Vol. 47, No. 3, pp 244-254, 2019
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Soil erosion and sediment yield estimation using remote sensing data and GIS in a Sitlarao watershed of north-western Himalayan region

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ARTICLE INFO

Article history:
Received : June, 2019
Revised : December, 2019
Accepted : December, 2019

Key words:
GIS
Himalaya
Remote sensing
RUSLE
Sediment yield
Soil erosion

ABSTRACT

Soil erosion (SE) is the primary reason of land degradation and responsible for declining soil quality and crop yield in the Himalayan region. Spatial SE risk assessment and sediment loss are necessitated to prioritize sub-watershed and implementing soil and water conservation planning of the watershed. In this study, revised universal soil loss equation (RUSLE) model with sediment delivery ratio (SDR) was integrated with geographic information system (GIS) to estimate SE and sediment loss in a watershed located in north-western Himalayan region of Uttarakhand state, India. Land use/land cover (LU/LC) was generated using high resolution remote sensing (RS) IRS LISS IV data, and vegetation cover (C), management practices (P) and soil erodibility (K) factor maps were generated using physiographic-soil map at large scale. The watershed is dominantly covered by cropland (46.78%) followed by forest (32.93%) and scrub / barren land (13.71%). Soil erodibility (K) factor varied from 0.033 to 0.061 in the watershed. Terrain slope length (L) and steepness (S) values were obtained from Carto-DEM (10 m) with the help of GIS. SE risk map based on RUSLE model revealed 36.4% area under high to very high risk of SE in the watershed. Average annual SE in croplands varies from 10.61 t $ha^{-1}yr^{-1}$ to 16.08 t $ha^{-1}yr^{-1}$, whereas dense forest and open scrub cover were predicted to be 4.14 t $ha^{-1}yr^{-1}$ and 26.04 t $ha^{-1}yr^{-1}$, respectively. Estimation of SDR based on soil and sediment clay ratio serves as most appropriate method to estimate SDR for small watershed and to estimate sediment loss for sub-watershed prioritization. SDR of the sub-watershed ranged from 0.32 to 0.71 with an average of 0.48. Topography and LU/LC appear to be major factors in governing SE in the watershed.

1. INTRODUCTION

Soil erosion (SE) due to water is a global environmental issue, which alters soil fertility and water attributes. SE process has accelerated during the last century with an estimated loss of 24 million tons (M t) of fertile top soil from the agricultural lands across the globe (FAO, 2011). It is one of the major causes of land degradation (Lal and Stewart, 1990; Pimentel *et al*., 1995) adversely affecting crop yield, water attributes, hydrological systems, and the climate (Lal, 1998). Land use and climate alterations actively hasten the SE process, representing a salient threat to the long-term sustainability of agriculture and ecosystem services. India loses 5334 M t of soil annually due to SE (Narayan and Babu, 1983). It has been apprehended as a serious problem, particularly in mountainous region (Dabral *et al*., 2008; Sharma, 2010). The north-western Himalayan belt is highly prone to SE, because of the instability due to ongoing tectonic activities (Sati *et al*., 2011). Garde and Kothyari (1987) documented high SE rate in the northern Himalayan region in the order of 20 to 25 t $ha^{-1}yr^{-1}$. Hilly terrain of Himalaya, where livelihood of people is mainly dependent on farming system, and especially on subsistence agriculture, are most vulnerable due to SE. Sustainable land management and soil conservation planning requires reliable information on SE. Policy makers and planners require quantification of SE rates and their spatial distribution in the watershed for their prioritization and conservation planning.

USLE equation (Wischmeier and Smith, 1978) and RUSLE model are the two most commonly used models to anticipate potential SE (Renard *et al*., 1997). Revised universal soil loss equation (RUSLE) is the amended version of USLE, based on the same empirical principles. The amendments are inclusion of monthly factors, influence of profile convexity / concavity using segmentation of irregular slopes, and advanced observation based equations for computing LS factor (Foster and Wischmeier, 1974; Renard *et al*., 1991). The sediment yield (SY) from watershed to streams is determined by combination of SE rate and sediment delivery ratio (SDR) (Williams, 1975; Arnold *et al*., 1998). It is an eminent fact that a substantial quantity of sediment produced by SE gets precipitated within the watershed, and only a fraction of it reaches to the stream system to be removed through the watershed outlet.

Assessment of sediment production is crucial to rectify the problems of reservoir sedimentation, channel morphology, water attributes, conservation and planning (Kothyari and Jain, 1997). Sediment production has been explicated as release of sediment from a watershed (Lane *et al*., 1997). It represents the efficiency of the watershed to move soil particles from areas of erosion to the point where SY is measured or watershed outlet, and is widely adopted for watershed prioritization studies (Fathizad *et al*., 2014; Kamaludin *et al*., 2013). Among the various methods for estimating SDR, predictive equations are the most widely used alongwith relative clay distribution in sediment and soil (Walling, 1983). A number of observation based regression equations have been formulated for estimation of SDR from hill slopes to streams based on watershed alone (Roehl, 1962; Walling, 1983; Ferro and Minacapilli, 1995). Osterkamp and Toy (1997) have reported that the SDR is not equivalent over a watershed; it oscillates with alterations in watershed area and slope. It has been propounded in SY modeling based reviews that there is no comprehensive equation to be used in all the settings. Therefore, region specific equation is the best approach to estimate SY (USDA, 1972; Ludwig and Probst, 1998; De Vente *et al*., 2011). SY is generally estimated as a product of gross SE and SDR. This is the most widely used approach in which gross SE is calculated by USLE model (Ebisemiju, 1990; Walling, 1983; Van Remortel *et al*., 2001; Amore *et al*., 2004; Bhattarai and Dutta, 2007; Boomer *et al*., 2008). RUSLE-SDR model was run by Sharda and Ojasvi (2016) to estimate SY, where SDR is acquired from the equation formulated for north Indian river basins.

