab	18.56	69.85
23	Rajasthan	89.07	71.48
24	Sikkim	1.94	18.80
25	Tamil Nadu	76.30	56.08
26	Telangana	41.45	85.87
27	Tripura	6.76	26.98
28	Uttar Pradesh	97.62	75.36
29	Uttarakhand	19.13	22.90
30	West Bengal	32.63	27.58
31	A & N Islands	2.75	48.93
32	Chandigarh**	0.50	-
33	Dadra & Nagar Haveli**	1.16	-
34	Daman & Diu	0.15	60.00
35	Lakshadweep	0.07	25.93
36	Puducherry	0.40	54.05
Total		**1,642.29**	**55.89**

**includes J&K and Ladakh area outside LOC that is under illegal occupation of Pakistan and China*

*** Inadequate data*

4.3 Potential Annual Yield of Timber from TOF

The accurate information on potential annual yield of timber from TOF is not available at State or national level. Therefore, FSI attempted to estimate the potential annual yield of timber from TOF using TOF inventory data. Estimates were generated State wise using estimation of dominant species. For each State, the estimates of growing stock were arranged according to species which were further arranged according to timber and other species. For calculation of potential annual yield, only timber species were considered. The rotation period of different timber species available with FSI from State Forest Departments and other sources were used. Using the estimates of growing stocks and rotation period of the species, annual potential yield was calculated for each State by applying Von Mantel's formula.

Table 4 gives information on State/UTs wise potential annual yield of timber from TOF. It is revealed from the table that Maharashtra is having highest potential annual yield of Timber (10.60 m.cum / year) in India followed by UP (7.47 m.cum / year) and Karnataka (6.28 m.cum / year).

Table: 4: State/UTs wise potential annual yield of timber from TOF

State/UTs	Growing Stock of TOF (m.cum)	Potential Annual Yield (m cum / yr)
Andhra Pradesh	67.68	3.14
Arunachal Pradesh	75.08	1.98
Assam	22.96	1.10
Bihar	40.46	2.00
Chhattisgarh	99.92	4.77
Delhi	1.69	0.11
Goa	4.03	0.18
Gujarat	82.6	4.67
Haryana	17.56	2.23
Himachal Pradesh	25.19	1.52
J&K and Ladakh *	125.14	2.42
Jharkhand	71.93	3.37
Karnataka	103.03	6.28
Kerala	55.26	2.55
Madhya Pradesh	106.39	5.76
Maharashtra	177.12	10.60
Manipur	6.07	0.30
Meghalaya	18.84	0.73
Mizoram	44.11	1.41
Nagaland	13.72	0.65
Odisha	95.02	4.32
Punjab	18.56	2.49
Rajasthan	89.07	5.47
Sikkim	1.94	0.09
Tamil Nadu	76.30	3.86
Telangana	41.45	2.12
Tripura	6.76	0.32
Uttar Pradesh	97.62	7.47
Uttarakhand	19.13	1.10
West Bengal	32.63	1.93
Andaman & Nicobar Islands	2.75	0.11
Chandigarh	0.50	0.04
Dadra &Nagar Haveli	1.16	0.04
Daman &Diu	0.15	0.01
Lakshadweep	0.07	0.003
Puducherry	0.40	0.02
Total	**1,642.29**	**85.16**

**includes J&K and Ladakh area outside LOC that is under illegal occupation of Pakistan and China*

4.4 Carbon Stock in TOF

To calculate the carbon stock in the TOF, the information on forest cover in TOF for each density class and carbon stock per hectare in each density class is required. The State wise information on forest cover in different density classes in TOF has been obtained from the forest cover maps of each State by excluding RFA of each State from the forest cover. The States where digital layers of RFA were not available, the layers of Green wash has been used for this purpose. The information on carbon stock per hectare in different density class and different pools for TOF/plantation have been obtained from field inventory data. Using the information of forest cover in TOF in different density classes and total carbon stock per hectare (including all pools), the estimates of carbon stock in forest cover of TOF has been calculated.

