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Sediment yield index based identification of critical sub-watershed for Kotani watershed using remote sensing and GIS

Dileshwari, MP Tripathi and Dhiraj Khalkho

Abstract
In this study an integrated approach to identify priority sub-watersheds by using the Sediment Yield Index (SYI) model of the All India Soil and Land Use Survey (AIS&LUS, 1991) has been used in Kotani watershed of Seonath basin, Chhattisgarh. The study watershed is divided into 17 sub-watersheds on the basis of drainage conditions. The SYI values of individual sub- watersheds have been computed and categorized into various classes such as very high, high, medium and low priority classes. The maximum SYI value of 1216.26 was computed in case of sub watershed 'SW8'whereas minimum value of SYI 827.81 was and in sub watershed 'SW5'.

Keywords: Composite erosion intensity unit, remote sensing and GIs, sediment yield index, watershed prioritization

Introduction

Soil and water are two basic natural resources for the survival of living and agricultural practices 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) [7]. Sediment particles originating from the watershed is the continuous process of erosion propagated along the river flow. When 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) [6]. 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) [3] is widely used method for prioritization of erosion prone areas for soil conservation measures. Jain and Goel (2002) [2] 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. Remote sensing and GIS software ILWIS (3.0) has been used for analysis of spatial distribution of erosion parameters for prioritization of watersheds. Pandey *et al.* (2007) [5], they divided Karso watershed of Hazaribagh, Jharkhand State, India into 200 m by 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. The watershed management planning highlights the management techniques to control erosion in the watershed area (Gajbhiye *et al.* 2014) [8]. Bali and Karale (1977) [1] suggested the criteria for choosing priority basins on the basis of sediment yield index (SYI). Khan *et al.* (2001) [4] 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 those facts in view, this study was undertaken in the Department of Soil and Water Engineering, IGKV, Raipur for prioritization of *Kotani* watershed area based on sediment yield index.

Study Area

Kotani watershed is a sub-basin of the Seonath River situated between 20^{0}17’56’’ to 21^{0}22’57’’ N latitude and 80^{0}22’57’’ E to 81^{0}28’48’’ E longitude. Drainage area of Kotani watershed is about 6951 Km^2 and average annual rainfall of the watershed is 1100 mm. Location of the study watershed is shown in Fig.1.

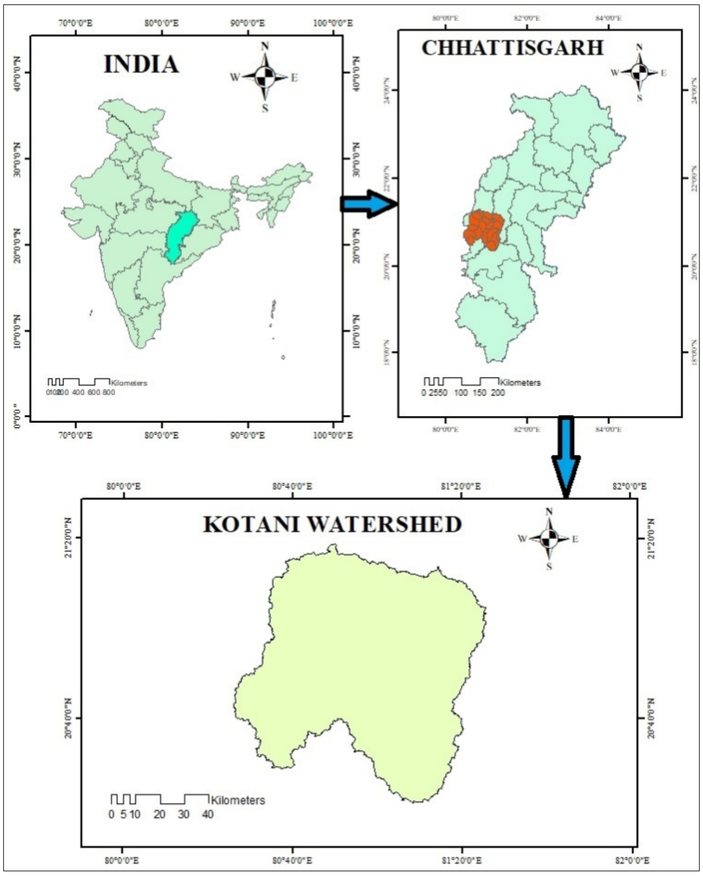


Fig 1: Location of the *Kotani* watershed

Materials and Methods

The methodology consists of determination of priority sub-watershed including generation of GIS based information system means various thematic maps information. A base map has been generated by SRTM DEM. The Kotani watershed has been divided into 17 sub-watershed and considering topography and drainage pattern. The land use map is prepared by LANDSAT 8 2020 and the soil texture map was acquired from Chhattisgarh State Watershed Management Agency, Raipur. Schematic flow chart for produced steps for identification and prioritization of sub watershed is shown in Fig.2.

