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SPATIAL IDENTIFICATION AND CLASSIFICATION OF SOIL EROSION PRONE ZONES USING REMOTE SENSING & GIS INTEGRATED 'RUSLE' MODEL AND 'SATEEC GIS SYSTEM'

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ABSTRACT
Soil erosion by water is pronounced critical problem in Himalayan regions due to anthropogenic pressure on its mountainous landscape. Its assessment and mapping of erosion prone areas are very essential for soil conservation and watershed management. The purpose of this study is to investigate the spatial distribution of average annual soil erosion in Ton Watershed (a sub-basin of Asan watershed) using Remote Sensing and GIS integrated 'RUSLE' Model and GIS based Hydrological Model of 'SATEEEC GIS system' in Dehradun district of Uttarakhand state. Remote sensing and GIS technologies were used to prepare required input layers in the form of Rain Erosivity factor (R), soil erodability factor(K), Length and steepness of Slope factors (LS), crop management factors (C) and support practice factor (P) to utilize in RUSLE and SATEEC GIS Models. One of the advantages of using SATEEC GIS system is no additional input data, other than those for RUSLE are required to operate the system. Vulnerability to soil erosion risk in the watershed revealed that 24.16 percent of area from RUSLE model, and 20.21 percent of area from SATEEC GIS system was in high soil erosion risk zone. Very low risk of erosion was observed at 68.18 percent and 57.12 percent of areas from SATEEC GIS system and RUSLE model respectively.

KEYWORDS: RUSLE, SATEEC GIS System, R-factor, LS-factor, Soil Erosion, ArcGIS.

INTRODUCTION
Soil erosion in watershed areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, rich fertile soil is eroded from the watershed areas. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality [1]. Although sedimentation occurs naturally, it is exacerbated by poor land use and land management practices adopted in the upland areas of watersheds. Uncontrolled deforestation due to forest fires, grazing, incorrect methods of tillage and unscientific agriculture practices are some of the poor land management practices that accelerate soil erosion, resulting in large increases in sediment inflow into streams [2]. Therefore, prevention of soil erosion is of paramount importance in the management and conservation of natural resources [3]. The application of RS and GIS techniques makes soil erosion estimation and its spatial distribution to be determined at reasonable costs and better accuracy in larger areas. A combination of RS, GIS, and RUSLE is an effective tool to estimate soil loss on a cell-by-cell basis [4]. GIS tools were used for derivation of the topographic factor from DEM data, data interpolation of sample plots, calculation of soil erosion loss and sediment yield [5]. To estimate soil erosion and to develop optimal soil erosion management plans, many erosion models, such as Universal Soil Loss Equation (USLE) [6], Water Erosion Prediction Project (WEPP) [7], Soil and Water Assessment Tool (SWAT) [8], and European Soil Erosion Model (EUROSEM) [9], have been developed and used over the years. The new version of the USLE model, called the Revised Universal Soil Loss Equation (RUSLE), a desktop-based model, was developed by modifying the USLE to more accurately estimate the R, K, C, P factors of soil loss equation, and soil erosion losses [10]. GIS-based Sediment Assessment Tool for Effective Erosion Control (SATEEC) system was used to estimate soil loss and sediment yield for any location within a watershed by a combined application of RUSLE and a spatially distributed sediment delivery ratio within the ArcView GIS software environment [11].

