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Landscape Ecological Planning in a Basaltic Terrain, Central India, Using Remote Sensing and GIS Techniques

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ABSTRACT

In the present study, detailed field survey in conjunction with remotely sensed (IRS-1D, LISS-III) data is of immense help in terrain analysis and landscape ecological planning at watershed level. Geomorphologically summit crust, table top summits, isolated mounds, plateau spurs, narrow slopes, plateau side drainage floors, narrow valleys and main valley floor were delineated. The soil depth ranges from extremely shallow in isolated mounds to very deep soils in the lower sectors. Very good, good, moderate, poor and very poor groundwater prospect zones were delineated. By the integrated analysis of slope, geomorphology, soil depth, land use/land cover and groundwater prospect layers in GIS, 29 landscape ecological units were identified. Each landscape ecological unit refers to a natural geographic entity having distinctive properties of slope, geomorphology, soil depth, land use/ land cover and groundwater prospects. The landscape ecological stress zone mapping of the study area has been carried out based on the analysis and reclassification of landscape ecological units. The units having minimum ecological impact in terms of slope, geomorphology, soil depth and land use/land cover were delineated under very low stress landscape ecological zones. The units having maximum ecological stress in the form of very high slopes, isolated mounds, table top summits and summit crust, extremely shallow soils, waste lands and very poor groundwater prospects were delineated into very high stress landscape ecological zones. The integrated analysis of remotely sensed data and collateral data in GIS environment is of immense help in evaluation of landscape ecological units and landscape ecological stress zones. The delineated landscape ecological stress zones in the watershed have been recommended for landscape ecological planning for better utilization of natural resources without harming the natural geo-ecosystem of the area.

Introduction

The optimum utilization and sustainable development of natural resources in general, land and water resources in particular on scientific lines without causing an imbalance to the natural geoeco-system is the major concern in present days. The watershed is a geo-hydrological unit area drained to a common point and considered it as a ideal unit for analysis and management of natural resources and environmental planning in any ridge to valley treatment (Akhouri, 1996).

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Planning and development of natural resources without endangering the environment is an important issue, the world is facing today (Sharma *et al.,* 1989; Khorram and John, 1991). For optimum utilization of natural resources in an area, the integrated watershed development approach is considered to be the most ideal as it helps in maintaining the ecological balance (Sahai, 1998). Watershed management implies the proper utilization of available land and water resources for optimum production with minimum hazards to natural resources and eco-system. Integrated resource survey at watershed level with the help of remotely sensed data and field surveys provides knowledge on the potential and limitations in resources planning and utilization, which is essential for formulating and execution of management strategies.

Remote sensing is a powerful spin off from space exploration and it has emerged as a useful tool for watershed characterization, conservation, planning and management in recent times (Saraf *et al.,* 2000). Satellite remote sensing provides a reliable and accurate information on natural resources, which is a pre-requisite for planned and balanced development at watershed level (Ravindran *et al.,* 1992). Remotely sensed data provides information for systematic analysis of various lithological, geomorphological, soil, hydrological and land use/land cover characteristics following the synoptic and multi-spectral coverage of a terrain.

Geographical Information System (GIS) has proved as a powerful tool in the field of natural resources management over the years. Several case studies have already been reported from different terrain segments across the world, illustrating the application potential of GIS in management of land, soil and water resources (Ghosh *et al.,* 1996 and Das *et al.,* 1996). GIS techniques having the capability of data storage, retrieval and manipulation, can play an important role in evolving suitable methods of arriving at alternate scenarios for natural resources development and environmental planning. Remote sensing represents a powerful technology for providing input data for measurement, mapping, monitoring and modeling within the GIS content (Noviline *et al.,* 1993). Recent advances in remote sensing and GIS provide very useful tools in undertaking integrated resource analysis. These two new technological tools have emerged to meet ever increasing demand for more precise and timely information. An integrated element of generating map information is the combination and comparison of a variety of data derived from different sources such as remotely sensed imagery, ground surveys and existing topographic and other maps (Chagarlamudi and Plunkett, 1993).

Landscape ecology connotes a physical land unit together with biotic components in a functional association (Forman and Godron, 1986). The landscape ecological processes are interactions of relief, geology, geomorphology, soils, land use/land cover and hydrological characteristics of the earth surface. Remote sensing technology has emerged as an efficient tool in providing reliable information on various natural resources of a region in a spatial format so essential for sustainable landscape planning (Roy *et al.,* 1991). In the present study an attempt has been made to analyse terrain characteristics and generate maps of slope, geomorphology, soil depth, land use/land cover and groundwater prospect thematic information using SOI topographical, remotely sensed and field survey data. The generated information has been integrated in GIS using union option to delineate landscape ecological units (LEU'S) and landscape ecological stress zones. The landscape ecological stress zoning will be of immense help in identification of ecologically stress zones for the ecological planning and management at micro level.

Study area

The Mohgaon watershed is located in Hingna Tahsil of Nagpur district and lies between latitudes 20°59'31" and 21°04'16" and longitudes 78°44'08" and 78°49'42" covering an area of about 47.5 sq km. The elevation is ranging from 340 to 420 meters above mean sea level. The climate is warm sub-humid with mean annual rainfall of 1127 mm of which about 89% is received during the south-west monsoon (June to October). Geologically the area is covered by basaltic lava flow of Lower Eocene to Upper Cretaceous, commonly known as "Traps". The natural flora of the area dominantly comprises of palas (*Butea frondosa*), teak (*Tectona grandis*), Babool (*Acacia arabica*), Ber (*Zizyphus jajuba*) and Kans (*Saccharum spontaneum*).

