Monitoring India's Forest Cover through Remote Sensing

J.K. Rawat[*], *Alok Saxena*[**] *and Sudhanshu Gupta*[***]

1.1 Introduction

Importance of Forests is globally recognized not only as important source of subsistence, employment, revenue earnings, raw materials to a number of industries but also for their vital role in ecological balance, environmental stability, biodiversity conservation, food security and sustainable development of a country. These have to be managed judiciously not only for environmental protection and other services but also for various products and industrial raw materials. Considering the crucial role forests play in the country's ecological stability and economic development, the current National Forest Policy aims at maintaining a minimum of 33 percent of country's geographical area under forest and tree cover. This requires periodic monitoring of the forest cover of the country for effective planning and sustainable development.

There appears to be no efforts at National level prior to 1910 for mapping and monitoring of forests, though forest maps were available at local level mostly in the working plan documents of State Forest Departments. Even Survey of India carried out forest survey and mapping at scales decided by Superintendent of Survey with the forest departments. After 1910, forest surveys were made ancillary to topographical surveys. In 1976, National Atlas and Thematic Mapping Organisation (NATMO), a Government of India organisation, published Forest Atlas of India depicting administrative and forest boundaries. These maps, however, did not depict the actual forest cover in the country since all legal forest areas did not necessarily contain forest crop.

Forest Survey of India (FSI), an organization under the Ministry of Environment & Forests (Government of India) was mandated in 1986 to monitor and map country's forest cover on biennial basis. Consequently, FSI has been carrying out assessment of forest cover in the country using satellite based remote sensing data and has been publishing its findings in State of Forest Report (SFR) every two years. Remote Sensing technology has provided users the means to create numerous maps quickly and efficiently, subject to quality and resolution of data. Forest cover maps of the country, the States and Union Territories are prepared and used for carrying out several spatial studies, such as monitoring changes in forest cover, areas under shifting cultivation, assessment of forest density, status of wildlife habitats, forest fragmentation, forest fire affected areas, etc. In this paper, a brief account of such forest cover mapping by FSI is presented.

1.2 Remote Sensing Based Forest Mapping and Monitoring

Application of satellite-based remote sensing in mapping, monitoring and management of natural resources has been recognized long ago. It was the National Remote Sensing Agency (NRSA) that in 1982 demonstrated that the space borne satellite

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data could conveniently do mapping of actual forest cover. Moreover, because of periodic availability of satellite data at short intervals of time, changes in the extent of forest cover at national and regional levels could be monitored in an unbiased and efficient manner. NRSA published two vegetation maps for the country using satellite data for the periods 1972-75 and 1980-82. Based on visual interpretation of false colour composites on 1:1 million scale for the two periods, NRSA study concluded that forest cover of the country reduced from 16.89% to 14.10% during the seven years. Although there were certain gaps in the quantitative assessments made by NRSA, the usefulness of satellite-based remote sensing technology in forest cover mapping was firmly established.

Almost simultaneously, the Forest Survey of India (FSI), an organization under the Ministry of Environment and Forests, government of India, also developed the capacity to interpret and classify the satellite data for assessment and mapping of forest cover. FSI, a premier national forest resources survey organization in the country, was created with effect from June 1, 1981 as a successor to Pre-investment Survey of Forest Resources (PISFR) to furnish data through countrywide comprehensive forest resources survey at regular intervals.

FSI used Landsat (MSS) imagery pertaining to the period 1981-83 for the first assessment of forest cover. The technique used for interpretation of satellite data was visual interpretation and scale of interpretation was 1:1 million. Interpretation was followed by extensive ground truthing. The forests were classified into dense forest (crown cover of more than 40%) and open forests (crown cover between 10-40%). Mangroves were delineated as a separate class. Degraded forests having crown cover of less than 10% were classified as scrub (a non-forest category). As per this assessment forest cover of the country was estimated to be 642,041 km² (19.52% of country's geographic area).

