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Sediment Yield Index (SYI) based prioritization of Benisagar reservoir catchment area using remote sensing and GIS

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ABSTRACT

An integrated approach to identify priority/critical sub-watershed by the Sediment Yield Index (SYI) model of the All India Soil and Land Use Survey (AIS&LUS, 1991) has been used for identification of priority sub-watersheds in Benisagar reservoir catchment of Madhya Pradesh. The SYI values of individual sub-watersheds have been computed in 36 sub-watersheds and categorized in very high, high, medium, low and very low priority classes. The significant variation in SYI values calls for conservation planning in cases of very high (13.15 sq km) and high (27.50 sq km) priority sub-watersheds. The SYI method of prioritization has been employed for identification of environmentally stressed sub-watersheds in Banisagar catchment and concluded that 41.93 sq km area which is nearly 50% of total catchment comes under very high and high priorities need immediate attention for soil conservation measures.

1. INTRODUCTION

Land and water are two basic natural resources for the survival of living systems on earth. The soil erosion in catchment areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, rich fertile soil is eroded from the catchment areas. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality. Particularly a monsoonal country like India, high intensity rains during the monsoon season causes severe erosion in croplands which leads to sedimentation of the water bodies (Rao *et al.,* 2014). Sediment particles originating from the watershed is the continuous process of erosion propagated along the river flow. When this flow accumulates into the reservoir, the sediment carried with the stream gets settled into the reservoir and reduces its capacity. Stream bank erosion and its associated sediment yield have tremendous negative impacts on water quality (Rao *et al.,* 2013). Reduction of storage capacity of a reservoir beyond a certain limit hampers the purpose of the reservoir for which it was designed. Several empirical models based on the geomorphological parameters were developed in the past to quantify the sediment yield. Sediment yield index (SYI) method proposed by Karale and Bali (1977) is widely used method for prioritization of erosion prone areas for soil conservation measures. Jain and Goel (2002) suggested an index based approach based on surface factor including soil type, vegetation, slope and various catchment properties such as drainage density, form factor, *etc.*for watershed prioritization.

Soil, being one of the potential resources of a watershed demands proper conservation and management and it could only be possible if its degree of degradation is assessed properly. Soil conservation strategies are to be planned according to the severity of the extent of the soil erosion problem. The severity of erosion can be evaluated by the priority delineation of the watershed considering many factors; the important among them is the silt yield index. The prioritization of watershed helps in taking up soil conservation measures on the priority basis. For the prioritization of watershed remote sensing and GIS software ILWIS (3.0) has been used for analysis of spatial distribution of erosion parameters. Pandey *et al.* (2007) divided Karso watershed of Hazaribagh, Jharkhand State, India into 200×200 m grid cells and average annual sediment yields were estimated for each cell of the watershed to identify the critically erosion prone areas of watershed. Bali and Karale (1977) suggested the criteria for choosing priority basins on the basis of sediment yield index. Khan *et al.* (2001) used sediment yield index (SYI) for priority watersheds delineation to undertake soil and water conservation measures using remote sensing and GIS techniques. In the absence of measured sediment data, a sediment yield index expressing the relative sediment yield from different basins used the basis for grading of basins in order of priority for soil and water conservation measures. Keeping this consideration in view, this study was taken for prioritization of Benisagar reservoir catchment area based on sediment yield index.

2. MATERIALS AND METHODS

The catchment of Benisagar reservoir selected for the study is located in Chhatarpur district of Bundelkhand region of Madhya Pradesh (India). The base map showing the location of study area is given in Fig. 1. The Benisagar dam is an earthen dam located at 24° 41' N latitude and 79°52' E longitude. The dam is constructed on confluence of Khurar and Rantiya River, which are tributaries of Ken River. The average annual rainfall of the Benisagar reservoir catchment area is 1076 mm. The cropping pattern of the study area is double cropping system (soybean and black-gram in *kharif* and wheat and gram in *rabi* season). The total geographical area of the Benisagar catchment reservoir is 72.5 sq km. For prioritization of environmentally stressed areas, the Benisagar catchment has been divided into 36 sub-watersheds (Fig. 2).

