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Watershed prioritization based on soil loss and conservation measures in eastern part of Doon Valley using remotely sensed data and geographical information system

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Abstract

A study was undertaken to determine the priority of sub-watersheds of Song river watershed, eastern Doon Valley, based on estimates of erosional soil loss using Universal Soil Loss Equation (USLE) and to suggest suitable soil conservation measures. Land-use/landcover, physiography-cum-soil maps prepared from IRS-IC-LISS-III data, terrain slope information obtained from topographic maps and rainfall-climatic data were used to provide inputs to USLE model. Average soil loss for each sub-watershed was computed and priority categories were determined. The priority classification indicated that out of 25 sub-watersheds 2, 6, 9, 5 and 3 sub-watersheds covering 9.0, 20.8, 39.0, 15.1 and 16.0 per cent area showed average annual soil loss of 54.8 to 56.4, 26.2 to 45.9, 18.7 to 22.3, 5.1 to 9.8 and 3.0 to 4.3 tons/ha respectively. These sub-watersheds fell in very high, high, medium, low and very low priority categories, respectively. Suitable soil conservation measures based on spatial erosional soil loss and as per priority categories have been suggested.

Additional keywords : Erosion, watershed prioritization, remote sensing

Introduction

Satellite remote sensing offers scientific input for the formulation of proper watershed management programmes and also addresses some of the parameters related to watershed development. One such parameter is an inventory of quantitative erosional soil loss and the priority classification of watersheds/sub-watersheds. Several parametric models have been developed to predict soil erosion and with a few exceptions, these models are based on soil, land-use/land cover, landform, climatic and topographic information (Bali and Karale 1977; Wischmeier and Smith 1978; Bali 1983; AISLUS and SAC 1987; Gawande 1990). Soil erosion is most frequently assessed using the USLE of Wischmeier and Smith (1978). Some of the inputs of this model namely, cover factor (C) *i.e.* land-use/land cover, soil erodibility (K) and to a lesser extent supporting conservation practice factor (P) can also be successfully derived from remotely sensed data (Saha *et al.* 1992).

The inventory on quantitative spatial erosional soil loss and the priority classification of sub-watersheds helps in taking up soil conservation measures on priority basis. Watershed characterization, prioritization and creation of database manually through conventional methods is time consuming, tedious and there are difficulties in handling large area and data. Voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of GIS techniques. Remote sensing and GIS techniques are useful in prioritization of watersheds very accurately and efficiently. This watershed is subjected to different degrees of erosion impairing the soil health. It is, therefore, indispensable to prioritize the sub-watersheds of the Song watershed and devise suitable conservation measures to have sustained agricultural production.

Materials and methods

Study Area

The study area is a part of Song river watershed, eastern Doon Valley and lies between 30°5' to 30°15' N latitudes and 78°5' to 78°25' E longitudes. The river is a sixth order stream forming a tributary to the Ganges. The watershed covers an area of approximately 1034.35 sq. km. Based on visual interpretation of IRS-IC-LISS-III FCC, drainage pattern, topographical map and Watershed Atlas of India, the Song watershed was delineated into 25 sub-watersheds (Fig. 1) according to main tributaries of Song river *i.e.* Suswa (A), Song (B) and Jakhan Rao (C). The code of the watershed is 2B5C7, where 2=water resource region, Ganges; B=basin; 5=catchment; C=sub-catchment and 7=watershed, Song Bindal. This code should be considered as a prefix to all sub-watershed codes.

Climate and geology

The area has sub-tropical climate with mean annual rainfall of approximately 2000 mm and mean annual temperature of 24°C. The soil moisture and temperature regimes are characterised by '*udic*' and '*hyperthermic*', respectively. The elevation ranges from 353 to 1875 m above MSL. The geology of the area comprises of phyllites, shales (quartzitic) and alluvium and the drainage pattern is of dendritic type. Physiographically the area is composed of five major landforms *viz.* mountains (steep to very steep slopes), hills (steep to moderately steep slopes), piedmont plain, river terraces and flood plains. Vegetation of the area comprises mainly of *chir, sal, khaur, sisham* and shrubs and grasses.

Data used

IRS-IC-LISS-III (October, 1996) geo-coded false colour composite (FCC) products (1:50,000 scale) were visually interpreted for physiographic delineation in conjunction with the Survey of India (SOI) topographic maps (53 J/3, 4, 7, 8; 53 F/ 15, 16). The rainfall data of the study area for the last five years (1991-95) was used for computing rainfall erosivity factor of the USLE. The landforms were further sub-divided on the basis of image characteristics like tone, texture and pattern and association alongwith topographic variations into 26 units (Table 1).