For estimation of carbon stock in the tree cover, the field data collected during TOF inventory has been used. The density of each sample plot has been estimated on the basis of crown cover of each plot. For determining crown cover of the plot, the crown width of each tree species found in the sample plot was used. Thus the density of each sample plot has been classified into three density classes namely VDF, MDF and OF. Thereafter, biomass of each sample plot was calculated on the basis of field inventory data. Biomass equations were used for expansion of woody biomass to take into account the biomass of small wood, leaves, foliage etc. Using biomass of each species and the carbon content percent, per hectare carbon stock was calculated for each sample plot according to different density classes. The above information was generated at physiographic zone level according to different density classes as mentioned above. The State level per hectare of carbon stock in different density classes were developed on the basis of State falling in a particular physiographic zone. The carbon stock for each State is then calculated using the areas of tree cover and average per hectare carbon stock for that State. Adding the carbon stock of all States, the total carbon stock in tree cover has been estimated. Thus the total carbon stock in TOF has been obtained by adding the carbon stock in forest cover of TOF and tree cover.

Table 5 presents the State / UT wise distribution of carbon stock in forest outside RFA /Green Wash and the tree covers. Odisha is having the highest carbon stock (151.49 million tonnes) in forests outside RFA / Green wash, whereas, the same in tree cover is highest in the State of Maharashtra (105.96 million tonnes).

In order to raise the growing stock of TOF and thereby to increase the carbon stock, various plantation approaches were highlighted by Ashutosh *et al*. (2019). According to their findings; tree planting on culturable wastelands & other available lands in the villages, tree planting along

- Roads (National Highways, State Highways and Other Roads)
- Railway lines including Railway Siding
- Rivers & Canals etc.

Table 5: Total Carbon Stock in TOF (Forest Cover Outside RFA & Tree Cover), ISFR 2019

State/UTs	Total Forest Cover Outside RFA/GW area (sq km)	Total Carbon Stock in forest cover outside RFA (million tonnes) (A)	Tree Cover area (sq km)	Carbon stock in Tree Cover (million tonnes) (B)	Total Carbon Stock in TOF (million tonnes) (A+B)
Andhra Pradesh	5,018	35.83	3,914	40.57	76.40
Arunachal Pradesh	7,967	71.70	848	8.10	79.80
Assam	8,183	58.09	1,408	12.85	70.94
Bihar	2,537	19.28	2,003	18.28	37.56
Chhatisgarh	13,195	116.79	4,248	50.44	167.23
Delhi	136.37	1.03	129	1.68	2.72
Goa	1,063	7.89	272	1.70	9.60
Gujarat	5,072	35.78	6,912	44.09	79.87
Haryana	1,229	8.86	1,565	20.42	29.29
Himachal Pradesh	4,796	40.98	829	8.38	49.36
J&K and Ladakh *	11,390	95.45	7,944	80.34	175.79
Jharkhand	11,402	96.86	2,657	31.55	128.41
Karnataka	16,104	139.98	6,257	55.35	195.33
Kerala	11,507	89.73	2,936	18.40	108.13
Madhya Pradesh	12,730	98.36	8,339	97.59	195.95
Maharashtra	16,139	128.66	10,806	105.96	234.63
Manipur	1,829	13.54	173	1.26	14.79
Meghalaya	2,275	20.83	710	5.16	25.98
Mizoram	270	2.07	441	3.20	5.27
Nagaland	3,759	29.17	362	2.63	31.80
Odisha	18,810	151.49	4,648	55.19	206.68
Punjab	1,065	8.06	1,592	20.78	28.83
Rajasthan	4,348	28.54	8,112	51.75	80.29
Sikkim	996	9.15	36	0.34	9.49
Tamil Nadu	8,775	66.20	4,830	52.07	118.28
Telengana	2,313	16.45	2,514	22.24	38.69
Tripura	2,275	21.24	231	1.68	22.91
Uttar Pradesh	5,611	39.98	7,342	95.82	135.80
Uttarakhand	7,513	66.29	841	8.51	74.80
West Bengal	9,825	70.74	2,006	18.31	89.05
Andaman & Nicobar Islands	521	5.42	41	0.44	5.86
Chandigarh	13.76	0.13	25	0.33	0.45
Dadra & Nagar Haveli	47	0.33	28	0.42	0.75
Daman & Diu	20.49	0.16	5	0.03	0.19
Lakshadweep	27.10	0.24	0.29	0.00	0.24
Puducherry	51.41	0.39	23	0.25	0.64
Total	198813	**1595.69**	**95027**	**936.12**	**2,531.81**