The advancement in spatial information technology augmented the current method of SE (Prasannakumar *et al*., 2011). A valid analysis of SE risk was carried out using RS data and GIS (Srinivas *et al*., 2002; Kouli *et al*., 2009; Kumar and Khushwaha, 2013; Csafordi *et al*., 2012). Integration of RUSLE with GIS has been appraised as an efficient method to estimate quantitative erosion and significantly better outcomes have been reported as compared to conventional methods (Irvem *et al*., 2007; Saroingsong *et al*., 2007; Alexakis *et al*., 2012). Studies indicate that spatial data inputs provided to the model by GIS and RS systems intensify the precision of RUSLE model in soil risk analysis (Kouli *et al*., 2009; Csafordi *et al*., 2012; Kumar and Khushwaha, 2013).

North western Himalayan region poses severe threat of land decay as a result of SE caused by water. Soil and water conservation plans are implemented on watershed basis for conserving soil against water erosion for managing natural resources in the region. Reliable and updated information on spatial distribution of SE risk in a watershed is essential prerequisite to suggest suitable preventive measures. Data on SE and sub-watershed sediment loss are required to prioritize watershed area for conservation planning. The present study has been attempted to derive SE factors using high resolution RS and terrain data to predict spatially distributed SE risk at large scale using the RUSLE model, and to estimate SDR of sub-watershed for predicting SY for prioritization of sub-watersheds for soil and water conservation planning in the watershed.

2. MATERIALS AND METHODS

Study Area

The study area is located between 30°25'N to 30°30'N latitudes and 77°45'E to 78°0'E' longitudes, covering an area of 805 ha. It is catchment of Sitlarao stream representing lesser Himalaya in north-west Himalaya in Dehradun, the capital city of Uttarakhand (India) (Fig. 1). The weather in this region is depicted as humid sub-tropical. The average per year temperature ranges between 15.0^{0}C to 27.9^{0}C. The rainfall varies from 1600 mm to 2000 mm, and 70% of it was recorded in monsoon months from June to September. July and August were the highest raining months. Geology of watershed has pre-cambrian rocks of lesser Himalayan. The lesser Himalaya consists of granite, quartzite, phyillite and pebbles, etc. Soils are sandy loam and sandy clay loam in texture. Forest, agriculture, scrub and settlements are major LU/LC. Agriculture is the principal occupation of the people. The main cropping seasons are *kharif* and *rabi*. Paddy and maize are the main crops of *kharif* season, and wheat is of *rabi* season. Sal (*Shorea robusta*) is the dominant tree species in the forest land.

Data Used

IRS Resourcesat-2 multispectral LISS-IV RS data (spatial resolution 5.8 m) acquired on 8th April 2016 was used to generate LU/LC of the study area. Carto-DEM derived from Cartosat-1 satellite having a spatial resolution of 10 m generated parameters like slope, aspect, flow direction, flow accumulation as well as drainage network. The products were used for estimation of LS factor values of the entire watershed. The Carto-DEM has vertical accuracy of 8 m (Santillana *et al*., 2016).

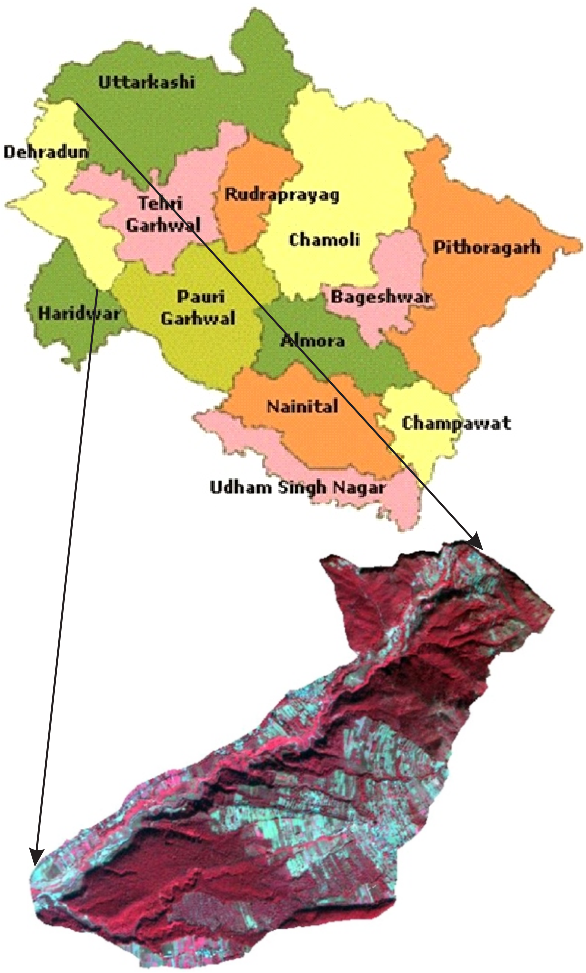

Fig. 1. Study area

Software Used

Images were processed by ERDAS Imagine, and GIS software Arc-Map ver. 10.2.2 was used to generate digital coverage of input parameters of the erosion model.

Field Data Collection

(i) Soil samples of each physiographic unit were collected in the watershed. Sample processing and analysis was done to identify the soil texture (sand, silt and clay) using hydrometer (Kroetsch and Wang, 2007) and soil organic carbon (OC) by Walkley Black method (Nelson and Sommers, 1996; Schumacher, 2002). Soil structure, drainage and permeability class were documented during the field survey.

(ii) Information regarding LU/LC was collected and their geographic locations were recorded with the help of GPS (Trimble). Land management practices followed by farmers in the watershed were recorded.

Methodology

(i) Estimating Soil Erosion (SE)

SE was estimated using RUSLE, an empirical model used to predict long term average rate of SE. It is most widely used empirical erosion model revision of USLE model (Wischmeier and Smith, 1978). It considers SE factors of climate, soil types, topography, vegetation cover, and management practices factors (Renard *et al*., 1991; Kinnell, 2008). The model is represented as:

$$A = R \times K \times LS \times C \times P$$

Where, A = the computed spatial average soil loss and temporal average soil loss per unit area (t ha^{-1}yr^{-1}), R = rainfall erosivity factor (MJ mm ha^{-1}h^{-1}), K = soil erodibility factor (Mg h MJ^{-1} mm^{-1}), LS = slope length and steepness factor, C = cover management factor, P = the conservation practice factor.

