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Soil erosion risk mapping for natural resource conservation planning in Karnataka region, Southern India

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ABSTRACT

District-wise soil erosion risk (SER) maps were prepared for the state of Karnataka with the objectives of prioritizing the districts of the state in order of the simplified weighted erosion risk index values, and to provide an estimate of the areas needing immediate attention in terms of conservation measures with the existing technology of natural resource management. The SER values for each district were computed by extracting the information on grid-wise soil erosion and soil loss tolerance limit values existing on the country-scale in a GIS environment. The results revealed that around 77% of the state can be considered as safe, and does not call for immediate soil conservation measures. The remaining area (4.18 M ha) requires conservation planning through prioritization. Six districts, *viz*., Koppal, Bagalkote, Belgaum, Gubarga, Bellary and Dharwad, with one-third of their areas showing net positive values require soil loss mitigation measures through phased planning. In order to obtain a clearer picture and categorize the districts based on their extent of vulnerability, the weighted erosion risk values were computed. Belgaum, Uttara Kannada and Bijapur were identified as the worst-affected districts in terms of soil erosion and therefore need immediate attention for natural resource conservation.

1. INTRODUCTION

Productive soils have always been the mainstay of prosperous civilizations, and great civilizations have fallen in the past because they failed to prevent the degradation of soils on which they survived (Diamond, 2005). The inherent productivity of many lands has been dramatically reduced as a result of soil erosion, accumulation of salinity and nutrient depletion (Scholes and Scholes, 2013). Global assessments of present-day land degradation indicate that the percentage of total land area that is highly degraded has increased from 15% in 1991 to 25% by 2011 (FAO, 2011; UNCCD Secretariat, 2013). Another 36% of the global land area is slightly or moderately degraded but exists in a stable condition, while only 10% is improving (FAO, 2011). In India, about 120.72 M ha area is affected by various forms of land degradation, of which 82.57 M ha is accounted for solely by water-induced soil erosion over 10 Mg $ha^{-1}yr^{-1}$ (NAAS-ICAR, 2010).

Among, the different Indian states, nearly 49% (9.40 M ha) of the total geographical area (TGA) of Karnataka is affected by water erosion (>10 Mg $ha^{-1}yr^{-1}$), placing it fifth among the Indian states in this regard (NAAS-ICAR, 2010). Further, the district-wise soil loss ranges from <5 to >40 Mg ha yr^{-1} (Ramamurthy *et al*., 2014). The above statistics only provide information on the amount of soil lost under the present set of conditions without taking into account the inherent resilient capacity of the soil to resist erosive forces. This capacity has been quantified through the adjusted soil loss tolerance limits (SLTL), or adjusted *T*-values (Mandal *et al.,* 2006), which is a dynamic, discrete and site-specific value estimated with the help of easily recorded minimum datasets. This approach led to the mapping of adjusted *T*-values for different agro-ecological regions and physio-graphic zones of India (Lakaria *et al*., 2008; Jha *et al.,* 2009; Lakaria *et al*., 2010).

The erosion and SLTL maps of any region or state can be combined together using a GIS platform to generate the SER map by following a simple protocol (Mandal and Sharda, 2013; Biswas *et al*., 2015). Such a map is expected to be the most simplified one for the purpose of conservation planning. Some studies have been carried out on the systematic and scale-specific assessment of SERs (Deumlich *et al*., 2006; Volk *et al*., 2010) to serve as tools for decision making by policy makers. Most development plans in India are usually made for and implemented at district level as the functional unit. This paper attempts to provide such information in the form of district-wise SLTL and SER maps prepared in a GIS environment for the state of Karnataka. The objectives of the current study were to: (i) prioritize the districts of the state in order of simplified weighted SER index values, and (ii) provide an estimate of the areas needing immediate attention in terms of conservation measures with the existing technology of natural resource management.

