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Estimation of soil erosion in Nagwan watershed, Hazaribagh using universal soil loss equation

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Abstract
The assessment of soil erosion for any particular region is of prime importance for adaptation of suitable measures which help to render its impact. The present study is pertaining to assess the average annual soil erosion loss from Nagwan watershed, Hazaribagh district, Jharkhand. Rainfall, topographic characteristics, soil and vegetation mainly influence the rate of soil erosion from an area. Therefore, in order to produce a realistic estimate of rates of soil erosion a method need to be adopted which will takes these factors into account while estimating soil erosion losses. The Universal soil loss equation (USLE) is one of such equation. It is a product of six causative factors namely Rainfall erosivity factor (R), soil erodibilty factor (K), slope length factor (L), slope steepness factor (S), Cover and management factor (C), Support practice factor (P). The different factors such as R, K, L, S, C and P factor were calculated individually for the watershed. The average annual soil erosion loss is estimated as 12.39 tones ha^{-1}year^{-1} with standard deviation of 49.95. The soil loss map was also generated by integrating all the erosion affecting factor in a raster calculator of ArcGIS platform.

Keywords: soil erosion, land degradation, watershed, ArcGIS, USLE

Introduction

Soil erosion from a catchment is a complex process, which is controlled by climatic, topographic, geologic, geomorphic, and land use characteristics. Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard of modern times worldwide (Eswaran *et al* 2001) [9]. Soil erosion is complex and dynamic phenomenon in which productive soil surface is detached, transported and accumulated at a distant place which resulted into exposure of sub surface soil (Felix-Henningsen, Morgan, Mushala, Rickson, & Scholten, 1997) [11] and siltation in reservoirs and natural streams elsewhere (Jain, Jain, & Sharma, 2005; Jasrotia, Dhiman, & Aggarwal, 2002; Sheikh, Alam, Shah, & Bhat, 1992; Sinha & Regulwar, 2015; Sreenivas & Venkataratnam, 2006) [12, 14, 23, 24, 16]. The major factors that affect soil erosion are related to land use and topography (Kothyari & Jain, 1997) [17]. Vegetation or plant cover tends to reduce soil erosion, its effectiveness depending on the height (Jain *et al*., 2005) [15] and continuity of the canopy and the density of ground cover and roots (Sheikh *et al*., 1992) [23]. Generally, forests are most effective in reducing erosion because of their large canopies. Globally, 1964.4 Mha of land is affected by human induced degradation (UNEP, 1997). Of which, 1,903 Mha land is subjected to water induced erosion and 543.3 Mha to wind erosion. From Indian perspective, it was estimated that out of the total geographical area of 329 Mha, about 167 Mha is affected by serious water and wind erosion (Sheikh *et al*., 1992) [23] and its includes 127 Mha affected by soil erosion and 40 Mha degraded through gully and ravines, shifting cultivation, water logging, salinity and alkalinity, shifting of river courses and desertification (Das, 1977) [5]. Narayan and Babu (1983) [22] estimated that in India about 5334 MT (16.4 t ha^{-1}) of soil is detached annually, about 29% is carried away by the rivers into the sea (Dabral, Baithuri, & Pandey, 2008; Sheikh *et al*., 1992) [7, 23] and 10% is deposited in reservoirs resulting in the considerable reduction in the storage capacity. Soil erosion in the catchment area and subsequent deposition in river, lakes, and reservoirs are of great concern (Jain & Goel, 2015) [13] as it not only causes loss of fertile soil but also resulting in loss of reservoir capacity and degradation of downstream water quality. Different soil erosion prediction model were developed for estimating annual soil losses and out of them the Universal Soil Loss Equation (USLE) is one of the most widely used models for predicting soil loss. Many case studies like soil loss prediction by Singh *et al*. (1981) [22], soil erosion and sediment yield estimation using GIS (Kothyari and Jain, 1997; Jain and Kothyari, 2000) [15, 17], have proved that integration of remote sensing and GIS techniques with USLE could be effectively used for predicting soil loss(Mahalingam, Malik, & Vinay, 2016) [18]. The average rate of soil erosion for different combination of crop system and management practices with a specified soil type, rainfall pattern, and topography can be estimated effectively using USLE (Alewell, Borrelli, Meusburger, & Panagos, 2019; Benavidez, Jackson, Maxwell, & Norton, 2018; Fagbohun, Anifowose, & Odeyemi, 2016; Jain *et al*., 2005; Pham, Degener, & Kappas, 2018) [1, 3, 10, 15, 19]. All the factors of the USLE are geographic in nature. Therefore, computation of these factors can be done easily and efficiently using geographical information system (GIS) with various data layers representing watershed boundary, slope, rainfall distribution, land use and management practices and soils. The combined data layers of a GIS help calculation of soil erosion per pixel. The USLE was used to estimate average annual soil loss from Nagwan watershed which is situated in the second most seriously eroded areas of the world.

