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Remote Sensing and GIS tools for Forest Resource Management-A Review

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ABSTRACT

Global importance and thus need to quantify the status of forest dynamics is increasing day by day. It is more so in the case of a country like India which is on the deficit side of forest cover in countering ecological balance. Information required for forest resource management includes extant, type of forest, felling/cutting, deforestation, afforestation, forest fire, forest flood, and extraction of bio-physical parameters like age of plantation, total biomass, canopy density etc. Widespread, vast span and difficult terrain, and inaccessibility makes it difficult to collect timely and periodic information about above mentioned parameter through conventional means. Forest mapping is one of the fields that witnessed the earliest application of remote sensing and GIS for nonmilitary purposes. using remote sensing data and GIS techniques, a forest manager can generate information regarding forest cover, types of forest present within an area of interest, human encroachment extent into forest land/protected areas, encroachment of desert-like conditions and so on [3].For the purpose of understanding the working of remote sensing and GIS, the basics are explained below.

Keywords: *Forest cover, Mapping, Remote sensing, GIS,*

INTRODUCTION

Remote Sensing (RS) offers a faster, more efficient, and more reliable data acquisition technique. RS data can be utilized for various thematic information extractions viz. Soils, vegetation, land use, and land cover including a different kinds of resources, hence is of multi-disciplinary utility. Most of the information required for watershed management planning can be extracted from the same database. The remotely sensed image constitutes to an integrated view of the landscape with all its features manifested together.

Remote sensing is a technique of obtaining information about objects through the analysis of data collected by instruments that are not in physical contact with the object of investigation. Remote sensing is the acquiring of information about an object or scene without touching it through using electromagnetic energy (energy-matter interaction)

Different object/matter has a different response in a different band depending on the kind of interaction involved. The composite plot of reflectance/response of an object in a different band is unique and can be called a spectral signature. Identification of an object is done base on the spectral signature.

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Resolutions: There are four types of resolution Spatial resolution: The measures of the smallest distance (linear or angular separation) between objects that can be resolved by the sensor.

Spectral Resolution: Refers to the dimensions (windows and wavelength regions of the EM spectrum to a specific sensor is sensitive.

Radio Metric Resolution: It refers to how many different intensity levels (grey levels0 can be discriminated by the remote sensor within a specific band.

Temporal Resolution: How often a remote sensing satellite can record data over the same area.

Understanding the different resolutions will help decide which satellite imageries are suitable for our purpose.

The accuracy of information extracted from remote sensing data is dependent on several factors such as sensor resolution, the season of the data, adequateness of files knowledge and ground truth collected, enhancement technique and classification algorithm used for information extraction, the skill of interpreter, etc. The accuracy is also area specific as sometimes, for example, topography hinders or helps in feature extraction.

Application of remote sensing for forest resource management

Different levels of remote sensing imagery are being used.

1. Aerial photographic.
2. Satellite-based optical remote sensing IRS-LISSS II and III and IV imageries, Hyperspectral imageries
3. Thermal band
4. Microwave Synthetic aperture Radar (SAR) interferometry

Information extraction of forest planning and management

Forest cover, composition, structure, crown density, regeneration status, site quality, type of interference, sensitive sports, boundaries, topographic features, soil fertility, depth, and moisture regime, climatic data, connectivity, and markets are the essential information required for forest resource management.

Remote sensing (Optical, thermal, and microwave based) coupled with GIS and global positioning Systems can reduce time and cost for collecting and analyzing spatial information. There are good numbers of indigenous satellites for natural resources mapping including forests resources (Table.1)

Table 1. Some important indigenous satellites with sensor band spatial resolution to be used for forest resource management

Satellite	sensor	Spatial resolution (m)	bands	Specific information
IRS-1C	LISS-3	23.5	B2, B3, B4,B5	Stereo capability
	PAN	5.8	0.52 -0.75	Small scale vegetation dynamics
	WiFS	188	B3, B4	Archived data available
IRS-ID	LISS-3	23.5	B2, B3, B4,B5	Stereo capability
	PAN	5.8	0.52 -0.75	Small scale vegetation dynamics
	WiFS	188	B3, B4	Archived data available
IRS- P6 (Resourcesat)	LISS-3	23.5	B2, B3, B4,B5	Data continuity
	LISS-4	5.8	B2, B3, B4,B5	XS data at larger scale and high accuracy
	AWiFS	55	B3, B4	Vegetation dynamics monitoring
IRS –P5 (Cartosat -1)	PAN	2.5	0.50-0.75	PAN Thematic mapping (~1:5,000 scale)
Cartosat-2	PAN	<1	0.50- 075	Thematic mapping (~1:4,000 scale)
Band details B1;0.45-0.52 μm, B2: 0.52-0.59 μm,B3: 0.62- 0.69 μm, B4: 0.77- 0.89 μm, B5: 1.55- 1.75 μm PAN: 0.52 0.75 μm				