2. MATERIALS AND METHODS

Study Area

The exercise was conducted on Karnataka (Fig. 1), the seventh largest state of India, comprising thirty administrative districts, and with a TGA of 19.18 M ha. With a population of 61.1 M, Karnataka accounts for about 5% of Country's population (GoI, 2011). Karnataka extends to about 750 km from north to south and about 400 km from east to west. The state has been divided into three major physiographic divisions, namely, the Deccan Plateau, Hill ranges and Coastal plains (NATMO, 1980). These divisions have been sub-divided into four regions based on their geographic location, *viz*., South Deccan Plateau, Western Ghats, Eastern Ghats and West Coast Plains. The climate of Karnataka varies widely from arid to semi-arid in the plateau region, sub-humid to humid tropical in the ghat region and humid tropical monsoon type in the west coast plains. The mean annual rainfall ranges from 350-1000 mm in the plateau region, from 2700-5000 mm in western ghats and from 3000-3600 mm in west coast plains. is a semi-arid area and has a predominantly hot and dry climate. The state has been divided into seven agro-ecological sub regions (Sehgal *et al*., 1992) and 10 agro-climatic zones by the state under National Agriculture Research Project.

According to Radhakrishnan and Vaidyanadhan (1994), the geological formations in Karnataka are placed under four main types, namely, (a) the Archean complex made up of Dharwar schists and granitic gneisses, which is the oldest formation and covers about 60% of the area, (b) the Proterozoic non-fossiliferous sedimentary formations of the Kaladgi and Bhima series, (c) the Deccan trappean and intertrappean deposits, representing one of the largest accumulations of basaltic continental lava covering an area of 0.5 M km^2, and (d) the tertiary and recent laterites and

