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Spatial characteristics of vegetation cover based on remote sensing and geographical information system (GIS)

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Abstract: The pattern of vegetation distribution on ground is always associated with particular topographic features. In order to understand the relationship between altitude, degree of slope and drainage network on one hand and the vegetation cover on other, topographical maps and Indian Remote Sensing satellite images (IRS-1A) on 1:50,000 scale were studied and IDRISI Geographical Information Software was used. The images were acquired in December 1989 and December 1990. This exercise demonstrated the control of elevation (altitude), relief and drainage on the spatial distribution of vegetation cover. The biotic factors are also responsible for the spatial distribution of vegetation. The vegetation of this area is mixed dry deciduous with few moist deciduous elements. The interpretation of satellite images resulted into five vegetation classes and GIS analysis indicates that the very dense forest was mostly confined to interfluve areas at variable relative relief, but particularly at higher elevation i.e. 400 and 800 m ASL. Open forests were found to be associated with settlements and agricultural fields. The sparse vegetation was common on interfluves and along nallas at high elevation. These results were strongly supported by ground surveys at selected locations.

Resumen: El patrón de distribución de la vegetación sobre el terreno suelo siempre está asociado a rasgos topográficos particulares. Con el fin de entender la relación entre altitud, pendiente y red de drenaje, por una parte, y la cubierta vegetal por la otra, se estudiaron mapas topográficos e imágenes de satélite de percepción remota de la India (IRS-1A) a escala 1:50,000, y se utilizó el paquete IDRISI de Información Geográfica. Las imágenes fueron adquiridas en diciembre de 1989 y diciembre de 1990. Este ejercicio demostró el control de la elevación (altitud), relieve y drenaje sobre la distribución espacial de la cubierta vegetal. Los factores bióticos son también responsables de la distribución espacial de la vegetación. La vegetación de esta área es seca, mixta, caducifolia, con pocos elementos caducifolios subhúmedos. La interpretación de las imágenes de satélite permitió distinguir cinco clases de vegetación, y el análisis de SIG indicó que el bosque muy denso estuvo mayormente confinado a áreas interfluviales con un relieve relativo variable, pero particularmente a elevaciones mayores, i.e. 400 y 800 m s.n.m. Se encontró que los bosques abiertos están asociados a asentamientos humanos y campos agrícolas. La vegetación rala fue común en los interfluvios y a lo largo de los arroyos en elevaciones mayores. Estos resultados estuvieron fuertemente apoyados por prospecciones de campo realizadas en localidades selectas.

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Resumo: O padrão de distribuição da vegetação no solo está sempre associado com as características particulares da topografia. Com o fim de perceber a relação entre a altitude, o grau de declive e a rede de drenagem por um lado e a cobertura de vegetação pelo outro, foram estudados mapas topográficos e as imagens do satélite Indiano de controlo remoto (IRS-1A) numa escala de 1:50.000 usando a aplicação informática de informação geográfica IDRISI. As imagens foram adquiridas em Dezembro de 1989 e Dezembro de 1990. Este exercício demonstrou o controlo da elevação (altitude), o relevo e a drenagem na distribuição espacial do coberto vegetal. Os factores bióticos também são responsáveis pela distribuição espacial da vegetação. A vegetação desta área é uma mistura seca e decídua com poucos elementos húmidos decíduos. A interpretação das imagens de satélite gerou cinco classes de vegetação e a análise GIS indicou que a floresta muito densa estava confinada principalmente às áreas de interflúvio a níveis de relevo relativo variável, mas particularmente a altitude elevada i. e. 400 e 800m ASL. Encontrou-se que as florestas abertas estavam associadas com núcleos de povoamento e campos de cultura. A vegetação esparsa era comum nos interflúvios e ao longo das "nallas" a grande altitude. Estes resultados estão fortemente apoiados por amostragens de campo em locais seleccionados.

Key words: Akkalkuwa tahsil, GIS overlay analysis, remote sensing, vegetation cover.