STUDY AREA

The study area is located in the western part of Doon valley, Dehradun district and Uttarakhand state in India. The sub-watershed 'Ton Watershed', which is a Sub-basin in 'Asan' watershed is selected to carry present investigation. The Ton watershed is a sub-basin of Asan watershed, the main river is 'Asan', which is called as Ton river in earlier days of the local people. The Asan river is tributary of Yamuna River. Geographical location of the study area covers a total of an approximately 145 sq km and lies between 77°45'33" and 77°57'46"and 30°24'39" and 30°29'05" as shown in Fig.1. The study area falls in western part of the Doon valley of Dehradun district having large area under hilly tract. The climate is humid to sub tropical varying from valley to the high mountain ranges of Himalayas. During rainy season 1625 mm rainfall is observed in the year. The area has a favorable climate for the growth of abundant vegetation due to reasonably good rainfall & elevation Dense & moderate mixed forest, shrubs, agriculture crops. Soils of the study area are found to be derived from alluvium parent material
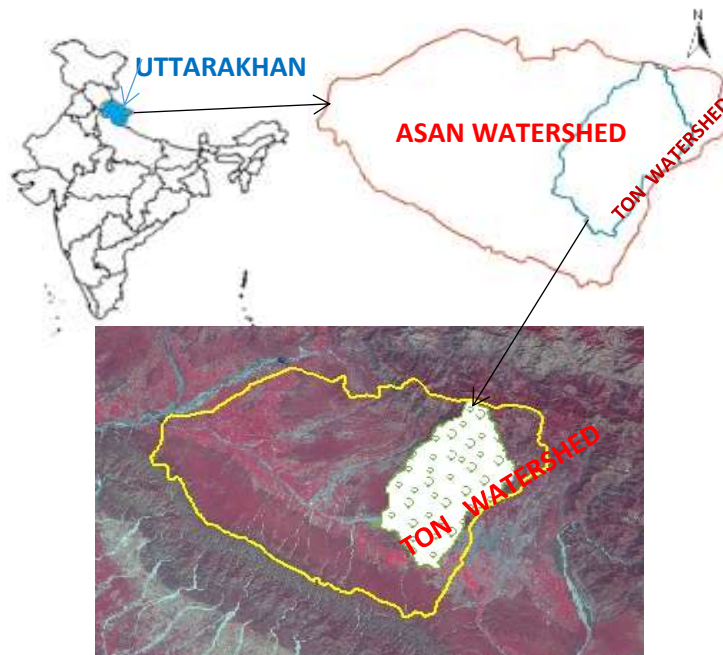

Figure 1: Location Map of Ton Watershed

MATERIALS

The input materials required to prepare different thematic maps using spatial and non spatial data. Spatial information in the form of Digital Elevation model (DEM), Satellite image, Soil information and non-spatial data in the form of rainfall data. The brief description of each thematic layers prepared using the spatial and non-spatial information are explained in the fallowing paragraphs.

Digital Elevation Model (DEM)

The contour lines having vertical intervals of 20-meters were digitized from a toposheet No. 53 F/15 (scale 1:50,000 scale) in ArcGIS environment to prepare vector layer. Surfacing function in 'Image Interpreter' was used to generate a DEM to represent as a surface or one-band image file where the value of each pixel was a specific elevation value. A pseudo color map prepared to differentiate variations in terrain as shown in Fig. 2.

Land use–Land cover

This thematic map is prepared using a satellite image of Landsat TM acquired on 14 Nov 2004. There are 7 basic classes are identified under 'supervised classification' with ground truth data in Ton watershed as shown in Fig.3. The basic classes are Agricultural crops, Fallow, Forest, Scrubland, Settlements, Dry river bed sand, Water and Tea gardens. The Land use-Land cover map is the basis for preparation of Crop cover (C-factor) and Crop Management factor (P-factor) maps.
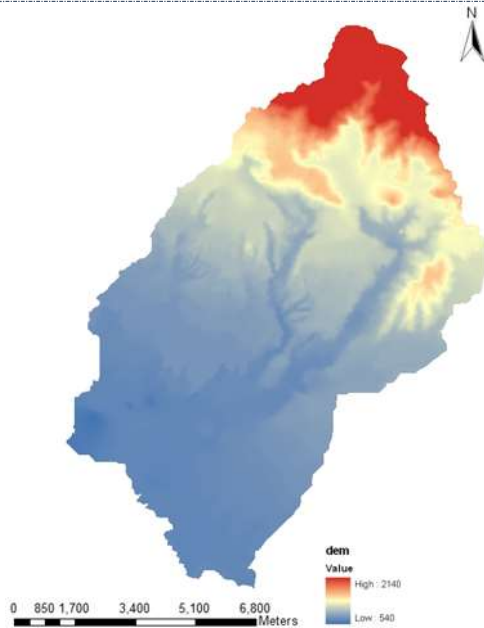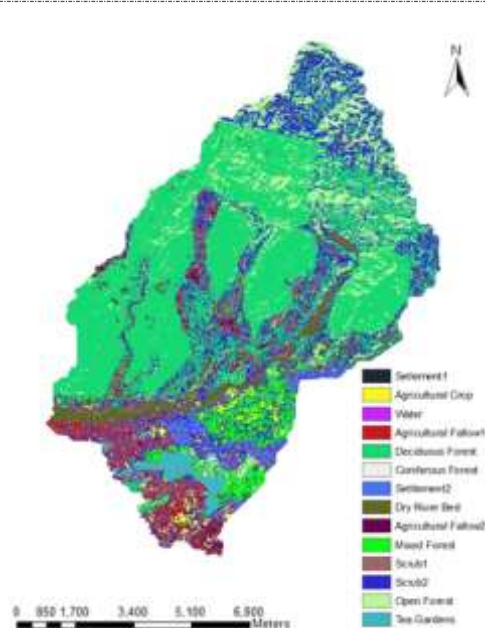
Figure 2: DEM of Ton watershed

