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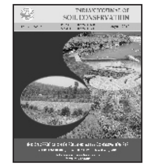

Soil erosion estimation and prioritization of Koshalya-Jhajhara watershed in North India

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ABSTRACT

Soil is a non-renewable resource present on the surface of the earth. It is dynamic and prone to continuous degradation due to adverse land use practices. Soil erosion is a serious problem arising from agricultural intensification and other anthropogenic activities. Its assessment is essential for planning and conservation works in a watershed or basin. In the present study, the revised universal soil loss equation (RUSLE) in geographical information system (GIS) environment has been used to estimate soil loss in Koshalya-Jhajhara (K-J) watershed in North India containing total area of 134.92 km^2. Raster maps for six factors of RUSLE have been prepared. These maps have been integrated so as to prepare soil erosion risk map which reflects five soil erosion risk categories. The results showed an area of 85.54% under very low to low category of soil erosion whereas 7.92% area under moderate soil erosion category. Only 6.54% of the watershed area falls under moderate high to high category of soil erosion. Erosion pattern in various sub-watersheds indicated maximum area of sub-watersheds (1, 2, 4, 5, 6, 7, 8, 9, 12 and 13) falling in the hilly region are in low to very low category of soil erosion risk whereas maximum area of sub-watersheds (0, 14, 15, 16, 17 and 18) are prone to high to very high soil erosion risk because of low vegetative cover, agricultural and human interventions.

1. INTRODUCTION

The soil erosion in any area can be calculated using different formulae/equations which exist in literature. These have been developed after long period of experiments worldwide. Universal soil loss equation (USLE) and RUSLE are most commonly used methods for the purpose of soil loss estimation. The empirically derived factor cannot give information about changes in surface flow, erosion processes and slope geometry (Moore and Burch, 1986). Water and wind are two main factors for soil erosion (Mishra *et al.,* 2018). Water erosion affects nearly 56% of the total degraded land and wind erosion affects about 28% of the total degraded land worldwide (Oldeman, 1994). The worldwide soil erosion rates range from 0.5 to 350 Mg $ha^{-1}yr^{-1}$. In some countries, about half of the agricultural prime lands are severely eroded. Annually, about 75×10^9 Mg of soil is lost worldwide (Lal, 1998). At global scale, an estimate of about 1960 M ha of land are prone to erosion, which represents about 15% of the earth's total land area, of which 50% is severely eroded, and much of that is being abandoned (Lal *et al.*, 2004). About 6×10^9 Mg yr^{-1} of soil is annually lost in India and China (Pimentel, 2006).

Soil is the most fundamental, basic and natural resource on earth, which is essential for survival of human being. It is the basis of all terrestrial life and is a vital resource for food, fuel, and fibres. The main function of soil may be considered as medium for plant growth but due to increasing demand of food, soil has multi-functionality including environmental quality, global climate change and repository for urban/industrial waste. World soils are now managed to: increasing food demand, filter air, purify water and store carbon (C) to offset the anthropogenic emissions of CO_2 (Blanco and Lal, 2008). The average annual soil loss of the Dikrong river basin was 51 t $ha^{-1}yr^{-1}$. About 25.61% of the watershed area came under slight erosion class. Areas were divided into five zones; moderate, high, very high, severe and very severe and the erosion potential of zones was computed as 26.51, 17.87, 13.74, 2.39 and 13.88%, respectively (Dabral *et al.*, 2008).

Water is responsible to wash out the soil particles from sloping and bare lands whereas the wind is responsible for loosening and detached soil particles from flat lands. Tillage erosion due to ploughing during crop production in agriculture lands is also cause of soil erosion (Naik *et al*., 2014). Soil erosion creates major threat to food production particularly in densely populated and rapidly growing regions of the world (Panigrahi *et al.*, 1996; Naik *et al*., 2015; Yousuf *et al.*, 2017). The mean value of C-factor in the Europe was estimated to be 0.1043. The forests had the lowest mean C-factor (0.00116), arable lands and sparsely vegetated areas having highest (0.233 and 0.2651, respectively). The average C-factor in arable lands was 19.1% (Panagos *et al*., 2015). The total annual potential soil loss in the Nethravathi basin located in the south-western part of India was about 473,339 t yr^{-1} that which is comparable with the measured sediment of 441,870 t yr^{-1} during the water year 2002 and 2003. The soil erosion rate due to increase in agricultural area was estimated about 14,673.5 t yr^{-1}. The probability zone map showed that the major portion of the study area falls under low probability zone and only a small portion came under high to very high probability zone (Ganasri and Ramesh, 2016).

