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Spatial Distribution of Soil Loss and Sediment Yield Based on SATEEC GIS System and Remote Sensing (Case Study, Ilam Dam Watershed-Lower Part, Iran)

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Abstract: The purpose of this study was to investigate the spatial distribution of annual soil loss and sediment yield in Ilam Dam watershed (lower part), Ilam Province, Iran, using Revised Universal Soil Loss Equation (RUSLE) model. Remote Sensing (RS) and Geographic Information System (GIS) technologies were used for erosion and sediment yield risk mapping, based on the this model. The R-, K-, LS-, C-and P-factors were obtained from monthly and annual rainfall data, soil map of the region, 50-meter Digital Elevation Model (DEM), Remote Sensing (RS) techniques (with use of NDVI) and GIS, respectively. The mean values of the R-, k-, LS-, C-and P-factors were 259.27 MJ mm ha^{-1} h^{-1} $year^{-1}$,0.18 t h MJ^{-1} mm^{-1},2.11, 0.52 and 0.13, respectively. The study indicated that the slope length (L) and slope steepness (S) of the RUSLE model (R^2 = 0.81) were the most effective factors controlling soil erosion in the region. The average annual soil loss and sediment yield is predicted up to 62.80 and 18.84 (t h^{-1} $year^{-1}$), respectively. The measured average annual sediment yield 16.58 (t h^{-1} $year^{-1}$) was very close to estimated value (18.84 t h^{-1} $year^{-1}$). Moreover, the results indicated that 43.43%, 9.01%, 11.23%, 11.22%, 25.10% of the study area was under minimal, low, moderate, high and extreme actual erosion risks, respectively. Since 36.32% of the region is under high and extreme erosion risk, adoption of suitable conservation measures seems to be inevitable. The RUSLE model integrated with RS and GIS technologies has great potential for producing accurate and inexpensive erosion and sediment yield risk maps in Iran.

Key words: GIS · Ilam Dam watershed (lower part) · RS · RUSLE · Sediment yield · Soil erosion

INTRODUCTION

Land degradation by soil erosion is a serious problem in Iran with an estimated soil loss of $2500x10^6$ t y^{-1} and about 94% of arable lands and permanent rangelands are in the process of degradation [1-3]. In terms of erosion, Iranian soils are under a serious risk due to hilly topography, soil conditions facilitating water erosion (i.e. low organic matter, poor plant coverage due to arid and semiarid climate) and inappropriate agricultural practices (i.e. excessive soil tillage and cultivation of steep lands). This widespread problem menaces the sustainability of Ilam Dam watershed which is the main surface source of drinking water for Ilam city, Iran. Soil erosion in this area strongly influences the ecological health of the city. Management practices to minimize these problems can be effectively planned out if the magnitude and spatial distribution of soil erosion are known.

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 accurately estimate the R, K, C, P factors of soil loss equation and soil erosion losses [4]. The USLE/RUSLE model has been integrated with Geographic Information Systems (GIS) and Remote Sensing (RS) to estimate soil erosion because RS and GIS techniques not only help users to manipulate and analyze the spatial data easily but also they help to identify the spatial locations that are sensitive to soil erosion [5-9].

RUSLE is a field scale model, thus it cannot be directly used to estimate the amount of sediment reaching downstream areas because some portion of the eroded soil may be deposited while traveling to the outlet of the watershed, or the downstream point of interest. To account for these processes, the Sediment Delivery Ratio (SDR) for a given watershed should be used to estimate

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the total sediment transported to the outlet. The SDR changes with the size of watersheds, thus, the SDR needs to be considered when RUSLE is applied for a large watershed.

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 [10, 11]. Wilson and Lorang [12] reviewed the applications of GIS in estimating soil erosion. They discussed the difficulty and limitations of previous research and concluded that GIS provided tremendous potentialities for improving soil erosion estimation. Wang *et al.* [11] used a sample ground dataset, Thematic Mapper (TM) images and DEM data to predict soil erosion loss through geostatistical methods. They showed that such methods provided significantly better results than using traditional methods. In general, remote-sensing data were primarily used to develop the cover-management factor through land-cover classifications[10,13], while 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 [11,14,15].

However, the above studies did not consider the sediment delivery ratio to estimate the sediment delivered to the downstream point of interest. Regional variations in sediment yields are very important since sediment delivery processes vary in space and time. Lin *et al.* [16] investigated the sediment delivery ratio based on the ratio receiving drainage length to total drainage length by using WinGrid system and computed soil erosion using USLE model. However, this system has separate component programs rather than being fully integrated with a GIS system. Hence, it is not readily available to soil erosion decision makers and it was developed for only research purposes. Instead of this approach, 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 [17].

The goal of this research is to estimate the soil loss and sediment yield in Ilam Dam watershed (lower part) on a cell basis using GIS, RS and SATEEC ArcView GIS so that the critical erosion prone areas and their soil and water conservation measures can be identified.

