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Modelling soil erosion risk in a mountainous watershed of Mid-Himalaya by integrating RUSLE model with GIS

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Abstract

Soil erosion is one of the major cause of land degradation and is a serious threat to food security and agricultural sustainability. Revised Universal Soil Loss equation (RUSLE) model using remote sensing (RS) and Geographical Information Systems (GIS) inputs was employed to estimate soil erosion risk in a watershed of mid-Himalaya in Uttarakhand state, India. Spatial distribution of soil erosion risk area in the watershed was estimated by integrating various RUSLE factors (R, K, LS, C, P) in raster based GIS environment. RUSLE model factor maps were generated using remote sensing satellite data (IRS LISS III and LANDSAT-8) and Digital elevation model. Agriculture (59%) was found to be the dominant land use system followed by scrub land (20%) in the watershed. Rainfall erosivity (R) factor was estimated using past 23 years rainfall data. SRTM DEM was used to generate slope length –steepness (LS) factor in this highly rugged terrain. Nearly 70% of the watershed is having steep to moderately steep slope (>40%). Satellite data was interpreted to prepare physiographic map at 1:50,000 scale. Surface soil samples collected in each physiographic unit was analyzed to generate soil erodibility (K) map. Soil erodibility factor ranged from 0.033 to 0.077 in the watershed. Soil erosion risk analysis showed that 36.25%, 9.31%, 15.80%, 15.27%, 11.46% and 11.89% area of watershed falls under very low, low, moderate, moderate high, high and very high erosion risk classes respectively. The average annual erosion rate was predicted to be 65.84 t/ha/yr. The soil erosion rates were predicted to vary from 3.24 t/ha/yr in dense mixed forest cover to 87.98 t/ha/yr in open scrub land. The soil erosion map thus generated employing remote sensing and GIS techniques, can serve as a tool for deriving strategies for effective planning and implementation of various management and conservation practices for soil and water conservation in the watershed.

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Introduction

According to the United Nations Convention to Combat Desertification (UNCCD) land degradation has been defined as any reduction or loss in the biological or economic productivity of the land brought about by anthropogenic activities, accelerated by natural processes and thereafter magnified by the impact of climate change and biodiversity losses (UNCCD, 1994). So much so is the intensity and problem of land degradation that it has been identified as one of the major global challenges in the path of sustainable development by the world leaders at the Rio+20 conference (Rio+20, 2012). Global assessments about land degradation shows an increase in the highly degraded area from 15% in 1991 to 25% by 2011 and it is predicted that if

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land degradation continue to occur at the current rate over the next 25 years, it would reduce the global food production by 12% (IFPRI, 2012). The entire land degradation process has accelerated during the last century with an estimated loss of 24 million tons of fertile top soil from the agricultural lands across the globe (FAO, 2011). Thus, soil erosion is one of the major causes of land degradation which involves a gradual process of removal of soil particles from land surfaces by runoff, thus, causing deterioration of soil and adversely affecting the productivity of all natural ecosystems including agriculture, forest and rangeland ecosystems (Lal and Stewart, 1990, Pimentel et al., 1995).

In a developing country like India both on and off site damages of soil erosion has far reaching social, political, economic and environmental implications (Pandey et al., 2007) thus posing a serious threat to long term sustainability of agricultural production and environmental quality. In Indian context, the north western Himalayan belt are highly prone to soil erosion, because of the instability due to ongoing tectonic activities (Sati et al., 2011) and in recent times the developmental activities synonymous to the anthropogenic interventions have contributed highly to the instability in the Himalayan region, thereby increasing incidents of erosion and landslides. Soil resource is necessary to maintain the productivity in hilly terrain of Himalaya, where livelihood of people is mainly dependent on farming system and especially on subsistence agriculture. Sustainable use of mountains depends upon conservation and potential use of soil and water resources (Ives and Messerli, 1989). It has been observed that loss of fertile top soil, because of surface and gully erosion, is a common phenomenon and agricultural land has expanded to areas having marginal soil cover (Hofer, 1998). Thus, natural resources in mountainous terrain are profoundly afflicting from land degradation as a result of intensive deforestation, overgrazing and subsistence agriculture due to population pressure, large-scale road construction and mining etc. Garde and Kothyari (1987) reported that the soil erosion rate in the northern Himalayan region is high and in the order of 20 to 25 t/ha/yr. Therefore in Northern Himalayan region advance management procedure to balance soil erosion and soil conservation is extremely necessary. Over the past 40 years, significant concerns have been raised over the degradation of the soil resources in the Himalayan mountainous regions as a result of the expansion of agricultural land and the increase in cropping intensity.

The Himalayan mountains are young and fragile characterized by steep slopes (evolved out of exogenic and endogenic processes and are precariously balanced), low soil depth, poor water holding capacity of the soil due to coarse texture and are highly prone to soil erosion (Sati et al., 2011). In addition high seismicity, depleted forest covers, occasions of climatic extremities like focused rainfall (cloud burst) and pressure of utilizing natural resources beyond the capacity has all led to accelerated erosion problems raising a question on the long term sustainability of mountain ecosystems (Jain et al., 2001). The mid-Himalayan region is the main agricultural zone of Himalayas, which caters to the food production requirements of vast rural population, through the various low input subsistence farming activities and practices. Thus assessment of erosion risk in the mountainous Himalayan region for sustainable growth and development and ecosystem balance is the need of the hour. However, delineation of areas on steep slopes as management units is difficult, thus planning, conservation and management of natural resources on watershed basis becomes more convenient and easier. The concept of using watershed as a development unit in India dates back to 1970s and since then several watershed programs have been launched in the country (Wani and Garg, 2009). The watershed not only serves as hydrological unit but it also acts as a socio-political-ecological unit which plays a very crucial role in determining food, social and economic security and providing life support services to the rural people.

Soil conservation strategies in a watershed are generally planned according to the severity of the problem in that watershed and this severity is determined by considering a number of important factors including annual soil loss, quantitative measure of topsoil etc. Although physical verification of soil loss in thousands of watersheds and micro-watersheds in a river basin was near to impossible task until the recent development in remote sensing and Geographical information system techniques. Soil erosion management strategies in Himalayan mountainous region are also constrained by dearth of such data, because actual measurements of soil loss from crop fields and mountainous regions are uncommon in the country. Reliable and updated information on watershed soil erosion is an essential prerequisite for prioritization of watershed as well as formulation of appropriate management programs, which are key components for sustainable development (Pandey et al., 2007). However, it becomes difficult to measure or predict the erosion in a precise manner due to the complexity of the variables involved in erosional process. The remote sensing data provide accurate, and near real time information on the various aspects of watershed such as land use/land cover, physiography, soil types, drainage characteristics, etc. It also assists in the identification of the existing or potential erosion prone areas and provides data inputs to many of the soil erosion and runoff models.

Rapid and detailed assessment of erosion hazards can be effectively done using Remote sensing data and GIS along with Digital elevation models (DEM) (Jain et al., 2001), by providing valuable inputs to various erosion models like USLE/RUSLE, MMF, WEPP, SWAT, ANSWERS, LISEM etc, which are having their own specific characteristics and application scopes (Boggs et al., 2001; Lim et al., 2005; Dabral et al., 2008; Lu et al., 2004; Tian et al., 2009). GIS compatibility and convenience in application at various scales makes USLE/RUSLE the widely used erosion model to predict soil loss across the globe. (Millward and Mersey, 1999; Jasrotia and Singh, 2006; Bonilla et al., 2010). It predicts spatial extent of soil erosion as well as erosion rates in ungauged watersheds using knowledge of the local hydroclimatic conditions and watershed characteristics (Angima et al., 2003). Jain et al. (2001) estimated soil erosion from a Himalayan watershed by using two different soil erosion models, i.e. the Morgan model and Universal Soil Loss Equation (USLE) model, using remote sensing and GIS generated input parameters. .

