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FOREST MANAGEMENT PLANNING FOR SOIL CONSERVATION USING SATELLITE IMAGES, GIS MAPPING, AND SOIL EROSION MODELING

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Forest management is the preferred option for soil conservation in mountainous watersheds. Generally, most soil conservation programs in India, including forest management, are carried out with physical reconnaissance surveys. However, recent technological advances have paved the way for planning soil conservation measures on a field scale in the watershed. This paper describes forest management planning for soil conservation based on the quantified soil erosion rate in the Kuniguda watershed of Orissa and Andhra Pradesh and a temporal analysis of the land uses. Temporal analysis of watershed land use was conducted using digital image data for the study area. Geographic information systems tools were used to quantify changes in land use. Results indicate that only 1% of forest cover was lost between the years 1989 to 1996. Agricultural land was only reduced by 1.5%, while bare land only increased by 2%. Shifting cultivation was the cause of increased bare land in the watershed. Forest growth was very high in 1996 as compared to 1989, with a significant increase of 18.4% in the fairly dense mixed forest land use category. Open scrub converted to more dense forest by 17.7%. This change in forest density was attributed to forest protection measures taken up in the study area. Based on the finding of land use changes, an extensive forest plantation program was suggested for the study area.

INTRODUCTION

Forest degradation, mismanagement of land resources, and subsequent soil erosion are severe concerns in today's world. Forest degradation has two main components: deforestation and violations of sustained-yield limits. Deforestation can be interpreted in terms of the conversion of forestland to other uses like shifting agriculture (cropping or grazing, followed by extended periods of fallow), permanent agriculture (cropping or grazing with little or no fallow), or urban uses. Based on Sundquist's (2000) study on global forestland degradation, the best estimate of the tropical deforestation rate is around 8% of the current tropical forest inventory per decade. As per his study, the global inventory of tropical land under shifting cultivation (including fallow) was 3 million km^2 by the 1980s.

Shifting cultivation is the prime example of land and forest resource mismanagement. It adds to the misery of forest degradation by reducing the fertility level of the soil, which is accelerated by soil erosion due to exposed land mass. It becomes almost impossible for the regeneration of the forest in an area under shifting cultivation (Sunquist, 2000; Szott et al., 1999). According to Szott et al. (1999), nutrient losses occur through off take in crop harvests during the cropping phase and through leaching, runoff, and erosion in the cropping phase in the area under shifting cultivation. The nutrient loss happens so fast that it makes the land uncultivable after two or three cropping seasons. Thus, the deforestation causes more damage to the local population than a momentary initial gain of bumper crop harvest (with availability of soil nutrient due to forest litter decomposition). Therefore, it is essential to evaluate the extent of the area under deforestation, the subsequent soil loss from it, and the land use changes.

In developing countries shifting cultivation is a serious threat to the existence of the forest resources and a cause of excessive soil erosion. This is due to unprecedented growth in the human population and a simultaneous shrinking in available resources for living. Forest degradation is rampant in India, especially in tribal inhabited mountainous watersheds. A study by Kushwaha (1991) suggested large scale shifting cultivation was occurring in northeastern India. He was of the opinion that this deforestation phenomenon is serious in every part of India.

Accurate information is required for effective management of natural resources and sound decision-making. The use of satellite imagery assists in making measurements of tropical deforestation far more accurately. Several studies have been completed on shifting cultivation in India (which is locally known as 'Jhum' cultivation). Everybody was concerned about the excessive vagaries it caused. Raman's (2001) study on the slash and burn culture in northeastern India suggested the severity of shifting cultivation. It created enormous loss to the country in the form of disappearance of very high value biodiversities.

Kushwaha (1991) used LANDSAT (MSS) imagery to detect shifting cultivation in northeastern India. He formulated a behavioral pattern (spectral separability of common land surface features) of different land cover types in the form of different MSS bands vs. mean digital value (spectral reflectance value).

Geospatial representation of these landscapes under stress from deforestation and subsequent soil loss is essential to promote corrective measures. Landscape analyses on a broad spatial scale have become more important for biodiversity conservation. Planning conservation becomes easier after finding the habitat status by its spatial representation (Roy and Tomar, 2000). Geographical Information Systems (GIS) coupled with remote sensing can provide an essential advantage to deal with such problems. Roy and Tomar (2000) used GIS to spatially model the disturbance (deforestation) regimes and integrate the ground-based non-spatial features to decide on the biodiversity characterization at a landscape level. They used Indian remote sensing (IRS) satellite images (time series information) for determining the landscape of their study area.

Kohl (2000) used the methodological approach that combined the assessment of the spatial distribution of deciduous trees by remote sensing techniques and GIS-based analyses. A prognosis of the potential spatial and temporal progress of the regeneration of forest was achieved by means of spatial extension models, regeneration models, and genetic models; and visualized in a mapped format. These maps helped evaluate the future diversity of transformed stands in terms of space and time, and are used as a tool for forest management and silvicultural planning.

The objective of this study is to determine the land use changes over the years on a temporal basis, and simultaneously suggest corrective measures for land resource development. For corrective measures planning, it has become essential to estimate the soil erosion rate on a spatial basis. Several studies have been conducted to quantify the soil loss on a spatial basis using remote sensing, GIS techniques, or a combination of both together with soil erosion models.

Use of GIS in soil degradation assessment is an accelerating process due to the advent of continuously improving technology (Al-Abed et al., 2000). Extensive literature exists on soil erosion studies using remote sensing data (Wu et al., 1997; Chao et al., 1997; Hong et al., 1997; Al-Abed et al., 2000). Very few studies have been conducted to estimate soil erosion loss by integrating the revised universal soil loss equation (RUSLE), remote sensing and GIS technology together. RUSLE is the most widely used method for estimating the extent of soil loss through erosion (Renard et al., 1991; Mallerowicz et al., 1994; Wang et al., 2000). The USLE in a modified form was used in Indian conditions (Panda et al., 2000).

A conservation program based on deforestation and soil loss amount can be proposed. Aerial or remotely sensed satellite images and GIS technology are essential to carve out a suitable soil conservation planning strategy. Many researchers have proposed conservation planning that uses the soil loss information (Padgitt, 1989; Tagwira, 1992; Nimbos et al., 1991). Roy and Tomar (2000) designed conservation programs based on their analysis of the landscape fragmentation and degradation using remote sensing and GIS. They found the information on landscape in a space and time perspective to facilitate their decision making process.

OBJECTIVES

The objectives of the study are to:

· Perform a multi-temporal analysis of two different images on different dates to detect land cover changes.

· Develop a decision strategy on a field scale by devising a soil conservation planning program for the sustainable utilization of land and forest resources.

STUDY AREA

This study was conducted in a mountainous watershed called the Kuniguda Watershed. It is named after the river that is the common confluence point of the entire contributing runoff area. It is a part of the Balimela and Sileru Catchment area which extends from 82^0 15’-82^0 30’ east longitude and 18^0 6’-18^0 15’ north latitude. The catchment area falls in the border of two states, Orissa and Andhra

Pradesh. This watershed contributes runoff to a reservoir for a hydroelectric power project situated at an elevation of approximately 800 meters above mean sea level (MSL). The total watershed area is 18068 ha or 180 sq. km (GIS map analysis). The map of the study area is shown in Figure 1.