Figure 3: Land Use – Land Cover Map of Ton Watershed

Soil data

This data collected form textural properties of soils covered in the watershed. A polygonised soil map prepared based on the types of soils covered in the catchment as shown in Fig.4. There are 6 verities of soil textural classes are identified from 'Ton' sub-basin. These are Loam, Silt Loam, Sandy Loam, Sandy clay Loam, Gravelly clay loam, Loam to Sandy Clay Loam. The higher portion of the catchment covered with Loamy soils and a least area of soils are covered with loam to sandy clay loam.

Rainfall data

Rainfall data collected from rain gauge stations available in the Ton watershed. In order to prepare R-factor map, rainfall data available from a Self recording rain gauges at Poanta Sahib village. From the average annual rainfall, 'R-factor' is calculated from raster calculator available in spatial analyst tool in ArcGIS environment. The rain gauge available in the watershed is shown in Fig.5

Figure 4: Soil Map of Ton Watershed

Figure 5: Rain gauge Location of Ton Watershed

METHODOLOGY

In this study, a remote Sensing and GIS integrated RUSLE equation and GIS based Hydrological model of 'SATEEC GIS system' were used to estimate spatial soil erosion of the Ton watershed. These models are utilized a common equation for computation of soil erosion. The RUSLE predicts Average annual soil loss for a given site as a product of six major erosion factors (equation 1), whose values at a particular location can be expressed numerically.

A = R * K * L * S * C * P ……………….Eqn…….(1)

Where,

A : computed annual soil loss per unit area [ton/ha/year]

R: Rainfall erosivity factor, an erosion index for the given storm period in [MJ mm·ha−1·hr−1·year−1]

K: Soil erodibility factor (soil loss per erosion index unit for a specified soil measured on a standard plot, 22.1 m long, with uniform 9% (5.16°) slope, in continuous tilled fallow) [ton·ha·hr·ha−1·MJ−1·mm−1].

L: Slope length factor (ratio of soil loss from the field slope length to soil loss from standard 22.1 m slope under identical conditions)

S: Slope steepness factor-Ratio of soil loss from the field slope to that from the standard slope under identical conditions

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

P:Support practice factor-Ratio of soil loss with a support practice contour tillage, strip-cropping, terracing to soil loss with row tillage parallel to the slope.

L,S,C,P factors are dimensionless parameters and they are normalized relative to standard plot conditions. The USLE and RUSLE is currently a globally accepted method for soil erosion prediction in the US and in other countries all over the world. These models have been accepted to be useful, accurate and reliable. In the present study, annual soil loss rates and severity were computed based on RUSLE in GIS environment using Arc GIS 9.3 and SATEEC GIS System using ArcView 3.2a, and the associated GIS packages. The whole methodology is explained in the form of flow chart as shown in Fig. 6
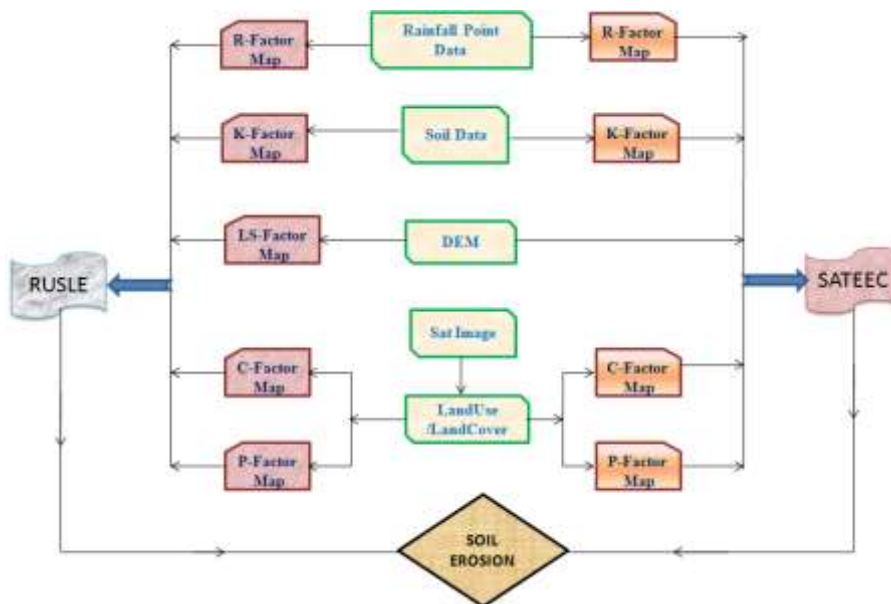

