Assessment of soil erosion in the fragile Himalayan ecosystem of Uttarakhand, India using USLE and GIS for sustainable productivity

S. K. Mahapatra[1,*], G. P. Obi Reddy[2], Ritu Nagdev[1], R. P. Yadav[1], S. K. Singh[2] and V. N. Sharda[3]

[1]ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, IARI Campus, New Delhi 110 012, India
[2]ICAR-National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur 440 033, India
[3]ICAR-Agricultural Scientists Recruitment Board, KAB-I, Pusa, New Delhi 110 012, India

In this study, we assess quantitative soil loss in the Himalayan ecosystem of Uttarakhand, India using universal soil loss equation and geographic information system. The analysis shows that about 359,000 (6.71%), 473,000 (8.84%) and 1,750,000 ha (32.72%) area is under moderately severe (15–20 tonne ha^{-1} year^{-1}), severe (20–40 tonne ha^{-1} year^{-1}) and very severe (40–80 tonne ha^{-1} year^{-1}) soil loss respectively. It clearly indicates that about 48.3% area of the state is above the tolerance limit of 11.2 tonne ha^{-1} year^{-1} of soil loss. This explains the need to undertake appropriate soil and water conservation measures to mitigate the topsoil loss in this fragile Himalayan ecosystem. Based on the degree of severity of soil loss, appropriate soil and water conservation measures need to be adopted on priority basis. The agriculture practices should be diversified with farm-forestry, agro-horticulture and/or agro-forestry to minimize soil loss in cultivated areas of the state. Such conservation programmes help mitigate accelerated soil erosion, restore the fragile ecosystems and generate employment opportunities for the needy.

Keywords: Conservation measures, erodibility, fragile ecosystems, geographic information system, universal soil loss equation.

SOIL erosion due to water is the major factor responsible for degradation of land resources. The loss of topsoil resulting in reduced productivity is a serious degradational hazard in the Indian subcontinent. Water erosion in the form of topsoil loss or terrain deformation, or both, is a widespread form of degradation and occurs in almost all agro-climatic zones of India. Mandal and Sharda[1] reported that soil erosion due to water is one of the major factors contributing to land degradation not only in India, but also in many other countries. It was reported that very high rate of soil erosion to the tune of 30–40 tonne ha^{-1} year^{-1} occurs in Asia, Africa and South America[2]. Further, it was reported that the average rate of soil loss is about 138 tonne ha^{-1} year^{-1} in Asia[3]. In the humid tropics of Asia, farmers generally grow subsistence crops in sloping terrain using highly erosive practices. Dhruvanarayana and Ram Babu[4] have reported that about 16.4 tonne ha^{-1} year^{-1} of topsoil is eroded annually in India out of which 29.0% is lost to the seas, 10.0% gets deposited in the reservoirs and the remaining 61.0% gets displaced from one location to another. The detrimental impacts of extensive soil erosion have been recognized as a severe problem for human sustainability as they create far-reaching impact on soil degradation, crop production, hydrological systems, water quality and environment[5]. Mahapatra *et al.*[6] used GLASOD methodology to assess soil degradation status of Jammu and Kashmir covering Trans, Greater and Lesser Himalayan region. However, this approach was lacking in quantitative estimation of soil loss. An understanding of nature, intensity and extent of soil erosion is, therefore, essential to protect the land resources for sustainable crop production. The integrated use of geographic information system (GIS) and universal soil loss equation (USLE) has been proved to be an efficient approach for the severity and spatial distribution of erosion[7–16]. The empirical method of USLE was used extensively to predict the severity and spatial distribution of soil erosion in India[17–23].

Uttarakhand, India is bestowed with highly diversified topography; this includes snow-covered peaks, perennial to seasonal glaciers, deep valleys, perennial streams and lakes. The northern states of India in general and Uttarakhand in particular have severe problems of water erosion because of high rainfall, weak geological formations, active seismicity and uncontrolled deforestation. Deforestation, burning, clearing and dibbling of seeds alone cause about 4.1 tonne ha^{-1} year^{-1} of soil material to roll down towards foothills due to steep to very steep slopes. Experimental results have shown that soil erosion from hill slopes (60%–70%) during the first, second and third year is 146.6, 170.2 and 30.2 tonne ha^{-1} year^{-1} respectively[24]. Based on the assessment of soil loss in

*For correspondence. (e-mail: sankarkmahapatra@yahoo.co.in)

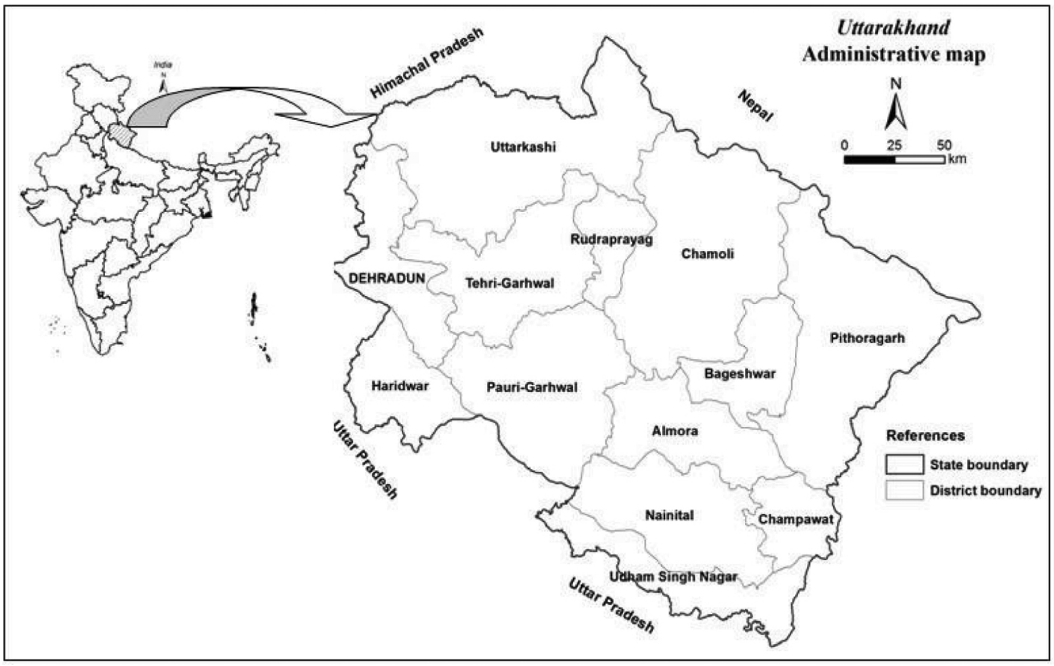

Figure 1. Location map of Uttarakhand, India.

different terrain conditions, various quantitative class limits of soil erosion have been reported by many workers. In the present study we estimate the quantitative soil loss in Uttarakhand by adopting integrated approach of USLE and GIS and suggest appropriate soil conservation measures for sustainable management of land resources in the state.

Materials and method

Study area

Uttarakhand lies between of 28°43′–31°27′N lat. and 77°34′–81°02′E long in the northern part of India with a total geographical area (TGA) of 5,348,000 ha (Figure 1). The state can be divided into two distinct physiographic regions, namely the hill region, that covers a major portion, and a narrow belt of Bhabhar and Tarai regions in the foothills of the Himalaya. The elevation of the hilly terrain in the state ranges from 200 m to a series of snow-covered peaks of more than 6000 m amsl. Broadly, there are six sub-divisions in the state, namely Greater Himalaya, Lesser Himalaya, Shiwalik hills, piedmont plains, Tarai plains and alluvial plains. Uttarkhand can be divided into several physiographic zones which run parallel to each other from the northwest to southeast direction. Although geological investigations have been made in many parts of the Himalayan mountain, its large tracts are still unexplored. As evident from the various studies, the state can be divided into three broad stratigraphical zones, namely (i) Outer or Sub-Himalayan zone with the sediments of Tertiary age, (ii) Central or Lower Himalayan zone, mainly composed of granite and crystalline rocks of unfossiliferous sediments, and (iii) Higher Himalayan zone with a series of highly fossiliferous sediments. The foothill belt of the region is entirely made up of Siwalik sediments. The Siwaliks constitutes thickness of detrital rocks, clays and conglomerates.

The climate of Uttarakhand can be characterized as temperate with distinct seasonal variations in temperature and affected by tropical monsoons. January is the coldest month with daily temperatures below freezing in the northern part of the state, whereas, July is the hottest month in the north with the daily temperatures rising from 7°C to about 21°C. However, May is the warmest month in the southeast with daily temperatures normally reaching about 38°C from a low of around 27°C. The state experiences a monsoonal climate with mean annual rainfall of 1606 mm. The southwest monsoon brings majority of the state's annual precipitation during July to September. Based on the variation in climate, landform and soil, the state has been divided into six distinct agro-ecological sub-regions[25]. The drainage system of the state can be divided into three main river systems, namely the Ganga, Yamuna and Kali. Major part of the region is drained by the Ganga river system.

