Monitoring Forests for Sustainability: Remote Sensing studies in India

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Abstract

Human forest interaction in India is particularly intense and large population increase, forest dwelling communities and livestock grazing from communities living adjoining forest areas has resulted in significant forest cover loss and degradation. Remote Sensing data including from Indian sensors has been of significant help in understanding the loss of forest cover, resource depletion and planning for sustainable use of forest. The Forest Survey of India (FSI) prepares biennial forest cover assessment and places the stage of forest report before Parliament. The result indicate since the enactment of Forest Conservation Act in 1980, significant aforestation and reforestation actually have resulted in stabilization of forest cover which is currently 67.4 million hectares. The various applications of Remote Sensing includes mapping, vegetation type, monitoring status of protected wildlife areas and sanctuaries. Remote Sensing has been useful in improving field sampling for assessment of growing stock, preparation of working plan and assessment of trees outside forest. In the area of wildlife, Remote Sensing data has been useful in wildlife habitat evaluation, assessing carrying capacity of herbivores and monitoring corridors critical for wildlife migration. Using remote sensing and geospatial modeling landscape level biodiversity assessment of the country has been carried out. Other applications of remote sensing is assessing the forest carbon cycle, the phytomass carbon storage and modeling the release of carbon due to deforestation and landuse changes. These case studies from India on use of remote sensing will be presented.

Background

The Indian landmass covers an area of 328.8 Million ha, roughly 2.5 percent of global landmass but is home to 16 percent of global human population and 1/5 of the livestock. Most of this increase has occurred in second half of 20th century. The increased population and associated increased demand of resources has led to significant impact on forest cover and has consequence in negatively impacting forest produce as well as various ecosystem services i.e., hydrology, soil conservation, wildlife support, biodiversity and environmental protection, these forests provide. This has happened in spite of beginning of scientific forestry in India in 1856 which in initial years had the objective of providing sustainable timber. The forests departments maintained records of various activities in forests, prepared management plans, i.e., Working Plans on 10-year cycles and also evolved many forest and silviculture management practices. In early seventies the Stockholm Conference on Human Environment (1972) led to appreciation of the role of forests in environment protection. In mid-seventies the Government of India became concerned due to dwindling number of tigers, a keystone species, in the country. Simultaneously, National Commission of Agriculture (NCA) in its report of 1976 recommended a two-pronged strategy of creation of Forest Development Corporations (FDC) for raising high value forest plantations for industrial use and Social Forestry Plantations (SFP) for meeting fuelwood and fodder deficiency in India. However both the strategies did not yield expected results and all around need for alternate model of forest management and environment protection was felt (Singh 2008).

Issues in Sustainable Forest Use in India

The opening paragraph of National Forest Policy aptly summed the issues in 1990 as "“Over the years, forests in the country have suffered serious depletion. This is attributable to relentless pressures arising from ever-increasing demand for fuel wood, fodder and timber; inadequacy of protection measures; diversion of forest lands to non-forest uses without ensuring compensatory afforestation and essential environmental safeguards; and the tendency to look upon forests as revenue earning resource. The need to review the situation and to evolve, for the future, a new strategy of forest conservation has become imperative. Conservation includes preservation, maintenance, sustainable utilization, restoration, and enhancement of the natural environment. It has thus become necessary to review and revise the National Forest Policy" (MoEF 1988).

Remote Sensing for Natural Resource Management

Since early seventies, Landsat of USA spurred the use of remote sensing for natural resource inventory, monitoring and management planning. The Indian RS programme comprising of Indian Remote Sensing Satellite series started with launch of IRS-1A in 1988 and was preceded by setting up of National Natural Resource management System (NNRMS), a virtual institutional framework for using RS data for national development. In less than two decades, the IRS series has grown into specialized Resourcesat, Oceansat and Cartosat series of satellites with sensors designed for land and water resource inventory and mapping, oceanography and cartography and large-scale mapping applications respectively. This capability covers panchromatic data at less than 1m resolution, panchromatic stereo data at 2.5m resolution and multispectral data at 5.8, 22,5 and 56m resolutions with different repeat cycles. A large vibrant and nationally relevant RS application programme has also developed which has been recently summarized by Navalgund et al., (2007) and subsequent paper covers only the forest theme.

