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PRIORITIZATION OF MICRO-WATERSHEDS FOR SOIL CONSERVATION IN GIRI CATCHMENT

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Abstract

The present study aims to estimate the amount and spatial distribution of soil loss risk to prioritize micro-watersheds in the Giri catchment for soil conservation. The study is based on remote sensing data (LISS-IV MX), drawn from the high resolution satellite images. The morphometric information has been extracted from drainage layers computed from topographical sheets and CARTOSAT Digital Elevation Model (DEM) with 30 m spatial resolution. The soil loss risk has been assessed employing the Revised Universal Soil Loss Equation (RUSLE). The study reveals that about 50 per cent of the micro-watersheds under study are highly prone to soil loss risk and therefore, need immediate soil conservation measures.

Introduction

Implementation of effective soil and water conservation measures in an area requires, among other things, a detailed understanding of the extent of risk and spatial distribution of soil erosion. It has immediate significance for conservation agencies, development agents and field technicians for a targeted and cost effective conservation intervention by identifying most vulnerable landscapes and setting of priorities (Bewket and Teferi, 2009). Numerous treatment measures in the form of engineering and agronomic practices are available. But all these measures are costly and cumbersome. Hence, identification of most vulnerable areas to apply suitable technologies as per the site conditions and their application in correct way is the most important to achieve the desired results (Panhalkar, 2011). Optimum and sustained productivity through scientific planning, requires basic knowledge on watershed for appropriate land resources inventories and a prioritization scheme for interpretation of land use capability with risk of land degradation as main criterion (Martin and Saha, 2007). The need for successful prioritization is heightened with increasing pressures from land use changes, population, climate change, and other growing threats to natural resources (Newbold and Siikamaki, 2009).

Land and water resources are threatened all over the country whether these are the very high rainfall areas of the north-east, the Himalayan and the sub-Himalayan regions or the peninsular part of the country (Shankar, 1999). Natural rates of denudation in the Himalayan region are very high in comparison to most other parts of the country (Rawat and Rawat, 1994). It has been reported that 28 to 77 per cent of the watershed areas of the Himalayan Rivers are in need of priority treatment for sediment control (Das et al., 1981, quoted in Sharma et al., 1991).

Notably, any particular micro-watershed may get the top priority due to various reasons, but, often, the intensity of land degradation is taken as the basis. The assessment of the physical parameters of the land is possible by analyzing the slope, soil, geomorphology, land use and other terrain characteristics with the help of GIS. Das et al. (2012) suggested that criteria for watershed prioritization are subjective in nature and difficult to implement in ground reality due to various reasons. In their study, highest priority indicates maximum soil erosion in the specific micro-watershed and confirms that it must be given maximum attention for soil conservation.

Many studies on watershed prioritization using both traditional and modern inputs have been conducted in various catchments in Himalayan regions. By virtue of its geographic location straddling over Shiwalik and Lesser Himalayan ranges which are considered one of the most fragile ecosystems in India, Giri catchment is equally environmentally sensitive part. Burgeoning human and livestock pressure, increasing built-up landscape mainly due to Shimla and Solan urban settlements and depleting forest cover together have led to degradation of natural resources especially that of land, water and forests in the Giri catchment. Therefore, a study on prioritization of sub-watersheds in Giri River catchment has been conducted from a spatial perspective to realize the following objective:

Objective of the Study

To estimate the soil loss risk at micro-watersheds scale and to suggest levels for prioritization and conservation of soils in Giri catchment of Himachal Pradesh.

Study Area

The Giri catchment located between 30° 26′ 41″ to 31° 15′ 29″ north latitudes and 77° 3′ 3″ E to 77° 44′ 9″ east longitudes (Fig. 1) extends about 92 km north to south and 64 km east to west covering an area of about 2647.49 km² with 337.44 km perimeter. It constitutes about 4.75 per cent of total geographical area of Himachal Pradesh. It is surrounded by Tons watershed in the east, Sutlej basin in north and north-west, Ghaggar basin in south-west and Yamuna basin in south. The Giri catchment has hilly and mountainous topography with altitude ranging from the lowest of 355 m to the highest of 3459 m above mean sea level.

Database

The present study has utilized remote sensing data (LISS-IV MX) of high resolution satellite images of 5 m cell-size acquired on December 26, 2011 and January 24, 2012. The satellite images have been used to generate the land use/land cover information. The Survey of India topographic sheets at 1:50,000 scale have been used for morphometric information related to drainage layers of the study area. For the relief and slope analysis, CARTOSAT Digital Elevation Model (DEM) with 30 m spatial resolution from National Remote Sensing Centre (NRSC) website acquired on February 29, 2012 has been used. Information regarding soil type has been generated from the maps published by National Bureau of Soil Survey and Land Use Planning, Nagpur. The temporal rainfall data have been collected from India Meteorological Department, Pune.

Methodology

The Giri catchment ridge line and micro-watersheds have been delineated from Survey of India topographic sheets in ArcGIS software utilizing scanning, geo-referencing, sub-setting and mosaicking operational steps.