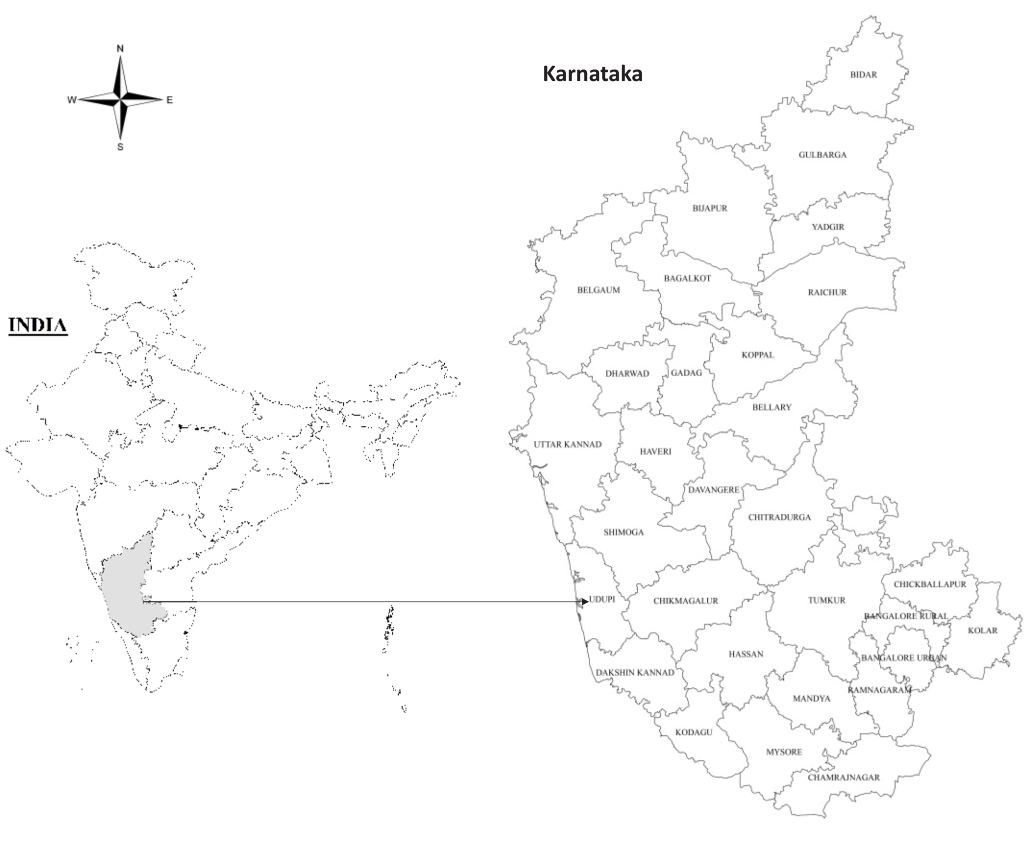

Fig. 1. Outline of the study area

alluvial deposits. The major soil orders in (a) the South Deccan Plateau are Alfisols, Inceptisols, Entisols, Aridisols and Vertisols, (b) the Western Ghats are Alfisols, Ultisols and Mollisols, (c) the West Coast are Ultisols and Entisols (Shiva Prasad *et al*., 1998). The state is dominated by red soils (all depths, all textures), with an aerial extent of 35% of the TGA followed by black soils (all depths, all textures), covering 27% of the TGA and alluvial soils (16% of the TGA). Karnataka has a forest cover of about 30.7 lakh has which is about 16% of the TGA. The net sown area of the state during 2014-15 is 53% of the TGA, with a cropping intensity of 122% (Government of Karnataka, 2016).

Soil Loss Tolerance Limits (SLTL) Map

The methodology followed for the development of SLTL values has been described earlier (Lakaria *et al.,* 2008; Biswas *et al*., 2015). In short, the soil mapping units selected for the development of the soil map of Karnataka, were used for preparation of the map. A two-way matrix presenting soil depths against soil state/groups was used as a guide in assigning the *T*-values for each soil mapping unit. The soil state/group for each mapping unit was obtained by employing a weighted additive model, wherein five indicators selected from the sensitivity analysis of the Water Erosion Productivity Project (Nearing *et al.,* 1990) were assigned scores and weighted as per their relative importance. The indicators are soil organic carbon and fertility parameters, basic infiltration rate and bulk density (by pedo transfer function using SSWATER), and soil erodibility factor, K (Kirkby and Morgan 1980). The 'T' values were computed for each 10x10 km grid point earmarked by NBSS&LUP for the preparation of maps related to soil resources and potential soil erosion rates (PSER) (Ramamurthy *et al*., 2014) published for the state of Karnataka. The values of *T* and PSER pertaining to the grid points located in the thirty districts of Karnataka were extracted from those earlier maps and new SLTL and PSER maps were carved out for the state on an Arc-GIS (version 9.3) platform.

Soil Erosion Risk (SER) Map

The spatial layers of SLTL and PSER maps were integrated using the Arc-GIS (version 9.3) software at 10x10 km grid levels to generate the SER statistics and map of Karnataka. The intersection of SLTL and PSER provides information on the actual risk associated with soil erosion. More specifically, the SER was computed for each point as follows:

SER = Median value of the PSER – *T*-value ...(1)

The potential rates of erosion (Ramamurthy *et al*., 2014) were classified into various ranges, *viz.*, < 5, 5-10, 10-15, 15-20, 20-40 and >40 Mg $ha^{-1}yr^{-1}$ representing slight, moderate, strong, severe, very severe and extremely severe erosion. For our purpose, we first reduced the classes to four as: (a) <5 Mg $ha^{-1}yr^{-1}$ with a mid-value of 2.5 Mg $ha^{-1}yr^{-1}$, (b) 5-10 Mg $ha^{-1}yr^{-1}$ with a mid-value of 7.5 Mg $ha^{-1}yr^{-1}$, (c) 10-20 Mg $ha^{-1}yr^{-1}$ with a mid-value of 15.0 Mg $ha^{-1}yr^{-1}$,and (e) 20-40 Mg $ha^{-1}yr^{-1}$ with a mid-value of 30 Mg $ha^{-1}yr^{-1}$. The class >40 Mg $ha^{-1}yr^{-1}$ was merged with 20-40 Mg $ha^{-1}yr^{-1}$ class with a mid-value of 30 Mg $ha^{-1}yr^{-1}$ because the area under the former class was the lowest (12%) in the state. As the PSER were defined as class ranges with no exact value, the mid-value of each class was considered for the ease of subtraction between PSER and *T*-values corresponding to each point in the map. The SER values thus obtained for an individual grid point was placed under one of the five categories created for conservation planning and prioritization purpose: <0,0-5, 5-10, 10-20 and 20-30 Mg $ha^{-1}yr^{-1}$. The SER map was generated for the state as a final product for conservation planners and other development agencies.