Forest resource management includes several information based actions for different remote sensing satellite or combination of RS and GIS can be (Table 2.) Creating spatial database is useful for forest resource management

Forest Cover Monitoring The forest cover at the national level is being biennially monitored using remote sensing data and it is estimated that India has 19.47% of forest cover (1989-91) out of the total expected 33% of forest cover as per India's forest policy. Satellite-based remote sensing especially using digital methods is a proven effective tool in the generation of information within a short span of time. After the spot application of aerial photographs, visual interpretation of False Colour Composite (FCC), and digital interpretation of IRS imageries (LISS II, III and IV)were used by NRSC for forest mapping and classification. Ground verification of using a predetermined spectral signature may enhance the accuracy of forest cover mapping.

Forrest Type Mapping and assessment of Distribution As per standard classified Indian forests in sixteen broad categories based on rainfall and altitude [1]. Due to changing climate, and biotic interference as spatial disturbances, the composition of tree species and forest type may be affected. Multi-temporal optical data of LISS III/IV combining biophysical characteristics of forest species and imageries selection may yield satisfactory forest type mapping.

Table 2. Different activities of forest resource management and application of optical remote sensing

Activities	Corresponding sensors of indigenous satellites
Forest vegetation spread / status – general status	LISS IV / LISSIII PAN, Freely available earth images viz., Bhuvan (IRSO), Google earth
Identification and inventorization of forest species	Temporal data of LISS IV/ LISS III, Hyper spectral data

Canopy mapping	IKONOS or QUICK BIRD high resolution imageries
Mapping and monitoring of surface water bodies	IRS 1D-PAN, LISS III, freely available earth images vis., Bhuvan (ISRO), Google earth –depending on availability
Generating digital elevation data of forest and surrounding area	PAN stereo pair of CARTOSAT1/ CARTOSAT 2/ LISS III, SRTM 90m x 90m (freely available), ASTER 30 X 30 m
Geological geomorphologic mapping	Microwave remote sensing / Hyper spectral remote sensing
Land capability, irrigability classification for planning afforestation	Slope – SRTM/ Stereo pair Soil texture – NBSSLUP map/ ground survey Erosion class- Terrain modelling (SRTM/stereo pair) Soil depth – direct ground measurements /inferences from terrain information Climate – collateral source
Wasteland, degraded land identification	IRS 1D/ 1C- PAN, LISS-IV/ LISS- III freely available earth images viz., Bhuvan (ISRO),Google earth
Prioritization of afforestation or restocking/ rehabilitations, planning for forest harvesting	Not directly through remote sensing, integration of various information like existingstock density, kind of species, status of degradation / erosion. Remote sensing in GIS environment
Socio economic profile spatial analysis	Primary database has to be built in GIS environment for subsequent intensive use
Real time forest fire mapping	Thermal imageries (Landsat)
Forest fire scar/ cutting/ felling	IRS -1D/ 1C, LISS- III, IRS P6 LISS IV/LISS III WiFS

Forest Stock Mapping

Three level of differentiation closed (40 and above), open (10-40%) and degraded (below 10%) crown cover could be obtained on a working scale of 1:250,000. NDVI based classification show saturation over 40% stocking density/canopy closures and needs review as information is at pixel level on thevigor of the canopy with less degree structural relationship of canopy closure.

Forest Inventory and Sampling

The satellite data facilitate in the generation of primary stratification units at the district/taluka level either through use of forest density maps or forest type classification it is possible to stratify the area into homogenous forest strata.

The Forest Volume Estimation and Generation of Volume Tables

The satellite-based multi-phase approach forest inventories provide data for further processing and computation of volume and yield tables. Data during the inventory could be systematically organized strata wise and suitable local and stand regressions could be generated for further computation for species-wise volumes. The predominant species volume equation generated may work as a base for the computation of total standing volume based on the plot enumeration data.