Table 1. Various soilscape units of Song watershed

Sr. No.	Mapping Units	Soil Association	Area ha	%
High Mountains (>1500 m)				
1.	Northern aspect with dense forest (M111)	Typic Hapludolls/* Mollic Hapludalfs +	6108.4	5.9
2.	Northern aspect with open forest (M112)	Typic Udorthents/ + Lithic Dystrochrepts*	1771.6	1.7
3.	Northern aspect with cultivated land (M113)	Dystric Eutrochrepts/ + Mollic Hapludalfs +	136.3	0.1
4.	Southern aspect with dense forest (M121)	Typic Hapludolls/** Typic Udorthents +	9777.7	9.4
5.	Southern aspect with open forest (M122)	Lithic Udorthents/** Typic Udorthents +	5565.4	5.4
6.	Southern aspect with cultivated land (M123)	Dystric Eutrochrepts/ + Typic Udorthents +	699.4	0.7
Low Mountains (<1500 M)				
7.	Northern aspect with dense forest (M211)	Typic Udorthents/ + Dystric Eutrochrepts*	3326.8	3.1
8.	Northern aspect with open forest (M212)	Dystric Eutrochrepts/ + Typic Udorthents +	2113.5	2.0
9.	Northern aspect with cultivated forest (M221)	Dystric Eutrochrepts/ + Typic Udorthents +	1137.4	1.1
10.	Southern aspect with open forests (M222)	Typic Udorthents/ + Lithic Eutrochrepts*	2854.4	2.7
Hills (Northern)				
11.	Steep (H1)	Lithic Udorthents**	236.6	0.2
Hills (Southern)				
12.	Crest (H2)	Lithic Udorthents/**	1792.2	1.7
13.	Side slopes, gently sloping (H21)	Mollic Hapludalfs/* Dystric Eutrochrepts*	10048.6	9.7

14.	Side slopes, moderately sloping (H22)	Typic Argiudolls/* Mollic Hapludalfs*	6659.5	6.4
15	Side slopes, strongly sloping (H22)	Mollic Hapludalfs/* Dystric Eutrochrepts*	1817.3	1.8
Piedmont (Upper Reaches)				
16.	Strongly dissected (P11)	Dystric Eutrochrepts/* Dystric Eutrochrepts +	14236.5	13.8
17.	Slightly dissected (P12)	Typic Hapludalfs/* Typic Udifluvents**	2854.1	2.8
18.	Gently sloping (13)	Dystric Eutrochrepts/* Mollic Hapludalfs*	48.2	trace
Piedmont (Lower Reaches)				
19.	Top (P21)	Dystric Eutrochrepts/* Dystric Eutrochrepts +	1426.0	1.4
20.	Side slopes (P22)	Mollic Hapludalfs/* Dystric Eutrochrepts*	11986.7	11.6
River Terraces (Song Terrace)				
21.	Lower (ST1)	Aquic Eutrochrepts/** Dystric Eutrochrepts +	3025.3	2.9
22.	Middle (ST2)	Mollic Hapludalfs/*	7111.8	6.9
23.	Upper (ST3)	Typic Hapludalfs/* Typic Eutrochrepts +	2401.7	2.3
Ganga Terraces				
24.	Middle (GT1)	Mollic Haplaquents/** Typic Haplaquents*	487.5	0.5
25.	Upper (GT2)	Mollic Hapludalfs/**	121.4	0.1
26.	Flood Plain	-	839.1	0.8
27.	River	-	5258.6	5.1
28.	Settlements	-	1318.3	1.3

*Fine-loamy textural class; **Coarse-loamy textural class; + Loamy sand texture.

Representative soil profiles were studied in different units and soil samples of dominant soils including surface soils (0-25 cm) were collected at observation points. Soil samples were analyzed in the laboratory for various physical and chemical properties to determine the erodibility factor (K) value of the USLE. In order to prepare soil map, sample strips were selected covering all the mapping units and intensive soil studies were carried out in each of these units to establish the soil association at family level (USDA 1975). The legend showing mapping units, the dominant soil types and area covered by them are given in table 1. The hill and mountain soils are skeletal having more than 35 per cent gravels of varying sizes, but piedmont zone has gravelly as well as non-gravelly soils of coarse to fine texture. The soils had fine loamy, coarse loamy textural class or loamy sand texture.

