Environmental Impact Assessment in a Watershed for Sustainable Land Management

M.Premalatha, S.K. Bhan and Li Fabin

[1] Indian Institute of Remote Sensing, Dehradun, India
[2] Chengdu Institute of Mountain Disaster and environment, Chengdu, China

1. Abstract

Extracting natural resources to their maximum level has resulted in reduction of the supply level per capita where the concurrent increase in population has resulted in increased demand. As the demand increases, people are interested in extracting more resources, which affects the sustainability of resource generation. In the present study, an approach is made to develop a methodology to assess the impact on the environment in a watershed by human intervention and of natural hazard.

Land use change was detected using Landsat MSS data and IRS LISS II data over a period of 14 years. Expected human intervention zones were generated by considering the road network and settlement locations, both separately and combined. Erosion was considered as a natural hazard parameter. Correlation maps between change expected and change occurred were generated and analyzed for the impact of particular parameters. Accordingly the study area was categorized for better spatial correlation index and a methodology was developed for environmental impact assessment in a watershed.

2. Introduction

Extracting natural resources to their maximum level has resulted in reduction of the supply level per capita where at the same time the increase in population has resulted in increased demand. As a result, supply and demand are no longer balanced. As the demand increases, people are interested in extracting more and more resources, which affects the sustainability of resource generation. It is essential to assess demand extracting the resources only to their optimum level, (not to the maximum level) so that the land resources are sustained for the future. The growing awareness of the significance of environmental threats, due to overexploitation of resources, has forced people all over the world to try to save the deteriorating environment. Environmental impact assessment (EIA) aims at achieving a judicious balance between economics and ecology. It is a quantifiable index to represent any alteration of environment conditions, or creation of new conditions, adverse or beneficial. In the present study an approach to assess the impact on the environment by human intervention and by natural hazards in a watershed, was studied using Geographic Information System (GIS) technique.

3. Study Area

The study area, Sitla Rao watershed, falls in the administrative district of Dehradun, India and lies between 30o 20'N to 30o 30'N and 77o 45'E to 78o 00'E and covers an area of 53.264 sq.km. The river Sitla Rao, a tributary of the Asan river, originates in the Himalayan range at the highest peak of 2229m above msl and joins the Asan river at an elevation of 440m above msl.

4. Data Used

Selection of a suitable multi-date data set is one of the basic requirement for assessing the changes that have happened and their impact on the environment. Following data are used in the present study.

- Survey of India (SOI) toposheet (No. 53F/15) on 1:50,000 scale
- Remote sensing data
- Landsat MSS data of 1979,
- IRS LISS II data of 1993
- Ground truth data and socio-economic data collected during the field visit.