Forest Cover Monitoring using RS

The use of the remote sensing data for forest density mapping and monitoring is well established. First national scale forest cover assessment was made by National Remote Sensing Agency in 1983 using Landsat MSS data and visual interpretation at 1:1M scale for two periods i.e. 1972-75 and 1980-82. The study highlighted a loss of 2.1 million ha of forests during this period. Since 1987 regular biennial mapping is being done by the Forest Survey of India using newer

RS data and digital classification technique. In the 2003 and 2005 forest cover assessments, the forest cover stood at 67.7 Million ha. While the total forest cover in past two decades has stabilized, deforestation continues to occur in specific pockets *i.e.* hot spots in north-east, shifting cultivation areas and areas where forest has been diverted for developmental activities including hydroelectric projects. Some areas, such as district Sonitpur in Assam state of India, are loosing nearly 5000 ha forest area annually (Srivastav *et al.* 2002).

Table 1. *Results of assessments of Forest Cover of India using RS technology by FSI*

Cycle	**Year**	**Satellite & sensor**	**Data period**	**Resolution (m)**	**Scale**	**Forest cover (km^2)**	**% of gross area**
1	1987	LANDSAT-MSS	1981–83	80	1:1 million	640 819	19.49
2	1989	LANDSAT-TM	1985–87	30	1:250 000	638 804	19.43
3	1991	LANDSAT-TM	1987–89	30	1:250 000	639 364	19.45
4	1993	LANDSAT-TM	1989–91	30	1:250 000	639 386	19.45
5	1995	IRS-1B LISS II	1991–93	36.25	1:250 000	638 879	19.43
6	1997	IRS-1B LISS II	1993–95	36.25	1:250 000	633 397	19.27
7	1999	IRS-1C/1D LISS III	1996–98	23.5	1:250 000	637 293	19.39
8	2001	IRS-1C/1D LISS III	2000	23.5	1:50 000	653 898	19.89
9	2003	IRS-1D LISS III	2002	23.5	1:50 000	677 816	20.62
10	2005	IRS-P6 LISS III	2004	23.5	1:50 000	677 088	20.60

The current mapping scheme of FSI, using IRS LISS-III 23m spatial resolution imagery, has three forest categories *viz.*, Dense Forest (>70% crown cover), Medium Dense Forest (40-70% crown cover) and Open Forest (10-40% crown cover), latest maps with map 3 crown cover classes (10-40 percent, 40-70 percent and >70 percent crown cover). Multi-temporal forest cover analysis when linked to geospatial modeling allows scenarios of forest cover on a future data. In one such study Talukdar *et al.* (2004) modeled and predicted the forest cover of Meghalaya state in India for the periods 2020 and 2050. Spatial modeling could be an immensely useful activity to understand the future of the forests, which are undergoing continuous changes such as those brought about by shifting cultivation, logging, diversion of forests for non-forestry purposes etc. provided such factors are operative in future too.

Vegetation Type Mapping

Preparation of maps identifying zones having similar characteristics with respect to important characteristics such as climate, vegetation types, plant functional types, forest types or biogeography is an important initial step in developing appropriate conservation plans. Multi-date SPOT Vegetation derived NDVI have been used to prepare global vegetation type maps at 1km spatial resolution under TREES project and South East Asia region, including India was classified by Aggarwal et al., (2003). Multi-temporal remote sensing data from IRS WiFS sensor (200m spatial resolution) has been used for preparing a vegetation cover map of India which was combined with climatic inputs derived Holdridge life zones and 35 cover classes and 17 vegetation cover types were mapped (Roy et al., 2006). The forest classes mapped have been related to detailed forest classification scheme of India developed by Champion and Seth (1968). These maps are of use in defining vegetation functional characteristics, monitoring changes in vegetation types and as inputs defining land in regional climate models.