Introduction

Timely and accurate information on natural resources is a prerequisite to their optimal utilization and effective manage- ment, particularly of remote and inaccessible areas. There is a need to obtain reliable data on vegetation resources at regional and micro-levels, which would help in planning forest management strategies for sustained yield and would benefit the society. Vegetation is the overall effect produced by abundance or scarcity or even diversity of the plant life.

Vegetation maps at community level are often useful in order to understand and explain vegetation occurrences and patterns. Vegetation mapping using interpretation of satellite remote sensing data provides qualitative characteristics of vegetation and can be adjusted to the requirements/objectives of the survey (Kuchler 1988). Ground-truthing is always required to verify the accuracy of vegetation classification.

Geographical Information Systems (GIS) is increasingly being used in the forest and vegetation studies. This requires reliable and up-to-date information on the extent, distribution and use of forest resources in time and space. Integration of remote sensing data and GIS is facilitated by a number of developments. Many workers (Danson 1987; Foody & Wood 1987; Woodcock *et al.* 1994; Young & Green 1987) have used remote sensing and GIS technique for mapping vegetation cover.

Ground data are used both for calibration and the subsequent accuracy assessment of the classified image. Its quality is, therefore, of fundamental importance. The technique of classification for land use/land cover with special reference to forest type mapping (Sudhakar *et al.* 1999), biodiversity studies (Prasad *et al.* 1998), vegetation discrimination (Prasad *et al.* 1999), habitat analysis (Pant *et al.* 1999) and land use/land cover mapping and change detection using satellite data have been carried out by Minakshi & Sharma (1999).

The objectives of the present study are:

1. To prepare map showing the spatial distribution of vegetation cover.
2. To survey the vegetation cover in the field for correlation.
3. To evaluate the relationship between vegetation cover and physiographic characteristics.

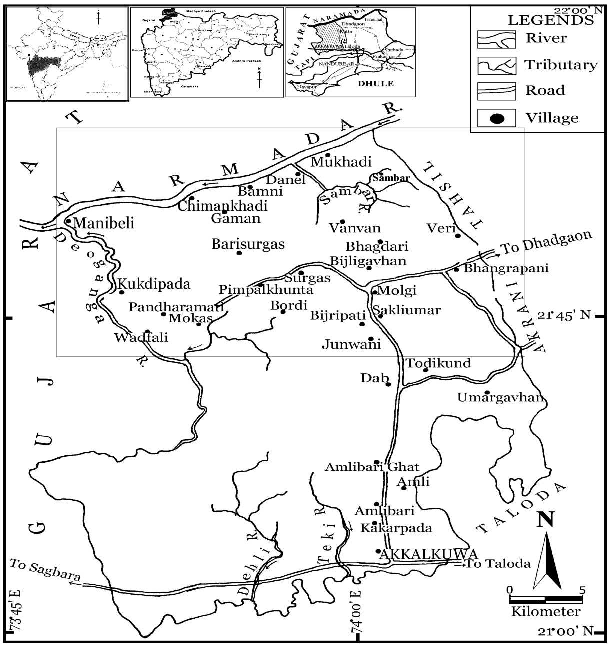

Fig. 1. Location map of the study area.

Study area

The study area (Akkalkuwa tahsil) is located between Tapi and Narmada rivers in the northwest part of Nandurbar district, Maharashtra, India. It lies between 73°45' and 74°15' E latitude and 21°30' and 22°00' N longitude (Fig. 1). It comprises an area of 846 km^2. The area is covered in Survey of India topographical maps 46G/13, 46G/14 46K/1 and 46K/2. The gradient of the area is from east to west. Being a mountainous region with rugged topography, most of the settlements are not easily accessible. The Akkalkuwa town and villages like Dab and Molgi are the main settlements.

The study area lies in the lower part of the Tapi valley and is separated from western Maharashtra by the valley of Godavari. The area is situated between various parallel ranges of Satpudas, which are an extension of the spurs of Sahyadris and lie in continuation with the trends of Vindhyas. The area forms a part of the Deccan Volcanic Province (Gunale *et al.* 1997) with a distinct topography, which is highly dissected, with umpteen numbers of cancerous gullies. The area drains into the Narmada and Tapi rivers through their large number of tributaries. In general, the climate of the area is tropical wet-dry and receives rains from southwest monsoon. The soils are deep black to shallow black brown and alluvial soils of southern regions. The main community of the area is mostly tribal. The population density of the area is about 115-150 persons km^{-2}.

