

Chapter

2 | Forest Cover



2.1 Introduction

The forest cover includes all lands which have a tree canopy density of more than ten percent when projected vertically on the horizontal ground, with a minimum areal extent of one hectare. The forest cover reported in the ISFR does not make any distinction between the origin of tree crops (whether natural or man-made) or tree species; and encompasses all types of lands irrespective of their ownership, land use and legal status. Thus, all the tree species along with bamboos, fruit bearing trees, coconut, palm trees etc. and all the areas including forest, private, community or institutional lands meeting the above defined criteria, have been termed as forest cover.

The assessment of forest cover of the entire country is carried out at an interval of two years by interpretation of satellite data. Therefore, the output is directly related to the strengths and limitations of the remote sensing technology. The process involves various steps, viz., image enhancement, registration, interpretation, ground truthing, validation by States Forest Departments, forest cover analysis and final documentation. Present assessment is based on interpretation of IRS Resourcesat-1 P6 LISS-III data pertaining to Oct 2008-Feb 2009 period. Along with mapping of forest cover of entire country thus covering all the States/UTs, forest cover in specific areas such

as Tribal districts, Hill districts and North-Eastern region, has been determined separately. Change in the forest cover has been worked out by comparing the current forest cover assessment with the outcome of previous assessment, i. e. ISFR 2009 after incorporating the interpretational changes therein.

The use of LISS-III sensor data, choice of 1:50,000 map scale and one hectare area as minimum mappable unit is based on various considerations like large areal extent of the country, short periodicity of two years between successive cycles, country level perspective of reporting, limited manpower and technological infrastructure at FSI and spatial scale of the available reference data for geographical reference. All these factors limit the data choice to medium spatial resolution wherein indigenous LISS-III data of 23.5m x 23.5m pixel size is considered as the best option. Taking into account the pixel size of the satellite data and the scale of available topographical reference maps (SOI Topo sheets of 1:50,000), this scale is considered as optimum for forest cover mapping. The minimum mappable area of one ha is a cartographic limit of this map scale corresponding to a discernible polygon of 2mm x 2mm size on the map.

Classification scheme for the purpose of assessment in this report is described as follows:

Very Dense Forest	All lands with tree canopy density of 70% and above
Moderately Dense Forest	All lands with tree canopy density between 40% and 70%
Open Forest	All lands with tree canopy density between 10% - 40%.
Scrub	Degraded forest lands with canopy density less than 10 %.
Non-forest	Area not included in any of the above classes.

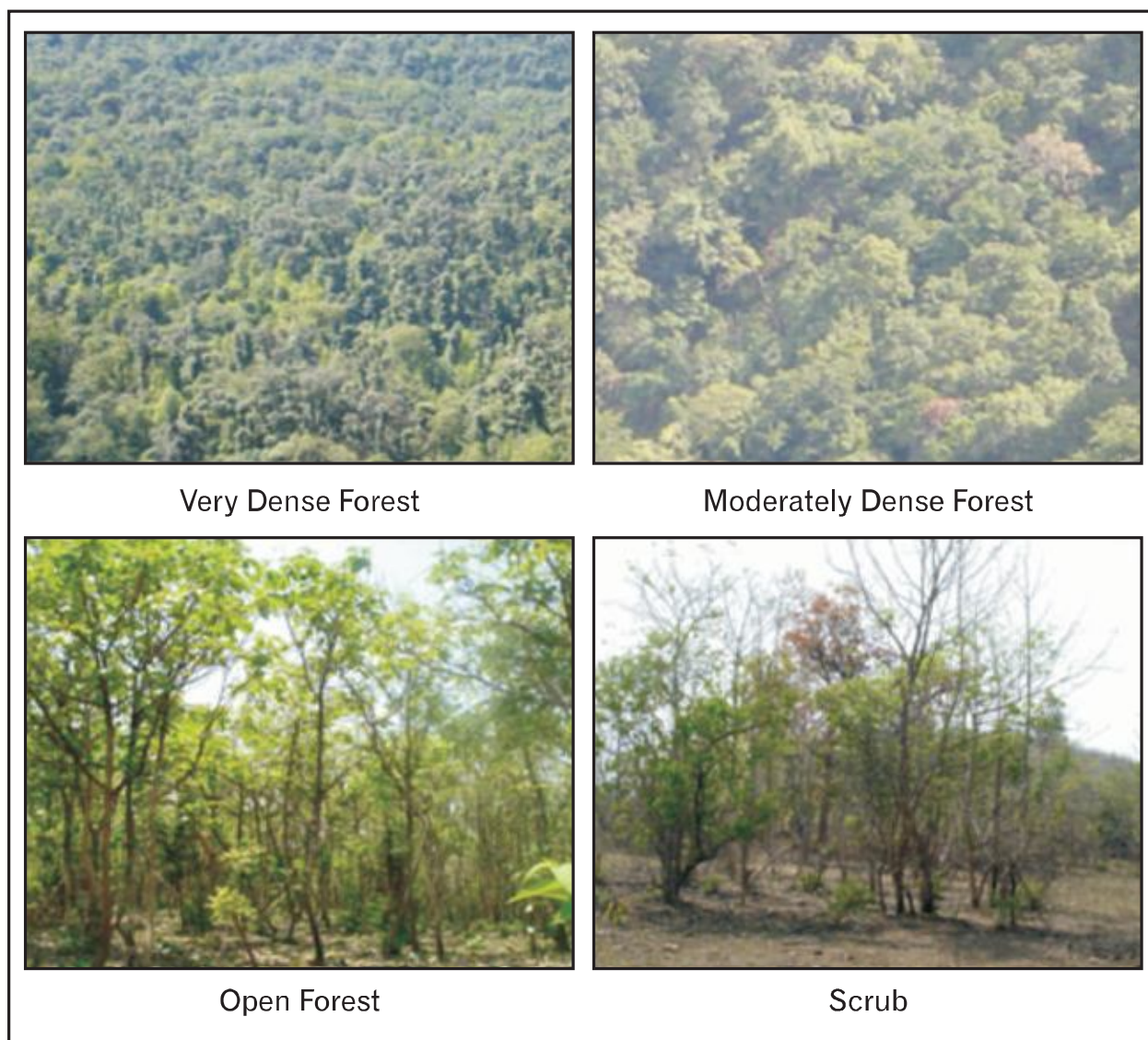


Fig 2.1.1 Different forest density classes and scrub

2.2 Satellite Data Used

The IRS P6 LISS-III satellite data in digital form corresponding to the period Oct 2008-Mar 2009 was procured for the entire country from National Remote Sensing Centre (NRSC), Hyderabad. The LISS-III sensor data has four bands; green and red bands in visible range whereas NIR and SWIR bands in infrared region of the electromagnetic spectrum. The sensor has a spatial resolution of 23.5m x 23.5m and a temporal resolution of 24 days. One LISS-III scene covers about 20,000 km² (141 km x 141 km) on the ground. Adjacent scenes from successive paths have an overlap of 15 to 20 percent. The entire country is covered by 313 LISS-III scenes.

The reflectance from the forests is dependent on the crown foliage and its chlorophyll content. Due to seasonal variability of the tree phenology over the year, season of satellite data acquisition is of utmost importance for forest cover assessment. Deciduous forests allow more reflectance from the ground surface during leafless period thus making their own detection and classification difficult. Hence, data of the spring-summer season is not suitable for interpretation of such forest types. During rainy season, the situation is compounded due to non-availability of cloud-free data and mixing of agricultural and other green covers with forest cover due to similarity in their spectral reflectance. Taking these limitations into consideration, satellite data of the period October to December is considered to be the most suitable for forest cover mapping of the entire country. However, in cases where cloud free data is not available for this period, data of January to March is procured. In case of Lakshadweep, cloud free LISS-III data for all the islands was not available. As an alternative, P6-AWiFS cloud free data with spatial resolution of 56m, was used to fill the

gaps in the wall to wall forest cover mapping of the entire country.

2.3 Methodology

The forest cover mapping exercise is primarily based on digital image processing (DIP) technique and involves a series of steps as shown in the schematic diagram in Figure 2.3.1.

Geometric rectification is an important step in relating image features to the corresponding ground objects and assigning geo-coordinates to the image features that involve appropriate warping, rotating and scaling. In the present ISFR, the geometric rectification of the data has been carried out primarily in reference to the previous cycle geo-referenced imageries to ensure that the successive forest cover maps have a high degree of image to image correspondence from the point of view of mapped features. It has been reinforced by Survey of India topographical maps of 1:50,000 scale, wherever necessary.