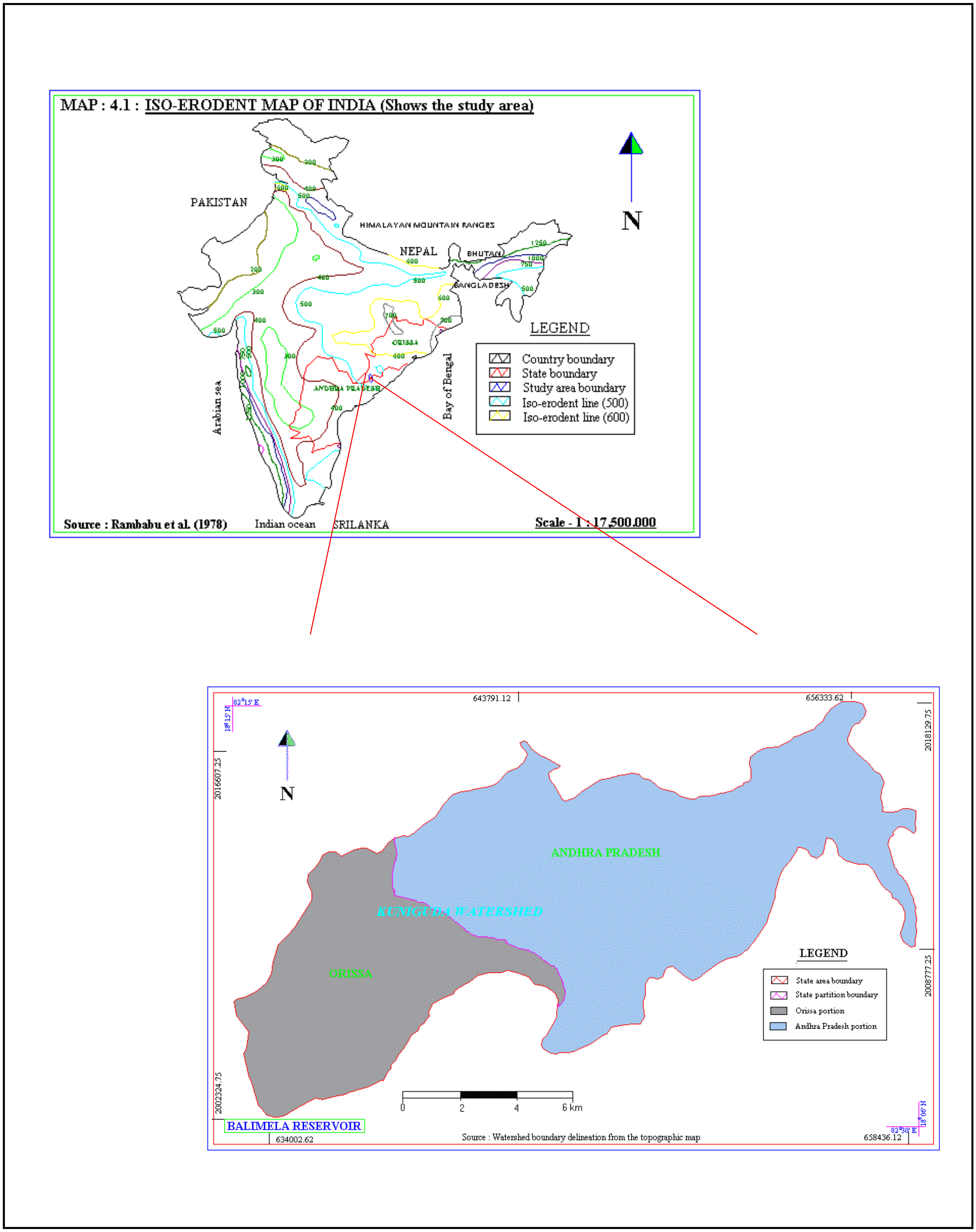

Figure 1. Map of the study area.

MATERIALS AND METHODS

Data sources

The following data were used for the study:

- Topographic map of the study area (1978), (scale - 1:50,000)
- Iso-erodent map of India (1978), (scale - 1:17,500,000)
- Rainfall and temperature data of the study area (1975 to 1995)
- Key to major soil classification chart by FAO/UNESCO
- Soil test report of the study area
- Nomograph for soil erodibility factor study
- IRS- 1A (LISS - II) digital data of the study area (02 February 1989)
- IRS- 1B (LISS - II) digital data of the study area (09 February 1996)
- False Color Composite (FCC) for both satellite images
- Ground truth information of land use in the watershed based on the ground coordinates and its comparison on the land use classification satellite image.
- Supporting conservation factors such as the tilling practice, direction of tillage, crop rotation in a crop calendar, etc.

Working procedure

Soil zone mapping

Panda et al. (2000) had already discussed the procedure for the integration of IRS-1B (LISS-II) remotely sensed satellite data and GIS technology for establishing the different USLE factors suited to the watershed in India. They used an iso-erodent map of India, laboratory report on the soil from the watershed, nomograph, topographic map, and drainage map of the study area to calculate the factors of the USLE. The satellite image provided the latest land use of the area, which was not feasible to procure from the non-updated topographic map. The GIS technology was used to create a large database of all the parameters used in the soil loss quantification process. Again, the GIS software package ARC/INFO was used in calculating the soil loss on a spatial basis for an area as small as approximately 1500 sq. meter. The modified universal soil erosion equation was used to integrate the information from maps created either by means of independent GIS usage or combined application of both GIS and remote sensing techniques (Panda et al., 2000). A schematic of the aggregate approach to create a soil loss zone of the watershed is provided in Figure 2.

The spatial soil loss information was based upon the following ranges. For the Indian conditions, the considered soil loss tolerance level is within the range of 4.5-11.2 tonnes/ha/yr. (Dhruvanarayan et al., 1983). Therefore, a range of classes based on the soil loss quantity in accordance to the tolerance range was considered. The soil loss zones are:

- Low: < 4.5 tonnes/ha/yr.
- Moderate: 4.5-11.2 tonnes/ha/yr.
- High: 11.2-25 tonnes/ha/yr.
- Very high: > 25 tonnes/ha/yr.