In this study, soil erosion model RUSLE input parameters and SATEEC GIS system were used to estimate spatial soil erosion and sediment yield of the Ilam Dam watershed (lower part), Ilam Province, Iran. The RUSLE model is a statistically-based water erosion model with six erosional factors [18] as follows:

$$A = R.\ K.\ L.\ S.\ C.\ P \qquad (1)$$

Where A is the average soil loss per unit area by erosion (t ha^{-1} $year^{-1}$), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), K is the soil erodibility factor (t h MJ^{-1} mm^{-1}), L is the slope length factor, S is the steepness factor, C is the plant cover and management practice factor and P is the conservation support practice factor. The L, S, C and P values are dimensionless. The spatial resolution of the data was set 50 meter.

The R factor is considered to be the most highly correlated index to soil loss at many sites throughout the world [18-30]. In this study in order to estimate the R factor, the annual and monthly rainfall quantities were obtained from the records of 8 stations for 22 years. Then, with use of the following equations, Fournier index and R factor were estimated for all the stations. Fournier index [27], F, is defined as:

$$F = \frac{\sum_{i=1}^{12} P_i^2}{\sum_{i=1}^{12} P} \qquad (2)$$

Where, P_i, is the mean rainfall depth in mm of month i and P is the mean annual rainfall in mm.

The Fournier index for all the rainfall records in the region was estimated (Table 1) using Eq.(2). In order to estimate the most appropriate R-factor based on the F index, the following R-F relationships [27] were used.

$$R - factor = \left(0,07397xF^{1,847}\right)/17.2 \quad \text{when F < 55 mm} \qquad (3)$$

$$R - factor = \left(\left(95,77 - \left(0,681xF\right) + \left(0,477xF^2\right)\right)\right)/17.2 \quad \text{when F = 55 mm} \qquad (4)$$

The average R-factor values for meteorological stations of the study watershed were obtained by averaging the yearly values from 1986 to 2008 and then, R-factor map layer was made in GIS. Table 1 listed the individual data sets and indicates the name of the station, elevation of the station, length of records in years and some calculated parameters (Rainfall, F and R).

The K factor is determined by using the nomograph [31] comprised of five soil and soil profile parameters. Algebraic approximation [18] of the nomograph is as below:

$$K = 2.73x10^{-6}xM^{1,14}\left(12 - a\right) + 3.25x10^{-2}\left(b - 2\right) + 2.5x10^{-2}\left(c - 3\right) \qquad (5)$$

Where, M is particle size diameter = {(%silt + %very fine sand) x (100-%clay)}, a is organic matter percentage, b is soil structure code and c is profile permeability class. The LS factor in RUSLE reflects the effect of topography on erosion. In this study, LS factor was calculated as follows[32,33]:

$$L = 1.4\left(\frac{A_s}{22.13}\right)^{0.4} \quad (6)$$

and

$$S = \left(\frac{\sin\beta}{0.0896}\right)^{1.3} \quad (7)$$

Where, A_S is specific watersheds area (m^2/m) and β is slope angle (degree).

In the USLE/RUSLE model, the C factor is derived based on empirical equations with measurements of ground cover, aerial cover and minimum drip height [18]. The most widely used indicator of vegetation growth based on the RS technique is the Normalized Difference Vegetation Index (NDVI), which for Landsat-ETM is given by the following equation:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (8)$$

Where NIR and R are near infrared and red bands, respectively. NDVI values range between-1.0 and +1.0.

The P factor reflects the impact of support practices dealing with the average annual erosion rate.

MATERIALS AND METHODS

Study Area: The study area is a mountainous watershed, called Ilam Dam watershed (lower part), located in the southeast of Ilam Province in the western Iran. The watershed area is 4885 ha, between latitudes 33°23' 42.15" to 33°27' 7.2" N and longitudes 46°20' 17.23" to 46°21' 23.19" E (Fig. 1). The elevations of the highest and lowest points are 1817 m and 940 m above mean sea level, respectively. Climatic conditions in the area are semi-arid (typical Mediterranean climate) with mean annual rainfall of about 592.78 mm and average temperature is 21.7 °C in summer and 4.7 °C in winter. Land use in the area mostly includes dry farmland, forestland, rangeland, orchard, waterbody, residential and built-up lands. The Ilam Dam is one of the most important dams in the western Iran that supplies drinking water to the Ilam City[35].

Methods: The R-factor map was calculated according to the relationship between elevation, rainfall and F factor. Firstly, we obtained the relationship between elevation and annual rainfall (R^2= 0.80). Secondly, the relationship between annual rainfall and R factor was obtained (R^2 =0.89). Then, the correlation between F and R factors was also obtained (R^2 =1). Finally, with writing algorithm in ILWIS software, R factor map in grid format was generated. According to Arnoldus (1980)[34], the F index is a good approximation of R to which it is linearly correlated. The R values for the study area are shown in Table 1.

In this study, the sand, silt, clay and organic matter percentages, soil structure and soil permeability data for the watershed were obtained from earlier reports published by watershed management bureau of the Ministry of Agriculture of Iran [35]. K values for the study area are shown in Table 2.

In this study, LS-factor map was derived from the DEM map of the region using the "Terrain Analysis" extension of "ArcView 3.2"[32,33].

