Efficient forest resources management through GIS and remote sensing

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The optimal and efficient management of forest resources call for reliable technologies with a provision to store, update, retrieve and analyse data. Towards this, tools like Geographic Information System (GIS) and Remote Sensing (RS) have been used for decision making and to derive meaningful outputs for plant resources conservation and management. The potential application of GIS is illustrated through various case studies ranging from development of Forest Resources Information System at divisional level to micro-level planning in Joint Forest Management areas. The studies related to plant diversity prospecting, inputs for forest working plans, etc. have also been discussed in the paper.

INDIA has a vast stretch of forests covering about 76.52 million ha as recorded forested area. In terms of legal status, forest is classified into reserved, protected and unclassed which constitute about 54.44, 29.18 and 16.38% of the total recorded area respectively. Since independence, a large portion of forested area was diverted to various non-forestry activities at an annual rate of 0.15 million ha. After the enactment of Forest Conservation Act[1], the forest diversions have been considerably reduced and the present rate of diversion is 16,000 ha annually[2].

The forest resources of the country are under great pressure owing to the increased demands from human and animal population resulting in degradation of our forest eco-systems. This has led to poor productivity and regenerative capacity. Hence monitoring of our forest resources is of great importance[3–6]. Biennial monitoring of the forest cover by Forest Survey of India (FSI) provides forest cover losses at district level. However, various other aspects related to efficient forest management through advanced tools like Geographic Information System (GIS) is minimal and not comprehensively studied at a scale required for initiation of actions. The collection and organization of existing scattered information with a provision to synthesize and update without much additional effort is needed for optimal resources management[7–11]. Similar capabilities are possible only through use of advanced technological tools, viz. Remote Sensing (RS) and GIS[12,13].

The natural resources mapping and monitoring has gained greater impetus with the launch of IRS-1A in 1988 followed by IRS-1B, IRS-1C and IRS-1D. They are providing satellite images of the entire country with enhanced capability to monitor and manage our forest resources[14–16].

The National Natural Resources Management System (NNRMS) of the country, being implemented by Department of Space (DOS), is providing services to various natural resources sectors by optimal integration of technologies and conventional data. The goal of NNRMS is to implement National (Natural) Resources Information System (NRIS) in the country involving the role of RS and GIS in creation, collection and maintainance of large data bank on natural resources and networking them through organized state and district nodes throughout the country for easy accessibility and use in efficient management of our natural resources[17].

In this paper we provide a set of case studies to illustrate the capabilities developed and the feasibility of handling large databases for decision making.

Forest Resources Information System

Effective forest resources management at the state level calls for Forest Resources Information System (FORIS) constituting spatially accurate, up-to-date forest cover details at the divisional level with a provision to hierarchically retrieve forest resources. FORIS differs from Management Information System (MIS) in integrating administrative and financial aspects along with forest resources information at various levels. Towards this end, the foremost requirement is to generate and organize both spatial and non-spatial forest resources data in the GIS domain[18–20].

As an example, we discuss FORIS developed for Sirsi forest division, Karnataka designed using Arc/Info v 7.0.3 on an IBM workstation. The various spatial themes created in the GIS were infrastructure, forest types, forest stock, drainage, slope, aspect details for the entire division. The non-spatial information created includes organized forest inventory in 131 locations providing enumeration and descriptive details on each plot and socio-economic data on about 700 villages from 1991 census obtained from NICNET. In addition to these

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details on the plot, the secondary derived variables given were volume per ha, basal area, number of trees per ha, forest type and cover stratum it belongs to.

The spatial and non-spatial data for the entire Sirsi division created on administrative and management hierarchical structure in the data base enabled in querying information on resources availability at various levels. The information generated as explained above is through top to bottom data integration. However, FORIS has provision to query bottom-up or across any level. The working of the FORIS is described in Figure 1. The following examples illustrate how one can query the requisite information from the created FORIS at various levels: I. Divisional level details on forest type, stock, etc. (Figure 2 shows the forest stock distribution of Sirsi division); II. Block level summary on areas, percentage area under notified forest, standing volume, etc. (Table 1 shows the details on blockwise areas and total growing stock of Sirsi); III. Block level details (Figure 3 shows blocks and compartments in a division and Table 2 shows the stratumwise volumes in a given block); IV. Compartment level details (Figure 4 shows distribution of compartments and their areas and Figure 5 shows forest type distribution and their area statistics); V. Plot level details (Table 3 shows the details of inventoried locations and the plot level estimates); VI. Details for a selected geographical extent (Figure 6 shows a 1 : 25,000 toposheet equivalent of forest stock distribution).