It is necessary to estimate the soil erosion in various sub-watersheds so as to prioritise these sub-watersheds for further treatment. In the present study an attempt has been made to estimate the soil erosion in K-J watershed situated in Lesser Himalayas using RUSLE model given by Renard *et al*., 1997.

2. MATERIALS AND METHODS

Study Area

The K-J watershed covers an area of 134.92 km^2 in districts of Solan (Himachal Pradesh) and Panchkula (Haryana). It is covered by Survey of India (SoI) Toposheet No. H43K13 and H43L1 on the scale of 1:50000 and bounded by 30″45' to 31”0' North latitudes and 76″45' to 77”15' East longitudes (Fig. 1). The maximum and minimum elevations in the area are 399 m and 1810 m above mean sea level (amsl), respectively. The hilly terrain covers an area of 81.14 km^2 whereas 53.78 km^2 is covered by plain land in the watershed. Koshalya and Jhajhara are two tributaries of Ghaggar river. Geologically, the area falls in lesser Himalayas and also extends up to Siwalik hills on south-west side. Many geological thrusts are present in the area like Jhajhara thrust, Barsar thrust, Koshalya thrust, Surajpur fault, Pinjore garden fault (PGF). The main thrust which passes through the area is Himalayan frontal thrust (HFT) between Siwaliks and lesser Himalaya (Malik and Nakata, 2003; Singh and Tondon, 2009).

Data Used and Methodology

To prepare the soil risk map of K-J Watershed, RUSLE has been used. To calculate various factors of RUSLE ancillary data like 17 years rainfall has been taken from Indian Meteorological Department (IMD) website shown in Table 1. The methodology followed in the present study is shown in Fig. 2. Soil Texture map shown in Fig. 3 have been collected from ICAR-National Bureau of Soil Survey (NBSS), Nagpur and Haryana Space Application Centre (HARSAC) and values of K-factor are taken from existing literature. DEM of area has been extracted from ASTER 30 m satellite data and LS factor has been calculated using the same. C and P factors have been generated from