The present study envisages the use of RUSLE model for assessment and quantification of annual soil erosion rate and developing soil erosion risk map of a mountainous watershed of river Maniyar in the Himalayan region using RUSLE and GIS technique. This particular area was chosen as it represents various characteristics of a typical mid Himalayan watershed including steep slopes with high slope variation, various LULC patterns and a predominance of agricultural area where low input subsistence farming is practiced. This study may contribute to our knowledge about the various factors affecting soil erosion in these fragile mid-Himalayan ecosystem and help us in adoption of various management strategies efficiently.

Material and Methods

Study area

The study was carried out in Maniyar watershed, which is located near Tehri dam in TehriGarhwal district in Uttarakhand, India (Figure 1).

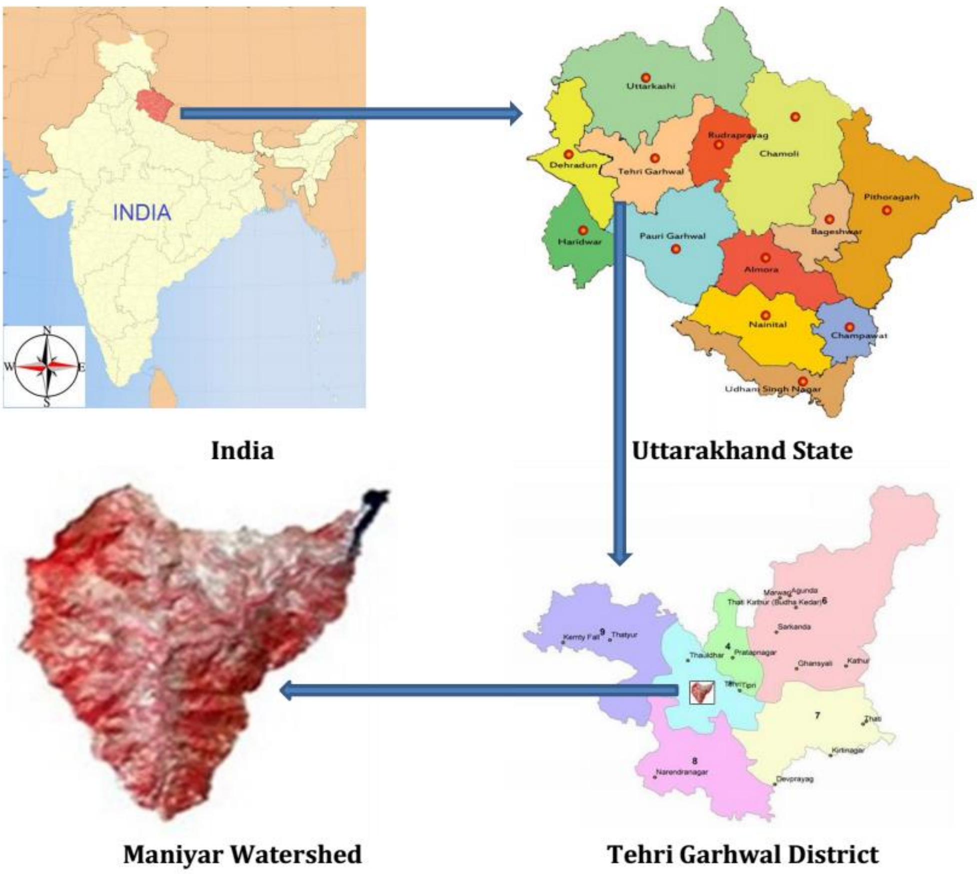

Figure 1. Location of the study area

It covers an area of 4428.5ha (44.29 sq.km) and lies between longitudes 78°28’0”E - 78°21’30”E and latitudes 30°20’0”N - 30°25’30”N. The region is highly undulating and exhibits the typical mountainous topography of North Western Himalayas, with an elevation between 667 to 2459 m above msl. The watershed is characterized by precipitous slopes, deep gorges, narrow valleys and rocky escarpments. The entire watershed consist of high hills and ridges which are deeply incised by the streams. The annual average rainfall is 1400 mm (1990-2013 period data) whereas the average number of rainy days (having daily rainfall >2.5 mm) is 61.5 days. Most parts of the watershed is highly inaccessible due to very steep sloping and rugged terrain. Geologically the area is represented by rocks of lesser as well Central Himalaya and contain mica gneiss, calcic gneiss, quartzite, marble, mica schist and amphibolite as major rock types. Agriculture land is the dominant land use system in the watershed followed by forest and scrub land. Rice, maize, vegetables and wheat are the major crops grown in the watershed.

Data used

Survey of India toposheet covering the study area was used as guide for carrying out field work as well as preparing road network. IRS P6 LISS III image of April and December months were used for accurate preparation of landuse/ land cover map by digitization based on field collected ground control points. SRTM DEM having 30m resolution was used for various hydro processing steps including generation of slope, aspect, flow direction, flow accumulation as well as drainage network maps. The products were used for estimation of LS factor values of the entire watershed. GPS receiver was used for recording the geographical coordinates of the various sampling points during field data collection. The values of various soil parameters, estimated by laboratory analysis of field collected soil samples were also used. The remote sensing as well as other spatial data were processed and analyzed using ERDAS imagine and Arc GIS10.1 softwares.

Methodology

The RUSLE model (Renard et al., 1997) was developed as an empirical model representing the main factors controlling soil erosion, namely climate, soil characteristics, topography, and land cover management. The equation is expressed as:

$$A = R \times K \times LS \times C \times P \quad (1)$$

where,

- A = predicted average annual soil loss per unit area [$ton \cdot ha^{-1} \cdot year^{-1}$],
- R = rainfall -runoff erosivity factor (rainfall and snowmelt) in [$MJ\ mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}$],
- K = soil erodibility factor [$ton \cdot ha \cdot hr \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$],
- LS = slope length-steepness factor (dimensionless),
- C = cover-management factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimensionless)
- P = conservation support practice factor (dimensionless).

The following section describes deriving of various factors of RUSLE from satellite data, DEM, rainfall data.

Data Processing and RUSLE factor generation

The above mentioned factors were generated using remote sensing as well as field derived information and further integrated in a GIS environment according to the following methodology to estimate soil erosion in the present study (Figure 2). The various RUSLE factor maps were generated in a digital GIS environment using Arc GIS 10.1 and ERDAS Imagine 2014, and the associated GIS packages. These factor maps were integrated employing RUSLE model to compute annual soil erosion rates and its severity.