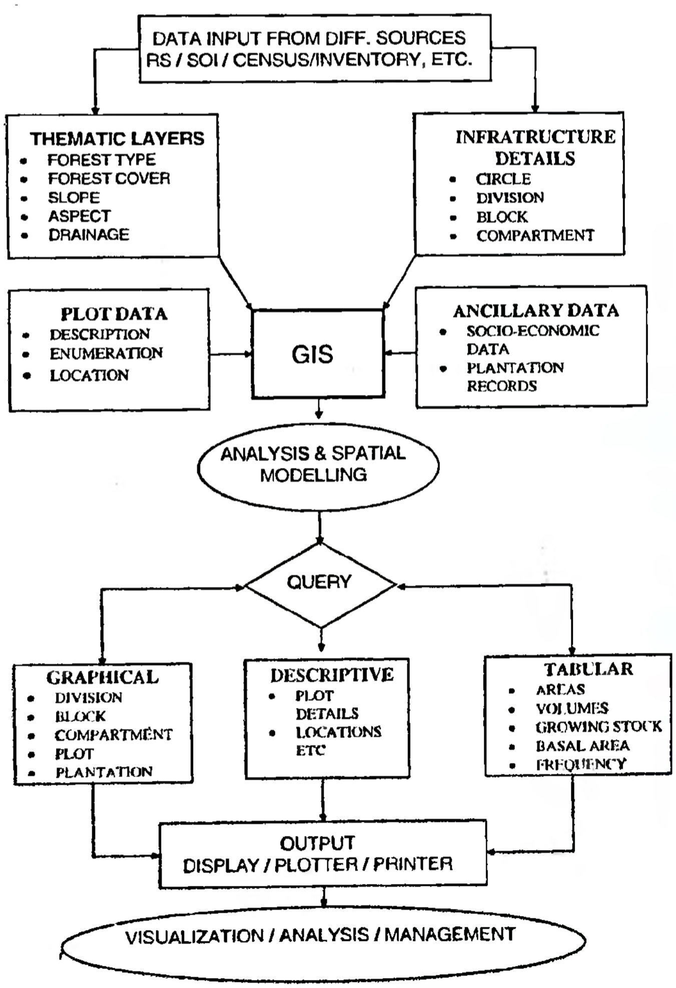

Figure 1. Flow chart showing the organization of Forest Resources Information System.

Thus, GIS facilitates as a tool for decision support. Similar efforts are to be made independently in all the divisions and subsequently the circles culminating in generating a state level FMIS on the lines of NRIS, which is being implemented by the Department of Space.

Monitoring and evaluation on the performance of people's participatory programmes at regional scale

Sequel to the National Forest Policy (1988), the forest management has widened the scope for people's participation in protection and conservation of forests[21,22]. This has enabled so far in 13 states of the country in the formation of Joint Forest Management (JFM) areas in the notified forests. Besides this, some states like Andhra Pradesh, in the marginal areas of revenue lands also people's participatory programmes are being initiated in the form of Vana Samrakshana Samithis (VSS), essentially a part of JFM activity[23,24].

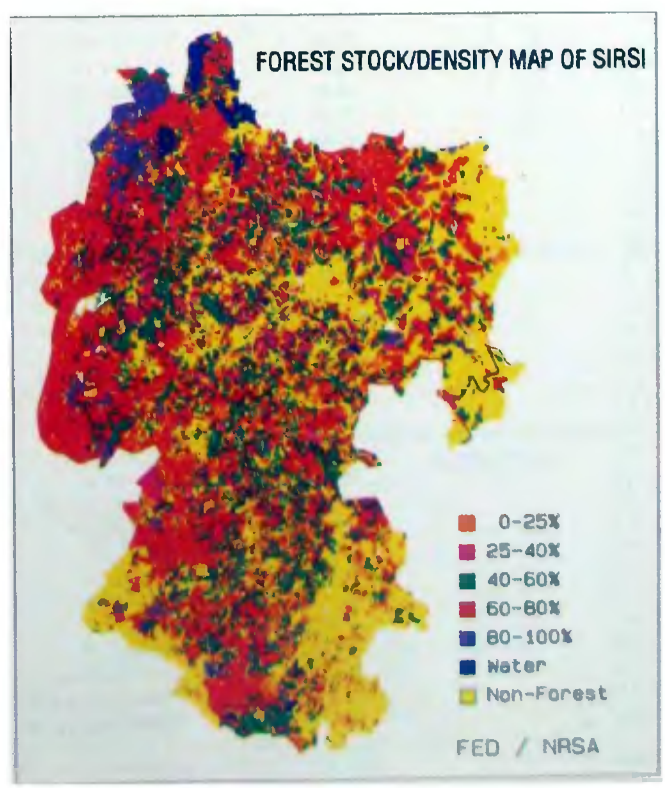

Figure 2. Forest density map of Sirsi forest division.

The JFM areas need to be qualitatively monitored and periodically evaluated for assessing the progress of JFM process. Such a large scale statewide monitoring of VSS, involving 3400 areas in Andhra Pradesh alone, is technically feasible through the use of IRS-1C/1D WiFS data. The WiFS data with its wide synoptic coverage of 810×810 km and review capability of every 5 days over any part of the region enhances the capability in temporal monitoring. The development of pre-identified and labelled VSS areas can be evaluated through vegetation index as a parameter to provide the greeness condition. This, however, has to be preceded by a baseline year data of the VSS areas. Subsequently, the monitoring of the VSS areas annually and comparing with the base year shows gradients in the greeness condition of different areas qualitatively. These areas will be indexed as the areas of progress and areas requiring attention. The state level GIS-based micro-plan evaluation contributes in making priorities and taking remedial actions strategically for the successful implementation of JFM.

Table 1. Sirsi division – Blockwise volumes

Block	Area (km^2)	Total volume (m^3)
I	41.97	521242.75
II	46.89	720741.35
III	83.57	1137888.21
IV	35.78	1070296.83
V	77.88	3738515.86
VI	86.27	1876449.74
VII	14.63	200848.16
VIII	27.81	514647.82
IX	41.80	648897.59
X	31.84	583532.60
XI	56.44	964547.85
XII	30.83	583590.36
XIII	21.08	368838.85
XIV	18.78	320967.73
XV	29.92	558560.92
XV	127.88	510341.67
XVII	42.31	933647.88
XVIII	26.015	54807.93
XIX	28.96	594265.67
XX	20.41	240165.84
XXI	13.62	542519.52
XXII	11.60	192154.02
XXIII	79.24	1028750.44
XXIV	53.72	608547.78
XXV	35.10	420791.67
XXVI	56.01	656169.72
XXVII	10.99	264106.49
XXVIII	134.37	2505767.90
XXIX	35.51	677672.55
XXX	58.00	1115913.40
XXXI	24.98	525670.25
XXXII	52.89	936177.43
NBA	245.25	3264582.64
Total	1602.40	29381619.40

Mean volume = 183.36 m^3/ha.