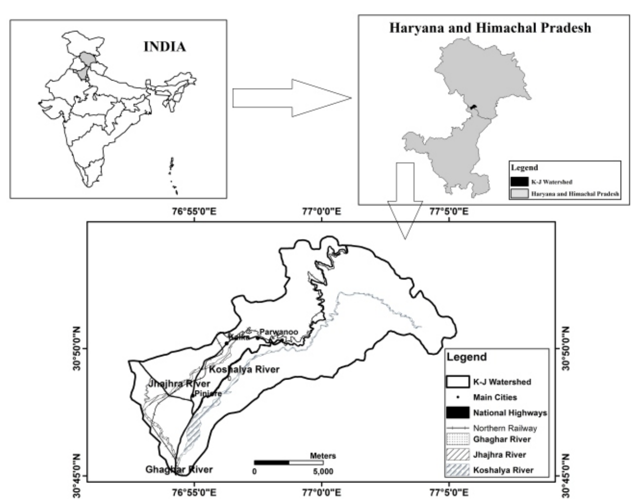

Fig. 1. Location map of Koshalya-Jhajhara watershed

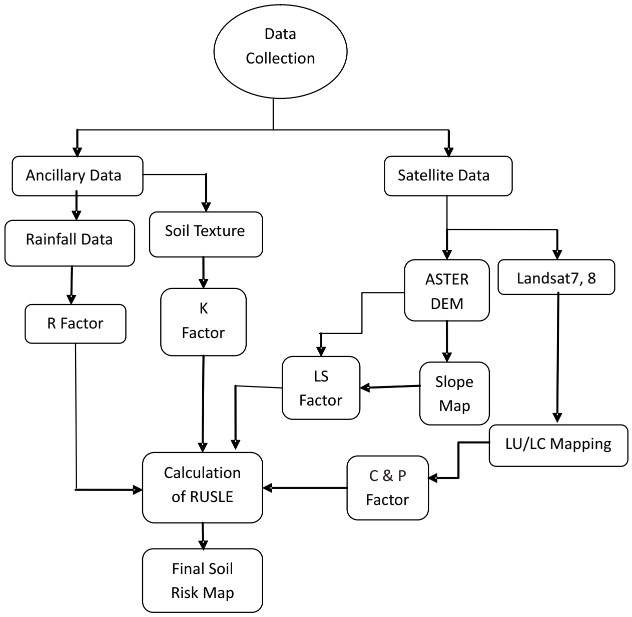

Fig. 2. Methodology flow chart

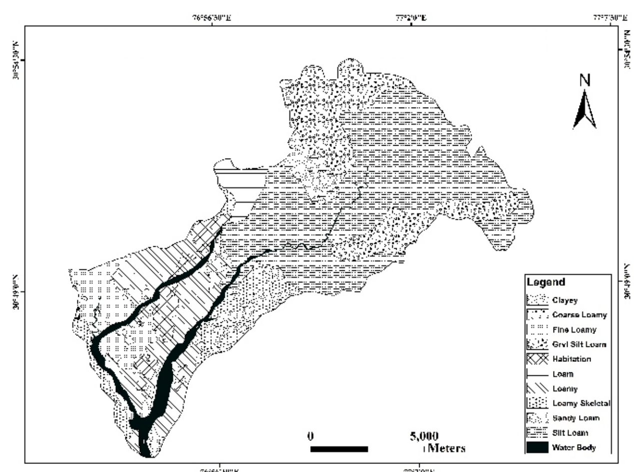

Fig. 3. Soil texture map of K-J watershed

LU/LC map of the area which has been prepared by using *rabi* and *kharif* seasons Landsat 7 and 8 satellite data of the years 1999-2000 and 2015-2016. All the factors have merged by using raster calculator and final soil risk map of the watershed has been prepared.

Soil Texture

The soil texture map of watershed is prepared by visual image interpretation of satellite imagery, maps published by NBSS and HARSAC, LU/LC and literature. There are nine soil types present in the watershed *i.e.* silt loam, sandy loam, loamy skeletal, loamy, loam, gravel silt loam, fine loamy, coarse loamy, clayey and habitation excluding river. The 40.41% area of the watershed is covered by silt loam and 15.43% area of watershed is covered by gravel silt loam. Soil texture map of the watershed is shown in Fig. 3 and the area statistics is given in Table 2.

Revised Universal Soil Loss Equation (RUSLE)

RUSLE given by Renard *et al*., 1997 is an improved form of USLE given by Wischmeier and Smith (1965 and 1978). The RUSLE model is most widely used around the world to predict long-term rates of rill erosion. In USLE, L and S factors were computed as two different parameters, whereas in RUSLE both are combined into a single factor (LS) and computed. The mathematical expression of RUSLE is:

$$A = R*K*LS*C*P \qquad ...(1)$$

Where, A = Computed average annual soil loss (t $ha^{-1}yr^{-1}$), R = Rainfall erosivity factor, K = Soil erodibility factor, LS = Slope length-steepness factor, C = Cover management factor, P = Conservation practice factor.

3. RESULTS AND DISCUSSION

Rainfall Erosivity Factor (R)

The R-factor is used to calculate the effect of rainfall on soil erosion. An average annual rainfall data is required to calculate R-factor using equation given below:

$$R = 81.5 + 0.375 * P_a \ (340 < P_a < 3500 \text{ mm}) \qquad ...(2)$$

Where, P_a is average annual rainfall. As the area is small and availability of single point data of rainfall of K-J watershed is available, eq. 2 would give only a single value of R, instead of raster file. Dhruvanarayana and Rambabu (1983) gave the following equation to estimate R which is:

$$R = 81.5 + 0.375 * A \qquad ...(3)$$

Where, A is average annual rainfall in mm. The R-factor is estimated using the rainfall data of past 17 years (1999 to 2015) downloaded from IMD website shown in Table 1. As per rainfall data available on IMD website the average annual rainfall is 1098.5 mm In K-J watershed.