In relating to C factor, we used a scene of Landsat ETM+ images acquired on April 15 2001(as this date coincides with maximum stage of vegetation growth) with a spatial resolution of 28.5 meter. The NDVI was used to calculate the spectral ground-based data, showing the highest correlation with the above-ground biomass [36].After a reversal linear transformation derived from training samples, the relationship between C and NDVI can be established as C = ((1-NDVI)/2),

Table 1: Calculated and estimated F, R and rainfall values of the meterological stations

Stations	Elevation (m)	Length of records (years)	Rainfall values (mm)	F values	R values (MJ mm ha^{-1} h^{-1} y^{-1})
Arkavaz	1290	21	506.00	89.15	199.45
Tulab	1600	10	531.69	100.20	309.61
Mishkhas	1250	13	426.29	76.23	195.99
Ghajar	1480	8	476.10	90.67	201.50
Siah Ab	1220	11	440.55	91.44	205.14
Gol Gol	1140	10	449.88	82.88	196.75
Ilam	1337	22	501.50	92.29	209.16
Ema	1090	19	478.69	93.61	215.47

Table 2: K values for different soil type and land capability units in Ilam Dam Watershed (Lower part)

Soil unit	Soil type	Land capability units	K values (t h MJ^{-1} mm^{-1})
1	Fragmental, mixed, mesic Lithic, Torriorthents	1.1.1	0.19
		1.1.2	0.21
		1.1.3	0.43
		1.2.2	0.36
		1.2.3	0.22
		1.3.1	0.19
		1.3.2	0.49
		2.1.1	0.41
		2.1.2	0.23
2	Fragmental, mixed, mesic Typic Torriorthents	1.2.1	0.23
		1.3.3	0.15
		2.2.2	0.24
3	Loamy-Skeltal,mixed,mesic Typic Torriorthents	2.2.1	0.17
4	Loamy, carbonatic, mesic Typic Torrifluvents	5.1.1	0.25
5	Loamy-Skeletal, carbonatic, mesic Typic Haplocambids	2.1.3	0.30
		2.3.1	0.25
6	Loamy-Skeletal, mixed, mesic Typic Haplocalcids	2.2.3	0.19
7	Loamy-Skeletal, carbonatic, mesic Typic Haplocalcids	2.1.4	0.26
8	Loamy, mixed, mesic Typic Haplocalcids	3.1.1	0.26
9	Fine-Loamy, carbonatic, mesic Typic Haplocalcids	2.1.5	0.35
		2.2.4	0.30
		3.1.2	0.26

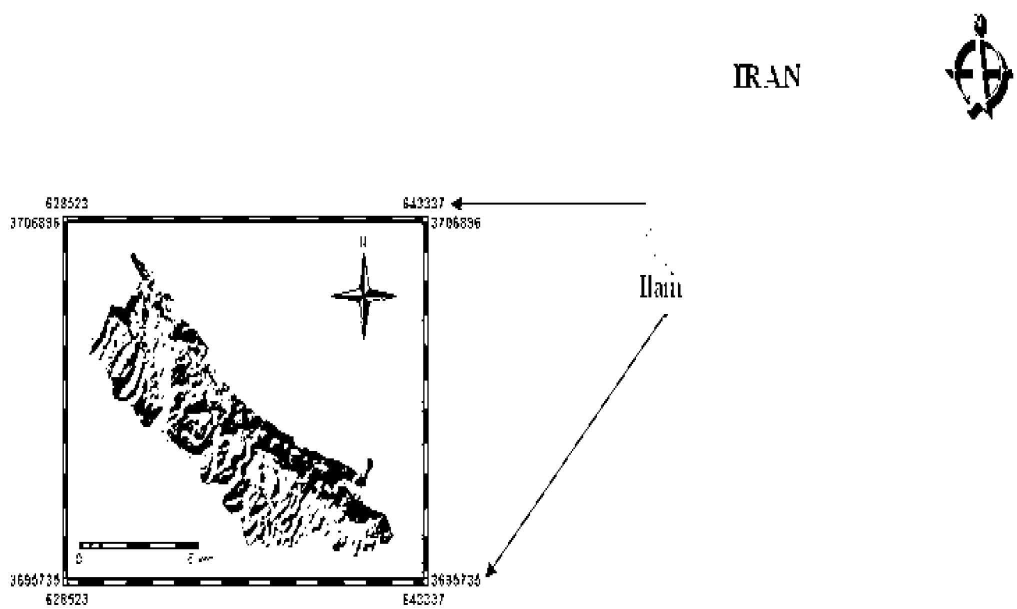

Fig. 1: Location of the study area

by which the C value in each grid cell can be specified[36] (Fig. 2). Fig. 2 depicts the C factor from the NDVI calculation.

Finally, in relation to P factor, as the this research work was applied in the area of non-agriculture, it was considered that there was no conservation practices(P) in non-agricultural areas. Therefore, the maximum value for P, that is 1.0, is assigned to this research work area [37].