The methodology consists of determination of priority sub-watersheds including generation of GIS based information system (various thematic maps and meteorological information). A base map has been generated by digitizing the Survey of India (SoI) toposheets as reference map for all other purposes. The watershed covered in SoI topographic maps no. 54P/13 (1:50,000). The catchment map of Benisagar reservoir has been divided into 36 sub-watersheds considering drainage pattern, contours and slope. The land use map was prepared by digital image classification of remotely sensed data with corresponding ground truth verification. The slope map of the Benisagar catchment has been generated from contour and point of elevations using SoI toposheets. The detailed field survey of the study area has been conducted for determination of soil depth and erosion intensity.

Sediment Yield Index (SYI) Method

The SYI method considered sedimentation as product of erosivity, erodibility and areal extent was conceptualized by All India Soil and Land Use Survey (AISLUS) in 1991. In this method, the sediment yield is considered as function of soil erodibility which depends on climate, physiographic, slope, soil characteristics (percentage of clay, silt and sand, permeability, porosity *etc*.), land use/land cover, soil management and sediment delivery which represents transportability and area of hydrologic entity.

The Sediment yield (SY) from a catchment may be expressed by the following relation:

$$SY = f \times D_i \times A \qquad .... (1)$$

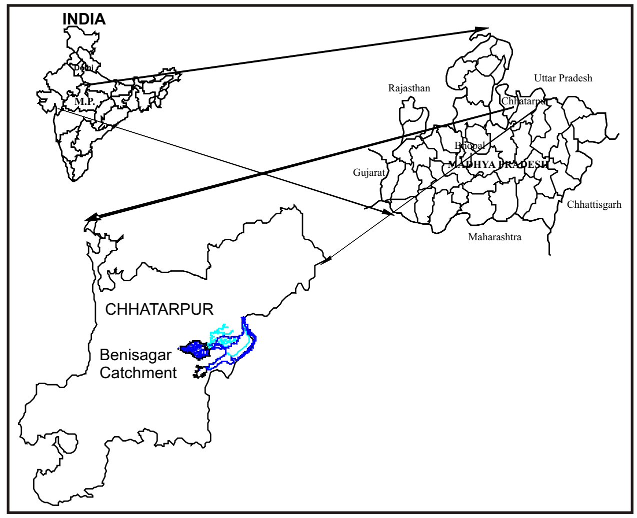


Fig. 1. Location map of Benisagar reservoir catchment in M.P. (India)

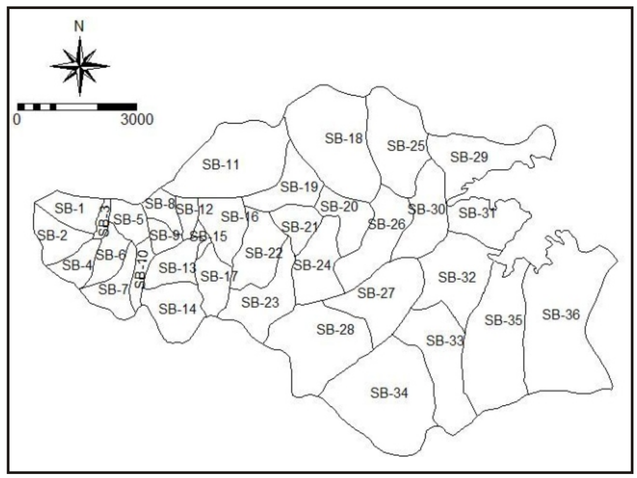


Fig. 2. Sub-watersheds of Benisagar reservoir catchment for prioritization

Where, f is the erosivity factor, D_i is the delivery ratio and A is the area of catchment.