Weighted Soil Erosion Risk (WSER)

Since the extent and severity of erosion risk in each district has large variations, it is difficult to identify the most affected district in the state. To overcome this problem and prioritize the districts, a simplified WSER index for each district was computed, which simultaneously combines information on two parameters: (a) percent geographical area of a district affected by soil erosion risk; (b) and their severity of soil erosion risk.

Since severity of erosion risk is expressed in a class with a pre-defined range, the median of each class-range was chosen: (a) to represent the class, and(b) as a weight to signify the severity of erosion risk in affected area. Therefore, weighted erosion risk is expected to assign high priority to districts with greater proportion (of the state) of total affected area under high erosion risk class.

$$WSER_j = \sum_{i=1}^{n} A_{ji} * W_i \quad ...(2)$$

j = the number of district in the state *i.e.* 30 and i = (1, 2, .., n) is the number of erosion risk classes *i.e.* 3.

Where, $WSER_j$ = weighted soil erosion risk for i^{th} district, A_{ji} = area under i^{th} class in j^{th} district, W_i = weight assigned for i^{th} class.

Further, for the ease of interpretation and classification, values of WSER were converted into WSER index using the given formulae:

$$WSERI_j = \frac{WER_j - WER_{Min}}{WER_{Max} - WER_{Min}} \quad ...(3)$$

Where, $WSERI_j$ = weighted soil erosion risk for j^{th} district, WER_{Min} = minimum value of WER among all the districts, WER_{Max} = Maximum value of WER among all the districts.

All the districts were ranked based on the WSER index values, with an indication that the higher ranked districts need to be assigned priority while developing natural resource conservation strategies. Biswas *et al.* (2015) prioritized districts requiring conservation measures through WSER index with the assumption that the geographical areas of all districts are almost same. While this is true for the state of Telangana where the variations in geographical areas of districts are not very high, in case of Karnataka, there is a large variation in the extent of geographical areas. Belgaum is the largest district in the state (13278 km^2), which is almost six times larger than the Bangalore urban (2163 km^2). This implies there would be a problem of scale effect, which might not be able to depict the true picture as far as prioritization is concerned. Therefore, to overcome the problem of scale effect, the WSER index has been modified by taking the share of each district in each class of erosion in the total areas under each erosion class in the state, by combining information on two parameters as shown below: (a) percent share in each class under the total area under that particular class in the state; (b) and their severity of soil erosion risk.

$$WSER_j = \sum_{i=1}^{n} S_{ij} * W_i \qquad ...(4)$$

j = the number of district in the state *i.e.* 30 and i = (1,2,.., n) is the number of erosion risk classes *i.e.* 3.

Where, $WSER_j$ = weighted soil erosion risk for i^{th} district, S_{ij} = share (%) of j^{th} district under i^{th} class in state, W_i = weight assigned for i^{th} class.

Since severity of erosion risk is expressed as a class with a pre-defined range, the median of each class-range was chosen: (a) to represent the class, and (b) as a weight to signify the severity of erosion risk in affected area. Therefore, weighted erosion risk is expected to assign high priority to districts with greater proportion of the state of total affected area under high erosion risk class. Therefore, the district having higher the value of WSER are the prioritized areas calling for urgent resource conservation measures.