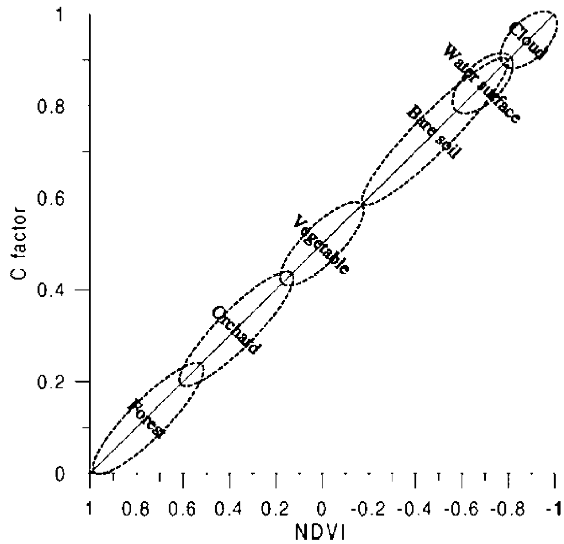

Fig. 2: Cover Management factor (C) from NDVI calculation compared with land cover information

RESULT AND DISCUSSIONS

RUSLE-factors: The values of the R, K, LS, C and P factors are shown in Table 3. Fournier indices and rainfall erosivity values were calculated using Eqs. (2), (3) and (4) for the rainfall intensity data of 8 stations. A very high and acceptable determination coefficient (R^2 = 1) was obtained between R factor values and F indices. R value estimation equation was calculated as: $R = 0.0277xF^2 - 0.3535xF + 5.568$.

The average annual R factor varies from 195.99 to 309.61 MJ mm ha^{-1} h^{-1} $year^{-1}$ and its total mean is 259.27 MJ mm ha^{-1} h^{-1} $year^{-1}$ (Table 3). The standard deviation (SD) is 22.19. There is more rainfall erosivity in the southwest and southeast of the watershed that coincides with higher elevation and ridge of study area (as shown with dark brown color in Fig. 3). In other words, lower R factors have a strong relationship with the lower elevation and rainfall values from the southwest and southeast mountain ridges to the northwest of the watershed. Using calculated and estimated R values for each station, input maps of R factor were generated with ILWIS (Fig. 3). The final R-factor map for the study area was presented in Fig. 3.

The average K value varies from 0.12 to 0.42 and its total mean is 0.18 t h MJ^{-1} mm^{-1} (Table 3). The standard deviation parameter is 0.06. K factor map was generated to show spatial distribution of erodibility (Fig. 4). It can be seen that higher amounts of K values coincides with Gurpi and Pabdeh formation that have the greatest sensitivity to erosion as shown with dark color.

Table 3: Values of R, K, LS, C and P factors

Parmeter	R	K	LS	C
Max.[a]	309.61	0.42	130	0.93
Min.[b]	195.99	0.12	0	0.19
Mean[c]	259.27	0.18	2.11	0.52
SD[d]	22.19	0.06	4.77	0.06

a: Maximum;b: Minimum;c: Mean and d: Standard Deviation
P factor = 1

Table 4: The minimum, maximum, mean and SD soil loss values of the study area

Parameter	Soil loss (t ha^{-1} $year^{-1}$)
Max[a]	6442
Mini[b]	0
Mean[c]	62.80
SD[d]	145.55

a, b, c and d are maximum, minimum, mean and standard deviation, respectively

A K factor map generated using these values is shown in Fig. 4.

Topography map was used to develop a map of slope length and slope steepness factor (LS). The LS factor was calculated by Eqs. (6) and (7) by using DEM of the watershed as well as considering the interactions between topography and flow accumulation (Fig. 5). It can be seen that the LS factor varies from 0 to 130 and its total mean is 2.11(Table 3). It worths mentioning that the majority of the region has LS values of less than 5. However, some specific areas with steep slopes (such as slopes along the rivers) have greater LS values. Our study area is characterized by decreasing elevation values from southwest and southeast reaches (ridges) to the northwest of watershed, with a maximum drop of 940 m. Fig. 5 shows the LS-factor grid map of the study area.

The C factor map was prepared based on NDVI as shown in Fig. 6. Generally, this factor has completely inverse relationship with NDVI. The C-factor varies from 0.19 to 0.93 and its total mean is 0.52 (Table 3). As seen from the Fig. 6, the greatest amount of this parameter coincides with lake in the northwest part of watershed (brown color) whereas the least amount is related to the area with dense forest vegetation (lighter color). Fig. 6 depicts the C factor from the NDVI calculation compared with the land cover information.

As there is no erosion control practice in the region, P-factor values are assumed as 1.0 for the study area.

Annual Soil Loss

Grid-based RUSLE implementation: Average annual soil loss was calculated by multiplying R, K, LS, C and P factors with use of SATEEC extension in ArcView GIS software environment. The resulting map for the study area can be seen in Fig. 7. Soil loss values (Table 4)