In the SYI method, a weightage based on land use, soil depth/erosion tendency and slope characteristics is assigned to each composite erosion intensity unit (CEIU) which in combination with delivery ratio provides sediment yield index. The area of each of the mapping units is computed and sediment yield indices (SYI) of individual sub-watersheds are calculated using the following equation:

$$SYI = \frac{\sum_{i=1}^{n} A_i \times W_i \times D_i}{A_w} \times 100 \qquad .... (2)$$

Where A_i is the Area of i^{th} unit, W_i is the weightage value of i^{th} mapping unit, n is the number of mapping units, A_w is the total area of sub-watershed, D_i is the delivery ratio assigned to the mapping unit. The clustering approach on the basis of SYI values as suggested by Jaiswal *et al.* (2014) has been used for grouping sub-watersheds in different groups ranging from very high to very low priority. All the sub-watershed have been categorized in different standard classes including very high (SYI > 1300), high (1300 > SYI ≥ 1200), medium (1200 > SYI ≥ 1100), low (1100 > SYI ≥ 1000) and very low (SYI < 1000).

Composite Erosion Intensity Unit (CEIU)

The composite erosion intensity mapping units are the relative erosivity values adjudged to be indicative of the combined effect of dynamic interrelationship of the factors in terms of active erosivity of the units. For the estimation of CEIU, three erosivity factors including soil depth, slope and land use each divided in five to seven different categories were considered during hierarchical querying and presented in Table 1. The weights for different categories of erosive factors were assigned ranging from 0 to 5. For computation of CEIU, land use, soil depth/erosion tendency and slope maps were prepared in ILWIS. Theses maps were then converted into individual erosion intensity unit (EIU) maps by assigning weights as given in Table 1. For this, an attribute table was created where weights for respective units were allotted and attribute map option was used to create EIU map. The weights of different erosivity criterion were added together for computation of CEIU for each unit. On the basis of CEIU, each unit of watershed can be divided into different erosion classes as presented in Table 2. A basic value of 10 was used in determining the weightage values that indicates a static condition of equilibrium between erosion and deposition. The range of weightage values assigned for CEIU in the study varied from 12 to 20, depending upon the variables within the CEIU.

Table: 1
Key factors used for evaluation of composite erosion intensity Mapping

S. No.	Land use/ weightage	Soil depth and erosion tendency/weightage	Slope (%)/ weight age
1	Cultivation/5	Deep and Moderate to negligible/1	0-20/1
2	Barren land/4	Moderately deep and Moderate to severe/2	20-35/2
3	Scrub or degraded forest/3	Moderately shallow and severe/3	35-50/3
4	Open forest/2	Shallow and Severe to very severe/4	50-80/4
5	Dense forest/1		Above 80/5

Table: 2
Output key for erosion intensity mapping

S. No.	Sum of Weightage	Erosion Intensity class
1	12-15	Very Severe
2	9-11	Severe
3	6-8	Moderate
4	4-5	Slight
5	0-3	Negligible

Delivery Ratio (D_i)

The proportion of the detached sediment reaching the reservoir is termed the delivery ratio (D_i). In this study, the value of the delivery ratio was adjudged for individual sub-watersheds based on the factors known to influence sediment delivery. Adjusted delivery ratios for various sub-watersheds were derived by considering the factor of distance from the active stream. The delivery ratios are assigned to all erosion intensity units depending upon their distance from the nearest stream. The criteria adopted for assigning the delivery ratio adopted in the study has been given in Table 3.