About 60% area of the state is covered by forest, whereas net sown area is only 0.14% and net irrigated area is 0.06%. Due to stony nature of land, crop cultivation is mainly undertaken in the river valleys and terraced slopes only. Piedmont plain covers nearly one-third of total arable land in the state. The foothills region is covered by Bhabhar and further down is the Tarai zone, which mainly covers the districts of Udham Singh Nagar, Haridwar and parts of Nainital, where intensive agriculture is practised. Uttarakhand has been characterized by various types of soil and all are susceptible to erosion. In the northern region of the state, soil ranges from gravel to stiff clay, whereas in the southern part, soils are shallow, gravelly and rich in organic matter. In the Bhabhar region, soils are coarse-textured, sandy to gravelly, highly porous and largely infertile. However, Tarai soils in the extreme southeastern part of the state are mostly clay loam, mixed with fine sand and humus. Moderately acidic soils in the state cover about 1,183,000.6 ha (22.2% of TGA), whereas slightly acidic soils cover an area of 2,300,000.6 ha accounting for about 43.1% of TGA[26]. The soils and climatic condition of the state are suitable to grow different types of agricultural crops. Rice, wheat, barley, maize and millets (kodo millet, finger millet, proso millet, barnyard millet) are the important food-grain crops grown in the state. Green gram, black gram, French bean, horse gram, lentil and peas are the major pulse crops.

Methodology

In the planning and implementation of soil and water conservation measures, it is desirable to have a quantitative estimate of soil erosion that would occur under a particular situation of crop, treatment and landscape. Soil loss prediction methods have been developed from impetus of plot experiments conducted in the United States. Systematic study on soil loss prediction from agricultural field was started in the US during the first half of the last century. Zingg[27] reported the relationship between soil loss and slope length. Musgrave[28] reported the first approximation of quantitative evaluation of water erosion factors. It is similar to the present-day USLE. Subsequently, with more comprehensive soil and land-use database, USLE was developed and later refined by Wischmeier and Smith[29,30].

Factors like rainfall erosivity, soil erodibility, topography, vegetative cover, and management and conservation practices affect soil erosion. Erosion due to water takes place in the form of sheet, rill and gullies. Sheet erosion predominantly takes place on sloping lands due to overland flow activity. Where overland flow concentrates, rills form (incipient gully) of erosion takes place. The excess concentrates of flow lead to gully erosion. On decreasing slopes of overland flow, eroded materials get deposited. Total erosion in the form of sheet, rill and gullies is considered as gross erosion. Sheet and rill erosion from a unit area of a field at a specified slope is defined as soil loss. The sediment flowing out of the area outlet is called sediment yield. It is deposition subtracted from gross erosion. The process of soil transport and deposition is complex. Several models based on a large number of parameters and input variables have been used to estimate soil loss and sediment yield.

Universal soil loss equation

The empirical model of USLE is used for the prediction of long-term average annual soil loss from a specified field area in specified cover and management conditions. The equation predicts the severity of soil loss due to sheet and rill erosion for a given site as a product of six factors. The USLE of soil loss is described as:

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

where A is the soil loss per unit area expressed (tonne ha^{-1} year^{-1}), R the rainfall erosivity factor (the number of rainfall erosion index units for a particular location), K the soil erodibility factor (soil loss rate per erosion index unit measured on a unit plot of 22.13 m (72.6 ft) length supposed to have uniform 9% slope continuously in clear-tilled fallow), L the slope length factor (ratio of soil loss from the field slope length to that from a 22.13 m (72.6 ft) length under identical conditions), S the slope steepness factor (ratio of soil loss from the field slope gradient to that of a 9% slope under otherwise identical conditions), C the cover and management factor (ratio of soil loss from an area with specified cover and management to form an identical area in tilled continuous fallow), and P the conservation practice factor (ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope).

Using the average conditions, the parameters of USLE were estimated at a particular grid area (10,000 ha). Limitations arising due to averaging of the parameters are in-built in the empirical formula itself. The USLE model was extensively used to assess soil erosion in varied terrain conditions of different states like Gujarat[19], Maharashtra[18], Orissa[23], Tripura[17] and in West Bengal[20].

Rainfall erosivity factor

Rainfall erosivity (R) is defined as an aggregate measure of the amount and intensity of individual rainstorms over a year and is related to total rainfall[31–33]. In the present study, the annual total value of erosion index (EI) has been fixed as EL_{30} for a particular location. Computation of EL_{30} from recording-type rainguage chart has earlier been computed by Singh *et al.*[34]. For the present study EI has been computed as follows

$$\mathrm{EI} - 79 + 0.363X,$$

where X is the rainfall (mm).

The iso-erodent map of India has been generated by Ram Babu *et al.*[35] and Ragunath *et al.*[36] by inclusion of additional rainfall data of new stations. Similarly, the R factor values at various grid points have been developed for Uttarakhand.

Erodibility factor

Soil erodibility factor (K) is defined as the rate of soil loss per erosion index unit from unit plot size[30]. It explains the rate at which different soils erode and it is different from soil erosion. The other factors like rainfall, crops grown and land use options also influence the rate of soil erosion on a given terrain. Soil parameters which influence soil erodibility include soil texture, stability of soil structure, soil permeability and infiltration, organic matter and soil mineralogy[34]. Since direct measurement of K from experimental run-off plot is expensive and time-consuming, a simple nomograph was developed by Wischmeier *et al*.[37]. The K factor for each grid point in Uttarakhand has been estimated using the following empirical equation

$$100\,K = 2.1\,M^{1.14}\,(10^{-4})\,(12 - a) + 3.25(b - 2) + 2.5(c - b),$$

where M is the per cent silt × (100 – per cent clay), a the per cent organic matter, b the soil structure code used in soil classification, which varies from 1 to 2 in all the soils of Uttarakhand, and c is the profile permeability code, which varies from 1 to 5 in all the soils of Uttarakhand.

Topographic factor

This includes the length (L) and degree (gradient) of slope (S), which affect the rate of soil erosion by water over a landscape. Slope length (L) may be defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases such that deposition begins or the run-off water enters well-defined channels. In general, the rate of erosion increases with increasing length and gradient of slope. The greater accumulation of run-off on longer slopes of terrain increases its detachment and transport capacities[34]. L can be defined as the ratio of field soil loss to the corresponding loss from 22.13 m slope length; its value can be expressed as

$$L = (\lambda/22.13)^m,$$

where λ is the field slope length (m) and m is a factor ranging from 0.2 to 0.9.

The slope steepness factor S can be expressed as the ratio of soil loss from the field slope gradient to that from the 9% slope under otherwise identical conditions. Through several modifications the S factor of USLE has assumed the following form[34]

$$S = 65.41 \sin^2 A + 4.56 \sin A + 0.065 \ldots$$

where A is the angle of the slope.

Combining the above two equations we get

$$LS = (\lambda/22.13)^m\,(65.41 \sin^2 A + 4.56 \sin A + 0.065).$$

The above equation has been used in the estimation of LS factor for all the grid points in Uttarakhand.

Cover and management factor

Cover and management factor is expressed as the ratio of soil loss from land cropped under specified conditions to soil loss from clean tilled fallow on identical soil and slope under the same rainfall. It reflects the combined effect of cover, crop sequence, productivity level, length of growing period, tillage practices, residue management and the expected time distribution of erosive rainstorm with respect to seeding and harvesting date in the locality. Several workers conducted experiments on soils with various types of covers to estimate C factor[34]. In order to compute the C factor for Uttarakhand, each grid point was selected on the basis of the main crop grown in that grid point (Table 1).

Conservation practice factor

P-factor can be expressed as the ratio of soil loss with a specific supporting practice to the corresponding loss with up and down cultivation. In order to restrict the influence of erosion because of intensive rain, the crop management practices are to be supported by different conservation practices through land management and shaping. The main conservation practices followed at each 10 × 10 km grid were compiled to compute the P-factor values in the state (field bunding, contour bunding, and contour cultivation)[38]. P-factor for contour cultivation[39] was used and values were assigned at grid-point level depending upon the main conservation practices, viz. contour bunding (0.20), field bunding (0.30) and cultivated fallow (1.00).

Database

The following information was utilized for assessing soil erosion using USLE at each grid point: Grid number, location (village), area (10 km interval), rainfall (annual, mm), silt + very fine sand (%), sand (%), organic matter (%), soil structure, permeability (cm/h), slope (%), slope length (m), and land use (a) forest, (b) agriculture, (c) fallow and (d) others.