Material and Methodology

Description of the study area

The Nagwan watershed situated at the Upper Damodar Valley, Hazaribagh district of Jharkhand state in India. It accounts for an area of 92.32 $km^2$and lies between $85^{0}16'41''$ and $85^{0}23'50''$ E longitude and $23^{0}59'33''$ and $24^{0}5'37''$ N latitude. Location map of the study area is shown in Figure 1. The area experiences sub-humid sub-tropical monsoon type of climate characterized by hot summers (40°C) and mild winters (4°C). The watershed receives an average annual rainfall of 1272.5 mm, out of which more than 80% is received during monsoon season (June–October). Agriculture is the chief economic occupation for farmer of the catchment.

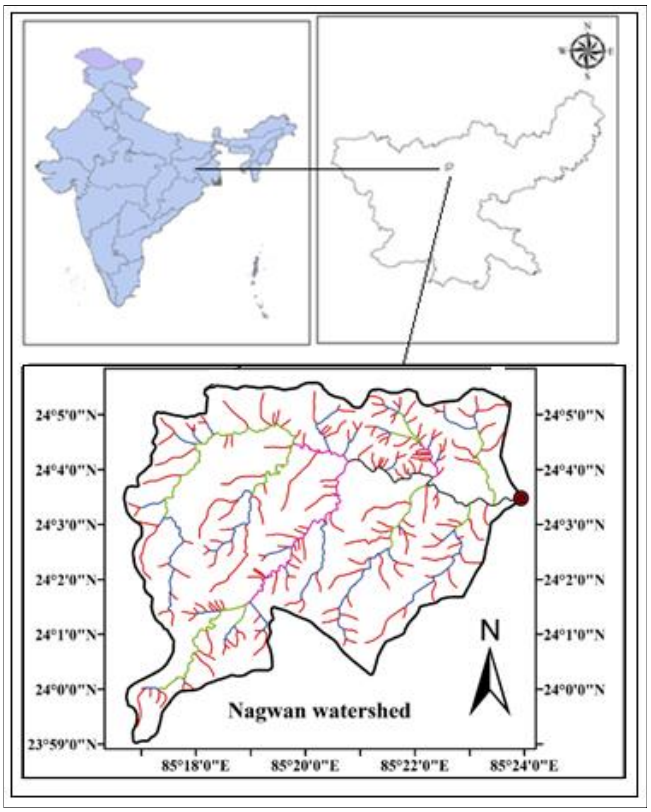

Fig 1: Location map of Nagwan watershed

Data Availability

For estimating rainfall erosivity, the annual rainfall data during the period from 1986- 2011 were collected from meteorological observatory at Central Rainfed Upland Rice Research Station (CRURRS), Hazaribagh.

Soil Data

Soil erosion in any particular region is affected by soil physical and chemical properties. Physical properties like texture, structure, organic matter content, content of salts, characterize the detachability and transportability of soil. Soil having high detachability and transportability are susceptible to erosion (Djuwansah & Mulyono, 2017) [8]. Soil data in the present study are required to assess/estimate susceptibility of soils to be eroded by the rainfall. Soil maps of the study area were obtained from DVC, Hazaribagh. Soil map of Nagwan watershed was prepared by Tripathi *et al*. (2003) [26]. ArcGIS software was used for digitizing scanned soil map of the watershed. Basic soil property such as sand, silt, clay, and organic carbon percentages were obtained from the Soil Conservation Department DVC, Hazaribagh, the details of which are given in Table 1.