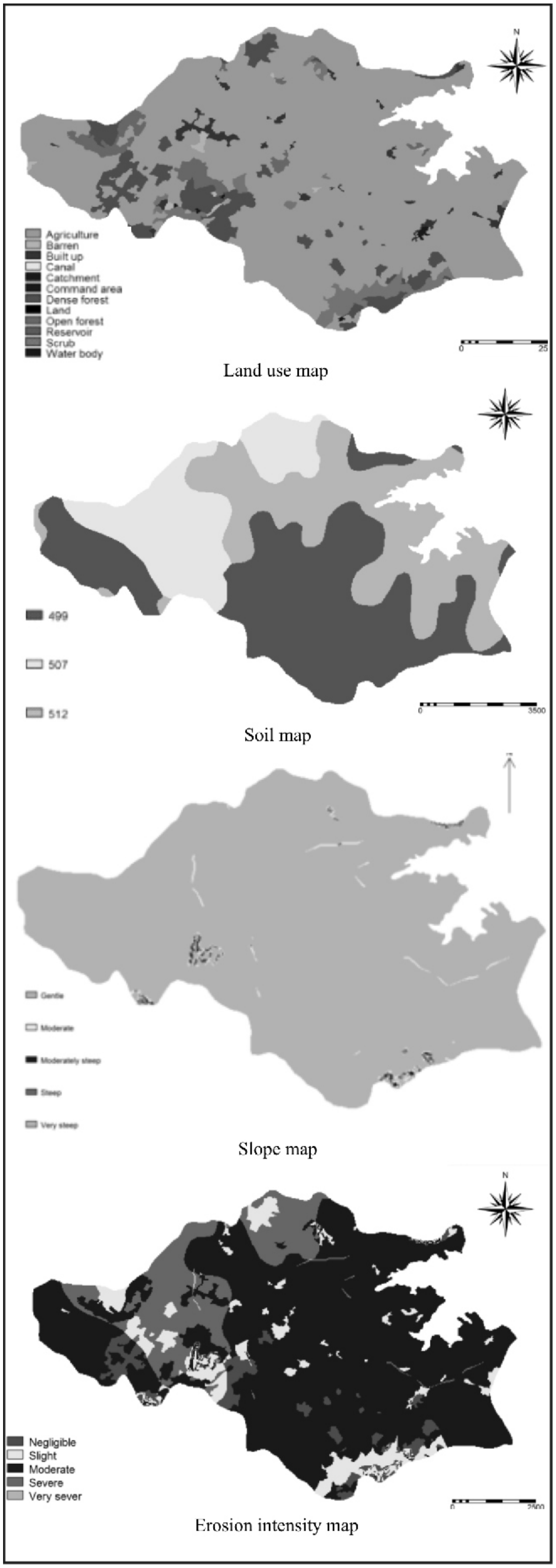
Table: 3
Criterions used for assignment of delivery ratio

Nearest Stream (km)	Delivery ratio
0-0.9	1.00
1.0-2.0	0.95
2.1-5.0	0.90
5.1-15.0	0.80
15.1-30.0	0.70

3. RESULTS AND DISCUSSION

The study area was divided into 36 sub-watersheds namely SB-1 to SB-36 and these sub watersheds were prioritized on the basis of sediment yield index. The land use map, slope map and erosion tendency map of the study area have been used to get CEIU map for Benisagar reservoir catchment (Fig. 3). The erosion intensity map indicates that out of 72.5 sq km, 9.3 sq km area falls under no and slight erosion intensity, 52.58 sq km area falls under moderate erosion intensity, 10.57 sq km under severe and 0.05 sq km under very severe erosion intensity class. The delivery ratio of study area varies from 0.7 to 0.9. The sediment yield index for each sub-watershed was estimated by equation (2). Priorities of the sub-watersheds were decided on the basis of sediment yield index value as given in the Table 4. The SYI for sub-watershed SB-25 was found as 1462 which was the highest among all sub-watersheds, whereas the minimum SYI of 1051 was computed for SB-5. From the analysis, it has been observed that eleven sub-watersheds, namely SB-12, SB-16, SB-20, SB-21, SB-27, SB-29, SB-30, SB-31, SB-33, SB-34 and SB-36 fall under high priority category with area of 28.31 sq km, four sub-watersheds, namely SB-18, SB-19, SB-25 and SB-35 fall under very high category with the area of 13.62 sq km.