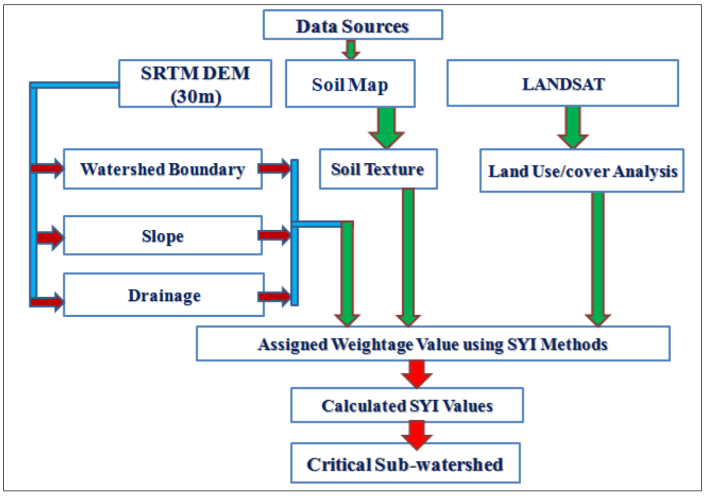


Fig 2: Schematic flow chart for prioritization of sub-watershed

Sediment Yield Index (SYI) Method

The SYI method is highly useful for prioritization of sub-watersheds according to erosion impact. In this study several important parameters were considered, including landuse/cover, soil type, and landscape drainage. Map layers were prepared for each parameter and used for assigning weighted values to calculate the SYI in t km^{-2} yr^{-1} according to the following equation:

$$\text{Sediment Yield Index (SYI)} = \sum \frac{(\text{Ai x Wi x Di})}{\text{Aw}} \text{x } 100 \ldots\ldots\ldots\ldots (1)$$

Where,

i = 1 to n

Ai = Area of i^{th} mapping unit

Wi = Weightage assigned to i^{th} unit

Di = Delivery ratio assigned to i^{th} unit

Aw = Total area of the watershed

The rate of soil loss was estimated for each sub-watershed, and then ranked into four priority ranking classes (very high, high, medium and low) according to the SYI values. Several map layers were prepared to determine the Wi in SYI model. Firstly, the weighted values for every factor were assigned on the basis of their risk level and then put the values in to the SYI equation. The weighted values were assigned using the weighted overlay tool in Arc Map. There are different ways by which the suitability assessment can be done. There have been studies of suitability assessment employing a “maximization“ or “worst case“ model (Space Applications Centre,1999), where the “worst“ parameter determines the suitability. As a result, a relatively less important parameter could determine the suitability in the final analysis. This anomaly arises because all parameters are considered to be of equal importance. The criteria for adoption, weighted values and total values that were applied for WI in the above equation (1) for SYI calculation are given in Table 1.

Table 1: Indicators used for Sediment Yield Index Calculation

S.N.	Parameters	Source	Criteria adopted for weighted values
1	Barren/bare land	Derived from LANDSAT™	It is the direct effect of human intervention in ecologically sensitive places. The higher the weightage value, the more barren terrain is covered.
2	Dense forest	Derived from LANDSAT™	Because vegetation is such an essential natural resource, and canals serve as an environmental indicator, a region's dense forest cover is an important indicator of human effect. The lower the weightage value, the more dense forest coverage there is.
3	Soil texture	Kumar and Sharma (2005)	In terms of calculating soil loss, soil texture is a critical factor. The sandy loam texture has been given a high rating.
4	Topography	SOI Top sheets on 1:50,000 scale	Slope is always significant since it has a direct impact on the amount of rainfall that falls on the soil. It varies depending on the slope's steepness and length. The greater the elevation, the greater the weight.