Table 1: Soil property of Nagwan watershed

Soil types	Sand (%)	Silt (%)	Clay (%)	Organic carbon (%)
Silty loam	51.3	29.4	19.3	0.56
Loamy sand	80.4	11.7	7.9	0.47
Sandy loam	62.95	20.09	16.96	0.29
Loam	50.77	22.52	26.71	0.26
Clay loam	34.35	22.26	43.39	0.22
Silty clay loam	39.74	24.53	35.73	0.31

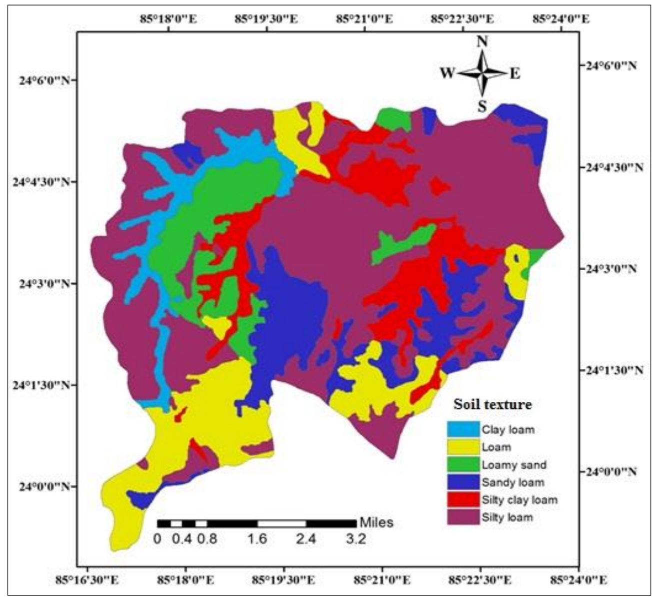

Fig 2: Soil map of the study area

Estimation of soil loss

Soil loss is the important parameters for planning of soil and water conservation measures. The rate of soil erosion from an area mainly depends upon rainfall, topographic characteristics, soil and vegetation. Therefore, a method which takes these factors into account while estimating soil erosion is expected to produce realistic estimate of rates of soil erosion (Das, 2008) [5]. The universal soil loss equation (USLE) is one of such equation.

Universal Soil Loss Equation (USLE) Method

Annual soil loss in form of runoff from different land forms and land uses of the watershed was estimated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE states that the field soil loss in, A, is the product of six causative factors as expresses by equation mention below.

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

where, A is the computed soil loss caused by sheet and rill erosion ($t\ ha^{-1}\ yr^{-1}$), R is the rainfall erosivity factor ($MJ\ mm\ h^{-1}\ ha^{-1}\ yr^{-1}$), K is the soil erodibility factor ($t\ ha\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$), L is the slope length factor (dimensionless), S is the slope steepness factor (dimensionless), C is the cover and management factor (dimensionless varies from 0 to1) and P is the support practice factor (dimensionless varies from 0 to1).

Calculation of Rainfall erosivity factor (R)

Rainfall erosivity factor (R) is the basic and important factor in the assessment of soil erosion. The R-factor is defined as the product of kinetic energy of rainfall (E) and the maximum 30-minute intensity (I_{30}) and expressed as EI_{30} (Wischmeier and Smith, 1978). Mathematically rainfall erosivity is calculated by

$$EI_{30} = \left(\frac{KE \times I_{30}}{100}\right) \quad (2)$$

Where, KE = Kinetic energy of the storm in metric tones/ha-cm.
I_{30} = maximum 30 minutes rainfall Intensity of the storm

$$KE = 210.3 + 89 \log I \quad (3)$$

Where, I = rainfall Intensity in cm/h and
In India, involving 45 gauging stations, distribution in different rainfall zones, simple linear relationship between erosivity index and annual or seasonal rainfall has been developed (Singh *et al.* 1981) [22] as expressed by equation:

Annual R factor, $R = 79 + (0.363 \times P)$ (4)

Seasonal R factor, $R_s = 50 + (0.389 \times P)$ (5)

Where, P is the rainfall in mm.
In present study, Equation 4 was used to calculate annual values of R factor in a year.