The results of the study confirmed that 41.93 sq km area (57.8% of total area) of Benisagar catchment can be kept under very high and high priority categories from sediment yield index point of view where immediate attentions are required and scientifically developed catchment area treatment plan should be implemented. Nineteen sub-watersheds, namely SB-1, SB-2, SB-3, SB-4, SB-6, SB-7, SB-8, SB-9, SB-10, SB-11, SB-13, SB-14, SB-15, SB-17, SB-22, SB-24, SB-26, SB-28 and SB-32 fall under medium priority category with the area 27.71 sq km (38.2%) and SB-5 and SB-23 were found in low category with area 2.84 sq km (3.9%). This area can be treated with agronomic measures for soil moisture conservation.



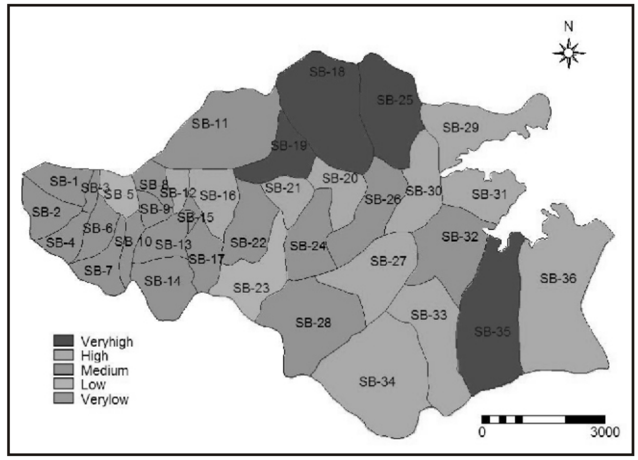


Fig. 3. Map depicting land use, soil, slope, erosion intensity and priority sub-watersheds in Benisagar reservoir catchment

Table: 4
Priority of sub watersheds based on sediment yield index

Sub-watersheds	Area (km^2)	SYI	Priority
SB-1	1.04	1133.72	Medium
SB-2	1.14	1118.62	Medium
SB-3	0.25	1192.41	Medium
SB-4	0.77	1120.00	Medium
SB-5	0.77	1051.84	Low
SB-6	0.86	1124.42	Medium
SB-7	1.11	1121.56	Medium
SB-8	0.62	1170.92	Medium
SB-9	0.47	1166.42	Medium
SB-10	0.56	1120.94	Medium
SB-11	4.14	1183.38	Medium
SB-12	0.44	1249.51	High
SB-13	1.13	1138.86	Medium
SB-14	1.69	1138.16	Medium
SB-15	0.19	1140.13	Medium
SB-16	1.44	1221.03	High
SB-17	1.11	1161.50	Medium
SB-18	4.5	1357.84	Very high
SB-19	1.52	1305.11	Very high
SB-20	1.28	1266.38	High
SB-21	0.93	1270.67	High
SB-22	1.8	1165.29	Medium
SB-23	2.07	1061.03	Low
SB-24	1.88	1107.21	Medium
SB-25	3.02	1462.96	Very high
SB-26	2.24	1120.62	Medium
SB-27	2.64	1270.34	High
SB-28	3.83	1120.39	Medium
SB-29	2.69	1275.06	High
SB-30	1.98	1280.61	High
SB-31	1.78	1272.22	High
SB-32	2.88	1118.13	Medium
SB-33	3.18	1249.92	High
SB-34	5.42	1252.10	High
SB-35	4.58	1417.90	Very high
SB-36	6.35	1307.21	Very high

4. CONCLUSIONS

Land and water are the two most valuable and vital resources essentially required, not only for sustenance of life but also for the economic and social progress of a region.

The prioritization of sub-watershed is a primary aspect of the catchment area treatment plan because the whole catchment area cannot be treated at the same time due to economic and technical constraints. The prioritization of sub-watershed helpful in identifying the stressed area can be done using SYI model without individual bias. The SYI method of prioritization has been employed for identification of environmentally stressed sub-watersheds in Banisagar catchment and concluded that 41.93 sq km area which is nearly 50% of total catchment comes under very high and high priorities need immediate attention for soil conservation measures.

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