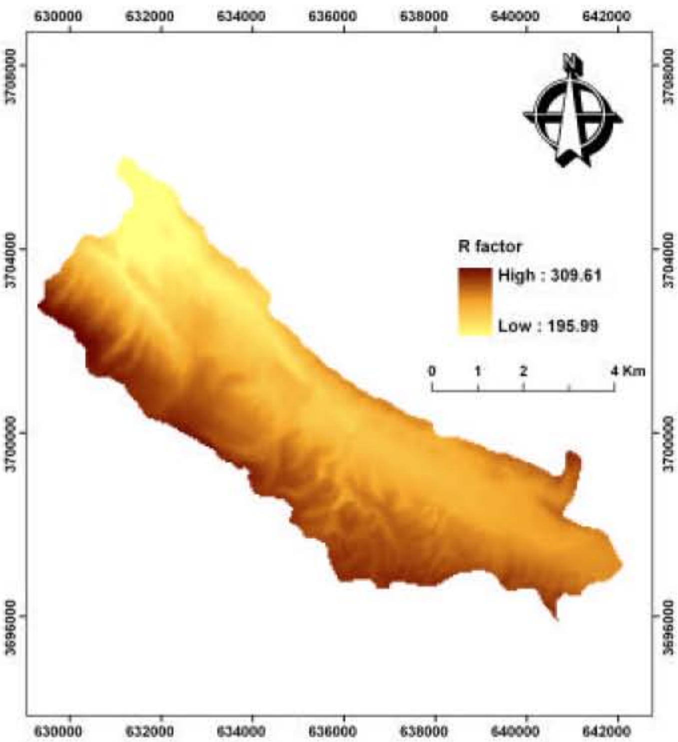

Fig. 3: Spatial distribution of R-factor

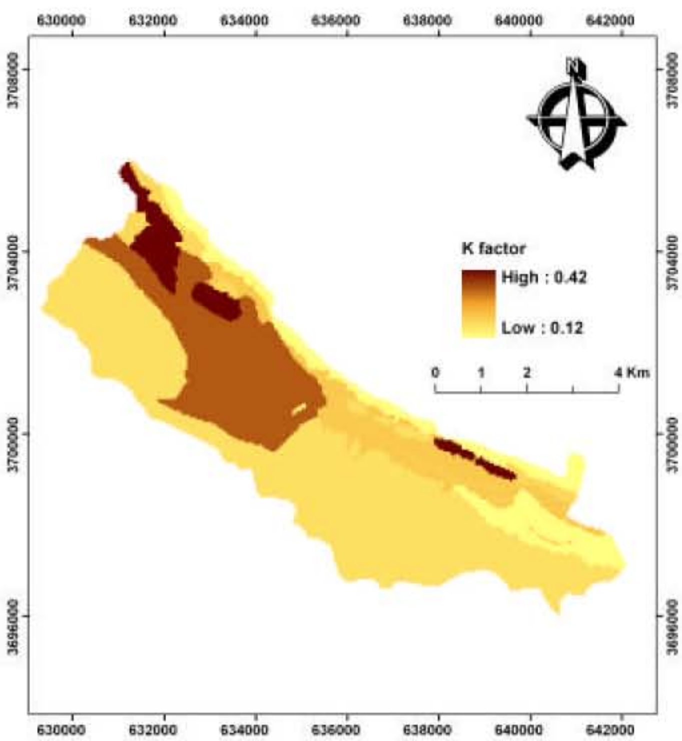

Fig. 4: Spatial distribution of K-factor

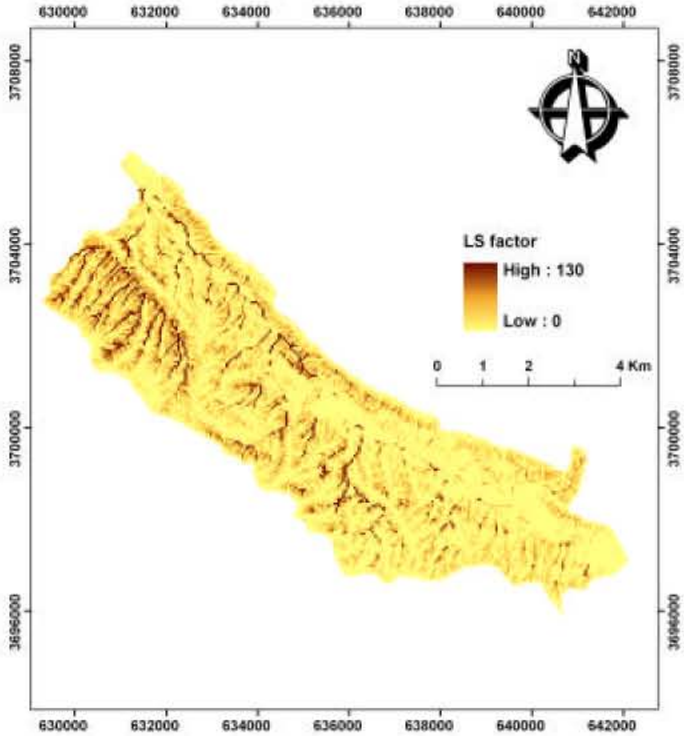

Fig. 5: Spatial distribution of LS-factor