Landsat (TM) imageries of 1985-87 were used for the second cycle of forest cover assessment. Interpretation was done visually at 1:250,000 scale. With better spectral and spatial resolution of satellite data, higher scale of interpretation and more extensive ground truthing led to improvement in estimation of forest cover. The results published in the form of SFR 1989 estimated forest cover of the country as 640,134 km² (19.47% of country's geographical area). Same satellite data and scale of interpretation was used for the third and fourth assessments. However, a significant development during this period had been the procurement of the then state of art computer (VAX-11/780) in 1989 for digital interpretation of satellite data. During the fourth assessment, satellite data of some parts of four states namely Bihar, Himachal Pradesh, Madhya Pradesh and Uttar Pradesh were also interpreted digitally.

In the mean time, India launched its remote sensing satellite (IRS). The fifth assessment (1995) was based on visual interpretation of imageries from IRS-1B (LISS-II) data was used, while for subsequent assessments (1997 and 1999) was based on data from IRS-1C (LISS-III). Scale of interpretation remained same (1:250,000 scale) and interpretation technique was largely visual with increasing input of digital interpretation.

Development of efficient digital image processing software (such as, ERDAS Imagin) and availability of reasonably priced powerful workstations and capacity

building of its technical manpower, enabled FSI to completely switch over to digital interpretation of satellite data. Consequently, FSI interpreted the satellite data of the entire country through digital image processing at 1:50,000 scale during its latest assessment of forest cover assessment (2001), the eighth in the series. This improvement in the methodology has led to generation of a new baseline data on forest cover as for the first time FSI could map forested areas as small as 1 ha in extent while in the previous assessments this limit was 25 ha. As per SFR 2001, the forest cover of the country has been assessed to be 675,538 km^2 (20.55% of the geographic area of the country).

A summary of important features of satellite data, sensors and their properties used for various assessments carried out so far for monitoring the forest cover of the country is given in table 1.

Table 1: Satellite Data for Forest Cover Assessments from 1987 to 2001

Assessment and Year	Data Period	Sensor	Data Form	Spatial Resolution	Spectral Resolution	Scale of Interpretation
I 1987	1981-83	Landsat - MSS	Hard Copy FCC	80 m	4 Bands	1:1 million
II 1989	1985-87	Landsat - TM	Hard Copy FCC	30 m	7 Bands	1:250,000
III 1991	1987-89	Landsat - TM	Hard Copy FCC	30 m	7 Bands	1:250,000
IV 1993	1989-91	Landsat - TM	Hard Copy FCC	30 m	7 Bands	1:250,000
V 1995	1991-93	IRS-1B LISS II	Hard Copy FCC	36.25 m	4 Bands	1:250,000
VI 1997	1993-95	IRS-1B LISS II	Hard Copy FCC	36.25 m	4 Bands	1:250,000
VII 1999	1996-98	IRS-1C/1D LISS III	Hard Copy FCC	23.5 m	4 Bands	1:250,000
VIII 2001	2000	IRS-1C/1D LISS III	Digital	23.5 m	4 Bands	1:50,000

1.3 Present Methodology of Forest Cover Mapping

The present methodology of forest cover mapping from satellite data using DIP software on 1:50,000 scale involves the following steps:

Acquisition of satellite data: The digital data of IRS-1C and 1D LISS III is acquired from NRSA in CD.. India is covered in about 340 scenes, of IRS 1C and 1D. One scene covers an area of about 20000 km^2, having an overlap of about 10% with adjoining scenes. While procuring the data, care is taken to ensure that it is cloud free (with not more than 10% cloud cover) and therefore data pertaining to the period from October-December is preferred.

Geometric Rectification of raw data: After downloading the data into computer, rectification is carried out in each image to provide Latitude and Longitude information into raw satellite scene using raster based geometric corrections. Rectification carried out in geographic projection is re-projected in shape of polygonal projection and the scene is geo-coded with using SOI toposheets.

Mosaicing of rectified scenes: Different scenes, which are already rectified, may have to be merged together to get one combined FCC (False Colour Composite). FCC of sheet is extracted from mosaiced scene in a chosen area of interest. Image is displayed in three bands 3, 2, 1. Masking of non-forest areas is done separately to extract forest areas on the basis of ground knowledge, cover map of previous cycles and on the basis of information available through SOI toposheets in the area of interest.