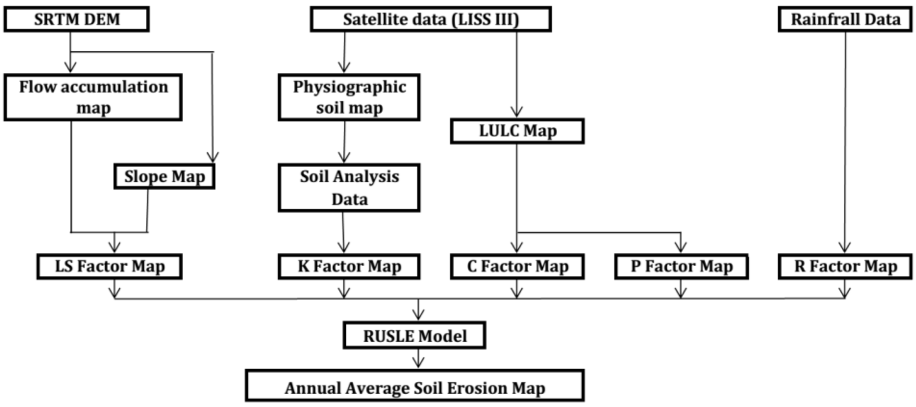

Figure 2. Methodology flow chart adopted in the study

R factor (rainfall erosivity factor)

The R factor is a measure of the erosive force of specific rainfall. It quantitatively expresses the erosivity of local average annual rainfall. R-factor computation requires long-term data of rainfall amounts and intensities. Since rainfall intensity of the study area could not be estimated in the absence of a recording type rain gauge, well established empirical equations using total rainfall (monthly, seasonal or annual) are widely employed. R factor was estimated using the rainfall data of past 23 years (1990-2013) obtained from Ranichauri University near the watershed, using empirical relationship (Babu et al., 2004).

$$R = 81.5+0.375*A \tag{2}$$

($340 \le A \le 3500$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 to detachment and transport of soil particles (grains or crumbs), under an amount and rate of runoff for a specific rainfall, measured under standard plot. The erodibility factor depends on physico-chemical properties of texture, organic matter content, permeability of soil and soil structure. Physiographic soil map was generated by interpretation of std. FCC at 1:50000 scale by onscreen digitization. The various physiographic units were delineated based on the landform, slope characteristics and land use land cover types. Filed work was planned in such a way to collect soil samples from each of the physiographic units present in the watershed. The number of samples (3-4 nos) from each unit was determined by the area covered by each unit. The collected soil samples were analyzed in the laboratory for texture, organic matter content and structural characteristics, which are essential for the determination of K factor. The following equation was used to compute K factor (Wischmeier and Smith, 1965; Renard et al., 1997)

$$K = 27.66 * m^{1.14} * 10^{-8} * (12-a) + 0.0043 * (b-2) + 0.0033 * (c-3) \tag{3}$$

Where:

K = soil erodibility factor (ton .ha. $h.ha^{-1}.MJ^{-1}.mm^{-1}$)
m = (Silt % + Sand %) x (100-clay %)
a = % organic matter
b = structure code: 1) very structured or particulate, 2) fairly structured, 3) slightly structured, 4) solid
c = profile permeability code: 1) rapid, 2) moderate to rapid 3) moderate, 4) moderate to slow, 5) slow 6) very slow

LS factor (Slope length and steepness factor)

The total erosion or sediment yield from a watershed depends not only on slope length but on steepness also. *LS* factor expresses the effect of local topography on soil erosion rate, combining effects of both slope length (L) and slope steepness (S). Various other factors such as compaction, consolidation and disturbance of the soil were also considered in addition to steepness and length while generating the LS-factor. Erosion increases with slope steepness but, in contrast to the L-factor representing the effects of slope length, the RUSLE makes no differentiation between rill and inter-rill erosion in the S-factor that computes the effect of slope steepness on soil loss (Renard et al., 1997; Krishna Bahadur, 2009). SRTM DEM with 30m resolution was used to compute LS factor using the spatial analyst and hydrology toolkits in ArcGIS software, following the method described by Moore and Burch (1986) and Mitasova et al. (1996).

$$LS = (\text{Flow Accumulation*Grid Size}/22.13)^{0.6} (\text{Sin[Slope]}*0.01745/0.0896)^{1.3} \tag{4}$$

Where, flow accumulation denotes the accumulated upslope contributing area for a given cell, Cell size denotes the size of grid cell (30m), Sin of Slope values in degree

C factor (Crop cover factor)

C factor represents the effects of vegetation % and crop types on soil erosion (Renard et al., 1997). Its value ranges from 0 (waterbodies) to 1 (barren land), because of the lack of vegetation, root biomass or other surface covers to resist soil erosion. Thus, it expresses the relation between soil erosion on bare area and erosion observed under a particular cropping system and indicates the role played by cover-type as well as density on soil protection. The C factor thus incorporates the effects of plant cover, level of production as well as the various associated cropping techniques into one single value. In the study, C factor map was generated using the land use/land cover (LULC) map prepared by visual interpretation of satellite data. The boundaries of the various LULC classes was verified and corrected during the field survey. The major crops grown in the study area are rice, maize, wheat, fruit trees and various vegetables. Majority of the study area is dependent on rainfall as sole water source for agricultural activities. Only very less area, near the channels at low elevation have irrigation facilities. Low input subsistence farming using local varieties, traditional farming practices and inputs is practiced in the entire area. The land use/land cover map was reclassified based on C factor values using tools in ArcGIS, 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; Rao, 1981; Suresh Kumar and Kushwaha, 2013).

P factor (Conservation Practice factor)

The P factor represents the effect of various conservation and support practices being taken up in the study area, on soil erosion. The various 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 soil erosion. It includes the effect of various practices such as contouring, terracing, strip cropping, bunds etc (Hyeon and Julien, 2011). In the study area various management practices like terracing, bunding, grass bunding etc are followed by farmers depending on the slope steepness and resource availability. In this study, P factor map was generated using the land use land cover map by assigning P values for each of the land use land cover types (Wischmeier and Smith, 1978).The map was reclassified based on P factor values using tools in ArcGIS, to yield P factor map in raster form.

All the inputs for RUSLE model execution were generated in GIS platform using remote sensing and field collected information. The various factor maps were generated and converted into raster format keeping uniform projection as well as cell size, to avoid erroneous execution and misinterpretation of results.

Results and Discussion

The various factor maps of RUSLE model (R, K, LS, C and P) generated using remote sensing and GIS inputs were integrated in a GIS environment using ArcGIS spatial analyst module in order to quantify and generate the soil erosion risk and severity maps of Maniyar watershed.

Land Use/Land Cover

Standard FCC of satellite data were visually interpreted for the information regarding land use/land cover type by making use of the interpretation keys. The map was digitized to prepare digital vector coverage and rasterized for spatial GIS analysis. The major types of land use/land cover interpreted were forest, agriculture, scrub land, river and settlement. Forest cover was further classified into dense mixed forest, dense pine forest, and open forest cover. Scrub land was further sub-divided into dense scrub and open scrub (Figure 3). Agriculture (58.9 %) formed the predominant land use/land cover type followed by scrub (23.52%). The major crops grown in the area were wheat, vegetables, mustard, fruit trees etc. Paddy was found to be cultivated in the valley, where irrigation facilities were available. Intensive agricultural practices on the steep sloping lands could be correlated with the enhanced soil erosion of Maniyar watershed. The LULC map was used to derive C and P factor maps (Table 1).

Table 1. Area under various land use/ land cover

Sl No	LULC	Area (sq. km) (%)	C factor	P factor
1	Cropland	26.29 (58.94%)	0.5	0.5
2	Dense mixed forest	1.85 (4.15 %)	0.008	1
3	Dense Pine forest	1.85 (4.15 %)	0.08	1
4	Open forest	2.64 (5.92 %)	0.4	1
5	Dense scrub	8.77 (19.66 %)	0.05	1
6	Open scrub	1.72 (3.86 %)	0.6	1
7	Settlement	0.16 (0.36 %)	1.0	0.0
8	River	1.32 (2.96 %)	0.0	1.0

Slope characteristics

The elevation of the watershed varied from 667 metres to 2459 metres above the mean sea level (Figure 4). The extracted DEM was used for generation of slope map (Figure 5). The entire watershed study area was classified into five different slope classes (Table 2), ranging from 0% to more than 60%. The slope analysis revealed that nearly 70% of land under study area is having slope more than 40% and nearly 90% of area is having slope more than 25%. Such degree of steepness in the slope is conducive to very high rates of soil erosion, even with slight or moderate amount of rainfall and soil disturbance. Also, higher slope accounts for very shallow soil depth, which limits crop cover establishment, which in turn is responsible for protecting the soil surface from erosive factors. Slope aspect map was also generated for the area (Figure 6). The entire study area was grouped into two aspects i.e., north and south aspects. This is important from plant growth point of view, as the aspect (direction) determines the amount of solar radiation received on soil surface and thus, the soil temperature and moisture available for plant growth and soil development.