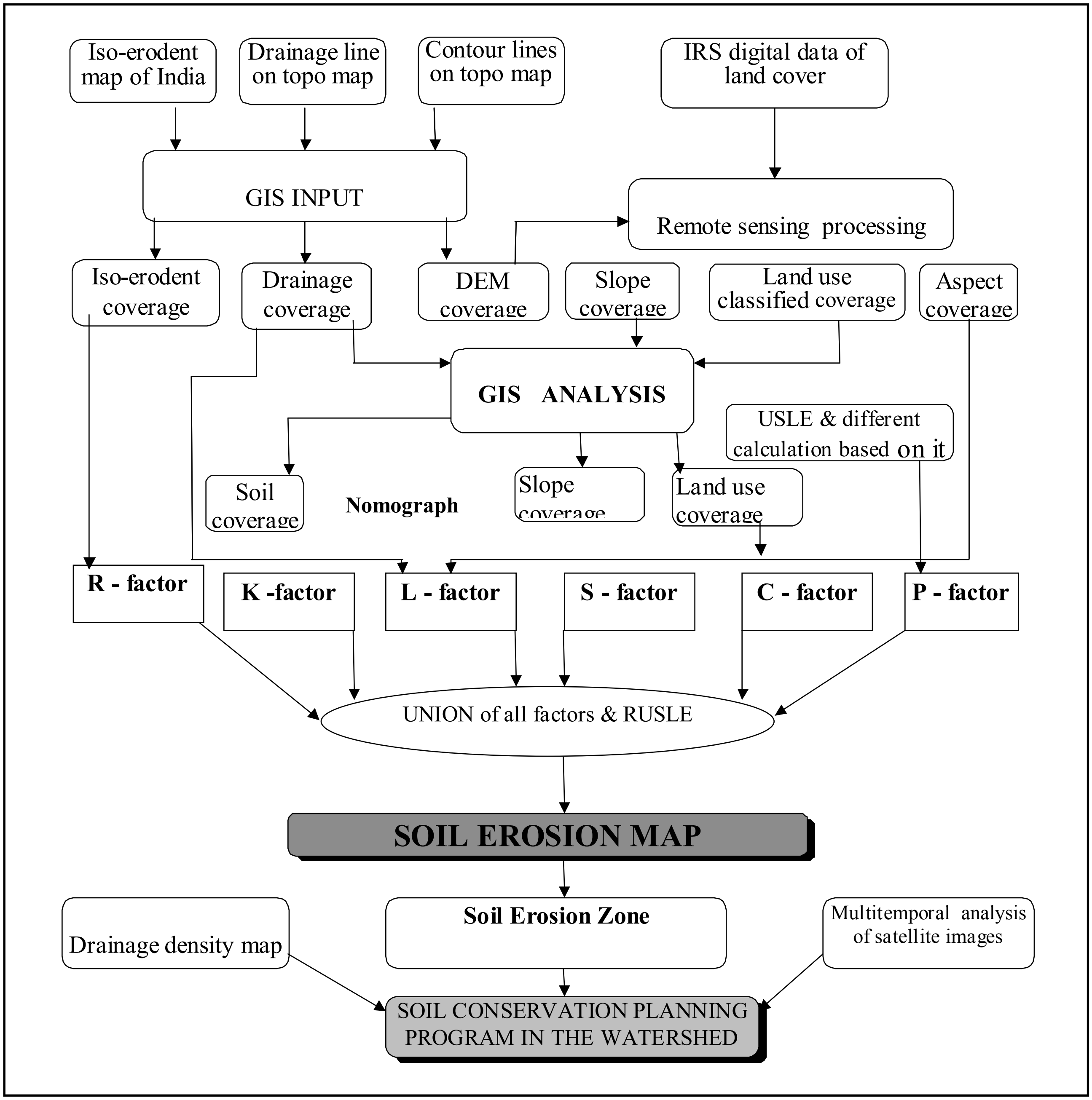

Figure 2. Schematic of the aggregate procedure involved in soil conservation planning program.

Change detection/multi-temporal analysis of land use and land cover

In this study, the forest cover change detection was the most important factor in the soil conservation planning program. There are two types of changes that occur over the years: a) seasonal change and b) annual change. Among these changes, the seasonal change is a very complex phenomenon in many cases. However, it is not a real change of land use. Agricultural changes and the forest changes of a deciduous nature are seasonal changes that can be restored in the next season. Annual changes are the real lasting changes of land use or land cover of the area. Deforestation, afforestation, and the newly created built up areas (urbanization) are examples of annual changes. Our objective in this study was to determine the annual changes.

Two satellite images, IRS-1B (LISS-II) of 9th Feb 1996 and IRS-1A (LISS-II) of 2nd Feb 1989, were used for the multi-temporal analysis of the study area. Figure 3 shows the procedure followed for this purpose. The image of the study area was cut from the scene (IRS-1A and 1B). Unsupervised classification was performed on both the images in the ERDAS environment. All possible classes were generated by the ISODATA classification technique of ERDAS. The SPSS Ward method of cluster merging was used to obtain information on cluster merging based on the Euclidean distance of cluster center values. These procedures gave the required six clusters (land use classes) from the images. Figure 3 illustrates the process involved in land use classification of the image from the computer compatible tape. Based upon the land use in the study area, we classified the land cover into these following six land uses. They are medium density forest, fairly dense mixed forest, fairly open mixed forest, open scrub, agricultural land, and hill top bare land. This land use classification suggests the type of forests present in the watershed. Forestland was categorized into four different subcategories (independent land use classes) as very dense, moderately dense, very thin, and open forest with mostly scrubs. The hill top bare land in the study area was due to shifting cultivation and a few stone quarries.

Both classified images were transferred to the ARC/INFO environment and merged together using the UNION command. Thus, a group of 36 classes was formed based on the temporal changes of land use classes from 1989 to 1996. Each land use class (say, agricultural land) in 1989 changed to six other land use classes in 1996, such as medium density forest, fairly dense mixed forest, fairly open mixed forest, open scrub, agricultural land, and hill top bare land. The land use temporal change detection procedure is shown in Figure 4.

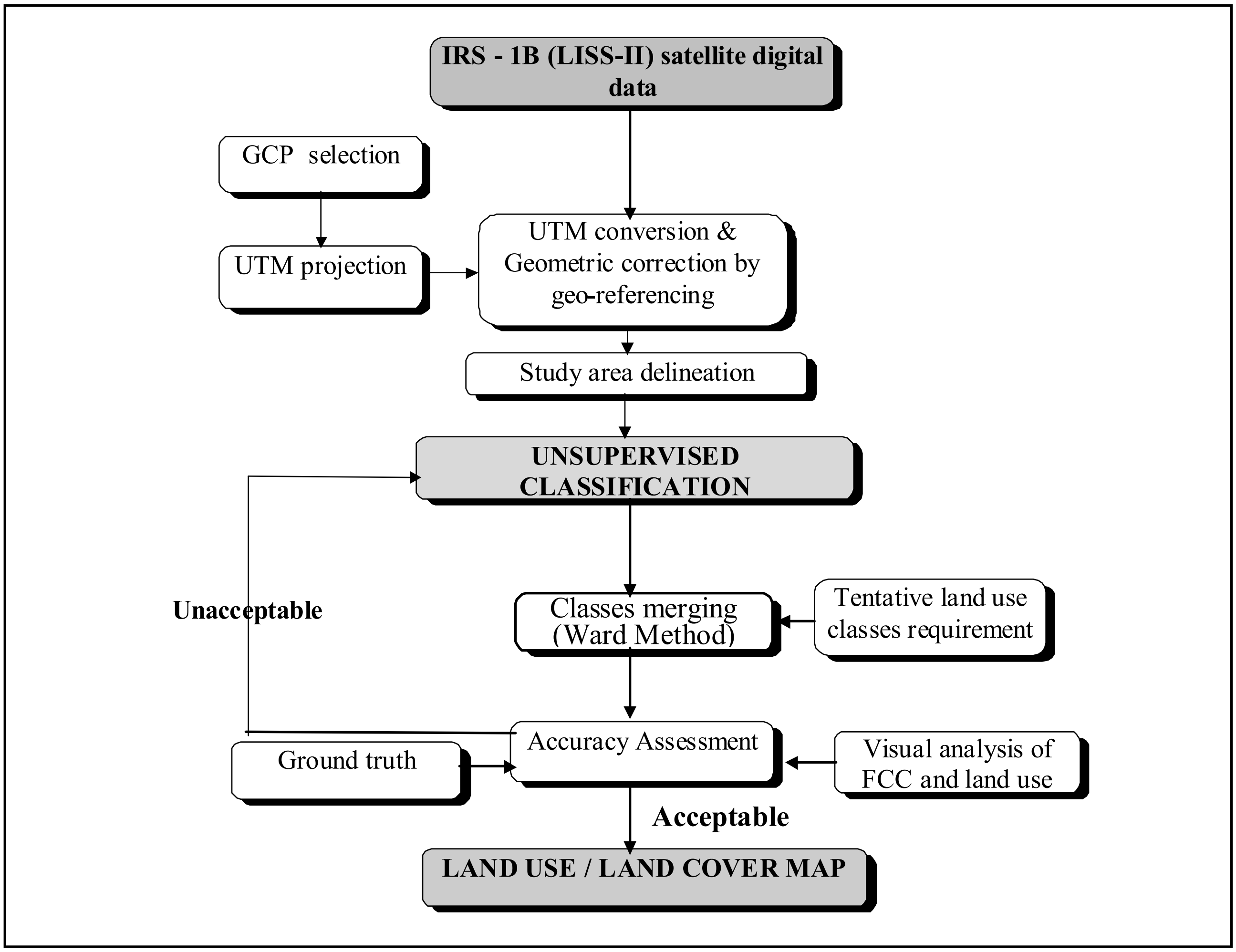

Figure 3. Schematic of land use classification process.