Materials and methods

Geomorphic data were obtained from the Survey of India topographical maps. Satellite imageries were analyzed for exploring the information on vegetation characteristics. The ground surveys were carried out for studying the plant community composition.

Morphometric data from topographical maps

Data regarding drainage network, elevation and relative relief were generated by, covering the study area with a grid mesh of size 500 m x 500 m, overlaid on Survey of India topographical maps (46G/13, 46G/14, 46K/1 and 46K/2 on 1:50,000 scale). Different categories of above parameters were created and for each category a score was assigned (Table 1).

Interfluve is the ridge or high ground between two adjacent nallas, streams or rivers.

Table 1. Categories of drainage, elevation and relative relief and a score for each.

Drainage	Score	Elevation (ASL in meters)	Score	Relative relief (m)	Score
Interfluve area	0	<200	1	0-50	1
River	1	200-400	2	50-100	2
Stream	2	400-600	3	100-150	3
Nallas	3	600-800	4	150-200	4
		800-1000	5	200-250	5
		>100	6	250-300	6
				300-350	7

The interfluves are generally characterized as an un-dissected land drained by lower order stream and gullies. Nallas are smaller than streams and represent large rocky or alluvial gullies. Such lower order streams are highly ephemeral in nature, and flow only during or after heavy monsoon rains. Relative relief is the measure of relief amplitude. Higher relative relief indicates steeper slopes and rugged topography, and low relative relief is characterized by undulating and gently sloping landforms. The data derived from topographical maps have been used to prepare three sets of maps that were used in the GIS environment to understand the nature of distribution of existing vegetation cover.

Fig. 2 shows absolute elevation of the study area. The drainage map was prepared based on the data obtained from Survey of India topographical maps. In the Fig. 3, three drainage types are shown i.e. rivers, streams, and nallas or interfluves area.

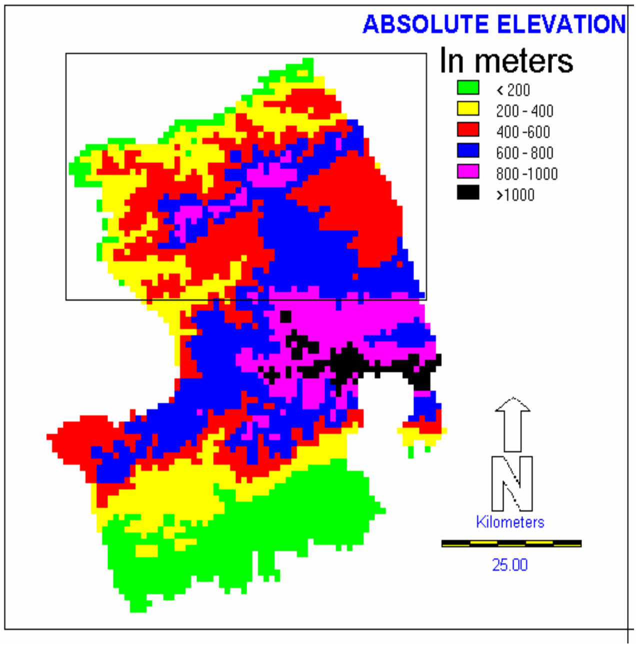

Fig. 2. Absolute elevation map of the study area.