Soil Erodibility Factor (K)

Soil erodibility factor (K) represents susceptibility of soil to erosion as well as the rate of runoff. Soils having high clay percentage has low K values of about 0.05 to 0.15, because of its resistant nature to detachment. Coarse textured soils are having low K values, near about 0.05 to 0.2 and these soils are easily

Table: 1
Annual rainfall in K-J watershed from 1999 to 2015

Year	Rainfall (mm)	Year	Rainfall (mm)
1999	1160	2008	876
2000	1189	2009	987
2001	1215	2010	898
2002	1176	2011	1087
2003	1755	2012	1133
2004	920	2013	1152
2005	956	2014	1132
2006	984	2015	987
2007	1067		

detached even in low runoff conditions. Medium textured soils, such as the silt loam soils are having moderate K values of about 0.25 to 0.4, as these are having moderate susceptibility to detachment and also produce moderate runoff. Soils having a high silt percentage are most erodible soils on earth. The soil erodibility factor (K) depends on nearly permanent soil properties and is thus considered to be constant throughout the year. For most soil types in US, K value tables have been developed and are available with soil conservation service offices. Wischmeier *et al*., 1971 developed a nomograph for predicting erodibility which is widely used in the absence of published value. In the nomograph, soil erodibility is predicted as a function of soil and soil profile properties like: percent Silt, percent very fine sand, percent clay, percent organic matter (OM), structure code (s) and permeability code (p).

Wischmeier, (1974) gave the regression equation for estimating erodibility factor values from nomograph. This equation is:

$$K = \frac{2.1 * 10^{-4}\ (12 - OM)\ M^{1.14} + 3.25\ (S - 2) + (p - 3)}{759.4} \quad ...(4)$$

Where, M is a function of soil primary particle size fraction given by:

$$M = (\%\ \text{silt} + \%\ \text{very fine sand}) * (100 - \%\ \text{clay}) \quad ...(5)$$

In this study due to non-availability of percent silt, percent very fine sand, percent clay data of K-J watershed, the standard values of K (on the basis of published literature) have been taken. The K-factor map of K-J Watershed shown in Fig. 4 and values of K for different soil types in the catchment area are given in Table 2.

Slope Length-Steepness Factor (LS)

LS factor accounts for the effect of topography on

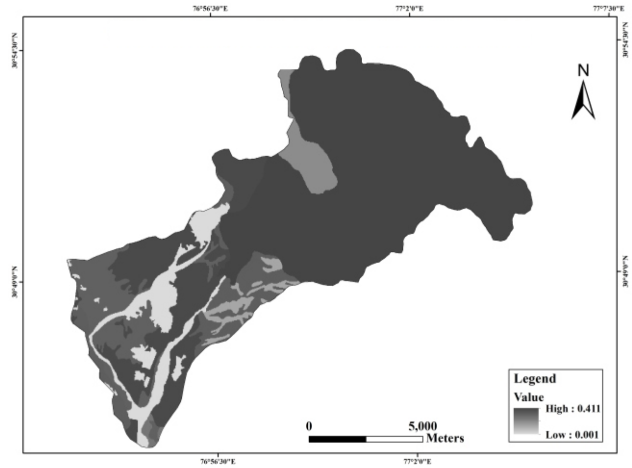

Fig. 4. K-factor map of K-J watershed

Table: 2
Area under different soil texture types and K values in K-J watershed

Texture	K-value	Area (km^2)	Area (%)
Silt loam	0.411	54.52	40.41
Sandy loam	0.233	4.54	3.36
Loamy skeletal	0.343	8.63	6.40
Loamy	0.398	18.31	13.57
Loam	0.396	3.55	2.63
Gravel silt loam	0.411	20.82	15.43
Fine loamy	0.336	11	8.15
Coarse loamy	0.284	0.47	0.35
Clayey	0.176	2.59	1.92
Habitation	0	6.04	4.48

soil erosion. The slope-length factor (L) is determined from eq. 6 given by Moore and Burch, 1986:

$$L = (/22.13)^{m} \quad ...(6)$$

Where, 22.13 is the RUSLE unit plot length (in metres) and m is a variable of slope length exponent. Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel.