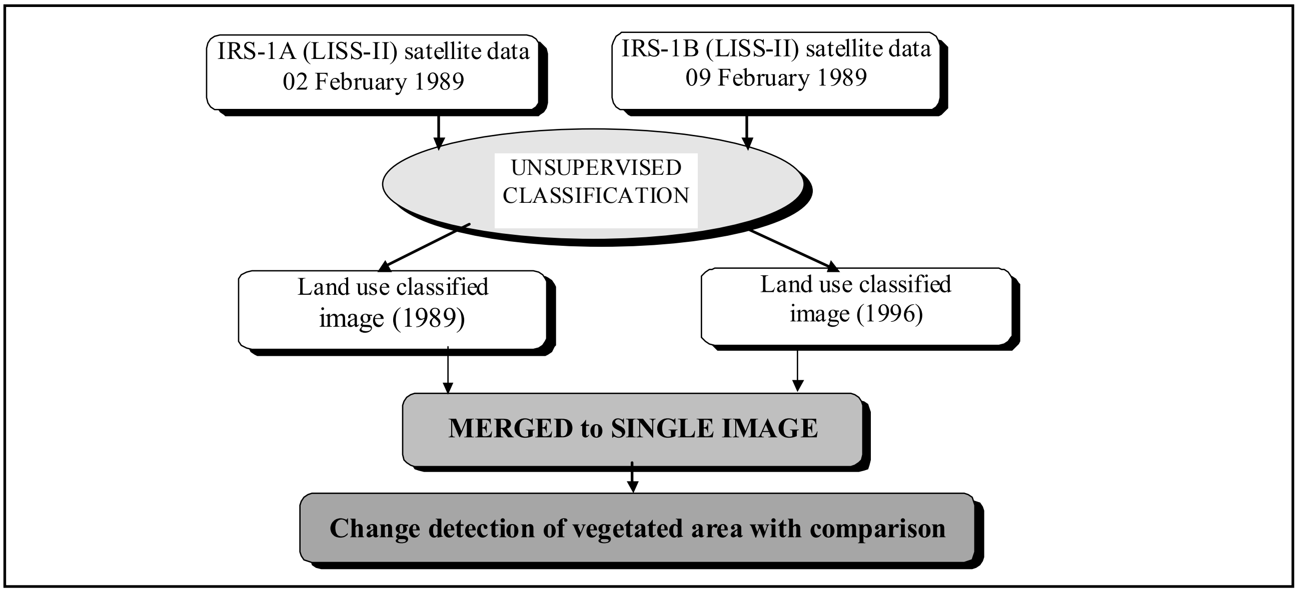

Figure 4. The schematic of the land use change detection procedure.

RESULTS AND ANALYSES

Land use characteristics

Land use classification map (1996)

The study area was mostly a forested watershed. The land use classification of the satellite map of 1996 (Figure 5) suggested that nearly 75% of the study area was in forest cover of different types. Only 15% of the study area with a low slope gradient area (1-5%) was in the agriculture land category. Agricultural land is generally vacant most of the year. Anther 10% of total watershed land use was in the bare land category, of which a major portion was flat hilltop. It was classified as hilltop bare land and was mostly due to slash and burn culture, which was abandoned by the farmers after 2-3 years of cropping when all the topsoil eroded. No significant water bodies (except the main river) were present in the study area. The area under different land use is provided in Table 1, which was calculated using the command function of ARC/INFO.

Land use classification map (1989)

In 1989, almost the same area (75% of the total watershed) was in different types of forest cover (Table 2). However, the area in individual forest categories showed large differences. For example, fairly dense mixed forest in 1989 covered only 9%, while 27.4% of the area was covered by this land use in 1996. The area in open scrub experienced a significant decrease from 1989 to 1996: the change of land cover was from 34.1% to 16.4%. In 1989, 16.6% of the study area was in the agriculture category. 8.2% of watershed area was in the hilltop bare land category. Figure 6 represents the watershed land use classification map of 1989.

Temporal analysis of land use

No significant change was found in the forest cover land use. Only 1% of forest cover was lost between the years 1989 and 1996. Agricultural land was only reduced by 1.5%, while bare land only increased by 2%. This increase in hill top bare land was due to the abandoning of land after shifting cultivation, when all the topsoil was washed away. Another factor for the increase in bare land was the expansion of stone quarries in the flat hilltops. The forest growth was very high in 1996 as compared to 1989. A significant increase of 18.4% in fairly dense mixed forest land use category within the 7-year span was encountered. Open scrub was reduced and converted to more dense forest