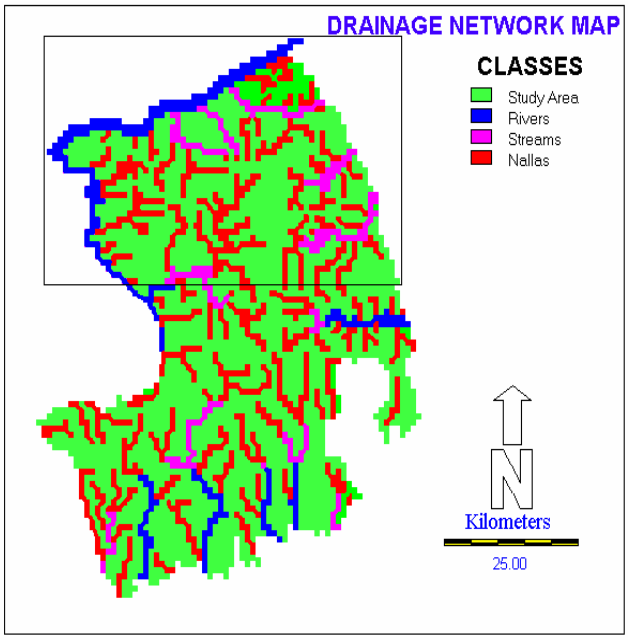

Fig. 3. Drainage network map of the study area.

Interpretation of satellite imageries

In order to understand the relationship between altitude and drainage network on one hand and the vegetation cover on other, topographical maps and Indian Remote Sensing satellite images (IRS-1A) on 1:50,000 scale were studied and analyzed. The images were acquired in December 1989 and December 1990. The imageries were geocoded. The imageries cover only the northern part of the study area.

The same mesh of 500 m x 500 m, which was used to extract the information from Survey of India topographical maps, was also used for deriving information about the vegetation classes from the satellite imageries. Satellite imageries were analyzed based on visual interpretation. Data were generated by, covering the study area with the same grid mesh of size 500 m x 500 m. The textural characteristics of vegetation stands are likely to provide information with respect to species richness and diversity (Prasad *et al.* 1998). Accordingly, five forest categories were identified based on the colour tone and texture on the imagery. Homogenous vegetation stands were delineated through visual interpretation of the satellite imageries. Based on visual interpretation of the satellite imageries, the vegetation has been classified into different forest density classes such as forest density <10%, 11-20%, 21- 40%, >40% and barren/exposed land and each category was assigned a score as 1, 2, 3, 4 and 5 respectively.

The IRS false colour composites (FCCs) for the year 1989 and 1990 provided the information about the land use and land cover

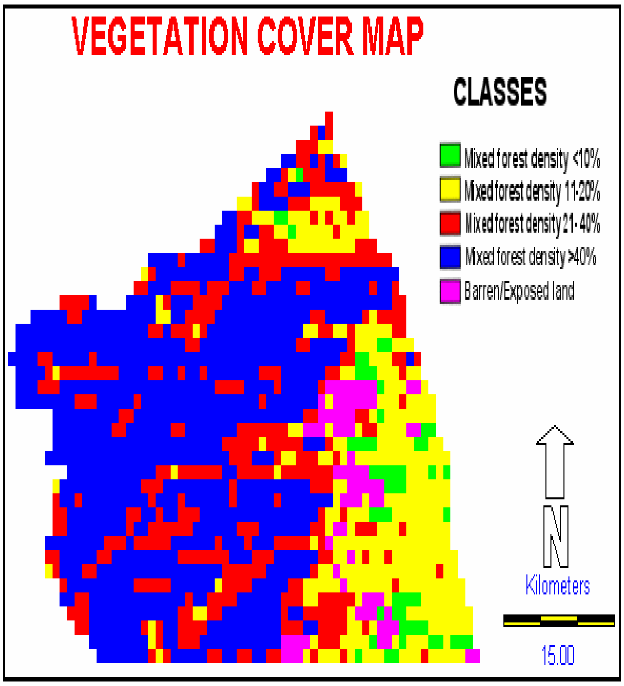

Fig. 4. Vegetation cover map based on visualinterpretation of satellite imageries.

of the study area. The map prepared for vegetation cover is illustrated in Fig. 4. As per the classification of forest types of India (Champion & Seth 1968), the vegetation in the study area can be classified under subgroup 3B/C2 of group 3 and interpreted as "Southern Moist Tropical Mixed Deciduous Forests".