The hybrid classification approach followed in forest cover mapping utilizes the capabilities of the algorithms to generate clusters of pixels having close association and then assigning information class i.e. appropriate forest cover density class etc. to each cluster. This is further supported by the interpreter's knowledge, information from collateral sources and the observations made during ground truthing. Since forest cover assessment of previous cycles is available in the FSI archives, this makes a sound basis for successive forest cover classification. The approach followed in the current assessment involves comparison of the current satellite data with the previous forest cover map and examining the discernible changes occurring due to improvement or degradation in the

forest cover. The forest cover has been updated by incorporating the polygons of such changes. Experience has shown that this approach has considerably reduced subjectivity in the image interpretation.

The interpretation work was carried out on 1°x1° SOI topographical sheets. This was followed by extensive field visits for ground truthing. In the current assessment about 1900 number of points were visited by the teams of interpreters who carried out interpretation of the satellite data pertaining

to those mapsheets. The field observations were incorporated in the classified maps highlighting the forest cover changes from the previous cycle assessment. The change maps were then communicated to the State Forest Departments for validation. Feedback received from them helped in incorporating necessary corrections, wherever required. District boundaries are overlaid on sheet-wise forest cover to generate district level forest cover. District estimates have been aggregated to generate State level information on forest cover.

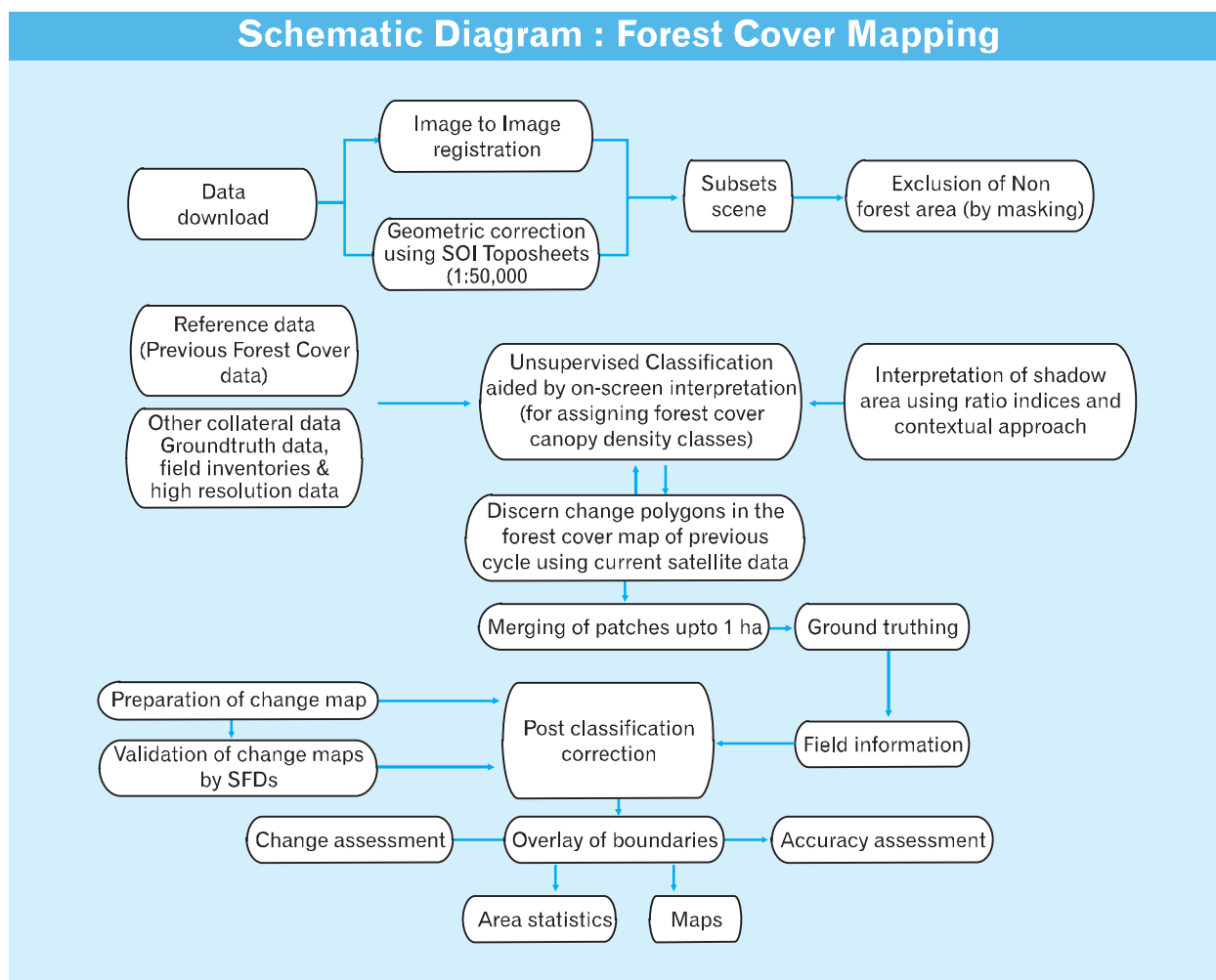


Fig. 2.3.1: Schematic diagram of the methodology followed in forest cover mapping

Biennial Cycle of Forest Cover Mapping: The Rationale

India is among the select few countries of the world carrying out a wall to wall forest cover monitoring on a two year cycle. This work involves the interpretation of over 300 satellite images, each covering about 20,000 km². area. The exercise also includes intensive ground truthing across the length and breadth of the country. The tree cover assessment is a sampling based exercise where data is collected from 10,000 sample plots on a cycle of two years. Keeping in view the purpose of the report, i.e. for policy and planning and the fact that changes in the cover are not likely to be very significant along with the quantum of work involved, the two year cycle is thought to be sufficient.

2.4 Limitations of Satellite Data used in Forest Cover Classification

The remote sensing data has certain inherent limitations that affect the accuracy of the forest cover mapping. Some of these limitations are mentioned below:

Since resolution of the LISS-III sensor data is 23.5 m, the linear strips of forest cover along roads, canals, bunds and railway lines of lesser width are seldom captured and their positional accuracy is not precise.

Young plantations and tree species with less chlorophyll or poor foliage are not discernible on satellite images.

Considerable ground details may be obscured due to clouds and shadows. Such areas are difficult to classify without the help of collateral data or ground truthing.

Gregarious occurrence of weeds like lantana in forest areas and agricultural crops like sugarcane, cotton etc. occurring in the

vicinity of forest area causes mixing of the spectral signatures which often makes precise forest cover delineation difficult.

2.5 Forest Cover: 2011 Assessment

The forest cover of the country has been classified on the basis of tree canopy density into pre-defined classes, viz., very dense forest (VDF), moderately dense forest (MDF) and open forest (OF). Scrub, though shown separately, is not counted in the forest cover. The country level forest cover is summarized in Table 2.5.1, and their proportion is depicted in a pie chart in percentage terms in Fig. 2.5.1 The area under VDF, MDF and OF includes mangrove cover of the corresponding density class.

As per current assessment, total forest cover of the country is 692,027 km² which works out as 21.05% of the geographical area of the country. In terms of density classes, area covered by VDF is 83,471 km² (2.54%), that with MDF is 320,736 km² (9.76%) and OF is 287,820 km² (8.75%).