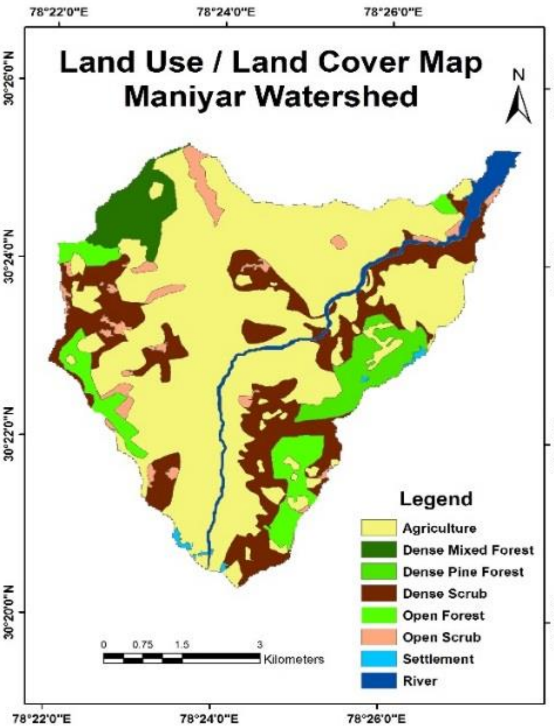

Figure 3. Land use Land cover map

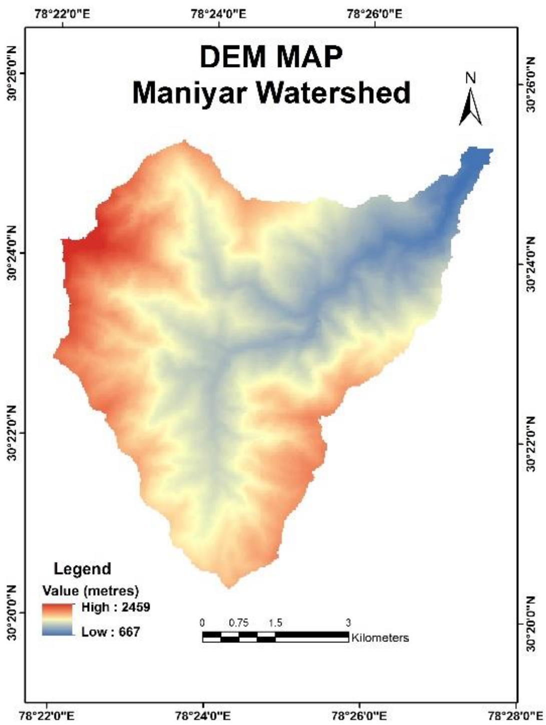

Figure 4. DEM of study area

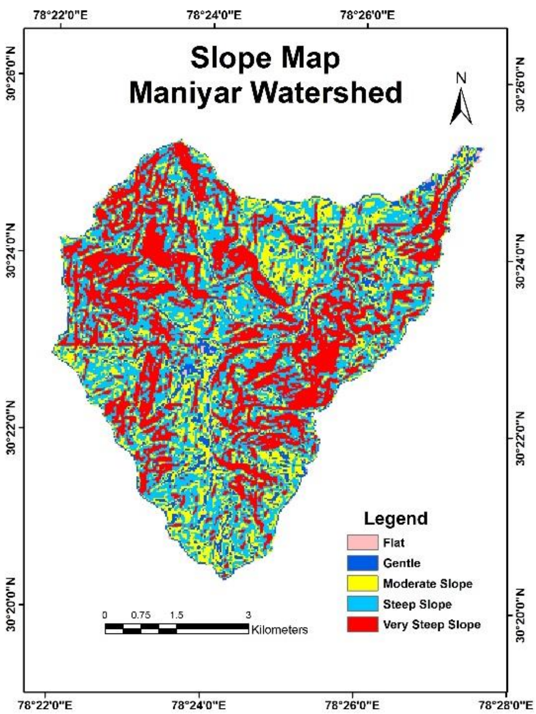

Figure 5. Slope map of study area

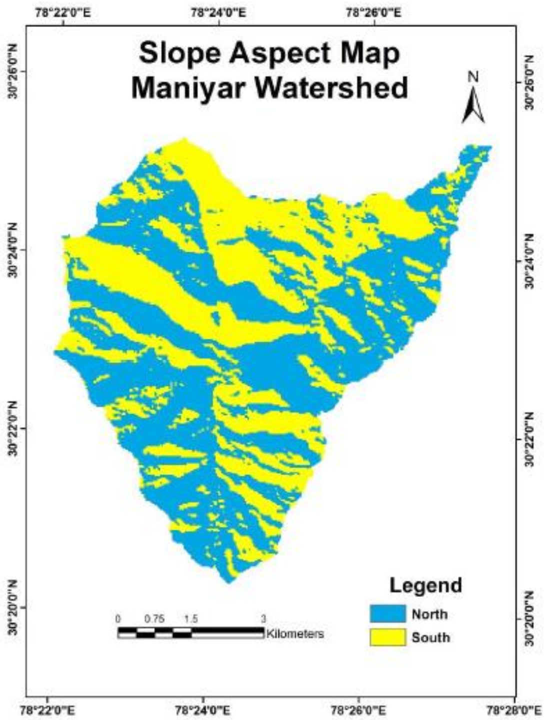

Figure 6. Slope Aspect map of study area

Table 2. Slope classes and distribution in the study area

Slope class	Slope values (%)	Area (sq.km)	% of Total area
Flat	0-10	0.48	1.01
Gentle	10-25	3.53	7.97
Moderate	25-40	9.36	21.13
Steep	40-60	16.15	36.47
Very steep	>60	14.77	33.34

Physiographic soil map

The physiographic soil map was prepared by visual interpretation of satellite imagery and with the help of slope map, aspect map and land cover land use map. Based on the landform, slope characteristics and land use / land cover pattern the study area was divided into 15 physiographic units excluding river (Figure 7). The major landform present in the study area is hills. The hilly landform was again divided based on variation in slope characteristics and aspect. The land use/land cover types present in various slope and aspect categories of hilly landform was considered for classification of area into 15 different physiographic units (Table 3). These physiographic units form the basis of soil sampling. It is the study of the factors and process of the landform evolution as the factors involved in physiographic processes are mostly the same as those influencing soil formations.

