Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium, July 1996). IAHS Publ. no. 236, 1996.

Prioritization of basins based a on silt yield index – an integrated approach

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Abstract A new method of introducing "Integrated Resources Units" (IRUs) to the Sediment Yield Index (SYI) model of the All India Soil and Land Use Survey, in order to identify critical hydrological units over a large basin, was tested in a drainage basin of the Western Ghats mountainous zone which receives heavy rainfall. The IRUs, compiled from integrated analysis, encompass the multiple basin resources of soils, slopes, drainage and the dynamic land-use pattern. The IRU has been used as the strategic unit for assigning the erosivity and transportability values of the detached material in the SYI model for deriving priority classes for sub-basins. The significant variation in SYI values calls for conservation planning in cases of high and very high priority sub-basins. A treatment-oriented land-use planning scheme, using Geographical Information Systems, was also formulated for sustainable development of the basin. If the suggested biological engineering practices were used on the priority sub-basins, there would be less erosion and consequently massive investments to control erosion, or worse, to rehabilitate the affected lands, could be reduced. The IRU approach is also helpful in monitoring the dynamic aspects of the basin and for redefining the management strategies accordingly.

BACKGROUND

Investigation of basins for conservation planning is expensive, and therefore requires a selective approach to identify smaller hydrological units which would be suitable for more efficient and targeted resource management programmes. The identification of these critical sub-basins which need soil and water conservation measures on a preferential basis is particularly important in hilly arid/semiarid basins subject to heavy rainfall. A criterion which can be used to determine priority for conservation planning, therefore, may be the maximum sediment yield of a basin.

The use of the Sediment Yield Index (SYI) model developed by the All India Soil and Land Use Survey, Government of India, is a well known means of providing criteria for priority delineation in river valley projects and flood prone rivers (AISLUS, 1991). The SYI conceptualizes sediment delivery into the water body as a multiplicative function of potential soil detachment representing the erosivity factor (weightage value) and transportability of the detached material (delivery ratio value).

In the present study, however, the mapping unit for assigning the weightage and delivery ratio values is the "Integrated Resources Unit" (IRU), which is based on multithematic and multi-source (map, ground and space based systems) data. The IRUs exhibit strong uniformity in bio-physical attributes and are expected to respond similarly to given intensities of human use and management strategies.

The approach was tested in a drainage basin of about 100 km^2 selected in the typically semiarid and difficult terrain of the Western Ghats mountainous area (73°45′-73°55′E and 19°16′-19°23′N). The area is located in the western plateau and hill agro-climatic region of the Indian peninsula. Increasing accumulations of sediment are being deposited in the drainage ditches, and ultimately in Yedgaon Reservoir, a drainage terminus for the basin. This siltation is largely due to poor conservation practices, scantily distributed vegetation cover, steep slopes and a generally dry climate with an erratic monsoon rainfall, resulting in high rates of erosion. If erosion is not stopped, further increases in runoff will ultimately destroy the productive value of the land. Hence, major conservation planning and rehabilitation efforts are necessary for sustainable development of this fragile environment.

DATA SETS AND METHOD

Realizing the importance of a comprehensive and integrated approach to the problem, basin resources were evaluated from multi-source data from:
(a) the geo-coded false colour composites of IRS LISS-II (December 1989 at 1:50000 scale) and Landsat-TM (October 1989 at 1:250000 scale) satellite images;
(b) Survey of India (SOI) topographic maps (1:250000/1:50000), Indian atlases of irrigation, agriculture and forests;
(c) meteorological data from the records of the local Irrigation Department;
(d) relevant reports on the basin; and
(e) ground survey information on soil and other terrain characteristics at the sample sites.

The major steps involved in prioritization of basins with respect to their SYI are:
(a) systematic delineation of sub-basins;
(b) basin resource surveys using multi-source data;
(c) generation of IRUs by overlay;
(d) assignment of weightage and delivery ratio values to each IRU;
(e) computation of SYI values for sub-basins; and
(f) demarcation of priority sub-basins.

DATABASE DEVELOPMENT

The land-use/cover mapping of the basin was carried out using IRS LISS-II data by standard visual interpretation techniques. A diverse set of collateral data were also used, besides ground truth survey. The basin was delineated into five broad land-use categories of thick forest, sparse forest, degraded pastures, open (with/without scrub) areas and agriculture (cropped lands and current fallows). The dates of the satellite image and the land-use/cover categories demarcated in the basin were chosen particularly from the point of view of soil erosion.

IRS data were visually interpreted for delineation of physiographic units. Different image elements such as colour, texture, pattern, association, etc. were considered to be useful in delineating physiographic units and in land-use mapping. Ancillary data used for the purpose were SOI topographic maps, and information from the soil pit studies. Finally, the soils were classified according to an established soil taxonomy (Soil Survey Staff, 1975). The underdeveloped soils (Lithic Ustorthents) are found in hilly regions with steep slopes, which comprise mainly forest areas. Degraded pastures, open (with/without scrub) areas and partly cultivated areas are the major land-use categories on the undulating uplands and subdued hills. Soils in these situations are classified into the association of Lithic Ustorthents/Vertic Ustropepts. The well developed moderately deep black agricultural soils (Typic Chromusterts) are situated generally on the plains and gently sloping areas of the basin.