Figure 6: Methodology of Flow Chart

Calculation of RUSLE Factor
Rainfall Erosivity (R)
R factor is the quantitative expression of the erosivity of local average annual precipitation and runoff causing soil erosion. It is a measure of the erosive force of a specific rainfall. R-value is greatly affected by the volume, intensity, duration and pattern of rainfall whether for single storms or a series of storms, and by the amount and rate of the resulting runoff. It is the average annual summation (EI) values in a normal year's rain. When other

factors are constant, storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (I). Storms less than 0.5 inches are not included in the erosivity computations because these storms generally add little to the total R value. R factors represent the average storm EI values over a 22-year record. R is an indication of the two most important characteristics of a storm determining its erosivity: amount of rainfall and peak intensity sustained over and extended period.

Rambabu *et al*. **[12]** developed a relationship between EI30 and daily and monthly rainfall amounts for Dehradun (India) region as given below:

$$EI30 = 3.1 + 0.533 * Rd \text{ (for daily rainfall in mm)}$$
$$EI30 = 1.9 + 0.640 * Rm \text{ (for monthly rainfall in mm)}$$

Based on regression equation, R can be determined as follows:

$$R = 22.8 + 0.6400 * Ra$$

where,

R = Rainfall erosivity factor (in metric unit), and
Ra = Annual rainfall (mm)

This point information can be converted to spatial distribution by IDW method in GIS environment. Once this R factor map is derived then by above formula, R factor map can be drawn and is shown in Fig.7

Soil Erodability Factor (K)

K factor is soil erodibility factor which represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. Soils high in clay have low K values, about 0.05 to 0.15, because they resistant to detachment. Coarse textured soils, such as sandy soils, have low K values, about 0.05 to 0.2, because of low runoff even though these soils are easily detached. Medium textured soils, such as the silt loam soils, have a moderate K values, about 0.25 to 0.4, because they are moderately susceptible to detachment and they produce moderate runoff. Soils having a high silt content are most erodible of all soils. They are easily detached tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.4.

Organic matter reduces erodibility because it reduces the susceptibility of the soil to detachment, and it increases infiltration, which reduce runoff and thus erosion. Extrapolation of the K factor nomograph beyond an organic matter of 4% is not recommended or allowed in RUSLE [13]. Soil structures affects both susceptibility to detachment and infiltration. Permeability of the soil profile affects K because it affects runoff. The maps were generated using the Inverse Distance Weighted (IDW) interpolation method on point data (vector layers) as shown in Fig: 8. Therefore, the map was adopted to apply it in the RUSLE model.

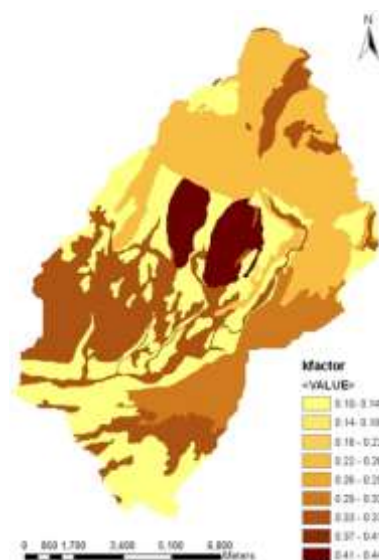
Figure 7: R-factor Map of Ton Watershed   **Figure 8: K-factor Map of Ton Watershed**

Slope Length and Steepness Factor (LS)

The (LS) factor expresses the effect of local topography on soil erosion rate, combining effects of slope length (L) and slope steepness (S). Thus, LS is the predicted ratio of soil loss per unit area from a field slope from a 22.1 m long, 9% (5.16°) slope under otherwise identical conditions. L factor and S factor are usually considered together.

L is the slope length factor, representing the effect of slope length on erosion. It is the ratio of soil loss from the field slope length to that from a 72.6-foot (22.1-meter) length on the same soil type and gradient. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition. Slope lengths are best determined by visiting the site, pacing out flow paths, and making measurements directly on the ground. Slope length values are generally too long when contour maps are used to choose slope length. The main areas of deposition that end RUSLE slope length are at the base of concave slopes. If no signs of deposition are present, the user will have to visualize where deposition occurs. The slope-ending depositional area on a concave slope is usually below where the slope begins to flatten. Another difficulty is determining if a channel is a concentrated flow channel that ends a RUSLE slope length. Channels that collect the flow from numerous rills are generally considered to be slope ending concentrated flow channels.