Methodology

Data Used

Indian Remote sensing satellite IRS-ID LISS-III digital data (path 99 and Row 57) acquired on 8th November 1999 (Fig. 1) and 7th March 2000 were used in the study (Table 1). The False Colour Composite (FCC) was generated from green, red and near-infrared (NIR) spectral bands (bands 2, 3 and 4). Linear enhancement techniques were applied to improve visual information on geomorphology, land use/ land cover and lineament pattern. Survey Of India topographical information on 1:50,000 scale and field soil survey data were used as ancillary information.

Data preparation

Based on the water divide line concept, the boundary of watershed was delineated (Strahler, 1964). The IRS-ID digital data collected for the periods of November 1999 and March 2000 were registered to SOI topographical sheet at 1:50,000 scale in EASI/PACE image analysis system using image to map registration algorithm. The ground control points (GCP's) common to the map and image were identified and collected to register the image at sub-pixel accuracy using a 2nd order polynomial transformation. The digitally registered image was subsequently used to generate thematic information.

Data Generation

Based on the topographical information, the drainage network of the basin was generated. Some of the first order steams were updated from satellite data. Based on the contour values, elevation grid was generated in GIS. Slope is calculated using elevation grid raster with slope function in SPANS ver 7.0 GIS environment. The FCC was generated for onscreen visual interpretation of various geomorphologic units. Visual interpretation techniques have been followed to generate geomorphology (landforms) map based on the tone, texture, shape, drainage pattern, color and differential erosion characteristics in conjunction with relief and morphometry of the basin. The soil depth map was generated based on the field soil survey data. The standard false colour composites of bands 4, 3 and 2 were used for land use/land cover classification using Maximum Likelihood Classification (MLC) algorithm. The training sets were identified for each land use/land cover class based on field knowledge of the study area. The final land use/land cover map was generated based on *kharif* and *rabi* seasons classified satellite data.

GIS Analysis

The drainage, contours, geomorphology and

Table 1: Details of the satellite remote sensing datasets used in the present study

IRS digital data	Path	Row	Sensors	Scale	Date
IRS-1D	57	99	LISS-III	1:50,000	8th November 1999
IRS-1D	57	99	LISS-III	1:50,000	7th March 2000

lineaments were digitized in SPANS 7.0 GIS as line vector layers. The covers were cleaned and topology was built to generate the thematic layers of slope, geomorphology, soil depth and lineaments. A buffer zones were generated for the lineaments. The thematic information of slope, geomorphology and lineament buffer zone were integrated using raster overlay (with union option) in GIS to delineate groundwater prospect zones. The slope, geomorphology, soil depth, land use/ land cover and groundwater prospect layers were integrated using union option in GIS, the landscape ecological units were delineated. In delineation of landscape ecological stress zones, the individual landscape ecological units were analysed and reclassified in GIS based on the landscape ecological characteristics of each unit in terms of slope, geomorphology, soil depth, land use/land cover and groundwater prospects.

Results and Discussion

Terrain characteristics

Analysis of landscape contour granulars, drainage pattern and image characteristics has helped in delineation of various terrain features. The study area is basically of volcanic origin and influenced by the actions of various fluvio-denudational processes. Physiographically, plateau plains of the Deccan lava flows dominate the northern and eastern parts with an elevation ranging from 430 to 450 m above mean sea level (msl). The middle parts of the area are characterized by narrow slopes with an elevation ranging from 370 to 430 m above msl. The plains are depositional in nature and extend from west to east with an elevation ranging from 350 to 370 m above msl.

Slope

The slope analysis reveals that the area under nearly level to level slopes (0-1%) is in association with table top summits and it accounts for approximately 20.86 percent of the study area (Fig. 2). The very gentle slopes (1-3%) are associated mainly with plateau spurs and occupies an area of about 17.08 percent. The plateau spurs and narrow slopes are in association with gentle slopes (3-5%) and it accounts for 29.45 percent of the area. The moderate slopes (5-10%) occupy mainly in the narrow slopes and plateau side drainage floors covering an area of about 13.44 percent. The strongly sloping (10-15%) lands are in association with plateau side drainage floors and it accounts for 14.39 percent. The northwestern part of plateau side drainage floor is under steep slopes with an area of about 4.78 percent of the study area.

Geomorphology

The study of geomorphological features and evolution of various landforms is of utmost importance in landscape planning and management (Sehgal *et al.*, 1988). Geomorphological processes are generally complex reflecting inter-relationship of variables such as a climate, geology, soils and vegetation (Buol *et al.*, 1993). The Deccan trap basaltic complex which is presumed to have gone through various denudational processes causing the various geomorphic entities. The present day landforms are the remnants of the "landscape reduction processes" retained after several erosional cycles (Subramanyam, 1981). In the present study, the analysis of remotely sensed data with ancillary information reveals that eight distinct geomorphic units exist in the basaltic landscape (Fig.3).

Summit crust

Occupying the top most parts of the landscape, the crust area is extremely flat and its sides show sharp discontinuance with surrounding units. This may be because of differences in basaltic flows. It is formed over the youngest basaltic flow.