**includes J&K and Ladakh area outside LOC that is under illegal occupation of Pakistan and China*

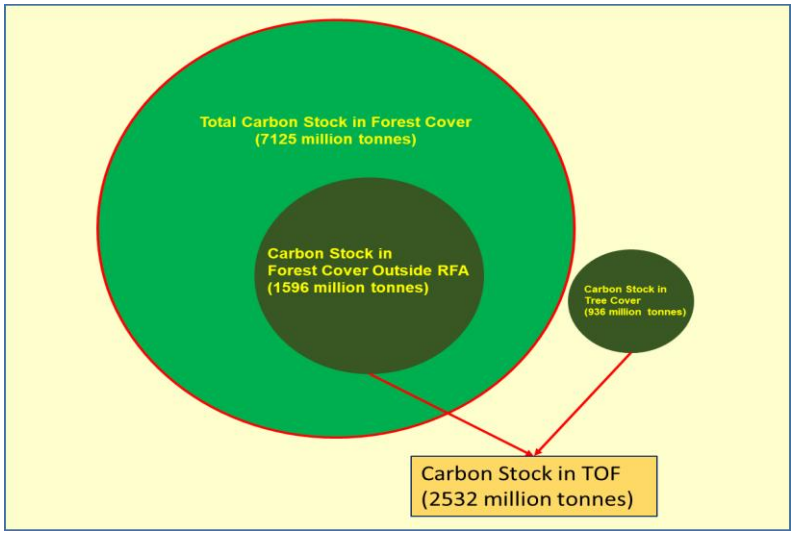

Figure 10: Distribution of Carbon Stock in TOF

Figure 10 highlights that 'Carbon Stock' in TOF is 2532 million tonnes, which is the total of carbon stocks in forest cover of TOF (1596 million tonnes) and carbon stocks in Tree Cover (936 million tonnes). Therefore, TOF is having a dominant role in contributing country's Total Carbon Stock.

Greening of Urban Spaces, Agro-forestry, afforestation on Culturable Wastelands, plantations along highways, railways tracks and canals are very important in expanding area under TOF and simultaneously raise carbon stock. A study done on NDC forestry target by FSI in 2019 highlighted an estimated value of 43.16 million hectare of land availability for plantation in the country (Ashutosh *et al.*, 2019). The study described the best possible different scenarios and magnitude of actions required for achieving the Nationally Determined Contributions (NDC) target for creating additional carbon sink through additional forest and tree cover in the country by 2030.

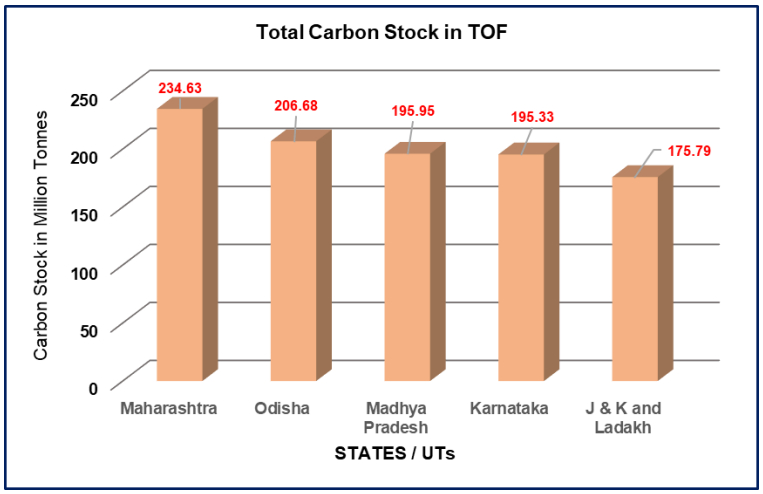

Figure 11: Top five States / UTs in Carbon Stock in TOF

Figure 11 shows the total carbon stock in TOF for top 5 States/UTs.

4.5 Species wise distribution of TOF at the National Level in Rural Areas

FSI generates estimates of diameter wise number of trees and volume in both rural and urban areas. The information is generally available in a class interval of 10 cm. However, in the present study the interval classes is widen to 20 cm. The interval classes considered for studying number of trees in TOF, as well as their estimated volume (in million m^3) has been considered as 10-30 cm, 30-50 cm and 50 + cm. The diameter class below 10 cm has been ignored due to its minimal contribution in volume estimation.