Table 2.5.1: Forest Cover of India

Class	Area (km ²)	Percent of Geographical Area
Forest Cover		
a) Very Dense Forest	83,471	2.54
b) Moderately Dense Forest	320,736	9.76
c) Open Forest	287,820	8.75

Class	Area (km ²)	Percent of Geographical Area
Total Forest Cover*	692,027	21.05
Scrub	42,176	1.28
Non-forest	2,553,060	77.67
Total Geographical Area	3,287,263	100.00

* Includes 4662 km² area under mangroves

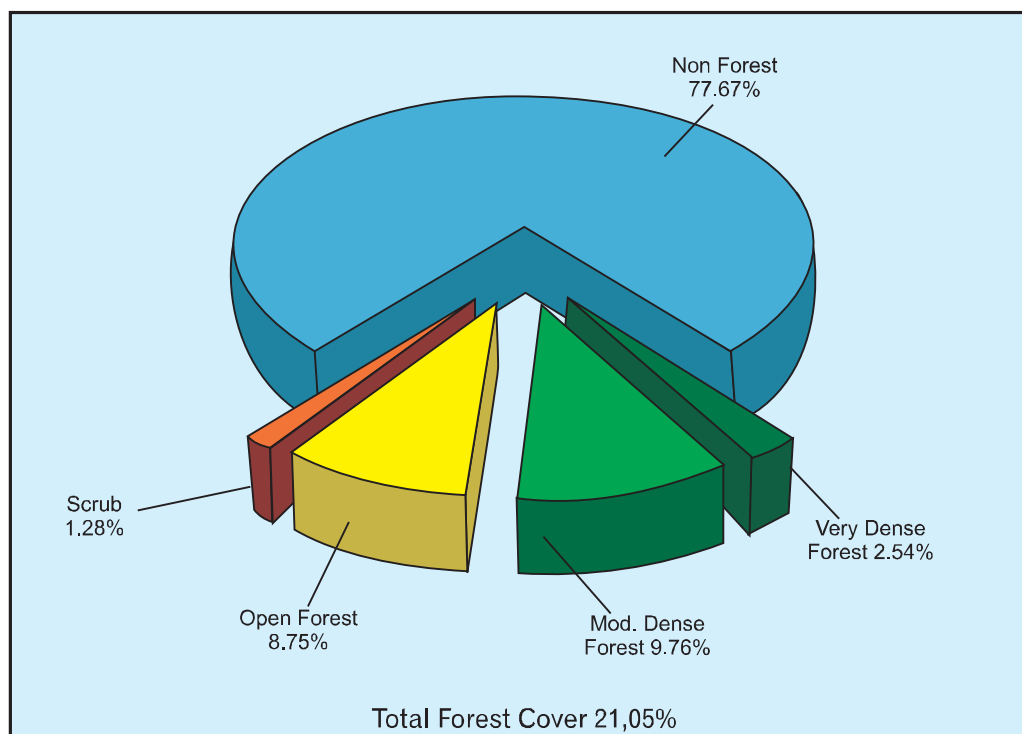


Fig. 2.5.1 : Pie-Chart showing Forest Cover of India

2.6 State/UT-wise Forest Cover

Forest cover of each State and UT of the country has been shown in the Fig. 2.6.1 and presented in the Table 2.6.1. Area-wise, state of Madhya Pradesh has the largest forest cover (77,700 km²) in the country followed by Arunachal Pradesh (67,410 km²), Chhattisgarh (55,674 km²), Maharashtra

(50,646 km²) and Orissa (48,903 km²). In terms of percentage of forest cover with respect to total geographical area, Mizoram with 90.68% has the highest, followed by Lakshadweep (84.56%), Andaman & Nicobar Islands (81.51%), Arunachal Pradesh (80.50%), Nagaland (80.33%), Meghalaya (77.02%) and Tripura (76.07%).

Forest Cover

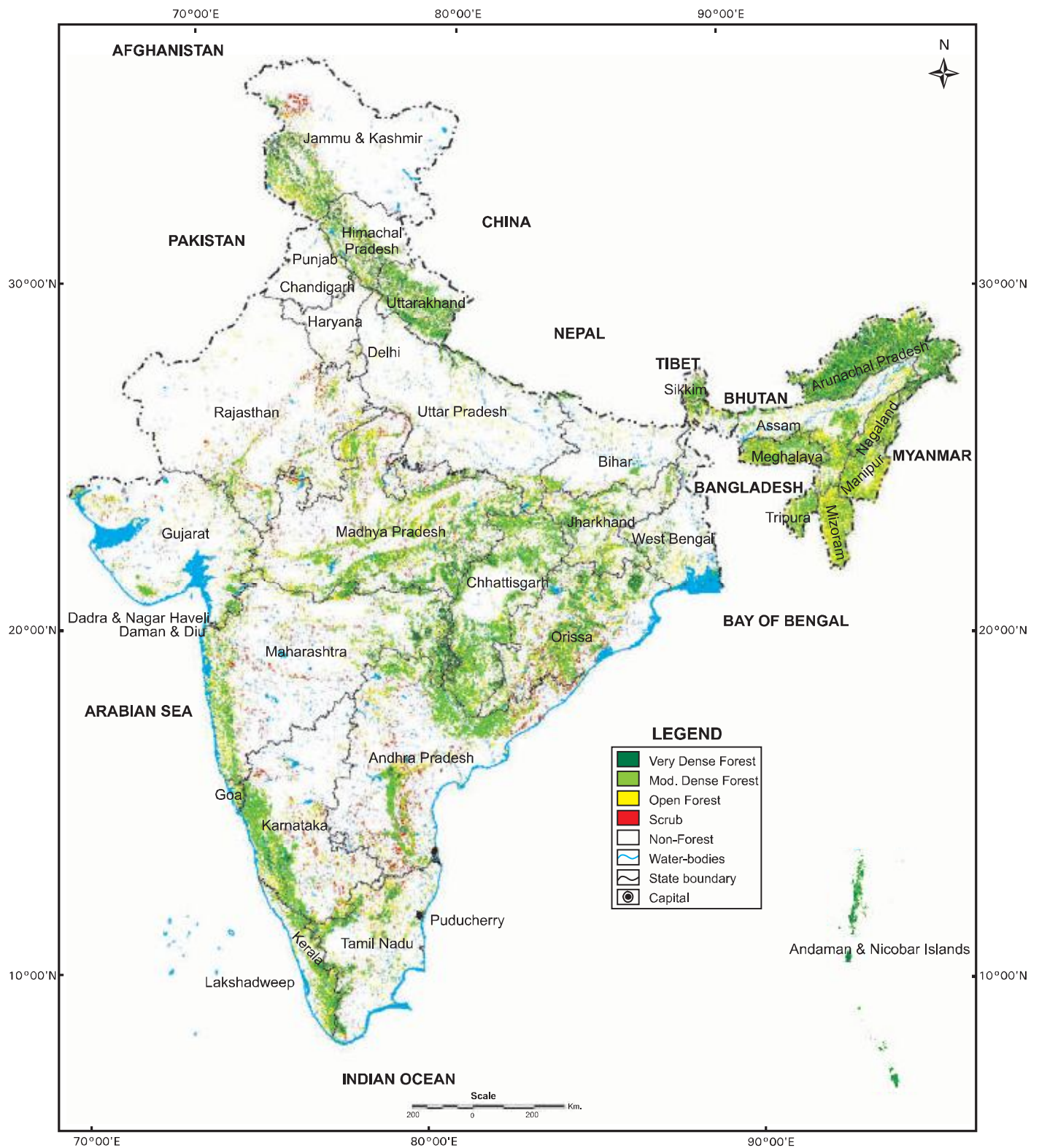


Fig. 2.6.1 Forest Cover Map of India

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State/UT	Geographical Area	2011 Assessment				Forest Cover Reported in ISFR 2009	Interpretational Change	Forest Cover 2009 as Revised (7+8)	Real Change from SFR-09 (6-9)
		Very Dense Forest	Mod. Dense Forest	Open Forest Forest	Total Forest Forest				
1	2	3	4	5	6	7	8	9	10
Andhra Pradesh	275069	850	26242	19297	46389	45102	1568	46670	-281
Arunachal Pradesh	83743	20868	31519	15023	67410	67353	131	67484	-74
Assam	78438	1444	11404	14825	27673	27692	0	27692	-19
Bihar	94163	231	3280	3334	6845	6804	0	6804	41
Chhattisgarh	135191	4163	34911	16600	55674	55870	-192	55678	-4
Delhi	1483	7	49	120	176	177	0	177	0
Goa	3702	543	585	1091	2219	2151	61	2212	7
Gujarat	196022	376	5231	9012	14619	14620	0	14620	-1
Haryana	44212	27	457	1124	1608	1594	0	1594	14
Himachal Pradesh	55673	3224	6381	5074	14679	14668	0	14668	11
Jammu & Kashmir	222236	4140	8760	9639	22539	22686	-149	22537	2
Jharkhand	79714	2590	9917	10470	22977	22894	0	2894	83
Karnataka	191791	1777	20179	14238	36194	36190	0	36190	4
Kerala	38863	1442	9394	6464	17300	17324	0	17324	-24
Madhya Pradesh	308245	6640	34986	36074	77700	77700	0	77700	0
Maharashtra	307713	8736	20815	21095	50646	50650	0	50650	-4
Manipur	22327	730	6151	10209	17090	17280	0	17280	-190
Meghalaya	22429	433	9775	7067	17275	17321	0	17321	-46
Mizoram	21081	134	6086	12897	19117	19240	-57	19183	-66
Nagaland	16579	1293	4931	7094	13318	13464	0	13464	-146
Orissa	155707	7060	21366	20477	48903	48855	0	48855	48
Punjab	50362	0	736	1028	1764	1664	0	1664	100
Rajasthan	342239	72	4448	11567	16087	16036	0	16036	51
Sikkim	7096	500	2161	698	3359	3357	2	3359	0
Tamil Nadu	130058	2948	10321	10356	23625	23338	213	23551	74
Tripura	10486	109	4686	3182	7977	8073	-88	7985	-8
Uttar Pradesh	240928	1626	4559	8153	14338	14341	0	14341	-3
Uttarakhand	53483	4762	14167	5567	24496	24495	0	24495	1
West Bengal	88752	2984	4646	5365	12995	12994	0	12994	1
A & N Islands	8249	3761	2416	547	6724	6662	0	6662	62
Chandigarh	114	1	10	6	17	17	0	17	0
Dadra & Nagar Haveli	491	0	114	97	211	211	0	211	0
Daman & Diu	112	0	0.62	5.53	6	6	0	6	0
Lakshadweep	32	0	17.18	9.88	27	26	0	26	1
Puducherry	480	0	35.37	14.69	50	44	6	50	0
	3287263	83471	320736	287820	692027	690899	1495	692394	-367