Slope analysis was carried out using a 1:50 000 SOI topographic sheet (20 m contour interval). Employing the standard procedure for calculating the slope degrees, 3 classes were identified, comprising gently sloping (5°), moderately to moderately steeply sloping (5-18°) and steep to very steep sloping (>18°).

The drainage network was derived from the SOI topographic sheet and modified for present conditions using the Landsat-TM imagery of October 1989. There are about six orders in the drainage system. Broadly, the drainage pattern is dendritic with a sub-parallel system existing adjacent to the stream course. The Pushpavati River and its tributaries are perennial in nature and carry the sediment load throughout the year. Drainage density, which is characterized by the average length of streams per unit area, was calculated for the basin and a map showing the low, medium and high drainage density categories was generated. The higher the density of the drainage network, the higher the channel flow, which contributes to the transport of suspended sediments. Generally, drainage lines may be recognized most clearly in the agricultural areas, followed by the wastelands and the forest areas in the basin.

Units demarcated for the basin were transferred to a base map of 1:50 000 scale drawn from SOI topographic maps. The basin was subdivided into 33 sub-basins which constitute individual tributaries of the lowest order, or a group of such tributaries. The area of each sub-basin was measured planimetrically and ranged from 1.4 to 7.0 km^2, which is considered a viable working size for implementation of conservation measures and other basin development programmes.

DATABASE ANALYSIS

Generation of Integrated Resources Units (IRUs)

All the basin resources were generated to the scale of 1:50 000. Given that all the thematic maps were now in a common coordinate system, a number of IRUs could be generated by integrating the databases described above. The IRU is the basic unit for assigning the weightage and delivery ratio values and subsequently to derive the priority ratings for each sub-basin by the SYI model. Taking all the four basin resources and their categories (three soils, three slopes, three drainage densities and five land-use types) into consideration, 135 IRU combinations could occur in the catchment by overlay analysis. In fact only 52 IRU combinations were present in the basin. The areal extent of each IRU was calculated planimetrically for each sub-basin.

Assignment of weightage and delivery ratio values to IRUs

The IRUs were assigned relative weightage values adjudged to be indicative of the combined effects of the dynamic interrelationships of the factors in terms of the potential for active erosivity in the IRUs. A factor *K*, which is regarded as an inertia factor signifying equilibrium between erosion and sedimentation, was assigned a value of 10, and was taken as a standard reference for comparison. Additions and subtractions from this value in discrete numbers were made to assess the collective effect of different attributes within an IRU. Any addition to this factor is indicative of erosion roughly in proportion to the added factor, whereas subtraction is suggestive of deposition. The range of weightage values assigned for IRUs in the study was from 12 to 20, depending upon the

Table 1 Computation of Sediment Yield Index values.

Sub-basin number	IRU symbol	Area (km^2)	Weightage value	Weightage product	Delivery ratio	Gross yield	SYI/ Priority class
19	H213	0.125	15	1.875	75	1.41	
	H122	0.350	13	4.550	80	3.64	
	H313	0.125	14	1.750	75	1.31	
	H215	0.075	20	1.500	80	1.20	
	H223	0.150	15	2.250	80	1.80	
	H323	0.125	15	1.875	80	1.50	
	H123	0.150	13	1.950	75	1.46	
	H223	0.075	15	1.125	80	0.90	
	H222	0.125	14	1.750	80	1.40	
	H121	0.075	12	0.900	80	0.72	
	H131	0.350	12	4.200	85	3.57	
	H132	1.000	13	13.000	85	11.05	
	L215	0.325	18	5.850	80	4.68	
	L214	0.340	13	4.420	80	3.54	
	L315	0.325	17	5.530	80	4.42	
	Total	3.715				42.60	1147/Medium
20	H214	0.175	15	2.625	80	2.10	
	H125	0.125	20	2.500	85	2.13	
	H123	0.175	13	2.275	75	1.71	
	H121	0.100	12	1.200	80	0.96	
	H131	0.275	12	3.300	85	2.81	
	H225	0.250	19	4.750	85	4.04	
	H213	0.125	15	1.875	75	1.41	
	H122	0.100	13	1.300	80	1.04	
	H132	0.500	13	6.500	85	5.53	
	L215	0.425	18	7.650	80	6.12	
	L214	0.875	13	11.375	80	9.10	
	L314	0.025	12	0.300	80	0.24	
	L315	0.875	17	14.875	80	11.90	
	Total	4.025				49.09	1220/High

variables within the IRU. The value of the delivery ratio was adjudged for individual IRUs based on the factors known to influence sediment delivery. Adjusted delivery ratios for various sub-basins were then derived by considering the factor of distance from the active stream. The delivery ratio values in the basin lay in the range 75-85.