Forest cover mapping and assessment

Biennial mapping of country's forest cover is being undertaken by Forest Survey of India through satellite data using visual interpretation techniques. So far assessment of forest cover has been made for the entire country six times successively. Table 4 gives the State of Forests showing forest cover distribution in the country.

An example of forest change assessment in parts of Adilabad (AP) is shown in Figure 7, which has been automated in GIS for successive mapping exercises. The cumbersome repeated exercise of manually interpreting, estimating areas and comparing with the previous estimates for change assessment involves an enormous effort and suffers from registration problems to bring out change maps[25,26]. This can be tackled in the GIS using automated change detection procedures for generation of change maps with precise area estimates on a time and reliable basis[27–36].

Inputs for preparation of forest working plans

The forest management plans conventionally are prepared for each forest division with 5–10% of sampling intensity for ground inventory involving 3–5 years of time frame. The management plan documents provide inputs on the sustainable yield measures for ensuring ecological stability. Working plan reports contain a historical account of the previous plans, administrative and financial operations as part I, while part II deals with quantitative aspects on stand and stock tables, yield regulations, etc.[37–39].

The entire operational procedure for generating inputs to management plans through remote sensing-based forest

Table 2. Blockwise stratum volume estimations

Stratum	Area (km^2)	Total volume (m^3)
M/1-1	0.59	4986.06
M/1-2	0.19	1607.56
M/2-1	0.57	6063.31
M/2-2	2.50	28269.78
M/2-3	0.52	6070.31
M/3-1	0.13	1140.08
M/3-2	1.43	19159.79
M/3-3	0.31	4958.76
M/3-4	1.58	4997.90
M/4-4	2.76	61525.16
BM/3-4	0.21	3785.54
MB/3-4	1.06	19306.27
MB/3-5	0.58	10599.52
MB/4-4	0.52	12059.17
MB/4-5	0.21	4823.67
PT	1.11	8284.94
AC	0.35	3410.31
Total	14.63	200848.16

inventory sampling and analysis could be automated in a GIS. The availability of high resolution satellite data of LISS III and PAN from IRS 1C/1D provide detailed type strata (phase I) and cover strata (phase II). These themes when incorporated in GIS help in optimizing sample point allocation up to compartment levels with a predetermined sample size[40–42]. The sample allocation in GIS increases the precision while reducing the tedious procedure of locating and transferring the inventory points on to a map. This information facilitates in identifying the exact location on the ground using Global Positioning System (GPS) for detailed ground enumeration. This enhances the accuracy in the estimations.

The plotwise esimated volume, basal area and frequency according to the type/cover stratum it belongs to, could be integrated and estimated in a bottom-up manner from a stratum, compartment, block and thereby to the divisional level with appropriate extrapolation procedures. Essentially, GIS reduces cumbersome aspects of area estimation under different hierarchical level and enhances the fidelity of the data while preserving accuracy and ease in computation. Besides this, the quatitative details along with their respective spatial outputs could be useful in visualization and offer various management options. An example of obtaining circle level management requirements in terms of divisionwise estimates is given in Table 5.

Forest type mapping

The nationwide information on forest type distribution prepared by Champion and Seth[43] in 1968 shows various forest types and the vegetation formations in the form of 16 types. This can neither provide spatial maps nor facilitate spatial integration of collateral data. So far no systematic attempt has been made to provide forest type status of India. The studies carried out by French Institute of Ecology[44] on the vegetation distribution has not been covered for the entire country. Such maps are required for the monitoring of biodiversity and changing landscape[45–47].

A programme towards this has been implemented in the GIS for Uttara Kannada district of Karnataka. By integrating spectrally separable broad forest types from the satellite data (Figure 8), climatic data on rainfall, temperature and physiography, the bioclimatic zones (Figure 9) have been delineated. These zones when integrated and extrapolated spatially using the taxonomic data collected on ground provided different sub-type formations under each forest type stratum (Figure 10). The availability of such bioclimatic-based forest maps in GIS would enhance the capability at the national level to account changes occurring in the natural forest system due to increased artificial management practices.

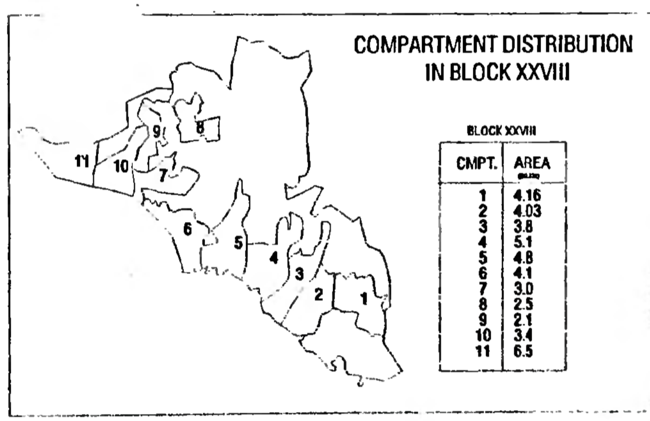

Figure 4. Compartment level details showing their distribution and area statistics.