Results and Discussions

Landuse/land covers (LULC)

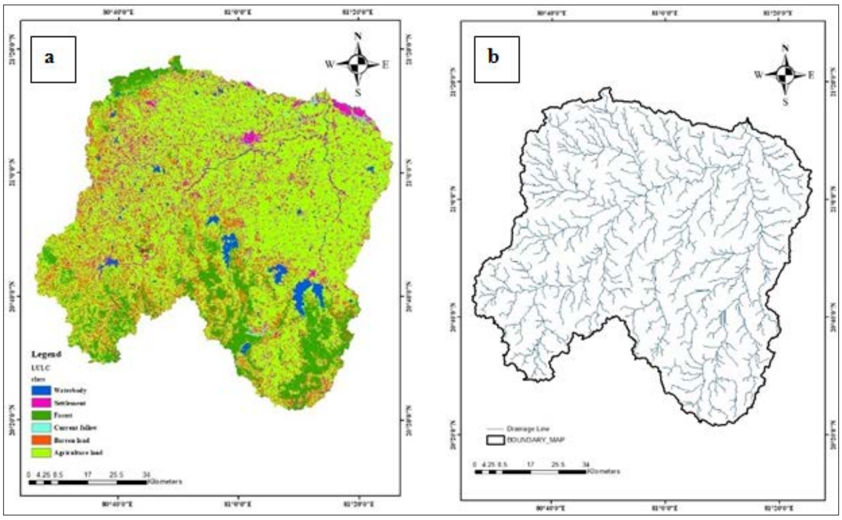
Forest covered 779 km^2, 11.20 percent of the study area and settlement areas occupied about 675 km^2 (9.71 percent) area of the Kotani watershed. Water bodies encompassed 199 km^2 (2.86 percent) area of the total land area. Agricultural land covered 4307 km^2, about 61.96 percent of the total land, with current fallow land occupying 278 km^2 or 3.99 percent of the total land area of watershed, and bare/barren land covered 713 km^2 or 10.25 percent land of the study area. Detailed information about the area under different land use classes are shown in Fig. 3(a) and Table 4. Accordingly, the weighted values areas signed on the basis of different sub-watersheds under the Kotani watershed. The status of LULC in the year 2021 indicates that the agricultural, forest and bare/barren classes are dominated among all land cover types.

Delivery ratio

The delivery ratio was adjusted for each of the erosion intensity unit. It is the percentage of eroded material that finally finds entry in watershed. Delivery ratio is assigned to all erosion intensity units, depending upon their distance from the nearest streams (Yadav *et al*. 2015) [9]. The criteria adopted for assigning delivery ratio is given in the Table 3.