Table 1. Cover and management (C-factor) values used in assessing soil erosion in Uttarakhand, Indis

Cover and management	C-factor value
Forest and grasslands	0.01
Degraded forest/wasteland	0.14
Croplands	0.20–0.61
Degraded (waste) lands	0.50
Fallow lands	1.00

Soil erosion map

The grid information (10 × 10 km) at 305 locations in Uttarakhand generated during soil resource mapping of erstwhile Uttar Pradesh by National Bureau of Soil Survey and Land Use Planning was compiled for the computation of USLE factors of *R*, *K*, *LS*, *C* and *P*[25]. The location number (grid number), latitude, longitude, annual rainfall (mm), silt + very fine sand (%), sand (%), organic matter (%), soil structure, permeability (cm/h), slope (%), slope length (m), land-use data, etc. were used for computing rainfall erosivity (*R*-factor), soil erodibility (*K*-factor), length and degree of slope (*LS*-factor), land cover (*C*-factor) and conservation practice (*P*-factor) values on a spread sheet for each grid point. In order to obtain the *R*-factor values at each grid point, iso-erodent map of Uttarakhand was used. The computed values of *R*, *K*, *LS*, *C* and *P* factors were used for generating thematic raster maps for each factor in Arc GIS environment. The average annual soil loss (t/ha) for each grid point was worked out as the product of all the parameters of USLE. The latitudes, longitudes and soil loss values were then used in GIS for generation of erosion map of the state. In addition to the soil erosion map, *R*, *K*, *LS*, *C* and *P* factor maps of Uttarakhand have been generated, categorized under different classes and class-wise area analysis has been carried out.

Results and discussion

Rainfall erosivity factor

Soil detachment by rainfall (raindrop splash) is usually the most noticeable activity during short-duration and high-intensity thunderstorms. Although soil erosion caused by long-lasting and less-intense storms is not as noticeable as that produced during high-intensity thunderstorms, the amount of total soil loss can be significant when it is considered over time. In general, run-off can take place whenever there is excess amount of water on a slope that cannot be absorbed into the soil or trapped on the surface. Low infiltration due to soil compaction, crusting or freezing accelerates the amount of run-off over a terrain. Run-off from agricultural lands is usually higher during spring months when the soils are saturated, snow is melting and vegetative cover is minimal. It is observed that the spatial distribution of rainfall erosivity factor (*R*) of Uttarakhand ranges from <400 to >700, which has been sub-divided into five mapping legends having a range of classes, i.e. <400, 400–500, 500–600, 600–700 and >700 respectively (Table 2 and Figure 2). Table 3 shows the district-wise area under different classes of rainfall erosivity factor. It can be observed that <400 rainfall erosivity values are found in Almora, Pauri Garhwal, Dehradun and Haridwar districts with an area about 47,060 ha (0.88% of TGA). The areas with 400–500 values of *R*-factor are mainly in Dehradun Uttarkashi, Tehri Garhwal, Rudraprayag and Chamoli districts with an area of 1,825,810 ha (34.14%). The southern parts like Almora, Bageshwar, Nainital, Champawat and Udham Singh Nagar have *R*-value range from 500 to 600, with an area of 1,112,380 ha (20.80%). The *R*-values ranging from 600 to 700 and above 700 are mainly found in Haridwar and Pauri Garhwal districts, with an area of 375,430 ha (7.02%) and 424,630 ha (7.94%) respectively.

Table 2. Rainfall erosivity (*R*-factor) classes in Uttarakhand

Class	Range of *R* values	Area	
		'000 ha	Percentage
1	<400	47.06	0.88
2	400–500	1825.81	34.14
3	500–600	1112.38	20.80
4	600–700	375.43	7.02
5	>700	424.63	7.94
6	Area not covered in the soil survey	1562.69	29.22

Soil erodibility factor

Soil erodibility is usually used to estimate the ability of soils to resist erosion, based on the physical characteristics of a given soil. Soils with faster infiltration rates, higher levels of organic matter and improved soil structure generally have greater resistance to erosion. The values of *K*-factor have been categorized into three classes, viz. <0.05, 0.05–0.10 and >0.10. Figure 3 and Table 4 show area and spatial distribution under each class of *K*-factor. Table 5 shows district-wise area under different classes of erodibility factor. *K* is found to vary from <0.05 to >0.10 in Uttarakhand. It is observed that *K* values of <0.05 cover mainly Dehradun, Uttarkashi, Tehri Garhwal, Rudraprayag, Almora and Bageshwar districts with an area of 682,940 ha (12.77%). *K* values ranging from 0.05 to 0.10 are observed in Haridwar, Pauri Garhwal, Chamoli, Nainital, Champawat, Rudraprayag and Udham Singh Nagar with an area of 1,486,740 ha (27.80%). The high *K* values of >0.10 cover mainly Dehradun, Uttarkashi, Tehri Garhwal and Bageshwar districts with an area of 1,615,630 ha (30.21%).

Topographic factor

The topographic factor has been computed through gradient and length of slope at each location of grid observation. In general, steeper the slope of a land greater the amount of soil loss by water. Soil erosion by water accelerates as the slope length increases due to greater accumulation of run-off. Often consolidation of small fields by removing the field bounds into larger ones results in longer slope lengths that increase the erosion potential

Table 3. District-wise erosivity (R-factor) in Uttarakhand

District	Area of different erosivity (R) factors in '000 ha (%) <400	400–500	500–600	600–700	>700	Area not surveyed	Total area
Almora	12.5 (0.23)	44.5 (0.83)	132.0 (2.47)	75.1 (1.40)	36.1 (0.67)	0.0 (0.0)	3.1 (5.61)
Bageshwar	0.0 (0.0)	43.3 (0.81)	97.3 (1.82)	20.7 (0.39)	14.1 (0.26)	55.0 (1.03)	230.4 (4.31)
Chamoli	0.0 (0.0)	357.2 (6.68)	18.0 (0.34)	0.0 (0.0)	0.0 (0.0)	386.9 (7.23)	762.2 (14.25)
Champawat	0.0 (0.0)	5.2 (0.10)	166.8 (3.12)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	172.0 (3.22)
Dehra Dun	20.6 (0.38)	268.7 (5.02)	4.4 (0.08)	2.7 (0.05)	0.7 (0.01)	0.0 (0.0)	297.1 (5.55)
Haridwar	10.7 (0.20)	28.9 (0.54)	13.9 (0.26)	90.7 (1.70)	87.3 (1.63)	0.0 (0.0)	231.5 (4.33)
Nainital	0.0 (0.0)	3.8 (0.07)	298.0 (5.57)	84.1 (1.57)	0.5 (0.01)	0.0 (0.0)	386.4 (7.22)
Pauri Garhwal	3.6 (0.07)	106.7 (2.0)	68.7 (1.28)	98.5 (1.84)	285.8 (5.34)	0.0 (0.0)	563.2 (10.53)
Pithoragarh	0.0 (0.0)	6.5 (0.12)	24.6 (0.46)	0.0 (0.0)	0.0 (0.0)	693.9 (12.97)	725.0 (13.55)
Rudraprayag	0.0 (0.0)	155.1 (2.90)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	27.3 (0.51)	182.3 (3.41)
Tehri Garhwal	0.0 (0.0)	389.6 (7.28)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	389.6 (7.28)
Udham Singh Nagar	0.0 (0.0)	12.5 (0.23)	288.6 (5.40)	3.5 (0.07)	0.5 (0.01)	0.0 (0.0)	305.2 (5.71)
Uttarkashi	0.0 (0.0)	403.5 (7.54)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	399.8 (7.48)	803.3 (15.02)
Total	47.3 (0.88)	1825.5 (34.13)	1112.3 (20.80)	375.4 (7.02)	424.9 (7.94)	1562.8 (29.22)	5348.3 (1.0)

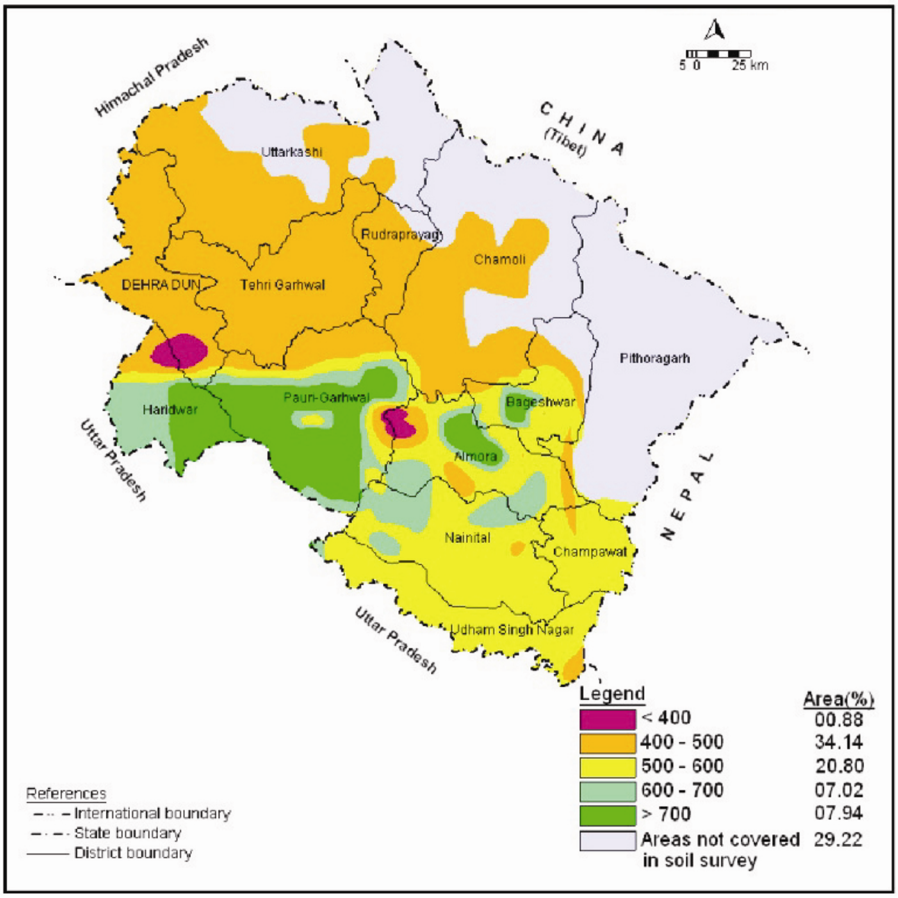

Figure 2. Rainfall erosivity (R-factor) map of Uttarakhand.