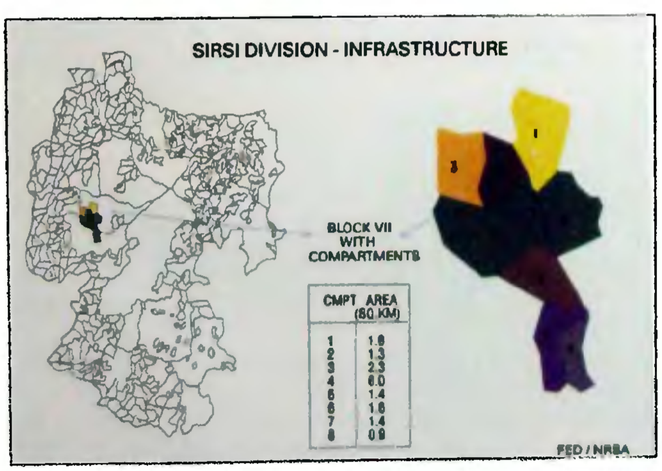

Figure 3. Block level details showing compartment distribution and their area statistics.

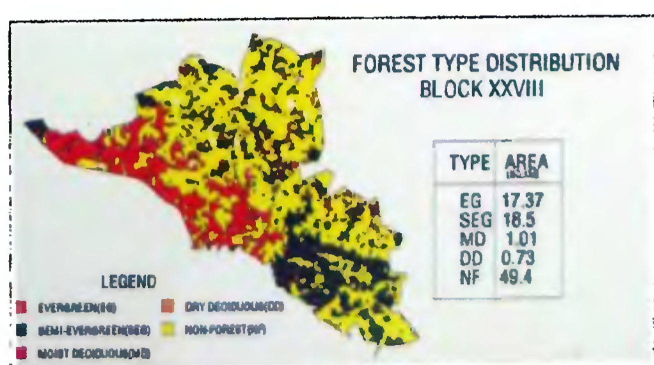

Figure 5. Forest type distribution and their area statistics in a given block.

Sites of biological importance

Utilizing the forest type maps (Figure 10) and field floristic data, the areas with rich biological diversity can be established in GIS. Depending on the species rarity or species of importance, it is possible to flag the areas in the GIS as sites of biological importance[48-50]. Identification of such biological sites facilitates searching of probable biogeographical areas for locating or reintroducing such important floristic components in the suitable habitats. The GIS-based conditional search, especially for sandalwood, red sanders, Dipterocarpus tree species, etc. can be searched in GIS from a known location and extending to other areas of suitable habitats[51-54].

The application of similar such endemic species flagging with geographic locations is best feasible in the GIS and implementable for threatened and endangered species of the country as identified by the Botanical Survey of India (BSI) in the form of red data book[55,56].

Identification of potential JFM areas and sustainability assessment

The availability of high resolution satellite data from IRS-1C/1D LISS III and PAN enhanced the resources mapping capability up to 1 : 15,000 scale. Such large scale data on forest cover showing various density levels, particularly the understocked areas having less than 20% crown cover (< 25% in Karnataka) are being considered as the potential JFM areas. The forest cover data organization and integration of other collateral data in GIS and analysed through a rule-based model help in generating forest zonation maps, viz. conservation

Table 3. Plotwise details

Sample no.	Block	Stratum	Lat.	Long.	Volume (m^3/ha)	Frequency (per ha)	Block area (m^2/ha)
36	XXXII	M/4-4	14°29′00″	74°39′20″	262.20	620	37.98
37	XXXII	M/4-5	14°28′30″	74°38′30″	220.27	460	27.64
38	XXXII	M/3-4	14°29′30″	74°39′30″	253.62	620	29.60
39	XXXII	MT/3-4	14°29′50″	74°39′30″	250.43	710	32.27
40	XXXII	M/3-4	14°29′30″	74°42′20″	315.70	800	43.18
41	XXXII	M/1-1	14°29′00″	74°42′00″	36.97	180	4.53
42	XXXII	M/3-4	14°27′50″	74°43′10″	242.49	540	32.17
43	XXXII	M/2-4	14°25′50″	74°43′20″	174.46	770	22.26
44	XXXII	M/3-4	14°25′10″	74°41′10″	251.71	470	35.90
45	MFS3	M/4-3	14°28′40″	74°42′00″	249.53	790	32.47
46	XXXI	M/5-4	14°23′55″	74°44′40″	133.14	540	19.22
47	XXVIII	M/2-1	14°20′20″	74°42′10″	248.19	200	39.98
48	XXIX	M/4-4	14°21′20″	74°44′30″	111.27	450	13.29
49	XXX	M/3-4	14°20′50″	74°38′40″	262.26	580	36.94
50	XXVIII	M/3-3	14°19′05″	74°44′20″	111.92	460	13.15

Table 4. Status of forest cover (percentage) in India based on satellite remote sensing (Area in million ha within parentheses)

Forest category	Years/No. of assessment						
	1972–75 NRSA	1981–83 1st	1985–87 2nd	1987–89 3rd	1989–91 4th	1991–93 5th	1993–95 6th
Dense	14.12 (46.55)	10.99 (36.14)	11.51 (37.84)	11.71 (38.50)	11.72 (38.55)	11.73 (38.57)	11.17 (36.72)
Open	7.38 (24.28)	8.41 (27.65)	7.83 (25.74)	7.60 (24.99)	7.61 (25.04)	7.59 (24.93)	7.95 (26.13)
Mangrove	0.10 (0.30)	0.12 (0.40)	0.13 (0.42)	0.13 (0.42)	0.13 (0.42)	0.14 (0.45)	0.15 (0.48)
Total	21.60 (71.03)	19.52 (64.20)	19.47 (64.01)	19.44 (63.92)	19.47 (64.01)	19.46 (63.96)	19.27 (63.34)

Source: SFR (1997), FSI (MOEn & F).