Table 2: 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



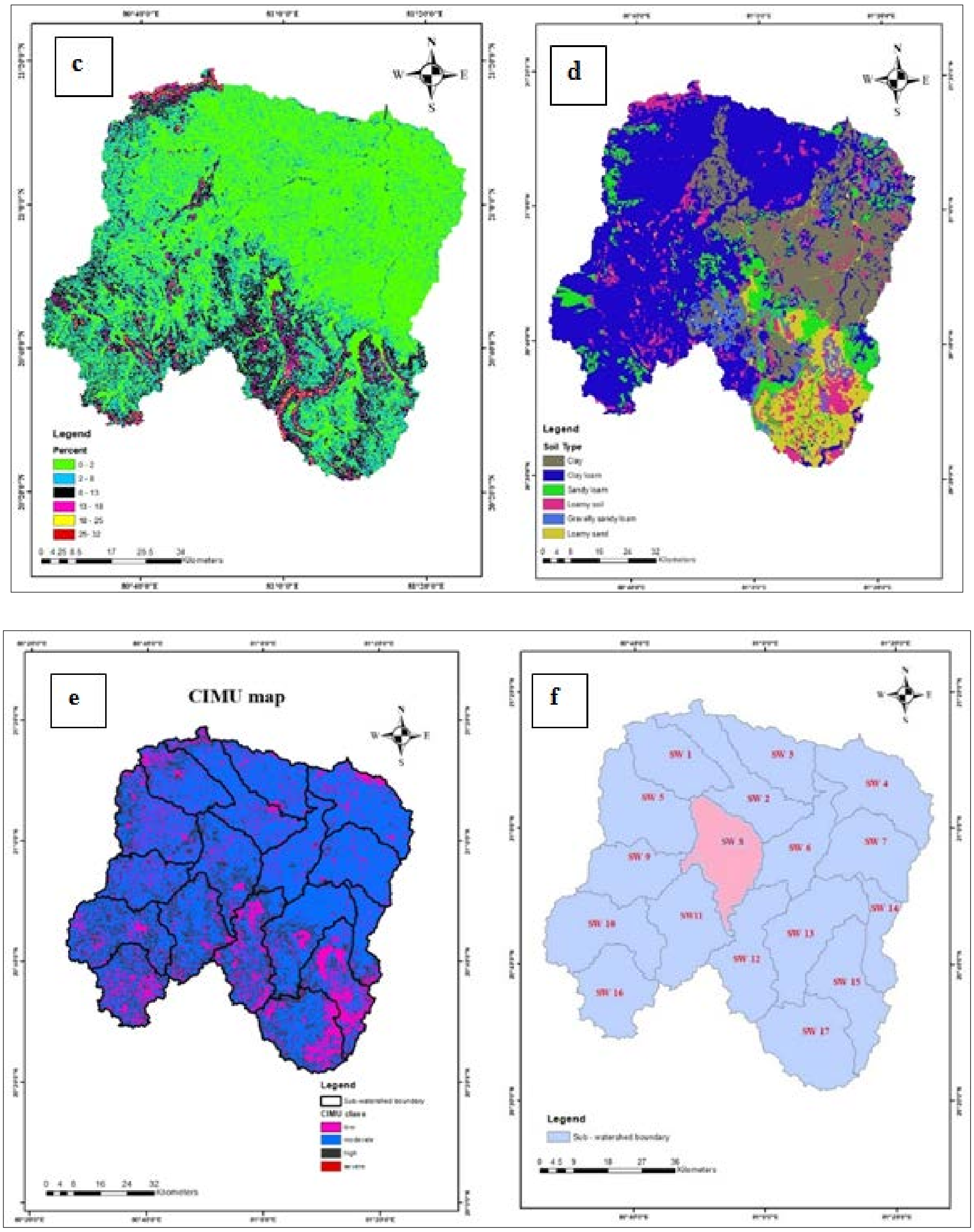


Fig 3: LULC (a), Drainage (b), Slope map (c), Soil texture (d), CIMU map (e) and Critical sub-watershed of Kotani watershed (f)

Table 3: LULC under different classes in Kotani Watershed

Sub-watersheds	Water body	Forest	Current Fallow	Agriculture	Settlement	Barren land
SW1	3.52	44.77	16.31	225.67	43.64	26.62
SW2	9.12	34.73	20.20	307.52	58.38	18.28
SW3	8.99	0.00	22.62	241.11	47.61	13.15
SW4	13.89	0.00	30.87	360.49	78.07	11.09
SW5	12.90	14.97	26.98	296.04	79.51	59.64
SW6	5.53	0.02	10.09	279.08	36.98	13.42
SW7	10.38	0.00	11.70	344.69	34.86	7.90
SW8	11.97	11.96	23.68	272.63	43.72	56.25
SW9	4.62	2.83	17.19	215.40	45.43	41.80
SW10	10.55	51.86	12.79	290.37	41.99	86.97
SW11	4.99	48.23	17.15	257.43	33.49	77.56
SW12	24.11	140.50	11.48	172.89	16.45	73.06
SW13	19.71	30.96	22.20	345.30	28.54	52.43
SW14	2.76	13.72	5.00	145.33	17.64	15.15
SW15	0.72	109.98	4.82	164.47	19.61	57.68
SW16	45.88	125.23	8.16	173.03	23.48	38.63
SW17	9.45	148.25	16.45	215.08	25.02	63.66
Total	199.09	778.01	277.69	4306.53	674.42	713.29
Area in%	2.86	11.19	3.99	61.96	9.70	10.26

Soil type

Clay loam soils are the dominant soil class in the study area, covering about 3567.89 km^2 or around 51.33% of the total area. Clay, loamy, Gravelly sandy loam and loamy sand 1385.3 km^2 (19.93%), 643.12 km^2 (9.25%), 610.86 km^2 (8.79%) and 513.97 km^2 (7.39%) of the study area, respectively. Higher weighted values have been assigned for sandy loam soils Fig. 3(d) because these can be eroded easily in comparison to other soil types in the study area.

Composite Erosion Intensity Map Unit (CIMU)

A composite erosion intensity unit map was prepared using the thematic map of slope, soil and land use/land cover. This composite map was then superimposed on the drainage map with sub watershed boundaries in order to obtain sub-watershed wise CIMU maps. As shown in the Fig. 3(e) moderately erosion is predominantly spread in the drainage area, covering an area of 67.65% of the total drainage area. The second predominant erosion in the drainage area is low erosion covering an area of 1414.89 km^2 which is 20.35% of the total drainage area. Table 5 shows the details of the composite erosion intensity mapping units of the study area.