S is the slope steepness. Represents the effect of slope steepness on erosion. Soil loss increases more rapidly with slope steepness than it does with slope length. It is the ratio of soil loss from the field gradient to that from a 9 percent slope under otherwise identical conditions. The relation of soil loss to gradient is influenced by density of vegetative cover and soil particle size
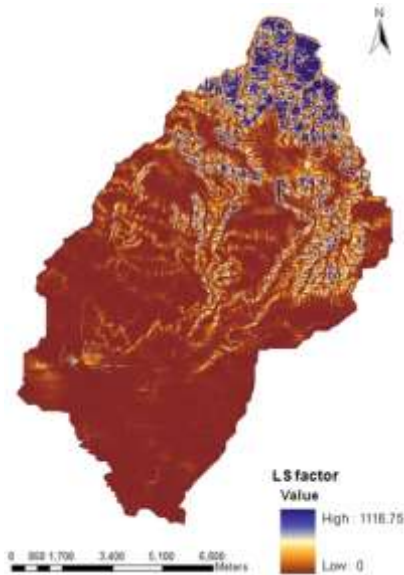

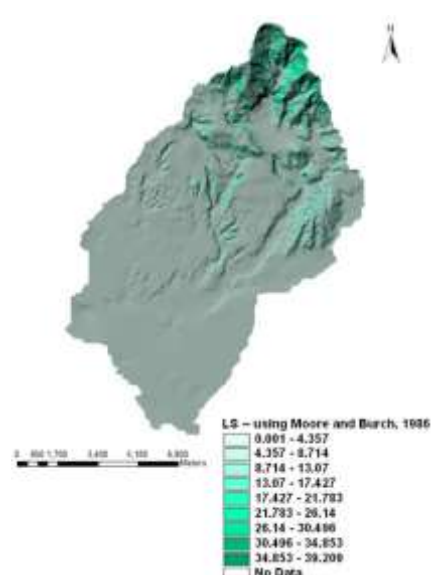*Figure 9: LS factor map for RUSLE Model*

Figure 10: LS factor map for SATEEC Model

The Digital Elevation Model (DEM) with a resolution of 20 m was used to calculate combined 'LS' factor map for RUSLE model (Fig: 9) and SATEEC GIS system (Fig:10). However, Zhang *et al*. [14] developed more accurate method to calculate the LS factor to estimate soil erosion at regional landscape scale. In this study both RUSLE equation and SATEEC GIS system computes the LS factor using Moore and Burch [15] equation as given below.

$$LS = \left(\frac{A}{22.13}\right)^{0.6} \ X \ \left(\frac{\sin\theta}{22.13}\right)^{1.3}$$

Where

A : Flow Accumulation, and sin (θ) is slope of the watershed

Crop Management Factor (C)
The C-factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The crop management factor expresses the effect of cropping and management practices on the soil erosion rate [16], and is considered the second major factor (after topography) controlling soil erosion. An increase in the cover factor indicates a decrease in exposed soil, and thus an increase in potential soil loss. RUSLE accounts for surface roughness in the C value calculation. Surface roughness ponds water in depressions and reduces erosivity of raindrop impact and water flow. If a C factor of 0.15 represents the specified cropping management system, it signifies that the erosion will be reduced to 15 percent of the amount that would have occurred under continuous

fallow conditions. However by considering the Landuse/landcover patterns of the study area the C-factor map prepared is shown in Fig.11
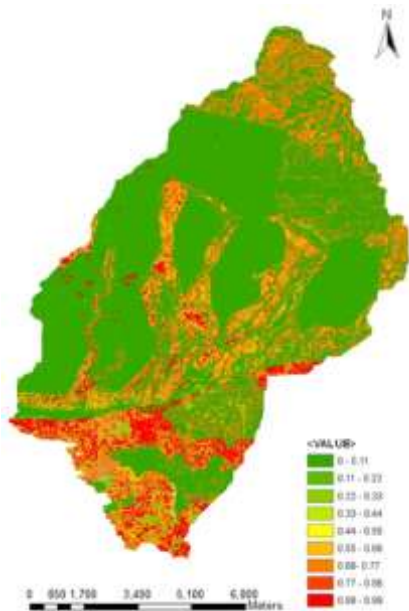