3. RESULTS AND DISCUSSION

Three different maps (erosion, tolerance and risk) generated by the procedures described in the previous sections along with area-distribution statistics were initially scrutinized for their trends. Based on the area distribution, the classes were narrowed down to three for allowing better comparison. Thus, the classes under potential erosion and risk were - < 5, 5-10 and >10 Mg $ha^{-1}y^{-1}$, while those for tolerance limits were <5, 7.5 and >10 Mg $ha^{-1}y^{-1}$. Results of thirty districts will be presented in this section.

Potential Rates of Soil Erosion

The district-wise areas subjected to different classes of annual potential soil loss have been shown in Table 1. A major part of the TGA of the state (52%) is prone to erosion rates exceeding 10 Mg ha^{-1}. More than 70% of the areas of five districts, *viz*., Bagalkot, Chamrajanagar, Dharwad, Koppal and Uttara Kannada have shown to exhibit a soil loss >10 Mg $ha^{-1}y^{-1}$, which is alarming, and may be immediately targeted for soil and water conservation measures. The second soil loss category of 5-10 Mg $ha^{-1}y^{-1}$, spread over an area of over 70,000 km^2 needs to be focused in terms of planning conservation strategies to prevent further escalation of erosion rates and increase chances of recovery. Among the districts, about 32 and 24% of Belgaum and Hassan, respectively lose soil in excess of 20 Mg $ha^{-1}y^{-1}$. Extremely severe erosion rates (>20 Mg $ha^{-1}y^{-1}$) occur in about 1.8 M ha of the state, with about 49% credited to the four districts of Belgaum, Hassan, Uttara Kannada and Chikmagalur.

Soil Loss Tolerance Limits (T)

The SLTL map of Karnataka has been shown in Fig. 2. Soils prone to high rates of erosion may not require immediate conservation measures if they have high *T*-values. On the other hand, soils with slight or moderate rates of erosion but with low *T*-values call for urgent conservation strategies (Lakaria *et al.,* 2008; Bhattacharyya *et al.,* 2008). This essentially means that although more than 52% of the TGA of Karnataka is prone to erosion rates in excess of 10 Mg $ha^{-1}y^{-1}$, 34 and 20% of the area of the state can tolerate soil loss up to 10 and 12 Mg $ha^{-1}y^{-1}$, respectively. On the other hand, 10% of the state can tolerate a soil loss of only 2.5 Mg $ha^{-1}y^{-1}$. Majority of such soils (58%) exist in the three districts of Belgaum, Gulbarga and Bagalkote. More than 85% of the geographical area of twenty districts of the state can tolerate soil loss up to the level of 5 Mg $ha^{-1}y^{-1}$, whereas the soils of Koppal (56% of the district), Bagalkote (48%), Belgaum (39%) and Gulbarga (34%) are the most fragile in the state in terms of their *T*-values.

Soil Erosion Risk (SER)

The preceding sections have indicated two conditions (erosion and tolerance) for prioritizing areas for soil conservation. The process of district level planning becomes easier when both the above conditions are combined into a single parameter, the SER (Biswas *et al*., 2015). An area with a positive value of SER demands measures for soil conservation. The SER map generated for Karnataka, by deducting the *T*-values from soil erosion rates has been shown in Fig. 3. Perusal of statistics (Table 2) reveals that around 77% of the state can be considered as safe, and does not call for immediate soil conservation measures. The remaining area (4.18 M ha) requires conservation planning albeit through prioritization. If we consider net positive SER values *i.e.* the cases where soil loss exceeds the *T*-values, we observe that more than one-third of Gubarga (35% of district), Bellary (37%), Dharwad (37%) and Belgaum (40%) require soil loss mitigation measures through phased planning. The worst affected districts in this

Table: 1
Extent of damage caused by soil erosion rates in different districts of Karnataka