Table 4: Composite Erosion Intensity Mapping Units of the Study Area

Sub-watersheds	Area (km^2)			
	Low	Moderate	High	Severe
SW1	71.25	253.61	33.91	0.93
SW2	80.53	341.83	24.54	0.75
SW3	56.63	263.20	12.87	0.00
SW4	91.69	390.87	10.96	0.00
SW5	103.89	316.87	67.87	0.47
SW6	42.76	289.42	13.24	0.00
SW7	44.76	356.61	8.03	0.00
SW8	65.67	294.96	59.28	0.26
SW9	51.66	229.47	45.24	0.54
SW10	89.13	302.16	100.91	1.48
SW11	72.93	279.51	85.02	1.17
SW12	133.36	220.32	83.74	0.51
SW13	64.59	375.13	59.16	0.42
SW14	31.98	150.96	16.53	0.00
SW15	106.89	180.20	68.30	1.37
SW16	168.41	198.35	46.81	0.61
SW17	138.37	259.01	78.23	2.51

Slope in percentage

The slope has major influence on the soil and water from the watershed and thereby influences the land use capability. The percentage slope determines the erosion susceptibility of the soil depending on its nature. The slope map was generated from the Digital Elevation Model. The contour was digitized using ARC GIS10.3. Slope is a key factor affecting the rate of soil loss. Areas in high altitude positions were assigned higher weighted values [Fig.3(c)].

Calculated SYI values for sub watershed prioritization

Table 4 and Fig. 3(f) give detailed information about the input values, prioritization ranking and prioritization categories of the different sub watersheds are given for Table 4 and similarly Fig 3(d). The sub-watersheds were broadly classified into four priority zones according to their composites cores as per the minimum and maximum values calculated by SYI modeling study. Prioritized classes were high (>1200), medium (1100– 1199), low (1000–1099), and very low (<1000). A map of sub-watershed prioritization was prepared according to these values, as shown in Fig. 3. This map identifies the sub-watersheds requiring priority conservation treatment. Sub-watersheds, SW8, were assigned as high priority, with values of 1216 sediment yield index. Most of the lands in these sub-watersheds are covered by agricultural land, forest and baren land. Sub-watersheds SW4, SW7 and SW13 were assigned medium priority. Sub-watersheds SW1, SW2, SW11, SW14, SW15 and SW17 have been prioritized as low category. The micro-watersheds with the lowest priority ranking were SW3, SW5, SW6, SW9, SW10, SW12 and SW16 which covered with forest and settlement and prioritized as low category having SYI values 963, 828, 892, 959, 996, 904 and 991 of Kotani watershed (Table 7). These ratings are due to the substantial forest cover, moderate extent of settlement, agricultural, and barren land. The sediment yield values for all such micro-watersheds are in tkm^{-2} $year^{-1}$. Good coverage of vegetation prevents soil loss and hence, these are assigned the least priority for conservation.

Table 5: SYI Values of sub-watersheds with priority ranks

SW	EIMU	Area in km^2	Weightage value	Weightage product	Delivery ratio	Gross sediment yield	SYI value	Priority ranks
SW1	Low	71.25	11	783.75	0.90	705.38	1060.70	8
	Moderate	253.61	14	3550.54	0.75	2662.91		
	High	33.91	16	542.56	0.80	434.05		
	Severe	0.93	20	18.60	0.70	13.02		
Total		359.70				3815.35		
SW2	Low	80.53	11	885.83	0.85	752.96	1022.38	9
	Moderate	341.83	13	4443.79	0.80	3555.03		
	High	24.54	15	368.10	0.70	257.67		
	Severe	0.75	21	15.75	0.70	11.03		