The slope length exponent m can be calculated as:

$$m = \beta / (1+\beta) \quad ...(7)$$

$$\beta = (\sin\alpha / 0.0896) / \{3.0\ (\sin\alpha)^{0.8} + 0.56\} \quad ...(8)$$

Where, α is the slope angle.

The slope steepness factor (S) is estimated using the relationships given by McCool *et al*., 1987.

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

$$S = (\sin \alpha / \sin 5.143)^{0.6} \; S \geq 9\% \; (i.e. \tan \alpha \geq 0.09) \quad ...(10)$$

For all trigonometric operations in ArcGIS, angles have been converted into radians. The LS factor map of K-J watershed is shown in Fig. 5.

Crop Cover Management Factor (C)

The crop cover management factor is the ratio of soil loss from an area with specified cover and management to that on identical area in tilled continuous fallow. The C-factor values used in this study are based on Wischmeier and Smith (1978) as well as the studies carried out in similar terrain conditions including Himalayan region. These values are updated for each land use/land cover type in LU/LC map of K-J watershed. The values of C-factor for each land use unit are given in Table 3 and map of C-factor shown in Fig. 6.

Conservation Practice Factor (P)

The P factor represents the effect of various conservation and support practices for arresting soil erosion being taken up in the area. In this study, P-factor map has been generated by using the land use/land cover map by assigning P values for each of the land use/land cover types according to Wischmeier and Smith (1978). The values of P-factor for each land use unit are given in Table 3 and map of P-factor is shown in Fig. 7.

Soil Erosion Risk Map

All factors involved in RUSLE as given in eq. (1) have been calculated Using raster calculator to prepare the final soil erosion risk map (Fig. 8). The area of the watershed falling under various erosion categories is shown in Table 4. The map indicates that the northern part of watershed do not have more erosion risk. The Doon parts and river banks are found to be prone to high soil erosion risk.

4. CONCLUSIONS

The K-J watershed falls from lesser Himalayas to Siwaliks foot hills making it prone to various degrees of erosion. The study concludes that 49.79 and 65.65 km^2 of the watershed which constitutes 85.54 5% of the

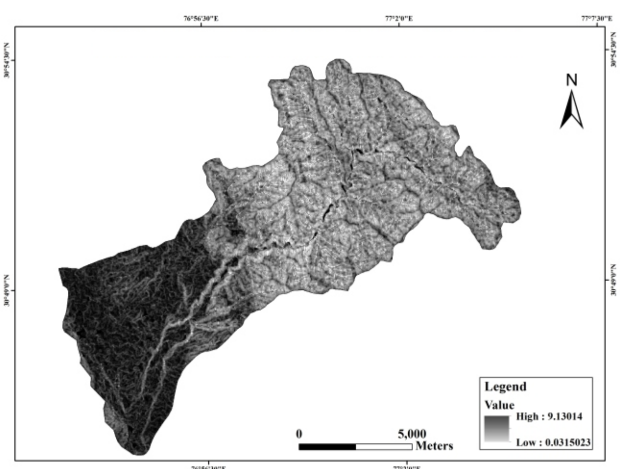

Fig. 5. LS factor map of K-J watershed

Table: 3
Values of C and P in K-J watershed

LU/LC Class	C	P
Dense forest	0.08	1
Scrub forest	0.6	1
Open forest	0.4	1
Built-up compact	1	0.001
Built-up sparse	1	0.002
Agriculture land	0.5	0.5
Water body	0.001	1