due to increased velocity of water. The LS values were used as input file to generate topographic factor map in GIS environment[30]. These have been grouped into six classes (Table 6 and Figure 4). Table 7 shows district-wise area under different classes of LS factor. The LS values range from <0.5 to >15 in the state. Values of <0.5 are observed in Pauri Garhwal and Champawat districts with an area of 988,500 ha (18.48%), whereas values of 0.5–1.5 are observed in Dehradun and Nainital districts with an area of 886,400 ha (16.58%). Uttarkashi, Tehri Garhwal, Haridwar and Almora districts show LS values of 1.5–5 with an area of 866,400 ha (16.20%). The LS values of 5–10 cover Tehri Garhwal, Rudraprayag and isolated places of other districts with an area of

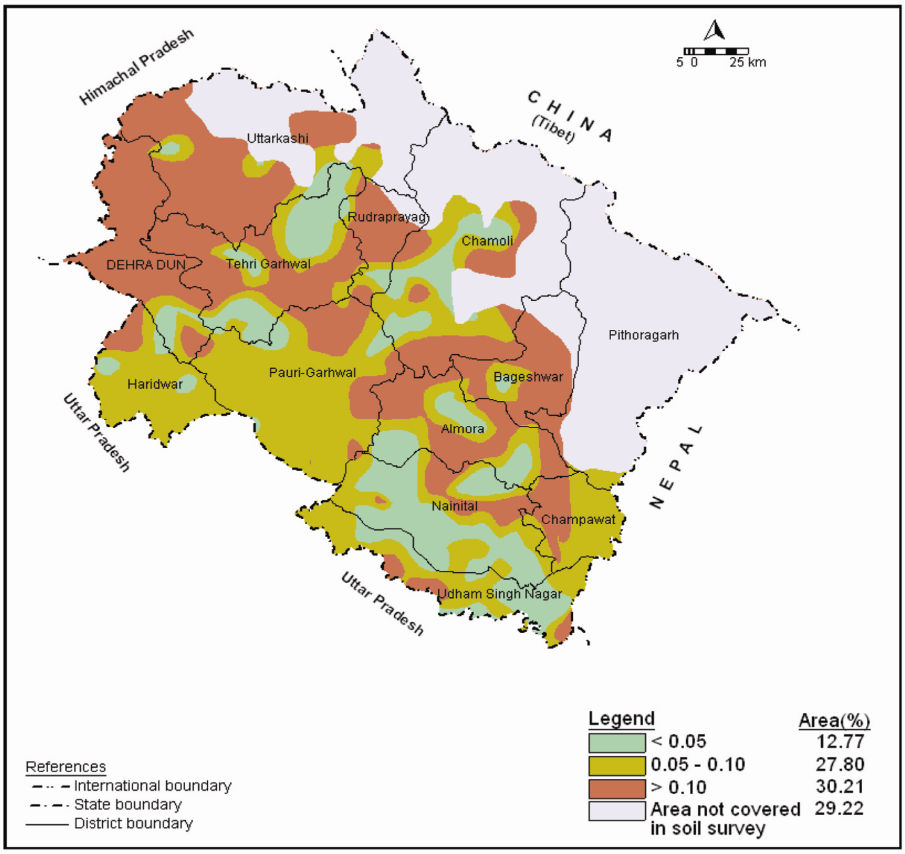

Figure 3. Soil erodibility (*K*-factor) map of Uttarakhand.

Table 4. Erodibility classes (*K*-factor) in Uttarakhand

		Area	
Class	*K*-values	'000 ha	Percentage
I	<0.05	682.94	12.77
II	0.05–0.10	1486.74	27.80
III	>0.10	1615.63	30.21
IV	Area not covered in the soil survey	1562.69	29.22

386,800 ha (7.23%). The *LS*-values of 10–15 and >15 cover mainly Tehri Garhwal, Chamoli and Dehradun districts with an area of 194,800 ha (3.64%) and 462,400 ha (8.65%) respectively.

Cover and management factor

Potential of soil erosion usually increases if the soil has no or very little vegetative cover. Plant and residue cover significantly protect the soil from the impact of raindrops. Further, it helps to slow down the movement of surface run-off and allows excess surface water to infiltrate. The erosion-reducing capacity of plant and/or residue cover depends on the type, extent and quantity of cover. Vegetation and residue combinations completely cover the soil and act as the most efficient system in controlling soil loss. Partially incorporated residues and residual roots also help surface water to move into the soil. The *C*-factor values of Uttarakhand range from 0.01 to 1.0. (Table 8 and Figure 5). Table 9 shows the district-wise distribution of *C*-values. Major areas of the state with *C*-factor value <0.4 include Tehri Garhwal, Rudraprayag, Haridwar, Pauri Garhwal, Bageshwar, Nainital, Champawat and Udham Singh Nagar with an area of 2,644,500 ha (49.44%). The *C*-factor values ranging from 0.4 to 0.6 are found in different parts of the state with an area of 878,140 ha (16.42%). The *C*-factors values 0.6–0.8 and >0.8 are found in Dehradun and Haridwar districts with an area of 68,990 ha (1.29%) and 194,130 ha (3.64%) respectively.

Soil erosion

Soil erosion due to water is a major concern in all the northern hilly states of India in general and Uttarakhand in particular. The peculiar terrain condition and high rainfall in the state pose a serious problem with regard to soil erosion. The often indiscriminate destruction of forests and woodlands leads to terrain deformation and accelerates soil erosion.

Table 5. District-wise soil (*K*-factor) in Uttarakhand

District	Area of different erodibility (*K*) factors in '000 ha (%) <0.05	0.05–0.10	>0.10	Area not surveyed	Total area
Almora	73.2 (1.37)	83.1 (1.55)	143.9 (2.69)	0.0 (0.0)	3.1 (5.61)
Bageshwar	5.7 (0.11)	30.0 (0.56)	139.7 (2.61)	55.0 (1.03)	230.4 (4.31)
Chamoli	87.8 (1.64)	144.5 (2.70)	142.9 (2.67)	386.9 (7.23)	762.2 (14.25)
Champawat	0.0 (0.0)	112.7 (2.11)	59.4 (1.11)	0.0 (0.0)	172.0 (3.22)
Dehra Dun	18.7 (0.35)	29.9 (0.56)	248.5 (4.65)	0.0 (0.0)	297.1 (5.55)
Haridwar	20.5 (0.38)	184.2 (3.44)	26.7 (0.50)	0.0 (0.0)	231.5 (4.33)
Nainital	199.4 (3.73)	130.8 (2.45)	56.1 (1.05)	0.0 (0.0)	386.4 (7.22)
Pauri Garhwal	26.4 (0.49)	419.9 (7.85)	116.8 (2.18)	0.0 (0.0)	563.2 (10.53)
Pithoragarh	0.0 (0.0)	13.6 (0.25)	17.5 (0.33)	693.9 (12.97)	725.0 (13.55)
Rudraprayag	15.1 (0.28)	27.1 (0.51)	112.9 (2.11)	27.3 (0.51)	182.3 (3.41)
Tehri Garhwal	113.5 (2.12)	89.2 (1.67)	186.9 (3.49)	0.0 (0.0)	389.6 (7.28)
Udham Singh Nagar	105.4 (1.97)	165.3 (3.09)	34.5 (0.64)	0.0 (0.0)	305.2 (5.71)
Uttarkashi	17.5 (0.33)	56.2 (1.05)	329.8 (6.17)	399.8 (7.48)	803.3 (15.02)
Total	683.2 (12.77)	1486.6 (27.80)	1615.6 (30.21)	1562.8 (29.22)	5348.3 (1.00)

Table 6. Topographic factor (*LS*) classes in Uttarakhand

Class	*LS*-values	Area '000 ha	Percentage
I	<0.5	988.5	18.48
II	0.5–1.5	886.4	16.58
III	1.5–5	866.4	16.20
IV	5–10	386.8	7.23
V	10–15	194.8	3.64
VI	>15	462.4	8.65
VII	Areas not covered in soil survey	1562.7	29.22