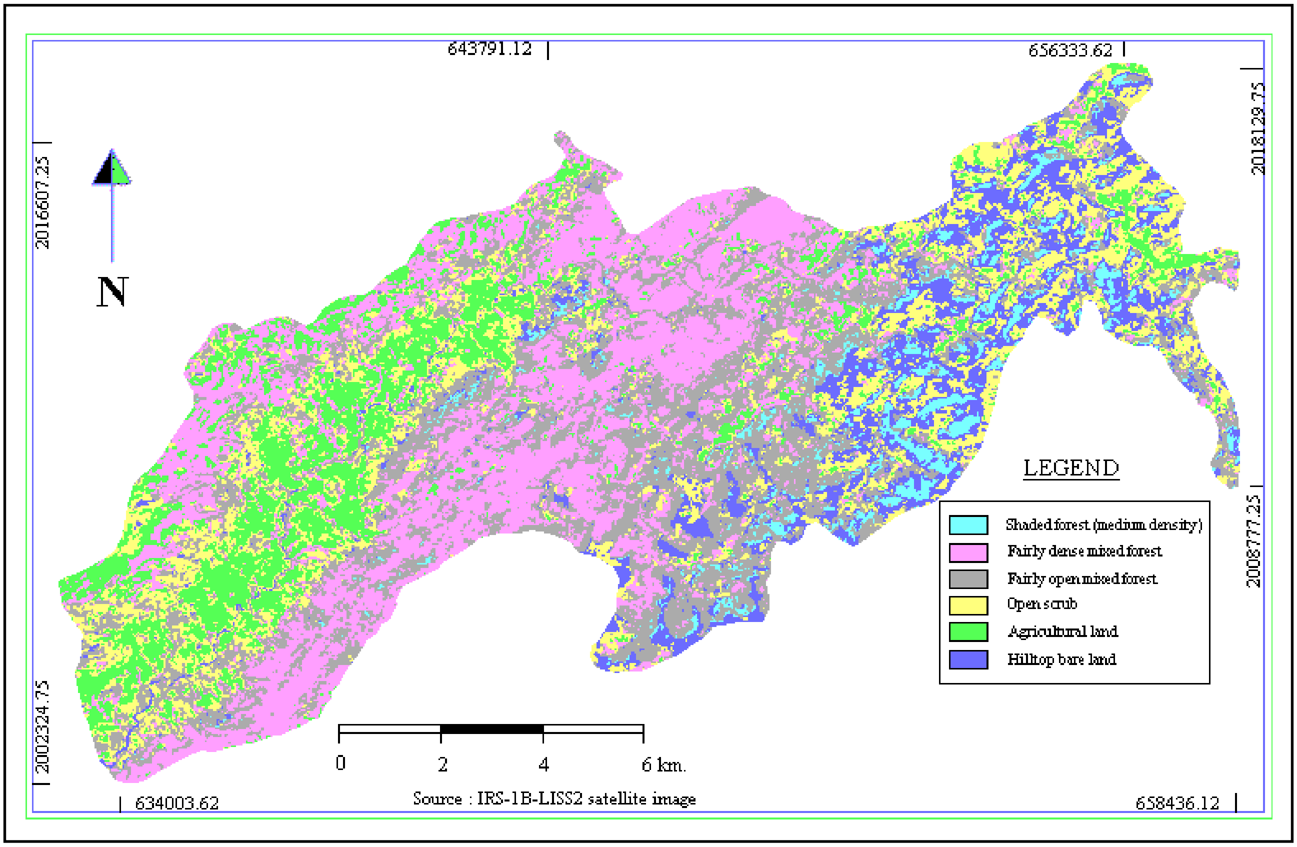

Figure 5. Land use classification map of the study area (1996).

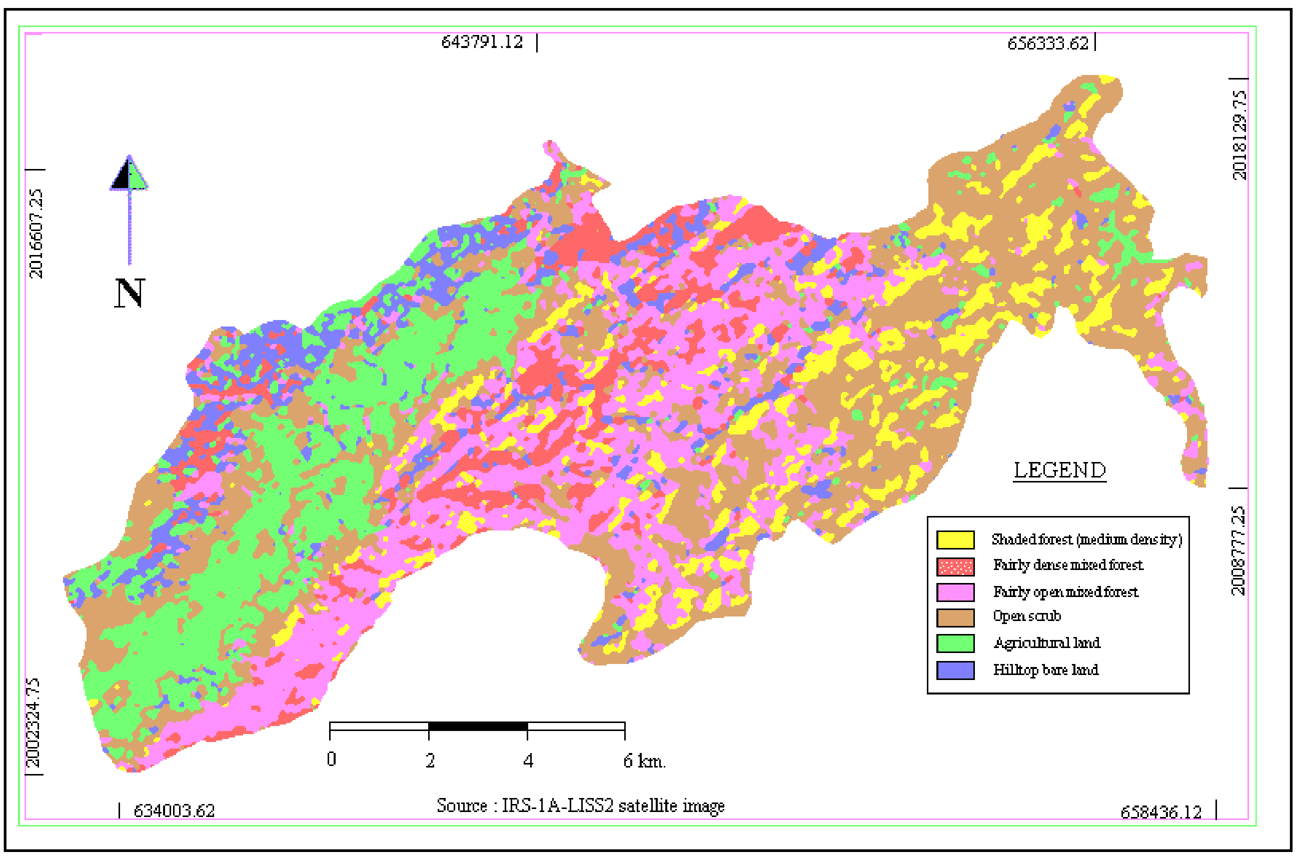

Figure 6. Land use classification map of the study area (1989).

Table 1. Area Covered Under Different Land Use in the Watershed in 1996

#	Land use classes	Area (in ha.)	Percentage (%)
1	Medium density forest	603.96	3.35
2	Fairly dense mixed forest	4955.01	27.42
3	Fairly open mixed forest	4976.38	27.54
4	Open scrub	2965.94	16.42
5	Agricultural land	2723.30	15.07
6	Hilltop bare land	1843.41	10.02
	Total	18068.00	100.00

Table 2. Area Covered Under Different Land Use in the Watershed in 1989

#	Land use classes	Area (in ha.)	Percentage (%)
1	Medium density forest	1795.60	9.94
2	Fairly dense mixed forest	1627.72	9.01
3	Fairly open mixed forest	4002.19	22.15
4	Open scrub	6163.31	34.11
5	Agricultural land	2993.08	16.57
6	Hilltop bare land	1486.11	8.22
	Total	18068.00	100.00

by 17.7%. This conversion was open scrub to fairly open mixed forest, and fairly open mixed forest to fairly dense mixed forest categories. The change in the fairly open mixed forest was insignificant, i.e., only a 5.4% increase within the same period. These changes were due to the soil conservation measures taken in this watershed over the Orissa portion from 1987 to 1989 under the "river valley scheme." Above all, the NGO project of "village green committees", formed in the watershed in this period (which is in action now) to safeguard the forest from deforestation, was the cause of forest regeneration. A fair amount of land under shrubs only was changed to medium to fair dense forest cover. The forest regeneration process was very significant over 7 years. In that process, the open scrubland changed to open forest (thin); thin forest cover converted to either medium density or high-density forest cover. Another important factor of forest sustenance was the very low population in the area.

From the study, we concluded that shifting cultivation severely impacted the watershed, although there was a small population. The local tribal people (Kandha), who have a very good penchant for slash and burn agriculture, contributed to an increase of 2000 hectares of land under shifting cultivation (calculated by temporal analysis). It also suggested that there was no effort in changing bare land into forest cover. Figure 7 shows the information regarding the land use/land cover changes over the 7-year period. Table 3 shows the changed area from one land use to another over the 7-year period.

Soil loss quantification

A soil conservation program for the study area was proposed based on different watershed characteristics, such as slope, aspect, land use/land cover, and spatial-temporal variability. Soil loss zoning was performed on the entire watershed. Again, separate soil losses were quantified based on different land uses, slope gradients, and soil types in the watershed. The quantitative approach in this respect would facilitate a meaningful soil conservation program for the study area. These soil loss quantifications were performed by the mathematical processing technique of spatial data of the ARC-INFO. Figure 8 shows a soil loss zone map for the watershed.