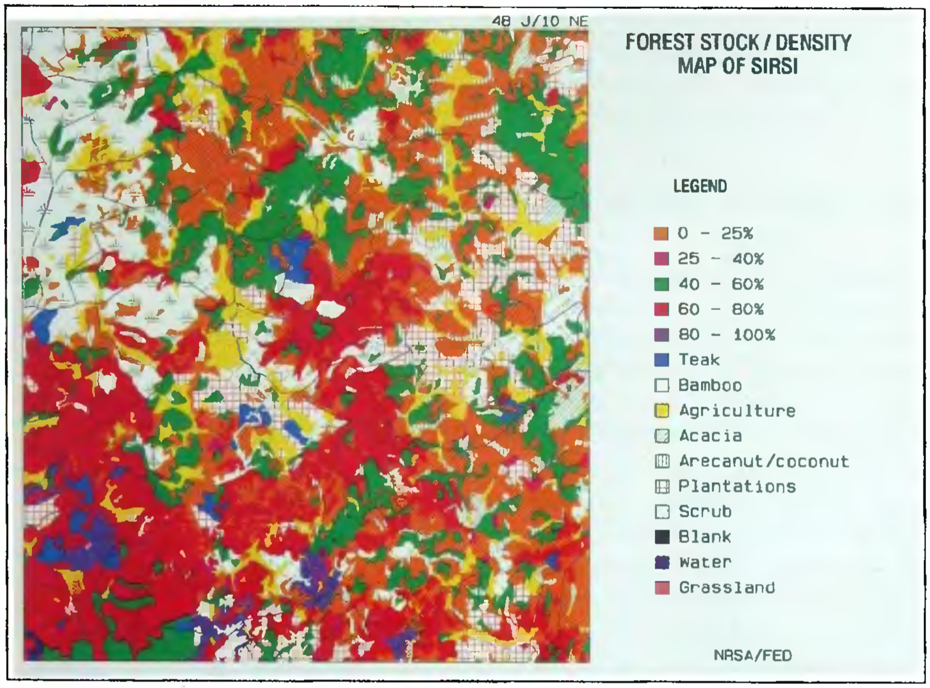

Figure 6. Forest density map for a selected geographical extent.

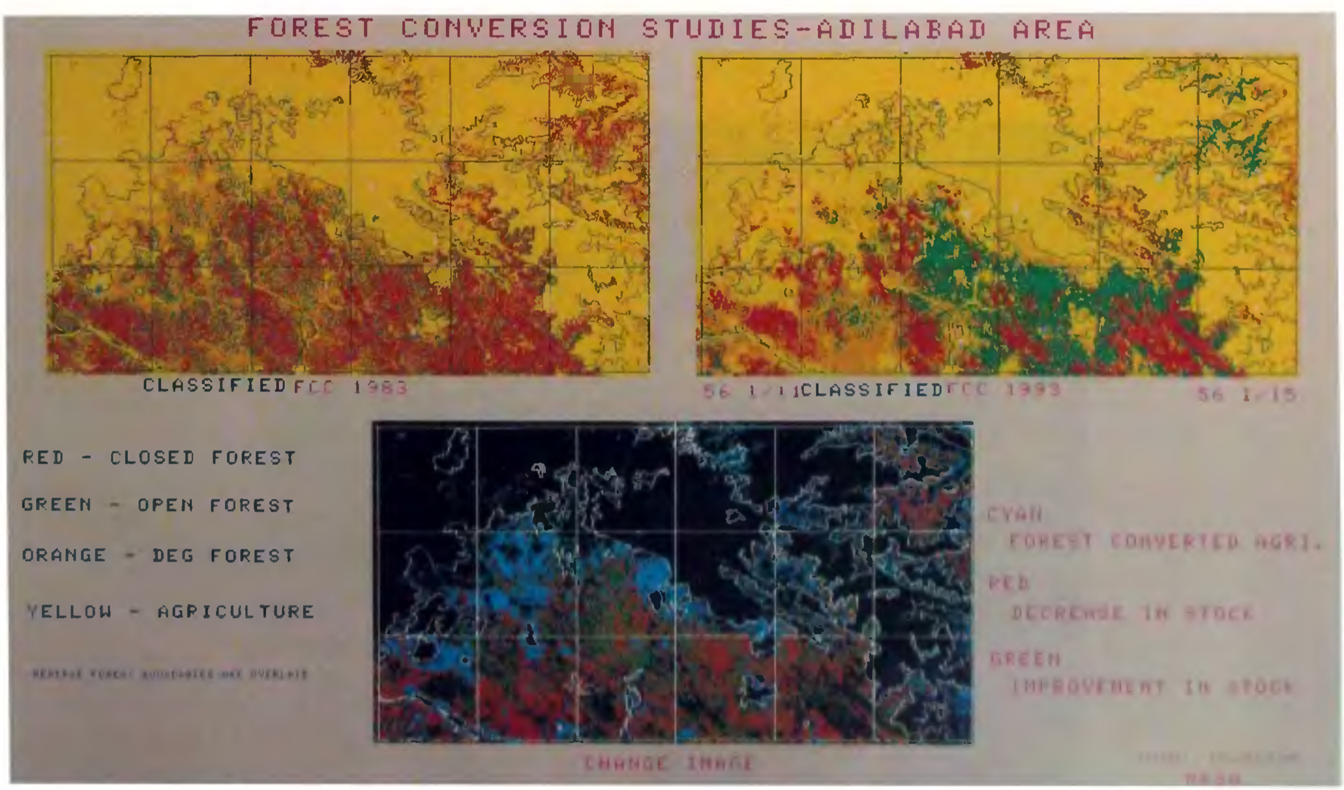

Figure 7. Change assessment in parts of Adilabad (AP).