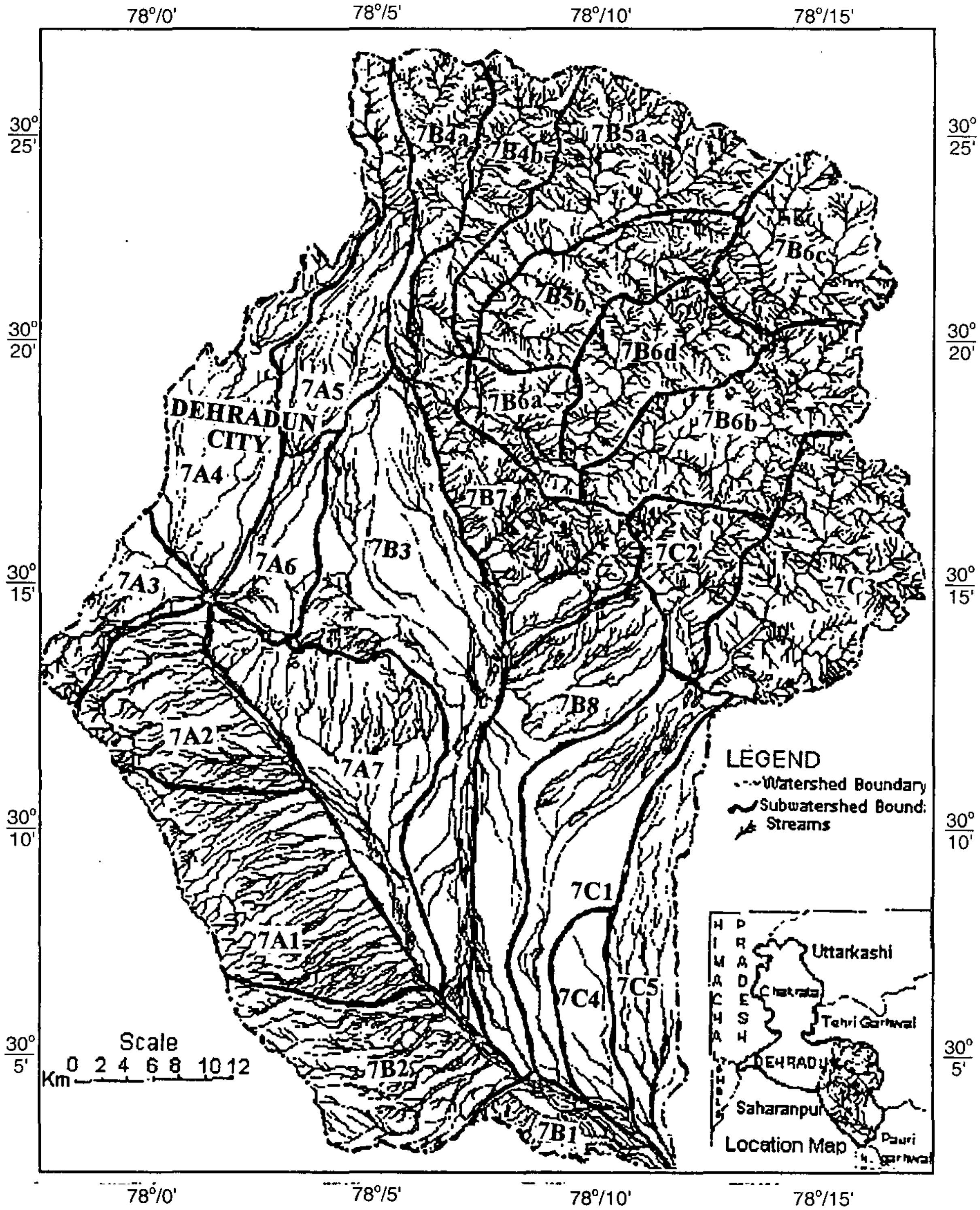

Fig. 1. Sub-watershed delineation of Song watershed.

Computation of soil loss : Methodology adopted for computing soil loss and prioritization of the sub-watersheds consisted of preparation of watershed, sub-watershed and drainage maps and their digitization; preparation of visually interpreted landuse/landcover and physiographic-cum-soil maps and their digitization; preparation of slope map from topographic map using digital elevation model and computation of soil loss and prioritization of sub-watersheds.