Classification of sub-basins

After computing the sediment yield indices for each sub-basin, priority ratings were assigned (Table 1 shows the calculations for sub-basin numbers 19 and 20, as an example). The sub-basins were then grouped into low, medium, high and very high priority (critical) classes. The priority classes and the corresponding SYI values are illustrated in Fig. 1. It is apparent that 26 of the total 33 sub-basins fall in the category of medium and high priority, constituting about 80% of the total basin. Studies on soil erosion assessment in the basin using GIS with multi-disciplinary knowledge-based rules and field observations, indicates that 90% of the area belongs to the categories of moderate to severe and severe erosion (Adinarayana *et al.*, 1994). This figure compares well with the occurrence of medium and high priority classes in the basin.

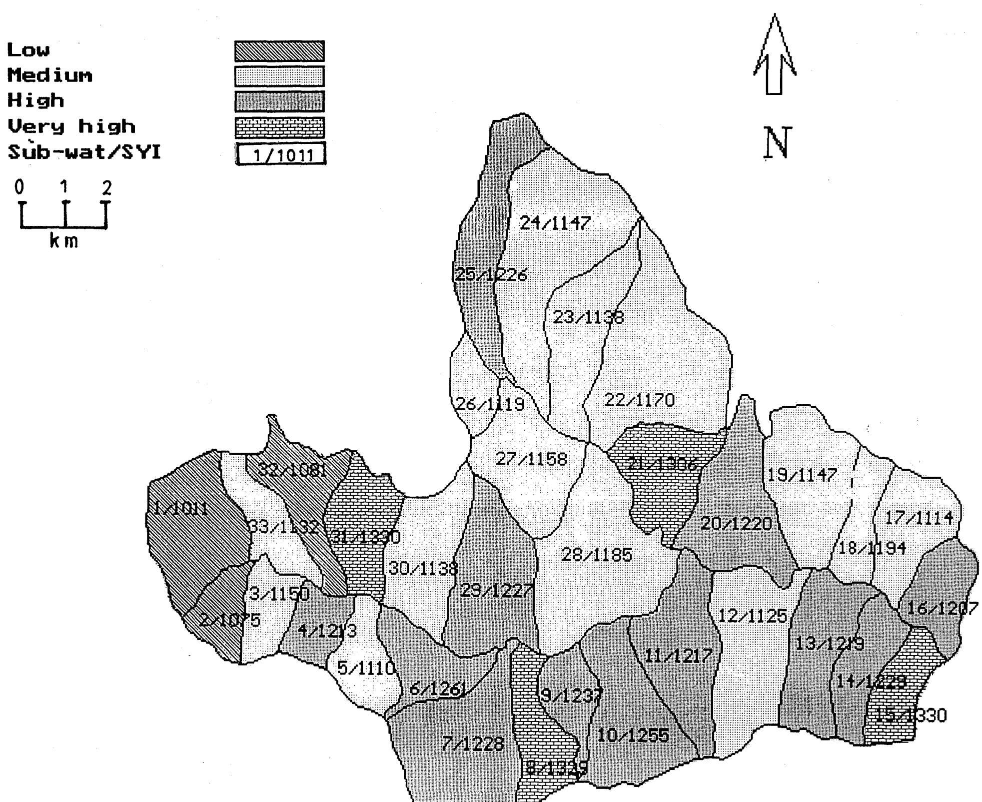

Fig. 1 Priority classes and Sediment Yield Index values for sub-basins.

CONSERVATION MANAGEMENT

A major step in the conservation planning process is inventorying and classifying the basin, judging its capacity to support land use on a sustained basis, and avoiding uses that degrade the land. A treatment-oriented land-use planning scheme, involving soil depth and slope steepness characteristics, was formulated through the use of multidisciplinary knowledge-based rules and field checks in an integral manner through use of Geographical Information Systems (GIS) (Adinarayana & Rama Krishna, 1995). This scheme allocates potential land-use units, with proper soil and water conservation measures, to the high rainfall hilly basins. The priority sub-basin delineation survey reveals significant variation in the SYI values among the sub-basins. This suggests that planners should concentrate on these critical, or high and very high priority, sub-basins for conservation planning schemes such as the GIS-assisted scheme developed in the present study. If these appropriate biological engineering practices could be employed on the basis of priority, there would be less erosion. Consequently massive investments to control soil erosion, or worse to rehabilitate the affected lands, could be reduced.

Acknowledgements This research project was financed by a research grant from the Department of Science and Technology, Government of India (through SERC Programme ES/23/077/89). The author wish to thank Prof. V. S. Chandrasekaran, Head of CSRE, for his constant encouragement and for providing facilities. I was ably assisted by N. Rama Krishna during entire course of the research work.

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