* Change in the above Table refers to change in the area with respect to 2009 assessment after incorporating interpretational changes.

2.7 Change in Forest Cover

Continuous technological developments in field of Remote Sensing as also the usage of appropriate Remote Sensing data often leave ample scope for refinement in interpretation carried out earlier on time scale. This is further improved by matching information from the collateral sources with objective to improve upon the previous interpretation of the features which were either masked due to snow/cloud cover or shadows or were not correctly interpreted due to non-availability of remote sensing data of proper season. Even human errors in interpretation, sometimes, contribute to such changes. Besides these, actual changes occurring in ground features are captured in successive assessments by superimposing data pertaining to the periods chosen for comparison and detecting the change polygons. This results into net difference in assessments of forest cover between two periods under consideration. This net difference is, therefore, composed of two separate entities:

1. Interpretational change due to technological/human factors;
2. Real change in forest cover during the intervening period between the two assessments.

2.7.1 Interpretational Change

This change pertains to the areas where the forest cover went undetected due to snow/cloud cover, poor reflectance from trees due to leaf-fall or poor image quality at the time of previous assessment. Sometimes, human error also contributed to the wrong

interpretation for want of correct ground information or data from secondary sources. In the present assessment, considerable use has been made of high resolution data for minimizing the interpretational errors/ascertainment of the ground features. Intensive sheet by sheet monitoring and extensive field visits by the interpretational teams along with collateral information from the state forest departments, have also contributed in rectifying the previous interpretation in some of the areas. The difference with respect to previous assessment which can be purely ascribed to aforementioned interpretational reasons, are termed as interpretational change. At country level, this has accounted for increase in assessment of forest cover to the extent of 1495 km² with respect to previous assessment i.e. ISFR, 2009.

2.7.2 Real Change

Real change in forest cover between the two assessment periods, reflects the actual change on the ground during the intervening period. This has been worked out after making adjustment for the interpretational change in the previous assessment. The real change can be attributed to either management interventions such as harvesting of short rotational plantations, clearances in encroached areas, biotic pressures, shifting cultivation practices etc. After taking into account the interpretational changes, the actual or real change in forest cover between the two assessment periods i.e. 2009-2011 works out to 367 km² on the negative side. This is presented in Table 2.7.1.

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Table 2.7.1: Actual Change in Forest Cover of States/UTs between 2009 and 2011

(Area in km²)

State/UT	Geographical Area	2009 Assessment (as modified)*				2011 Assessment				Change			
		Very Dense Forest	Mod. Dense Forest	Open Forest	Total Forest	Very Dense Forest	Mod. Dense Forest	Open Forest	Total Forest	VDF (7-3)	MDF (8-4)	Open (9-5)	Total (10-6)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Andhra Pradesh	275069	850	26377	19443	46670	850	26242	19297	46389	0	-135	-146	-281
Arunachal Pradesh	83743	20873	31574	15037	67484	20868	31519	15023	67410	-5	-55	-14	-74
Assam	78438	1461	11558	14673	27692	1444	11404	14825	27673	-17	-154	152	-19
Bihar	94163	231	3248	3325	6804	231	3280	3334	6845	0	32	9	41
Chhattisgarh	135191	4163	34911	16604	55678	4163	34911	16600	55674	0	0	-4	-4
Delhi	1483	6.76	49.84	119.98	176.58	6.76	49.48	119.96	176.2	0	-0.4	-0	0
Goa	3702	543	578	1091	2212	543	585	1091	2219	0	7	0	7
Gujarat	196022	376	5249	8995	14620	376	5231	9012	14619	0	-18	17	-1
Haryana	44212	27	463	1104	1594	27	457	1124	1608	0	-6	20	14
Himachal Pradesh	55673	3224	6383	5061	14668	3224	6381	5074	14679	0	-2	13	11
Jammu & Kashmir**	222236	4140	8760	9637	22537	4140	8760	9639	22539	0	0	2	2
Jharkhand	79714	2590	9899	10405	22894	2590	9917	10470	22977	0	18	65	83
Karnataka	191791	1777	20181	14232	36190	1777	20179	14238	36194	0	-2	6	4
Kerala	38863	1443	9410	6471	17324	1442	9394	6464	17300	-1	-16	-7	-24
Madhya Pradesh	308245	6647	35007	36046	77700	6640	34986	36074	77700	-7	-21	28	0
Maharashtra	307713	8739	20834	21077	50650	8736	20815	21095	50646	-3	-19	18	-4
Manipur	22327	701	5474	11105	17280	730	6151	10209	17090	29	677	-896	-190
Meghalaya	22429	410	9501	7410	17321	433	9775	7067	17275	23	274	-343	-46
Mizoram	21081	134	6149	12900	19183	134	6086	12897	19117	0	-63	-3	-66
Nagaland	16579	1274	4897	7293	13464	1293	4931	7094	13318	19	34	-199	-146
Orissa	155707	7073	21394	20388	48855	7060	21366	20477	48903	-13	-28	89	48
Punjab	50362	0	733	931	1664	0	736	1028	1764	0	3	97	100
Rajasthan	342239	72	4450	11514	16036	72	4448	11567	16087	0	-2	53	51
Sikkim	7096	500	2161	698	3359	500	2161	698	3359	0	0	0	0
Tamil Nadu	130058	2926	10343	10282	23551	2948	10321	10356	23625	22	-22	74	74
Tripura	10486	109	4702	3174	7985	109	4686	3182	7977	0	-16	8	-8
Uttar Pradesh	240928	1626	4563	8152	14341	1626	4559	8153	14338	0	-4	1	-3
Uttarakhand	53483	4762	14165	5568	24495	4762	14167	5567	24496	0	2	-1	1
West Bengal	88752	2987	4644	5363	12994	2984	4646	5365	12995	-3	2	2	1
A & N Islands	8249	3762	2405	495	6662	3761	2416	547	6724	-1	11	52	62
Chandigarh	114	1	10	6	17	1.35	9.55	5.88	16.78	0.35	-0.4	-0.1	-0.22
Dadra & Nagar Haveli	491	0	114	97	211	0	114	97	211	0	0	0	0.00
Daman & Diu	112	0	0.62	5.03	5.65	0	0.62	5.53	6.15	0	0	0.5	0.50
Lakshadweep	32	0	16.71	9.77	26.48	0	17.18	9.88	27.06	0	0.47	0.11	0.58
Puducherry	480	0	34.1	15.87	49.97	0	35.37	14.69	50.06	0	1.27	-1.2	0.09
	3287263	83428	320238	288728	692394	83471	320736	287820	692027	43	498	-908	-367

*Assessment of forest cover made in 2009 as modified after incorporating the interpretational changes.