Integration of thematic information

In order to understand the nature of relationship between the elevation, the degree of slope (represented by relative relief), and the type of drainage on one hand and the vegetation cover on the other, the window based IDRISI geographic information software was used. The GIS analysis could not be carried out for the entire study area because the available satellite data covers only the northern part of the study area. Therefore, the entire study is restricted to the area covered by images. The four coded (with scores) thematic or information layers converted to raster format, which were used in the final analysis, are as follows:

1. Information Layer 1 - forest classes (5)-based on interpretation of images.
2. Information Layer 2 - elevation classes (6) - derived from topographical maps.
3. Information Layer 3 - relative relief classes (7)-derived from topographical maps.
4. Information Layer 4 - drainage type classes (4)-derived from topographical maps.

Using these data and IDRISI geographic information software all the four thematic layers were combined by using the 'overlay' procedure. The rule-based system for forest-land use planning employed by Kushwaha & Oesten (1995) has been adopted here after some modifications.

The overlay procedure was used to develop a four-digit code system for each pixel. Thus, the first digit of the code represents the forest category, the second digit corresponds to the elevation class, the third digit stands for the relative relief class, and the last digit represents the drainage type. For example, the code 1210 for a pixel, indicates that the first digit '1' stands for forest category, which is <10%; the second digit '2' shows elevation, which is between 200 and 400 m above sea level; third digit '1' gives an idea of relative relief, which is 0-50 m and the fourth digit '0' represents that there are no major drainage lines but the pixel is dominated by interfluve area.

Results

Ground surveys

The ground surveys were limited to few selected sampling locations only. These locations were selected on the basis of forest density classes used for interpretation of satellite images. For ground verification of vegetation cover, 30m × 30m quadrats were laid because the tree canopy at some localities was very large. The quadrats were laid at selected locations based on altitudinal variations and anthropogenic disturbances. The position of each tree within the quadrat was measured with a tape and marked on the graph paper. The crown canopy cover was marked at four points. This is done by looking directly above and marking the edge of the tree crown on the ground. The distance from the tree trunk was measured. The distance between trees was measured.

The data was presented on the graph paper by taking appropriate scale. The relative canopy cover for each species and total cover for each locality were calculated by the following formulae:

$$\text{Total canopy cover (\%)} = \frac{\text{Total area covered by all species}}{\text{Total area sampled}} \times 100$$

$$\text{Relative canopy cover (\%)} = \frac{\text{Length of the cover of one species}}{\text{Total length of the cover of all species}} \times 100$$

GIS analysis

Using the data obtained through above methods and IDRISI GIS, four thematic layers were combined by using the overlay procedure. With 5 vegetation classes, 6 elevation classes, 7 relative relief classes, and 4 drainage classes, 840 different combinations are possible. However, since many possible combinations have no pixels or very small number of pixels (<1%), only 29 combinations were finally used. These code categories represent more than half of the area included in the GIS analysis. The analysis reveals that code 4330 cover the maximum area (5.25%). The code suggests that in these areas the vegetation cover is >40%, the general elevation is between 400 and 600 m above mean sea level, the relative relief is low (100-150 m) and the area generally lacks major drainage lines. Other codes covering significant area are 4340, 4230, 4430, 4333 and 3330.

In order to get a better idea about the nature of the spatial distribution of different forest categories with respect to elevation, relief and drainage, the results of the analysis are summarized in Table 2. The main observations are as follows:

1. Sparse vegetation (<10% forest cover) is confined to moderate altitude (between 400 and 800 m) and areas dominated by relatively gentler slopes (relative relief <150 m). Such low-density areas typically occur on interfluves and along nallas. They are generally absent along the main river and streams. The topographic characteristics suggest that the area is likely to highly degraded due to human activities.

2. Open forest (forest cover 11 to 20%) is generally observed at lower altitude (<400 m ASL) and low slopes (relative relief <150 m). This category forest is commonly found on interfluves. Some-times along nallas and streams also such open forest is observed. The highest frequency recorded is of the code 2320, which is around 2% of the total area covered by satellite imageries.