5. Methodology

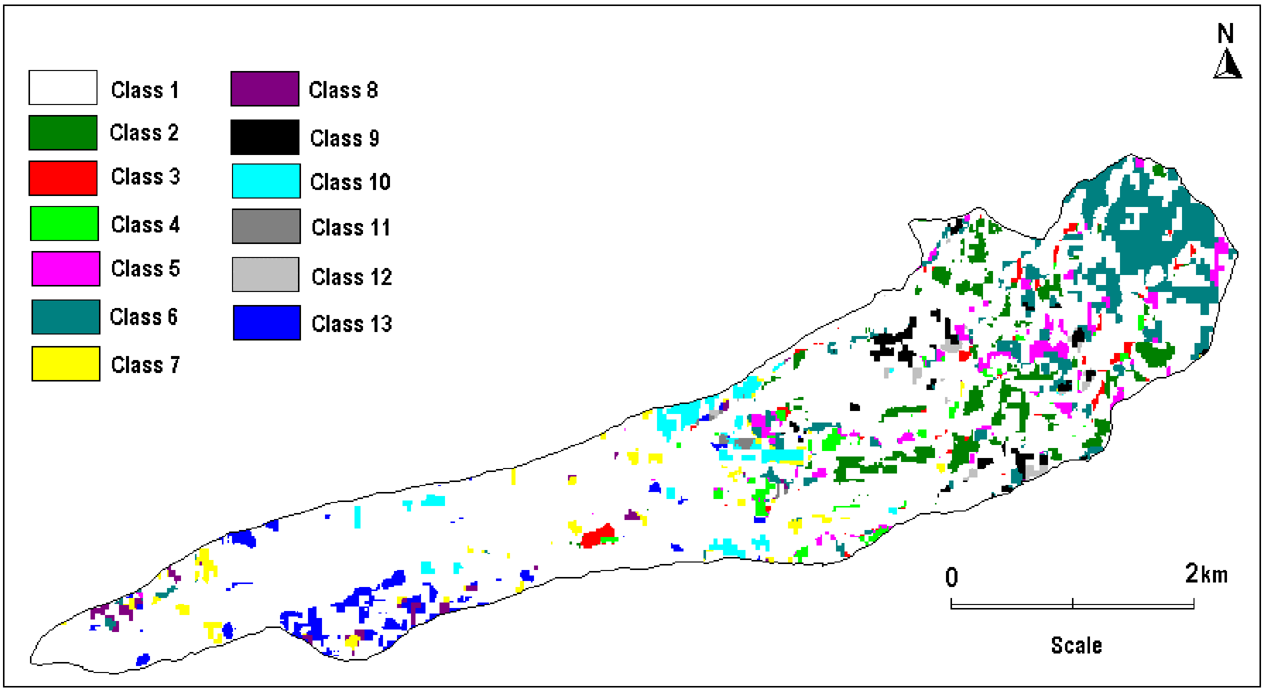
Satellite data were rectified using the SOI toposheet as the base map. Watershed boundaries were digitized and the image under the boundary extracted using the digitized boundary polygon as the mask. The temporal data set (1979 and 1993) was classified using the ground truth data collected during the field visit. Using the confusion matrix method, the accuracy of the training sets was evaluated; it was about 93% (Table.1) for MSS data and 92% (Table-2) for LISS II data. A parallelepiped algorithm was used as a first pass for the maximum likelihood classifier for better accuracy (Garg. et. al. 1995). The classified data was transferred to a GIS platform (Arc/Info), and change detection was done using logical selection. By analyzing the types of changes that happened in the study area, (Figure.1). The road network and settlement locations were considered as the human intervention factor and erosion as the natural factor that cause of the changes. To identify the impact of each factor, the factors were considered separately in the first instance. A flow chart of the methodology is presented in Figure 2.

Table 1. Confusion matrix of training sets used for Landsat MSS (1979) data classification

Class	Pixels	Dense forest	Open forest	Dense scrub	Open scrub	River course	Cultivation	Built-up area	Barren land
Dense forest	394	**94.4**	2.3	1.3	1.8	0.0	0.3	0.0	0.0
Open forest	138	5.2	**93.2**	0.9	0.7	0.0	0.0	0.0	0.0
Dense scrub	175	1.1	1.1	**91.4**	3.4	0.0	1.1	0.6	0.6
Open scrub	70	0.0	2.7	5.3	**92.0**	0.0	0.0	0.0	0.0
River course	207	0.5	0.5	0.0	2.3	**88.7**	3.4	2.2	0.9
Cultivation	91	0.0	1.1	0.0	1.1	2.7	**88.2**	2.4	1.2
Built-up area	43	0.0	1.6	1.6	0.0	0.0	3.4	**91.1**	2.3
Barren land	15	0.0	0.0	0.0	0.0	0.0	0.0	6.7	**93.3**

Table 2 Confusion matrix of training sets used for IRS LISS II data (1993) classification

Class	Pixels	Dense forest	Open forest	Dense scrub	Open scrub	River course	Cultivation	Built-up area	Barren land
Dense forest	1193	**93.2**	4.6	0.6	1.5	0.0	0.0	0.0	0.1
Open forest	601	3.5	**91.7**	2.9	1.7	0.0	0.0	0.0	0.2
Dense scrub	247	0.4	1.6	**96.4**	0.8	0.0	0.8	0.0	0.0
Open scrub	493	0.0	0.8	4.1	**94.7**	0.0	0.4	0.0	0.0
River course	612	0.0	0.0	0.0	0.0	**93.1**	0.2	6.5	0.0
Cultivation	285	0.0	0.0	0.0	0.0	3.2	**95.4**	1.4	0.0
Built-up area	130	0.0	0.0	0.0	0.0	0.0	3.1	**93.1**	3.8
Barren land	69	0.0	0.0	0.0	0.0	0.0	0.0	7.8	**91.4**