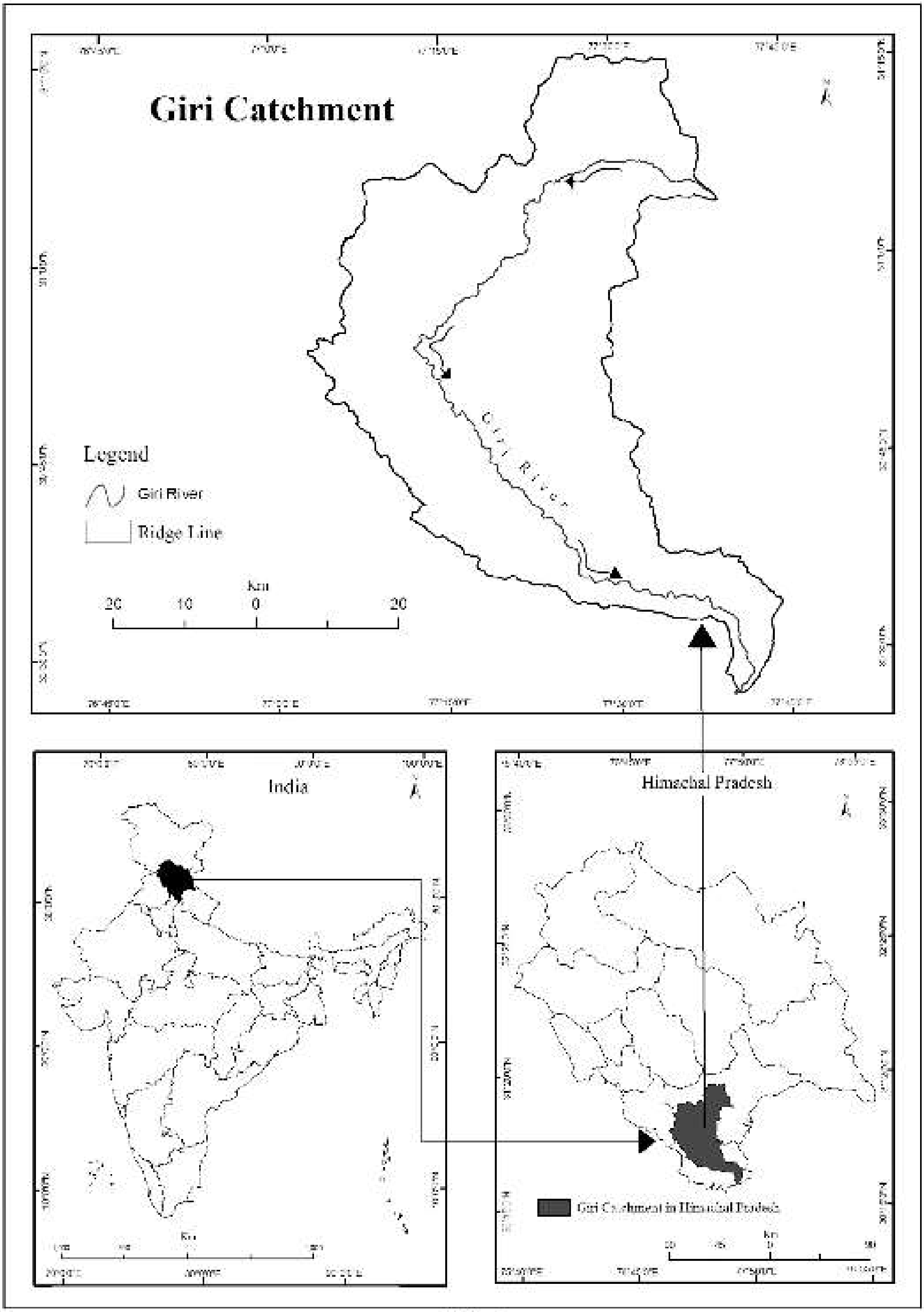

Giri Catchment
Legend
Giri River
Ridge Line
Km
20 10 0 20
Giri River
India
Himachal Pradesh
Giri Catchment in Himachal Pradesh

Fig. 1

The soil loss risk has been assessed employing the Revised Universal Soil Loss Equation (RUSLE). The RUSLE employs a combination of following inputs for assessing the soil loss potential:

Rainfall Erosivity Factor (R)

The equation developed by Babu et al. (1978) and Singh et al. (1981) has been used to compute the rainfall erosivity factor:

$$R_{factor} = 79+0.363R$$

where, R is the average annual rainfall in mm.

An average annual value of 'R' has been calculated by using precipitation data of stations like Narkanda, Solan and Paonta Sahib located in the northern, western and southern parts of the study area for the period of 2004-10. The point data of these three meteorological stations have been interpolated using "spline" algorithm in the ArcGIS software.

Soil Erodibility Factor (K)

The soil erodibility factor (K) is the average soil erodibility factor (tons/ha/year). The 'K' factor has been computed based on the information available in literature about soil types found in the study area. The 'K' values are usually estimated using the soil erodibility nomograph method, which uses per cent silt plus very fine sand (0.002-0.1 mm), per cent sand (0.1-2 mm), per cent organic matter and soil structure and permeability classes to calculate 'K' factor (Thakur, 2012). The soil erodibility nomograph is a popular tool for estimating 'K' values. Values for 'K' typically range from about 0.10 to 0.45 (McCool et al., 1995).

Topographic Factor (LS)

It has been calculated as:

$$L = (\text{Flow Accumulation x Grid Size}/22.13)^m$$

(Sheikh et al., 2011).

where, 22.13 = RUSLE unit plot length (m) and 'm' is variable slope length exponent. Slope length is horizontal distance from the origin of overland flow to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a defined channel. Slope length exponent m is calculated as:

$$m = \beta/1+\beta$$

$$\beta = (\sin\theta/0.0896)/(3.0(\sin\theta)^{0.8}+0.56)$$

where, θ is slope angle.

The flow accumulation map has been re-corrected by using following conditional statement in raster calculator:

CON ([FlowAccu.img] <= 0, 1, [FlowAccu.img])

This conditional equation assigns value 1 to all the grids having flow accumulation values equal to zero and remaining pixels original values.

S = Slope steepness factor

It has been evaluated as per McCool et al., 1987 quoted in Thakur 2012.

$S = 10.8\sin\theta+0.03$ S< 9% (i.e. $\tan\theta<0.09$)

$S = [\sin\theta/\sin 5.143]^{0.6}$ S> 9% (i.e. $\tan\theta>0.09$)

Cover Management Factor (C)

The most extensively used indicator of vegetation growth based on satellite imageries is the Normalized Difference Vegetation Index (NDVI). The C values in each cell have been calculated as suggested by Fathizad et al. (2014):

$$C = [(1\text{-NDVI})/2]$$

Conservation Practices (P)

The information on conservation practices (P) followed in various land use/land cover classes has been computed based on (Roose, 1977; Singh et al., 1981; Narain et al., 1994; quoted in Kumar and Kushwaha, 2013).

Average Annual Soil Loss (A)

The average annual soil loss has been calculated as follows:

$$A = R.K.L.S.C.P$$

where, A= Annual average soil loss (tons/ha/year)
R= Rainfall erosivity factor (MJ mm /ha/year)
K= Soil erodibility factor (tons/ha/ year)
L= Slope length factor (unit less)
S= Slope steepness factor (unit less)
C= Crop cover factor (unit less)
P= Conservation practices factor (unit less)
All the input maps have been multiplied in raster calculator to generate the soil erosion potential map of Giri catchment.

Results and Discussion

Rainfall Erosivity Factor (R)

The annual soil loss yield in a catchment could be estimated by summing up erosivity of individual rainfall storm of the year (Wischmeier and Smith, 1978, quoted in Kumar and Kushwaha, 2013). The average annual erosivity factor, R, is an index of erosivity at a particular location. The spatial distribution of R value in the Giri catchment has been portrayed in the form of rainfall erosivity factor map (Fig. 2). Fig. 2 reveals that southern part of the study area has high rainfall erosivity. As one moves from the central parts to southern tip, R-factor continuously increases. The rainfall erosivity (R-factor) is the highest (about 568 J/ha^{-1}) near Paonta Sahib located in southern part of the catchment where Giri river falls into the Yamuna river. From the central part of the catchment, rainfall erosivity decreases towards west. The north-west areas recorded the lowest (about 451 J/ha^{-1}) R-value in the study area. The interpolated rainfall erosivity distribution reveals uneven pattern responsible for varying soil detachment in the Giri catchment.

Soil Erodibility Factor (K)

The soil erodibility factor (K) represents the average soil erodibility (tons/ha/year). Some soil types are naturally more prone to soil erosion due to their physical structure. Erodibility is a function of soil texture, organic matter content and permeability. K-factor represents both susceptibility of soil to get eroded and the rate of runoff (Milliward and Mersey, 1999; Ranzi et al., 2012; Thakur, 2012). Determination of the K-factor has been obtained from Sharma et al. (2003), Sheikh et al. (2011), Thakur (2012), Kumar and Kushwaha (2013) and Tirkey et al. (2013).