3. Relatively dense forest (forest cover 21 to 40%) is observed from low to high elevation (200 to 800 m ASL). The slopes are low to moderately steep (relative relief between 50 and 200 m). This category forest is common on the relief between 100 and 150 m. Although relatively dense forest is present along streams, nallas and also along the rivers, it is more common on interfluves. The highest frequency recorded in this category is of the code 3330, which is 2.23% of the total area covered by imageries.

4. Very dense forest (forest cover >40%) is generally found on altitude between 200 and 800 m ASL, but more commonly on moderately high altitude (between 400 and 800 m ASL). The slopes are steeper as indicated by high relative relief (100-250 m). Such patches of very dense vegetation are common on interfluves and along nallas at high altitude and rivers at low altitude. The highest frequency recorded is of the code 4330, which is 5.25% of the total area covered by imageries.

All the species in the community are not

Table 2. Relationship between vegetation coverand altitude, relative relief and drainage type.

Forest Density Classes	Altitude Range (ASL in meters)	Relative Relief (m)	Drainage
<10%	400-800	<150	Interfluves nallas
11-20%	400-800	<150	Interfluves Nallas Streams
21-40%	200-800	50-200	Interluves Nallas Streams Rivers
>40%	200-800	100-250	Interfluves and Nallas at high altitude
Barren/Exposed Land	400-800	0-100	Close to Interfluves and Nallas

equally important to determine the structure of community. Out of total species present in the community, relatively few exert a major controlling influence by virtue of their size, structure, physiognomy and number. The size and structure of canopy is an important measure to determine the community. Canopy cover is defined by the extent of ground area covered by the spread of tree branches and leaves (Ravindranath & Premnath 1997) or it is the proportion of ground occupied by a perpendicular projection of the aerial parts of individuals of species under consideration (Greig-Smith 1983). It indicates the openness of the ground to sunlight and suggests the gaps available for natural regeneration of grasses and herbaceous growth. Good canopy cover suppresses grass and herbaceous growth. Thus canopy cover data is important for decision on vegetation management. The total area covered by an individual species suggest the dominance level / forest cover in that particular representative sampling unit. The forest canopy is a critical component of the biosphere. The important influence of the forest on microclimate and habitat value depends on the structure of the canopy.

The results of study are presented in Table 3. The area under each species (i.e. relative dominance) has been calculated (refer Fig. 1 for locations). It was not possible to survey all the area under study because of the inaccessibility to the area.

Discussion

One of the primary applications of remote sensing is to identify patterns of vegetation distribution on the ground and to assess changes in vegetation over time. The interpretation of images and GIS analysis indicates that the very dense forest was mostly confined to interfluve areas at variable relative relief, but particularly at higher elevation i.e. 400 and 800 m ASL.This may be due to inaccessibility of the area, because the terrain is

Table 3. Individual species cover at different localities indicating cover value.