Remote sensing and Biodiversity Studies

The forest management while through its forest inventory and zonation of the area can revolve around ecologically sensitive and diversity-wise rich areas through the use of satellite data applications in conjunctive use of other ancillary data discussed as above in the zonation.

Forestry Conversion Studies

With the rapid destruction of forests and encroachment, the use of multi-temporal satellite data using digital analysis procedures may be tool for change detection. The study carried out using multi-temporal satellite data of 1983 & 1993 in parts of 'Andhra Pradesh of Adilabad district showed the area decreased up to 25% of the total area studied whereas improvement in the quality of the area is only 6-7%

Forest Fire Damage

IRS data have been used to identify forest ground fire-damaged areas. In a study in parts of Nagarglole wildlife sanctuary, 1991 accounted for damage of an area of 68 km2. Subtraction of NDVI values between consecutive IRS IB/ IC / ID imageries has been successfully used in central India for fire damage detection.

Plant Regeneration Monitoring

From selected fire scars, variability in rates of recovery after fire in different Mediterranean plant communities located in several areas of Catalonia have been detected using NDVI dynamics. Regression models on the dynamics of the regression process –monitored by the NDVI response were used.

Hyperspectral remote sensing

It uses a large number of contiguous bands of demarcating minute differences among features that are not discernible using broad bands. Due to more number of bands the accuracy of hyperspectral remote sensing has been found better in forest resource mapping and change detection

Microwave Remote Sensing: Forestry Application

With a limited capacity of optical sensors, like a limited zone of interaction with forest plants, difficulty in retrieving below crown information (height and biomass estimation) and even full range of crown density, could and atmospheric interference, etc. Triggered the application of microwave remote sensing in forest mapping. For retrieval of vegetation characteristics and biophysical parameters of the forest, multi-frequency and multi-polarization synthetic Aperture Radar (SAR) is being employed widely specially-, L- and C-band.

Table 3. Radar Frequencies and corresponding wavelengths

Band	Frequency (GHz)	Wavelength (cm)
Ka	27 - 40	0.8- 1.1
K	18 - 27	1.1 – 1.7
Ku	12 - 18	1.7 – 2.4
X	8 – 12.5	2.4 – 3.8
C	4 - 8	3.8 - 7.5
L	1 - 2	12 - 30
P	0.3 - 1	30 -100

SAR application in forestry:

Theoretically, the frequency (wavelength), polarization, incidence angle, look direction, and resolution are the sensor parameter deciding its capabilities, while important target parameters are surface roughness, complex dielectric constant, structural geometry, slope angle, and orientation of the target. Though the sensor and target as seen by the threw sensor are dependent upon the wavelength, the local angle of the sensor which is a function of both the look angle of the sensor and the slope angle of the target, and, the look direction which affects the geometry of the target in question.

The roughness and geometry of an object are the main determining parameters deciding microwave interactions. The unique physical geometry of the forest combined with penetration capacity and hence deep interaction of microwave with the forest [2] makes the SAR backscatter an important determinant for key biophysical variables such as tree density and above-ground biomass [15];[12]. Cross polarization ration (HV/HH and HV/VV) is the best parameter for retrieval of forest vegetation parameters [11].

P-bandHH and VV revealed high correlation between mean PPD and tree diameter at breast height (DBH), also the mean PPD was found to be related to stand age, height, basal area and trunk biomass [7].

SAR data at higher incidence angles (steep) has potential applications in characterizing forest vegetation parameters such as tree height, basal area and total-biomass [10]. Multi-polarization SAR data is useful in delineating water-inundated wetland vegetation and also useful in detecting flooding beneath the forest canopy [4]. Long wavelength SAR backscatter (P and L band) is more sensitive to forest biomass than shorter wavelength (C-band) backscatter and the relationships saturate at certain biomass levels [5]. C-band was also found to be a good estimator of forest biomass due to its sensitivity to canopy heterogeneity. For the estimation of tree density, C-VV and C-HV have been found best combination. The use of higher frequencies (Ka and X-band) has been successful in distinguishing different forest types, whereas L-band has been found to be the most significant frequency channel for estimating tree woody volume and basal area. A fairly good sensitivity to LAI was found mainly at Ka-band [8].