Protected Area Monitoring

The Wildlife (Protection) Act (1972) recognizes the vital contribution of the Protected Areas (PAs) towards conservation of natural resources. This value arises from retention of the representative sample of the natural region, its wild biota and the preservation of biological diversity for environmental stability of the surrounding region *viz*., land fertility, gene pool preservation, water availability quality maintenance, etc. PAs also provide scenic and aesthetic surroundings for recreation and tourism. With 96 national parks and 510 wildlife sanctuaries, an area of 15.6 Mha is classified as PA. The PA are regularly monitored by RS-based mapping. Several detailed studies on a large scale (1:12,500) for creating spatial satellite image-based database has been funded by Ministry of

Environment and Forests, Government of India and covering five protected areas *viz.*, Kaziranga N.P., Dudhwa N.P., Corbett N.P., Tadoba-Andhari T.R. and Indira Gandhi Wildlife Sanctuary has been recently completed (Singh and Kushwaha, 2008).

Preparation of Working Plans

Timber volume and the total growing stock are the key information required for the forest planning and management and earlier full field-based techniques have been replaced by remote sensing derived delineation of forest strata and in development of sampling designs. Remote sensing data facilitates in the stratification of forests within the limits of resolving capacity of the sensors system, which in-turn reduces the sampling error and allows the growing stock assessment with fewer samples. Most of the territorial forest divisions have working/management plans and these are revised every ten years. From aerial photographs, tree height, crown diameter, crown cover and number of trees can be estimated using photo interpretation techniques. The information so obtained can be correlated to the actual on ground using two-stage inventory design. Regression model can be developed for stratification of timber volume on air photos. Standard aerial volume tables are available for many species for quite some time. A two-stage sampling design involving photo-interpretation and ground measurements or for large areas, multi-stage sampling technique, comprising visually or digitally classified RS data as first stage followed by photo-interpretation and ground measurements in subsequent stages has been suggested as cost-effective inventory approach (Köhl and Kushwaha, 1994).

Porwal et al., (1994) has demonstrated on the use of satellite data for working plan preparation and growing stock assessment. Similarly, Dutt et al., (1996) assisted in preparation of Working Plan of Karwar Forest Division in Karnataka.

Forest Fire Monitoring and Management

Forest fires are a major cause of degradation of India's forests. While data on fire are weak, it is estimated that the forest area prone to forest fires annually ranges from 33 per cent in some states to over 90 per cent in others. Deciduous and coniferous forests experience more fires than other forest types. Among various floristic regions, the north-eastern region suffers maximum from the fires due to the age-old practice of shifting cultivation and spread of fires from jhum fields. About 90 per cent forest fires in India are started by humans. Early warning of fires through risk modeling, fire alerts and monitoring are required for proper mitigation and management. Many studies on fire risk assessment, fire detection and monitoring involving remote sensing, GIS, GPS have been carried out globally as well as in India. The NRSC has developed a web-based system, INFRASS to detect fires and disseminate the information to forest departments of different sates users in real time.

More than 95 per cent of the forest fires in India are man-made. Forest understorey is burnt year after year by local people for deriving benefits like cattle grazing, fodder, accessibility for timber/firewood extraction etc. Recurrent burning hampers forest regeneration and arrests plant succession. The Himalayan coniferous forest comprising having fir (*Abies sp.*), spruce (*Picea smithiana*), deodar (*Cedrus deodara*), chirpine (*Pinus roxberghii*), blue pine (*P. wallichiana*) etc, are very prone to fire. The factors governing fire occurrence and spread are: fuel loading (type and moisture), temperature, humidity, wind (both speed and direction), slope, aspect and the accessibility. A general rapid assessment of the forests for their proneness to fire could be worked out using a combination of information generated from remote sensing and field data. Jaiswal et al., (2002) carried out a RS and GIS based forest fire risk zonation study of Gorna subwatershed (Madhya Pradesh) an area regularly subjected to forest fires. Using RS-derived indices and weighting the layers on basis of forest fire risk resulted in identification of 30 percent area under high risk category, which also matched with actual occurrence of forest fires as mapped through burnt scar areas.

Wildlife Conservation

The role of remote sensing in wildlife conservation has emphasized quick appraisal of habitat attributes, identification of new sites for protected areas and current status of corridors. Remote sensing need to be supplemented with ground survey methods such as counting animals, trapping, collection of droppings, investigations of feeding sites as well as ground mapping of habitats. However, in all wildlife habitats, remote sensing can aid sampling by ground surveys through stratification. The GIS-based modeling of species-habitat relationships is one form of habitat suitability analysis.