Table 5. Uttara Kannada circle – Summary of the forest inventory and timber volume estimates

Division	Area represented	Total estimated volume (million m^3)	Reliability at block* (%)	Reliability at division* (%)
Sirsi	0.0005	22.09	92	99
Honnavar	0.0007	33.59	95	98
Haliyal	0.0005	37.14	90	98
Karwar	0.0005	22.79	90	98
Yellapur	0.0007	29.49	90	99

Division	Max. vol. (m^3/ha)	Min. vol. (m^3/ha)	Max. freq.	Min. freq.	Max. block area (m^2)	Min. block area (m^2)
Sirsi	392.52	18.39	960	20	43.18	2.27
Honnavar	476.00	10.47	940	20	65.17	0.27
Haliyal	444.28	10.83	1240	50	52.09	0.84
Karwar	484.95	9.09	1030	70	52.34	0.90
Yellapur	496.69	8.38	1260	60	71.99	0.62

Division	Mean vol. (m^3/ha)	No. of blocks above mean	No. of blocks below mean	Mean block area (m^2)	Mean freq.
Sirsi	158.94	20	12	20.57	362
Honnavar	187.08	44	3	23.67	387
Haliyal	164.02	16	11	20.80	377
Karwar	176.84	45	21	23.28	473
Yellapur	199.08	20	16	24.80	402

Uttara Kannada circle estimated mean volume = 172 m^3/ha.
Uttara Kannada circle estimated mean basal area = 22.6 m^2/ha.
Uttara Kannada circle estimated mean no. of trees = 400/ha.
Total no. of blocks = 208.
No. of blocks above mean volume = 108.
No. of blocks below mean volume = 100.
*Reliability as a measure of accuracy has been computed as a percentage of the estimate to its standard error.

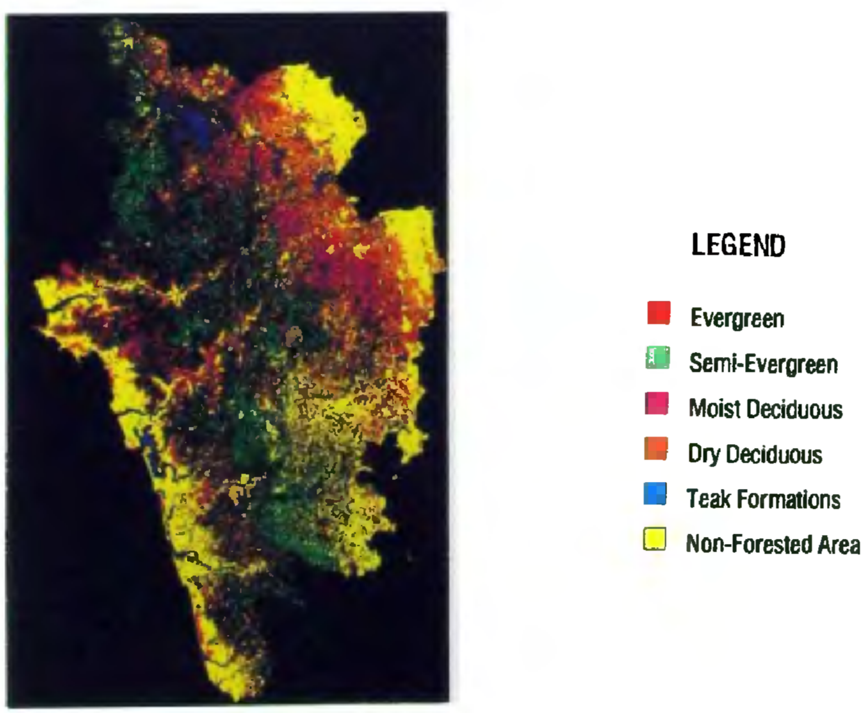

Figure 8. Forest type map of Uttara Kannada.

(zone I), protection (zone II), manipulation (zone III) and JFM areas (zone IV). The zone IV areas in association with village locations and their population of human and livestock facilitate to organize the priority areas for VFC formations in GIS.

Besides the above, using the simple spatial prognostic models in GIS and MAI (mean annual increment), the area can be projected for its fuel and fodder potential and demand by human and livestock. When the JFM programmes are implemented successfully, it is possible to project the supply–demand scenarios for the next 25–50 years highlighting areas needing management intervention[57–59]. The detailed study with examples is also presented in the current issue.

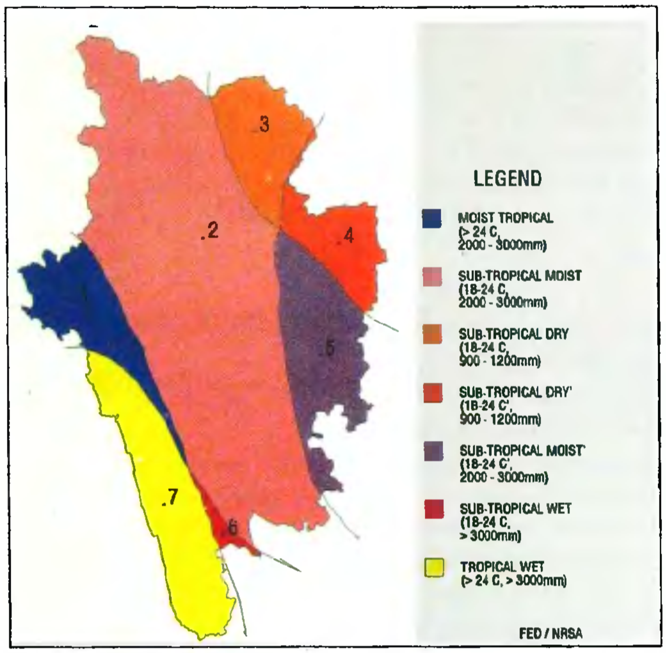

Figure 9. Bioclimatic zones of Uttara Kannada.