Table 6: Estimated Number of Trees ('000) in Rural Areas for Top 20 Species

Sl.No	Species	Diameter Class (cm)				
		10-30	30-50	50+	Total	Percent
1	*Mangifera indica*	425973	92821	25816	544610	9.50
2	*Azadirachta indica*	365948	95033	4761	465742	8.13
3	*Acacia arabica*	182038	47301	1477	230816	4.03
4	*Cocos nucifera*	130384	63569	406	194359	3.39
5	*Butea monosperma*	159938	30347	1214	191499	3.34
6	*Tectona grandis*	160424	9946	682	171052	2.98
7	*Zizyphus mauritiana*	142439	12425	513	155377	2.71
8	*Eucalyptus species*	128509	13782	727	143018	2.50
9	*Areca catechu*	138321	36	32	138389	2.41
10	*Hevea brasiliensis*	104802	5603	4	110409	1.93
11	*Prosopis juliflora*	104031	2426	200	106658	1.86
12	*Borassus flabelliformis*	16095	83648	983	100726	1.76
13	*Grewia oppositifolia*	96921	2676	0	99597	1.74
14	*Prosopis cineraria*	50209	33881	1324	85414	1.49
15	*Populus species*	80970	2854	21	83845	1.46
16	*Leucaena leucocephala*	74330	2417	126	76873	1.34
17	*Madhuca latifolia*	23407	30100	21511	75018	1.31
18	*Dalbergia sissoo*	59928	12767	363	73058	1.27
19	*Terminalia tomentosa*	59431	8370	953	68754	1.20
20	*Pinus excelsa*	45159	19770	2050	66979	1.17

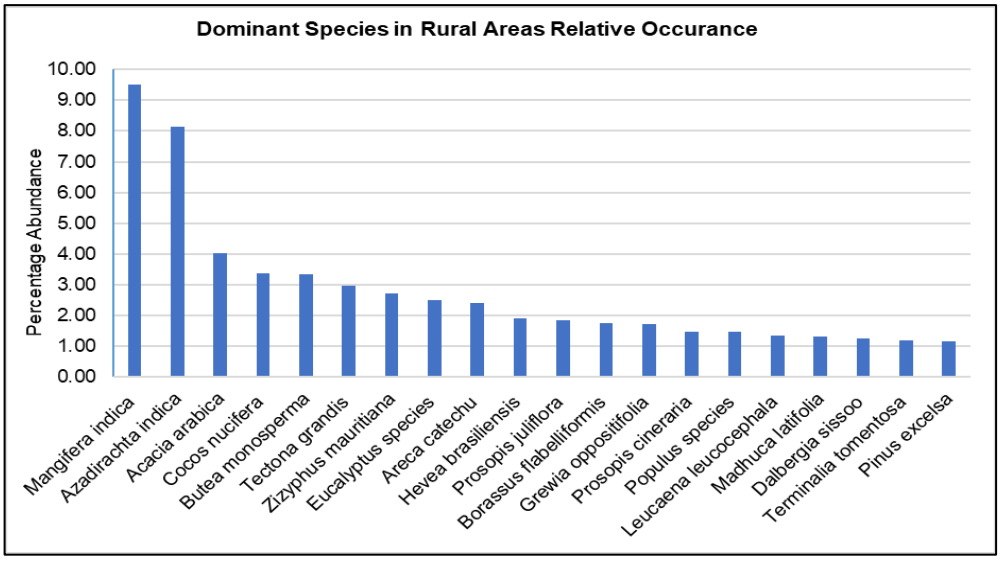

Figure 12: Relative Occurrence of 20 Dominant Species in Rural Areas

Table 7: Estimated Volume (m cum) in Rural Areas for Top 20 Species

Sl.No.	Species	Diameter Class (cm)				
		10-30	30-50	50+	Total	Percent
1	*Mangifera indica*	45.70	65.09	86.08	196.87	12.70
2	*Azadirachta indica*	43.59	66.71	14.49	124.79	8.06
3	*Madhuca latifolia*	2.71	19.81	58.06	80.58	5.23
4	*Borassus flabelliformis*	3.63	55.17	1.87	60.67	3.94
5	*Acacia arabica*	20.09	28.61	2.98	51.68	3.35
6	*Cocos nucifera*	25.40	23.78	0.85	50.03	3.24
7	*Butea monosperma*	18.92	22.06	4.39	45.37	2.94
8	*Pinus wallichiana*	10.69	19.43	12.28	42.40	2.75
9	*Tamarindus indica*	2.80	13.63	23.95	40.38	2.62
10	*Ficus religiosa*	0.97	3.69	33.30	37.96	2.20
11	*Tectona grandis*	17.70	6.85	6.12	30.67	1.99
12	*Ficus bengalensis*	0.65	2.84	25.29	28.78	1.74
13	*Eucalyptus species*	12.30	10.04	1.76	24.10	1.57
14	*Dalbergia sissoo*	11.63	11.01	1.22	23.86	1.55
15	*Prosopis cineraria*	4.78	16.26	2.47	23.51	1.52
16	*Syzygium cumini*	5.23	11.76	5.67	22.66	1.47
17	*Shorea robusta*	6.02	8.85	6.27	21.14	1.37
18	*Zizyphus mauritiana*	13.18	6.53	1.07	20.78	1.35
19	*Terminalia arjuna*	4.20	9.93	4.37	18.50	1.20
20	*Terminalia tomentosa*	6.39	6.09	2.54	15.02	0.97