Class 1 - No change
Class 2 - Dense forest to open forest
Class 3 - Dense forest to dense scrub
Class 4 - Open forest to dense scrub
Class 5 - Open forest to open scrub
Class 6 - Dense scrub to open scrub
Class 7 - Dense scrub to cultivated area
Class 8 - Dense scrub to settlement
Class 9 - Dense scrub to barren land
Class 10 - Open scrub to cultivated area
Class 11 - Open scrub to settlement area
Class 12 - Open scrub to barren land
Class 13 - Cultivated area to settlement area

Figure 1. Land use change from 1979 to 1993.

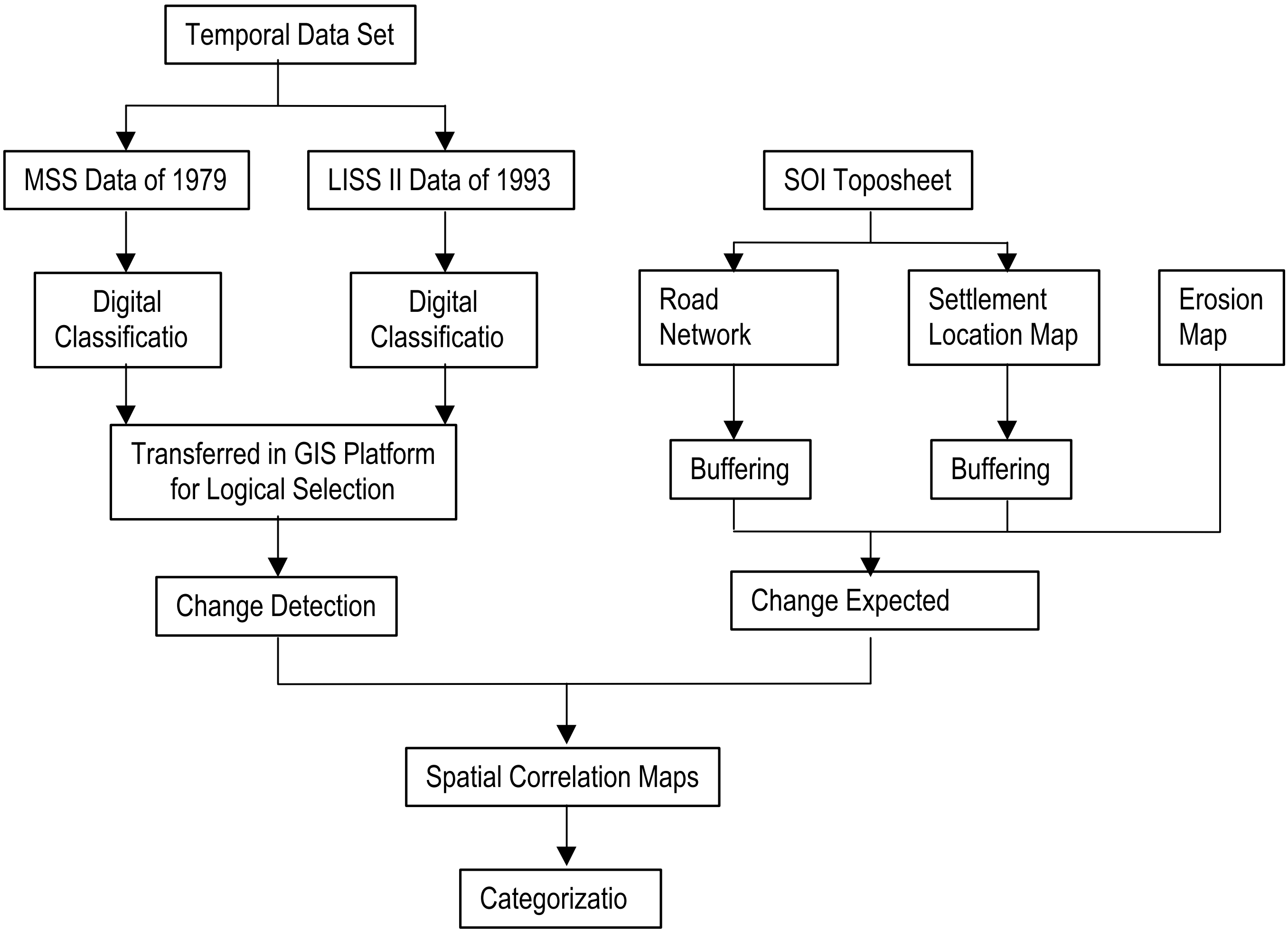


Figure 2. Methodology Scheme.

5.1 Accessibility by road network