District	Geographical area (km^2)	Area (km^2) affected by erosion ($Mg\ ha^{-1}y^{-1}$)			% of district affected by erosion ($Mg\ ha^{-1}y^{-1}$)		
		<5	5-10	>10	<5	5-10	>10
Bagalkot	6608.09	78.01	1014.24	5515.84	1.2	15.3	83.5
Bangalore rural	2297.44	660.78	1278.93	357.73	28.76	55.67	15.6
Bangalore urban	2163.33	791.43	999.74	372.16	36.58	46.21	17.2
Belgaum	13277.82	1429.54	2612.98	9235.30	10.77	19.68	69.6
Bellary	8311.13	2363.32	2091.50	3856.31	28.44	25.17	46.4
Bidar	5387.76	291.59	2052.52	3043.65	5.41	38.10	56.5
Bijapur	10472.40	141.42	4655.09	5675.89	1.35	44.45	54.2
Chamrajanagar	5622.50	473.01	1013.61	4135.88	8.41	18.03	73.6
Chikballapur	4210.93	1088.99	1812.09	1309.85	25.86	43.03	31.1
Chikmagalur	7241.32	608.32	2871.82	3761.18	8.40	39.66	51.9
Chitradurga	8359.58	970.24	3410.04	3979.30	11.61	40.79	47.6
Dakshina Kannada	4494.63	0.32	3029.74	1464.57	0.01	67.41	32.6
Davangere	5930.43	232.97	2118.70	3578.76	3.93	35.73	60.3
Dharwad	4281.44	20.85	833.52	3427.07	0.49	19.47	80.0
Gadag	4666.50	70.14	1952.84	2643.52	1.50	41.85	56.6
Gulbarga	10932.92	479.97	6475.76	3977.19	4.39	59.23	36.4
Hassan	6807.27	562.58	2152.03	4092.66	8.26	31.61	60.1
Haveri	4850.68	98.06	1804.00	2948.62	2.02	37.19	60.8
Kodagu	4094.08	558.69	1341.02	2194.37	13.65	32.76	53.6
Kolar	3902.78	76.16	2584.98	1241.64	1.95	66.23	31.8
Koppal	5415.43	386.55	899.30	4129.58	7.14	16.61	76.3
Mandya	4924.67	1289.17	2078.55	1556.95	26.18	42.21	31.6
Mysore	6184.05	1906.96	1940.80	2336.29	30.84	31.38	37.8
Raichur	8449.05	743.61	3663.75	4041.69	8.80	43.36	47.8
Ramanagara	3505.57	324.95	1106.52	2074.10	9.27	31.56	59.2
Shimoga	8021.33	493.30	3512.51	4015.52	6.15	43.79	50.1
Tumkur	10516.66	2198.88	3934.60	4383.18	20.91	37.41	41.7
Udupi	3879.91	984.45	1996.70	898.76	25.37	51.46	23.2
Uttara Kannada	10068.65	395.94	2551.82	7120.89	3.93	25.34	70.7
Yadgir	5278.23	23.33	3200.47	2054.43	0.44	60.64	38.9
State	190156.6	19743.53	70990.17	99422.88	10.4	37.3	52.3

regard are Koppal and Bagalkote with 52 and 56% of their areas, respectively exhibiting net positive SER values.

Narrowing down further, we have found that 10% of the TGA of the state (1.8 M ha) out of the 4.18 M ha with net positive SER values, calls for immediate attention of the state-level planners, as SER in these areas are greater than 5 Mg $ha^{-1}y^{-1}$ *i.e.* the soil loss in these areas is 5 Mg $ha^{-1}y^{-1}$ over and above the tolerance thresholds. Of the 1.8 M ha with SER values >5 Mg $ha^{-1}y^{-1}$, 40% occurs in the four districts of Gadag, Belgaum, Chamrajanagar and Raichur. Further, the districts of Chamrajanagar, Gadag, Koppal and Bagalkote (in that order) are the most risk prone with more than one-fifth of their TGAs showing SER values exceeding 5 Mg $ha^{-1}y^{-1}$.