Roy *et al.* (1995), Porwal *et al.* (1996) and Kushwaha *et al.* (2000, 2001) have used remote sensing and geospatial modeling to evaluate the habitats for goral, *Nemorhaedus goral* in Rajaji National Park, sambar, *Cervus unicolor* in Kanha National Park and Great Indian One-horned Rhino, *Rhinoceros unicornis* in Kaziranga National Park, respectively. Roy *et al,.* (1995) have used landscape variables such as interspersion (Is) and juxtaposition (Jx) along with other habitat variables like roads, settlements, water, slope and forest types in a linear Habitat Quality (HQ) model to calculate overall habitat quality for goral (*Nemorhaedus goral*) in Rajaji National Park, India:

$$HQ = (0.2 \times Is/8) + (0.8 \times Jx/12) + (0.2 \times RDF)$$

where, RDF is relative disturbance factor calculated as a function of restrictive (slope and water) and disturbance (settlements and roads) factors. “Is” is interspersion and “Jx” is juxtaposition. Porwal *et al.,* (1996) converted vegetation, terrain and water parameters into food and shelter value and calculated habitat suitability for sambar in Kanha National Park in central India. This method of habitat suitability assessment is operationally easy. Kushwaha *et al.,* (2001) have used rules/criteria and map overlay method of habitat modeling for goral habitat evaluation in Chilla Sanctuary of Rajaji National Park.

Wildlife Corridor Monitoring

A network of protected areas connected by corridors has been proposed as a wildlife conservation strategy in India (Rodgers & Panwar 1988). Based on location of wildlife sanctuaries and protected areas a number of critical corridors have been identified in the country of different animal species. Some of the important elephant and other large mammal corridors in India are: Ariankavu Pass in Tamil Nadu and Kerala; the Chilla–Motichur corridor and the Rajaji–Corbett corridor in Uttaranchal; the Kallar–Jaccanari corridor in Tamil Nadu; and the Siju–Rewak corridor in Meghalaya (Johnsingh & Williams 1999). However, these corridors are under threat due to various anthropogenic factors. Nandy et al. (2007) studied the changes in the Chilla–Motichur corridor over a period of 33 years using temporal satellite imagery from the years 1972, 1990, and 2005. The on-screen visual interpretation of three-period imagery followed by change matrix analysis revealed considerable corridor loss between 1972 and 2005 (17.56 km^2). Despite the fact that this corridor was identified in the early 1980s, its conservation status has constantly declined over time.

Biodiversity Characterisation at Landscape Level

Remote sensing can play a very useful role in the assessment of biodiversity using three-pronged approach i.e. forest type mapping using satellite imagery, landscape characterization, wherein the forest type map is input, followed by field-based assessment of actual biodiversity. Many landscape parameters *viz*., porosity, patch size and shape, interspersion, juxtaposition etc. have a direct relationship with a variety of vegetation features like biodiversity, physiognomy etc. Finally, the biodiversity value estimated from field survey is attached to each landscape unit to generate the biological richness maps on 1:250,000. A nationwide project on biodiversity characterization covering three-forth of the geographical area of India was carried out by IIRS between 1998 and 2007. A software, *SPLAM* was developed for this purpose. The Phase-III part of the project covering remaining area is currently in progress.

Trees Outside Forests – Resource Assessment

Decreasing forest cover and forest policies in India led to decline in forest product availability in the country while the demand especially for fuelwood and raw material for paper, match and plywood industry increased. This led to increased sourcing of supply from trees outside the forests (TOF). This resource was totally missed in forest statistics. Early attempts to estimate TOF were largely dependent on multi-stage field surveys and carried out for smaller states. The need for national scale TOF assessment led to development of a RS-based methodology by Forest Survey of India (Pandey 2008). The approach uses high resolution multi-spectral data from LISS-IV (5.8 m spatial resolution) to map settlements, water bodies, tree cover and agriculture land cover classes at 1:50,000 scale. Field data on tree number and GBH is then collected in tree cover in areas outside forests, agricultural land and urban areas. This approach has given a national estimate of 5.16 billion trees outside the forests that have a wood volume of 1.62 billion cum. This estimate is of great significance since this places TOF resource to be one third of the wood resource of the India's forests, that is estimated as 4.7 billion m^3. However, due to being based on sub-sample of districts, it does not lend itself to district-level or local wood-balance or resource requirement vis-a-vis use studies.