The Scientific proven data have reported a good correlation between L-band HH backscatter showed good correlation with forest stand density [13]. Using multi-frequency, multi-polarization SAR data [14] estimated forest biomass and found that the backscattering coefficients increase with increasing forest biomass and saturation at 5tha-1, 100 tha-1 and 200 tha-1for C-, L- and P-bands, respectively.

Application of Synthetic Aperture Radar (SAR) in forestry

Boreal forestland applications

Clear-cuts: Due to the lower backscatter of clear cuts than the natural forest, clear-cuts can be mapped clearly in HH-polarization data in any of the C- , L- or P-band frequency. Different structures of tree architecture, local topography (e.g., site preparation), and slash are observed in the SAR image. Snow wetness, slope and aspect relative to illumination, and surface roughness are the factors affecting the contrast between the clear-cuts and forest vegetation hence most suitable season to map clear-cuts is when clear-cuts are covered by wet snow.

Fire scars

Forest fires could be crown fires or ground fires or both. The reduces dielectric constant, changes of tree architecture, composition, ground characteristics (vegetation, roughness), and density due to forest fire can be mapped using SAR data at a suitable frequency, polarization and incidence angle. During wet conditions (spring season, following the fire event, the burned forest can be mapped efficiently.

Tropical Forestland Applications

Cover type mapping

Images with shallow incidence angles are preferred which provide better discrimination for forestland cover and preserve information on deforested areas. Dry season imagery showa better discrimination between forestland classes, compared with wet season imagery.

Deforestation mapping

Deforestation mapping can be done using multi-temporal SAR data at shallow incidence leangles and during dry conditions. Cross-polarization (HV or VH0 data provides better discrimination of manmade features and helps in deforestation mapping.

Forest flood mapping

Mapping of forest flood includes mapping of the extent of flooding, floodplain lakes, and floodplain vegetation (aquatic or terrestrial). The recommended configurations for forest flood mapping include medium incident angle (30 º-40 º), c-band for low aquatic vegetation, and low frequency for water under a closed canopy. Multi-frequency multi-temporal are required for mapping dynamic systems of periodic flooded area.

Mapping of fire scars

Steep angles allow better discrimination between burned and un-burned forest for crown fire type. Response time is critical for mapping fire scars; hence acquisition should be one during or close to the end of the dry season. The multi-date acquisition increases chances to map fire scars (crown fires) Acquisitions during the fire period (dry state) and early in the wet season provide the optimal SAR dataset.Monitoring and management of forest fires is very important in tropical countries like India, where 55 percent of the total forest cover is prone to fires annually causing adverse ecological, economic, and social impacts [9].

Forest biomass estimation

Forest biomass determination in very important for a carbon sequestration point of view all SAR frequencies, backscatter from the cross-polarized channel consistently has a higher correlation with forest biomass, Microwaves at lower frequencies such as L-band (2.0-1.0 GHz)and P-band (1.0-0.3GHz) are better able to penetrate the canopy and interact more extensively with its structural components (leaves, branches, trunks). Microwaves at higher frequencies(C-band, 3.8-7.5 GHz) tend to interact primarily with the upper portion of the canopy. HV polarization at longer wavelengths can be mere effectively used to characterize forest biomass. SAR backscatter saturates at a biomass that depends on radar wavelength. Due to backscatter saturation, C-band can measure forest biomass up to approximately 200 tha-1Since harvest is often difficult, forest inventory-based biomass assessments are undertaken. A two-stage biomass inventory design employs forest type and density stratification on satellite imagery, followed by on-ground biomass assessment, adopting simple random or stratified random sampling design [6].

Forest species identification

Polari metric data-canopy architecture and the consequent scattering mechanism. Backscatter mechanism – direct backscatter from branches (single bounce/volume scattering), backscatter from trunks (single bounce), scattering from branch-ground interaction (double bounce), scattering from trunk-ground interaction (double bounce), and direct backscatter from the ground (surface scattering). The relative contribution of each of these depends on the nature of the canopy and imaging parameters such as incidence angle and frequency. This help in the identification of forest species in a broad category. Components within the canopy and imaging parameters such as incidence angle and frequency. This helps in the identification of forest species in a broad category. Components within the canopy (leaves and twigs)may play a significant role in the scattering and attenuation interactions depending on frequency. Polari metric data is very useful for forest vegetation characterization and species identification. The suitability and status of sites/forest areas for a particular species of wildlife can also be assessed using remote sensing data using multi-criteria analysis [13].