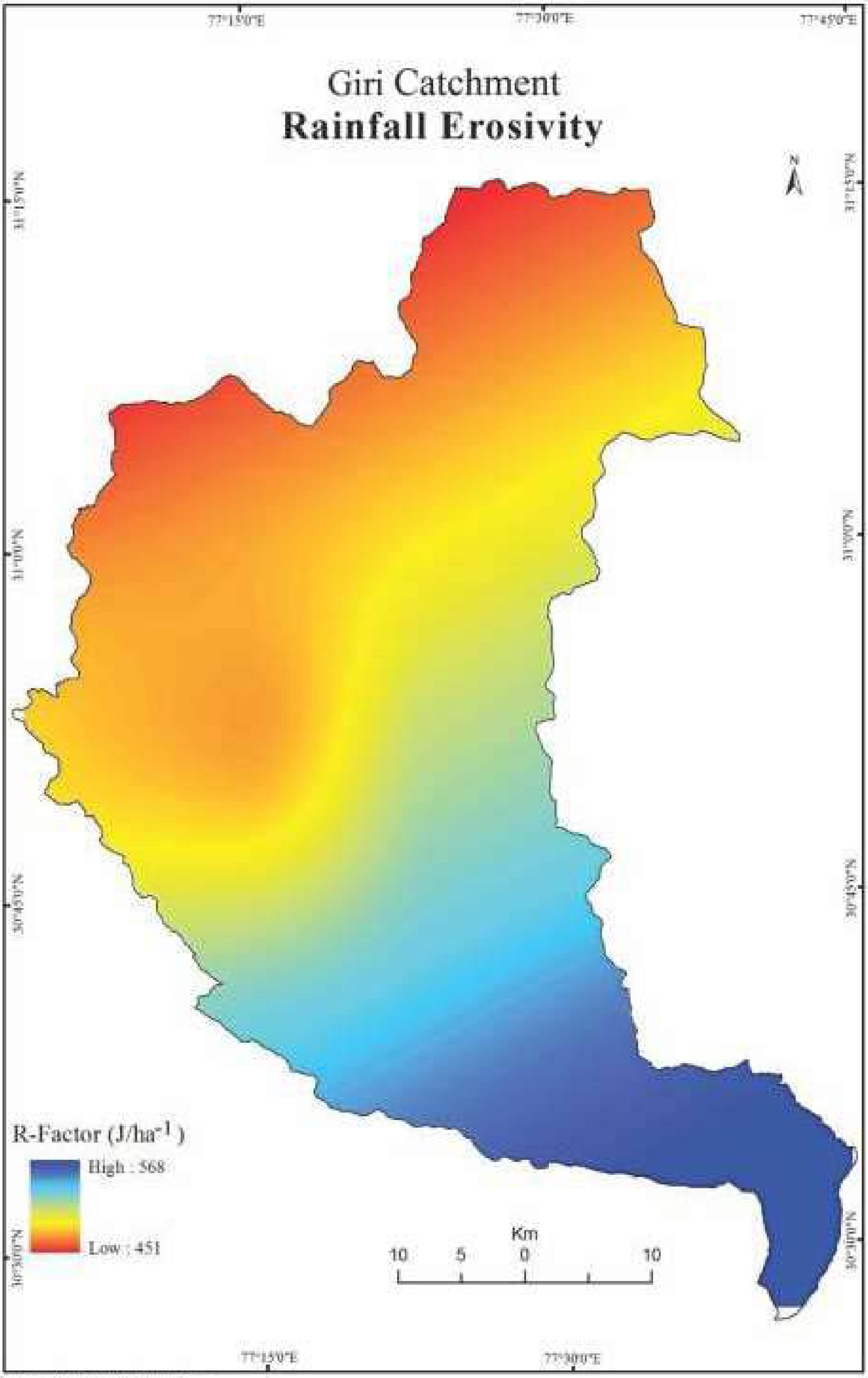
Fig. 3 reveals that K factor based on soil class, textural properties, organic matter and soil permeability varies from 0.22 to 0.45 in the study area. The study reveals that a linear strip running from north to south almost uninterruptedly on the western flank of the catchment is characterized with low soil erodibility. A few patches of low soil erodibility have also been identified in northern area. Figure 3 further reveals that large part of the catchment is under high soil erodibility.

Topographic Factor (LS)

The LS factor expresses the effect of local topography on soil erosion rate, controlled by combined effects of slope length (L) and slope steepness (S) (Farhan et al., 2013). Increase in slope length and slope steepness can produce higher overland flow velocities and correspondingly higher soil erosion (Thakur, 2012).

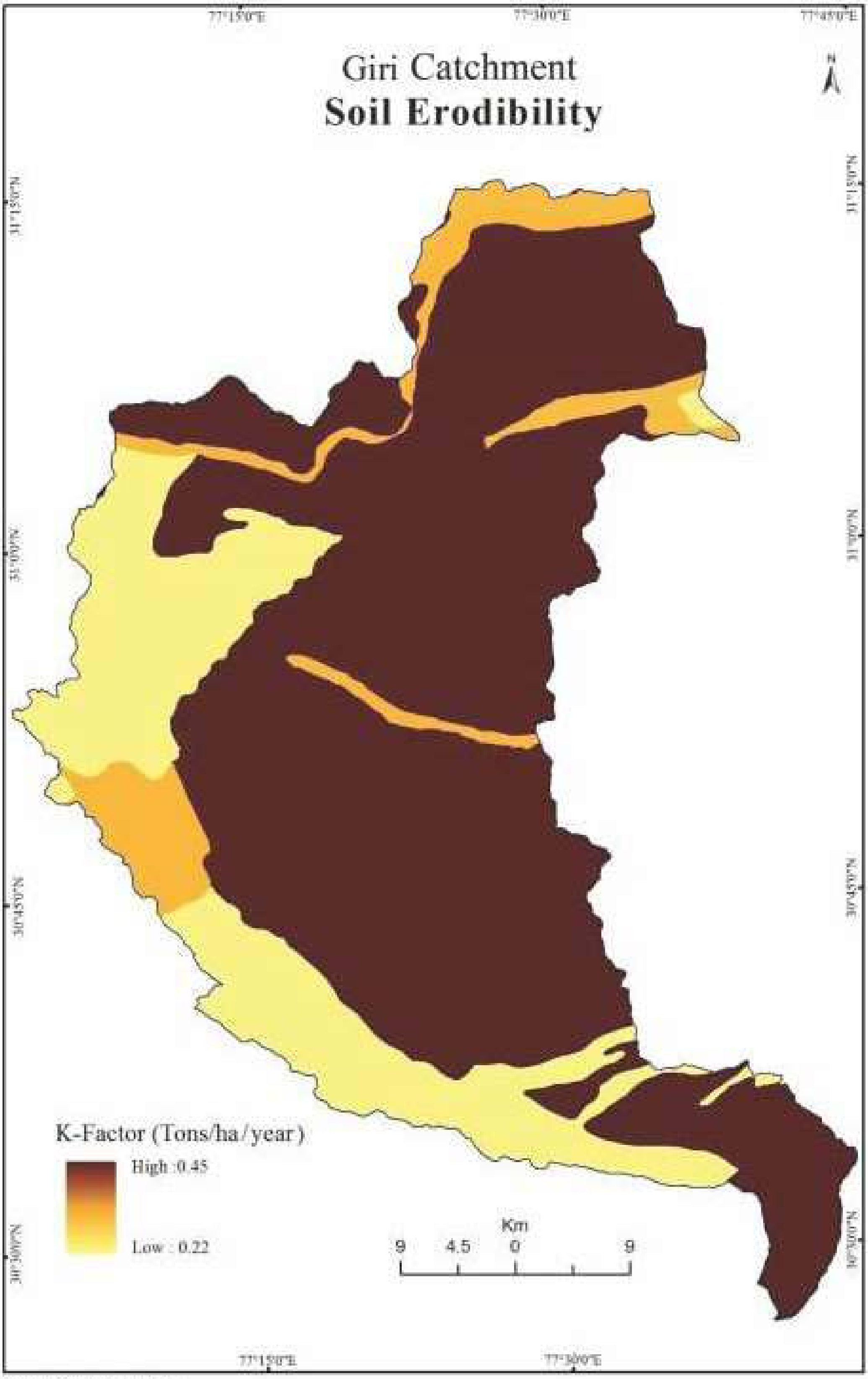
(i) Slope Length

The slope length is defined as the distance from the source of runoff to the point where either deposition begins or runoff enters a well-defined channel. Slope steepness factor reflects influence of slope steepness on erosion. Longer the slope length, greater is the amount of cumulative runoff, likewise, steeper the slope of the land, higher is the velocities of the runoff which contribute to erosion



Source: Computed by authors

Fig. 2



Source: Computed by authors

Fig. 3

(Wishchmeier and Smith, 1978, quoted in Ashiagbor et. al., 2013).