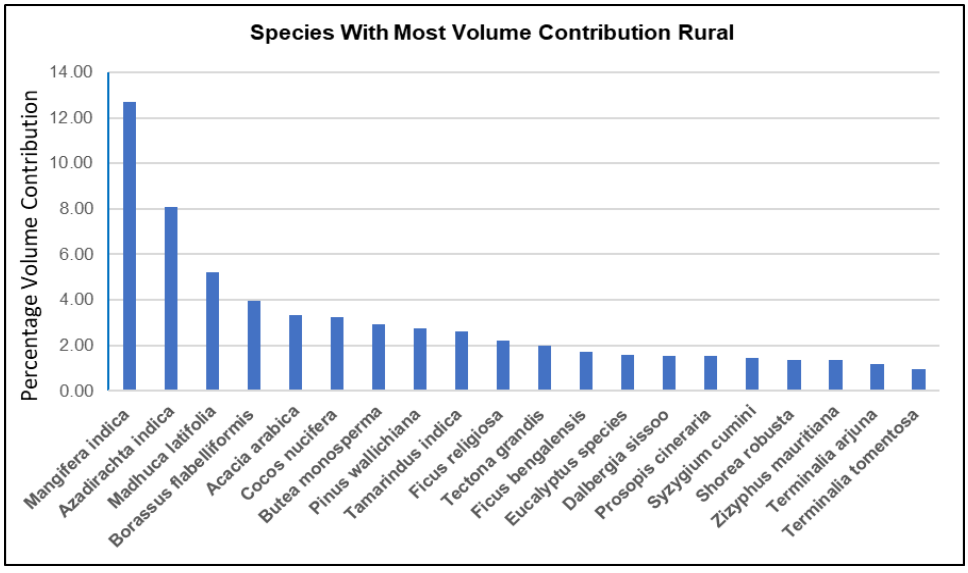

Figure 13: Volume Contribution of 20 Dominant Species in Rural Areas

The rural areas, tree species *Mangifera indica* (Mango) is highest in number (9.50%), followed by *Azadiracta indica* (Neem) (8.13%). In terms of volume also *Mangifera indica* shown the maximum volume (12.7%) followed by *Azaradicta indica* (8.06%). In rural India, Figure 12 and 13 is showing its pictorial depiction. India is dominant with vast coastline having bright sunshine, humid atmosphere and warm climate. These factors have led to dominance of coconut in the coastal areas of the country. Similarly, Mango being a dominant tropical fruit with very high commercial value; is predominant in southern part of India, especially below 23.5 degree latitude i.e. tropic of cancer.

4.6 Species wise distribution of TOF at the National level in Urban Areas

Similar to rural area, the number of trees and volume of top 20 tree species, of different dimeter classes in urban area at the National level are given in table 8 and 9 respectively. Figure 14 and 15 are showing its pictorial depiction. The diameter class distribution of species gives an idea of structure of standing tree species by its corresponding estimated volumetric distribution, and which is an important information for management of the resource.

Table 8: Estimated Number of Trees ('000) in Urban Areas for Top 20 Species

Sl.No	Species	Diameter Class (cm)				
		10-30	30-50	50+	Total	Percent
1	*Cocos nucifera*	53382	10808	30	64220	17.19
2	*Areca catechu*	30878	9	4	30891	8.27
3	*Mangifera indica*	21223	6453	851	28527	7.64
4	*Azadirachta indica*	17979	5452	605	24036	6.43
5	*Hevea brasiliensis*	12009	59	1	12069	3.23
6	*Artocarpus heterophyllus*	9546	2403	90	12039	3.22
7	*Tectona grandis*	10357	1112	27	11496	3.08
8	*Psidium guyava*	7113	26	13	7152	1.91
9	*Eucalyptus species*	4666	1173	88	5927	1.59
10	*Moringa species*	5194	544	19	5757	1.54
11	*Leucaena leucocephala*	5247	209	8	5464	1.46
12	*Prosopis juliflora*	4480	444	15	4939	1.32
13	*Melia azadirachta*	3951	361	10	4322	1.16
14	*Acacia auriculiformis*	3863	318	5	4186	1.12
15	*Swietenia mahagoni*	3830	270	16	4116	1.10
16	*Syzygium cumini*	2875	1100	75	4050	1.08
17	*Anacardium occidentale*	3710	257	3	3970	1.06
18	*Morinda oleifera*	3812	122	4	3938	1.05
19	*Pongamia pinnata*	3309	457	20	3786	1.01
20	*Borassus flabelliformis*	984	2613	19	3616	0.97