**Includes Jammu & Kashmir area outside LOC that is under illegal occupation of Pakistan and China.

Table 2.7.1 gives the change in forest cover for all the States/UTs in all the three canopy density classes. The overall change at the country level as compared to the previous assessment of 2009, after making adjustment for interpretational changes, works out to 367 km² on the negative side. The States/UTs which have shown positive changes are Punjab (100 km²), Jharkhand (83 km²), Tamil Nadu (74 km²), Andaman & Nicobar (62 km²), Rajasthan (51 km²) and Orissa (48 km²), whereas states like Andhra Pradesh (281 km²), Manipur (190 km²), Nagaland (146 km²), Arunachal Pradesh (74 km²), Mizoram (66 km²), Meghalaya (46 km²) have shown negative changes. At the country level, there

is net improvement of 43 km² in very dense forest and 498 km² in moderately dense forest category. Open forest area has reduced by 908 km².

2.8 Reasons for Change

During the course of ground truthing of the change areas, efforts have been made to ascertain the reasons for change in forest cover in the States/UTs. Based on the information collected by the FSI officials in consultation with the field officials of the State Forest Departments (SFD), main reasons for aforesaid changes are summarized in Table 2.8.2.

Table 2.8.1 Reasons for Change

Andhra Pradesh	Management interventions like harvesting of short rotation crops followed by new regeneration/plantations, forest clearances in some encroached areas.
Andaman and Nicobar Islands	Recovery of coastal vegetation in Tsunami affected areas, shelterbelt plantations and increase in mangrove cover.
Arunachal Pradesh	Change in forest cover in the state is because of shifting cultivation and biotic pressure.
Assam	Decrease in forest cover is mainly attributed to illicit felling, encroachments in insurgency affected areas and shifting cultivation practices.
Bihar	Enhanced plantation activity outside forest areas in recent times contributed towards increase in forest cover.
Chhattisgarh	Submergence of forest areas in catchments of the dams.
Jharkhand	Increase in forest cover is mainly on account of effective protection by the Village Forest Protection Committees and plantation activities undertaken in the state.
Manipur	Decrease in forest cover in the state is due to shortening of shifting cultivation cycle and biotic pressure.
Meghalaya	Decrease in forest cover in the state is due to shortening of shifting cultivation cycle and biotic pressure.
Mizoram	Decrease in forest cover in the state is due to shortening of shifting cultivation cycle and biotic pressure.
Nagaland	Decrease in forest cover in the state is due to shortening of shifting cultivation cycle and biotic pressure.
Orissa	Main reason for the increase in forest cover is due to effective protection by the JFM committees and regeneration of shifting cultivation areas.
Punjab	Growth of young plantations carried out under externally aided Project and Agro-forestry activities in TOF areas.
Rajasthan	Regeneration in forest areas and extensive plantation activities.
Tamil Nadu	Regeneration in forest areas and extensive plantation activities in and outside forests.

The change matrix given in Table 2.8.2 throws light on the change dynamics in various density classes as also in scrub areas between the intervening period of two successive assessments (2009 and 2011). Current assessment reveals that there is an

improvement with 311 km² MDF and 20 km² OF to VDF category whereas an improvement of 2929 km² OF to MDF is reported. Likewise, there is a shift of 229 km² and 21 km² from VDF to MDF and OF categories respectively.

Table 2.8.2: Forest Cover Change Matrix for India between 2009 and 2011.

(Area in km²)

Class	VDF	MDF	OF	Scrub	NF	Total ISFR 2009
Very Dense Forest	83133	229	21	0	45	83428
Moderately Dense Forest	311	316054	1903	81	1888	320238*
Open Forest	20	2929	281917	455	3406	288728
Scrub	0	82	488	41305	175	42050
Non-Forest	7	1442	3491	335	2547545	2552820
Total ISFR 2011	83471	320736	287820	42176	2553060	3287263*
Net change	43	498	-908	126	240	

*Difference in the totals is due to rounding off decimals.

2.9 Forest Cover in Hill Districts

National Forest Policy (1988) aims at maintaining two third of the geographical area in hills of the country under forest and tree cover. Keeping this in view, forest cover in the hills of the country are presented separately. For this purpose, hill districts as identified by the Planning Commission for

Hill Areas and Western Ghats Development Programme are taken into consideration for forest cover analysis thereof. In all, there are 124 hill districts as marked by superscript 'H' in the district-wise Tables of forest cover in Chapter 9. Table 2.9.1 gives a state-wise summary of forest cover in the hill districts of the country.

Table 2.9.1: Forest Cover in Hill Districts

(Area in km²)

State/UT	No. of Hill Districts	Geo. Area	Forest Cover				% of G.A.	Change*	Scrub
			Very Dense Forest	Mod. Dense Forest	Open Forest	Total Forest			
Arunachal Pradesh	13	83743	20868	31519	15023	67410	80.50	-74	122
Assam	3	19153	741	5725	6519	12985	67.80	-18	33
Himachal Pradesh	12	55673	3224	6381	5074	14679	26.37	11	328
Jammu & Kashmir	(a)14	101388	2814	6289	6953	16056	15.84	1	295
	(b)**	120848	1326	2471	2686	6483	5.36	1	1810
Karnataka	6	48046	1492	14920	6788	23200	48.29	0	506
Kerala	10	29572	1105	7305	5277	13687	46.28	-13	52
Maharashtra	7	69905	318	7237	7947	15502	22.18	-6	1384

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States/UTs	No. of Hill Districts	Geo. Area	Forest Cover				% of G.A.	Change*	Scrub
			Very Dense Forest	Mod. Dense Forest	Open Forest	Total Forest			
Manipur	9	22327	730	6151	10209	17090	76.54	-190	1
Meghalaya	7	22429	433	9775	7067	17275	77.02	-46	485
Mizoram	8	21081	134	6086	12897	19117	90.68	-66	1
Nagaland	8	16579	1293	4931	7094	13318	80.33	-146	3
Sikkim	4	7096	500	2161	698	3359	47.34	0	363
Tamil Nadu	5	22789	962	3370	2040	6372	27.96	5	210
Tripura	4	10486	109	4686	3182	7977	76.04	-8	72
Uttarakhand	13	53483	4762	14167	5567	24496	45.80	1	271
West Bengal	1	3149	714	663	912	2289	72.69	0	0
Grand Total (2011)	124	707,747	41,525	133,837	105,933	281,295	39.74	-548	5936

* The change in the above Table refers to change in the area with respect to 2009 assessment after incorporating interpretational changes.

** Refers to area outside LOC that is under illegal occupation of Pakistan and China.

The forest cover in the hill districts of the country is 281,295 km², which is 39.74% of the total geographical area of these districts. Though, as per the definition of the hill districts, entire geographical area of these districts does not constitute the hilly terrain but the forest cover shown in the above table does provide a good basis to frame the policy guidelines. All districts of the States of Arunachal Pradesh, Himachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and Uttarakhand are hill districts. The percentage of forest cover in these nine states is 63.07% of their geographical area.

After incorporating the interpretational changes in previous forest cover assessment, current assessment shows a decrease of 548 km² in all the hill districts of the country put together.

2.10 Forest Cover in Tribal Districts

Tribal communities have lived in a symbiotic relationship with forest through ages. Forests play a very significant role in tribal economy and all their socio-cultural practices are woven around forests. As such, it is very important to monitor and analyze the forest cover situation in the tribal areas. In this section, an overview of forest cover in the tribal districts of the country has been presented. In all, there are 188 tribal districts in 26 States/UTs as identified by the Government of India under the Integrated Tribal Development Programme (marked with superscript 'T') in the district-wise Table of forest cover in Chapter 9. Table 2.10.1 presents a summary of forest cover in tribal districts of the country.