Road network map was prepared form SOI toposheet. Based on the frequency of usage, the roads were classified into four categories i.e. main roads (metal), secondary roads (paved), cart track (unmetal) and foot path. Four types of buffer zones (Muhd and Kei M 1996) were created considering the degree of human intervention along the road. The are:

- Zone 1 : < 200m from main roads
- Zone 2 : 200m - 400m from main roads
  : < 200m from secondary roads
- Zone 3 : 400m - 600m from main roads
  : 200m - 400m from secondary roads
  : < 200m from cart track
- Zone 4 : Other area

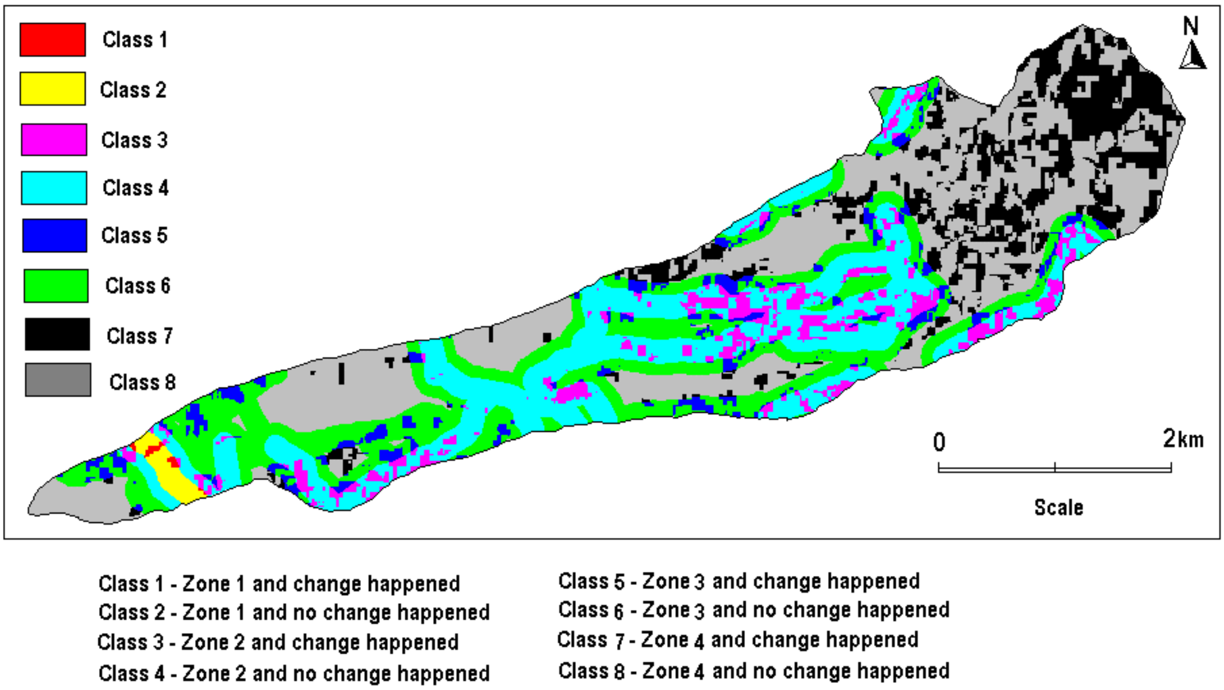


Figure 3. Spatial correlation between road network and actual change.