Catchment area treatment plans

The forested areas in the country largely represent the major catchments providing means of sponging water and in ensuring perpetual water seepage into the downstream. Besides this, depending on the environmental conditions and favourability, several catchments in the country largely dictate and regulate flash floods occurring in the major rivers, and serve as sources for locating hydro-power projects/irrigation reservoirs. The areas requiring control measures for reducing runoff and soil erosion are technically feasible by identifying areawise catchment treatment plans (CTPs) for subsequent detailed measures on the ground.

A study has been carried out for Rangit Hydro Power Project in Sikkim to suggest various area-specific treatments in terms of contour bunding, binding, runoff diversion zones, landslide-prone areas, gap filling, afforestation, river bank erosion areas, gully plugging, etc. utilizing a GIS-based modelling with case specific Condition Search Algorithm for each treatment. An example of this on runoff diversion sites identified through the model in GIS is shown in Figure 11.

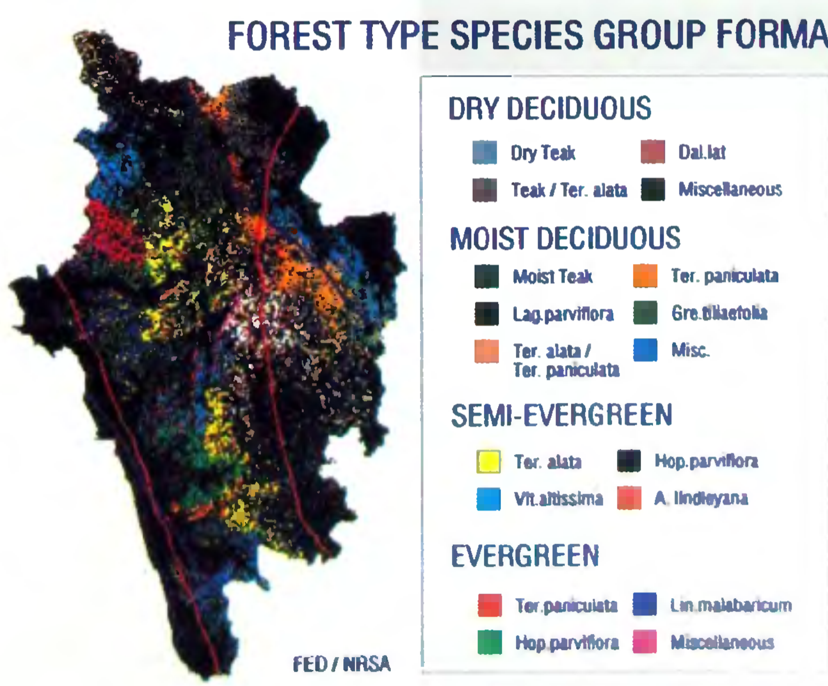

Figure 10. Forest type species group formations in Uttara Kannada.

The GIS-based spatial analysis in all the major river catchments of the country provides area specific Catchment Treatment Plans. These plans help in periodically evaluating and monitoring the catchment properties to harness higher yields of water resources.

Plant bioprospecting zones

India, by virtue of its varied climates and latitudinal gradients exhibits most possible diverse ecosystems enriched by large biological diversity[60]. The tropical