The average soil loss of the watershed was estimated as 10.8 tonnes/ha/yr in 1996. A very high percentage (81.6%) of watershed area was found to be coming under the low range of soil loss zone, i.e. < 4.43 tonnes/ha/yr. Eleven percent of the watershed area was within the permissible level of soil loss in the Indian condition, i.e., 4.43-11.2 tonnes/ha/yr (Dhruvanarayan et al., 1983). Only 8% of the land was under the high or very high soil loss category. This was due to forest land cover of different types in the watershed that influenced soil erosion reduction. Agricultural lands and bare lands had the greatest potential for soil erosion.

Average soil loss from different land uses in 1996 is shown in Table 4. As expected, the hill top bare land had the highest average soil loss amounting 85.2 tonnes/ha/yr. This high extent of soil loss suggests the extreme vagaries associated with shifting cultivation. Agricultural land had the second highest soil loss. The soil loss from open scrub land use was only 1.1 tonnes/ha/yr. All other forest land uses contributed less than 0.6 tonnes/ha/yr of soil loss.

SOIL CONSERVATION PLANNING PROGRAM

The factors affecting erosion by water are climate, soil type and properties, vegetation (including the forest cover and cultivation), and topography (Schwab et al., 1981). In our study, we could not manage the climate and soil properties easily. However, the vegetation of the watershed as well as its topography could be changed to reduce soil loss due to water erosion. Various engineering measures (Panda et al., 2001), soil conservation supporting agricultural practices, and forest management programs could be planned to reduce the soil erosion rate in the watershed. In this paper, a strategic forest (vegetation) management program was proposed as a soil conservation measure.

Generally, soil conservation measures are taken by reconnaissance surveys. However, this research provided a basis for proposing a large-scale soil conservation program, especially forest management planning, without any direct physical information from the watershed.

Afforestation

Large-scale forest plantation

On the very steep slope lands where terrace construction is not possible, an afforestation program should be undertaken. This program is designed to change the vegetation density and reduce soil loss. The sites chosen for the plantation measures were hilltop bare land (could be determined from the land use classification map) where the forest could be safe to grow and create new soil from forest litter. Figure 9 shows the places for the plantation program. It was determined by the GIS analysis of the land use classification map of 1996. Some of the local and fast growing varieties of trees could be proposed as forest plantation. They were Gambhari (*Gmelina arboria*), Simuli (*Bombax cieba*), Sunari (*Kasia fistula*), Chakunda (*Cassia ciarnea*), Krushna Chuda (*Poinciana regia*), Sal (*Pterocarpus marsapium*), and others.

Forest protection

In the study area, it was concluded that the forest cover is increasing from the year 1989. This increase in forest cover and density was only possible due to the “forest protection measures” projects. Hence the best possibility for saving the soil loss of the watershed was to go for large scale forest protection measures. These measures were proposed in the fairly open mixed forest and open shrub areas. This success of this program can be seen from the multi-temporal analysis of the two satellite images of the study area.

Avenue plantation

Trees could be planted along the roads, which could check the erosion in the depression of the roadside waterways. This roadside plantation (avenue plantation) program was proposed in the area

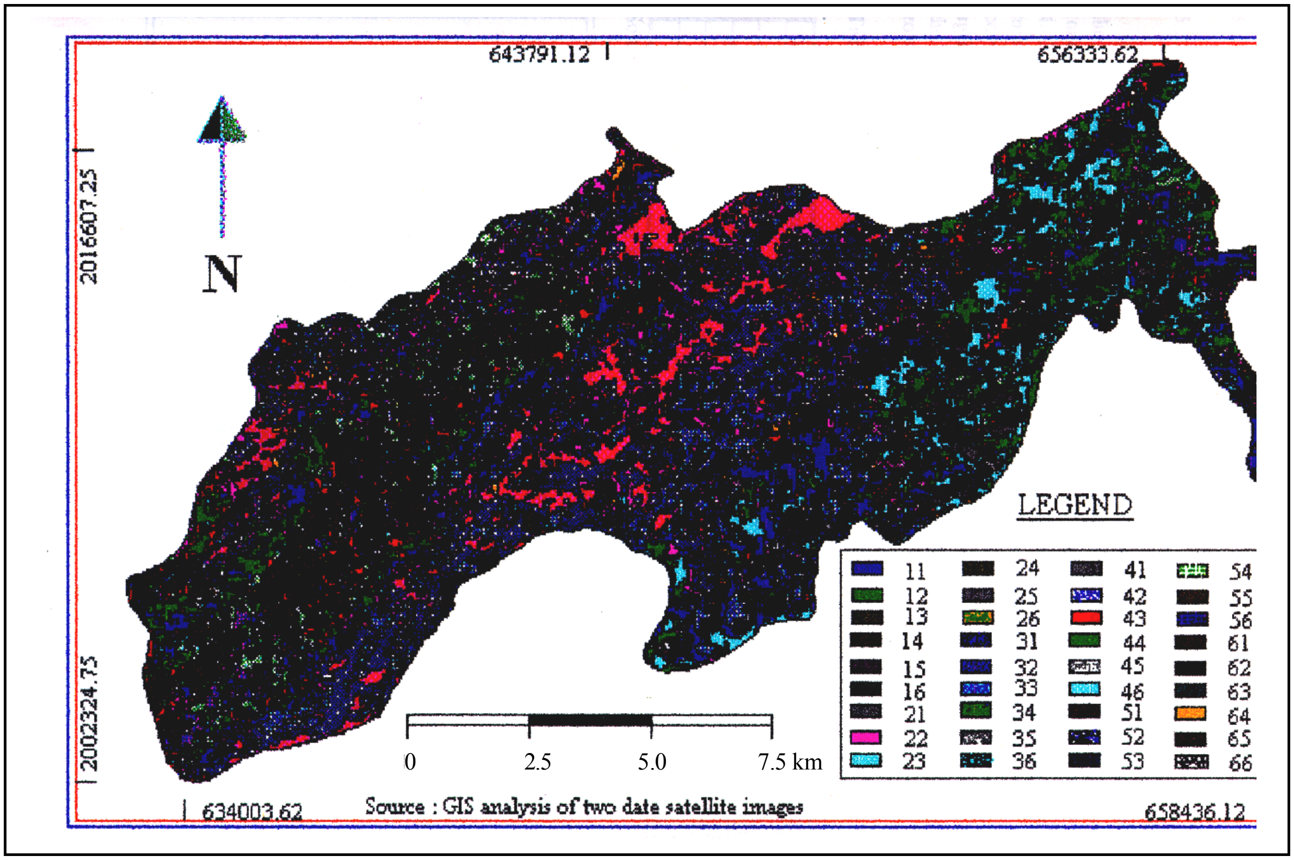

Figure 7. Land use/land cover changes in the watershed from year 1989 to 1996. (N.B. Refer to Table 3 for legend explanation).