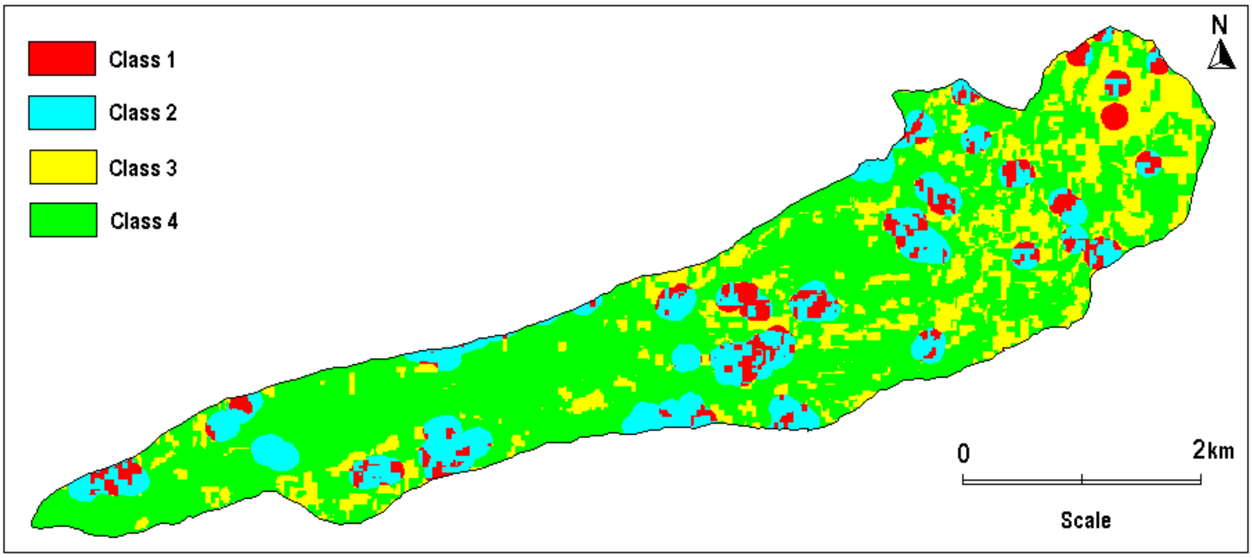
Zone 1 and Zone 2 were considered as the areas of moderate to severe human intervention and the change was expected in these zones. Zone 3 and Zone 4 were considered as areas of slight to no human intervention and change was not expected in these zones. A spatial correlation map, shown in Fig. 3, was prepared from the above said buffer zone map and the change detected map. The overall spatial correlation index of the changes happened and the change expected was calculated. As the overall spatial correlation index was very poor, the study area was categorized based on the spatial correlation by visually analyzing the correlation map. Spatial correlation index for each category was calculated.

5.2 Influence zone around settlement locations

The settlement locations were digitized from SOI the toposheet. A buffer zone of 200m around the settlements was created considering the fact that the area near the dwelling places is likely to be affected. The spatial correlation map was prepared from the settlement buffer zone map and the change detected map and is presented in Fig. 4. The study area was categorized based on the influence of settlement location as a factor of human intervention, by following the same procedure was followed in assessing the influence of road network.