Table top summits

This geomorphic unit has extreme flatness, long slope length and low drainage density, which is favourable for high infiltration and deep

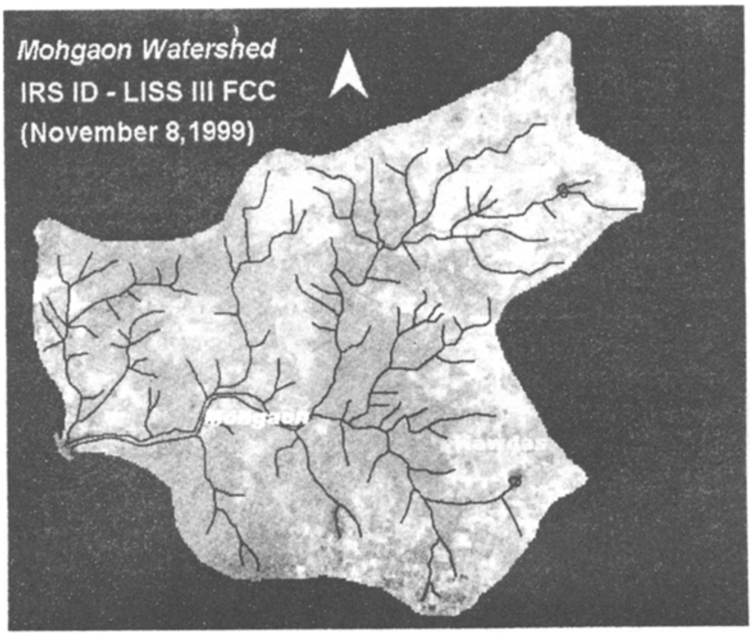

Fig. 1. IRS-ID (LISS-III) FCC (November 8, 1999) of Mohgaon watershed

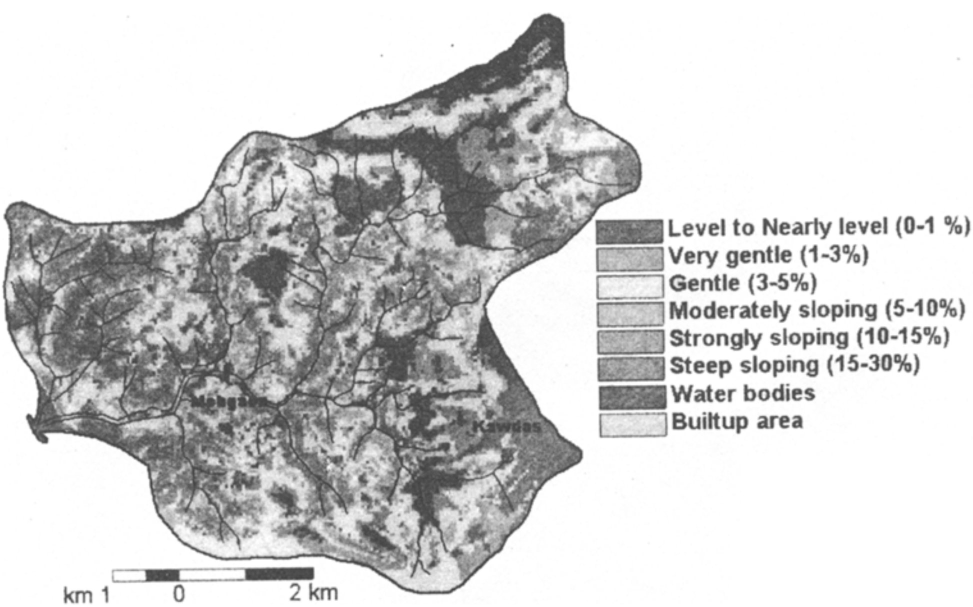

Fig. 2. Slope map of Mohgaon watershed

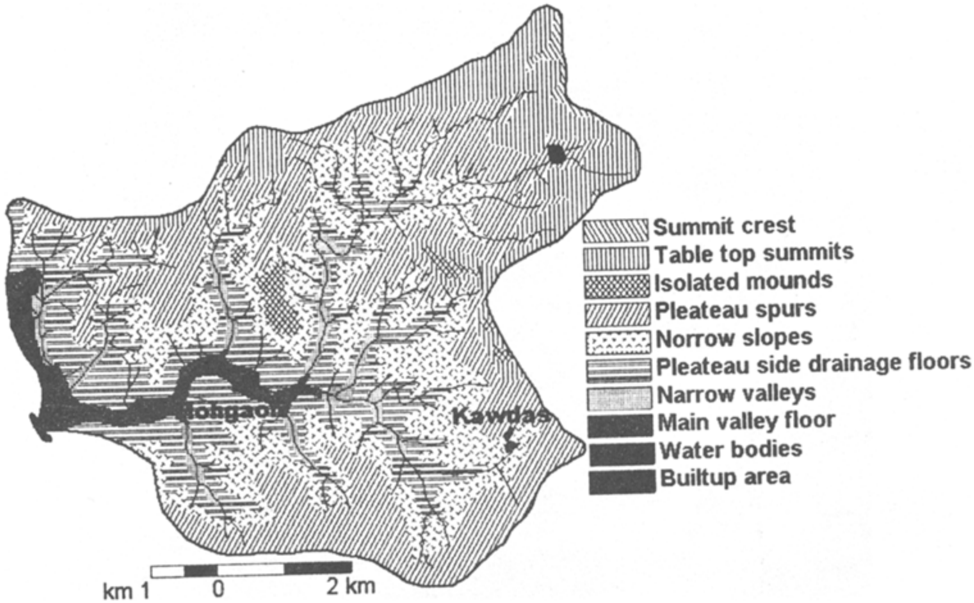

Fig. 3: Geomorphology of Mohgaon watershed

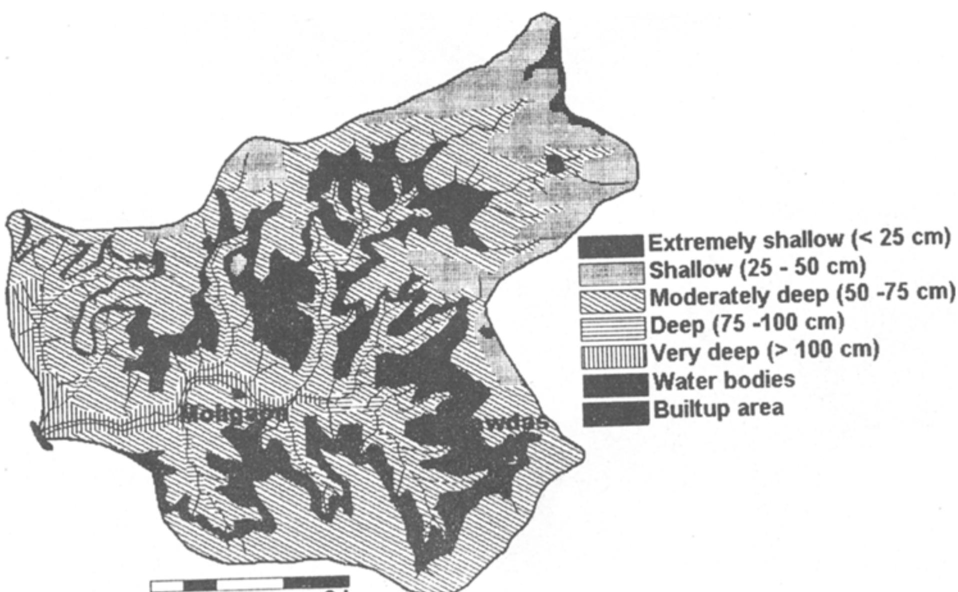

Fig. 4: Soil Depth map of Mohgaon watershed

weathering due to relatively greater stability than summit crust. Sheetwash, rill and incipient gullies are dominant erosional processes. This unit is spread mainly in the eastern and north-eastern parts and it accounts for 11.56 percent of the study area.

Isolated mounds

The circum-denudational processes are the dominant geomorphological processes on the basaltic terrain and it resulted in isolated mounds as remnants. Due to the headward erosional processes these remnants are reduced in height as well as in width in course of time.

Plateau spurs

Due to the headward erosional processes and retreat of slope the plateau spurs are formed by prograding towards main land. Severe sheet and slope-wash are the dominant erosional processes acting in this zone. The severity will depend on the land cover and human intervention. This unit occupies a major part of the area i.e., 30.20 percent of the total area.

Narrow slopes

This restricted narrow and elongated geomorphic unit occupies below the plateau spurs. Due to the short steep slope gradient and high drainage density, this zone is subjected to rill and gully erosion conditions rendering this area predominant in skeletal conditions. It accounts for 25.88 percent of the area.

Plateau side drainage floors

This geomorphic unit occupies the lower slopes and is interrupted by the narrow slopes. Due to moderate slopes and medium drainage density, mainly of second and third order streams, this zone is under alternative wet and dry conditions, inturn causing different rates of weathering. It occupies the central part with an area of about 21.82 percent.

Narrow valleys

This geomorphic unit is formed mainly because of steep slopes on either side of the major streams and by erosional processes at higher elevations and depositional processes in lower slopes. This unit is mainly covered with basaltic alluvium and colluvium material with admixture of silt, clay, pebbles and cobbles.

Main valley floor