State/UT	No. of Tribal Districts	Geo. Area	Forest Cover 2011				% of GA	Change*	Scrub
			Very Dense Forest	Mod. Dense Forest	Open Forest	Total Forest			
Andhra Pradesh	8	87,090	239	16,613	8,449	25,301	29.05	-266	2,368
Arunachal Pradesh	13	83,743	20,868	31,519	15,023	67,410	80.50	-74	122
Assam	16	50,137	648	4,599	6,749	11,996	23.93	-12	93
Chhattisgarh	9	92,656	3,614	24,477	11,966	40,057	43.23	-3	89
Gujarat	8	48,409	322	2,944	3,500	6,766	13.98	-1	393
Himachal Pradesh	3	26,764	950	1,067	1,214	3,231	12.07	0	139
Jharkhand	8	44,413	1,677	6,067	6,218	13,962	31.44	73	341
Karnataka	5	26,597	1,248	7,642	4,249	13,139	49.40	0	55
Kerala	9	27,228	1,073	7,017	5,006	13,096	48.10	-13	52
Madhya Pradesh	18	139,448	5,639	20,275	16,387	42,301	30.33	-11	2,097
Maharashtra	11	138,272	7,275	11,389	10,848	29,512	21.34	3	2,127
Manipur	9	22,327	730	6,151	10,209	17,090	76.54	-190	1
Meghalaya	7	22,429	433	9,775	7,067	17,275	77.02	-46	485
Mizoram	8	21,081	134	6,086	12,897	19,117	90.68	-66	1
Nagaland	8	16,579	1,293	4,931	7,094	13,318	80.33	-146	3
Orissa	12	86,124	5,268	14,442	13,588	33,298	38.66	-1	2,552
Rajasthan	5	38,218	0	2,442	3,907	6,349	16.61	1	941
Sikkim	4	7,096	500	2,161	698	3,359	47.34	0	363
Tamil Nadu	6	30,720	697	2,392	3,653	6,742	21.95	18	404
Tripura	4	10,486	109	4,686	3,182	7,977	76.04	-8	72
Uttar Pradesh	1	7,680	409	475	435	1,319	17	-1	1
West Bengal	11	69,403	2,962	4,475	4,863	12,300	17.72	1	28
A&N Islands	2	8,249	3,761	2,416	547	6,724	81.51	62	57
Dadra & Nagar Haveli	1	491	0	114	97	211	42.97	0	1
Daman & Diu	1	72	0	1	3	4	5.03	0	0
Lakshadweep	1	32	0	17	10	27	84.56	1	0
Grand Total	188	1,105,744	59,849	194,173	157,859	411,881	37.25	-679	12,785

* The change in the above Table refers to change in the area with respect to 2009 assessment after incorporating interpretational changes.

NB Figures are rounded off to the nearest digits.

The total forest cover in the tribal districts is 411,881 km², which is 37.25% of the geographical area of these districts. After incorporating the interpretational changes in previous forest cover assessment, current assessment shows a decrease of 679 km² in all the tribal districts of the country put together.

2.11 Forest Cover in the North-Eastern States

North-eastern region of the country comprising eight states, namely; Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, is endowed with rich forest resources. The region, which constitutes only 7.98% of the

geographical area of the country, accounts for nearly one fourth of its forest cover. Because of its biodiversity richness, the region has been identified as one of the 18 biodiversity hot spots of the world. One distinct feature of land use is the prevalence of shifting cultivation in hilly parts of almost all the states of this region. Shifting cultivation has traditionally been the main source of livelihood of the tribal people and is intricately linked to their socio-cultural life.

The total forest cover in the region is 173,219 km², which is 66.07% of its geographical area

in comparison to the national forest cover of 21.05%. Very dense, moderately dense and open forests constitute 14.73%, 44.29% and 40.98% respectively. After incorporating the interpretational changes in previous forest cover assessment, current assessment shows an actual decrease of forest cover to the extent of 549 km² in the north-eastern region. The main reason for this decrease is attributed to the biotic pressure and shifting cultivation in the region. State-wise forest cover in the region, along with the changes as compared to the previous assessment is shown in Table 2.11.1.

State/UT	Geographical Area	Forest Cover 2011				% of GA	Change*	Scrub
		Very Dense Forest	Mod. Dense Forest	Open Forest	Total			
Arunachal Pradesh	83,743	20,868	31,519	15,023	67,410	80.50	-74	122
Assam	78,438	1,444	11,404	14,825	27,673	35.28	-19	182
Manipur	22,327	730	6,151	10,209	17,090	76.54	-190	1
Meghalaya	22,429	433	9,775	7,067	17,275	77.02	-46	485
Mizoram	21,081	134	6,086	12,897	19,117	90.68	-66	1
Nagaland	16,579	1,293	4,931	7,094	13,318	80.33	-146	3
Sikkim	7,096	500	2,161	698	3,359	47.34	0	363
Tripura	10,486	109	4,686	3,182	7,977	76.04	-8	72
Grand Total	262,179	25,511	76,713	70,995	173,219	66.07	-549	1,229

* Change in the above table refers to change in the forest cover after incorporating the interpretational changes in assessment 2009.

2.12 Forest Cover in Different Altitude Zones

Forest cover in higher altitudes has special ecological significance. Therefore, information on distribution of forest cover in different altitude zones is useful from policy and planning perspective for hill States. In the ISFR 2009, Digital Elevation Model from data of Shuttle Radar Topography Mission (2006) was generated to determine forest cover in different altitude zones in all the States and

UTs. The altitude zones for the purpose of analysis were taken as 0-500m, 500-1000m, 1000-2000m, 2000-3000m and above 3000 meters. The Digital Elevation Model (DEM) used in the analysis has a resolution of 90m, which is appropriate for national/sub-national level information of this kind. In the current cycle, same approach has been followed. Altitude zone wise forest cover of the country is given in Table 2.12.1. The state-wise information has been given in the respective sections of Chapter 9.

Table 2.12.1: Forest Cover in Altitude Zones (Area in km²)

Altitude Zone	VDF	MDF	OF	Total	% of Total FC	% of GA* of Zone
0-500m	29138	156877	171345	357360	51.64	15.57
500-1000m	21667	98472	78156	198295	28.65	33.85
1000-2000m	14609	37266	24559	76434	11.04	72.42
2000-3000m	14275	19231	7141	40647	5.87	66.33
Above 3000m	3782	8890	6619	19291	2.79	8.04
Total	83471	320736	287820	692027	100	21.05

* Zone-wise geographical area worked out on the basis of SRTM DEM.

2.13 Area above 4000 meter Altitude

Vegetation cover is commonly observed below an altitude level usually defined by a boundary called tree line. However, there is no fixed altitudinal height for the existence of this line. A sizeable part of the country's area lies in high altitude mountainous region under permanent snow/glaciers, steep slopes and rocks which are very difficult for tree growth due to severe climatic and topographical

constraints. Although, some forest patches have been observed beyond 4000m altitude, these are considered exceptions. If the areas above this altitude are considered incapable of supporting forest growth and are excluded from rest of the geographical area of the respective state, the percentage-wise forest cover of hilly states shall go up. This has been worked out in Table 2.13.1. At the country level, the forest and tree cover would go up to 25.22% after excluding the area above 4000m.

Table 2.13.1: Forest Cover in Hill States above 4000 meters Altitude (Area in km²)

States	Geographical Area (GA)	Geographical Area		Forest & Tree Cover	Forest & Tree Cover % after exclusion of area above 4000m
		Above 4000m	Below 4000m		
Arunachal Pradesh	83743	6514	77229	67902	87.92
Himachal Pradesh	55673	21119	34554	15291	44.25
Jammu & Kashmir	222236	141313	80923	29236	36.13
Sikkim	7096	3161	3935	3382	85.95
Uttarakhand	53483	11028	42455	25137	59.21
Total	422231	183135	239096	140948	58.95

2.14 Forest Cover in Different Forest Types

Forest type maps provide a basis for characterizing forests in terms of floristic

composition and ecological value. Recently, FSI has completed mapping of forest types of India, based on Champion & Seth classification (1968) on 1:50,000 scale. In this first ever attempt at the national level,

extensive study in GIS framework using the relevant layers like soil, rainfall, temperature along with the remote sensing data, details from the working plans, thematic maps of FSI, inventory information etc. was carried out. The exercise involved extensive ground truthing, covering the entire country. 178 types were discerned on satellite images

which were also duly checked on the ground. The district-wise forest type maps of the entire country have been prepared. Using the forest type maps, distribution of forest cover in different forest types has been determined for the country. In this ISFR, information is being presented up to the type group level in Table 2.14.1.