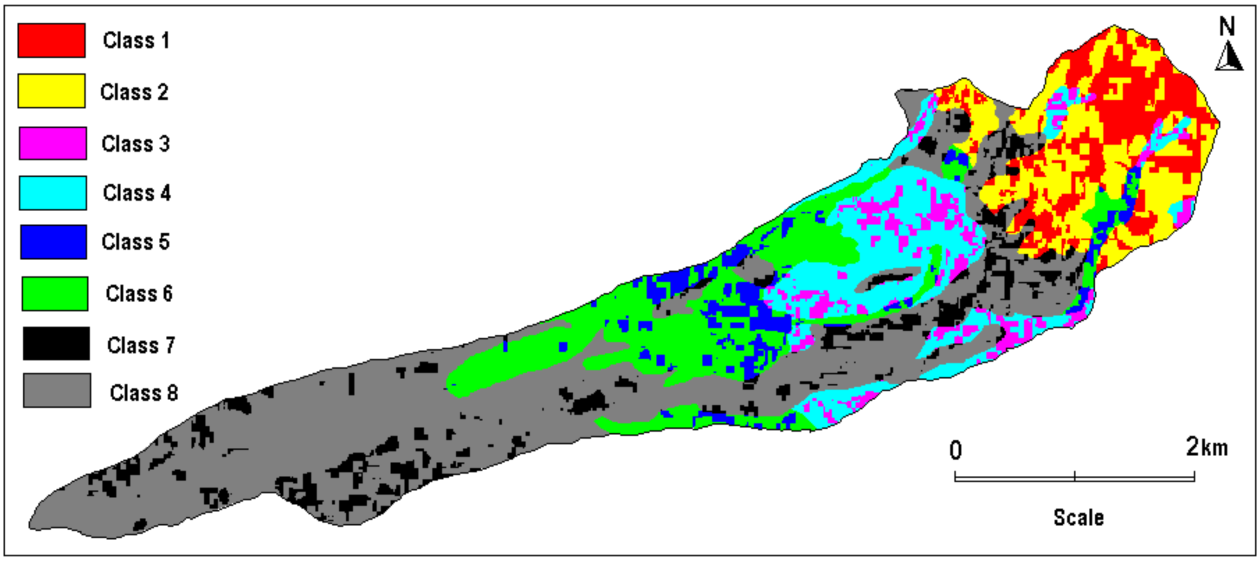
5.3 Influence of erosion as a natural hazard

Erosion is an important factor in hilly terrain, and can change a pocket of land drastically, if it is active. Slow erosion over a long period also affects the environment as the fertile surface soil is removed from one place and deposited elsewhere. The areas where the erosion is moderate to very severe were considered as ‘change expected’ regions, and based on this, a spatial correlation map was prepared (Fig. 5). As in the earlier cases, the study area was categorized by analyzing the influence of erosion.



Class 1 - Change expected and change happened
Class 2 - Change expected and no change happened
Class 3 - Change not expected and change happened
Class 4 - Change not expected and no change happened

Figure 4. Spatial correlation between settlement location and actual change.



Class 1 - V.Severe to severe erosion and change happened
Class 2 - V.Severe to Severe erosion and no change happened
Class 3 - Moderate to Severe erosion and change happened
Class 4 - Moderate to Severe erosion and no change happened
Class 5 - Slight to Moderate erosion and change happened
Class 6 - Slight to Moderate erosion and no change happened
Class 7 - V.Slight to Slight erosion and change happened
Class 8 - V.Slight to Slight and no change happened

Figure 5. Spatial correlation between erosion and actual change.

6. Results and Discussions

The classified temporal data set was compared for change (Table 3). Dense forest has suffered degradation over 2.704 sq. km. which has resulted in 2.210 sq.km. open forest. The 'open forest' class increased by 0.511 sq. km. Even though there was degradation on 1.101 sq. km. That turned to land under open scrub. Other changes are depicted in the change matrix in Table 4.

Road accessibility and the settlement locations play an important role in analyzing such changes e.g. from open 'scrub' to `cultivation' near the secondary roads in the middle portion of the study area and from 'open forest' to 'open scrub' nearer to the settlement location in the hilly region of the study area. During field visits it was observed that cultivation has been done underneath the planted sal trees (planted by the forest department to preserve the forest reserve), which was classified as open. May be in due course this area may be totally converted to cultivated land.