Classification of forest cover using NDVI: Interactive method of display is used for assigning threshold values for each class (open, dense and scrub) on the basis of the ground knowledge to highlight forest/vegetated areas. Density class of forest cover and colour is accordingly allocated. Survey of India toposheets is used for delineating boundaries of each district and classified map of forest cover is generated.

Flow chart of methodology of dynamic forest cover mapping using remote sensing is shown in figure-1

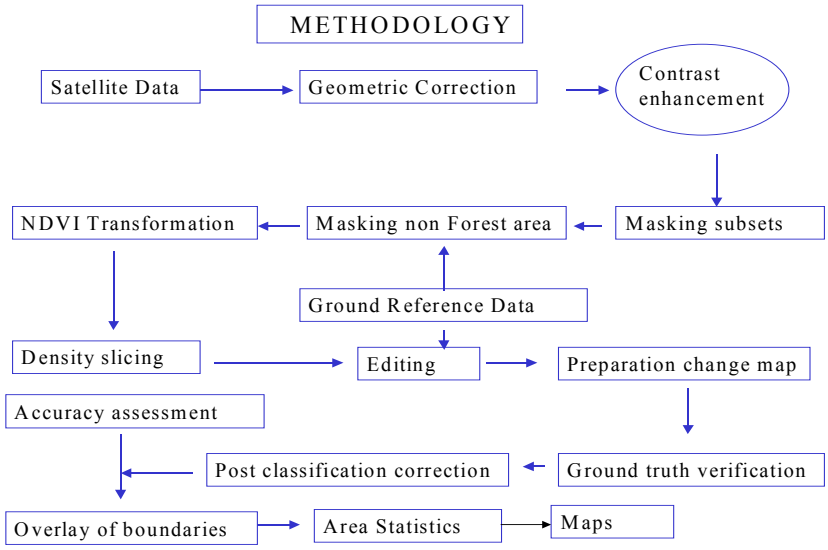

Figure1.0- Flow chart of Forest cover mapping using remote sensing

1.4 Recent Developments in Forest Cover Assessment:

In its latest assessment of 2001, taking advantage of advancements in remote sensing and improvement in digital interpretation qualities, FSI has provided a much more comprehensive status of forest cover in the country than in the previous assessments. Some of the new features incorporated in this assessment are:

- For the first time FSI has interpreted the satellite data of the entire country digitally. In earlier estimates, interpretation has been largely visual. Digital interpretation has the advantage of overcoming subjectivity prevalent in visual method.

- Due to absorption of digital image processing technique, it has been possible for FSI to interpret the data on 1:50,000 scale. This has resulted in providing more realistic information on forest cover as areas having forest cover down to 1 ha could be delineated while in earlier assessments, forest cover down to 25 ha could only be delineated. Similarly blanks down to 1 ha within forested areas can be separated. The entire exercise has resulted in new base-line information on forest cover.

- As perennial woody vegetation (including bamboos, palms, coconut, apple, mango etc.) has been treated as tree and thus all lands with tree crops, such as agro-forestry

plantations, fruit orchards, tea and coffee estates with trees etc., have been included in forest cover.

- Mangrove cover has been classified into dense and open mangrove cover. The area of mangrove cover so assessed has been merged in the respective area figures of dense and open forest cover.

- A classification is not complete unless its accuracy is assessed. For the first time an independent and systematic assessment of accuracy of satellite data interpretation was made. An error matrix was generated by comparing classified forest cover with the actual forest cover on the ground at 3,608 locations spread throughout the country. High resolution PAN data was used as proxy for ground verification. The overall accuracy of forest cover classification was found to be 95.9%.

- Though forest cover in areas as less as 1 ha in extent could be assessed using satellite data, significant tree cover exists in patches of less than 1 ha and in linear shapes along roads, canals, etc. and scattered trees that can not be assessed using remote sensing. An attempt is made for the first time to assess such tree cover using ground inventory method.

The abstract of forest cover assessment 2001 is given in Table 3.