Estimation of soil loss : The erosional soil loss analysis was computed using USLE and GIS techniques and the equation is put in the following form

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

where, A = computed soil loss per unit area ; R = rainfall erosivity factor; K = soil erodibility factor; L = slope length factor; S = slope steepness factor; C = crop cover and management factor; P = conservation practice factor.

Based on the equation, soil loss estimated for the watershed was computed and methods used for determining various factors are described below.

Rainfall erosivity factor (R) : Bergsma (1980) suggested the equation to estimate R and the form of equation is as given below.

$$R = 0.1059\ a.b.c. + 52$$

Where, R = Rainfall erosivity factor (cm/hr); a = average annual precipitation (cm); b=maximum 24 hours precipitation with recurrence interval of two years (cm); c=one hour maximum precipitation with recurrence interval of two years (cm)

The annual R-values were determined to be 1066 and 500 for the plains and hilly areas respectively.

Soil erodibility factor (K) : The 'K' factor for each soilscape unit was calculated using field and laboratory estimated soil physical and chemical properties like texture, organic matter content, structure and permeability of the soil. Using data of these characteristics, the 'K' value varied from 0.33 to 0.61.

Slope and slope length factor (LS) : Derivation of 'LS' factor value for each soilscape unit was performed by computing slope length and gradient using the Survey of India topographical maps and following nomogram (Wischmeier and Smith, 1978). LS factor value for the soilscape units ranged from 0.10 to 7.0.

Crop cover and management factor (C) : The factor 'C' for different landcover types was determined using information on landuse/landcover types derived from soil-landuse map and following the tables given by Wischmeier and Smith (1978). The 'C' factor values used for different landuse/landcover types are given below.

dense forest (0.003); moderately dense forest (0.005); degraded forest (0.05); plantation (0.008); intensive cultivation (0.80); low intensive cultivation (0.60); current fallow (0.60); horticultural plantation (0.01); scrubs (0.05); barren lands (0.80).

Practice factor (P) : Practice factor values were chosen based on field survey information and research findings and it varied from 0.50 to 0.80.

The area weighted average annual soil loss under different sub-watersheds was computed from the values of R, K, L, S, C and P using USLE (Table 2). For the categorization of sub-watersheds into different priority classes, the following boundary values were determined.

Priority Category	**Soil Loss (tons/ha)**
I (Very high)	>50
II (High)	25-50
III (Medium)	10-25
IV (Low)	5-10
V (Very low)	<5

Results and discussion

Landuse landcover and soils : The landuse of the area comprised of high intensity cultivation, low intensity cultivation (few crops), current fallow, horticultural plantation, forests (dense, moderately dense and degraded forests of *Pinus roxburghii and Shorea robusta*), scrubs, plantation and barren lands covering 7.8, 5.5, 2.4, 0.03, 19.0, 47.0, 2.9, 1.7, 2.0 and 4.7 per cent area of the watershed, respectively. Settlements and river covered 1.3 and 5.5 per cent area respectively. The dominant soils in the watershed and their extent of distribution are given in table 1.

Watershed prioritization analysis : The USLE was used as criterion for the sub-watersheds prioritization so that the recommended/suggested treatment measures would result in checking the soil loss. Its role also signifies soil conservation measures to be taken up on priority. The data on soil loss in different sub-watersheds and their priority categories are presented in table 2 and discussed below.

Priority I : Out of 25 sub-watersheds, 7B5a and 7b6c, covering 9.0 per cent area, recorded average annual soil loss of 54.8 to 56.4 tons/ha qualified for the very high priority soil conservation treatments. These have poor landcover *i.e.*, dominated by open and degraded forests, scrubs and barren lands. Beside this, large watershed area (70-80%) has steep slope (25-35 and >35%) resulting in high LS factor which is dominant factor causing soil erosion. The vegetation and slope play an important role with reference to the susceptibility of an area to erosion (Morgan 1979). Many workers have also used this model for the prioritization of watersheds and reported similar findings (Chaudhary *et al.* 1992; Saha *et al.* 1992; Rao *et al.* 1994).