Table 3. Comparitive results of Landsat MSS (1979) classified and IRS LISS II (1993) classified data

Class	Classified area (1979) (sq. km.)	Classified area (1993) (sq. km.)	Change in area (sq. km.)
Dense forest	12.153	9.449	-2.704
Open forest	5.941	6.452	+0.511
Dense scrub	10.942	6.039	-4.903
Open scrub	5.414	9.165	+3.751
River course	3.258	3.291	+0.033
Cultivation	11.207	12.760	+1.553
Built-up	2.812	3.474	+0.662
Barren land	1.535	2.634	+1.099

Table 4. Change matrix of landuse changes from 1979 to 1993

Class	Dense forest	Open forest	Dense scrub	Open scrub	River course	Cultivation	Built-up area	Barren land
Dense forest	**9.402**	2.210	0.487	0.029	0.003	0.012	0.000	0.010
Open forest	0.017	**4.199**	0.556	1.101	0.002	0.023	0.008	0.012
Dense scrub	0.021	0.009	**4.715**	4.317	0.001	0.779	0.373	0.737
Open scrub	0.004	0.009	0.013	**3.827**	0.142	1.030	0.109	0.280
River course	0.001	0.002	0.001	0.021	**3.107**	0.035	0.053	0.072
Cultivation	0.002	0.019	0.012	0.051	0.016	**10.7414**	0.336	0.027
Built-up area	0.002	0.004	0.019	0.062	0.017	0.107	**2.817**	0.326
Barren land	0.000	0.000	0.129	0.157	0.003	0.030	0.053	**1.527**

Spatial correlation between the change expected because of road accessibility and the actual change happened is presented in Figure 3. The spatial correlation index was calculated for 'change expected' versus actual 'change happened', and 'no change expected' versus 'no change happened' for the total study area. The zonal correlation index is presented in Table-5. As the overall correlation coefficient with 'change expected' was 0.1813, the study area was categorized based on visual analysis of the spatial correlation map. The new spatial correlation index calculated for each stratum is tabulated in Table-8.

Table 5. Zonal spatial correlation index of road accessibility versus change detected map

	Area of the Buffer zone (sq.km.)	Area of `change happened' in each zone (sq.km.)	Area of `no change happened' in each zone (sq.km.)	Correlation index
Change expected Zone 1	0.593	0.078	0.515	0.1315
Zone 2	14.194	3.305	10.889	0.2328
No change expected Zone 3	13.633	2.450	11.183	0.1797
Zone 4	24.844	7.282	17.562	0.7069

Table 6. Spatial correlation index of settlement location versus change detected map

	Area of the Buffer zone (sq.km.)	Area of `change happened' (sq.km.)	Area of `no change happened' (sq.km.)	Correlation index
Change expected zone	10.604	3.143	7.461	0.2964
No change expected zone	42.660	9.972	32.688	0.7662

The spatial correlation map was prepared by considering settlement location as a factor of human intervention. Cultivation area (1979) nearer to settlement location was converted to built-up class in the lower part of the study area. The overall correlation index is presented in Table-6. The overall correlation for change expected was 0.2964. It was attempted to stratify the study based on visual analysis of the correlation map by considering the buffer zone from settlement location alone, and found that the buffer area of settlement location in combination with the road network provides a better representation of the actual changes. The spatial correlation index was calculated for the combined buffer zone and is given in Table-8.

Table 7. Spatial correlation index of erosion versus change detected map

Erosion status	Area (sq.km.)	Area of `change happened' (sq.km.)	Area of `no change happened' (sq.km.)	Correlation index
Change expected zone Severe to Very Severe	9.324	4.347	4.887	0.4708
Moderate to Severe	8.034	2.247	5.787	0.2797
No change expected zone Slight to moderate	10.108	2.244	7.864	0.778
V. Slight to Slight	25.908	4.347	21.561	0.8322