Fig. 4 reveals that slope length factor varies from the lowest of 0.09 to the highest of 7656 in study area. Higher slope length has been identified in northern parts of the catchment. Medium slope length has been observed in the upper course of Giri river valley, while southern parts are characterized by low slope length.

(ii) Slope Steepness (S)

Fig. 5 reveals spatial distribution of slope steepness factor in the study area. S-factor varies from the lowest of 0.03 to highest of 4.25 in the catchment. In the southern parts of Giri river valley medium slope steepness predominates, while high slope steepness has been observed all over the remaining catchment.

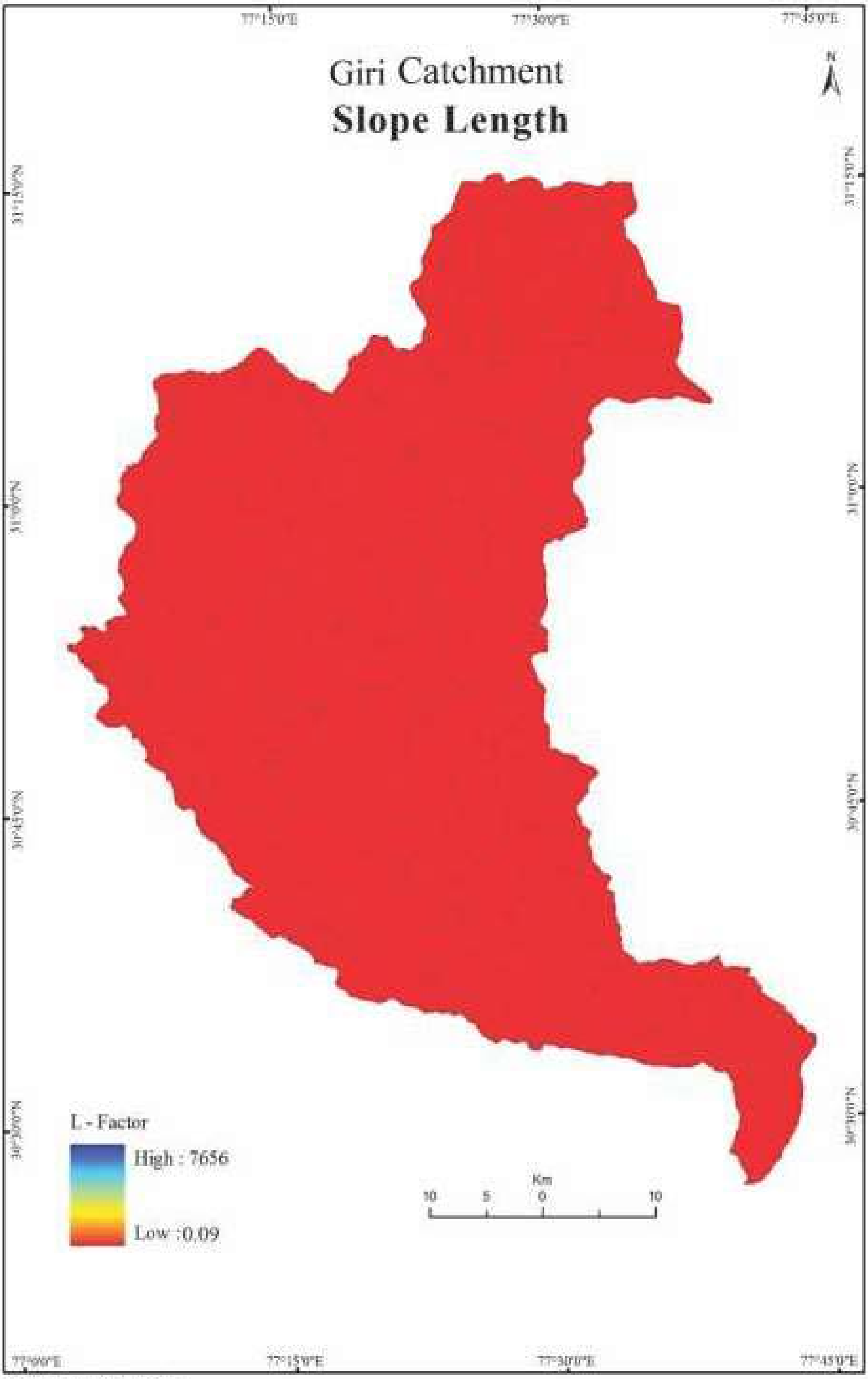
Cover Management Factor (C)

The land cover and management factor represents the effects of vegetation, management and erosion control practices on soil loss, the value of which ranges from 0 in water bodies to slightly greater than 1 in barren land. The plant cover factor C, expresses the relation between erosion on bare soil and erosion in areas under cultivation and plant cover (Toy et al., 1999, quoted in Tirkey et al., 2013). As the vegetation cover increases, the soil loss decreases. In RUSLE model, the 'C'-factor is derived on the basis of empirical equations with measurements of ground cover, aerial cover and minimum drip height (Wischmeier and Smith, 1978, quoted in Thakur, 2012).

The most extensively used indicator of vegetation growth based on satellite imageries is the Normalized Difference Vegetation Index (NDVI), which ranges from -1.00 to 1.00 in the study area. Fig. 6 exhibits the 'C' factor derived from NDVI calculation. It is evident from the figure that there is inverse relationship between the vegetal cover and C-factor. Higher vegetal cover is related with low possibility of soil loss. C-factor in the study area ranges from the lowest of 0.13 to the highest of 0.56 (Fig. 6). Therefore, all vegetated areas in the Fig. 6 are exhibiting low C-values in red to yellow tone indicating possibility of low soil loss. Such areas have been scattered in pockets in south, central-east and ridges of north-western parts of the catchment. In contrast, high C-values in blue tinge indicate possibility of higher soil loss (Fig. 6).

Conservation Practices (P)

Among the RUSLE factors, values for the P-factor are the least reliable. The P-factor mainly represents how surface conditions affect flow paths and flow hydraulics (McCool et al., 1995). P-factor reflects the effects of practices that will reduce the amount and rate of the water runoff and thus, reduces the amount of erosion, the higher the supporting practice; the lower is the value of the P-factor (Ranzi et al., 2012). The information on conservation practices (P) followed in various land use/land cover classes have been collected through land use/land cover mapping. 'P' value for each land use/land cover class in this study has been extracted from Roose (1977), Singh et al. (1981) and Narain et al. (1994) quoted in Kumar and Kushwaha, 2013. In the present study, conservation practice factor (P) ranges from 0.00 to 1.00 (Fig. 7). The highest value is assigned to areas with almost nil conservation practices. Figure 7 reveals that P-value is very low in Giri River bed and its tributaries and few agricultural areas in northern part of the catchment. The highest P-value shown in blue colour is found in areas having dense as well as sparse vegetation in the catchment.