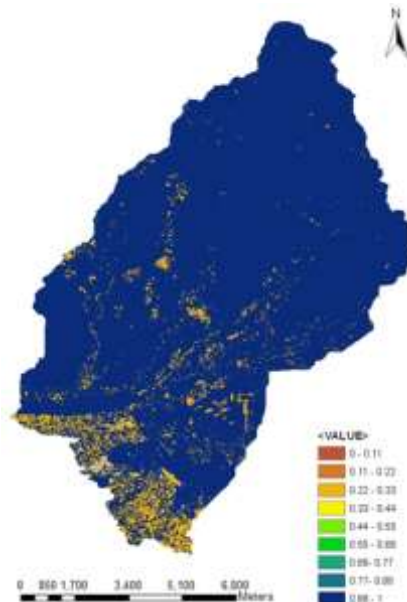
Figure 11: C-factor Map of Ton watershed

Figure 12: P-factor Map of Ton watershed

Conservation Practice Factor (P)

Conservation practice factor expresses the effect of conservation practices that reduce the amount and rate of water runoff, which reduce erosion. It is the ratio of soil loss with a specific support practice on croplands to the corresponding loss with slope-parallel tillage [17]. As with the other factors, the P-factor differentiates between cropland and rangeland or permanent pasture. For the purpose of this factor, the rangeland/permanent-pasture option is based on the support operation being performed infrequently, whereas in the cropland option the support operation is part of the annual management practice. The P-factor map prepared based on the Landuse/Landcover map of the Ton watershed as shown in Fig.12.

RESULTS AND DISCUSSION

The estimation of soil erosion prone areas are carried in two phases. The first phase of application using RUSLE equation with prepared thematic layers of R, K, LS, C, P factors. And the second phase of application is using a hydrological model of SATEEC GIS system of 1.8 version with the same thematic layers of RUSLE factors. The only difference in the application of both models is 'LS' factor. In the RUSLE equation the 'LS' factor prepared using Moore& Burch equation using raster calculator, whereas in SATEEC model the 'LS' factor calculated using in built option available in the model. The results and discussions for the two phases of the model application are narrated in the fallowing paragraphs.

RUSLE Model Application

The input thematic layers prepared namely R, K, LS, C, P factors of the RUSLE model were integrated within the raster calculator option of the spatial analyst tool in ArcGIS environment in order to quantify and generate the maps of soil erosion risk and severity for Ton watershed. Average annual soil loss of 10 ton/ha/year was estimated for the whole catchment, and the final soil loss map compiled using the RUSLE model indicates a minimum of 0.0 to a maximum of 38.6 ton/ha/year (Fig. 13). Generally, if the estimated value is high, it means a higher rate of sediment yield, while a lower value denotes a lower rate of sediment yield [18].
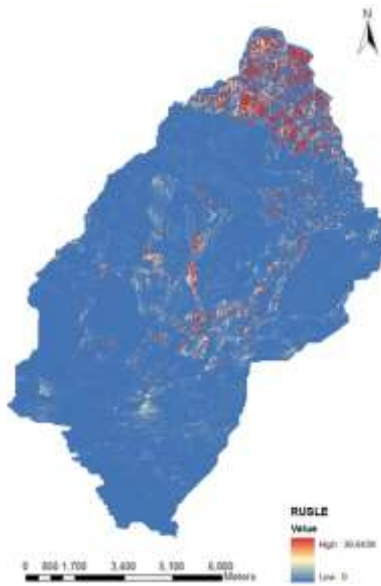
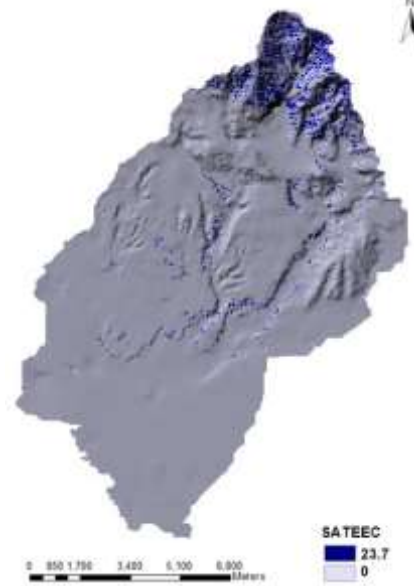*Figure 13: Soil Erosion Map of RUSLE Model*

Figure 14: Soil Erosion Map of SATEEC GIS System

The Ton watershed was classified into five soil erosion risk categories (Fig. 15). The area and proportion of soil erosion risk classes are illustrated in Table 1. Potential soil erosion risk and severity (Table 2) increase from the upper to the lower reaches of the catchment. It is obvious that surface erosion can vary spatially due to rainfall variability, topographic and morphological changes, different soil types and characteristics, and human-induced disturbances. However, soil erosion is very severe between Bakarna and Kandoli Block areas accounts for 48.1% of the total watershed soil loss.