Data selection for forestry application

Shallow angles provide better discrimination for forestland cover mapping and preserve information on deforested areas (riparian vegetation, regeneration, crop etc.). Steep angles provide a better distinction between forest and non-forest in a flat area. End-of-dry season imagery shows better discrimination between forest land classes, compared with wet season imagery. The wet season allows better discrimination of forestland classes when combined with a dry season acquisition. Multi-date acquisitions (wetland dry season) combined with a texture contrast channel offer the best results. Multi-temporal datasets or dry conditions are prepared (end of the dry season is best). Fine imagine mode should be used to detect roads, fine features, and riparian vegetation. Cross-polarization (HVor VH) provides better discrimination of man-made features (depolarization)

Geographical Information System (GIS)

1. A GIS is a collection of computer hardware, software, and database for capturing, storing, updating, manipulating, analyzing, and displaying all forms of spatially reference data, commonly referred to as different thematic maps (spatial interpolation, integration, exploring relationship between them and finally used in decision making. In the case of watershed planning, resource map, land use map, different socioeconomic map, land capacity classification maps etc. Can be prepared and analyzed in GIS environment to prepare an action plan.

GIS Application in Forest Resource Management:

Creating a spatial database in GIS framework of a different theme, and integrating information to decision making regarding is the main objective for efficient forest resource management.

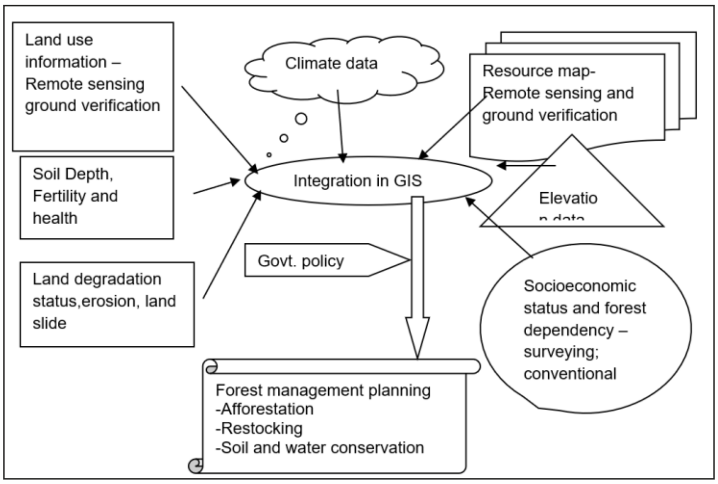

Fig. ***Framework of GIS integration of various information, essential for forest resource management***

The GIS approach has been proved helpful in the operationalization of forest management information gathered through several means for effective forest management. Data input, updating organization of database, retrieval, and analysis for specific forest resource management options of the potential application of GIS. Primary data collection is the task, where GIS role is limited though may be helpful even in planning for data collection. Here caution, that the quality of output of data analysis through GIS will mainly depend on the accuracy/quality of database generated. The collection and creation of database is sole responsibility of user organization or agencies/individuals. The capability of data integration and analysis of GIS may be used as decision support tools for forest management. The database in GIS should necessarily be used for the generation of reliable spatial maps preferably of higher scale (1:25,000 or better). Freely available information especially remote sensing imageries, digital elevation data and other collateral information need to be utilized after verifying for accuracy.

The organization and aggregation of database at block/district level would enhance efficient forest working. Decisions of land use or forest resources management warrants scores of information to be collected and analyzed in a decision-making framework. Creation of forest management information system by means of collecting and integrating reliable data/information in GIS environment is the goal at outset.

Future scope

The main background purpose of consistently and repeatedly supervisor forests over larger areas, it is preferable to use remote sensing data and automated image analysis techniques. Several types of remote sensing data, including aerial photography, multi-spectral scanner (MSS), radar (Radio Detection and Ranging), Lidar (Light Detection and Ranging) laser and Videography data have been used by forest agencies to detect, identify, classify, evaluate and measure various forest cover types and their changes.

Over the past decades tremendous progress has been made in demonstrating the potentials and limitations for identifying and mapping various earth surface features using optical remote sensing data. For large areas, satellite imagery has been shown effective for forest classification, and consequently mapping. It is stressed that one of the advantages of the use of remote sensing in forest survey is the relative short time in which most of the required information can be obtained.

Conflict of interest: The authors declare that the research review was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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