Table 3: Forest Cover as per 2001 assessment

Class	Area (km²)	Percent of Geographic Area
Forest Cover		
a) Dense	416,809	12.68
b) Open	258,729	7.87
Total Forest Cover*	675,538	20.55
Non-forest		
Scrub	47,318	1.44
Total Non-forest**	2,611,725	79.45
Total Geographic Area	3,287,263	100.00

*includes 4,482 km^2 under mangroves (0.14 % of country's geographic area)
**includes scrub

The state and UT wise forest cover is shown in table 4. Madhya Pradesh with 77,265 km^2 forest cover has the maximum forest cover among all the States/UTs followed by Arunachal Pradesh (68,045 km^2) and Chhattisgarh (56,448km^2).

Table 4: Forest cover in States/UTs in India (Area in km²)

State/UT	Geo-graphic Area	Forest Cover				Scrub
		Dense	*Open*	*Total*	Percent	
Andhra Pradesh	275,069	25,827	18,810	44,637	16.23	9,907
Arunachal Pradesh	83,743	53,932	14,113	68,045	81.25	141
Assam	78,438	15,830	11,884	27,714	35.33	224
Bihar	94,163	3,372	2,348	5,720	6.07	122
Chhattisgarh	135,191	37,880	18,568	56,448	41.75	200
Delhi	1,483	38	73	111	7.51	4
Goa	3,702	1,785	310	2,095	56.59	0
Gujarat	196,022	8,673	6,479	15,152	7.73	2,408
Haryana	44,212	1,139	615	1,754	3.97	88
Himachal Pradesh	55,673	10,429	3,931	14,360	25.79	566
Jammu & Kashmir	222,236	11,848	9,389	21,237	9.56	3,087
Jharkhand	79,714	11,787	10,850	22,637	28.40	976
Karnataka	191,791	26,156	10,835	36,991	19.29	3,245
Kerala	38,863	11,772	3,788	15,560	40.04	71
Madhya Pradesh	308,245	44,384	32,881	77,265	25.07	3,452
Maharashtra	307,713	30,894	16,588	47,482	15.43	6,137
Manipur	22,327	5,710	11,216	16,926	75.81	190
Meghalaya	22,429	5,681	9,903	15,584	69.48	259
Mizoram	21,081	8,936	8,558	17,494	82.98	467
Nagaland	16,579	5,393	7,952	13,345	80.49	47
Orissa	155,707	27,972	20,866	48,838	31.36	5,782
Punjab	50,362	1,549	883	2,432	4.83	30
Rajasthan	342,239	6,322	10,045	16,367	4.78	4,925
Sikkim	7,096	2,391	802	3,193	45.00	341
Tamilnadu	130,058	12,499	8,983	21,482	16.52	3,180
Tripura	10,486	3,463	3,602	7,065	67.38	44
Uttar Pradesh	240,928	8,965	4,781	13,746	5.71	678
Uttaranchal	53,483	19,023	4,915	23,938	44.76	598
West Bengal	88,752	6,346	4,347	10,693	12.05	149
Andaman & Nicobar	8,249	6,593	337	6,930	84.01	0
Chandigarh	114	5	4	9	7.51	0
Dadra & Nagar Haveli	491	151	68	219	44.60	0
Daman & Diu	112	2	4	6	5.53	0
Lakshdweep	32	27	0	27	85.91	0
Pondicherry	480	35	1	36	7.45	0
Total	**3,287,263**	**416,809**	**258,729**	**675,538**	**20.55**	**47,318**

1.5 Change in Forest Cover

Any direct comparison of 2001 assessment with 1999 assessment would be invalid since technique (digital, in place of visual) and scale (1:50,000 in place of 1:250,000) of interpretation were different. The difference between forest cover as assessed in 2001 from that assessed in 1999 is not entirely due to change on the ground during the intervening period. Substantial proportion of it may have occurred over a longer period of time but could be detected only now due to technical reasons. Also, certain forest cover might have got included due to inclusion of certain tree crops in the forest cover not included earlier (such as, trees in orchards, tea and coffee estates, etc). In the art of interpretation of digital data, it is well known that use of coarser resolution overestimates forest cover in the large contiguous forested areas and underestimates it in other areas. Any variation in the forest cover noted when comparing forest cover assessed digitally at 1:50,000 scale with that done visually at 1:250,000 scale would consist of, besides actual change on the ground, difference due to technical factors mentioned above. If differences on account of these technical factors could be separated out, only then the change in forest cover on the ground during the intervening period can be estimated.