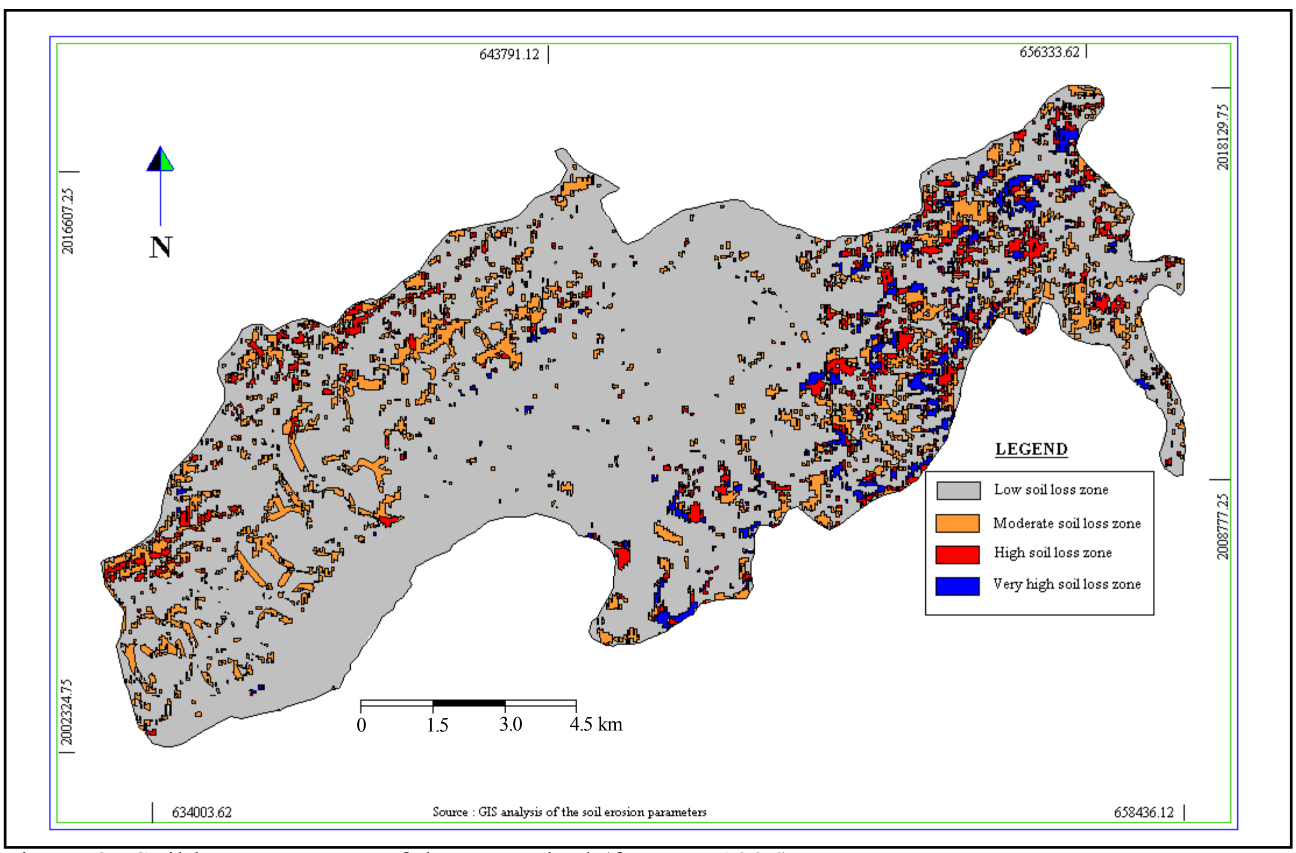

Figure 8. Soil loss zone map of the watershed (for year 1996).

Table 3. Land Use Changes from 1989 to Different Land Uses in 1996

#	Land use of 1989	Area (in ha)	Changes to LU of 1996	Area (in ha)	%	Leg end	Total %
1	Medium density forest	1795.60	Medium density forest	209.85	11.68	11	100
			Fairly dense mixed forest	217.73	12.12	12	
			Fairly open mixed forest	706.14	39.33	13	
			Open scrub	250.43	13.95	14	
			Agricultural land	41.42	2.31	15	
			Hilltop bare land	370.03	20.61	16	
2	Fairly dense mixed forest	1627.72	Medium density forest	64.34	3.95	21	100
			Fairly dense mixed forest	1198.57	73.63	22	
			Fairly open mixed forest	250.64	15.41	23	
			Open scrub	21.42	1.31	24	
			Agricultural land	80.51	4.95	25	
			Hilltop bare land	12.24	0.75	26	
3	Fairly open mixed forest	4002.19	Medium density forest	51.09	12.77	31	100
			Fairly dense mixed forest	1755.22	43.86	32	
			Fairly open mixed forest	1685.29	42.11	33	
			Open scrub	227.38	5.68	34	
			Agricultural land	115.15	2.88	35	
			Hilltop bare land	168.19	4.20	36	
4	Open scrub	6163.31	Medium density forest	323.42	5.25	41	100
			Fairly dense mixed forest	663.34	10.76	42	
			Fairly open mixed forest	1764.87	28.64	43	
			Open scrub	1673.55	27.15	44	
			Agricultural land	553.50	8.98	45	
			Hilltop bare land	1184.67	19.22	46	
5	Agriculture land	2993.08	Medium density forest	12.80	0.43	51	100
			Fairly dense mixed forest	304.35	10.17	52	
			Fairly open mixed forest	327.53	10.94	53	
			Open scrub	662.24	22.12	54	
			Agricultural land	1615.25	53.97	55	
			Hilltop bare land	70.90	2.37	56	
6	Hilltop bare land	1486.11	Medium density forest	3.98	0.27	61	100
			Fairly dense mixed forest	758.50	51.04	62	
			Fairly open mixed forest	246.01	16.55	63	
			Open scrub	126.83	8.54	64	
			Agricultural land	314.65	21.17	65	
			Hilltop bare land	36.13	2.43	66	

devoid of forest cover (agriculture land area). The road map was digitized to show the proposed program in Figure 10.

Horticulture plantation

This program was planned considering the economic condition of the poor tribal population in the watershed. In the moderate slope range of the open scrubland and bare land area, this program could