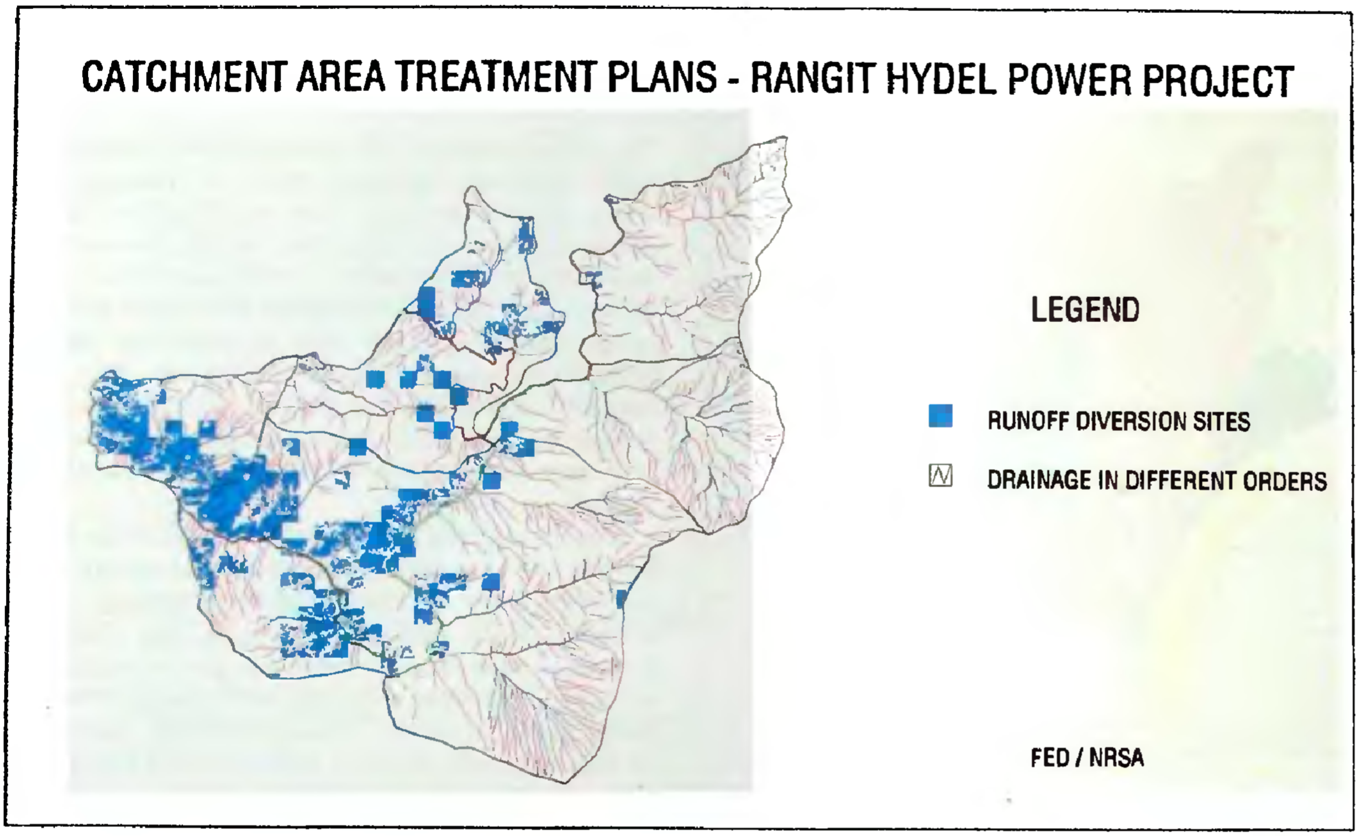

Figure 11. Proposed run-off diversion sites in a micro-catchment area of Rangit, Sikkim.

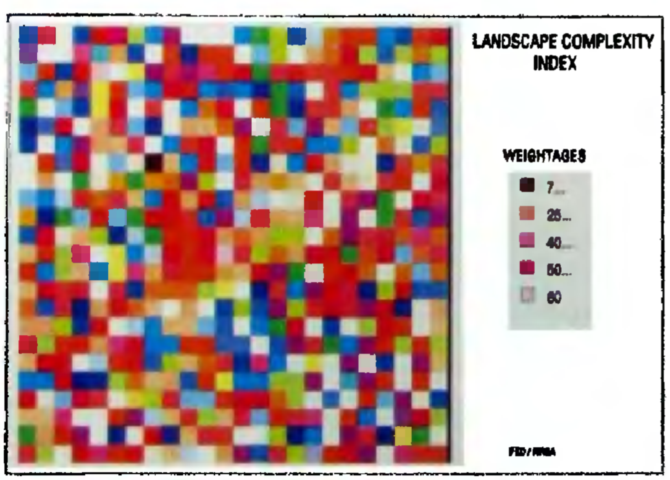

Figure 12. Landscape complexity map of the study area in parts of Uttara Kannada.

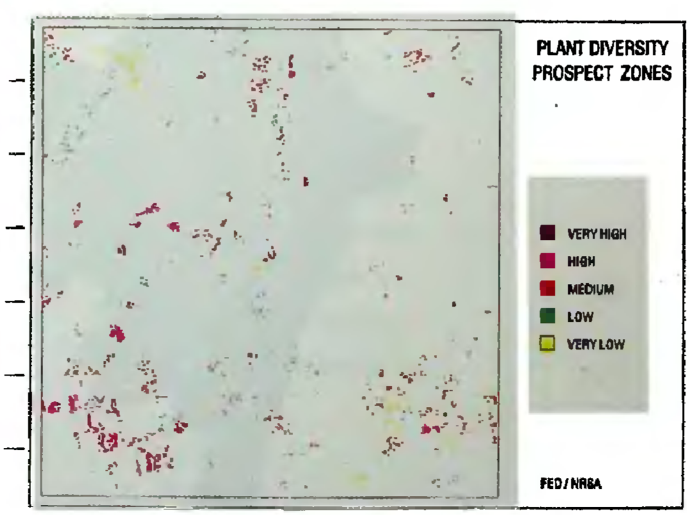

Figure 13. Probable plant diversity zones derived through landscape analysis.

climate adding further to the complexity, resulted in identifying India as one of the 12 megadiversity spots. Also, out of the 18 ecological hot-spots of the world, two of them, viz. Western Ghats and northeastern Himalayas, are in India. It is estimated that about 45,000 plant species form the plant diversity component of India[61–63].

Identification and categorization of probable biologically diverse zones at landscape level could be achieved through spatial modelling using landscape complexity measures derived from patch characteristics (richness, frequency, shape, etc.) of the vegetation, patch type contiguity index (searching purity of pixels belonging to the same type or in permutation in a 3×3 window) and physiography[64–70]. Figures 12 and 13 show examples of spatially derived landscape complexity map and the plant diversity prospect zones in parts of Uttara Kannada.

Summary

The critical issues requiring efficient forest resources management and assessment calls for better characterization of vegetation at various spatial scales and levels. This requires an efficient decision support technology with a provision for easy updating, integrating data from various sources in different formats. Relational database handling of non-spatial attributes, analytical tools to generate information with various combinations, retrieving facility in the form of maps, tables, etc. is possible through GIS. The various case studies highlighting the advantages of GIS, particularly in characterizing the plant resources ranging from resources information systems to micro-level planning and biodiversity prospect zoning have been discussed along with examples. The paper emphasized the importance and stressed the need for integration of plant resources information in the GIS for better visualization and interpretability in optimal planning and management of our forest resources.

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