(ii) Data Processing and RUSLE Factor Generation

R-factor (rainfall erosivity factor)

The R-factor is a measure of erosive force of rainfall. It quantitatively expresses the erosivity of local average annual rainfall. R-factor computation needs long-term data of rainfall amounts and intensities. Well established empirical equations using total rainfall (monthly, seasonal or annual) are widely employed. In this study, R-factor was estimated using the rainfall data of past 20 years (1998-2017) from Automatic Weather Station which was near to the watershed, using empirical relationship (Babu *et al*., 2004).

$$R = 81.5 + 0.375 * A \ (340 \le A \le 3500 \text{ mm})$$

Where, A: Average Annual Rainfall (mm).

K-factor (soil erodibility factor)

Soil erodibility factor (K) is a quantitative expression of the inherent susceptibility of soil for separation and movement of soil particles under an amount, and runoff rate for a particular rainfall. It depends on physico-chemical properties of texture, organic matter content, permeability and soil structure. The visual interpretation of IRS LISS IV Std. FCC at 1:10000 scale was used to generate physiographic soil map. Various physiographic units were delineated based on the landform, slope characteristics and LU/LC types. Surface (0-20 cm) soil samples were collected from each of the physiographic unit in the watershed. Three to four soil specimens were taken from each unit. The collected samples were analyzed in the laboratory for soil texture, organic matter content and structural characteristics, which are essential for determination of K-factor. The following equation was used to compute K-factor (Wischmeier and Smith, 1965; Renard *et al*., 1997).

$$K = 27.66 * m1.14 * 10\text{-}8 * (12\text{-}a) + 0.0043 * (b\text{-}2) + 0.0033 * (c\text{-}3)$$

Where, K is the soil erodibility factor (t ha^{-1} h ha^{-1} MJ^{-1} mm^{-1}), m is the particle size parameter (% silt + % very fine sand) * (100 − % clay), a is the organic matter content (%), b is the soil structure code (1. very structured or particulate, 2.

fairly structured, 3. slightly structured 4. solid), and c is the soil permeability class (1. rapid 2. moderate to rapid 3. moderate 4. moderate to slow 5. slow 6. very slow). Soil map was then re-categorized on the basis of K-value of each map unit to prepare spatial distribution of soil erodibility map.

LS factor (slope length and steepness factor)

The total erosion and SY from a watershed depends not only on slope length but on steepness also. The length of the slope and steepness of terrain influence the erosive potential of water. The more are slope length and steepness, the higher will be the erosion, and vice-versa. LS factor demonstrates the combined effect of local topography in terms of slope length (L) and steepness (S) on SE rate. It can be determined either by field measurement or digital elevation model (DEM). In this study, DEM was used to derive L-factor and S-factor. The LS factor was estimated using the equation given by Mitasova *et al.* (1996). The rate of erosion increases with increase in S-value, but the RUSLE did not show difference between rill and inter-rill erosion in the S-factor (Renard *et al*., 1997; Krishna Bahadur, 2009). L-value and S-value for each pixels were determined by Carto-DEM of 10 m spatial resolution. Slope steepness in degree was measured by spatial analyst tool of the Arc-GIS, whereas slope length was determined by hydrology tool of spatial analyst where flow accumulation map was prepared. Flow accumulation map illustrates the number of pixels receiving surface runoff.

The slope-length factor (L) was determined by the equation mentioned below:

$$L = (\lambda/22.13)^m \quad ...(1)$$

Where, 22.13 is the RUSLE unit plot length (in meters) and m is a variable slope length exponent. Slope length λ is defined as the horizontal distance from the origin of overland flow to the point. The slope length exponent m can be calculated as:

$$m = \beta/(1+\beta) \quad ...(2)$$

$$\beta = (\sin\theta/0.0896)/[3.0(\sin\theta)^{0.8} + 0.56] \quad ...(3)$$

Where, θ is the slope angle. The slope steepness factor (S) was measured using the relationship described by (McCool *et al.,* 1987).

$$S = 10.8\sin\theta + 0.03 \qquad S < 9\%(i.e. \tan\theta < 0.09) \quad ...(4)$$

$$S = \left(\sin\theta/\sin 5.143\right)^{0.6} \qquad S \geq 9\%(i.e. \tan\theta \geq 0.09) \quad ...(5)$$

Angles were converted into radians to perform trigonometric operations in Arc-GIS. LS factor was computed by employing the above cited equations using the DEM with the cell size of 10 m flow accumulation raster, which denotes the accumulated upslope contributing area for a given cell and slope map.

C-factor (crop cover factor)

C-factor is allocated to various LU/LC types (Millward and Mersey, 1999). It is the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled continuous fallow (Wischmeier and Smith, 1978). Its value ranges between 0 (water bodies) and 1 (scrub land), because of lack of vegetation, root biomass or other surface covers fail to resist SE. Thus, it expresses the relation between SE on bare area and erosion observed under a particular cropping system, and indicates the role played by land cover-type as well as cover density on soil protection. Allocating C-values to LU/LC demands high precision. In this study, C-factor map was generated using the LU/LC map which was generated by visual interpretation of satellite data. The boundaries of the various LU/LC classes were verified and corrected during the field survey. The major crops cultivated in the study area are rice, maize, wheat and vegetables. Rainfall is the sole water source for agricultural activities in major part of our study area. Only very less area adjacent to the channels stream had irrigation facilities. Low input subsistence farming using local varieties, traditional farming practices and inputs are practiced in the watershed. The LU/LC map was reclassified based on C-factor values using tools in Arc-GIS, which assigned C-factor values based on Wischmeir and Smith (1978), as well as previous studies undertaken in similar regions, including Himalayas by various researchers (USDA,1972; Kumar and Kushwaha, 2013).

P-factor (conservation practice factor)

P-factor is the soil-loss ratio with a particular assistance practice to corresponding soil loss with up and down slope tillage (Renard *et al*., 1997). Various crop management practices normally reduce the amount and rate of runoff water by influencing drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by runoff on soil, eventually reducing SE. It includes impact of various methods like contouring, terracing, strip cropping, field bunding, stone wall etc. These established conservation strategies remarkably reduced the risk of erosion (Hyeon and Julien, 2006; Arunbabu and Logeswari, 2018). In the watershed, management practices such as terracing, bunding, grass bunding etc. are followed by farmers, depending on slope steepness and resource availability. P-factor values were assigned to several LU/LC types by using LU/LC map, accounting the management practices being followed by farmers in these cover classes. The map was reclassified based on P-factor values using tools in Arc-GIS, to generate P-factor map in raster format.

