P 50 Prioritization of Sub-watersheds for Watershed Management Using Remote Sensing and GIS

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Abstract

This paper illustrates the utility of remote sensing and GIS to the analysis of critical smaller units (sub-watersheds) of a watershed, and assessment of their priority for watershed management, based on a concept that takes into account various aspects of erosion and sedimentation.

1. INTRODUCTION

It is often difficult and economically unfeasible to consider a big watershed at once for the management. Division of a watershed into smaller units (sub-watersheds), and their evaluation on critical condition based on factors indicating degradation, is the best way to prioritize sub-watersheds for efficient management.

The study area, Kulekhani watershed (27^0 34' and 27^0 42'N, 85^0 1' and 85^0 12'E), located in the central region of Nepal (elevation range 1,500 m - 2,600 m), drains into Kulekhani reservoir that supports one third of the total hydroelectric power generation in Nepal. Agricultural land covers large area (45 percent), and population density is comparatively high. It experienced big erosion disaster in 1993 (Dhakal, 1995) that brought concern about the life of the reservoir. A large number of landslides induced by rain caused loss of life, destruction of cultivated as well as forested land, change in river morphology, and a large amount of sedimentation into the reservoir. These background demand a practical, sound watershed management. A concept of analysis of critical sub-watersheds to determine their priority for watershed management was presented, taking into account the future occurrences of landslides, annual soil erosion, and degradation due to disaster of 1993, using remote Sensing, and GIS.

2. METHODS OF STUDY

Fifty-two sub-watersheds were delineated in the study area based on their drainage pattern in relation to the main stream. Landslide hazard index (indicating future occurrences of landsliding), soil loss tolerable limit exceeding index (indicating critical annual erosion), and disaster impact index (indicating degradation from disaster of 1993) were the parameters included to evaluate total degradation of the sub-watersheds. Figure 1 is the flow diagram of the study.

2.1 Landslide hazard index

The landslides interpreted from the stereopairs of black and white vertical aerial photographs (1: 20,000) were plotted on a topographic map, and stored in a GIS after finalizing from field checking. Layers of slope-gradient, slope aspect, elevation, drainage basin order, distance from ridge, distance from valley were produced from a Digital Elevation Model (DEM), generated from digitized contours using Triangulated Irregular Network (TIN) model. Geology and land use/ cover layers were derived from digitizing the available maps. Each of these factors were divided into several classes. Critical factors and classes to landsliding were investigated by applying a multivariate statistical analysis, quantification scaling type II (Q-S II) (Hayashi, 1952) by combining the site characteristics of non-landslide and the landslide groups data (Dhakal et al. 1997, 1999). The scores of the classes of factors were used to obtain cumulated score at each grid-cell of the rasterized watershed layer, based on which they were classified into unstable and stable. The landslide hazard index (LHI) for each sub-watershed was calculated as: [(unstable grid-cells in the sub-watershed / total unstable gird-cells) / (total grid-cells in the sub-watersheds / total grid-cells in the study area)].

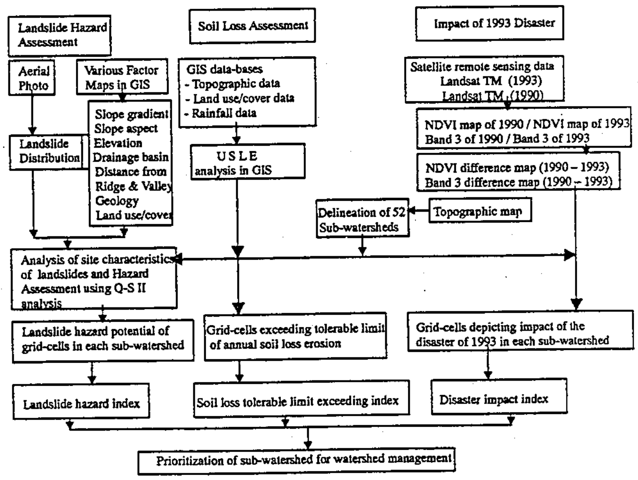

Figure 1 Work flow diagram of the study

2.2. Soil loss tolerable limit exceeding index

The widely known Universal Soil Loss Equation (USLE) (Wischmeier et al., 1978) was used to estimate soil loss rate (surface and rill) using a GIS. The USLE enables the approximate prediction of average annual soil erosion in each grid-cells of the rasterized watershed layer based on soil, rainfall, topography, and land use. The USLE can be written as:

A = RKLSCP

where, A: Computed soil loss per unit area, R: Rainfall erosion index, K: Soil erodibility factor, LS: Topographic factor, C: Cover and management factor, P: Support practice factor

The soil loss obtained at each grid-cell was compared to the tolerable soil loss limit for midland, Nepal where a soil loss of 10 tons/ha/year is considered reasonable for well managed land (Laban, 1978). Soil loss tolerable limit exceeding index (STEI) for each sub-watershed was calculated as [(grid-cells exceeding soil loss tolerable limit in sub-watershed / total grid-cells exceeding soil loss tolerable limit) / (total gird-cells in the sub-watershed / total grid-cells in the study area)].

2.3 Disaster impact index

Landsat TM data of 1990 and 1993 were used to detect changes such as eroded areas or sediment deposited areas due to 1993 disaster in each sub-watershed. After geometric correction and normalization of the images, Normalized Difference Vegetation Index (NDVI, (IR-R)/(IR+R)) image was produced for both images, from which an image of NDVI image difference was derived. Similarly an image of Band 3 (0.62-0.69 μm) difference was produced from two images. The threshold values were set for both NDVI and Band 3 difference images to determine the areas undergone impact in vegetated, and non vegetated areas respectively. The disaster impact index (DII) was calculated as: DII = [(changed pixel in the sub watershed / total changed pixel) / (total pixels in the sub-watershed / total pixels in the study area)].

3. RESULTS

The total degradation index of each sub-watershed was calculated as follows(Table 1):

Total degradation index of sub-watershed (TDI)= 0.35 * LHI + 0.35* STEI + 0.3 * DII

The fifty-two sub-watersheds were then divided into four categories as high, moderate, low, and least priorities (Figure 2). Least prioritized sub-watersheds are those for which individual indices as well as total degradation index are less than 1. Total degradation index less than 1.1, between 1.1 and 1.4, and larger than 1.4 were classified as low, moderate, and high priority, respectively.

4. CONCLUSIONS

The integration of remote sensing and GIS can successfully be used in the evaluation of sub-watershed taking into account various erosion and sedimentation aspects which require large spectrum of geomorphological, geological, hydrological, and land use/cover data bases, in addition to information on temporal changes. The utility of temporal satellite remotely sensed data to incorporate up-to-date information on degradation of the sub-watershed is outstanding.