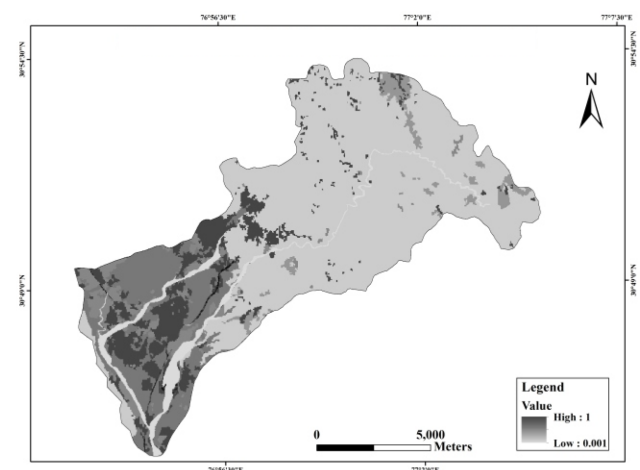

Fig. 6. C-factor map of K-J watershed

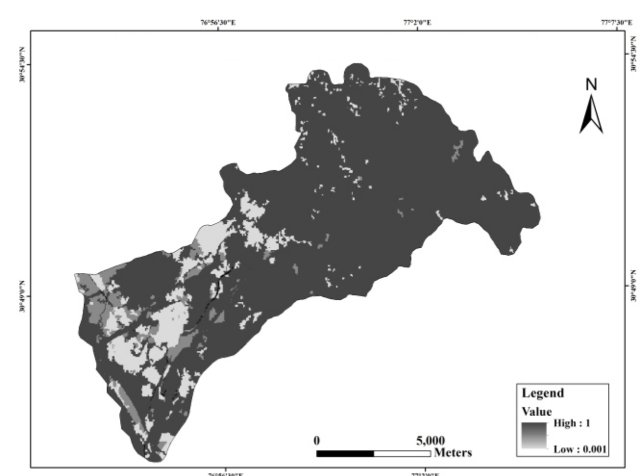

Fig. 7. P-factor map of K-J watershed

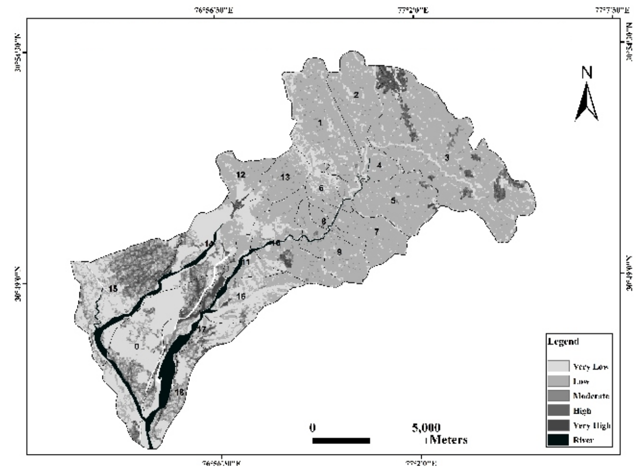

Fig. 8. Soil erosion risk map of K-J watershed

Table: 4
Area under various soil erosion categories

Soil erosion classes	Soil loss ($t\ ha^{-1} yr^{-1}$)	Area (km^2)	Area (%)
Very low	0-10	49.76	36.88
Low	10-25	65.65	48.66
Moderate	25-50	10.68	7.92
High	50-100	6.56	4.86
Very high	100-200	2.26	1.68
Total area		134.92	100

total watershed, falls under very low to low category of soil erosion. An area of 10.68 km^2 which is 7.92% of the total watershed area, falls under moderate category of soil erosion. Only 6.54% of the area of the watershed falls under moderate high to high category of soil erosion. The erosion pattern in various sub-watersheds indicates that the sub-watersheds falling predominantly in the hilly region *i.e.* the sub-watersheds 1, 2, 4, 5, 6, 7, 8, 9, 12 and 13 have low to very low soil erosion risk which may be attributed to the presence of hard rocks and also strong forest cover. The maximum area of sub-watersheds 3, 10 and 11 are in moderate to high risk category because of low hill terrain and human interventions in forest land. The maximum area of sub-watersheds 0, 14, 15, 16, 17 and 18 are prone to high and very high soil erosion risk. This may be attributed to low vegetative cover, agricultural areas and human interventions. These sub-watersheds are in Doon part of the K-J watershed and needs to be treated on priority.

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