(iii) Estimating Sediment Yield (SY)

The most prevailing method to predict SY is to estimate it as a product of gross SE and SDR. Therefore, SDR is needed for estimation of this variable (Ouyang and Bartholic, 1997). The SY of watershed was calculated by multiplying mean gross SE rate per year and SDR. In the present study, a simple method to compute SDR of the watershed proposed by Walling (1983) considering the percentage of clay in the sediment and in the soil was adopted. In the study, average clay percent of the soils of each watershed were obtained from the soil map. In post rainy season, 3-4 sediment samples were collected from the stream bed of each sub-watershed, and analyzed to determine clay content in the sediments. These values were used to estimate SDR of each sub-watershed. The SDR is calculated using the following equation:

$$SDR\,(\%) = C\,soil\,(\%) / C\,sed\,(\%)$$

Where, *C soil (%)* = the content of clay in the soil (%), *C sed (%)* = the content of clay in sediment (%).

Several researchers developed region specific relationship for predicting SY (USDA, 1972). They developed relationships between SDR and drainage area. Sharda and Ojasvi (2016) developed an empirical equation to compute SDR based on drainage area. They used the data of river basins of India to develop the model depending upon reservoir sedimentation (CWC, 2015), and SE statistics from 16 large reservoir basins (basin area greater than 1,000 km^2) situated in North India. The formula used is given as:

$$SDR = 1.817\,A^{-0.132}$$

This equation was also used to compute *SDR* of each sub-watershed.

Average annual SY of each sub-watershed was computed using the SDR value of each sub-watershed and average annual SE estimated using RUSLE model as:

$$SY = SE \times SDR$$

Where, *SY* = Average annual sediment yield ($t\ ha^{-1}\ yr^{-1}$), *SDR* = sediment delivery ratio, *SE* = annual soil erosion rate of sub-watershed ($t\ ha^{-1} yr^{-1}$).

Event Wise Sediment Delivery Ratio in the Watershed

One of the sub-watersheds in the watershed was instrumented to measure surface runoff and sediment sampling at the outlet of the sub-watershed. The surface runoff was estimated using digital water level recorder (DWLR), and SY was estimated by collecting surface runoff sample in a sediment tank for some rainfall events during 2016-17. These measurements were used to compute SDR of the sub-watershed. Total surface runoff of the day was computed using stage level DWLR. Surface runoff water collected from watershed outlet and sediment concentration were analyzed to determine total sediment washed from the sub-watershed. SE of the sub-watershed for these rain events were calculated using RUSLE model. Then, SDR of each rain events was computed.

3. RESULTS AND DISCUSSION

The combination of erosion determinants defined in RUSLE model was used to assess the possible SE rate for each picture element. Slope analysis (Fig. 2 and Table 1) of the watershed revealed that 9.78% area had very steep to steep slope, and 12.02% and 17.9% area with moderate and gentle slope, respectively. The watershed was dominantly covered by cropland (46.78%) followed by forest (32.93%), barren land (13.71%), orchard (3.61%) and riverbed (2.95%), respectively (Fig. 3). The soils of watershed were sandy loam to loam in texture and moderately deep to deep in depth class. SE determinants derived for the watershed are discussed as:

Factors Affecting SE in the Watershed

RS inputs along with GIS were used to derive SE determinants of RUSLE model for the catchment area. SE factor maps such as soil erodibility (K), vegetation cover

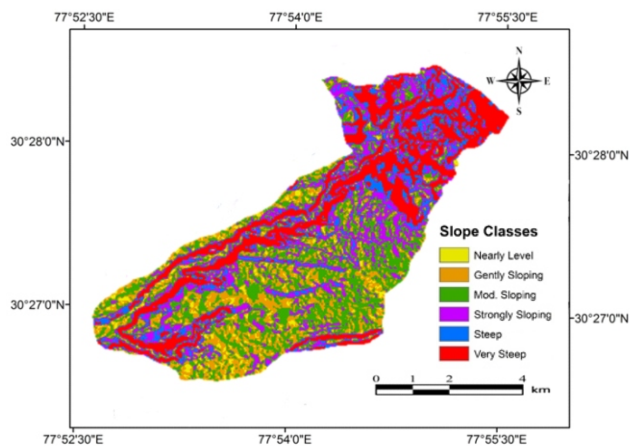

Fig. 2. Slope class map

Table: 1
Slope class values with area covered

S.No.	LS class	Slope value %	Area (%)
1	Nearly Level	0-10	54.3
2	Gently Sloping	10-25	17.9
3	Mod. Sloping	25-50	12.02
4	Strongly Sloping	50-75	6.00
5	Steep	75-100	3.75
6	Very Steep	>100	6.03

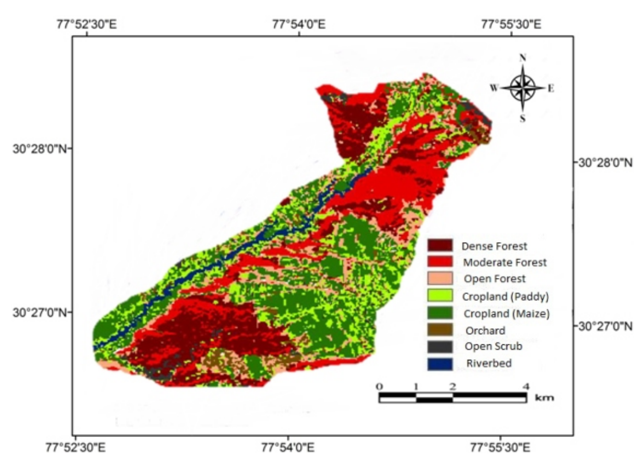

Fig. 3. Land use land cover map

(C), management practice (P), and topographic factor (LS) maps were generated of the watershed. These factors of the watershed are discussed as:

Rainfall erosivity (R) factor: It reflects an interaction between kinetic energy of raindrops and soil surface. The value of R varies with the precipitation during a specific period of time (Wischmeier and Smith, 1978). In the present study, the monthly rainfall inputs of 20 years (1997 to 2017) were analyzed (Table 2). These inputs were provided by IMD weather station located very near (20 km) to the watershed. The rainfall erosivity factor (R) was estimated employing the rainfall erosivity relationship given by Babu *et al*. (2004). As only one weather station was available, therefore single R-factor value was obtained. The R-factor value was estimated to be 823.09 MJ mm $ha^{-1}h^{-1}$. The area of the watershed was only 805 ha, therefore, a single R-factor value was taken for entire watershed and assumed as homogenous. Similar R-factor values have been estimated in various studies in India. Mahapatra *et al.* (2018) observed that the spatial distribution of rainfall erosivity factor (R) of Uttarakhand ranges from <400 to >700 MJ mm $ha^{-1}h^{-1}$, Similarly, in a study carried out in Shivalik Himalayan region, Kumar and Kushwaha (2013) reported a value of 383 MJ mm $ha^{-1}h^{-1}$, where the rainfall amount is less. Similarly, Kalambukattu and Kumar (2017) estimated R-factor value of 606 MJ mm $ha^{-1}h^{-1}$ for Chamba (Tehri Garhwal) in mid-Himalaya of Uttarakhand. A correlation between R-factor and SE has been reported in various parts of the world (Ferro *et al*., 1991; Renard and Freimund, 1994).

Soil erodibility factor (K): It indicates the susceptibility of soil to erosion and the rate of runoff (Wischmeier and Smith, 1978). The K-factor values depend on soil properties (*i.e.* soil texture, soil structure, soil permeability, soil organic matter) and are defined by measurements of soil loss under a standard unit plot condition (22.1 m long and slope of 9% without vegetation cover). Soil erodibility factor map was generated with the help of physiographic soil map (Fig. 4). The K-value for each map unit was computed (Table 3) and it ranged from 0.033 to 0.061 in the watershed (Fig. 5). The higher K-values indicate high amount of silt and very fine sand, and low OC that results in poor aggregation and

Table: 2
Average monthly rainfall, T_{max} and T_{min} from (1998-2017) for Sitlarao watershed

Average 1998-2017	Rainfall (mm)		T_{max} (°C)	T_{min} (°C)
Jan	41.56		19.9	5.8
Feb	23.86		21.7	7.5
March	38.88		25.8	11.3
April	17.71		31.6	16.0
May	27.62		34.9	19.9
June	185.64		34.2	22.3
July	682.52		30.8	22.4
Aug	705.65		29.9	22.0
Sept	215.02		29.9	20.2
Oct	16.69		28.9	15.2
Nov	7.58		25.5	10.5
Dec	15.66		21.6	6.8
Total	1978.38	Mean	27.9	15.0

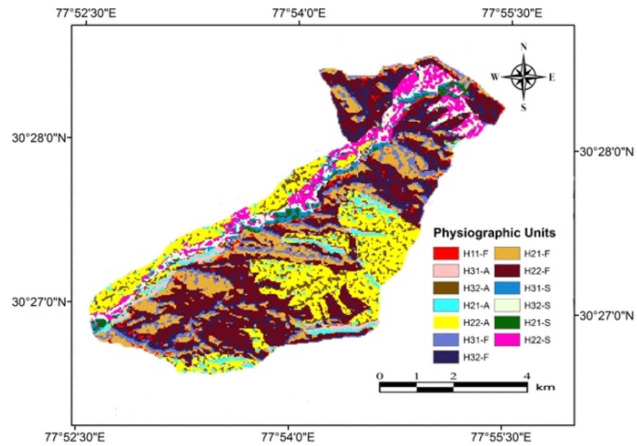

Fig. 4. Physiographic map

Table: 3
Physiographic units with K-values

Physiographic unit	Texture (Surface)	O.C. %	Soil erodibility factor (K) values
H11-F	Silty clay loam / Sand loam	0.97-0.45	0.061
H21-F	Sandy loam	0.68-0.32	0.054
H22-F	Silty clay loam / Sandy loam	0.81-0.42	0.049
H31-F	Loam / Silty clay loam	0.85-0.37	0.039
H32-F	Loam / Sand loam	0.77-0.41	0.045
H21-A	Silty clay loam / Sand loam	0.86-0.68	0.038
H22-A	Sandy loam	0.89-0.45	0.037
H31-A	Silty clay loam / Sand loam	0.85-0.41	0.046
H32-A	Sandy loam	0.82-0.49	0.045
H21-S	Loam / Silty clay loam	0.89-0.54	0.053
H22-S	Loam / Sand loam	0.58-0.43	0.043
H31-S	Loam / Silty clay loam	0.76-0.34	0.033
H32-S	Loam / Sand loam	0.61-0.32	0.041

(H1 - Hill top, H2 - Middle Slope, H3 - Lower slope) - (1 - North, 2 - South) - (A - Agriculture, F - Forest, B - Scrub land

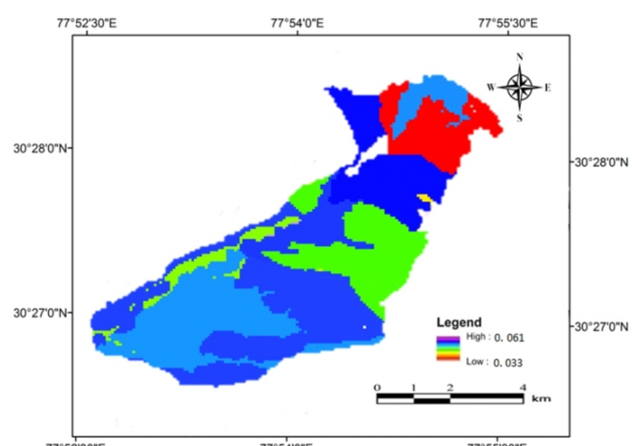

Fig. 5. Soil erodibility factor map

increased erosion (Kamaludin *et al*., 2013). Gupta and Kumar (2017) reported K-value in the range of 0.039 to 0.064 Mg h $MJ^{-1}mm^{-1}$ in soils of mid-Himalayan landscape. Analysis exhibited that SE is more likely to occur in higher slope areas due to low organic matter and poor soil structure. It also revealed that the areas of moderate to gentle slope contain more OC (0.97-0.89%) and good structure of soil (fine granular), whereas areas with steep to very steep contain less OC (0.68-0.32%) and lattice/massive structure. The average percentage of sand, silt and clay in watershed is 59, 22 and 17, respectively. Soils in a watershed are characterized as sandy loam, sandy clay loam and loam texture.