Calculation of soil erodibilty factor (K)

Soil erodibility factor (K) is closely related to various properties of soil by virtue of which a particular soil becomes susceptible to be eroded, by either water or wind. The K-factor is expressed as soil loss per unit area per unit R for a unit plot of 22.13 m long having a uniform slope of 9% under continuous fallow and tilled along to the slope).
Mathematically soil erodibility can be expressed as,

$$K = \frac{A_o}{S \times \left(\sum EI\right)} \quad (6)$$

Where, K = soil erodibility factor
A_o = observed soil loss
S = slope factor
$\sum$ EI = total rainfall erosivity index

A simple nomograph was developed by Wischmeier *et al.*, (1971) to determine the K value using five soils types viz, percent of silt (MS; 0.002 — 0.05 mm), percent of very fine sand (VFS; 0.05 — 0.1 mm), percent of sand greater than 0.1 mm, percentage of organic matter content (OM), structure (S) and permeability (P) An analytical relationship for nomograph developed by Wischmeier *at al.* (1971) is given by the Equation 7.

$$100K = 2.1 \times 10^{-4} M^{1.14}(12 - a) + 3.25(b - 2) + 2.5(c - 3) \quad (7)$$

Where, K = soil erodibility factor,
M = percentage silt, very fine sand and sand > 0.10 mm, (%)
A = organic matter content, (%)
B = structure of the soil, (very fine granular = 1, fine granular = 2, coarse granular = 3, blocky, platy or massive = 4)
C = permeability of the soil (rapid = 1, moderate to rapid = 2, moderate = 3, slow to moderate = 4, slow = 5, very slow = 6)
For this purpose soil map of Nagwan watershed was digitized in the ArcMap extension of ArcGIS 10.1. Then the values of K factor for respective soil texture unit were attributed and raster maps of K factor were prepared.

Calculation of slope length factor (L)

The slope length factor is dimensionless because it is simply a ratio of the soil loss from a given slope length to the plot size 22.13 m length of slope. It is mathematically expressed as given in equation 8.

$$L = \left(\frac{\lambda}{22.13}\right)^m \quad (8)$$

where, λ is the field slope length, m is the exponent varying from 0.2 for slope less than 1%, 0.3 for slope from 1% to 3%, 0.4 for slope from 3% to 5% and 0.5 for slope more than 5% slope.

Calculation of slope steepness factor (S)

Slope steepness factor is defined as the ratio of soil loss from the actual field slope gradient to soil loss from a 9% slope under identical conditions (Renard *et al.*, 1997). Soil loss increases rapidly with slope steepness. Mathematically the slope steepness factor (S) is evaluated from equation 9.

$$S = \left[0.065 + 0.045G + 0.0065G^2\right] \quad (9)$$

where, G is the slope gradient in percent.
The effect of topography on soil erosion is accounted by the LS factor in USLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S).

Cover and management factor (C)

The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978). It measures the combine effect of vegetation cover and management variables. The factor is based on plant cover, production level and cropping techniques. Typical values of C for different crop cover condition are presented in Table 2.

Table 2: C- Factors values of different land use/land cover

Practice	C-factor
Bare soil	1.000

Forest or dense shrubs, high mulch crop	0.001
Savanna or prairie grass in good condition	0.01
Over grassed savanna or prairie grass	0.10
Soya bean	0.20-0.50
Wheat	0.10-0.40
Rice	0.10-0.20
Ground nut	0.30-0.80

Source: Wischmeier and smith (1978), Roose (1977), Singh *et al.* (1981) [22],

Support practice factor (P)

The P-factor is the ratio of soil loss from field having a certain soil conservation practice to that with up and down slope ploughing (Wischmeier and Smith, 1978). Specific cultivation practices affect erosion by modifying the flow pattern & direction of runoff and by reducing the amount of runoff (Renard and Foster, 1983) [21]. The value of P factor for different erosion control practices are given in Table 3.

Table 3: P- Factor value of different conservation practices

Erosion-control practice	P-factor value
Barren land	1.0
Dense forest	0.8
Fallow land	1.0
Moderate dense forest	0.8
Open forest	0.8
River bed	1.0
Farming along hill slopes	0.8
Farming on undulating terrain	1.0

Source: Wischeier and smith (1978), Roose (1977), Chan (1981a)

Result and Discussion

Rainfall erosivity (R) factor

The daily precipitation data were used for estimating the average annual precipitation (AAP) of the watershed. Because within the premises of watershed only one rain gauge station was there, so data of only that station was used for representation of rainfall of whole watershed. The estimated AAP were used to compute the rainfall erosivity i.e. R-factor of USLE. The R-factor was found to be 540.92 MJ mm $ha^{-1}h^{-1}$ yr^{-1} and is shown Figure 3.