Source: Computed by authors

Fig. 4

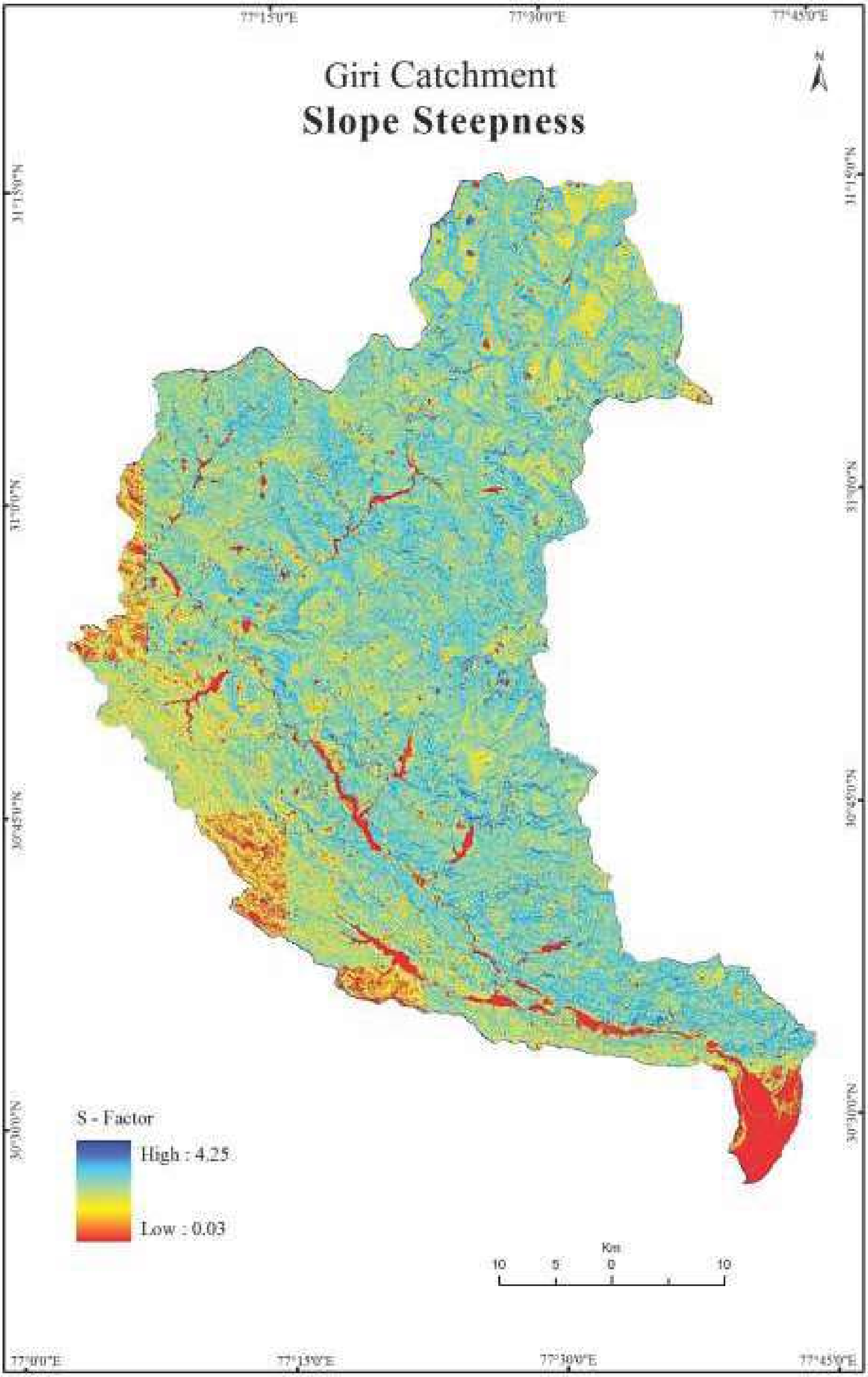


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Fig. 5

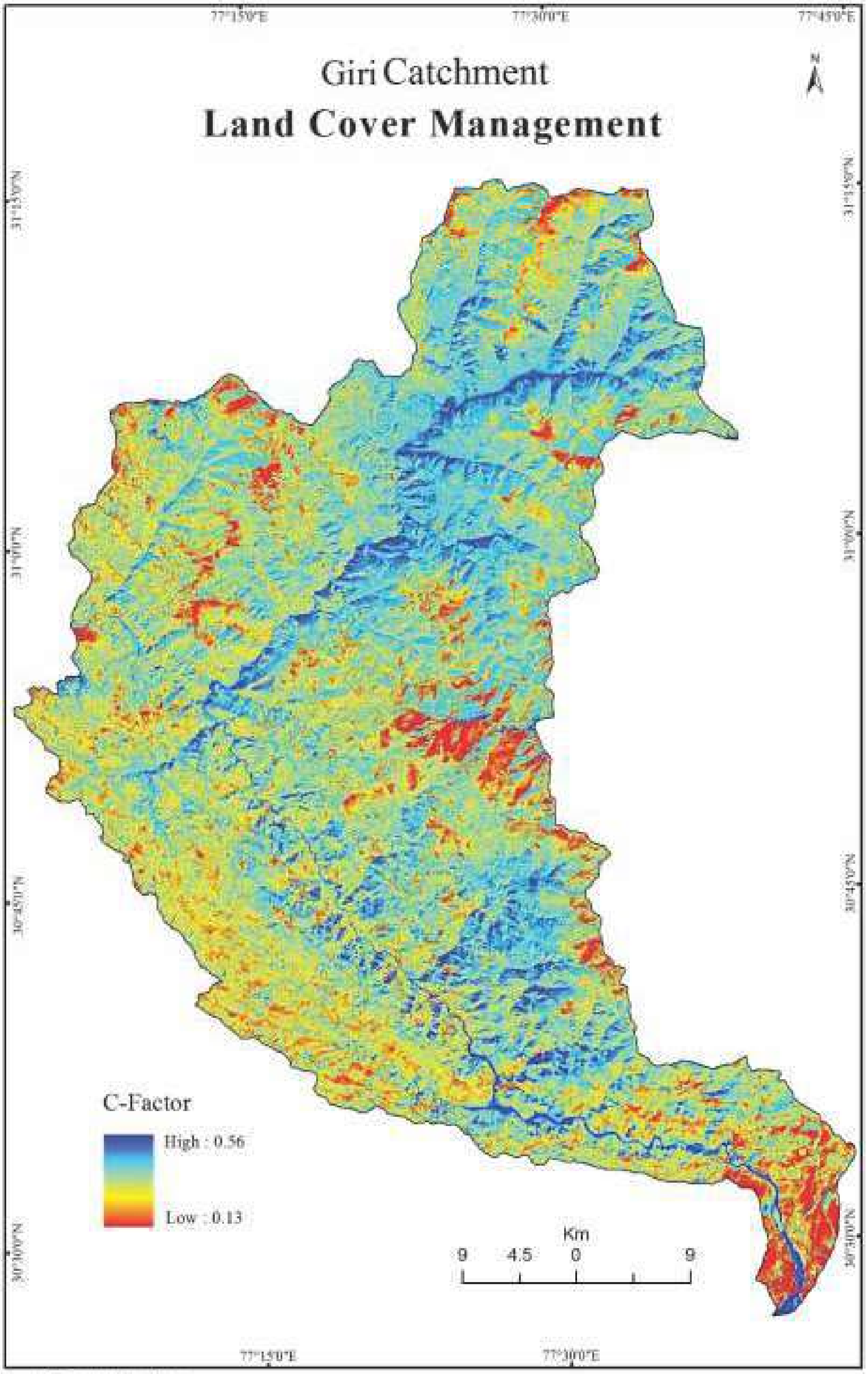

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Fig. 6

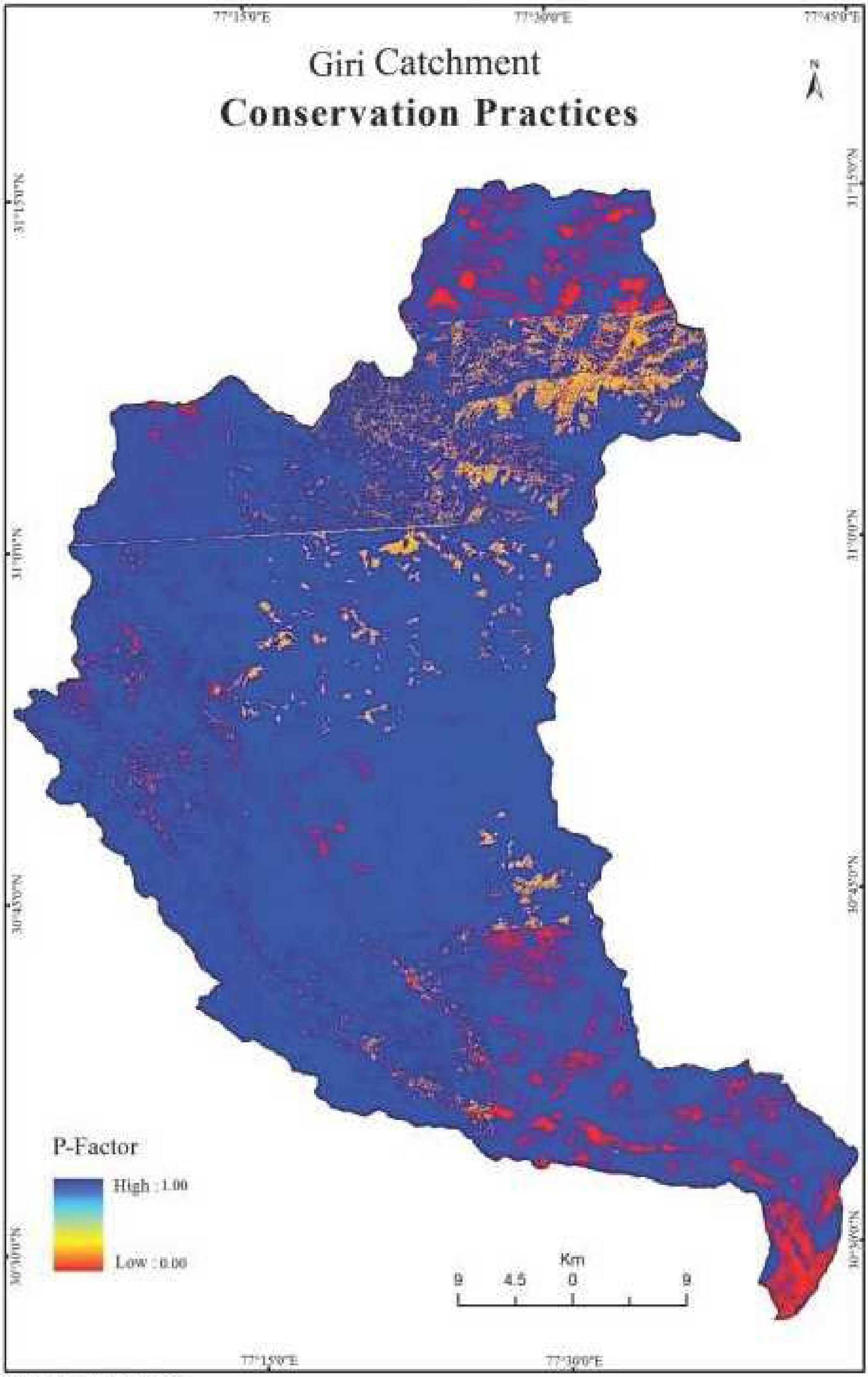

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Fig. 7

Annual Soil Loss Risk Estimation (A)

Figure 8 indicates that annual soil loss risk varies from low (less than 10 tons/ha/year) to extreme (more than 75 tons/ha/year) categories in the Giri catchment. The average annual soil loss risk of 39.26 tons/ha/year has been observed in the Giri catchment. Figure 8 and Table 1 show that, about 15 per cent area of the catchment falls under less than 10 tons/ha/year category of soil loss risk, considered as permissible soil loss limit (Mandal and Sharda, 2011).

The spatial distribution of soil erosion risk reveals that as topography changes, the soil loss potential also varies in the study area. The entire alluvial tract adjoining river beds mainly in the southern parts and few individual patches in the northern hilly parts are least prone to soil erosion (less than 10 tons/ha/year) and hence safe (Fig. 8).

The medium average soil loss risk ranges between 10 to 25 tons/ha/year. It comprises about one third area of the catchment. This zone of soil loss risk has been identified in the south, south-west and west in the arc shape along the ridge (Fig. 8). The high soil loss risk belt accounting for about 25 to 50 tons/ha/year occupies about 22 per cent area of the catchment (Table 1). This area is unevenly distributed which is characterized with exposed ridges adjoining the very high soil loss risk areas. The very high soil erodibility ranges between 50 to 75 tons/ha/year. It constitutes about 8 per cent area of the catchment which is sprawling over the high ridges of the north-east and middle-eastern parts of the catchment. The very high soil erodibility zone largely shares boundary with extreme soil erodibility class (more than 75 tons/ha/year). The extreme soil loss risk category accounts for a little more than one-fifth area of the catchment. This very critical area straddling over the north-south is found mainly in the eastern side of the Giri River. The main concentration is found in the central-eastern part of the catchment (Fig. 8).