Table 3. Areal distribution of various physiographic units

Physiographic Unit	Area (sq.km)	Area (%)	K factor
Very steep hill-North-Forest (H111)	2.21	5.14	0.038
Very steep hill-South-Forest (H121)	7.03	16.36	0.045
Very steep hill-North-Agriculture (H112)	4.09	9.52	0.036
Very steep hill-South-Agriculture (H122)	1.08	2.513	0.065
Very steep hill-North-Scrub (H113)	2.09	4.86	0.044
Very steep hill-South-Scrub (H123)	4.01	9.33	0.077
Steep hill-North-Forest (H211)	2.11	4.91	0.058
Steep hill-South-Forest (H221)	0.69	1.61	0.055
Steep hill-North-Agriculture (H212)	5.97	13.89	0.076
Steep hill-South-Agriculture (H222)	6.20	14.43	0.051
Steep hill-North-Scrub (H213)	1.25	2.91	0.033
Steep hill-South-Scrub (H223)	0.35	0.81	0.050
Moderate hill-North-Agriculture (H312)	2.07	4.82	0.066
Moderate hill-South-Agriculture (H322)	1.79	4.17	0.061
Valley-Agriculture (V-Agri)	2.03	4.72	0.058

R factor

R factor was generated using 23 years rainfall data, employing the relationship given by Babu et al. 2004. The R factor value was estimated to be 606.5 MJ mm $ha^{-1}h^{-1}$ and as we had a single value no map was generated and was used as value along with other factors. As the study area doesn't have any record of daily rainfall intensity and since the area of watershed was only 44.29 sq km, a single R factor value was assumed for the whole area.. Similar R factor values have been estimated in various studies in India as well as abroad. The R factor value for Daltonganj watershed in Jharkhand was estimated to be 114.3 MJ mm $ha^{-1}h^{-1}$ (Tirkey et al., 2013). Similarly in a study carried out in Shivalik Himalayan region, Suresh Kumar and Kushwaha (2013) has reported a value of 383 MJ mm $ha^{-1}h^{-1}$, where the rainfall amount is less. Similar R factor values were also reported by Farhan et al. (2013) from a study undertaken in Jordan, Prasannakumar et al. (2012) from Western Ghats region, from Krishnagiri watershed region of Tamilnadu by Elangovan and Seetharaman (2011). Singh et al. (1981) has reported that the value of *R* factor ranges from about 250 – 1250 MJ mm $ha^{-1}h^{-1}$ in western Rajasthan and coasts of Maharashtra and Karnataka, respectively.

K factor

K factor values were estimated using the soil information generated from laboratory analysis of soil samples from various physiographic units.. Soil parameters used for K factor are soil texture (% of sand, silt and clay), soil organic matter, soil permeability class and soil structure class. K value of soils in the watershed varied from 0.033 to 0.077 (Table 3). The organic matter and soil texture were found to have high influence on K factor values. Waterbody as well as settlement were assigned K factor value equal to zero. The calculated K factor values were assigned to various physiographic units and reclassified to yield a K factor map depicting the spatial distribution of K factor values (Figure 8). Similar K factor values were reported earlier by Farhan et al. (2013) in an extensive study carried out in Kufranja watershed, Northern Jordan and by Ashiagbor et al. (2013) from a study in Ghana.

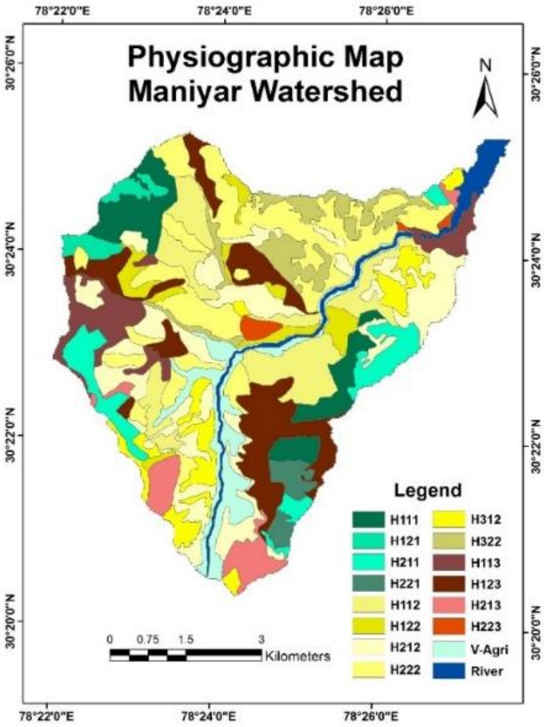

Figure 7. Physiographic map of study area

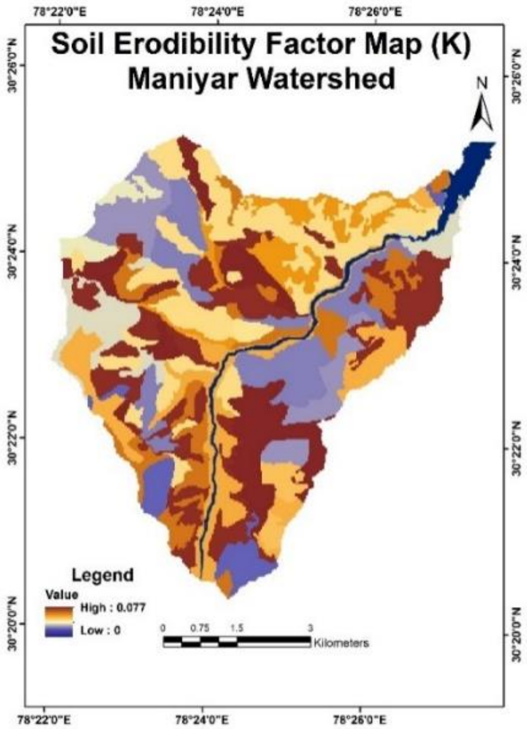

Figure 8. Spatial distribution of K factor

LS factor

LS factor map was created using the flow accumulation and slope maps generated by DEM analysis. LS factor values ranged from 0 (low) to 556.2 (high) in the watershed (Figure 9), with mean and standard deviation of 15.28 and 34.61 respectively. Majority of the study area had LS values less than 30 and only some areas near streams exhibited values more than 50. The high values may be due to the highly dissected terrain and abrupt slope changes near the drainage channels. Similar LS values have already been reported by various researchers in various regions and landscapes including mountainous sub watershed in western Ghats of Kerala (Prasannakumar et al., 2012), Densu river basin of Ghana (Ashiagbor et al., 2013), Kufranja watershed of Jordan (Farhan et al., 2013), Loess Plateau in north China (Sun et al., 2014) and Pathri Rao sub watershed in Shivalik region of Uttarakhand, India (Suresh Kumar and Kushwaha, 2013). All these studies unanimously agreed that higher LS factor values are observed in hilly and gully regions as well as mountainous areas with very steep topography and these areas are prone to sever erosion, due to topography. The unexpectedly high LS values observed in and near channels were excluded form RUSLE estimation, by using a stream network mask. Thus the impact of very high LS values on soil erosion estimation was reduced to the possible minimum to avoid abnormal results.

C factor

The C factor values of the watershed ranged from 0.008 to 0.6 (Table 1). Spatial distribution of crop cover factor is given in Figure 10. They were assigned based on land use land cover map and values obtained mainly from various studies. The values ranged from 0.008 in dense mixed forest to 0.6 in case of open scrub. Higher values of C factor indicate no cover effect and soil loss comparable to that from bare soil, while lower C means a very good vegetation cover effect and less soil loss comparable to bare soil and hence less or negligible erosion.. So in Maniyar watershed open scrub is highly prone to erosion whereas the various forest types are least prone to erosion. The scrub was also found to have low NDVI values, indicating very less crop cover on ground in comparison to other classes. Similar C factor values were used in various erosion studies by earlier researchers (USDA, 1972; Tirkey et al., 2013).