LS factor

In the study area, steep sloping area had higher steepness factor and lowest slope length factor. It was found that 54.5% area of watershed area have LS value <10, and 17.9%, 12.02%, 6%, 3.75%, 6.03% areas have LS values between 10-25, 25-50, 50-75, 75-100, and >100, respectively (Table 1). Very high and high risk erosion areas in watershed were found to be associated with moderate steep to steep sloping area (Fig. 6). Similar LS values were estimated in mountainous sub watershed in mid-Himalayas (Kalambukattu and Kumar, 2017) and Shivalik hills of Uttarakhand, India (Kumar and Kushwaha, 2013). Area with high LS values correspond to increase in the velocity of surface runoff water on the land surface that results in increased SE rates (Haan, 1994). SE rates increase with increase in LS values governed by the topography (Wischmeier and Smith, 1978; Renard *et al*., 1994).

C-factor

The C-factor is the ratio to compare soil loss under vegetation cover with bare soil. Its value ranges from zero for completely preserved soil, to one for bare soil surface. Vegetation cover provides efficient protection to soil against SE. Removal or degradation of vegetation cover significantly increases SE. C-values allotted to various LU / LC in the watershed are depicted in Table 4. Spatial distribution of crop cover factor value ranged from 0.004 for dense forest to 0.06 in case of open forest. Higher values of C-factor indicate minimal vegetation cover and provide no protection to soil against SE. These soils are compact with high bulk density and poor infiltration rate causing higher surface runoff generating high SE. In the watershed, barren / fallow is highly prone to erosion whereas the various forest covers are less prone to SE. Similar C-factor values were used in different erosion studies done by various researchers (USDA, 1972; Tirkey *et al*., 2013; Gupta and Kumar, 2017; Kalambukattu and Kumar, 2017; Jena *et al*., 2018).

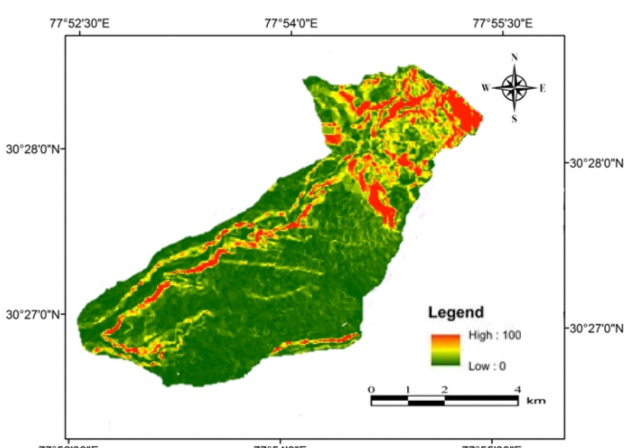

Fig. 6. Slope length and steepness factor map

Table: 4
C and P-value corresponding to land use land cover

S.No.	LU/LC class	Area %	C-factor	P-factor
1	Dense Forest	13.71	0.004	0.8
2	Moderate Forest	15.18	0.006	0.8
3	Open forest	4.05	0.06	0.8
4	Cropland (Paddy)	25.36	0.25	0.3
5	Cropland (Maze)	21.42	0.35	0.4
6	Orchard	3.61	0.1	0.5
7	Open Scrub land	13.71	1	1
8	Riverbed	2.95	0.0	1

Cover management practices (P) factor: Management practices in different LU/LC types were recorded during field survey in the watershed. Cropland field management practices adopted by farmers were observed during the field survey and collected through interview of the farmers. Farmlands in the watershed are terraced fields and field bunds are maintained by farmers every year prior to rainy season. Farmers do stone pitching on risers of terraces. Terraces are 4-6 m wide and irregular in shape. Paddy fields were well bunded, whereas maize fields were not bunded to keep in well drained condition. Natural vegetation cover areas were categorized as reserve forest with no conservation measures. The P-values were assigned based on management conditions to various LU/LC based literature recommended for various management practices (Table 4). The value of P-factor ranges from 0.3 to 1, in which the highest value was assigned to areas with no conservation practices (barren land); the minimum values correspond to dense forest. Agricultural lands were terraced and their bunds were stabilized by grasses, and with stones / boulders at many places. Similar P-factor values of RUSLE model were also estimated in other studies conducted in various areas (Kumar and Kushwaha, 2013; Tirkey *et al*., 2013; Sun *et al*., 2014; Reddy *et al*., 2016; Gupta and Kumar, 2017; Kalambukattu and Kumar, 2017).

SE Risk Assessment

SE rate per year was estimated employing RUSLE model and the watershed was classified into five SE risk classes (Fig. 7). The results demonstrated that 29% of the total catchment area was facing high to very high (75-100 t $ha^{-1}yr^{-1}$) SE risk, nearly 20.2% area had moderate