A comparison of 2001 assessment with that of 1999 is given in Table 5. It shows an overall positive difference of 38,245 km^2 or 6.0 % in the forest cover of the country. There dense forest cover is significantly higher by 34,580 km^2 or 9.0 % (mangrove cover estimates of 1999 assessment has been included in dense forest for comparison purpose) while the open forest has higher by 3,665 km^2 or 1.4 %.

Table 5: Comparison of 2001 with 1999 assessment

Assessment	1999 Assessment	2001 Assessment	Net Difference
	(a)	(b)	(b-a)
Dense Forest	382,229	416,809	+34,580
Open Forest	255,064	258,729	+3,665
Total	637,293	675,538	+38,245

1.6 Other Maps Generated by FSI based on Forest Cover Spatial Data

The spatial information on forest cover generated by FSI on biennial basis has been used for several other related studies. Also, in the past, FSI prepared thematic maps of forest areas based on aerial photographs. About 80 % of the country's forest area has been covered by these maps. A large number land use classes are shown in these maps prepared at 1:50,000 scale. In addition, FSI has voluminous data from field inventory of forest resources in forest and non-forest areas. In forest areas, data has been collected from sample plots laid out in grids of 2.5' x 2.5'. Combining this information with the spatial information on the forest cover, a few nationwide studies have been undertaken in the past by FSI. A brief account of these studies is given in the following paragraphs.

Forest Fire Maps: FSI has also prepared forest fire maps in 1995 for the entire country. The exercise was repeated in 1999 for the state of Uttaranchal. In 1995, FSI as a special

study procured satellite data (IRS-1B, LISS-II) on 1:1million scale pertaining to period between May and June'1995 and visually interpreted it to map forest areas affected by fire. In 1999, it procured IRS-1D (Wifs) data of Uttaranchal and interpreted it digitally to map areas affected by forest fire.

Mining zones within Forest Areas: As a part of special study in 1998, FSI, took up the exercise of estimating the effect of mining activities in the three mineral rich states of India viz- Jharkhand, Orissa and Chhattisgarh. One of the objectives was to assess the extent of forest cover in areas leased for mining. The forest cover maps were prepared using IRS-I B (LISS-II) and IRS I C (LISS-III) satellite data of 1996-1998. Now, FSI is providing digital forest cover maps to The Indian Bureau of Mines, Nagpur for mineral rich areas. Such maps are used by the Govt. of India in taking decisions regarding extension lease for mining in the forest areas.

Maps of areas affected by shifting cultivation in North-Eastern Region: In 1998, FSI prepared a map of the areas in the North-Eastern (NE) region of the country affected by shifting cultivation. Satellite data at two years interval corresponding to the period 1987-89, 1989-91, 1991-93, 1993-95 and 1995-97 on 1:250,000 scale was used and visual interpretation method was followed to delineate shifting cultivation areas. This exercise helped in assessing actual area affected by shifting cultivation in NE region over a period of ten years.

Forest Cover change maps in Project Tiger Areas: FSI has also prepared forest cover change maps of 18 Project Tiger Areas between 1983 and 1987. The maps were found very useful by the park authorities for management purpose.

Forest cover within Biosphere Reserves: Mapping of forest cover in 6 Biosphere Reserve (namely Great Nicobar, Manas, Nanda Devi, Neelgri, Nkorek, Sunderbans and Dribru-Saikhowa) was done in 2000-2001 by interpretation of satellite data of year 1987-89 and 1995-97. The change in the forest cover in these Biosphere Reserves was also assessed.