Soil loss through water erosion

In Uttarakhand, quantitative soil loss was estimated using USLE through derived information on factors of erosivity (*R*), soil erodibility (*K*), topography (*LS*), cover and management (*C*) and conservation practice (*P*). The computed soil loss in the state has been categorized into six classes of erosion hazards, namely very slight (<5 tonne ha^{-1} $year^{-1}$), slight (5–10 tonne ha^{-1} $year^{-1}$), moderate (10–15 tonne ha^{-1} $year^{-1}$), moderately severe (15–20 tonne ha^{-1} $year^{-1}$), severe (20–40 tonne ha^{-1} $year^{-1}$), and very severe (40–80 tonne ha^{-1} $year^{-1}$). Figure 6 and Table 10 show the spatial distribution of estimated soil loss in Uttarakhand. Table 11 shows the district-wise distribution of soil loss status of the state. It is observed that about 500,000 ha (9.36%) and 309,000 ha (5.78%) area is affected by very slight and slight soil loss respectively, covering mainly Pauri Garhwal, Nainital and Udham Singh Nagar districts. The moderate and moderately severe classes occur in Pauri Garhwal, Naintal, Champawat and Udham Singh Nagar districts with an area of 394,000 ha (7.37%) and 359,000 ha (6.71%) respectively. The severe and very severe erosion classes are found mainly in the districts of Dehradun, Uttarkashi, Tehri Garhwal, Rudraprayag, Chamoli and Bageshwar with an area of 473,000 ha (8.84%) and 1,750,000 ha (32.72%) respectively.

Soil loss tolerance

This is a limit which denotes the maximum level of soil erosion that will permit crop productivity to be sustained economically and indefinitely. Considerable work has been done on this aspect and tolerance limits ranging from 4.5 to 11.2 tonne ha^{-1} $year^{-1}$ have been reported[40]. Soil loss in excess of 11.2 tonne ha^{-1} $year^{-1}$ affects the effectiveness of water conservation structures. This stage leads to gully formation which in turn obstructs the cultural activities[34]. Analysis shows that moderate, moderately severe, severe and very severe classes cover an area of 394,000 (7.39%), 359,000 (6.71%), 473,000 (8.84%) and 1,750,000 ha (32.72%) of the state TGA and exceed the tolerance limit of 11.2 tonne ha^{-1} $year^{-1}$. It is also evident that surface soil is lost every year from different regions of the state leading to a huge amount of nutrient loss in a year. In terms of fertilizer loss, this accounts for a staggering loss of nutrients in a year. Hence, it is evident from the analysis that there is an urgent need to adopt appropriate soil conservation measures in Uttarakhand.

Soil and water conservation

The Himalayan region in general and Uttarakhand in particular are home to many varieties of flora and fauna, where biodiversity still continues to exist in abundance. However, this land of rich biodiversity has its problems too. Severe soil erosion is one such problem which poses a serious threat to sustainability. Moreover, the region,

Table 7. District-wise topography (*LS*-factor) in Uttarakhand

District	Area of different topography (*LS*) factors in '000 ha (%)							
	<0.5	0.5–1.5	1.5–5	5–10	10–15	>15	Area not surveyed	Total area
Almora	46.0 (0.86)	78.4 (1.47)	148.8 (2.78)	22.4 (0.42)	4.5 (0.08)	0.0 (0.0)	0.0 (0.0)	3.1 (5.61)
Bageshwar	56.9 (1.06)	43.0 (0.80)	56.1 (1.05)	19.4 (0.36)	0.0 (0.0)	0.0 (0.0)	55.0 (1.03)	230.4 (4.31)
Chamoli	82.6 (1.55)	12.7 (0.24)	29.1 (0.54)	32.8 (0.61)	33.7 (0.63)	184.3 (3.45)	386.9 (7.23)	762.2 (14.25)
Champawat	154.6 (2.89)	6.8 (0.13)	10.4 (0.19)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	172.0 (3.22)
Dehra Dun	35.6 (0.67)	167.8 (3.14)	48.9 (0.91)	16.5 (0.31)	10.2 (0.19)	18.1 (0.34)	0.0 (0.0)	297.1 (5.55)
Haridwar	36.3 (0.68)	71.8 (1.34)	81.7 (1.53)	19.0 (0.36)	11.2 (0.21)	11.5 (0.21)	0.0 (0.0)	231.5 (4.33)
Nainital	73.2 (1.37)	131.4 (2.46)	119.6 (2.24)	54.6 (1.02)	7.5 (0.14)	0.0 (0.0)	0.0 (0.0)	386.4 (7.22)
Pauri Garhwal	249.0 (4.65)	119.0 (2.23)	90.4 (1.69)	40.5 (0.76)	23.6 (0.44)	40.7 (0.76)	0.0 (0.0)	563.2 (10.53)
Pithoragarh	16.1 (0.30)	12.7 (0.24)	2.3 (0.04)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	693.9 (12.97)	725.0 (13.55)
Rudraprayag	22.5 (0.42)	18.4 (0.34)	32.6 (0.61)	40.2 (0.75)	21.5 (0.40)	19.9 (0.37)	27.3 (0.51)	182.3 (3.41)
Tehri Garhwal	39.9 (0.75)	43.8 (0.82)	71.7 (1.34)	64.1 (1.20)	42.6 (0.80)	127.5 (2.38)	0.0 (0.0)	389.6 (7.28)
Udham Singh Nagar	75.8 (1.42)	119.0 (2.23)	54.9 (1.03)	34.7 (0.65)	16.4 (0.31)	4.4 (0.08)	0.0 (0.0)	305.2 (5.71)
Uttarkashi	1.0 (1.87)	61.5 (1.15)	119.9 (2.24)	42.5 (0.80)	23.5 (0.44)	56.1 (1.05)	399.8 (7.48)	803.3 (15.02)
Total	988.5 (18.48)	886.4 (16.58)	866.4 (16.20)	386.9 (7.23)	194.8 (3.64)	462.4 (8.65)	1562.8 (29.22)	5348.3 (1.00)

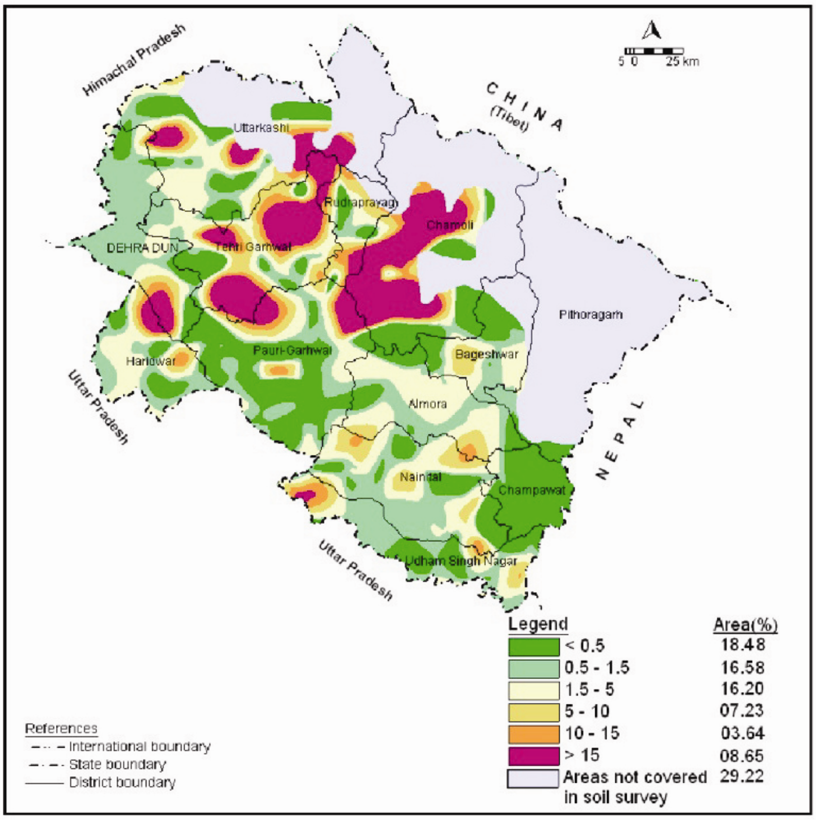

Figure 4. Topography (*LS*-factor) map of Uttarakhand.

being one of the most hazard-prone belts in the Asian continent, is susceptible to earthquakes, landslides and floods. Under these circumstances, adoption of appropriate soil and water conservation measures is necessary to conserve biodiversity and sustainability. Conservation measures can have only a short-term impact, unless they are accompanied by objectives to tackle the underlying causes. Thus, the knowledge of the causes of soil erosion and adoption of appropriate conservation measures is essential for sustainable productivity in the state.

Causes of soil erosion

Soil erosion in Uttarakhand is both due to anthropogenic activities and natural causes, and is continuing over the years with varying intensities. Besides, anthropogenic activities like uncontrolled deforestation and unscientific landuse, including shifting cultivation have accelerated the process of soil erosion. The major causes of erosion in the state could be attributed to weak geological formation, active seismicity and deforestation.