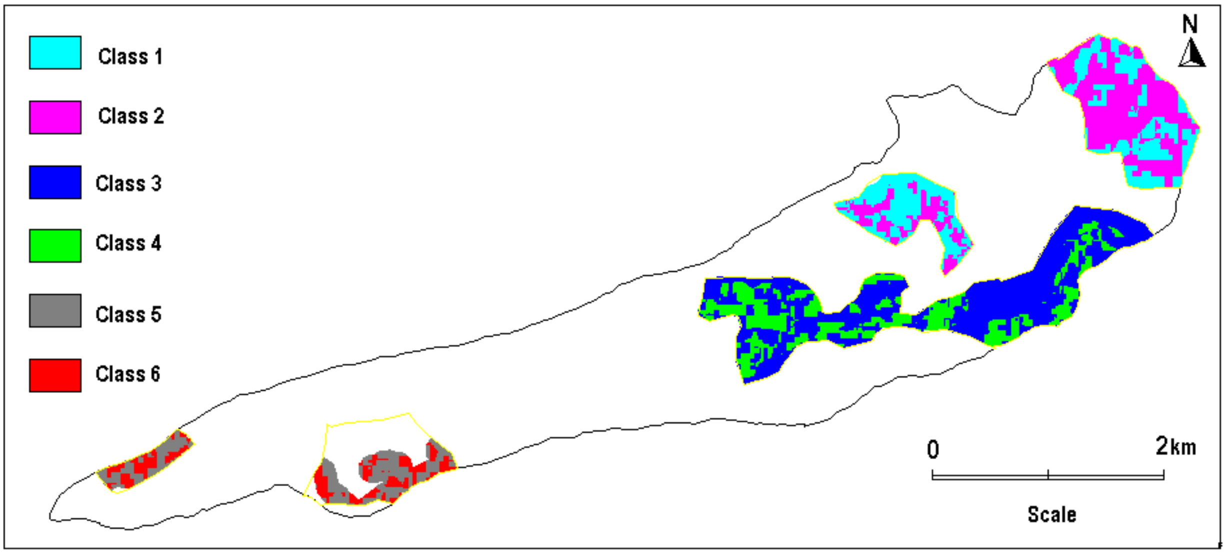
In areas having severe to very severe erosion, the changes were from dense scrub to open scrub or open forest to open scrub. In areas of moderate to severe erosion, dense forest to open forest, open forest to open scrub, or open forest to open scrub were observed. In other areas i.e. areas having very slight to moderate erosion, the types of change were observed to be mostly due to human intervention. Based on these observations, areas having moderate to very severe erosion were considered as 'change expected' areas for the correlation of erosion map and landuse map and the result is shown in Table-7. As in the earlier cases, the study area was categorized based on visual analysis of the correlation map. The correlation index for the category is given in Table-8.

The combined categorization based on all the three factors as presented in Fig. 6. As the stratum demarcation is purely subjective, the spatial correlation index could have been increased by reducing the size of the polygon. Obviously, a small polygon of actual change falling within the buffer zone / change expected zone will have 100% spatial correlation, (i.e. correlation of 1.0), if only that small element is considered.

Table 8. Spatial correlation index of *stratum based on visual analysis

Factor	Change expected area (sq. km.)	Change happened area (sq. km.)	Spatial correlation index
Road network	3.241	1.968	0.60722
Settlement location and Road network combined	1.745	0.983	0.56332
Erosion	5.243	3.815	0.72764

*Stratum area is different for different factor of consideration



Class 1 - Change expected and no change happened in stratum 1 based on ersosion
Class 2 - Change expected and change happened in stratum 1 based on ersion
Class 3 - Change expected and change happened in stratum 2 based on road network
Class 4 - Change expected and no change happened in stratum 2 based on road network
Class 5 - Change exteced and no change happened in stratum 3 based on settlement location combined with road network
Class 6 - Change exteced and change happened in stratum 3 based on settlement location combined with road network

Figure 6. Categorized map of Sitla Rao Watershed based on human intervention factors and natural hazard.

7. Conclusion

Digital image processing, integrated with GIS is a good way to analyze changes in an environment. Human intervention and natural hazards as factors of environmental changes can be assessed through Remote Sensing and GIS. In the present study it was found that direction of human movement, population growth trend and settlement area expansion trend/direction are to be considered when analyzing the effects of human intervention. It is suggested that a prediction model can be developed and tested to evalute the present methodology.

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