This geomorphic unit is predominantly depositional in nature. Due to nearly levelled slopes and very less drainage density the eroded and transported material from higher slopes was deposited depending upon the micro-relief conditions. The deposited basaltic alluvium consists of clay, silt and gravel.

Soil Depth

The different geomorphological processes in conjunction with type of parent material greatly influence the type of soils formed in topographic sequence under specific geo-pedological environmental conditions (Das and Roy, 1979; Reddy *et al.*, 1999). The soil survey data reveals that soils in summit crust, isolated mounds and narrow slopes are extremely shallow with an area of about 27.40 percent of the study area. These soils are under excessively drainage conditions and underlain by weathered basalt (Fig. 4). The soils in tabletop summits are shallow and excessively drained. The plateau spurs and plateau side drainage floors are under moderately deep soils and moderate drainage conditions. These soils occupy 51.96 percent of the total area. The deep soils are in association with narrow valleys with an area of about 3.69 percent of the area. Very deep soils are in association with main valley floor. The narrow valleys and main valley floor soils are predominantly under fluvial depositions and admixed with clay and clay loam.

Land use/land cover

The information on land use/land cover is essential in the analysis of environmental processes and problems (Anderson *et al.*, 1976). The analysis of *kharif* and *rabi* seasons' land use/ land cover characteristics reveals that majority of area is under single cropping system. The area under single crop accounts for 51.45 percent because of its monsoonal climatic conditions and rainfed cropping system (Fig. 5). Cotton, pigeon pea and sorghum are the main *kharif* crops. The scrub forest area is mainly on plateau spurs and narrow slopes and it accounts for 21.51 percent of the study area. The thick deciduous forest is restricted to plateau side drainage floors and occupies nearly 15.25 percent of the area. The wastelands are spread mainly in plateau spurs and tabletop summits with an area of about 5.50 percent. The double cropped area occupies the main valley floor and table top summits and it accounts for 5.43 percent of the area. The irrigated crops are mainly cotton, sugar cane and citrus. Water bodies and built up lands occupy 0.21 percent and 0.08 percent of the total geographical area respectively. The analysis of land use/land cover shows that deciduous and scrub forests are under pressure because of deforestation and encroachments for agricultural activities. The majority of area is under exposure of sheet and rill erosion activities after harvesting of *kharif* crops.