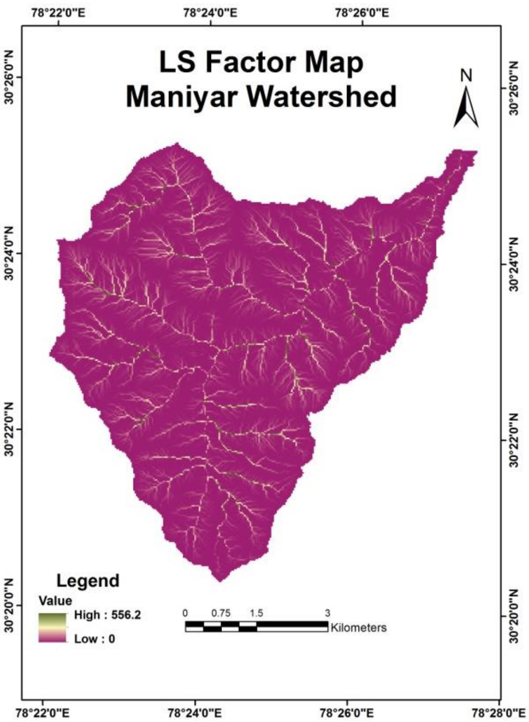

Figure 9. Spatial distribution of LS factor

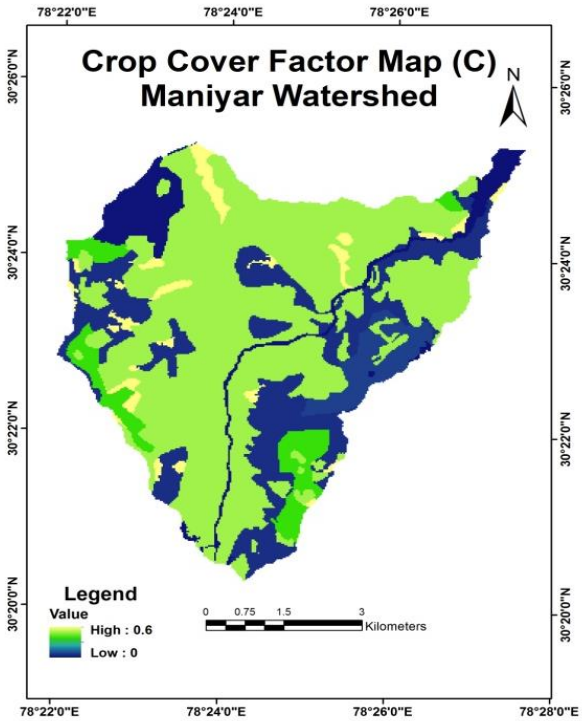

Figure 10. Spatial distribution of crop cover management (C) factor

P factor

Erosion control practice factor was derived based on the land use land cover map of the study area. The values were assigned from previous studies conducted in similar areas (Suresh Kumar and Kushwaha, 2013; Tirkey et al., 2013 and Sun et al., 2014). P factor values ranged from 0.5 to 1 in the study area (Table 1). Majority of the study area is under forest as well as scrub, and there is no control practices adopted in these land uses, giving them a P factor value of 1.0, whereas the agricultural lands having some conservation practices like bunding, terracing etc are having lower P factor value of 0.5 (Figure 11).

Soil erosion Risk Assessment

After preparation of all the RUSLE factor maps, they were overlaid using raster calculator in GIS environment to obtain the average annual soil erosion (A) map with values ranging from 0 to 1961 t/ha/yr, in the entire study area. The average annual soil loss in the watershed was found to be 65.84 t/ha/yr. The higher estimated A values indicate higher rate of sediment yield compared to the lower sediment yield rates associated with lower A values. Soil erosion was classified into six soil erosion risk classes (Figure 12) of very low (0-10 t/ha/yr), low (10-25 t/ha/yr), moderate (25-50 t/ha/yr), moderate high (50-100 t/ha/yr), high (100-200 t/ha/yr), very high (>200 t/ha/yr). The spatial distribution of soil erosion risk classes in the study revealed that 36.25% of the watershed has very low erosion, 9.31 % has low, 15.8 % has moderate, 15.27% has moderate high, 11.46% has high and 11.89% area is under very high erosion risk class (Table 4).

Table 4. Areal extent of soil erosion risk classes

Soil erosion classes	Soil loss (tons/ha/yr)	Area (sq.km)	Area (%)
Very low	0-10	15.75	36.25
Low	10-25	4.04	9.31
Moderate	25-50	6.86	15.80
Moderate High	50-100	6.63	15.27
High	100-200	4.98	11.46
Very High	>200	5.16	11.89

Results indicated that higher values of soil erosion are mainly observed on abrupt slopes neighboring the drainage lines, including streams and river. This may be due to the higher availability of weathered materials for the runoff to carry. The higher slope regions are also affected by rills, gullies as well as mass movement of sediments, which were clearly visible during field surveys and is a common phenomenon in the study area because of the fragile geomorphology. Average soil erosion rate per LULC class was also estimated (Figure 13) and it was found that dense mixed forest is having least erosion rates (3.24 t/ha/yr), whereas highest erosion rates are found in open scrub with a value of 87.98 t/ha/yr. The total amount of soil eroded will be highest from agricultural fields as they cover nearly 60% of study area and most of the cropped areas are rainfed.