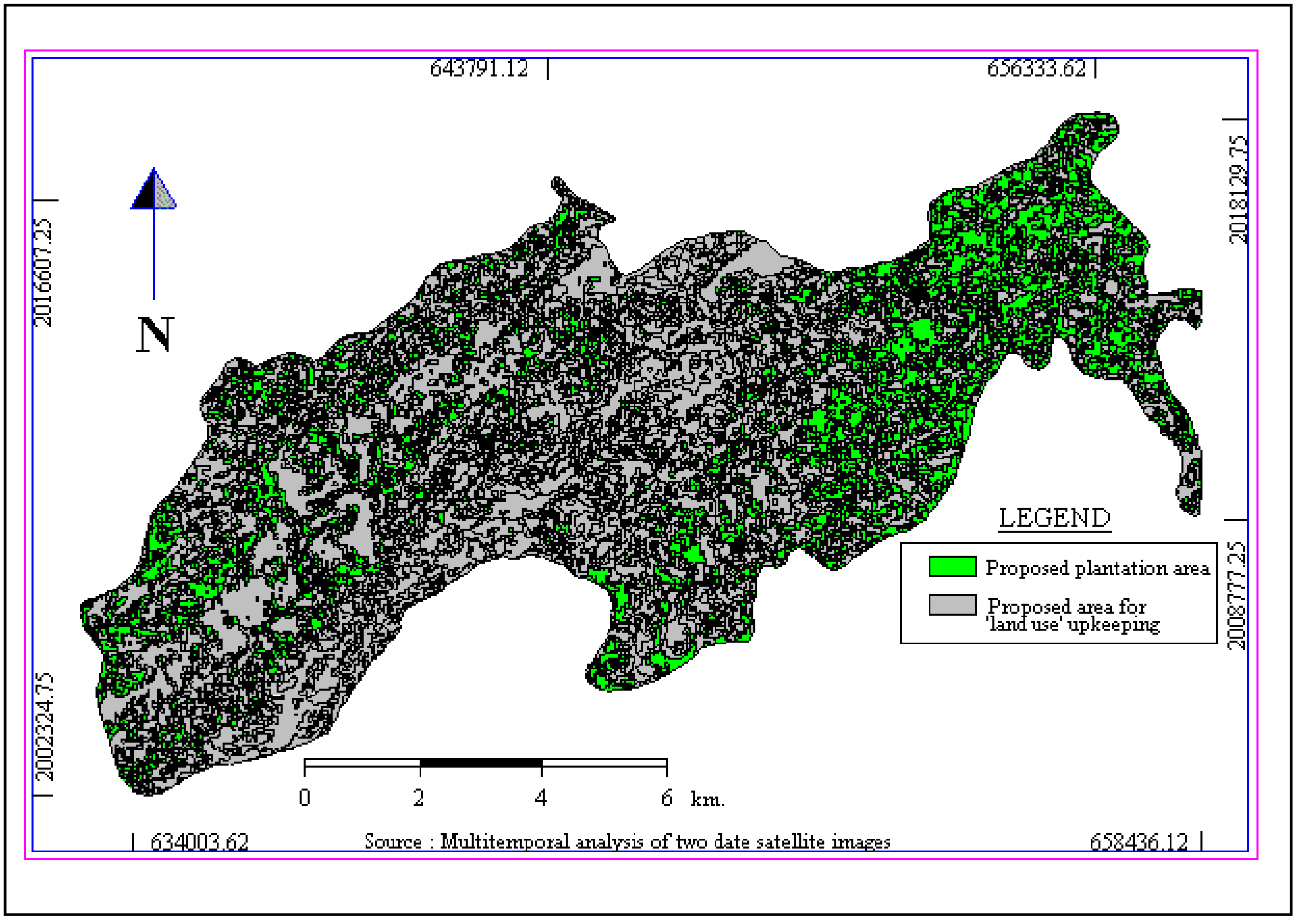

Figure 9. Proposed plantation program site in the watershed.

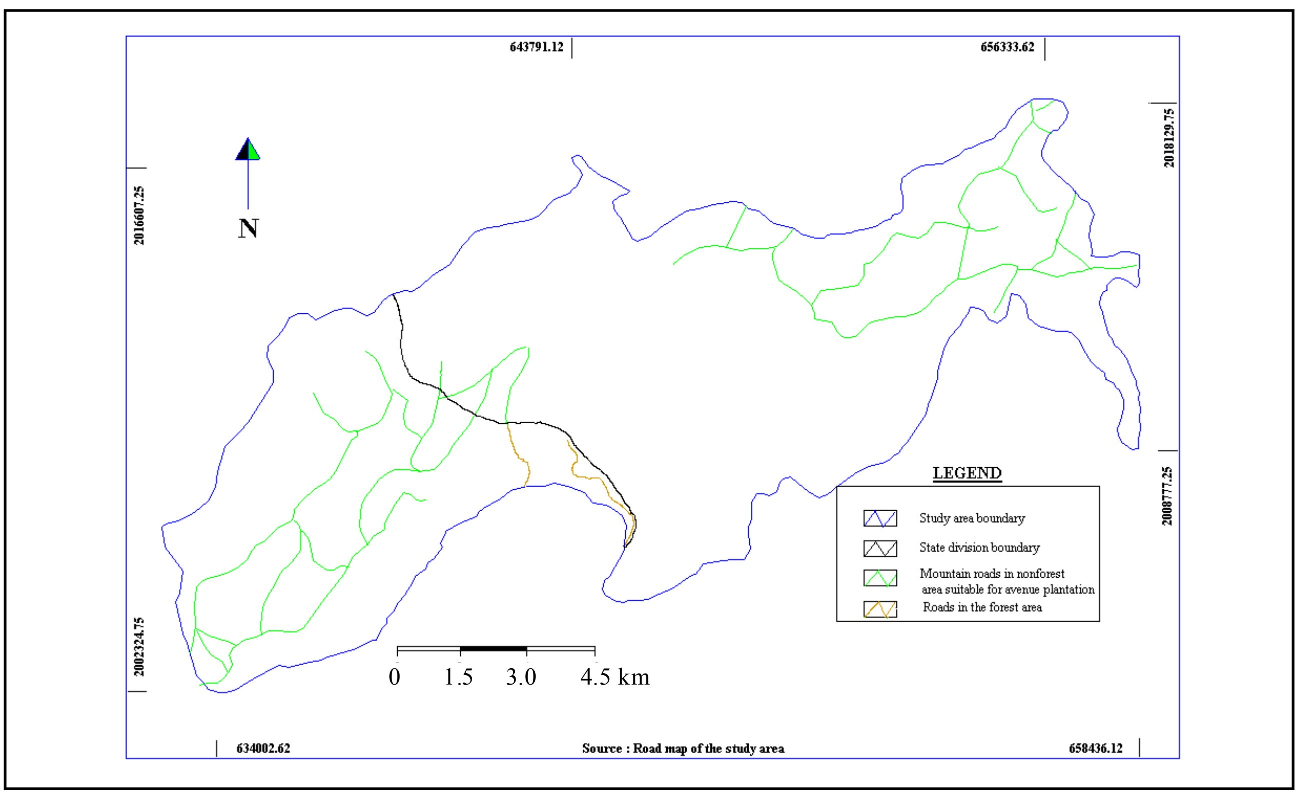

Figure 10. Proposed avenue plantation program in the watershed.

Table 4. Soil Loss Amount from Different Land Use

#	Land use classes	Area (in ha)	Average soil loss (in t/ha/yr.)
1	Medium density forest	603.95	0.412
2	Fairly dense mixed forest	4955.01	0.234
3	Fairly open mixed forest	4976.38	0.566
4	Open scrub	2965.94	1.1
5	Agricultural land	2723.30	11.22
6	Hilltop bare land	1843.41	85.20

be carried out. Various locally acceptable fruit tree varieties could be proposed for horticulture plantation. They were lemon (Citrus medica), orange (Citrus sps.), jack fruit (Artocarpus integrifolia), mango (Magnifera indica), and others, which are suitable for the local tropical climate.

CONCLUSION

The methodology developed to determine the change in land use, especially the forest cover of inaccessible mountainous watersheds, is promising. It could very accurately provide information regarding forest management. Remote sensing (use of satellite images) and GIS techniques were very useful tools for the study. Remote sensing and GIS integration helped in calculating the land use changes in great detail. The advent of GIS technology made it possible to estimate soil loss amount as a function of land use from the soil erosion model (Panda et al., 2000). The multi-temporal image analysis was conducted to verify land use changes in the watershed over the years and facilitate recommendations for a soil conservation program (especially forest resources management) in the study area. GIS was a perfect tool to capture data, create a database, and analyze the data to provide a conclusion. The mathematical programming of ARC/INFO software was a powerful function which made the smallest calculation based on a huge dataset a possibility.

The other conclusions drawn from this study, based on soil loss quantifications, were that the hill top bare land and the agricultural land in the study area had the highest soil loss of 85.2 tonnes/yr/ha and 11.2 tonnes/yr/ha, respectively, as compared to other land uses. Thus, conservation planning should focus on these land uses. An important observation from this study was the favorable impact of forest protection compared to forest plantation. Forest protection could help in forest regeneration without practical human interference. Forest regeneration because of protective measures was clearly shown by the positive land use changes in the watershed from 1989 to 1996. The authors favor forest protection measures as a means to regenerate forest cover and conserve soil resources.

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