Groundwater Prospect Zones

Analysis of data on drainage, geology, geomorphology and lineament characteristics of a terrain in an integrated way facilitates effective evaluation of ground water potential zones (Krishna Murthy and Srinivas, 1995; Saraf and Choudhuray, 1998). Analysis of lineament pattern in the area reveals that the drainage is mainly controlled by the lineaments trending NE-SW, NW-SE and E-W directions. The ground water potential zones were delineated based on the integration of slope, drainage pattern, geomorphology and lineament buffer zones layers using union option GIS. The delineated zones were verified with ground data. The results show that very good groundwater prospect zone is associated with main valley floor and narrow valleys with deep to very deep soils and it accounts for 8.33 percent of the study area (Fig. 6). Good ground water prospect zone was identified in association with plateau side drainage floors with moderate deep soils and it occupies 21.82 percent of the area. The majority of the area is under moderate groundwater prospect in association with narrow slopes and plateau spurs covering about 56.08 percent of the area. The poor and very poor ground water potential zones are associated with isolated mounds, table top summits and summit crusts, which are acting mainly as runoff zones and occupies 12.17 and 1.61 percent respectively.

Landscape Ecological Units

The slope, geomorphology, soil depth, land use/land cover and groundwater prospect layers were integrated using union option in GIS to analyze the landscape ecological properties. The analysis reveals that there are 29 distinctive landscape ecological units in the study area (Fig. 7 and Table 2). Each landscape ecological unit refers to a natural geographic entity having distinctive properties of slope, geomorphology, soil depth, land use/land cover and groundwater prospects. These units are characterized by interactions of various processes of geology, geomorphology, hydrology, soils, vegetation and climate on the earth surface. The major landscape ecological unit is identified as plateau spurs with slope ranging from 0-1 to 3-5 percent, moderately deep soils, moderate groundwater prospect conditions and single cropped area. It occupies nearly 19.2 percent of the area mainly in the southern and eastern parts. The analysis shows that the major landscape ecological units are associated with the land use/land cover of single cropped area and scrublands.

Landscape Ecological Stress Zones

The landscape ecological stress zone mapping of the study area has been carried out based on the analysis and regrouping of landscape ecological units on the basis of the ecological impact of each zone. The units having a minimum ecological impact in terms of slope, geomorphology, soil depth, land use/land cover and groundwater prospects were delineated under very low landscape ecological stress zone (Ruzicka and Miklos, 1982 and 1986). The units