Sampling village	% Canopy cover	Plant species (Relative % canopy cover)
Gaman	26	*Tectona grandis* L.(68), *Mitragyna parvifolia*(15), *Boswellia serrata* Roxb.(08), *Bombax malabaricum* DC.(05), *Buchanania lanzan* Spreng.(02), *Holoptelea integrifolia* (Roxb.) Planch.(01), *Acacia catechu* (L.) Willd.(01), *Diospyros melanoxylon* Roxb.(01),
Pimpal-khunta	67	*Madhuca latifolia*(Roxb.) Chevalier(39), *Mitragyna parvifolia* (Roxb.) Korth.(13), *Butea monosperma(*Lamk.*)* Taub.(10), *Mangifera indica* L.(10), *Dendrocalamus strictus*(Roxb.) Nees(05), *Tectona grandis* L.(05), *Syzygium cumini* (L.) Skeels(04), *Terminalia cuneata* Roxb.(03), *Grewia & Ziziphus* sp.(02), *Gmelina arborea* Roxb(02), *Tamarindus indica* L.(02), *Ziziphus rugosa* Lamk.(01),
Pandhara-mati	44	*Tectona grandis* L. (39), *Diospyros melanoxylon* Roxb.(11), *Butea monosperma* (Lamk.) Taub.(09), *Terminalia alata* Heyne ex Roth.(08), *Holarrhena antidysenterica* Wall.(08), *Aegle marmelos* (L.) Corr.(07), *Grewia asiatica* L.(05), *Holoptelea integrifolia* (Roxb.) Planch.(05), *Cassia fistula* L.(03), *Boswellia serrata* Roxb.(02), *Erythrina indica* Lamk.(02), *Morinda citrifolia* L.(01),
Sakali-umar	27	*Tectona grandis* L.(19), *Butea monosperma*(Lamk.) Taub.(17), Terminalia alata *Heyne ex Roth.(16),* Madhuca latifolia*(Roxb.) Chevalier.(15),* Emblica officinalis *Gaertn.(07),* Albizia lebbeck *(L.) Willd.(06),* Terminalia bellirica*(Gaertn) Roxb.(06),* Dendrocalamus strictus*(Roxb.) Nees.(05),* Holarrhena antidysenterica *Wall.(04),* *Lagerstroemia parviflora* Roxb.(04), *Diospyros melanoxylon* Roxb.(03),
Junwani	18	*Buchanania lanzan* Spreng.(24), *Tectona grandis* L.(22), *Diospyros melanoxylon* Roxb.(13), *Boswellia serrata* Roxb. (10), *Morinda citrifolia* L. (08), *Terminalia cuneata* Roxb. (08), *Vitex negundo* L.(07), *Holoptelea integrifolia* (Roxb.) Planch. (05), *Ziziphus jujuba* (L.) Gaertn.(02),
Surgas	48	*Vangueria spinosa* Roxb.(10), *Erythrina indica* Lamk.(23), *Trema orientalis* (L.) Bl.(10), *Wrightia tinctoria* R.Br.(06), *Mallotus philippensis*(Lam.)Muell.-Arg.(19), *Ficus racemosa* L.(21), *Melia composita* Willd.(10),

rugged, high elevation and remote from human habitation. Dense vegetation cover was also observed along rivers and nallas at low elevation. This may be due to more availability of water. The dense forest was common on interfluves and along nallas. It is generally found on relief between 100 and 150 m but also at high relief that is inaccessible to the local inhabitants. It is strongly supported by the ground surveys (Table 3). The open forests were also common on interfluves and along nallas and streams but not common along the rivers. This may be due to nearness to human settlements, lower relative relief and gentle slopes. The important reason for this is severe tree felling and forest degradation due to temporary agricultural fields (shifting cultivation). Open forests were found to be associated with agricultural fields. The sparse vegetation was common on interfluves and along nallas at high elevation and may be because of poor soil cover and/or due to shifting agricultural practices. As these were found at relief <150 m, it is most likely be due to the severe impact of anthropogenic activities. While defore-station or forest exploitation typically proceeds in small openings (in shifting cultivation) or in a more diffuse manner (selective cutting), the accumulated effect of the associated land cover trans-formation is felt over larger areas.

The village Gaman was having a vegetation cover of 26 % and it was further supported by the remote sensing data (Fig. 4). The village Pimpalkhunta represented maximum area under vegetation canopy cover (67 %) and as per remote sensing data it has been put under the category of 'forest density more than 40 %'. It best correlates the remote sensing data and ground surveys.

The village Junwani was fairly disturbed due to anthropogenic activities as it was easily accessible by road. It showed the vegetation canopy cover of 18 % only and was supported by remote sensing data. It can be very clearly observed in Fig. 4, where this village area was put under the category of 'forest density 11-20 %'. It is equally true for all other villages sampled.

Conclusions

The GIS analysis indicates that interfluve areas at variable relative relief, particularly at higher elevation i.e. 400 and 800 m ASL, supports very dense forest, may be due to the remoteness of the area from human settlements. Dense vegetation was also noticed along watercourses. The agricultural fields were found to be associated with open forests. These forests become open because of easy accessibility and nearness to human settlements. The interfluves areas and nallas at high elevation where there was poor soil cover due to shifting agricultural practices, supports only sparse vegetation, especially regenerating vegetation. These were found at relief <150 m. Shifting cultivation, selective felling of trees and grazing by domestic livestock exerts pressure on vegetation regeneration which has resulted in sparse distribution and fragmentation of good forest pockets. It has been supported by ground surveys.