Mapping of Alpine Pasture: Alpine Pastures in Himalayan region were mapped by FSI in 1989-90 using satellite data pertaining to period 1981-84

Mapping of forest cover affected by cyclone in Orissa: Super cyclone struck Orissa coast in October 1999, adversely affecting 11 districts of the state. Mapping of damage to forest vegetation (including mangroves) was attempted by temporal study of satellite data of two heavily affected districts (Kendrapara and Jagatsinghpur). LISS III (IRS 1C) scenes of pre and post cyclone were used for this assessment

Mapping of trees outside forests (TOF): A large number of tree plantations (blocks and linear along roads, canals, etc.) and woodlots exist outside the boundaries of forest areas. As these are small in extent, it is difficult to map the TOF using multispectral LISS data with resolution of 23.5 m. FSI has developed a methodology for mapping TOF by fusing LISS III and corresponding PAN data (resolution 5.8 m). The methodology has been successfully tried in Bijnor district of Uttar Pradesh and now being used for mapping TOF in other districts as well. Such maps for 15 districts have been completed.

Species-composition maps of forests of India: FSI has recently prepared species-composition maps for the entire country. For this exercise, forest species were classified into 24 major species compositions. The entire area of the country was divided into grids of 2½' x 2½' and in each grid forest species composition was determined using information from thematic maps, stock maps of state forest departments and inventory forms used in ground inventory conducted by FSI.

Growing Stock maps: FSI has also prepared growing stock maps for Western Ghats, NE regions and Himalayan Region using inventory data collected for each 2½' x 2½' grids in the forested areas. Volume factors were developed for each grid depending on species composition and forest density. Thereafter, aboveground woody volume was estimated and depicted in map form.

Forest cover in Great Indian Canal Project Area: Ministry of Water Resources, Government of India has taken up a massive project of Great Indian Canal Linking all the rivers in the country. It will pass through many forest areas and the project will require clearance under the Forest Conservation Act, 1980. FSI has prepared forest cover maps and quantified forest areas falling in the route of the proposed Great Indian Canal.

Conclusion

FSI is the principal organisation in the country generating national level information (spatial and non-spatial) on forest resources. The information can be put to purposeful application if it is made available to the users in a convenient and efficient manner. FSI is involved proactively in the process to develop National Spatial Data Infrastructure (NSDI). Till the NSDI is fully functional, FSI has been using various means to disseminate its spatial and non-spatial data to the users. Traditionally, FSI has been supplying paper maps to the users but recently it has taken initiative to provide spatial data in digital form also. FSI publishes the findings of the biennial forest cover assessments in form of State of Forest Reports. So far 8 such publications have been made. These are available free of cost on request. FSI has also published 163 inventory reports so far, 87 special study reports and other publications. These reports contain a lot of spatial information (maps) and are available on request. FSI had launched its official Website (www.fsiorg.net) in 2002. It is updated regularly and all latest information is available to users including shape files of State-wise forest cover maps. All the statistical data on forest resources and indicative forest cover maps are easily available to users having Internet facility.

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Abstract

Forests are ecological as well as socio-economic resource Maps showing distribution of forest cover are of immense value not only for management of forests and wildlife but also for environmental conservation. Use of remote sensing data for assessment of forest cover of the country was first demonstrated in 1982 by the National Remote Sensing Agency (NRSA), Department of Space. Subsequently, Forest Survey of India (FSI), an organization under Ministry of Environment & Forests, Government of India, started assessing forest cover of the country and monitoring changes therein using remote sensing data on a two-year cycle. Its first assessment based on satellite data pertaining to the period between 1983-85 was published in 1987 as State of Forest Report 1987 (SFR, 1987). The last assessment is SFR, 2001, based on digital interpretation of satellite data pertaining to the year. The latest assessment i.e., 2001 assessment shows a substantial increase of 38,245 km² compared to previous assessment. However, this increase is mainly due to use of improved quality of satellite data, use of digital image interpretation and change in scale from 1:250,000 to 1:50,00. Due to this many small patches of forests ranging between 1 and 25 ha, which could not be discerned earlier could be detected and added to the forest cover of the country. Forest Survey of India is also using satellite data for carrying out special forest related nation wide studies, a brief account of which is given in this paper.

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