Table 1: Area and proportion of each soil erosion risk class

Erosion Risk Class	Numerical range (t/ha/year)		Percentage (%)		Area (ha)	
	RUSLE	SATEEC	RUSLE	SATEEC	RUSLE	SATEEC
Minimal	0 -1	0-1	57.12	68.12	8282.4	9877.4
Low	1 - 2	1 - 3	8.3	6.27	1203.5	909.15
Moderate	2 - 5	3 - 6	10.42	5.34	1510.9	774.3
Severe	5 - 15	6 - 13	11.55	12.09	1674.75	1753.05
Extreme	>15	>13	12.61	8.12	1828.45	1177.4

The distribution of risk classes and soil severity zones (Fig. 17) show that 57.12 % of the watershed has minimal soil loss, 8.3 % is low, 10.42 % and 11.55 % is moderate and severe, while extreme soil erosion occupies 12.61 % of the watershed. The highest soil loss values are clearly correlated with slope steepness. The upper and lower reaches of the Ton watershed is dominated by moderate and steep slope categories: 10° - 18°, 18° - 30° and 30° - 40°.
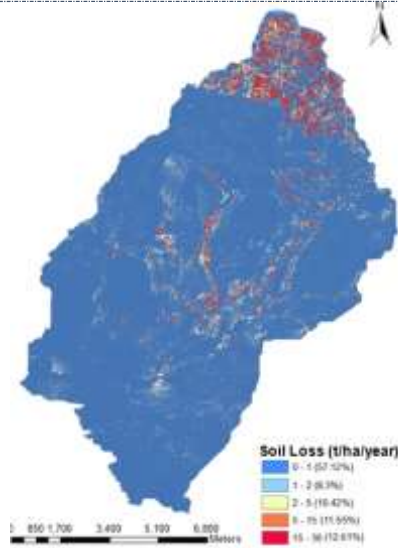
Figure15: Spatial distribution of erosion risk categories   *Figure 16: Spatial distribution of erosion risk*

Using RUSLE Model   *categories Using SATEEC Model*

SATEEC GIS System Application

The thematic layers of R,K,C,P,DEM and boundary of the catchment are utilized as input to the SATEEC GIS system. After DEM initialization, the LS factor map prepared using Moore & Burch for further process. The final soil loss map compiled using the SATEEC GIS System model indicates a minimum of 0.0 to a maximum of 23.7 ton/ha/year (Fig. 14). The Ton watershed was classified into five soil erosion risk categories (Fig. 16). The area and proportion of soil erosion risk classes are illustrated in **Table 1**. Potential soil erosion risk and severity (**Table 2**) increase from the upper to the lower reaches of the catchment similar fashion of RUSLE model. The distribution of risk classes and soil severity zones (Fig. 18) show that 68.12 % of the watershed has minimal soil loss, 6.27 % is low, 5.34% and 12.09 % is moderate and severe, while extreme soil erosion occupies 8.12 % of the watershed.
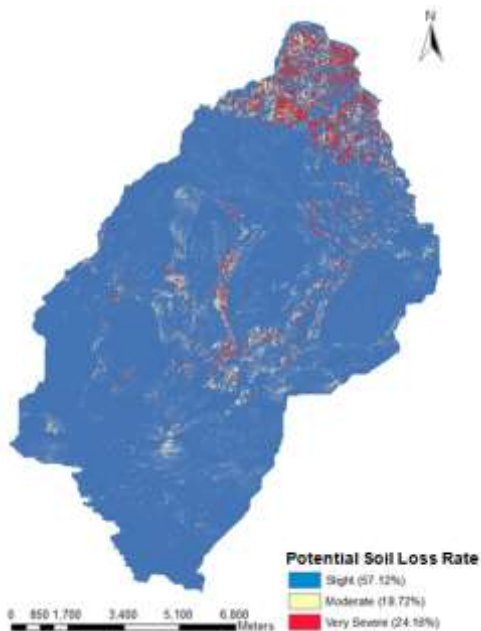