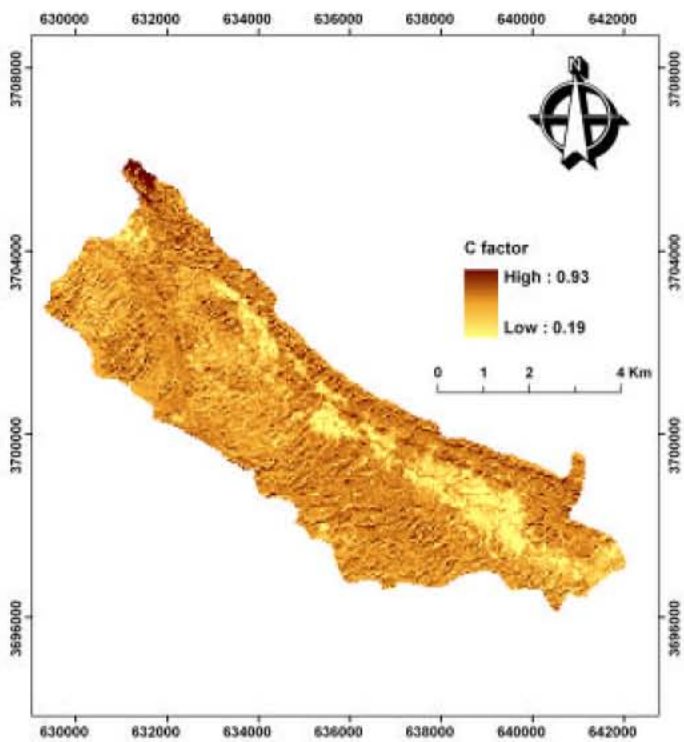

Fig. 6: Spatial distribution of C-factor

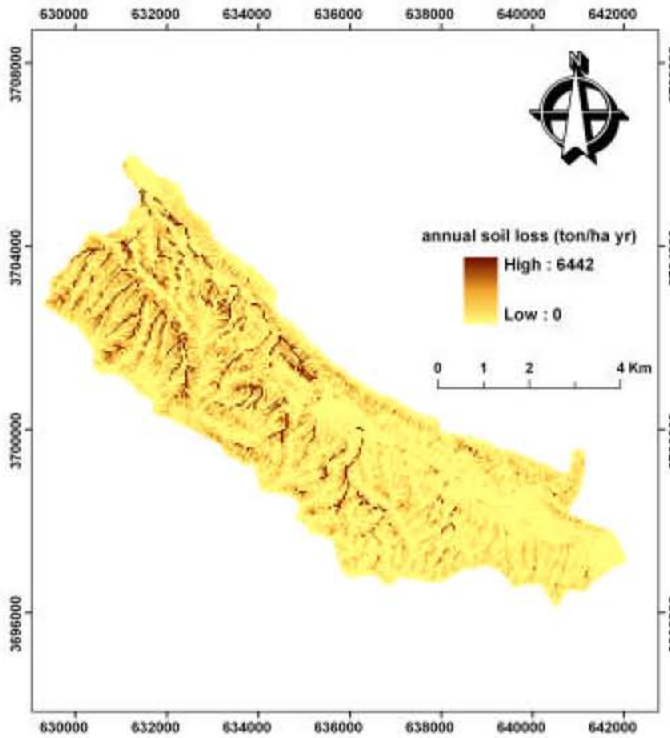

Fig. 7: Spatial distribution of soil loss (gradual)

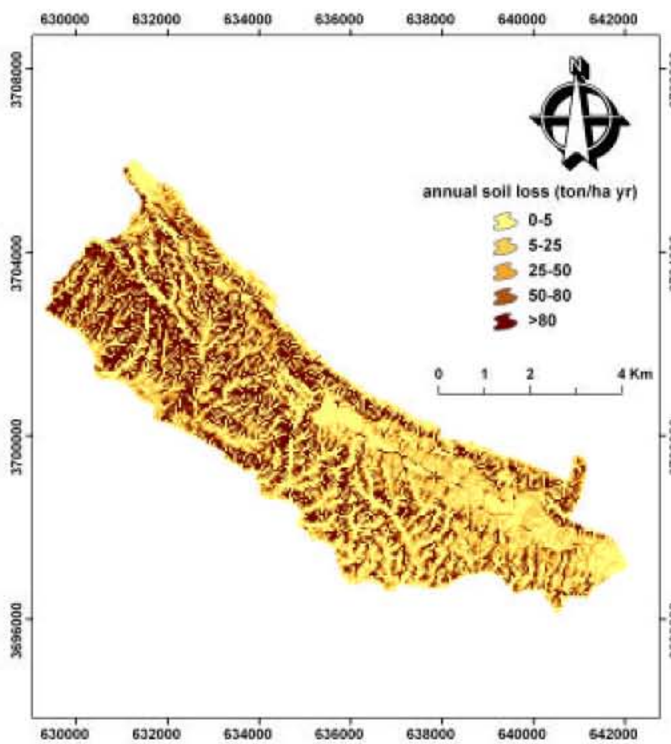

Fig. 8: Spatial distribution of soil loss (ordinal)