Total		447.65				4576.68		
SW3	Low	56.63	11	622.93	0.90	560.64	963.17	13
	Moderate	263.20	12	3158.38	0.80	2526.70		
	High	12.87	14	180.18	0.65	117.12		
	Severe	0.00	0	0.00	0.00	0.00		
Total		332.70				3204.45		
SW4	Low	91.69	9	825.21	0.90	742.69	1113.18	2
	Moderate	390.87	14	5472.18	0.85	4651.35		
	High	10.96	13	142.53	0.70	99.77		
	Severe	0.00	0		0.00	0.00		
Total		493.52				5493.81		
SW5	Low	103.89	9	935.05	0.90	841.54	827.81	17
	Moderate	316.87	10	3168.72	0.80	2534.98		
	High	67.87	14	950.11	0.70	665.08		
	Severe	0.47	22	10.36	0.70	7.25		
Total		489.10				4048.85		
SW6	Low	42.76	9	384.80	0.90	346.32	891.93	16
	Moderate	289.42	12	3473.02	0.75	2604.76		
	High	13.24	14	185.36	0.70	129.75		
	Severe	0.00	0		0.00	0.00		
Total		345.41				3080.83		
SW7	Low	44.76	11	492.32	0.90	443.08	1107.36	3
	Moderate	356.61	14	4992.48	0.80	3993.99		
	High	8.03	20	160.54	0.60	96.32		
	Severe	0.00	0	0.00		0.00		
Total		409.39				4533.40		
SW8	Low	65.67	9	590.99	0.90	531.89	1216.26	1
	Moderate	294.96	16	4719.36	0.80	3775.49		
	High	59.28	18	1067.04	0.75	800.28		
	Severe	0.26	17	4.39	0.60	2.63		
Total		420.16				5110.29		
SW9	Low	51.66	9	464.91	0.90	418.42	958.84	14
	Moderate	229.47	12	2753.64	0.80	2202.91		
	High	45.24	16	723.84	0.70	506.69		
	Severe	0.54	20	10.80	0.60	6.48		
Total		326.91				3134.50		
SW10	Low	89.13	9	802.19	0.90	721.97	996.04	11
	Moderate	302.16	12	3625.87	0.80	2900.70		
	High	100.91	18	1816.45	0.70	1271.52		
	Severe	1.48	24	35.59	0.65	23.13		
Total		493.69				4917.32		
SW11	Low	72.93	10	729.32	0.90	656.39	1083.63	6
	Moderate	279.51	14	3913.14	0.80	3130.51		
	High	85.02	16	1360.26	0.70	952.18		
	Severe	1.17	20	23.42	0.60	14.05		
Total		438.63				4753.13		
SW12	Low	133.36	11	1467.00	0.90	1320.30	904.45	15
	Moderate	220.32	10	2203.20	0.80	1762.56		
	High	83.74	16	1339.79	0.65	870.86		
	Severe	0.51	20	10.18	0.70	7.13		
Total		437.93				3960.85		
SW13	Low	64.59	9	581.27	0.90	523.14	1105.02	4
	Moderate	375.13	14	5251.78	0.80	4201.42		
	High	59.16	19	1124.04	0.70	786.83		
	Severe	0.42	20	8.37	0.70	5.86		
Total		499.29				5517.25		
SW14	Low	31.98	11	351.79	0.90	316.61	1004.60	10
	Moderate	150.96	12	1811.47	0.80	1449.18		
	High	16.53	18	297.61	0.80	238.09		
	Severe	0.00	0	0.00	0.70	0.00		
Total		199.47				2003.88		
SW15	Low	106.89	11	1175.79	0.80	940.63	1075.97	7
	Moderate	180.20	14	2522.77	0.80	2018.22		
	High	68.30	18	1229.38	0.70	860.57		
	Severe	1.37	20	27.38	0.70	19.17		
Total		356.76				3838.58		
SW16	Low	168.41	11	1852.52	0.90	1667.27	991.13	12
	Moderate	198.35	12	2380.14	0.80	1904.11		
	High	46.81	16	748.96	0.70	524.27		
	Severe	0.61	22	13.38	0.70	9.36		
Total		414.17				4105.02		
SW17	Low	138.37	11	1522.08	0.80	1217.66	1086.74	5

	Moderate	259.01	14	3626.07	0.80	2900.86		
	High	78.23	19	1486.33	0.70	1040.43		
	Severe	2.51	21	52.73	0.70	36.91		
Total		478.12				5195.86		

Table 6: Prioritized SYI Values of Erosion Intensity Rates with Sub-watershed code

Priority category	SYI	Sub-watershed code
High	>1200	SW8
medium	1100-1199	SW4, SW7, SW13
low	1000-1099	SW14, SW2, SW1, SW15, SW11, SW17
very low	<1000	SW10, SW16, SW3, SW9, SW6, SW5, SW12

Conclusions

The SYI method of prioritization has been employed for identification of environmentally stressed sub-watersheds in *Kotani* watershed which is nearly 420.16 km^2 area (6.04%) comes under high priorities and needs immediate attention for soil conservation measures.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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