Soil Loss Risk Assessment and Prioritization

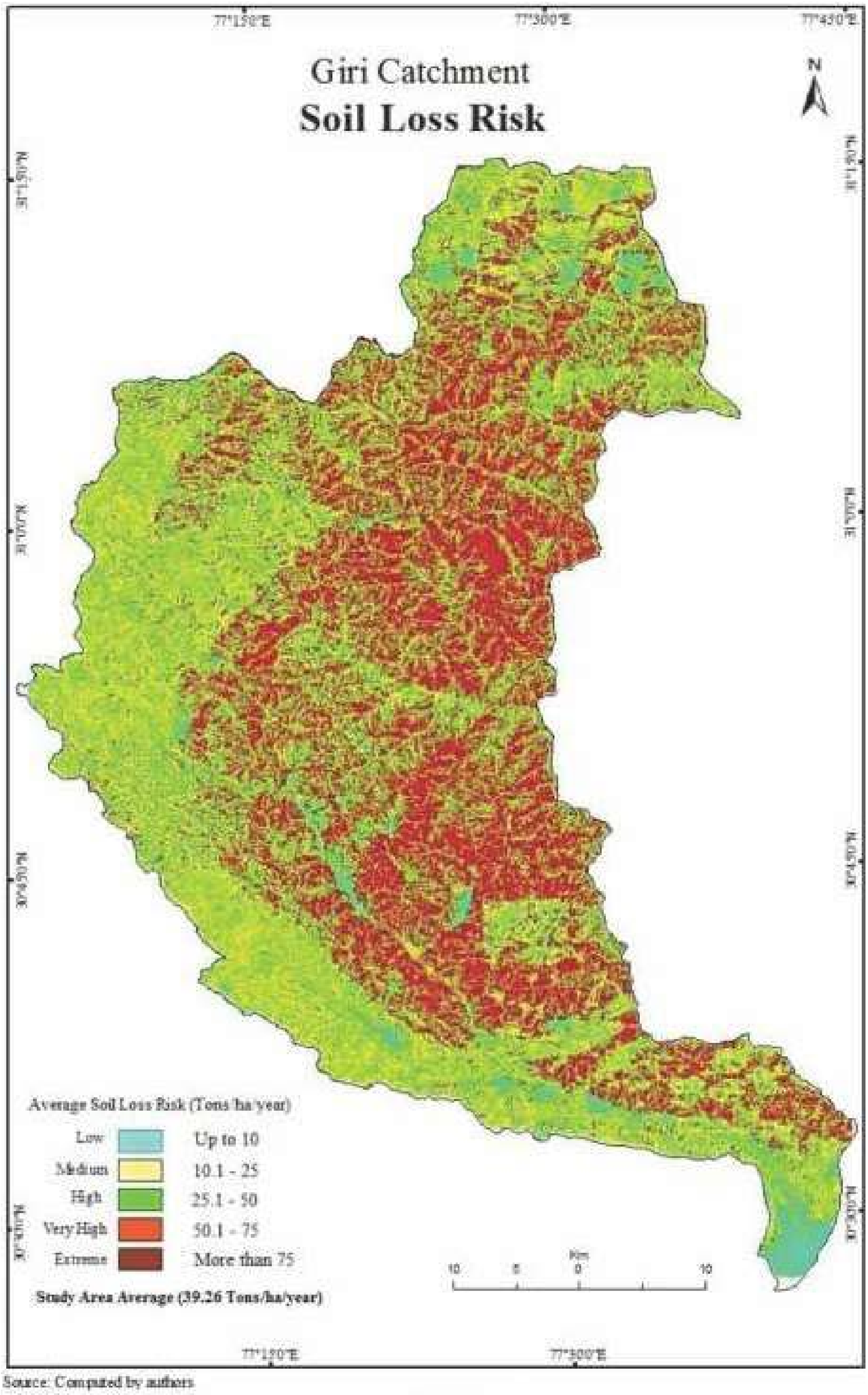
Based on the vulnerability and susceptibility of soil resource loss, the prioritization of micro-watersheds for conservation and planning has been undertaken and portrayed in Table 2 and Fig. 9. The micro-watersheds on the basis of soil loss risk (Table 2) have been classified into five priority categories as per the area under beyond permissible soil loss limit (more than 10 tons/ha/year). As the area beyond permissible soil loss limit increases in any micro-watershed, the urgency and priority for its conservation also increases.

Ten micro-watersheds namely MW-1, 5, 6, 7, 8, 11, 13, 14, 20 and 25 have been categorized as areas of very high priority for conservation, because these geo-hydrological units have more than 95 per cent area beyond permissible limit of soil loss (Table 2). Within this category there are micro-watersheds like MW-6, 8 and 11 in which about 99 per cent area

Table 1
Giri Catchment: Categories of Annual Soil Loss Risk

Soil Loss Categories	Soil Loss (tons/ha/year)	Area (km²)	Area (per cent)
Low	Less than 10	398.97	(15.07)
Medium	10-25	898.29	(33.93)
High	25.1-50	582.18	(21.99)
Very High	50.1-75	202.53	(7.65)
Extremely High	More than 75	565.50	(21.36)
Total	**-**	**2647.49**	**(100.00)**

Source: Computed by Authors



Source: Computed by authors

Fig. 8

Table 2
Giri Catchment: Micro Watershed-wise, Area under Soil Loss Risk Classes

Micro Watersheds	Area under Permissible Limit (<10 ton/ha/year)		Area under Beyond Permissible Limit (>10 tons/ha/year)		Total Area	Priority Level
	(km^2)	(per cent)	(km^2)	(per cent)	(km^2)	
MW-6	0.43	1.06	40.30	98.94	40.73	Very High
MW-11	1.05	1.15	89.98	98.85	91.03	Very High
MW-8	0.90	1.48	59.92	98.52	60.82	Very High
MW-7	1.39	2.36	57.43	97.64	58.82	Very High
MW-13	1.17	2.45	46.56	97.55	47.73	Very High
MW-20	3.36	2.80	116.51	97.20	119.87	Very High
MW-1	2.20	3.07	69.50	96.93	71.70	Very High
MW-25	3.60	3.53	98.35	96.47	101.95	Very High
MW-5	4.63	3.64	122.49	96.36	127.12	Very High
MW-14	2.48	3.95	60.25	96.05	62.73	Very High
MW-19	4.34	6.37	63.84	93.63	68.18	High
MW-27	6.56	6.83	89.48	93.17	96.04	High
MW-26	10.38	7.58	126.52	92.42	136.90	High
MW-12	9.43	9.78	87.04	90.22	96.47	High
MW-2	14.92	11.26	117.55	88.74	132.47	Moderate
MW-10	13.28	14.04	81.32	85.96	94.60	Moderate
MW-21	16.33	14.18	98.82	85.82	115.15	Moderate
MW-17	23.43	18.04	106.46	81.96	129.89	Low
MW-22	18.85	18.97	80.51	81.03	99.36	Low
MW-4	24.84	20.95	93.75	79.05	118.59	Very Low
MW-3	22.89	23.80	73.29	76.20	96.18	Very Low
MW-23	36.85	24.11	115.99	75.89	152.84	Very Low
MW-15	43.89	31.72	94.47	68.28	138.36	Very Low
MW-16	22.72	31.74	48.86	68.26	71.58	Very Low
MW-18	42.85	32.51	88.96	67.49	131.81	Very Low
MW-24	44.00	35.86	78.70	64.14	122.70	Very Low
MW-9	22.89	36.05	40.60	63.95	63.49	Very Low
Giri Catchment	**398.97**	**15.07**	**2248.53**	**84.93**	**2647.50**	**Low**

Source: Computed by Authors

is beyond permissible soil loss limit class followed by MW-7 and 13 in which about 98 per cent area is beyond permissible soil loss limit . MW-1, 5, 14 and 25 have about 96 per cent area beyond permissible limit of soil loss and thus fall under very high priority level (Table 2). These 10 micro-watersheds account for 29.56 per cent of the total area of Giri catchment (Table 3) that require conservation of soils at very high priority.

Four micro-watersheds (MW-12, 19, 26 and 27) have been identified as areas of high priority level as 90 to 93 per cent of their area is beyond permissible soil erosion limit (Table 2; Fig. 9). Among these MW-19 and 27 have about 93 per cent area, followed by MW-26 with about 92 per cent area and MW-12 with about 90 per cent area under beyond the permissible limit of soil loss (Table 2). These four micro-watersheds account about 15 per cent area of catchment (Table 3). These are located in middle-southern parts of the study area adjoining to the areas of very high priority micro-watersheds except MW-19 which is located in the north.