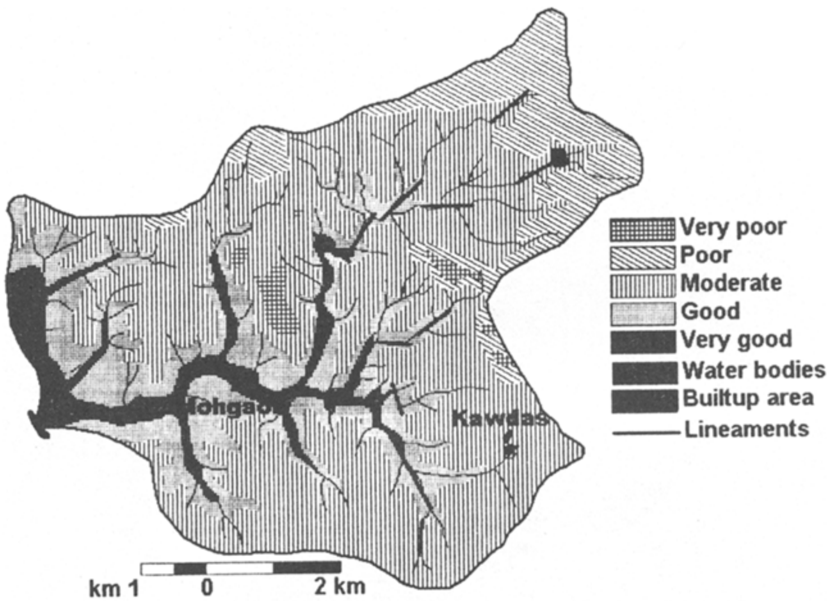

Fig. 5: Groundwater Prospect map of Mohgaon watershed

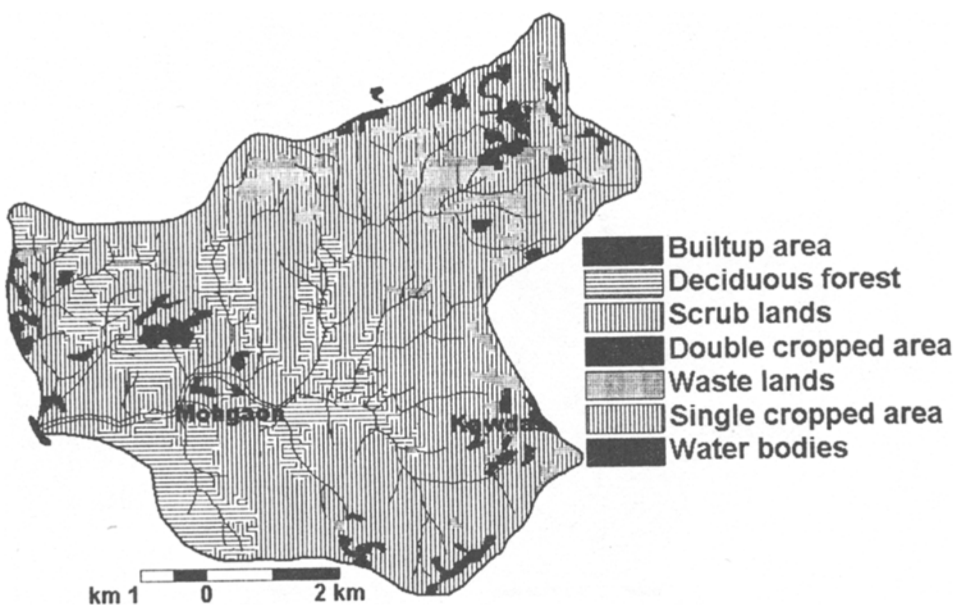

Fig. 6: Land use/Land cover map of Mohgaon watershed

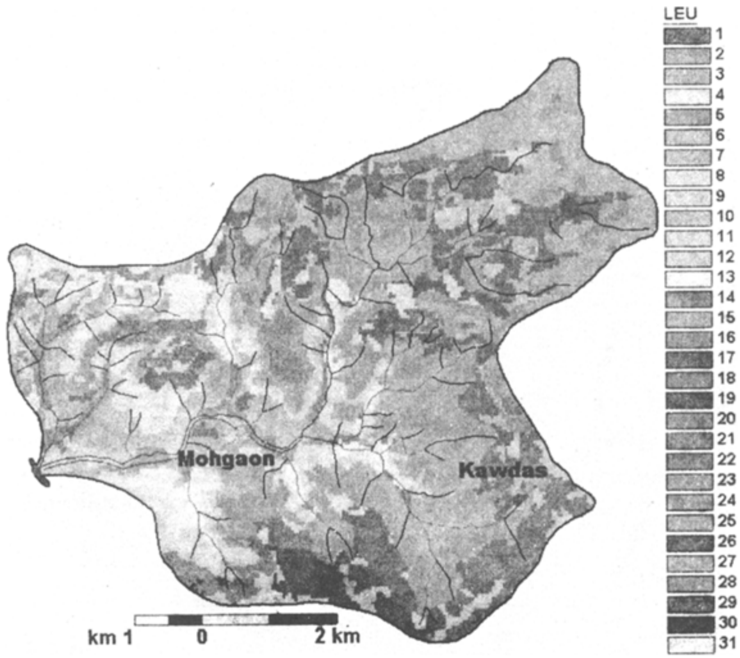

Fig. 7. Landscape Ecological Units of Mohgaon watershed

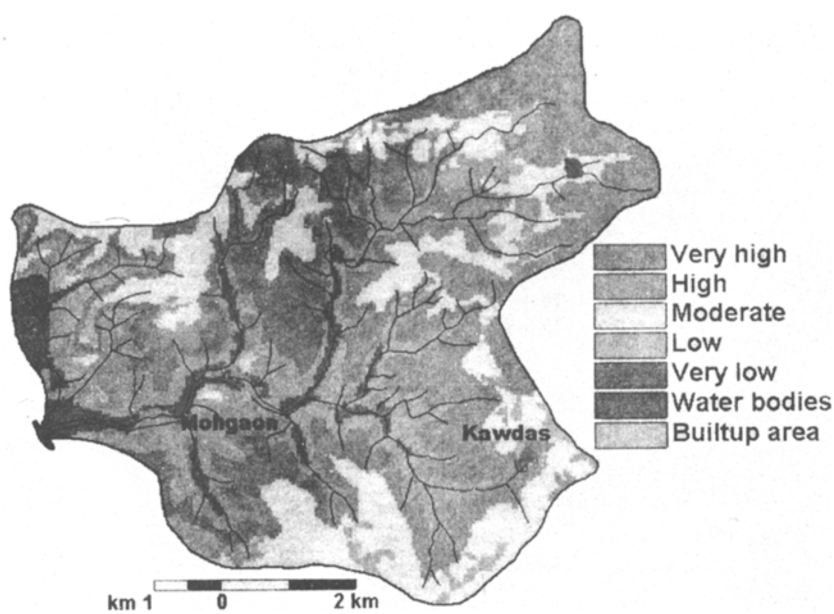

Fig. 8. Landscape Ecological Stress Zones of Mohgaon watershed

Table 2: Characteristics of Landscape Ecological Units (LEU's) of Mohgaon Watershed