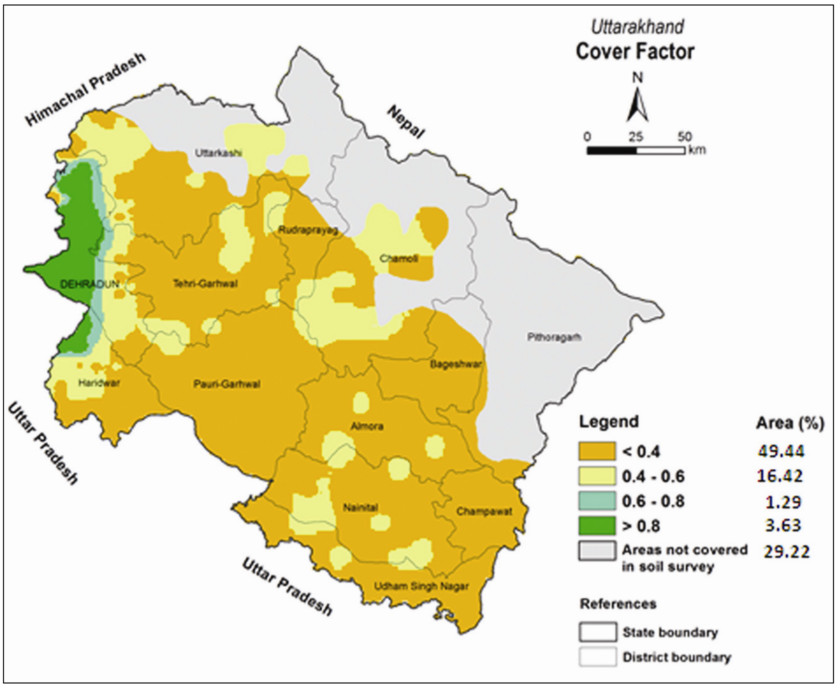

Figure 5. Cover and management (*C*-factor) map of Uttarakhand.

Table 8. Cover factor (*C*-factor) classes in Uttarakhand

Class	*C*-values	Area ‘000 ha	Area Percentage
I	<0.4	2644.05	49.44
II	0.4–0.6	878.14	16.42
III	0.6–0.8	68.99	1.29
IV	>0.8	194.13	3.63
V	Area not covered in the soil survey	1562.69	29.22

Weak geological formation and active seismicity: The geological formation of the entire northern region of India, including Uttarakhand is weak and unstable. Geotectonic movements make the land mass unstable, resulting in landslides and mass movements. The soils of this region are developed on stratified soft sedimentary and tertiary rocks, which are also susceptible to erosion. During monsoon, the incessant rains or cloud bursts make these soils malleable and easily detachable, resulting in solifluction and sheet erosion down the slopes.

Deforestation: During field survey massive deforestation activities were noticed in Uttarakhand. Incidents of widespread deforestation and mining in many parts of the state are common. Very good dense forests are being converted into poor stock, thin degraded fallow lands. Considerable areas under forest have been brought under agriculture in the recent past. Deforestation and forest degradation are the leading causes of water erosion in undulating and steep-sloping hills. The situation has been aggravated further due to high population pressure, demands for fuel and timber, etc.

Suggested conservation measures

There is need to develop site-specific strategies and resource conservation techniques to preserve soils, production potential, sustain productivity, conserve *in situ* rainwater, minimize soil erosion, mitigate droughts, moderate floods downstream, harvest and recycle inevitable run-off and ensure environmental security[41].

Agronomic measures

Agronomic measures on cultivated lands are recommended in mildly sloping areas (1%–6%) with the objective of maximizing conservation of *in situ* rainfall for sustained and higher production. Contour farming, i.e. up and down cultivation is generally practised by farmers for the sake of convenience, which facilitates run-off water to attain higher velocity resulting in more run-off and soil erosion. Farm operations such as ploughing, seeding and interculturing along the contour lines or across the slope help in the formation of natural ridges and furrows, which act as a series of mini barriers and reservoirs to intercept rainwater reducing run-off and soil nutrient loss.

Intercropping allows canopy legumes such as groundnut, green gram, black gram, soybean and cowpea under inter-row spaces of crops like maize, sorghum and castor. It provides adequate cover on the ground and thereby

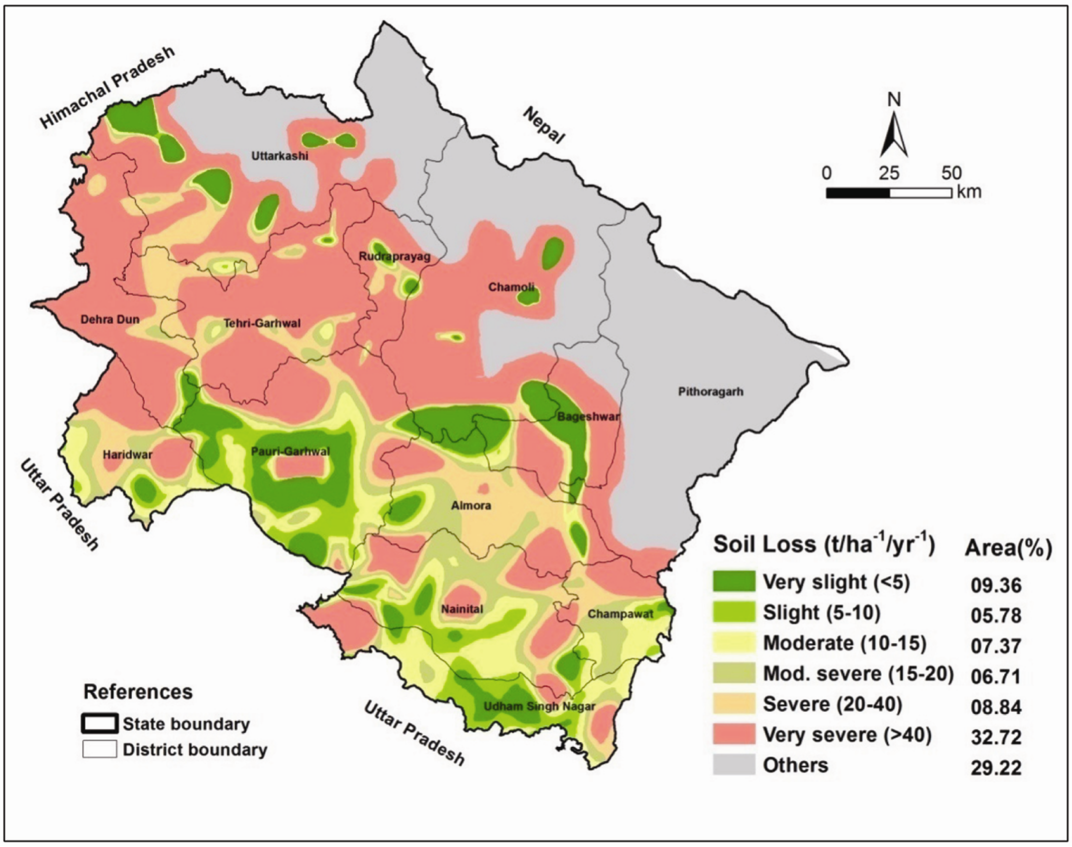

Figure 6. Soil loss map of Uttarakhand.

Table 9. District-wise cover and management (*C*-factor) in Uttarakhand

District	Area of different cover and management (*C*) factors in '000 ha (%)					
	<0.4	0.4–0.6	0.6–0.8	>0.8	Area not surveyed	Total area
Almora	221.9 (4.15)	78.2 (1.46)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.1 (5.61)
Bageshwar	175.2 (3.28)	0.2 (0.0)	0.0 (0.0)	0.0 (0.0)	55.0 (1.03)	230.4 (4.31)
Chamoli	215.2 (4.02)	160.1 (2.99)	0.0 (0.0)	0.0 (0.0)	386.9 (7.23)	762.2 (14.25)
Champawat	172.0 (3.22)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	172.0 (3.22)
Dehra Dun	49.4 (0.92)	48.8 (0.91)	35.1 (0.66)	163.9 (3.06)	0.0 (0.0)	297.1 (5.56)
Haridwar	151.4 (2.83)	40.5 (0.76)	13.0 (0.24)	26.6 (0.50)	0.0 (0.0)	231.5 (4.33)
Nainital	234.8 (4.39)	151.6 (2.83)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	386.4 (7.22)
Pauri Garhwal	528.6 (9.88)	34.7 (0.65)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	563.2 (10.53)
Pithoragarh	31.1 (0.58)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	693.9 (12.97)	725.0 (13.55)
Rudraprayag	124.3 (2.32)	30.7 (0.57)	0.0 (0.0)	0.0 (0.0)	27.3 (0.51)	182.3 (3.41)
Tehri Garhwal	253.5 (4.74)	127.4 (2.38)	6.3 (0.12)	2.4 (0.04)	0.0 (0.0)	389.6 (7.28)
Udham Singh Nagar	257.4 (4.81)	47.8 (0.89)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	305.2 (5.71)
Uttarkashi	229.3 (4.29)	158.1 (2.96)	14.8 (0.28)	1.3 (0.02)	399.8 (7.48)	803.3 (15.02)
Total	2644.0 (49.44)	878.1 (16.42)	69.1 (1.29)	194.2 (3.63)	1562.8 (29.22)	5348.3 (1.00)

reduces erosion risk apart from biological insurance to increase productivity of rainfed arable lands.