Weighted Soil Erosion Risk (WSER)

Weighted erosion risk (WER) index for each district was computed. The index placed Belgaum district on topmost priority (Table 2) as it is the most severely affected district of the state, while the districts of Uttara Kannada and Bijapur were placed at the second and third positions, respectively. It can be inferred that seven (Belgaum, Uttara Kannada, Bijapur, Gulbarga, Bellary, Raichur and Bagalkote) of the top ten districts prone to the risk of soil erosion are located in the northern and central parts of the Karnataka, and therefore are the critical districts as far as prioritization of resource conservation measures need to be taken up. These districts are also highly drought prone as evident from the fact in droughts occurred in about 9-11 years during the period of 2001-2014 (KSNDMC, 2017). Earlier, the districts of the northern and central parts of the Karnataka were classified as highly to extremely vulnerable to climate variability (Kumar *et al.,* 2016), and under very low to low categories of sustainability livelihood security (Kumar *et al.,* 2014). From above discussion, it clear that these districts belonging to northern and central parts of the Karnataka require the urgent attention of the policy planners to devise comprehensive and holistic planning to sustain the

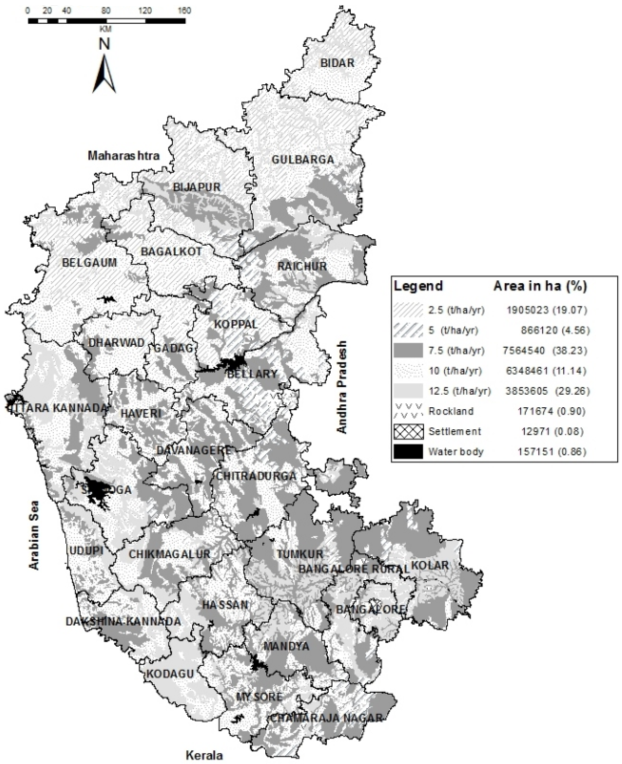

Fig. 2. Soil loss tolerance map of Karnataka

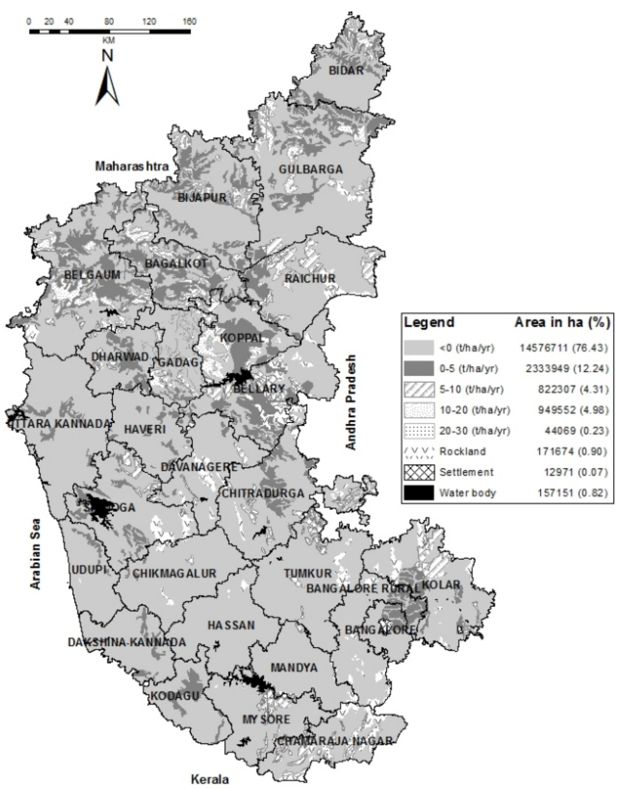

Fig. 3. Soil erosion risk map of Karnataka

natural resources and enhance the resilience of crop production system. Bangalore urban, Ramnagara, Kolar and Udupi were found to be the safest districts of Karnataka with respect to WSER values.

Table: 2
District-wise area under different soil erosion risk ranges (Mg ha^{-1} y^{-1}) and ranks for prioritization

District	S_jW_i value for different class			WSER value	Rank
	<5	5-10	>10		
Bagalkot	0.99	10.72	83.22	94.92	10
Bangalore rural	8.37	13.51	5.40	27.28	29
Bangalore urban	10.02	10.56	5.61	26.20	30
Belgaum	18.10	27.61	139.33	185.04	1