Landscape Ecological unit	Geomorphology	Slope (%)	Soil Depth	Groundwater prospects	Land use/Land cover	Area (sq km.)	Area (%)
1	Plateau spurs	0-1 --- 3-5	Moderately deep	Moderate	Single cropped area	9.12	19.20
2	Narrow slopes	10-15 --- 15-30	Extremely shallow	Moderate	Single cropped area	6.05	12.74
3	Table top summits	0-1 --- 3-5	Shallow	Poor	Single cropped area	3.89	8.19
4	Plateau side drainage floor	3-5 --- 5-10	Moderately deep	Good	Deciduous forest	3.84	8.08
5	Narrow slopes	5-10 --- 10-15	Extremely shallow	Moderate	Scrub lands	3.62	7.62
6	Plateau side drainage floor	3-5 --- 5-10	Moderately deep	Poor	Scrub lands	3.39	7.14
7	Plateau side drainage floor	1-3 --- 3-5	Moderately deep	Good	Single cropped area	3.05	6.42
8	Plateau spurs	1-3 --- 3-5	Moderately deep	Moderate	Scrub lands	1.99	4.19
9	Narrow slopes	10-15 --- 15-30	Extremely shallow	Moderate	Deciduous forest	1.78	3.75
10	Plateau spurs	3-5 --- 5-10	Moderately deep	Moderate	Waste lands	1.41	2.97
11	Main valley floor	0-1 --- 1-3	Very deep	Very good	Single cropped area	1.26	2.65
12	Plateau spurs	0-1 --- 1-3	Moderately deep	Moderate	Double cropped area	1.02	2.15
13	Narrow valleys	1-3 --- 3-5	Deep	Very good	Deciduous forest	0.92	1.94
14	Plateau spurs	1-3 --- 3-5	Moderately deep	Moderate	Deciduous forest	0.70	1.47
15	Table top summits	1-3 --- 3-5	Shallow	Poor	Double cropped area	0.67	1.41
16	Table top summits	1-3 --- 3-5	Shallow	Poor	Waste land	0.66	1.39
17	Narrow slopes	10-15 --- 15-30	Extremely shallow	Moderate	Waste land	0.54	1.14
18	Narrow valleys	3-5 --- 5-10	Deep	Very good	Single cropped area	0.41	0.86
19	Narrow slopes	5-10 --- 10-15	Extremely shallow	Moderate	Double cropped area	0.39	0.82
20	Main valley floor	0-1 --- 3-5	Very deep	Very good	Scrub lands	0.39	0.82
21	Isolated mounds	0-1 --- 3-5	Extremely shallow	Very poor	Single cropped area	0.38	0.80
22	Narrow valleys	1-3 --- 3-5	Deep	Very good	Scrub lands	0.38	0.80
23	Table top summits	1-3 --- 3-5	Shallow	Poor	Scrub lands	0.29	0.61
24	Main valley floor	0-1 --- 3-5	Very deep	Very good	Double cropped area	0.27	0.57
25	Summit crust	1-3 --- 3-5	Extremely shallow	Poor	Single cropped area	0.26	0.55
26	Plateau side drainage floor	1-3 --- 3-5	Moderately deep	Good	Double cropped area	0.23	0.48
27	Isolated mounds	3-5 --- 5-10	Shallow	Very poor	Scrub lands	0.17	0.36
28	Main valley floor	0-1 --- 1-3	Very deep	Very good	Deciduous forest	0.17	0.36
29	Isolated mounds	1-3 --- 3-5	Shallow	Very poor	Single cropped area	0.11	0.23
30	Water bodies	-	-	-	-	0.10	0.21
31	Builtup area	-	-	-	-	0.04	0.08
Total	-	-	-	-	-	47.50	100

having maximum ecological stress in the form of very steep slopes, denudational landscape, extremely shallow soils, wastelands and very poor groundwater prospects zones were delineated into very high landscape ecological stress zone and the rest into intermediate classes of stress zones. The analysis of the present study reveals that very high and high landscape ecological stress zones are spread mainly in the uplands of the area (Fig. 8 and Table 3). These zones are subjected to rill and gully erosion with slopes ranging from 10-15 percent to 15-30 percent, extremely shallow soils, poor to very poor groundwater prospects, single cropped, wastelands and scrub lands. The moderate stress zone is identified in the southern and northern parts of the area. The low and very low stress zones were identified in the lower sectors which are having deep soils, double cropped areas and good to very good ground water potential. The analysis of landscape ecological stress zones will help in identification of zones which are having ecologically degraded condition to take immediate measures to restore fragile ecology of the micro unit. Based on the severity of the landscape ecological stress the management action plan has been prepared to mitigate further degradation of landscape ecology and sustainable geo-environmental management of the study area.

Conclusions

The present study demonstrates that in terrain analysis and generation of various thematic information for landscape ecology mapping, remotely sensed data provides a reliable source of information. The analysis of remotely sensed data in conjunction with collateral data in GIS environment is of immense help in delineation of landscape ecological units and landscape ecological stress zones. The integrated analysis of slope, geomorphology, soil depth, land use/ land cover and groundwater prospect characteristics in GIS has generated 29 landscape ecological units with an area ranging from 0.23 to 19.20 sq km were identified in the Mohgaon watershed. Each landscape ecological unit refers to a natural geographic entity having distinctive properties of slope, geomorphology, soil depth, land use/land cover and groundwater prospects. Landscape ecological zones were analysed and regrouped into classes of ecologically stress zones which require immediate attention to maintain fragile geo-ecosystem of the area. The evolved landscape ecological stress zones in the watershed have been recommended for various management practices such as soil and water conservation through check dams, rock fill dams, vegetation bounding, diversified farming systems ie., agro-forestry, agro-horticulture, fodder and fuel wood for better utilization of natural resources without harming the natural geo-ecosystem of the area. The results were validated in the field with selected random sample strips and found good correlation among the considered parameters, delineated landscape ecological units and landscape ecological stress zones.

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References

Akhouri A P (1996). Remote sensing approach for watershed based resource management in Sikkim Himalaya - A case study, Photonirvachak, J. Indian Soc. Remote Sensing, 24: 69-83.

Anderson J R, Hardy E E, Roach J T and Wirmer R E (1976). A land use and land cover classification system for use with remote sensing data. Professional paper, No.964 USGS. Reston Verginia : 28.

Buol S W, Hole F D and Mc Craken R J (1973). Soil genesis and classification. Iowa State University Press, Oxford & IBH Publishing Co., New Delhi.