Tillage makes the soil surface more permeable to infiltration of rainwater. This practice also reduces run-off, soil and nutrient losses and enhances crop yields. Conservation tillage by covering 30% of the soil surface with crop residues was found to be effective within the framework of conservation of natural resources and sustained production.

Mulching is an important agronomic practice that not only prevents soil erosion by dissipating kinetic energy of raindrops but also facilitates infiltration, reduces evaporation and improves soil structure which eventually enhance crop yield. In low-rainfall areas, mulching helps

Table 10. Soil erosion (soil loss) classes in Uttarakhand

Soil loss class	Rate of soil loss (tonne ha^{-1} $year^{-1}$)	Area ‘000 ha	Area Percentage
Very slight	<5.0	500	9.36
Slight	5.0–10.0	309	5.78
Moderate	10.0–15.0	394	7.37
Moderately severe	15.0–20.0	359	6.71
Severe	20.0–40.0	473	8.84
Very severe	>40.0	1750	32.72
Area not covered in the soil survey	–	1563	29.22

Table 11. District-wise soil loss in Uttarakhand

District	Area under different soil loss classes (tonne ha^{-1} $year^{-1}$) in ‘000 ha (%) <5	5–10	10–15	15–20	20-40	> 40	Area not surveyed	Total area
Almora	32.7 (0.61)	12.1 (0.23)	21.4 (0.40)	51.2 (0.96)	104.5 (1.95)	78.1 (1.46)	0.0 (0.00)	300.1 (5.61)
Bageshwar	48.9 (0.91)	5.3 (0.10)	10.1 (0.19)	9.3 (0.17)	8.0 (0.15)	93.8 (1.75)	55.0 (1.03)	230.4 (4.31)
Chamoli	72.8 (1.36)	3.1 (0.06)	4.9 (0.09)	5.5 (0.10)	6.8 (0.13)	282.2 (5.28)	386.9 (7.23)	762.2 (14.25)
Champawat	8.3 (0.16)	12.5 (0.23)	39.0 (0.73)	38.5 (0.72)	23.3 (0.44)	50.4 (0.94)	0.0 (0.00)	172.0 (3.22)
Dehra Dun	8.8 (0.16)	2.6 (0.05)	3.0 (0.06)	6.0 (0.11)	32.3 (0.60)	244.4 (4.57)	0.0 (0.00)	297.1 (5.56)
Haridwar	9.0 (0.17)	13.7 (0.26)	43.3 (0.81)	51.8 (0.97)	43.9 (0.82)	69.8 (1.30)	0.0 (0.00)	231.5 (4.33)
Nainital	31.5 (0.59)	68.7 (1.28)	81.7 (1.53)	78.5 (1.47)	47.9 (0.90)	78.1 (1.46)	0.0 (0.00)	386.4 (7.22)
Pauri Garhwal	157.5 (2.95)	103.0 (1.93)	87.9 (1.64)	47.2 (0.88)	41.6 (0.78)	125.9 (2.35)	0.0 (0.00)	563.2 (10.53)
Pithoragarh	2.0 (0.04)	0.4 (0.01)	0.5 (0.01)	0.3 (0.01)	0.3 (0.01)	27.6 (0.52)	693.9 (12.97)	725.0 (13.56)
Rudraprayag	8.7 (0.16)	3.4 (0.06)	5.2 (0.10)	7.4 (0.14)	15.6 (0.29)	114.7 (2.14)	27.3 (0.51)	182.3 (3.41)
Tehri Garhwal	2.7 (0.05)	1.2 (0.02)	5.5 (0.10)	20.0 (0.37)	74.1 (1.39)	286.0 (5.35)	0.0 (0.00)	389.6 (7.28)
Udham Singh Nagar	48.8 (0.91)	78.3 (1.46)	81.4 (1.52)	28.7 (0.54)	13.1 (0.25)	54.8 (1.03)	0.0 (0.00)	305.2 (5.71)
Uttarkashi	68.7 (1.29)	4.9 (0.09)	10.2 (0.19)	15.4 (0.29)	60.7 (1.13)	243.6 (4.56)	399.8 (7.48)	803.3 (15.02)
Total	500.8 (9.36)	309.2 (5.78)	394.0 (7.37)	359.8 (6.73)	472.2 (8.83)	1749.4 (32.71)	1562.8 (29.22)	5348.3 (100.00)

in conserving moisture in the soil profile while in high rainfall areas, it reduces run-off and soil loss, resulting in higher crop yields.

Mechanical measures

Contour bunding is one of the proven and widely used mechanical measures in soil conservation. It consists of constructing narrow trapezoidal or parabolic-shaped bunds on a gentle slope (0.5%–6.0%) and is generally recommended for low-rainfall areas (<800 mm) and relatively permeable soils. The bunds may be open-ended to slowly drain-off excess water after it infiltrates into soil or is hooked up at the ends to absorb entire impounded water into soil. The former is recommended in high-rainfall areas, while the latter is more suitable in the low-rainfall regions for intercepting rainwater.

Bench terracing is the most commonly used conservation measure in hill and mountainous areas for reduction of degree and length of slope, to reduce intensity of scouring action of run-off flowing down hillslopes. This practice consists of construction of step-like fields or benches along contours by cut-and-fill method to reduce the length as well as degree of slope for either impounding rainwater for cultivation or channelizing it for safe disposal. Depending upon soil, climate, topography and crop requirements, bench terraces may be of table-top or level-type, outwardly sloping or inward sloping with mild longitudinal grades for run-off disposal. Based upon land slope and width, it is recommended as minimum of 4.5 m for slopes varying from 15%–25%, and 3 m for slopes between 25%–33%.

Grassed waterways are essential on agricultural lands where a suitable natural drainage way is not available to safely drain excess run-off water. A waterway is a natural or artificially constructed channel discharging concentrated run-off from a slope, a terrace system or any other land surface safely at non-erosive velocity. An evaluation of grass species for waterways in alluvial soils of Doon valley showed that *Panicum repens* was the best suitable variety for waterways. Other grass varieties like *Brachiaria mutica*, *Cynodon plectostachyus, Cynodon dactylon* and *Paspalum notatum* were also found suitable in the Doon valley area. The suitability of grass depends on its density of cover, ease of establishment and forage yield obtained from it. Locally suitable grasses such as guinea (*Panicum maximum*), napier and sambuta in sub-humid lower Himalayas, khus (*Vetiveria zizanioides*), bhabhar and munj (*Saccharum spontaneum*) in Shiwalik have been found promising.

Permanent gully-control structures

Three basic types of permanent structures are employed in gully stabilization: (i) drop spillways, (ii) chute spillways and (iii) drop inlet spillways. Chute spillways are used at the gully head to convey water safely to bed. The drop spillways are used along the gully bed as grade-stabilization structures for preventing gully bed and side erosion. The drop inlet structures are used at appropriate locations in the gully for storage of water, in addition to gully stabilization. Chute structures are particularly adopted for gully head control, and they could be used for drops up to 5–6 m. Drop inlet spillway is used in a gully towards downstream part for storage of water. This structure not only helps in protecting the gully, but also in water storage. The stored water could be used for irrigation or other farm activities.

Conclusion

Assessment of quantitative soil loss using USLE and GIS in Uttarakhand clearly indicates that soil erosion is a serious hazard. The present study reveals that moderate and moderately severe erosion occur in Pauri Garhwal, Nainital, Champawat and Udham Singh Nagar districts with an area of 394,000 ha (7.37% of TGA) and 359,000 ha (6.71% of TGA), respectively. However, severe and very severe erosion occurred in Dehradun, Uttarkashi, Tehri Garhwal, Rudraprayag, Chamoli and Bageshwar districts with an area of 473,000 ha (8.84% of TGA) and 1,750,000 ha (32.72% of TGA) respectively. Sheet erosion and landslides contribute substantially to soil loss resulting in the decline of productivity of agricultural land. Anthropogenic activities like indiscriminate deforestation are the leading causes of soil erosion. However, natural effects like weak geological formation, active seismisity, high rainfall, cloud burst, etc. also aggravate soil erosion. Therefore, assessment of quantitative soil loss, understanding the causes of soil erosion and adoption of conservation measures are imperative for sustained productivity and livelihood security in Uttarakhand.