Watershed Monitoring and Development

Diwakar et al., (2008) describe innovative tools and techniques that involve user-friendly delivery of EO products and services for the benefit of the rural community and help them in decision making for integrated watershed development at local level. Using high-spatial-resolution data availability, the technology has been adopted for large scale natural resource mapping in the form of geo-database generation, baseline creation, action plans for watershed development and GIS-based monitoring. Specific usage of the technology has been in the areas of watershed prioritization, resources inventory, land and water resources action plan, monitoring of implementation, multi-temporal impact assessments and post-project evaluations. While the study was carried out is a number of watersheds in Karnataka, it clearly illustrated the significant role of remote sensing in end-to-end sustainable development activity at grass root level.

Biomass Mapping

Forest biomass is an important component of terrestrial carbon pool but its assessment is very difficult due to its large spatial variability, range (5 – 300 t/ha), variation in tree density and tree trunks and multi-layered tree canopies that are not amenable to optical remote sensing. Optical remote sensing data have been used for forest type and density stratification, which when combined with field inventory is useful in preparing biomass maps. Spectral-biomass relations using area-specific models have been adopted under an ongoing project to prepare a phytomass C pool map or the country (Dadhwal et al., 2008). In future large area maps would be geherated using spaceborne SAR and LIDAR data. In case of SAR coherence and interferometric cloud model have been useful. While aerial LIDAR has been used in a number of studies globally for biomass mapping, analysis of space borne LIDAR have shown estimation of tree height, an important parameter in biomass mapping.

Role of Forests in Terrestrial Carbon Cycle

Net carbon flux from forests in India due to land use change (deforestation and afforestation) for the period 1982 to 2002 using IPCC 2006 guidelines has been estimated by Kaul et al., (2009). Using state-level information on RS-derived deforestation with forest C density, soil C density it was estimated that Indian forests were a source of C (5.65 TgCa-1) during 1982-1992 period but became a small sink (1.09 TgCa-1) during 1992-2002. While most of the studies on Indian forests have estimated a small C source (reviewed in Kaul et al., 2009), small C sink in Indian forests was also estimated by Ravindranath et al (1997). The estimated source strength during 1982-1992 period is similar in magnitude to long-term modeling study by Chhabra et al (2004). Over a century (1880-1996), the cumulative net C flux due to land use changes was estimated to be as large as 3.25-5.4 PgC. There is uncertainty associated with initial phytomass C density, so only deforestation could have contributed to 2.34-3.24 PgC while remaining emissions are due to degradation of forests.

Recent approaches of development in India, especially in Himalayan regions focus emphasis on micro-level planning and execution of resource conservation programs. Escalation of biotic pressure on natural resources has made the already fragile Himalayan ecosystem vulnerable to a variety of ecological maladies. The degradation of the forests due to road construction, market forces, environmental degradation, over population etc. has changed the traditional sustainable use of these resources. Moreover, the transformation of nomadic pastoralism to nuclear transhumance (migration by only one or two person per family) has increased the resource extraction process. Landholdings are small and fragmented, consisting mostly marginal uplands. In these type of mountain substance agriculture system, the demands on the forest are numerous and fairly self-evident. The consumption pattern in the region is firmly correlated to its natural resource base in area and invariable most of the energy demands are met by the forest resource The scenario calls for mindful resource planning, and ever increasing capabilities of remote sensing data and availability of analysis tools like GIS can play very useful role in sustainable use of forests.

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References

Agrawal, S., Joshi, P.K., Shukla, Y., Roy, P.S., (2003) SPOT VEGETATION multitemporal data for classifying vegetation in south central Asia. *Curr. Sci.* **84**, 1440–1448..

Champion, H.G. and Seth, S.K., (1968) *A Revised Survey of the Forest Types of India*. Manager of Publications, Government of India, New Delhi.

Chhabra, A., Dadhwal, V.K. (2004) Assessment of Major Pools and Fluxes of Carbon in Indian Forests. *Climatic Change*, **64**: 341–360.

Dadhwal, V.K., S. Singh and Prashant Patil (2009). Assessment of phytomass Carbon Pools in Forest ecosystems in India. *NNRMS Bulletin*: 41-57.