Chagorlamudi P and Plunkett G W (1993). Mapping applications for low cost remote sensing and

Table 3: Characteristics of Landscape Ecological Stress zones and Management planning

1	2	3	4	5
2, 3, 5, 9, 16, 17, 21, 23, 25, 27, and 29	Very high	17.45 (37.17 %)	Subjected to rill and gully erosion with slopes ranging from 10-15% to15-30%, extremely shallow to shallow soils, very poor to poor groundwater prospects, single cropped area, scrubs and wastelands are the main land use/ land cover classes.	Runoff management structures like gully control structures, stone terracing & contour bunding development of pastures afforestration and social forestry.
6, 10, 15 and 19	High	5.70 (12.11 %)	Headward erosion, slopes ranging from 5-10% to10-15% with shallow to moderately deep soils, poor to moderate groundwater prospects and waste lands, scrubs and single cropped area are the dominant land use/ land cover classes.	Diverging drainage channels, afforestration, social forestry, silvi-pasture and horticulture crops.
1, 8 and 26	Moderate	11.48 (24.37 %)	Alternative erosion and deposition actions, slope ranging from 1-3% to 3-5%, soils are mainly moderately deep, moderate groundwater prospects, single cropped area and scrub lands are the main land use/ land cover classes.	Terrace bunding, vegetative bunding runoff regulation structures and land leveling.
4, 7, 12, 14, 20, 22 and 28	Low	9.29 (19.24 %)	Subjected to colluvium deposits, slopes ranging from 1-3% to 3-5%, moderately deep to deep soils, moderate to good groundwater prospects, deciduous and double cropped area are the dominant land use/ land cover classes.	Land levelling, land mulching, contour cultivation and strip cropping.
11, 13, 18 and 24	Very low	2.98 (6.36 %)	Depositional processes are dominant, slopes ranging from 0-1% to 1-3%, soil depth varies from deep to very deep, good to very good groundwater prospects, single and double cropped areas are the dominant land use/ land cover classes.	Drainage channel management to avoid water logging and salinization processes.

1. Landscape Ecological units, 2. Landscape Ecological Stress Zone, 3. Area and percentage, 4. Description and 5. Management plan

geographic information systems, 14 (17) : 3181-3190.

Das K K, Ravan S A, Negi S K, Jain A and Roy P S (1996). Forest cover monitoring using Remote sensing and GIS- A case study in Dhaulkhand range of Rajaji National park (U.P.). Photonirvachak, J. Indian Soc. Remote sensing, 24 (1): 33-42.

Das S N and Roy B B (1979). Characterisation of caternary soils (India), Indian Jour. Agric. Chem, 12 : 43-51.

Forman R T and Godron M (1986). Landscape ecology, New York: Wiley.

Ghosh S, Sen K K, Rana U, Rao K S and Saxena K G (1996). Application of GIS for land use/ land cover change analysis in a Mountainous terrain. Photonirvachak, J. Indian Soc. Remote sensing, 24 (3):193-202.

Krishna Murthy J and Srinivas G (1995). Role of geological and geomorphological factors in ground awter exploration- a case study through remote sensing techniques, Int. J. Remote sensing, 16 : 2595-2618.

Khorram S and John A B (1991). A regional assessment of land use/ land cover types in Sicily with Landsat TM data. Int. journal of Remote sensing, 12 (1) : 69-78.

Novaline Jaga R M, Sundaram A and Natarajan T (1993). Wasteland development using GIS techniques, 14 (17) : 3249-3257.

Ravindran K V, Pramod Kumar, Tiwari A K, Kudrat M, Ravi shankar H M and Bhave S K (1992). Integrated approach for resources planning using remote sensing and geographiucal information system - a case study of Song watershed. Proc. Nat. Symp. on R.S. for sustainable development : 11-15.

Reddy Obi G P, Esther Shekinah D, Maurya U K, Thayalan S, Jagdish prasad, Ray S K and Bhasker, B P (1999). Landsacpe-soil relationship in part of Bazargaon plateau, Maharashtra, Geographical Review of India, 61(3) : 280-291.

Roy P S, Ranganath B K, Diwakar P G, Vohra T P S, Bhan S K, Singh I J and Pandian V C (1991). Tropical forest type mapping and monitoring using Remote sensing. Int. Journal of Remote sensing, 12 (11) : 2205-2225.

Ruzicka M and Miklos L (1982). Landscape - ecological planning (LANDEP) in the process of territorial planning, Bratislava, Ekologica (CSSR), 1(3) : 297-312.

Ruzicka M and Miklos L (1986). Basic premises and methods in landscape ecological planning (Modelling), Bratislave: Slovenska Academic Ved.

Saraf A K and Choudhuray P R (1998). Integrated remote sensing and GIS for ground water exploration and identification of artificial recharge sites, Int. J. Remote sensing, 19 (10): 1825-1841.

Sahai B (1998). Remote sensing in rural development. Photonirvachak, J. Indian Soc. Remote Sensing, 16 : 5-12.

Sehgal J L, Sharma P K and Karale R L (1988). Soil resource inventory of Punjab using remote sensing techniques. J. Indian Soc. Remote Sensing, 16 : 39-47.

Sharma K D, Singh Surendra, Singh Nepal and Bohra D N (1989). Satellite remote sensing for detecting temporal changes in the grazing lands. J. Indian Soc.Remote sensing, 17 (4) : 55-59.

Strahler (1964). Quantitative geomorphology of basins and channel networks. Handbook of Applied Hydrology, (Ed.Ven Te Chow), McGraw Hill Book Company, New York.

Subramanyan V (1981). Geomorphology of the Deccan volcanic province in Deccan Volcanism and related basalt provinces in other parts of the world. Geological Survey of India, Memoir (3) (Subbarao K V and Sukheswala R N Eds.) : 101-116, GSI, Bangalore.