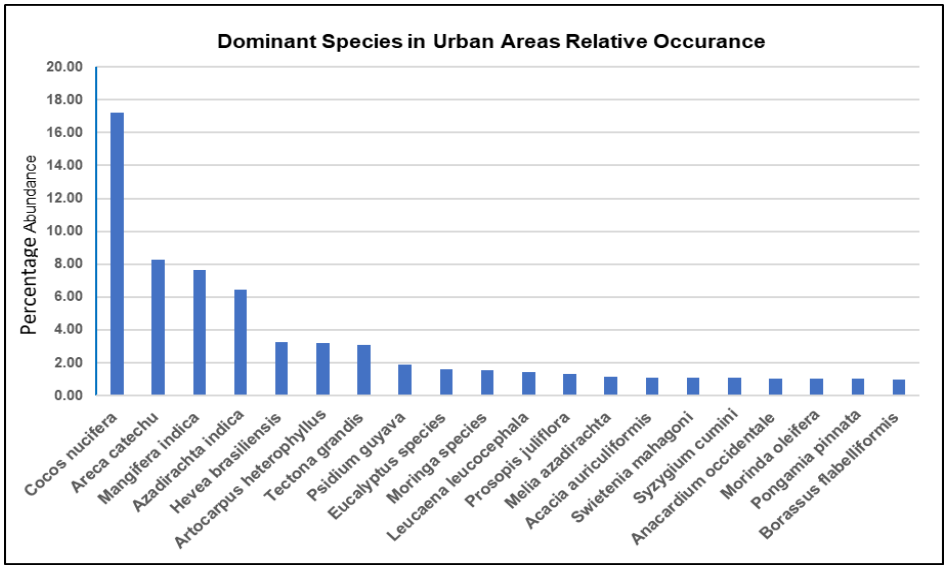

Figure 14: Relative Occurrence of 20 Dominant Species in Urban Areas

Table 9: Estimated Volume (m cum) in Urban Areas for Top 20 Species

Sl.No.	Species	Diameter Class (cm)				
		10-30	30-	50+	Total	Percent
1	*Cocos nucifera*	9.96	3.92	0.08	13.97	13.93
2	*Mangifera indica*	2.98	5.26	3.21	11.45	11.42
3	*Azadirachta indica*	2.44	4.36	2.09	8.89	8.87
4	*Ficus religiosa*	0.19	1.04	4.98	6.21	6.19
5	*Artocarpus*	1.25	1.52	0.28	3.06	3.05
6	*Ficus bengalensis*	0.10	0.51	2.44	3.05	3.04
7	*Tectona grandis*	1.52	0.87	0.11	2.49	2.49
8	*Tecoma stans*	0.01	0.00	2.20	2.21	2.20
9	*Tamarindus indica*	0.19	0.81	1.12	2.12	2.11
10	*Eucalyptus species*	0.58	1.01	0.28	1.87	1.86
11	*Sananea samom*	0.09	0.41	1.22	1.72	1.71
12	*Syzygium cumini*	0.44	0.91	0.27	1.62	1.62
13	*Borassus flabelliformis*	0.19	1.39	0.03	1.61	1.61
14	*Dalbergia sissoo*	0.52	0.63	0.15	1.30	1.30
15	*Hevea brasiliensis*	1.21	0.03	0.00	1.24	1.24
16	*Bombax ceiba*	0.24	0.55	0.35	1.13	1.13
17	*Moringa species*	0.61	0.38	0.06	1.05	1.05
18	*Ficus racemosa*	0.13	0.45	0.42	1.00	1.00
19	*Delonix regia*	0.24	0.58	0.14	0.96	0.96
20	*Ficus virene*	0.07	0.27	0.59	0.94	0.94