Table 2. Estimated average annual erosional soil loss, priority categories and suggested management recommendations

Sub-watershed code	Area (ha)	Area (%)	Soil Loss (tons/ha)	Priority category	Suggested management recommendations*
7A1	6744.1	6.3	3.1	V	C
7A2	3783.7	3.7	3.8	V	C
7A3	1933.7	1.9	9.1	IV	B
7A4	4841.5	4.7	9.9	IV	B
7A5	3871.6	3.7	20.3	III	B
7A6	1918.1	1.8	7.0	IV	B
7A7	5789.4	5.6	20.7	III	B
7B1	2519.9	2.4	6.1	IV	B
7B2	4411.9	4.3	5.1	IV	B
7B3	7959.9	7.7	22.2	III	B
7B4a	2499.2	2.4	26.2	II	A
7B4b	2651.2	2.6	26.9	II	A
7B5a	5015.1	4.8	54.8	I	A
7B5b	3352.5	3.2	35.6	II	B
7B6a	1920.8	1.9	20.8	III	B
7B6b	4239.7	4.1	34.7	II	A
7B6c	4342.0	4.2	56.4	I	A
7B6d	2971.1	2.9	45.4	II	A
7B7	3528.2	3.4	18.7	III	A
7B8	7419.2	7.2	22.3	III	B
7C1	5331.1	5.1	22.0	III	B
7C2	2286.7	2.2	18.7	III	B
7C3	5794.2	5.6	47.1	II	A
7C4	2238.9	2.2	20.3	III	B
7C5	6070.2	5.9	4.3	V	C

Total area (ha) 103435.00

*A=Control of biotic interference, reforestation gap, filling, safe disposal of runoff, gully plugging and afforestation of gullies to check erosion and control of landslides

B=Bunding, terracing, land leveling, farm forestry and orchards and construction of gradient control structures

C=Normal practices to continue

Priority - II : Six sub-watersheds (7B4a, 7B4b, 7B5b, 7B6b, 7B6d and 7B7) covering 20.8 per cent area had average annual soil loss ranging from 26.2 to 47.1 tons/ha. Higher rate of erosion in these sub-watersheds could be attributed to poor landcover and steeper slopes. The dominant land-use is open and degraded forests and barren lands. About 60 to 80 per cent of the area has steep slopes (>35%) resulting in high 'LS' factor values (Saha *et al.* 1992; Rao *et al.* 1994).

Priority - III : Nine sub-watersheds (7A5, 7A7, 7B3, 7B6a, 7B7, 7B8, 7Cl, 7C2 and 7C4) exhibited soil loss from 18.7 to 22.3 tons/ha from an area of 41.4 per cent of watershed. Comparatively lesser soil erosion from these sub-watersheds could be due to less steeper slopes *i.e.*, most of the sub-watersheds are located in the residual hills, piedmont areas and terraces (Ganges and Song terraces) and have better landcover *i.e.*, dense forests and well managed intensive cultivation practices. Vegetative cover improve the physical, chemical and biological properties of soils and also reduces the runoff and soil loss (Zatcher 1982).

Priority IV : Five sub-watersheds *viz.* 7A3, 7A4, 7A6, 7B1, 7B2 and 7B3 covering 15.1 per cent area had annual soil loss of 5.1 to 9.8 tons/ha. The surface cover of forests and other vegetation is very good in these sub-watersheds. Besides this, slope, soil characteristics, surface condition *i.e.*, present landuse, and existing soil conservation practices influence the runoff and sediment yield from the catchment (Pandey *et al.* 1981; Shanware *et al.* 1988).

Priority - V : Three sub-watersheds (7A1, 7A2, and 7A5) covering 16.4 per cent area had soil erosion within the permissible/tolerance limit *i.e.*, 3.1 to 4.3 tons/ha. Very good forest cover has contributed in reducing the soil loss from these sub-watersheds. The farmers of the area adopted well managed cultural practices which might have controlled the soil loss to greater extent. Vegetation protects the soil against impact of falling rain drops, increases the roughness of the soil surface, reduces the speed of surface runoff, binds the soil mechanically and improves the physical, chemical and biological properties of the soil (Zatcher 1982).

Control measures

It is evident from erosional soil loss that there is an urgent need for soil conservation measures to arrest the alarming soil erosion problems in different sub-watersheds. Suggested/recommended soil conservation measures to check the acute problem of soil erosion and to improve the status of existing natural resources of the watershed are given in table 2.

It is evident from the studies that prioritization of sub-watersheds done on the basis of spatial erosional soil loss using USLE is necessary for conservation planning. The sub-watersheds were categorized into five priority categories and soil conservation measures suggested accordingly. The sub-watersheds falling in priority treatments I, II and III covering 69.0 per cent area of the watersheds showed average annual soil loss of 18.7 to 56.4 tons/ha and call for immediate soil conservation planning. The high rate of soil erosion in the sub-watersheds could be attributed to poor landcover *i.e.*, degraded and open forests, barren lands, scrubs, high intensity cultivation and steep slopes.

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