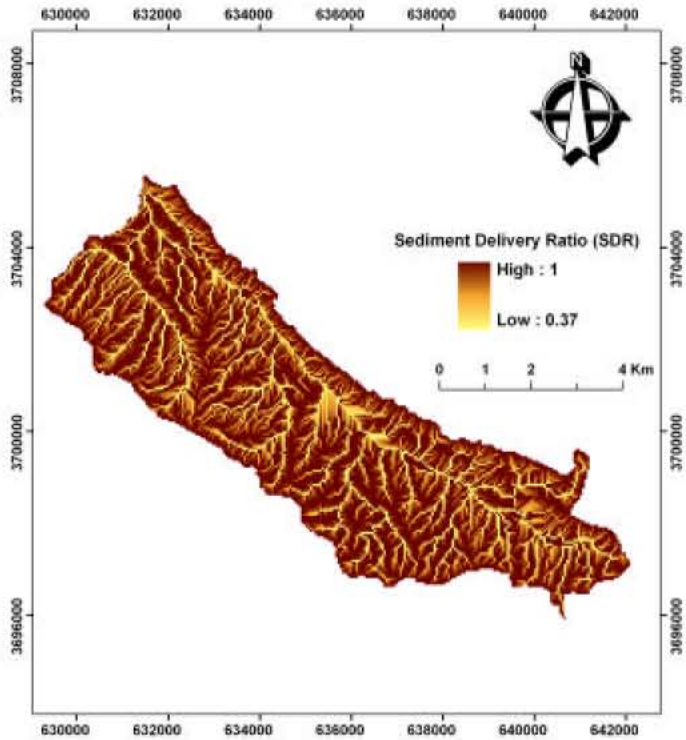

Fig. 9: Spatial distribution of sediment adding ratio (Based on USDA SCS, 1972)

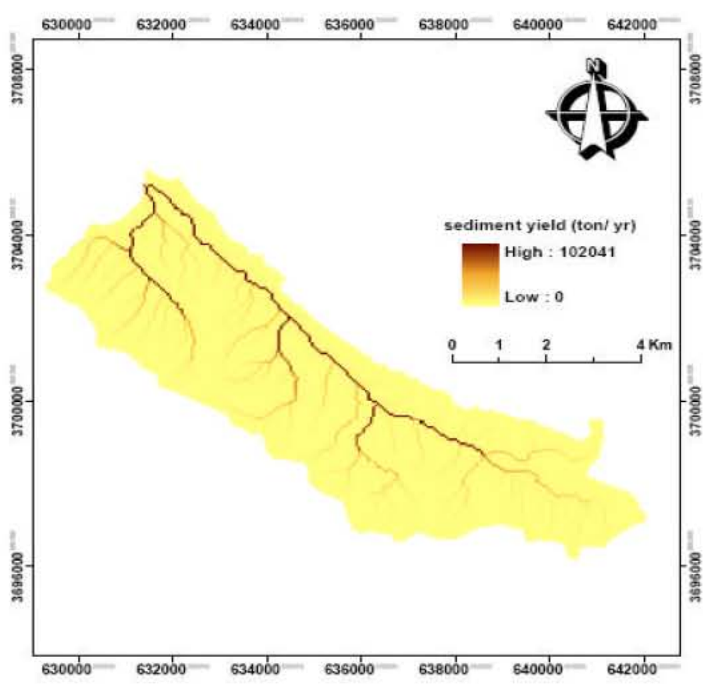

Fig. 10: Spatial distribution of sediment yield (Based on USDA SCS, 1972))

Table 5: The correlation and regressions among the annual soil loss and RUSLE factors of the study area

RUSLE factors	Annual soil loss
R	$R^2 = 0.0192$, y =-1.257x + 430.04
K	$R^2= 0.0205$, y = 568.45x + 114.2
LS	$R^2= 0.815$, y = 30.072x + 9.2573
C	$R^2= 0.0172$, y = 451.93x-72.631
P	$R^2= 0.044$, y = 1245.92x-808.16

Table 6: Area and amount of soil loss of each soil erosion risk category of the study area

Erosion categories	Numeric range (t ha^{-1} $year^{-1}$)	Area percentage (%)
Minimal	0-5	43.43184
Low	5-25	9.015353
Moderate	25-50	11.23167
High	50-80	11.22013
Extreme	80-6470	25.101

Table 7: SDR methods, amount of delivery ratio and sediment yield in the study area

SDR	Delivery Ratio	Sediment yield (t ha^{-1} $year^{-1}$)
Vanoni (1975)	0.30	18.84
Boyce (1975)	0.15	9.42
USDA SCS (1972)	0.37	23.24

ranged between 0 and 6442 (t ha^{-1} $year^{-1}$), with mean value of 62.80 (t ha^{-1} $year^{-1}$). The standard deviation is 145.55.

Statistical correlations and regression relationships between RUSLE factors and the annual soil loss value for the study area are provided in Table 5. It is clear that the strongest correlation is between the LS factor and annual soil loss value (R^2=0.81) while the correlations between remaining factors of RUSLE and annual soil loss were found to be very low.

Fig. 8 shows that the average annual soil loss in most of the area is between 0 to 25 t ha^{-1} $year^{-1}$. With regard to the spatial variation, the southwest part of the watershed and also ridge area in northeast has more erosion than the southeast part. However, it should be noted that areas with amount of erosion greater than 80 t h^{-1} $year^{-1}$ have been distributed in the watershed non-uniformly (Fig. 8 and Table 6). The reason for this high soil loss is related to its close relationship with topography (LS factor). A classified map for the study area is given in Fig. 8.