Bellary	29.93	22.10	58.18	110.20	6
Bidar	3.69	21.68	45.92	71.30	17
Bijapur	1.79	49.18	85.63	136.60	3
Chamrajanagar	5.99	10.71	62.40	79.10	15
Chikballapur	13.79	19.14	19.76	52.70	25
Chikmagalur	7.70	30.34	56.75	94.79	11
Chitradurga	12.29	36.03	60.04	108.35	8
Dakshina Kannada	0.00	32.01	22.10	54.11	24
Davangere	2.95	22.38	53.99	79.33	14
Dharwad	0.26	8.81	51.70	60.77	22
Gadag	0.89	20.63	39.88	61.40	21
Gulbarga	6.08	68.42	60.00	134.50	5
Hassan	7.12	22.74	61.75	91.61	12
Haveri	1.24	19.06	44.49	64.79	19
Kodagu	7.07	14.17	33.11	54.35	23
Kolar	0.96	27.31	18.73	47.01	28
Koppal	4.89	9.50	62.30	76.70	16
Mandya	16.32	21.96	23.49	61.77	20
Mysore	24.15	20.50	35.25	79.90	13
Raichur	9.42	38.71	60.98	109.10	7
Ramanagara	4.11	11.69	31.29	47.10	27
Shimoga	6.25	37.11	60.58	103.94	9
Tumkur	27.84	41.57	66.13	135.54	4
Udupi	12.47	21.09	13.56	47.12	26
Uttara Kannada	5.01	26.96	107.43	139.41	2
Yadgir	0.30	33.81	31.00	65.10	18
Weights	2.5	7.5	15	-	-

4. CONCLUSIONS

The study reveals that although 9.4 M ha of Karnataka suffers from a soil loss in excess of 10 Mg ha^{-1}yr^{-1}, about 4.18 M ha of Karnataka needs immediate protection measures, as indicated by positive values of SER. We classified the districts of the state according to the simplified WSER values with the objective of sensitizing the policy makers to prioritize the most prone districts and develop immediate resource conservation strategies for those districts. In this regard, the districts of Northern and Central Karnataka, representing fragile eco-systems need urgent attention as compared to Southern Karnataka highly prone to soil erosion as compared to Southern Karnataka. Further, among the Northern districts, Belgaum, Uttara Kannada and Bijapur have been identified as the worst-affected. Therefore, WSER is a more useful indicator for policy makers and planners as compared to the soil loss or soil loss tolerance limit values considered alone, in order to prioritize regional soil and water conservation activities.

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