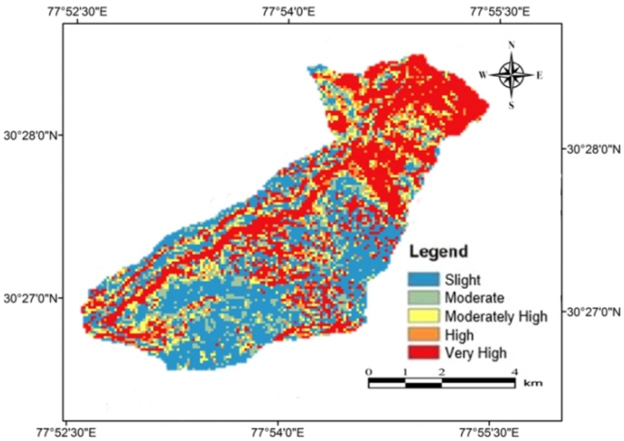

Fig. 7. Soil erosion risk map

erosion (10-25 t $ha^{-1}yr^{-1}$), and 34.3% area with slight erosion (0-10 t $ha^{-1}yr^{-1}$) risk (Table 5). The most salient elements influencing SE in mountainous catchment areas are topographic and vegetation cover factors (King *et al*., 2005; Zhou *et al*., 2008). Average SE rate of LU / LC was also determined, and it was found that dense forest have lowest SE rates (4.14 t $ha^{-1}yr^{-1}$), whereas highest erosion rates are found in open scrub land with a value of 26.04 t $ha^{-1}yr^{-1}$ (Fig. 8). Open scrub having very poor vegetation cover provided poor protection to land surface as well as this area had higher surface runoff and had caused higher SE. Open forest land had 19.15% SE rate. Maize and paddy were the major crops grown in the watershed. Maize cropland was estimated to have SE of 16.08 t $ha^{-1}yr^{-1}$ whereas of paddy crops SE rate was 10.61 t $ha^{-1}yr^{-1}$. Croplands are terraced fields and study revealed that cropland with maize crop was estimated to have higher erosion rate (25-30%) than the paddy cropland. It may be attributed to maize fields having higher slope (15-20% slope) and are lying at upper part (higher elevation) of the watershed, whereas paddy fields are at lower part (lower elevation) of the watershed with lesser slope (10-15%) than maize fields. Moreover, maize fields are un-bunded and favor surface runoff water removal from the surface, whereas paddy fields are bunded to have stagnation of water during growing period. Maize field crop also provides less protection cover than the paddy fields, thus it promotes higher erosion than paddy cropland in the watershed. Thus, maize crop needs to have inter cropping with legume or crop mulching to provide more vegetation cover to soil surface as protection to reduce SE. Terraces in the paddy fields were found poorly bunded, therefore these fields are facing high SE. It is suggested to provide proper bunding and grasses on bunds to control surface runoff to avoid breaking of bunds and to reduce SE.

Average annual SE rate was also estimated for the sub-watershed, and it was found that it varies from 4.87 t $ha^{-1}yr^{-1}$ to 59.04 t $ha^{-1}yr^{-1}$ among the 09 sub-watersheds. (Fig. 9 and Table 6). SW-1, SW-2, SW-3, SW-4 and SW-5 sub-watersheds

Table: 5
Soil erosion potential with erosion rate and area covered

Erosion Potential	Class t $ha^{-1}yr^{-1}$	Area (km^2)	% Area
Slight	0-10	2.71	34.3
Moderate	10-25	1.12	20.2
Moderately high	25-50	0.97	9.1
High	50-75	0.83	7.4
Very high	75-100	2.37	29

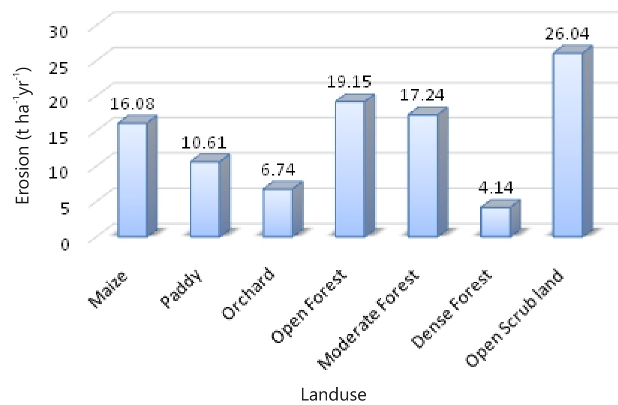

Fig. 8. Average soil loss under various land use system

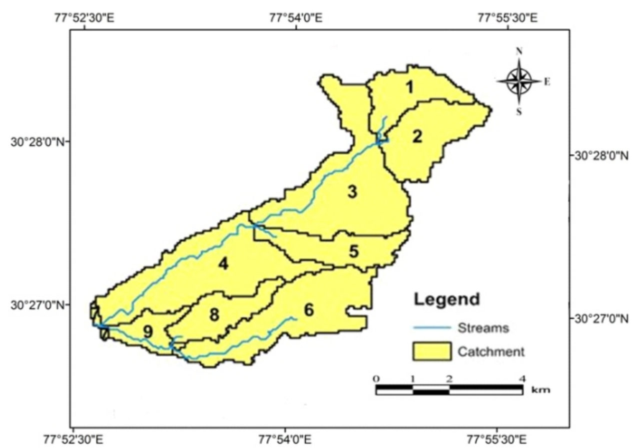

Fig. 9. Sub-watershed map

(covering an area of 71.03% of watershed) were predicted of moderate to moderately high rate of SE. Other sub-watersheds (SW-6, SW-7, SW-8 and SW-9) had slight rate of SE (<10 t $ha^{-1}yr^{-1}$). Sub-watershed SW-1 was predicted of highest average annual SE rate as its 75% area is having slope more than 20%, and 49.4% area is under maize cropland. Sub-watershed SW-8 with lowest average annual SE rate had 98% area with less than 20% slope, and 70% area is under forest cover. The analysis revealed that sub-watershed with higher SE have higher slope and predominant in agriculture. Thus, topography and LU/LC appears to be the dominant factor governing SE in the watershed. Similar, observations have been reported by Jain *et al.* (2001).

Several researchers used RUSLE model to predict SE rates in Shivalik and mountainous landscape of Himalaya

Table: 6
Sediment delivery ratio, average soil erosion and sediment yield with area covered in sub-watershed

Sub-watershed	Area (%)	Av. Clay percent in soil (a %)	Av. Clay percent in sediment (b %)	SDR value (a/b)	Average Soil Erosion t ha^{-1}yr^{-1}	Sediment Yield t ha^{-1}yr^{-1}
SW-1	7.62	15	27.69	0.54	59.04	32.2
SW-2	10.47	17	32.5	0.52	34.29	18.1
SW-3	23.28	22	45	0.48	30.49	14.9
SW-4	21.78	20	41.5	0.48	34.24	16.7
SW-5	7.88	14	25.8	0.54	18.88	10.3
SW-6	17.49	18	36.5	0.49	9.7	4.8
SW-7	0.51	19	26	0.73	10.24	7.5
SW-8	6.71	15	27	0.55	4.87	2.7
SW-9	4.22	11	18.9	0.58	12.36	7.2

(Kumar and Kushwaha, 2013; Kalambukattu and Kumar, 2017). Topography and poor agricultural management practices have led to higher SE rate in these landscapes. Soils in these landscapes are fragile in nature and are immature. Low OC content in these soils resulted in poor aggregation and less adhesive forces, making them susceptible to SE. A similar study conducted by Dabral *et al*. (2008) in Dikrong river basin of Arunachal Pradesh for 17 years using USLE model indicated average annual soil losses up to 51 t ha^{-1}yr^{-1}.