Thus, the exercise demonstrates the control of elevation, relief and drainage on the spatial distribution of vegetation cover. The results of the study emphasize the fact that the majority of dense forestland is confined to inaccessible and remote areas, where the altitude is high and the relief is rugged (i.e. minimum biotic disturbance),which has been strongly supported by ground surveys at selected locations.

Based on the relative percentage cover of individual species (relative dominance), the plant communities in this area are *Tectona-Madhuca-Buchanania* and *Mitragyna-Diospyros-Butea*.

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References

Champion, H.G. & S.K. Seth. 1968. *A Revised Survey of Forest Types of India.* The Manager of Publications, Govt. of India, Delhi.

Danson, F.M. 1987. Estimating forest stand parameters using airborne MSS data. *In: 13th*

Annual Conference of The Remote Sensing Society, University of Nottingham, Sep. 7-11.

Foody, G.M & T.F. Wood. 1987. The use of the Landsat TM data in a GIS for environmental monitoring. *In: 13th Annual Conference of The Remote Sensing Society*. University of Nottingham, Sep. 7-11.

Greig-Smith, P. 1983. *Quantitative Plant Ecology*. 3rd edn. Butterworth, London.

Gunale, V.R., V.S. Kale, N.J. Pawar, D.R. Shirke, A.S. Gadgil, D.N. Patil & M. Katdare. 1997. *Status of Flora and Fauna in and around Sardar Sarovar Project, Maharashtra - A Project Report.* Department of Environmental Sciences, Pune University.

Kuchler, A.W. 1988. The classification of vegetation. pp. 67-80. *In:* A.W. Kuchler & I.S. Zonneveld (eds.) *Vegetation Mapping.* Kluwer Academic Publishers, London.

Kushwaha, S. P. S. & G. Oesten. 1995. A rule-based system for forest land use planning. *Journal of the Indian Society of Remote Sensing* **23**: 115 - 124.

Minakshi, R. Chaurasia & P.K. Sharma. 1999. Land use/land cover mapping and change detection using satellite data - A case study of Dehlon block, district Ludhiana, Punjab. *Journal of the Indian Society of Remote Sensing* **27**: 115-121.

Pant, A., S.G. Chavan, P.S. Roy & K.K. Das. 1999. Habitat analysis for Sambar in Corbett National Park using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing* **27**: 133 -139.

Prasad, K.V., T. Rajagopal, Y. Kant, S. Srinivas & K.V.S. Badarinath. 1998. Studies on biodiversity using semivariogram approach from IRS-1C LISS-III data. *Journal of the Indian Society of Remote Sensing* **26**: 103 -112.

Prasad, K.V., Y. Kant & K.V.S. Badarinath. 1999. Vegetation discrimination using IRS-P3 WiFS temporal dataset - A case study from Rampa forests, eastern ghats, A.P. *Journal of the Indian Society of Remote Sensing* **27**: 149-154.

Ravindranath, S. & S. Premnath. 1997. *Biomass Studies - Field Methods for Monitoring Biomass* Oxford & IBH Publ. Co. Pvt. Ltd, New Delhi

Sudhakar, S., G. Shridevi, I.V. Ramana, V.V. Rao & A.K. Raha. 1999. Techniques of classification for land use / land cover with special reference to forest type mapping in Jaldapara Wildlife Sanctuary, Jalpaiguri district, West Bengal - a case study. *Journal of the Indian Society of Remote Sensing* **27**: 217-224.

Woodcock, C.E., J.B. Collins, S. Gopal, V.D. Jakabhazy, X. Li, S. Macomber, S. Ryherd, V.J. Harward, J. Levitan, Y. Wu, & R. Warbington. 1994. Mapping forest vegetation using Landsat TM imagery and a canopy reflectance model. *Remote Sensing and Environment* **50**: 240-254.

Young, J.A.T. & D.R. Green. 1987. Is there really a role for remote sensing in Geographic Information System. *In:* 1*3th Annual Conference of The Remote Sensing Society.* University of Nottingham, Sep 7-11.