1. Mandal, D. and Sharda, V. N., Assessment of permissible soil loss in India employing a quantitative bio-physical model. *Curr. Sci.*, 2011, **100**, 383–390.
2. Barrow, C. J., *Land Degradation*, Cambridge University Press, Cambridge, UK, 1991.
3. Sfeir-Younis, A., Soil conservation in developing countries. Western Africa Projects Department/The World Bank, Washington, DC, USA, 1986.
4. Dhruvanarayana, V. V. and Ram Babu, Estimation of soil erosion in India. *J. Irrig. Drain. Eng.*, 1983, **109**, 419–434.
5. Lal, R., Soil erosion impact on agronomic productivity and environment quality: critical reviews. *Plant Sci.*, 1998, **17**, 319–464.
6. Mahapatra, S. K., Rana, K. P. C., Sidhu, G. S. and Walia, C. S., Assessment of degradation status of Jammu & Kashmir soils for their amelioration. *J. Indian Soc. Soil Sci.*, 2000, **48**, 572–576.
7. Cox, C. and Madramootoo, C., Application of geographic information systems in watershed management planning in St. Lucia. *Comput. Electron. Agric*., 1998, **20**, 229–250.
8. Erdogan, E. H., Erpul, G. and Bayramin, I., Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural environment. *Environ. Monit. Assess.*, 2007, **131**, 153–161.
9. Gong, J., *Geography Information System*, Science Publishing, Beijing, China, 2001.
10. Guobin, F., Shulin, C. and Donald, K. M., Modelling the impacts of no-til practice on soil erosion and sediment yield with Russle, SEDD and Arc View GIS. *Soil Till. Res.*, 2006, **85**, 38–49.
11. Lim, K. J., Sagong, M., Engel, B. A., Tang, Z., Choi, J. and Kim, K. S., GIS based sediment assessment tool. *Catena*, 2005, **64**, 61–80.
12. Mitasova, H., Hofierka, J., Zlocha, M. and Iverson, L. R., Modeling topographic potential for erosion and deposition using GIS. *Int. JGIS*, 1996, **10**, 629–642.
13. Molnar, D. K. and Julien, P. Y., Estimation of upland erosion using GIS. *Comput. Geosci.*, 1998, **24**, 183–192.
14. Reddy, G. P. O., Maji, A. K., Chary, G. R., Srinivas, C. V., Tiwary, P. and Gajbhiye, K. S., GIS and remote sensing applications in prioritization of river sub basins using morphometric and USLE parameters – a case study. *Asian J. Geoinform.,* 2004, **4**: 35–49.
15. Wu, Q. and Wang, M., A framework for risk assessment on soil erosion by water using an integrated and systematic approach. *J. Hydrol*., 2007, **337**, 11–21.
16. Yitayew, M., Pokrzywka, S. J. and Renard, K. G., Using GIS for facilitating erosion estimation. *Appl. Eng. Agric.*, 1999, **5**, 295–301.
17. Bhattacharrya, T., Ram Babu, Sarkar, D., Mandal, C. and Nagar, A. P., Soil erosion of Tripura, a model for soil conservation and crop performance. NBSS Publication No. 97, NBSS&LUP, Nagpur, 2002.
18. Challa, O., Kurothe, R. S. and Gajbhiye, K. S., Soil erosion in Maharashtra. NBSS Publ. No. 82, NBSS&LUP, Nagpur, 2001.
19. Kurothe, R. S., Soil erosion map of Gujarat. *Indian J. Soil Converv*., 1997, **25**, 9–13.
20. Narain, P., Ram Babu, Ram Mohan Rao, M. S., Sehgal., J., Batta, R. K., Sarkar, D. and Thampi, C. J., Soil erosion map of West Bengal. *Indian J. Soil Conserv*., 1993, **21**, 6–10.
21. Reddy, G. P. O., Kothare, R. S., Sena, D. R., Harindranath, C. S., Naidu, L. G. K., Sarkar, D. and Sharda, V. N., Soil Erosion of Goa. NBSS Publ. No. 155, NBSS&LUP (ICAR), Nagpur, 2013, p. 54.
22. Reddy, G. P. O. *et al.*, Assessment of soil erosion in tropical ecosystem of Goa, India using universal soil loss equation, geostatistics and GIS. *Indian J. Soil Conserv.*, 2016, **44**, 1–7.
23. Sahoo, A. K., Sarkar, D., Sah, K. D., Maji, A. K. and Dhyani, B. L., Soil erosion of Bihar. NBSS Publ. No. 126, NBSS&LUP, Nagpur, 2005.
24. Singh, A. and Singh, M. D., Effects of various stages of shifting cultivation on soil erosion from steep hill slopes. *Indian For.*, 1978, **106**, 115–121.
25. Singh, S. P. *et al.*, Soils of Uttar Pradesh for optimizing land use. NBSS Publ. No. 68 (Soils of Indian Series), NBSS&LUP, Nagpur, 2003, p. 91.
26. Maji, A. K., Reddy, G. P. O. and Sarkar, D., Acid soils of India – their extent and spatial distribution. NBSS Publ. No. 145, NBSS&LUP, Nagpur, 2012, p. 138.
27. Zingg, R. W., Degree and length of land slope as it affects soil loss in runoff. *Agric. Eng.*, 1940, **21**, 59–64.

28. Musgrave, G. W., Quantitative evaluation of factors in water erosion – a first approximation. *J. Soil Water Conserv*., 1947, **2**, 133–138.
29. Wischmeier, W. H. and Smith, D. D., Predicting rainfall-erosion losses for cropland east of the Rocky Mountains-Guide for selection of particles for soil and water conservation. Agricultural Handbook No. 282, United States Department of Agricutlure, 1965.
30. Wischmeier, W. H. and Smith, D. D., Predicting rainfall erosion losses – a guide to conservation planning. Agricultural Handbook No. 537, USDA, 1978.
31. Moore, T. R., An initial assessment of rainfall erosivity in East Africa. Technical Communication 11, Department of Soil Science, University of Nairobi, Kenya, 1978.
32. Hudson, N. W., *Soil Conservation*, Batsford, London, UK, 1981.
33. Wenner, C. G., *Soil Conservation in Kenya*, Ministry of Agriculture, Nairobi, 1981.
34. Singh, G., Babu Ram and Chandra, S., Soil loss prediction research in India. ICAR Bulletin No. T-12/D-9, Central Soil and Water Conservation Research and Training Institute, Dehradun, 1981.
35. Ram Babu, Tejwani, K. G., Agarwal, M. C. and Chandra, S., Rainfall erosion potential and iso-erodent map of India. Central Soil and Water Conservation Research and Training Institute, Dehradun, Bull. No. 2, 1978, pp. 1–47.
36. Raghunath, B., Khullar, A. K. and Thomas, P. K., Rainfall energy map of India. *Indian J. Soil Conserv*., 1982, **10**, 1–17.
37. Wischmeier, W. H., Johnson, C. B. and Cross, B. V., A soil erodibility homograph for farm land and construction sites. *J. Soil Water Conserv.*, 1971, **26**, 189–193.
38. Singh, G., Sastry, G. and Bharadwaj, S. P., Watershed responses to conservation measures under different agro-climatic regions of India. *Indian J. Soil Conserv.*, 1990, **18**, 16–22.
39. Kurothe, R. S., Determination of ‘C’ and ‘P’ factors of the USLE for important crops and management practices in Vasad region. Annual Report, Central Soil and Water Conservation Research and Training Institute, Dehradun, 1991–92, pp. 100–101.
40. Mannering, J. V., The use of soil tolerance as strategy for soil conservation. In *Soil Conservation Problem and Prospects* (ed. Morgan, R. P. C.), John Wiley, Chichester, UK, 1981, pp. 337–349.
41. ICAR, *Handbook of Agriculture*, Sixth (Revised) Edition. Directorate of Information and Publications of Agriculture, Indian Council of Agricultural Research, New Delhi, 2009.

ACKNOWLEDGEMENTS. We thank the Director, ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur and the Director, ICAR-Indian Institute of Soil & Water Conservation, Dehradun for providing necessary facilities and support for the present study.

Received 21 August 2017; accepted 2 November 2017

doi: 10.18520/cs/v115/i1/108-121

Errata

Exploring effective factors on energy data of some benzofuran derivatives

Pouya Karimi, Somayeh Makarem and Hamid Ahmar
[*Curr. Sci*., 2018, **114**, 2092–2098]

The affiliation of Somayeh Makarem should read as

[2]Department of Chemistry, Karaj Branch, Islamic Azad University, Karaj, Iran

instead of

[2]Department of Chemistry, Karaj Branch, Islamic Azad University of Karaj, Kraj, Iran

We regret the error.
– Authors

Groundwater dynamics in North Bihar plains

Rajiv Sinha, Surya Gupta and Santosh Nepal
[*Curr. Sci.*, 2018, **114**, 2482–2493]

Page 2485:

Please read the equation in Figure 2:

$\Delta S = \Delta h * \mathrm{Sy}$
as
$\Delta S = \Delta h * \mathrm{Sy} * A$.

Please read the equation in column 2:

$\Delta \mathrm{S} = \mathrm{Sy} * \mathrm{d}h/\mathrm{d}t * \mathrm{A}$
as
$\Delta S = \mathrm{Sy} * \Delta h * A$

where ΔS is the change in GWS, Sy the specific yield, Δh is the change in groundwater level and A is the area of the grid.

We regret the errors.
– Authors