Table 1 Total degradation and other indices for the sub-watersheds

SW	LHI	STEI	DII	TDI	SW	LHI	STEI	DII	TDI	SW	LHI	STEI	DII	TDI
1	1.8	1.5	2.0	1.76	18	1.4	1.7	1.1	1.37	35	0.7	0.8	0.7	0.73
2	0.9	0.6	3.4	1.71	19	1.3	1.8	1.0	1.34	36	0.4	0.9	0.6	0.63
3	1.7	0.8	2.0	1.55	20	1.1	1.5	2.4	1.68	37	0.8	0.5	0.6	0.66
4	1.6	0.5	1.5	1.26	21	0.4	1.7	0.9	0.98	38	0.0	0.9	0.5	0.45
5	0.4	0.4	0.8	0.51	22	1.3	1.0	1.4	1.24	39	0.0	1.8	1.3	1.01
6	1.5	1.1	1.6	1.43	23	1.8	1.3	0.8	1.30	40	0.8	0.8	0.8	0.80
7	1.1	1.9	1.1	1.33	24	0.4	1.1	0.5	0.62	41	0.4	0.7	0.7	0.59
8	1.3	1.5	0.8	1.22	25	1.2	0.3	0.5	0.69	42	1.1	1.8	1.0	1.27
9	1.4	1.0	0.7	1.05	26	0.4	2.0	0.1	0.77	43	1.3	1.0	1.4	1.26
10	1.8	1.0	1.0	1.25	27	0.5	1.6	1.3	1.10	44	1.1	1.1	1.2	1.13
11	1.4	1.6	1.4	1.47	28	0.6	1.2	0.6	0.78	45	1.0	1.8	0.6	1.07
12	1.4	1.7	1.1	1.40	29	0.3	1.3	0.8	0.77	46	0.9	0.8	0.8	0.85
13	1.3	1.4	1.1	1.26	30	1.4	0.6	0.9	0.96	47	1.7	2.5	0.8	1.63
14	1.0	1.9	1.0	1.26	31	0.3	0.5	0.5	0.43	48	1.9	1.6	0.9	1.49
15	1.7	1.0	1.0	1.27	32	0.2	0.8	0.4	0.44	49	1.3	2.4	0.3	1.30
16	1.8	1.1	1.0	1.31	33	0.0	0.9	0.2	0.34	50	1.2	1.0	0.8	1.02
17	1.6	2.1	1.9	1.84	34	0.2	0.8	0.6	0.56	51	1.5	1.7	1.7	1.65
										52	0.9	1.1	2.6	1.57
										Reservoir	-	-	-	-

SW = Sub-watersheds, LHI = Landslide Hazard Index
STEI = Soil Loss Tolerable Limit Exceeding Index, DII = Disaster Impact Index
TDI = Total Degradation Index

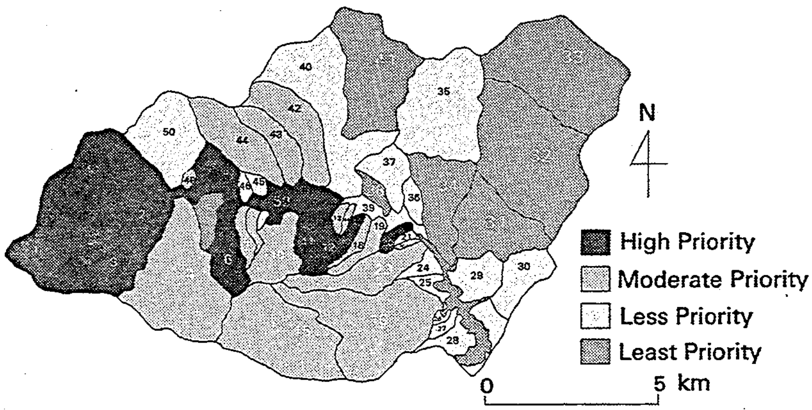

Figure 2 Prioritization map for watershed management, Kulekhani watershed, Nepal

References

Dhakal, A. S., T. Amada, and M. Aniya, 1999. Landslide Hazard mapping and the Application of GIS in the Kulekhani Watershed, Nepal. *Mountain Research and Development*, 19 (1): 3-16.

Dhakal, A. S., T. Amada, and M. Aniya, 1997. A GIS approach to landslide susceptibility mapping: A case study from the Kulekhani watershed, Nepal, *Proceedings of the 18th Asian Conference on Remote Sensing*, Kuala Lumpur, JS-6-1-6-6.

Dhakal, A. S., 1995. Disaster of 1993 experienced by Nepal, *Proceedings of the International Sabo Symposium*, Tokyo, pp. 115-122.

Hayashi, C., 1952. On the prediction of phenomena from qualitative data and the quantification of qualitative data from the mathematico-statistical point of view, *Annals of the Institute of Statistical Mathematics*, 3: 69-98.

Laban P., 1978. *Field Measurements on Erosion and Sedimentation in Nepal,*. Department of Soil and Water Conservation, Ministry of Forest, HMG/Nepal, 30pp.

Wischmeier, W. H., and D. D. Smith, 1978. *Predicting Rainfall Erosion Losses - A Guide to Conservation planning*. US Department of Agriculture, Agriculture Hand Book No. 537, 58 pp.