Assessment on Soil Erosion Risk Zone: The quantitative output of predicted soil loss was divided into five ordinal categories according to the soil erosion rate standard, technological standard of soil and water conservation SD238-87, issued by The Ministry of Water resources of China as shown in Table 6 [38]. As seen from the table, most areas of the watershed fall within the minimal (43.43%) and low erosion category (9.01%), which is mostly seen in the southeast and south part of the watershed. About 36.32% of the watershed is categorized from high to extreme erosion risks which are mostly found in the west and southwest part of the watershed (Table 6). Reason for this high soil loss is related to its close relationship with the slope length (L) and slope steepness (S) (r^2=0.81). In this area, priority must be given to protection of forest and afforestation of bare lands to reduce soil loss and sediment yield.

Annual Sediment Yield: In this study, three area based methods i.e. USDA SCS (1972)[39], Boyce (1975)[40] and Vanoni (1975)[41] were used in SATEEC to compute the SDR map. The average SDR values for the study area range from 0.15 to 0.37 and the average total sediment yields in the outlet of the watershed range from 9.42 to 23.24 t h^{-1} $year^{-1}$ as shown in Table 7.

As seen from the Table 7, the sediment yield (18.84 t h^{-1} $year^{-1}$) obtained using the Vanoni(1975) method was almost close to the measured sediment yield at the hydrometric station of the Water Resources Department of Ilam Province (16.58 t h^{-1} $year^{-1}$). Therefore, in this study, Vanoni(1975) method was selected for calculation of SDR and generation of sediment yield map. In this method, the average annual SDR and sediment yield varies from 0.37 to 1 and 0 to 102041 t $year^{-1}$(average sediment yield is 18.84 t h^{-1} $year^{-1}$), respectively (Fig. 9 and Fig. 10). Calculation results compare well with other studies and local data [42, 35], which demonstrates that a feasible method and technical approach to apply the GIS technology and RUSLE Model to estimate sediment yield in Ilam Province.

CONCLUSIONS

A quantitative assessment of soil loss and sediment yield on grid basis was carried out using the well-known RUSLE with a view to identify the critical erosion-prone zones for conservation planning in a study watershed in The Western Iran. Detailed data for the computation of the R, C and P factors were not available; therefore these parameters were estimated either by means of general or approximation formulae (i.e. R factor) or by processing available satellite images (i.e. for the extraction of C) and

GIS(P factor). Moreover, the estimation of LS factor was performed with the use of a GIS automated technique to generate L and S factors. All the maps of R, K, LS, C and P were integrated to generate erosion and sediment yield risk map to find out spatial distribution of soil loss and sediment yield within GIS environment in the study area.

The average annual soil erosion for the Ilam Dam watershed (lower part) was found to be 62.8 t ha^{-1} $year^{-1}$. About 53% of the watershed area was found out to be under minimal and low erosion class which was covering the southeast and south parts of the watershed. About 36.32% of the watershed is categorized under high to extreme erosion risks which were mostly found in west and southwest parts of the watershed. Since 36.32% of the region is under high and extreme erosion risk, adoption of suitable conservation measures seems to be inevitable. So, generation of soil loss map could locate high erosion risk areas for soil conservationist and decision maker. Major factors effecting soil erosion in the study area were found to be L and S parameters of RUSLE (R^2=0.81). In this area, priority must be given to the protection of forested lands and afforestation of steep barren lands and maximization of plant coverage. Meanwhile, the estimated average annual sediment yield (18.84 t h^{-1} $year^{-1}$) was close to measured annual average value (16.58 t h^{-1} $year^{-1}$). The results of RUSLE model demonstrated that this is a feasible method to apply the RS, GIS and RUSLE integrated model to estimate the sediment yield of the watershed.

Establishing of database through conventional methods is time consuming, tedious and difficult to handle. In the present study, attempt was made to utilize RS data for obtaining land use/land cover data which are essential prerequisites for generation of RUSLE factors. Thus, RS and GIS techniques can play significant role in generation of parameters from remote areas of watersheds for the purpose of soil erosion and sediment yield modeling as well as watershed management. The strength of GIS relies on its ability to handle spatial data and attribute information at a higher level of resolution. Thus, RS and GIS techniques can assist in developing management scenarios and provide options to policy makers for handling soil erosion problem in the most efficient manner for prioritization of watershed areas for treatment. The representation of model input and output also facilitates examination of a wider range of alternatives than would be possible by using standard methods.

Notation and Abbrivations:

RUSLE Revised Universal Soil loss Equation
USLE Universal Soil Loss Equation
RS Remote Sensing GIS Geographic Information System
DEM Digital Elevation Model NDVI Normalized Difference Vegetation Index
R Rainfall Erosivity K Soil erodibility
L Slope length S Slope steepness
C Plant Cover and Management Practice P Conservation Support Practice
SDR Sediment Delivery Ratio TM Thematic Mapper
t ha^{-1} $year^{-1}$ Ton/hectare year MJ mm ha^{-1} h^{-1} $year^{-1}$ Megajoul millimeter/ hectare hour year
t h MJ^{-1} mm^{-1} Ton hour/ Megajoul millimeter F Fournier index
ILWIS Integrated Land and Water Information System
USDA United State of Department of Agriculture
SATEEC Sediment Assessment Tool for Effective Erosion Control

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