Table 2.14.1: Forest Cover in Different Forest Type Groups

Group	% of Forest Cover
Group 1- Tropical Wet Evergreen Forest	2.92
Group 2- Tropical Semi-Evergreen Forest	13.79
Group 3- Tropical Moist Deciduous Forest	19.73
Group 4- Littoral and Swamp Forest	0.69
Group 5-Tropical Dry Deciduous Forest	41.87
Group 6- Tropical Thorn Forest	2.25
Group 7- Tropical Dry Evergreen Forest	0.13
Group 8- Subtropical Broadleaved Hill Forest	2.69
Group 9- Subtropical Pine Forest	2.63
Group 10- Subtropical Dry Evergreen Forest	0.03
Group 11- Montane Wet Temperate Forest	0.69
Group 12- Himalayan Moist Temperate Forest	4.12
Group 13- Himalayan Dry Temperate Forest	0.84
Group 14, 15, 16- Sub Alpine and Alpine Forest	2.55
Plantation/TOF	5.07
Total	100.00

Note: Difference in tabulated information with that reported in ISFR 2009, is primarily due to the reason that earlier table was based on quantification of forest types as per their zonation shown in pictorial/diagrammatic presentation by Champion and Seth in their classical book on 'Forest Types of India'. However, information in the present table is given as per actual assessment work carried out by FSI for a national project under NNRMS. Based on this study, National Atlas on Forest Types of India is published by FSI

2.15 Mapping of Coral Reefs using Remote Sensing Data

Reef ecosystems are the oldest and most diverse shallow water ecosystems in the sea. Reefs protect shorelines and store carbon and calcium in the form of carbonates. Reefs are very sensitive to environmental conditions.

Changes in coral health and vitality (disease, algal overgrowth, bleaching etc.) may be more sensitive indicators of changing environmental conditions. The coral provides shelter for many animals in this complex habitat, including sponges, nudibranchs, fish (like Blacktip Reef Sharks, groupers, clown fish, eels, parrotfish, snapper and scorpion

fish), jellyfish, anemones, sea stars (including the destructive Crown of Thorns), crustaceans (like crabs, shrimp and lobsters), turtles, sea snakes, snails and molluscs (like nautilus and clams).

Despite proximity to the coastal areas, coral reefs are relatively inaccessible for observations and present significant technical challenges in the design of an observing strategy. Among the physical challenges, waves, currents and the complex forms of reefs make coastal waters a challenging environment for mapping, research or monitoring. Coral reefs are often remote, relatively large and shallow. Therefore, optical remote sensing techniques can provide an efficient and cost effective approach to map and monitor the condition of coral reefs. Coral reef maps can provide specific information about extent and area to environmentalists and user

community in developing effective management plans. To generate coral reef maps of the four locations viz. Lakshadweep, Gulf of Kachchh, Gulf of Mannar and Andaman & Nicobar Islands, the Ministry of Environment and Forests, Govt. of India sanctioned a project to Forest Survey of India, Dehradun in the year 2003 titled Assessment, Mapping and Monitoring of Coral Reefs along the Coastal Regions of India using Remote Sensing and GIS.

Mapping of coral reefs in the four regions and preparation of digital maps of Coral Reefs on 1:50,000 scale and coral reef Atlas has been completed using LISS III data. Andaman & Nicobar reefs have been mapped using Quick Bird data and digital maps have been prepared on a higher scale. GIS for Gulf of Mannar National Park (GOMNP) of 21 islands has been developed.

Region-wise area of different classes are given in following tables:

Lakshadweep		
S. No.	Class Name	Area Km ²
1	Shallow Lagoon	107.15
2	Deep Lagoon	135.88
3	Inlet	0.48
4	Lagoonal Patch Reef	1.60
5	Beach/Exposed Sand	9.78
6	Lagoon(Shallow Sandy)	110.21
7	Sea Grass/Algae	9.77
8	Boulders/Dead Corals	7.31
9	Live Corals Zone (Open/Scattered)/Aligned Coral Zone	29.77
10	Live Corals Zone (Dense)/Aligned Coral Zone	7.24
11	Coralline shelf	118.00
12	Live Corals Zone (Deep Lagoon)	57.17
13	Live Corals Zone (Intermediate Depth)	4.48
14	Coral Knolls	2.47
15	Reef Front(Live Corals)	3.48

Gulf of Kachchh		
S. No.	Class Name	Area Km ²
1	Turbid Water	7.62
2	Mud	90.01
3	Sand	13.13
4	Matty Algae	3.82
5	Algae with Mud and Sand	30.04
6	Inner Reef (Live Corals with Algae)	77.11
7	Outer Reef (Live Corals with Algae)	26.77
8	Algal Ridge(Live Corals with Algae)	14.81
9	Sea Grass/Algae	5.74
10	Live Corals (More than 80%)	16.25
11	Deep Water Live corals	5.46
12	Dead Corals with Sand and Algae	1.01
13	Dead Corals	2.28
14	Sandy Substrate	2.52
15	Reef Slope (No Live Corals)	0.19
16	Windward Reef Front	3.60

Forest Cover

Gulf of Mannar		
S. No.	Class Name	Area Km ²
1	Sand	1.65
2	Sandy Substrate	18.56
3	Sandy Substrate Deep	34.12
4	Sea Grass	11.16
5	Rubbles Zone	1.01
6	Live Corals Zone with Sea Grass	9.15
7	Dead Corals	2.45
8	Windward Reef Front	3.22
9	Algal Ridge	0.32

Andaman & Nicobar Islands		
S. No.	Class Name	Area Km ²
1	Sandy Beach	16.71
2	Sandy Substrate(<5 m)	49.07
3	Sandy Substrate Deep (>5 m)	67.23
4	Rocks with Sandy Substrate	25.52
5	Live Corals with Rocks	5.74
6	Live Corals with Sand	3.12
7	Exposed Rocky Land	5.20
8	Sea Grass	0.04
9	Dead Corals	0.12

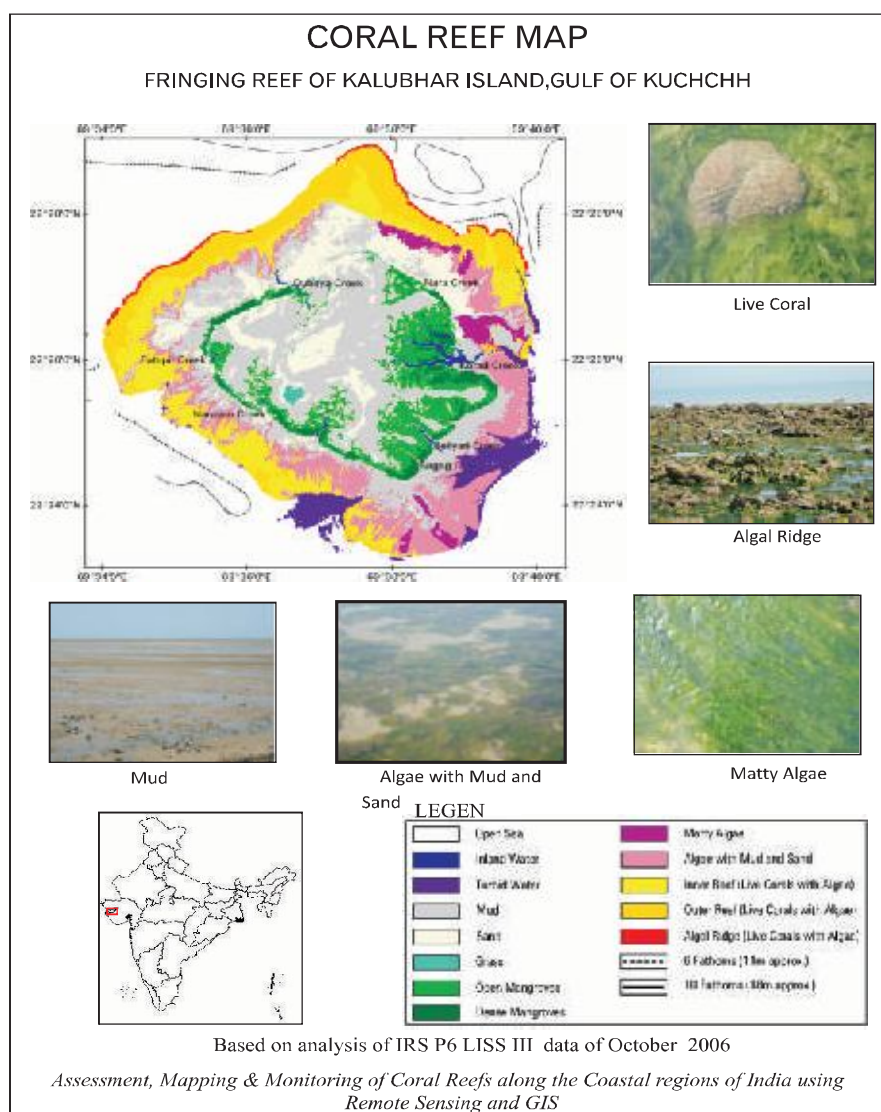


Fig. 2.15.1 Map of Kalubhar Island.