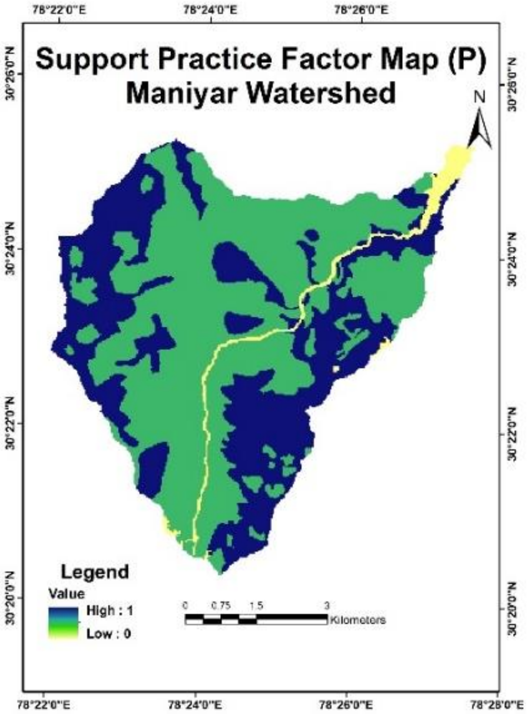

Figure 11. Spatial distribution of P factor

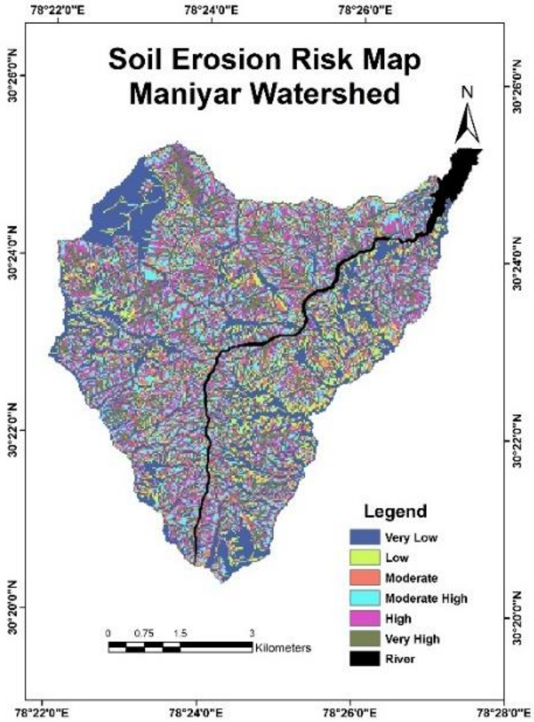

Figure 12. Soil erosion risk map of area

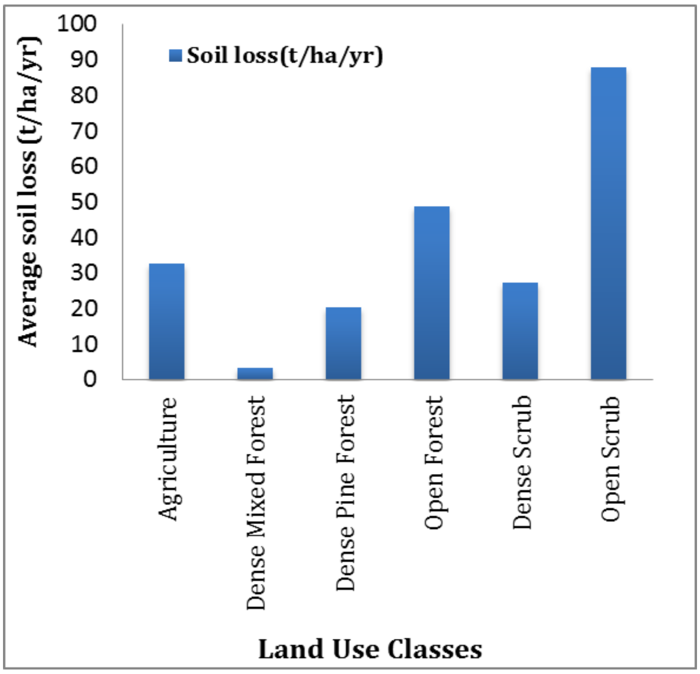

Figure 13. Average soil loss under various land use systems

The results are comparable with other studies undertaken in areas where similar terrain, soil, climatic characteristics as well as land use patterns prevail (Shiono et al., 2002; Lee and Lee, 2006; Adediji et al., 2010), where annual average erosion rates were found to be 0-45 t/ha/yr. Haile and Fetene (2011) reported maximum erosion rates of 50-60 t/ha/yr in upland regions of Kilie catchment in Ethiopia, where slope gradient is 8-13^0. A similar study conducted by Dabral et al. (2008) in Dikrong river basin of Arunachal Pradesh for 17 years using USLE model has indicated average annual soil losses upto 51 t/ha/yr.

They also reported that 25.61% of total area is under slight erosion, whereas 26.51, 17.87, 13.74, 2.39 and 13.88 percentages of area were under moderate, high, very high, severe and very severe erosion potential zones. In another significant study carried out in Pathri Rao sub-watershed in the Shivalik region of Himalayas, using RUSLE 3D and GIS techniques Suresh Kumar and Kushwaha (2013) has predicted average annual soil erosion rates to be 35.47 t/ha/yr. Their results also indicated that lowest erosion rates (8.50 t/ha/yr) are in areas of very dense forest cover, whereas the lowest rates (134.9 t/ha/yr) are associated with open forest area in the steep slopes of hilly terrain. Another study conducted by Poreba and Prokop (2011) in the hilly mountain terrain of Meghalaya, using Cs^{137} technique has given annual erosion values ranging from 29 to 79 t/ha/yr. Similarly, the average soil erosion rates of India have been estimated as 0.5 - 5 t/ha/yr for areas under natural vegetation, 0.3-40 t/ha/yr for cultivated lands and range of 10-185 t/ha/yr in case of bare soil regions (Singh et al., 1981; Morgan, 2005). Increase in agricultural activities on moderate and steep slopes has accelerated the erosion process. The expansion of agricultural activities in the fragile moderate and steep slopes of study area along with poor adoption of soil conservation measures accelerated the soil erosion rates and will ultimately result in decline of soil quality and fertility status

From the study it is quite evident that majority of the area (63%) have soil erosion rates above 10 t/ha/yr, which is a matter of grave concern from natural resource conservation and agricultural production point of view. Many reasons can be pointed out for these higher rates including increased agricultural activities, poor adoption of soil and water conservation measures, high intensity rainfall, less vegetative cover on surface, fragile slopes etc. These high rates of erosion if left unattended will result in soil degradation rendering the agricultural areas unsuitable for cultivation thus, ultimately leading to reduced productivity in the region. Also, the high sediment load emanating from the study area may pose a serious threat to the nearby dam reservoir, if continued without any check. The various RUSLE factors like LS, C and P, can be modified significantly by human beings for controlling erosion rates. The C and P factors can be modified through various measures like afforestation, adopting various cropping patterns and sequences suitable for the particular area, management practices like "terracing" bunding etc. LS factor, most sensitive for soil erosion can also be modified by reducing the slope length as well as slope steepness, by breaking the slope by means of construction of contour walls, bench terraces, check dams in gullies etc. Adoption of various soil and water conservation measures as well as strategies, which are very crucial for controlling runoff and erosion should be done in various land use systems in the area, after a thorough analysis of their respective topographical, soil as well as land characteristics.

Conclusion

The present study was aimed to quantitatively assess soil erosion rates in Maniyar watershed in the Himalayas using RUSLE model in a GIS environment considering various datasets like rainfall, vegetation cover, soil as well as topographic characteristics. The study revealed that nearly 70% of area is having slope more than 40%, which has a positive impact on erosion rates. The average annual soil erosion rate of Maniyar watershed was found to be quite high, with a value of 65.84 t/ha/yr. The entire area was divided into six erosion risk classes, ranging from 0 to 1961 t/ha/yr. Erosion rates greater than 10 t/ha/yr was observed in nearly 63% of watershed, which necessitates immediate intervention for conservation approaches. The maximum area contributing to soil erosion is under agriculture, which are mainly rainfed. High intensity rainfalls, high LS factor due to terrain characteristics, increased human interventions as well as low vegetative coverage on ground can be identified as the major causes of high erosion rates. The computed erosion rates were found to be comparable with reported works in other areas of Himalayan region, and elsewhere, thus validating RUSLE model. This study calls for immediate adoption of various soil and water conservation measures in the watershed, on a high risk priority basis. The use of remote sensing and GIS inputs has enabled us to study and understand the erosion scenario in this hilly mountainous watershed, where traditional soil erosion studies stands no chance due to rugged terrain and inaccessibility of many areas which makes ground data collection very difficult. While this study using remote sensing and GIS enabled us to identify high erosion risk zones, the prediction accuracy and capability of model can be improved further by providing more micro-scale rainfall data as well as C factor values using NDVI. This study reveals that RUSLE model along with remote sensing and GIS inputs can be a powerful tool for assessing soil erosion risk and thus for effective adoption of conservation and management strategies, in various hilly mountainous watersheds. This type of studies helps us to identify high erosion prone areas within a particular watershed or small study area, and to prioritize planning as well as implementation of soil and water conservation measures at those areas.

References

Adediji, A., Tukur, A.M., Adepoju, K.A., 2010. Assessment of Revised Universal Soil Loss Equation (RUSLE) in Katsina area, Katsina state of Nigeria using remote sensing (RS) and Geographic Information System (GIS). *Iranica Journal of Energy & Environment* 1(3): 255-264.

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K., Weesies, G.A., 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment* 97(1-3): 295-308.

Ashiagbor, G., Forkuo, E.K., Laari, P., Aabeyir, R., 2013. Modeling soil erosion using RUSLE and GIS tools. *International Journal of Remote Sensing & Geoscience* 2(4): 1-17.

Babu, R., Dhyani, B.L., Kumar, N., 2004. Assessment of erodibility status and refined Iso- Erodent Map of India. *Indian Journal of Soil Conservation* 32(2): 171–177.

Boggs, G., Devonport, C., Evans, K., Puig, P., 2001. GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. *Land Degradation and Development* 12(5): 417-434.

Bonilla, C.A., Reyes, J.L., Magri, A., 2010. Water erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, central Chile. *Chilean Journal of Agricultural Research* 70(1): 159-169.