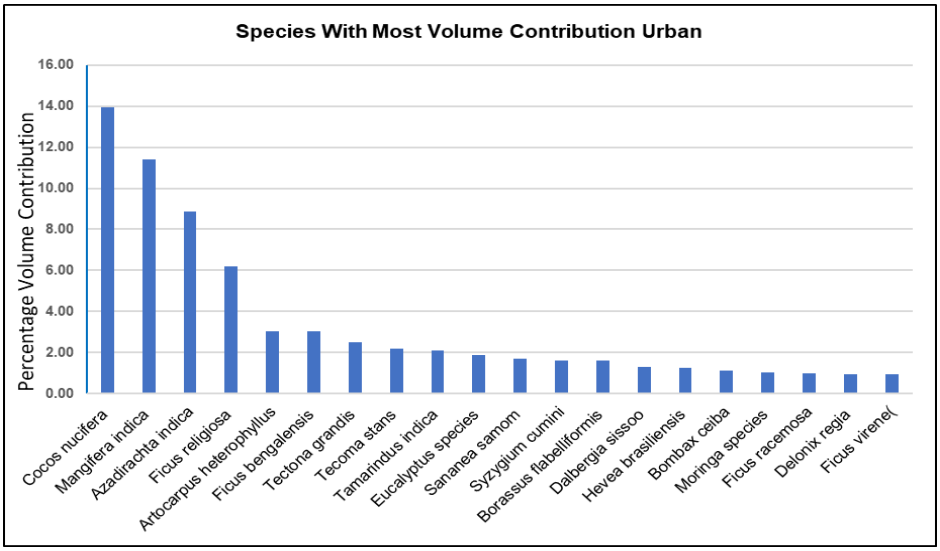

Figure 15: Volume Contribution of Top 20 Dominant Species in Urban Areas

Among, urban tree species, the number of *Cocos nucifera* (Coconut) (17.19 %) is maximum, followed by *Areca catechu* (Palm) of count (8.27%). On the other hand, *Cocos nucifera* (Coconut) is having maximum volume (13.93%), followed by *Mangifera indica* (11.42%) in urban areas.

4.7 Distribution of TOF in Block, Linear and Scattered strata

The plot size for Block and Linear strata is 0.1 ha square plot and 10 m ×125 m strip, respectively. In case of scattered stratum, the plots of size 3.0 ha square in non-hilly areas and 0.5 ha square in hilly areas are laid out. The tree cover of the rural area comprises, area of block and linear patches between 0.1 ha to 1.0 ha. For estimation of tree cover; the area, of block and linear patches are computed from the remote sensing based classification of the TOF for the selected grids. The blocks and linear patches having area more than 1.0 ha are clumped and eliminated as the same has been included in the forest cover. The blocks and linear patches with less than 1.0 ha area are taken for the estimation of tree cover. The total tree cover of the State is obtained by adding the estimated area of block, linear and scattered tree formations.

It is highlighted in table 10 that **'Scattered'** plantations present 61.5 % stratum wise volume followed by **'Block'** plantations, which is 31.74 % of the entire contribution. Therefore, these two strata have more than 90 % of TOF volume of the entire country.

Table 10: Stratum wise distribution of volume in TOF (Rural Areas) in different States /UTs

S.No.	State/UTs	Percent Contribution		
		Block (%)	Linear (%)	Scattered (%)
1	Andhra Pradesh	54.58	0.63	41.22
2	Arunachal Pradesh	82.91	0.00	16.89
3	Assam	66.77	0.14	26.97
4	Bihar	30.45	0.66	65.11
5	Chhattisgarh	30.87	0.18	65.16
6	Delhi	7.02	0.38	3.90
7	Goa	56.40	0.02	16.76
8	Gujarat	11.18	0.29	83.73
9	Haryana	10.70	23.31	57.51
10	Himachal Pradesh	65.19	0.00	31.92
11	J&K and Ladakh *	18.01	0.00	79.96
12	Jharkhand	38.33	0.03	56.09
13	Karnataka	19.03	0.25	78.51
14	Kerala	61.20	0.00	8.28
15	Madhya Pradesh	10.54	0.49	82.23
16	Maharashtra	6.71	0.22	89.49
17	Manipur	74.19	0.73	23.29
18	Meghalaya	75.07	0.00	22.96
19	Mizoram	94.42	0.00	4.12
20	Nagaland	81.87	0.00	16.74
21	Odisha	27.24	0.17	64.67
22	Punjab	16.59	7.87	63.74
23	Rajasthan	7.73	0.34	89.44
24	Sikkim	92.29	0.00	7.13
25	Tamil Nadu	35.73	0.04	49.35
26	Telengana	38.15	0.13	60.32
27	Tripura	84.37	0.00	9.48
28	Uttar Pradesh	38.96	1.95	51.31
29	Uttarakhand	36.23	0.45	55.90
30	West Bengal	2.14	0.60	73.47
31	A & N Islands	82.77	0.00	16.51
32	Chandigarh	13.14	0.00	6.59
33	Dadra & Nagar Haveli	64.69	0.00	30.00
34	Daman & Diu	53.64	0.00	20.44
35	Lakshadweep	62.33	0.00	0.60
36	Puducherry	37.76	0.00	25.99
	Total	**31.74**	**0.65**	**61.50**