2.16 Accuracy Assessment of Forest Cover

The remote sensing based forest cover classification is subject to errors in interpretation and classification due to limitation of spatial, spectral, temporal and radiometric resolutions. In addition, errors also creep in on account of cloud or shadow effects, or seasonal variation in the canopy of deciduous trees or bushy and agricultural vegetation getting mixed with forest crop etc. Combined together, all these errors influence the accuracy of assessment while classifying the remote sensing data.

For assessing the accuracy of classification based on remote sensing data, generally an error matrix (also termed as confusion matrix) is prepared by comparing agreement and disagreement between remote sensing derived classification with the reference data (ground truth) on a class-by-class basis at randomly selected locations. Error matrix is an array of numbers arranged in rows (generally map classification) and columns (generally ground truth). It is a square matrix as both numbers of rows and columns are equal, representing different classes (VDF, MDF, OF etc.) whose classification accuracy is to be assessed. The randomly selected locations or sampling units, which are presented in the matrix, can be pixel or a group of pixels or a polygon. In this study, group of pixels are the sampling units. An entry made along the major diagonal of the error matrix implies agreement which means that the classification at a sampling unit matches with the corresponding ground truth and, therefore, suggests that the classification is correct. The non-diagonal elements indicate disagreement or wrong classification.

The percentage of correctly classified sampling units (i.e. sum of all diagonal elements) out of the total considered sampling units in the error matrix provides measure of 'overall accuracy' of the assessment. Similarly, accuracy of each class can be measured by calculating the percentage of correctly classified sampling units (diagonal element) out of the total sampling units considered for that class in row or column. It is pertinent to mention here that the accuracy assessment in this chapter signifies accuracy of classification. It does not relate to cartographic accuracy. Moreover, it also does not speak about the accuracy of area statistics given under different density classes.

2.16.1 Methodology

The sampling design is very crucial for assessing the accuracy of classification. It should ensure representation of the entire spatial population. Similarly, the selection of appropriate sampling size is also very important. Literature searches have recalled that if the area of assessment is large or the classification has a large number of vegetation/land use classes, then the minimum number of samples should be more than 50 sampling units per class. However, it may vary according to relative importance of the category and variability within each category. Keeping this in mind, 5729 sample points were considered for accuracy assessment in this report.

Ideally, the sampling units should be randomly selected from the entire assessment area, i.e. country and ground truth data should be collected from all such points, but there are certain limitations in this approach. The other alternative as suggested

in the literature is the use of high resolution satellite data as ground truth for preparing error matrix. FSI is procuring high resolution satellite data of LISS-IV Mx (Multispectral with spatial resolution of 5.8 m) for classification of Trees Outside Forest for 60 randomly selected districts spread over the entire country for a cycle of two years. The time period of procuring this data coincides with the satellite data procured for forest cover mapping. As such, this data can be used as proxy to ground truth. With the help of high resolution satellite data, it is possible to differentiate between very dense forest, moderately dense forest, open forest, scrub and non-forest.

For the purpose of preparing error matrix, only 53 districts were selected as other districts did not have LISS-IV Mx scenes for the same period. These districts were well spread over the entire country and, therefore, formed a representative sample. Since these districts were selected randomly for TOF inventory, the condition of randomness was also fulfilled. In the selected districts, only those LISS IV scenes were identified, which are having significant forest cover. These scenes were then rectified with the help of rectified LISS-III scenes used for forest cover assessment so as to avoid any error due to rectification. The number of sample points to be selected from different districts were taken proportional to forest cover of the districts, which were distributed to different LISS-IV scenes. These number of points were randomly distributed throughout the LISS-IV scenes. In the rectified LISS IV scenes, sample points were overlaid. At each point, a grid of 1.0 ha was prepared and forest density class was observed in the grid. The same exercise was done at all the points

falling in the district. The district-wise list of sample points was then sent to the unit responsible for forest cover classification. The same methodology (i.e. a grid of 1.0 ha) has also been followed in recording the classification against each point. From two sets of information, error matrix has been generated.

2.16.2 Results

The error matrix has been prepared for a total of 5729 sample points and given in Table 2.16.1. The diagonal element, that is, the number 515 for very dense forest (VDF) at row 1 and column 1 implies that all the 515 sampling points have been correctly classified as VDF. Whereas, the off-diagonal number 16 in row 1 (VDF) and column 2 (MDF) implies that 16 sampling points, which are registered as MDF during the ground survey have been classified as VDF. Further, a simplified error matrix has been prepared by grouping land use classes into 'forest' and 'non-forest'. This is done by combining VDF, MDF and OF into one class viz. 'forest' and scrub and non-forest classes into 'non-forest'. The simplified error matrix is given in Table 2.16.2.

The error matrix (Table 2.16.1) reveals that out of the total 5729 sampling points where observations were made, classification of 5269 sampling points (the sum of the elements along the main diagonal of the matrix) was found correct. The 'overall accuracy' of classification, therefore, works out to be 91.97%. This is quite high implying that classification procedure followed at FSI is well above the acceptable limit. In the remote sensing technology, accuracy of more than 85% is considered satisfactory.

Table 2.16.1: Error Matrix

Classification classes	Ground truth (based on field inventory data)						User's Accuracy (%)
	VDF	MDF	OF	Scrub	NF	Total	
VDF	515	16	13	1	2	547	94.15
MDF	15	1872	130	6	79	2102	89.06
OF	1	6	1127	4	128	1266	89.02
Scrub	0	1	0	74	2	77	96.10
NF	1	8	43	4	1681	1737	96.78
Total	532	1903	1313	89	1892	5729	
Producer's Accuracy (%)	96.80	98.37	85.83	83.15	88.85		
Overall Accuracy	91.97%						
Overall Kappa Statistics	0.88						

Table 2.16.2: Simplified Error Matrix

Classification classes	Ground truth (based on field inventory data)			User's Accuracy (%)
	Forest	Non-Forest	Total	
Forest	3695	220	3915	94.38
Non-Forest	53	1761	1814	97.08
Total	3748	1981	5729	
Producer's Accuracy (%)	98.59	88.89		
Overall Accuracy	95.23%			
Overall Kappa Statistics	0.89			

In the simplified error matrix (Table 2.16.2) classification of 5456 sample points was found to be correct, yielding an overall accuracy of 95.23%.

Besides the overall accuracy, accuracy of individual classes has also been determined by calculating Producer's accuracy and User's accuracy.

The producer's accuracy is derived by dividing the number of correct sampling points in one class divided by the total number of points as derived from reference data. The producer's accuracy measures how well a certain area has been classified. It includes the error of omission which refers to the proportion of observed features on the ground that are not classified in the map.

Greater the error of omission the lower is the producer's accuracy.

Similarly, user's accuracy can be obtained by dividing the correct classified units in a class by the total number of units that were classified in that class. The user's accuracy is, therefore, a measure of reliability of the map. It informs the user how well the map represents what actually is found on the ground. One class in the map can have two types of classes on the ground. The 'right' class, which refers to the same land-cover-class in the map and on the ground and 'wrong' classes, which show a different land-cover on the ground than predicted on the map. The latter classes are referred to as errors of commission. The more errors of commission exist, the lower would be the user's accuracy.

From Table 2.16.1 it is found that the producer's accuracy for VDF, MDF, OF, Scrub and Non-forest classes are 94.15, 89.06, 89.02, 96.10 and 96.78 percent respectively. Similarly, user's accuracy for these classes are 96.80, 98.37, 85.83, 83.15 and 88.85 percent respectively. These levels of accuracy are satisfactory and acceptable. The user's accuracy for forest and non-forest classes are found to be 94.38 and 97.08 percent respectively while producer's accuracy for these classes are 98.59 and 88.89 percent respectively.

To further authenticate the results of accuracy, the Kappa analysis, which is a multivariate technique, provides a statistics

known as K_{HAT} . This coefficient gives a measure of overall agreement of matrix. In contrast to the overall accuracy- (the ratio of the sum of diagonal values to total number of sampling units in the matrix) the Kappa coefficient takes also non-diagonal elements into account. This statistics usually ranges between 0 and 1 and is used to indicate whether the correct values of the error matrix are due to true agreement or due to chance agreement. Any classification having kappa coefficient more than 0.6 is considered as statistically sound. K_{HAT} calculated from the error matrix given at Table 2.16.1 is equal to 0.88, which indicates that an observed classification is 88% better than one resulting from chance.