Diwakar P.G., Ranganath B.K., Gowrisankar D., Jayaraman V. (2008) Empowering the rural poor through EO products and services—An impact assessment. *Acta Astronautica* **63**: 551 – 559

Dutt, C.B.S., Uday Lakshmi, V., Singh, I.J. and Das, K.K., (1996) *Remote sensing based management plan inputs for Karwar Forest Division*, Report, NRSA, Hyderabad.

IIRS (2002) Biodiversity characterization at landscape level in north-eastern India using remote sensing and geographical information system. Report, Indian Institute of Remote Sensing, Dehradun, India

Jaiswal R.K., Mukherjee S., Raju K.D., Saxena R. (2002) Forest fire risk zone mapping using RS and GIS. *Internat. J Applied Earth Observation and Geoinformation*, **4**: 1-10.

Johnsingh, A. J. T., Williams, A. C. (1999). Elephant corridors in India: Lessons for other elephant range countries. *Oryx*, **33**: 210–214.

Kaul M., Dadhwal V.K., Mohren G.M.J (2009) Land use change and net C flux in Indian forests. *Forest Ecology and Management*, **258**: 100-108.

Köhl, M., Kushwaha, S.P.S. (1994) A four-phase sampling method for assessing standing volume using Landsat TM data, aerial photography and field measurements. *Commonwealth Forestry Review,* **73**: 35-42.

Kushwaha, S.P.S., P.S. Roy, A. Azeem, P. Boruah & P. Lahan. 2000. Land area change and rhino habitat suitability analysis in Kaziranga National Park, Assam. *Tigerpaper* **27**: 9-17.

Kushwaha, S.P.S., S. Munkhtuya & P.S. Roy. 2001. Mountain goat habitat evaluation in Rajaji National Park using remote sensing and GIS. *J Indian Society of Remote Sensing* **28:** 293-303.

MoEF (988) *National Forest Policy*, 1988. Ministry of Forests and Environment, Government of India, New Delhi, India.

Nandy, S., Kushwaha, S.P.S. and Mukhopadhyay, S. (2007). Monitoring the Chilla-Motichur wildlife corridor using geospatial tools. *Journal for Nature Conservation* 15(4):237-244.

Navalgund R.R., Jayaraman V., Roy P.S. (2007) Remote Sensing Applications: An overview. *Current Science*, **93**: 1747-1766

Pandey D (2008) Trees outside the foreest (TOF) resources in India. *International Forestry Review*, **10**: 125-133.

Porwal, M.C., Dabral, S.L. and Roy, P.S. (1994) Revision and updating of stock maps using remote sensing and geographic information system. *Proc. Remote Sensing for Environmental Monitoring and Management with Special Emphasis on Hill Regions*, IIRS, Dehradun, pp.334-342.

Porwal, M.C., P.S. Roy, & V. Chellamuthu. (1996) Wildlife habitat analysis for sambar (*Cervus unicolor*) in Kanha National Park using remote sensing. *International Journal of Remote Sensing* **17**: 2683-2697.

Ravindranath, N.H., Somashekhar, B.S., Gadgil, M. (1997) Carbon flows in Indian forests. *Climatic Change*, **35**: 297–320

Rodgers, W. A., Panwar, H. S. (1988). Planning a wildlife protected area network in India, Vols. I and II. Dehradun: Wildlife Institute of India.

Roy, P.S., S.A. Ravan, N. Rajadnya, K.K. Das, A. Jain & S. Singh. (1995) Habitat suitability analysis of Nemorhaedus goral- a remote sensing and geographic information system approach. *Current Science* **69**: 685-691.

Roy P.S., Joshi P.K., Singh S., Aggarwal S., Yadav D., Jegannathan C. (2006) Biome mapping in India using vegetation type map derived using temporal satellite data and environmental parameters. *Ecological Modelling*, **197**: 148-158.

Singh K.D. (2008) Forest, farms and trees: recent trends and future prospects. *Internat..Forestry Review*, **10**:103-114

Srivastava S., Singh T.P., Singh H., Kushwaha S.P.S and Roy P.S. (2002) Assessment of large-scale deforestation in Sonitpur district of Assam. *Current Science*, **82**: 1479-1484.