Dabral, P.P., Baithuri, N., Pandey, A., 2008. Soil erosion assessment in a hilly catchment of north eastern India using USLE, GIS and Remote Sensing. *Water Resources Management* 22(12): 1783–1798.

Elangovan, A.B., Seetharaman, R., 2011. Estimating Rainfall Erosivity of the Revised Universal Soil Loss Equation from daily rainfall depth in Krishanagiri Watershed region of Tamil Nadu, India. International Conference on Environmental and Computer Science IPCBEE, IACSIT Press, Vol. 19. Singapore.

FAO. 2011. The state of the world's land and water resources for food and agriculture (SOLAW) - Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome, Italy.

Farhan, Y., Zregat, D., Farhan, I., 2013. Spatial Estimation of Soil Erosion Risk Using RUSLE Approach, RS, and GIS Techniques: A Case Study of Kufranja Watershed, Northern Jordan. *Journal of Water Resource and Protection* 5(12): 1247-1261.

Garde, R. J., Kothyari, U.C., 1987. Sediment yield estimation. *Journal Irrigation and Power (India)* 44(3): 97-123.

Haile, G.W., Fetene, M., 2011. Assessment of soil erosion hazard in Kilie catchment, East Shoa, Ethiopia. *Land Degradation and Development* 23(3): 293-306.

Hofer, T., 1998. Do land use changes in the Himalayas affect downstream flooding? Traditional understanding and new evidences. *Memoir Geological society of India* 19: 119-141.

Hyeon, S.K., Julien, P.Y., 2006. Soil erosion modeling using RUSLE and GIS on the IMHA watershed. *Water Engineering Research* 7 (1): 29-41

IFPRI,. 2012. 2011 Global Food Policy Report. International Food Policy Research Institute, Washington, DC. USA. Available at: http://www.ifpri.org/cdmref/p15738coll2/id/126897/filename/127108.pdf [access date: 05.08.2016]

Ives, J.D., Messerli, B., 1989. The Himalayan Dilemma- reconciling development and conservation. United Nations University, Routledge, New York, USA.

Jain, S.K., Kumar, S., Varghese, J., 2001. Estimation of soil erosion for a Himalayan watershed using GIS technique. *Water Resources Management* 15(1): 41-54.

Jasrotia, A.S., Singh, R., 2006. Modeling runoff and soil erosion in a catchment area, using the GIS, in the Himalayan region, India. *Environmental Geology* 51(1): 29-37.

Krishna Bahadur, K.C., 2009. Mapping soil erosion susceptibility using remote sensing and GIS: a case of the Upper Nam Wa Watershed, Nan Province, Thailand. *Environmental Geology* 57(3): 695-705.

Kumar, S., Kushwaha, S.P.S., 2013. Modelling soil erosion risk based on RUSLE-3D using GIS in a Shivalik sub-watershed. *Journal of Earth System Science* 122 (2): 389–398.

Lal, R., Stewart, B.A., 1990. Advances in Soil Science. Vol. 11, Soil Degradation. Springer Verlag, New York, USA. 345p.

Lee, G.S., Lee, K.H., 2006. Scaling effect for estimating soil loss in the RUSLE model using remotely sensed geospatial data in Korea. *Hydrology and Earth System Sciences Discussions* 3: 135-157.

Lim, K.J., Sagong, M., Engel, B.A., Tang, Z., Choi, J., Kim, K.S., 2005. GIS based sediment assessment tool. *Catena* 64(1): 61–80.

Lu, D., Li, G., Valladares, G. S., Batistella, M., 2004. Mapping soil erosion risk in Rondônia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degradation & Development* 15 (5): 499-512.

Millward, A.A., Mersey, J.E., 1999. Adapting the RUSLE to model soil erosion potential in mountainous tropical watershed. *Catena* 38 (2): 109-129.

Mitasova, H., Hofierka, J., Zlocha, M., Iverson, L.R., 1996. Modeling topographic potential for erosion and deposition using GIS. *International Journal of Geographical Information Systems* 10(5): 629-641.

Moore, I.D., Burch, G.J., 1986. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal* 50(5): 1294–1298.

Morgan, R.P.C., 2005. Soil Erosion and Conservation, 3rd Edition. Blackwell Publishing, Malden, USA. 303p.

Pandey, A., Chowdary, V.M., Mai, B.C., 2007. Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. *Water Resources Management* 21(4): 729- 746.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., Mcnair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267 (5201): 1117-1123.

Poreba, G.J., Prokop, P., 2011. Estimation of soil erosion on cultivated fields on the hilly Meghalaya plateau, north-east India. *Geochronometria* 38 (1): 77-84.

Prasannakumar, V H. Vijith, S. Abinod, N. Geetha., 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers* 3(2): 209-215.

Rao, Y.P., 1981. Evaluation of cropping management factor in universal soil loss equation under natural rainfall condition of Kharagpur, India. In: Proceedings of Southeast Asian regional symposium on problems of soil erosion and sedimentation, Asian Institute of Technology, Bangkok, p. 241-254.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. .Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). U.S. Department of Agriculture, Agricultural Research Service, Agriculture Handbook No. 703, Washington DC, USA. 384p.

Rio+20, 2012. Report of the United Nations Conference on Sustainable Development. Rio de Janeiro, Brazil 20–22 June 2012

Sati, S.P., Sundriyal, Y.P., Naresh, R., Surekha, D., 2011. Recent landslides in Uttarakhand: nature's fury or human folly. *Current Science* 100 (11): 1617-1620.

Shiono, T., Kamimura, K., Okushima, S., Fukumoto, M., 2002. Soil loss estimation on a local scale for soil conservation planning. *Japan Agricultural Research Quarterly* 36(3): 157-161.

Singh, G., Chandra, S., Babu, R., 1981. Soil loss and prediction research in India. Central Soil and Water Conservation Research and Training Institute, Bulletin No.T-12/D9, Dehra Dun.

Sun, W., Shao, Q., Liu, J., Zhai, J., 2014. Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China. *Catena* 121: 151-163.

Tian, Y.C., Zhou, Y.M., Wu, B.F., Zhou, W.F., 2009. Risk assessment of water soil erosion in upper basin of Miyun Reservoir, Beijing, China. *Environonment Geology* 57(4): 937–942.

Tirkey, A.S., Pandey, A.C., Nathawat, M.S., 2013. Use of satellite data, GIS and RUSLE for estimation of average annual soil loss in Daltonganj watershed of Jharkhand (India). *Journal of Remote Sensing Technology* 1(1): 20-30.

UNCCD. 1994. Elaboration of an International convention to combat desertification in countries experiencing serious drought and/or desertification, particularly in Africa. United Nations, General Assembly. A/AC.241/27 12 September 1994, Article 2. Available at: http:// www.unccd.int/Lists/SiteDocumentLibrary/conventionText/conv-eng.pdf [access date: 05.08.2016]

USDA-SCS , 1972. National Engineering Handbook, Section 4, Hydrology Chapter 21. Design Hydrographs. US Department of Agriculture, Washington DC, USA. Available at: http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18393.wba [access date: 05.08.2016]

Wani, S.P., Garg, K,K., 2009. Watershed management concept and principles. Available at: http://oar.icrisat.org/3914/1/1._Watershed_Management_Concept.pdf [access date: 05.08.2016]

Wischmeier, W.H., Smith, D.D., 1965. Predicting rainfall-erosion losses from cropland east of the rocky mountains: Guide for selection of practices for soil and water conservation. U.S. Department of Agriculture, Agricultural Research Service, Issue 282 of Agriculture Handbook. Washington DC, USA. p. 47.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses: A guide to conservation planning. U.S. Department of Agriculture, Agricultural Research Service, Issue 537 of Agriculture Handbook. Washington DC, USA. p. 58.