Moderate level of priority has been recorded by MW-2, 10 and 21 by having 85 to 90 per cent area beyond permissible soil loss limit (Table 2). About 13 per cent of the total area of Giri catchment falls under moderate level of priority (Table 3).

MW-17 and 22 fall in low priority areas, because these have about 80 to 85 per cent area under beyond permissible soil loss limit (Table 2; Fig.9). About 82 per cent area of MW-17 and 81 per cent area of MW-22 are beyond permissible soil loss limit (Table 2). These 2 micro-watersheds account for 8.66 per cent area of whole catchment (Table 3). Study reveals that there are 8 micro-watersheds namely MW-3, 4, 9, 15, 16, 18, 23 and 24 which by virtue of less than 80 per cent of their area falling under beyond permissible limit of soil loss are categorized as areas of very low priority level (Table 2). These micro-watersheds share 33.83 per cent area of whole catchment (Table 3). On the whole the study highlights that 52 per cent of the micro-watersheds comprising 45 per cent of the study area fall under critical soil loss category where more than 90 per cent of the area is beyond the permissible soil loss limit; hence requires high priority for soil conservation. However, Giri catchment as a whole falls under low level of priority for soil conservation (Table 2).

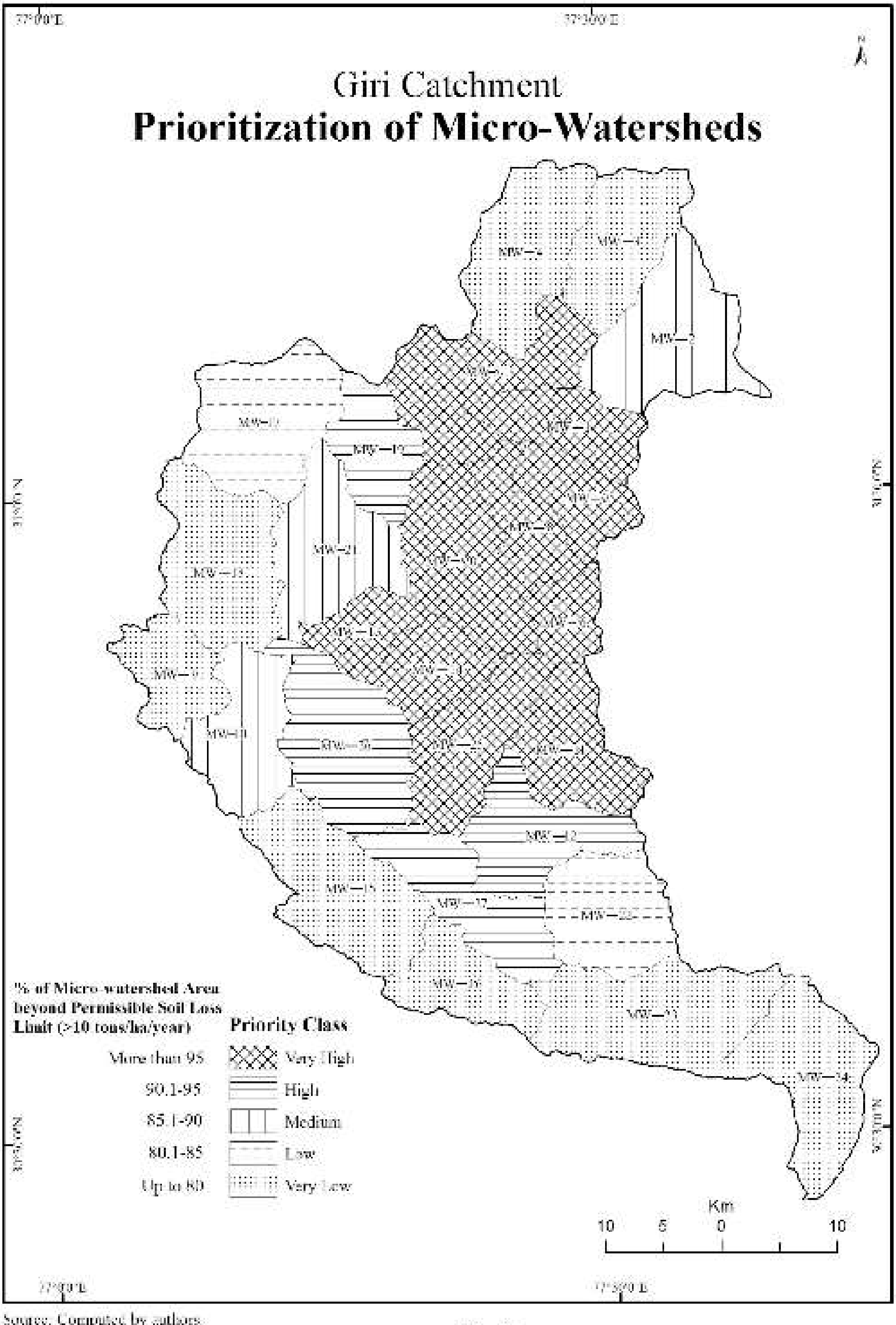
Key Findings

The average annual soil loss risk of about 39 tons/ha/year has been observed in the Giri catchment. The study about spatial distribution of soil loss risk affirms that about 15 per cent area of the catchment falls under less than 10 tons/ha/year category of soil loss risk which is considered permissible soil loss limit. Thus, about 85 per cent area of the catchment is under more than 10 tons/ha/year category of soil loss risk that requires prioritization for soil conservation, Among the

Table 3
Giri Catchment: Priority Classes for Micro-watershed Management

Priority Class	Percentage of Micro-watershed Area beyond Permissible Soil Loss Limit (>10 tons/ha/year)	Number of Micro-watersheds	Total Area (km²)	Percentage of Total Area
Very High	More than 95	10	782.50	29.56
High	90.1-95	04	397.59	15.02
Moderate	85.1-90	03	342.22	12.93
Low	80.1-85	02	229.25	8.66
Very Low	Up to 80	08	895.55	33.83

Source: Computed by Authors



Source: Computed by authors

Fig. 9

total 27 micro-watersheds, 10 micro-watersheds have recorded more than 95 per cent of their area beyond permissible soil loss limit. These micro-watersheds accounting 29.56 per cent area of the catchment have been accredited as areas of very high priority. Four micro-watersheds which accounted about 15 per cent area of the catchment accredited in high priority class because 90 to 95 per cent of their area is beyond permissible soil loss limit. Three micro-watersheds accounting 13 per cent area of the catchment fall in moderate priority class. These micro-watersheds have 85 to 90 per cent of their area beyond the permissible soil loss limit. About 8.6 per cent area of the catchment which is shared by two micro-watersheds having 80 to 85 per cent area beyond permissible soil loss limit has been accredited as low priority area. The remaining 8 micro-watersheds which account about 34 per cent area of the catchment have been categorized as areas of very low priority.

The study reveals that about 50 per cent of the micro-watersheds fall in the categories of high to very high soil loss risk and therefore, need immediate land management planning and soil conservation measures under natural and agricultural conditions. It is matter of concern to the agricultural communities, policy makers, scientists, watershed managers and stakeholders to arrest the soil loss risk for sustainable management and development of the catchment.

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