Figure 17: Spatial Distribution of Potential   *Figure 18: Spatial Distribution of Potential*
Soil Risk Zones-RUSLE Model   *Soil Risk Zones –SATEEC Model*

CONCLUSION

The present study identified the occurrence of higher severity of soil erosion from RUSLE model for the Ton watershed compared to SATEEC GIS model. The mean soil loss estimated for the Ton watershed was 10 ton/ha/year, with the five erosion risk classes, ranging from 0.0 to 38.6 ton/ha/year and its corresponding areas of 82.824 km^2 (8282.4 hectares) and 27.144 km^2 (2714.4 hectares) were classed as low, moderate and 35.032 km^2 (3503.2 hectares) are very severe soil erosion zones. Similarly, mean soil loss estimated for the Ton watershed was 7.6 ton/ha/year, with the five erosion risk classes, ranging from 0.0 to 23.7 ton/ha/year from SATEEC GIS system model and the areas of 98.774 km^2 (9877.4 hectares) and 16.8345 km^2 (1683.45 hectares) were classed as suffering low to moderate and 29.3045 km^2 (2930.45 hectares) are very severe soil erosion zones. The Remote Sensing and GIS integrated RUSLE model denotes that Ton watershed larger area suffer soil erosion, and SATEEC GIS model reveals lesser soil erosion risk. The graphical presentation of results of both models are clearly shows the discrimination of erosion classes as shown in Fig.19. The overall results reveals that Ton watershed suffer a very less area of the catchment suffer extreme erosion prone areas and most of the area comes under non erosion prone zones.
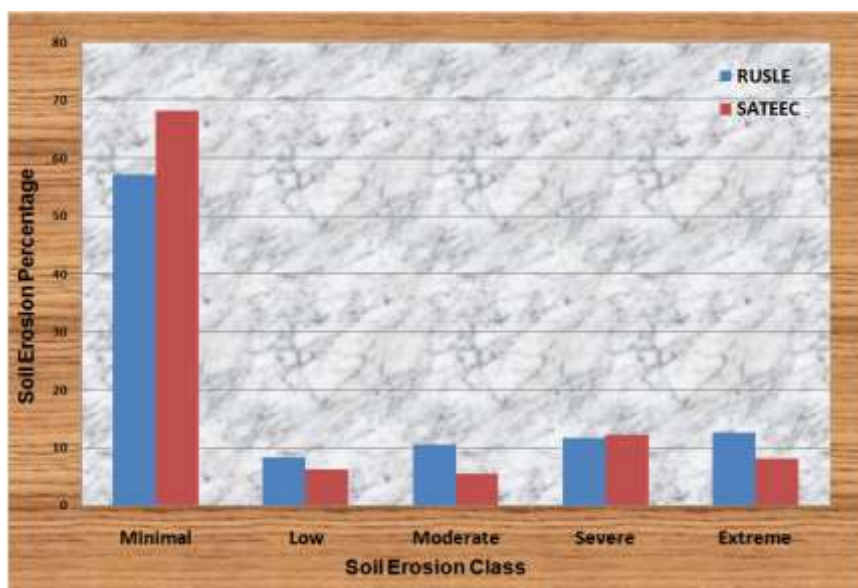

Figure 19: Soil Erosion classes of RUSLE and SATEEC Models

Spatial analysis denoted high soil erosion rates in the upper and mid reaches of the catchment in both RUSLE and SATEEC models. Here, long and continuous human disturbance and deforestation, with the combined effect of K, LS, and C factors, account for high soil erosion loss across the study area. Accordingly, soil erosion becoming more serious on moderate and steep slopes transformed into cultivated or range land. Therefore, the expansion of cultivated cereals increase the susceptibility of soils to erosion, and the cultivated lands with poor conservation measure exhibit higher rate of soil erosion and decline in soil fertility.

It is postulated elsewhere that the RUSLE parameters can be altered significantly by human activities [13]. The C and P factors can be improved to reduce the soil erosion loss through afforestation and shifting community environmental practice. The LS factor also can be modified by shortening the length and steepness of slopes by the construction of contour walls and stone terraces. Construction of soil conservation measures is vital to control runoff and soil erosion across different agro ecological zones and under various land uses. More data on rainfall and its duration and intensity provided a basis for calculating erosive of rainfall. Field measurements of rainfall erosion in the form of direct measurements and simulated rainfall are highly recommended. Finally, the present investigation has demonstrated that GIS and RS techniques are simple and low-cost tools for modeling soil erosion, with the purpose of assessing erosion potential and risk for the watersheds of Uttarakhand regional watersheds.

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