SY Estimation of Sub-Watershed

Sitlarao watershed was sub-divided into 09 sub-watersheds using Carto-DEM processed in Arc-GIS. SDR of each sub-watershed was computed based on method described by Walling (1983) and drainage area based empirical equation given by Sharda and Ojasvi (2016) for North India. This empirical equation was used to compute SDR for sub-watersheds, and it was found that SDR values are >1 which is not possible. Therefore, it was concluded that this empirical equation cannot be used as it has been developed for large basin area. In the present study, SDR was from Walling (1983) method to estimate average SY of each sub-watershed. SDR values ranged from 0.48 to 0.73 among the 09 sub-watersheds (Table 6). Highest SDR value of 0.73 was observed in sub-watershed SW-7, and the lowest value of 0.48 for sub-watersheds SW-3 and SW-4. Average SE of each sub-watershed was computed from SE map generated using RUSLE model. SY from sub-watershed ranged between 2.7 t ha^{-1}yr^{-1} and 32.2 t ha^{-1}yr^{-1} (Table 6). Highest estimated SY was from SW-1 and lowest from SW-8. The present study exhibited the effectiveness of GIS usage in estimating SY of the sub-watershed. Based on average SY, sub-watershed can be prioritized for planning and implementation of various soil and water conservation activities in the watershed.

Measurement of Event Wise SDR of a Sub-Watershed

Surface runoff and SY of 08 rainy days were analyzed for SW-1 during the years 2016-2017. Average SE of the sub-watershed was computed using RUSLE for the daily rainfall. Average SY of sub-watershed was computed based on total surface runoff on the day and sediment concentration measured from sample of the sediment tank. The SDR values for these eight rainy days ranged from 0.32 to 0.71 with an average of 0.48 (Table 7). Highest SDR was observed from the received rainfall of 73.15 mm, and lowest on the day with rainfall of 20.32 mm. The average SDR value was found to correspond with the SDR value computed using method described by Walling (1983).

Drainage area based methods cannot be used for small watersheds as these empirical equations have been developed for large basin. The SDR computed using drainage area equation proposed for northern region of India by

Table: 7
Values by hydrological event for rainfall, intensity, runoff, sediment yield and SDR for Sitlarao watershed

Event	Rainfall (mm)	Rainfall Intensity (mm hr^{-1})	Runoff (mm)	Av. Sediment Yield (ton)	Av. Soil erosion (ton)	SDR (%)
19/Aug/2016	46.73	51.59	21.02	0.030	7.18	0.42
26/Aug/2016	33.52	64.66	11.28	0.020	5.15	0.39
05/Sept/2016	57.91	57.44	30.11	0.040	8.89	0.45
11/Sept/2016	66.53	61.18	36.60	0.060	10.22	0.59
30/July/2017	20.32	3.15	3.50	0.010	3.12	0.32
31/July/2017	73.15	4.89	43.26	0.080	11.23	0.71
03/Aug/2017	104.14	24.92	71.51	0.090	15.99	0.56
21/Aug/2017	53.84	25.27	26.74	0.030	8.27	0.36

Sharda and Ojasvi (2016) were computed were >1, which is unrealistic. Therefore, in the present study, SDR values were calculated from Walling (1983) method and were found more realistic. It was validated with the measured SDR for SW-1. These sub-watersheds represent first order streams; therefore, SDR values were observed to be high. Due to smaller drainage length, large amount of sediments drained off to streams. For prioritizing sub-watershed in case of small watershed, drainage area based method was unsuitable. Therefore, it is recommended to use SDR derived from Walling method for smaller watershed for computation of SY from the watershed. This is easy and more reliable method to implement for watershed prioritization based on SY. Average SY was computed 0.010 to 0.090 t $ha^{-1}yr^{-1}$ in the watershed.

4. CONCLUSIONS

The present study aimed to estimate SE and SY in the Sitlarao watershed using RUSLE model in GIS environment. The study revealed that nearly 36.4% area of watershed falls under high to very high risk of SE. Open scrub land was predicted to have the highest (26.04 t $ha^{-1}yr^{-1}$) average SE than other land cover categories followed by open forest (19.15 t $ha^{-1}yr^{-1}$) and moderate forest cover (17.24 t $ha^{-1}yr^{-1}$). The watershed was divided into 09 sub-watersheds by processing Carto-DEM in Arc-GIS to prioritize the area of the watershed for conservation planning. SDR of sub-watersheds was estimated and it ranged from 0.48 to 0.73 in the watershed. Due to lesser drainage area, these sub-watersheds had exhibited high SDR. Thus, it indicates that most of the eroded soils got drained off to streams. SY of these sub-watersheds varies from 2.7 t $ha^{-1}yr^{-1}$ to 32.2 t $ha^{-1}yr^{-1}$. Sub-watershed wise average SY information helped in prioritization of sub-watershed for conservation planning in the watershed. This study revealed that integration of RUSLE model with GIS provided reliable estimate of SE susceptible region in the catchment area. Estimation of SDR based on soil and sediment clay ratio (Walling, 1983) serves as most appropriate method for small watershed for estimating sediment loss and sub-watershed prioritization. The proposed method can be quite useful in identifying high erosion prone areas within the watershed, and for prioritizing and suggesting conservation measures to reduce SE. High LS factor due to steep terrain characteristics and LU/LC types alongwith poor agriculture management practices were identified as the major cause of high SE rates in the watershed.

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