** includes J&K and Ladakh area outside LOC that is under illegal occupation of Pakistan and China*

5. Conclusion

TOF play a significant role in the socio-economic lives of people both in rural and urban areas of the country by enriching the people and society at large economically as well as ecologically. The management of TOF assumes high significance in the country for realising much higher potential which it offers in generating wood based economy and ecosystem services including carbon sequestration. Periodic assessment of TOF resources including its spatial distribution is prerequisite for its scientific management in the country. FSI is mandated with this task however there is need for continuous improvement in the methodology and inclusion of more number of variables in the assessment. The organization will have to be further strengthened particularly in terms of man power, to address the emerging information needs on TOF. There has been regular refinement in methodologies in the last three decades to quantify TOF resources using various statistical designs and estimates with better precision. The advancement of technologies in the field of remote sensing, satellite image processing and availability of high resolution satellite data made the methodology much precise and easier. The progression of science may further refine the existing method of TOF assessment in near future.

TOF also act as an important source for timber and fuel wood to meet the demands of fast growing population of the country. There is a need to put focus on increasing the growing stock per hectare or yield of TOF by better management and planning. There is also a need for a separate policy on TOF to ensure its expansion and sustainable management for multiple ecological benefits, timber production, carbon sequestration and for obviating pressure from the natural forests.

Occupying nearly 9% of the geographical area of the country, TOF are significant natural, renewable resource which make vital contribution to the agro-ecology, socio-economy of the rural areas, environmental amelioration in the urban areas and feed wood based industries with the raw material and thus generate significant employment. TOF form a nearly 38% of the carbon sink in forest & tree cover of the country. TOF offers the path for achieving the national policy goal of 33% of forest & tree cover in the country. Through expansion of TOF, particularly in agro-forestry and on culturable waste lands, India can substantially increase its carbon sink to achieve its international commitments of NDC and LDN by 2030.

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Appendix I

Volume equations for prominent tree species in Trees Outside Forest (TOF)

Sl.No.	Name	Volume Equation
1	*Acacia arabica*	$V=-0.048108+5.873169\ D^2$
2	*Areca catechu*	$V=0.0239-0.6266\ D+5.4067\ D^2$
3	*Azadirachta indica*	$V=0.17553-0.71434\ \sqrt{D}+7.94663\ D^2$
4	*Borassus flabelliformis*	$V=0.0239-0.6266\ D+5.4067\ D^2$
5	*Butea monosperma*	$V=0.0417-0.47789\ D+3.50714\ D2+9.76048\ D^3$
6	*Cocos nucifera*	$V=0.0239-0.6266\ D+5.4067\ D^2$
7	*Dalbergia sissoo*	$V=0.00331+0.000636\ D^2*10000$
8	*Eucalyptus species*	$V=0.02894-0.89284\ D+8.72416\ D^2$
9	*Grewia oppositifolia*	$V=0.0418481-1.140567\ D+9.817616\ D^2$
10	*Hevea brasiliensis*	$\sqrt{V}=-0.153973+2.724109\ D$
11	*Leucaena leucocephala*	$V=0.03646-0.91545\ D+7.71869\ D2+1.15753\ D^3$
12	*Madhuca latifolia*	$V=0.074069-1.230020\ D+7.726902\ D^2$
13	*Mangifera indica*	$V=0.108-1.706\ D+7.559\ D^2$
14	*Pinus excelsa*	$V=0.128812-2.285176\ D+11.950158\ D^2$
15	*Populus species*	$V=0.081467-1.063661\ D+6.452918\ D^2$
16	*Prosopis cineraria*	$V=0.17553-0.71434\ \sqrt{D}+7.94663\ D^2$
17	*Prosopis juliflora*	$V=0.081467-1.063661\ D+6.452918\ D^2$
18	*Tectona grandis*	$\sqrt{V}=-0.40589+1.98158\ D+0.987373\ \sqrt{D}$
19	*Terminalia tomentosa*	$\sqrt{V}=-0.203947+3.159215\ D$
20	*Zizyphus mauritiana*	$V=0.076856-1.359767\ D+8.72548\ D^2-0.59144\ D^3$



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