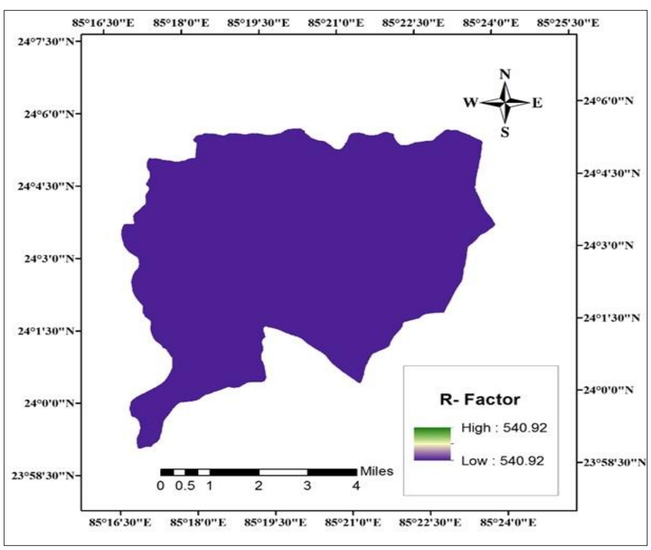

Fig 3: Rainfall erosivity (R) factor map of Nagwan watershed

Soil erodibility (K) factor

The soil erodibility (K) factor is a quantitative description of the inherent property to erode particular soil type. It is a function of complex interaction of soil physical and chemical properties affecting detachability, transportability and eventually the infiltration capacity. The K factor reflects the fact that different soils erode at different rates while the other factors causing erosion remaining the same. Soil texture is the principal entity affecting the K-factor, but the soil structure, organic matter content, and permeability also contribute to some extent. In the study area, six types of soil groups are present and each group are having varying soil characteristics. The soil erodibility factor K varied from 0.19 to 0.34 t ha h ha^{-1} MJ^{-1} mm^{-1} as presented in Table 5. A map for the K-factor was developed based on the soil map and soil erodibility texture.

Table 5: Represents the soil erodibility for different soil types

Soil types	Soil erodibility
Silty loam	0.33
Loamy sand	0.29
Sandy loam	0.34
Loam	0.25
Clay loam	0.19
Silty clay loam	0.26

Slope length & steepness (LS) factor

The length (L) and steepness (S) of the slope when combined it is termed as topographic index. The LS-factor in the present study area varied from 0 to 19.54 as shown in Figure 4.

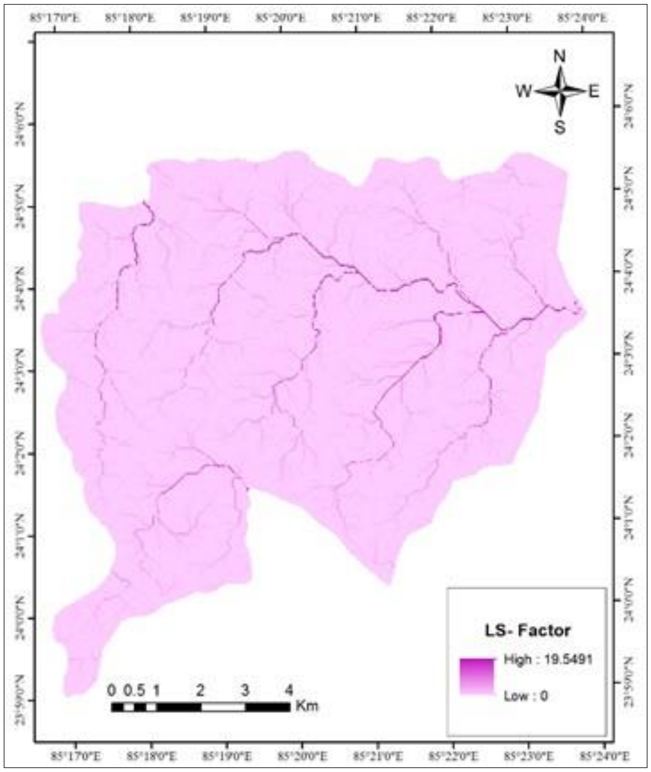

Fig 4: Topographic factor map of the Nagwan watershed

Cover and management (C) factor

The ratio of soil loss under cropped land to that from bare land is represented by crop management factor- C. The value of C ranges from 1 to nearly 0. Higher values indicate no cover effect and soil loss comparable to that from a tilled fallow, while lower value of C represents strong cover effect with no erosion (Erencin, 2000). The cropping management factors for different land use patterns in the Nagwan watershed are given in the Table 6. The C-factor in the present study area varied from 0.009 to 1.000 as shown in a Figure 5.

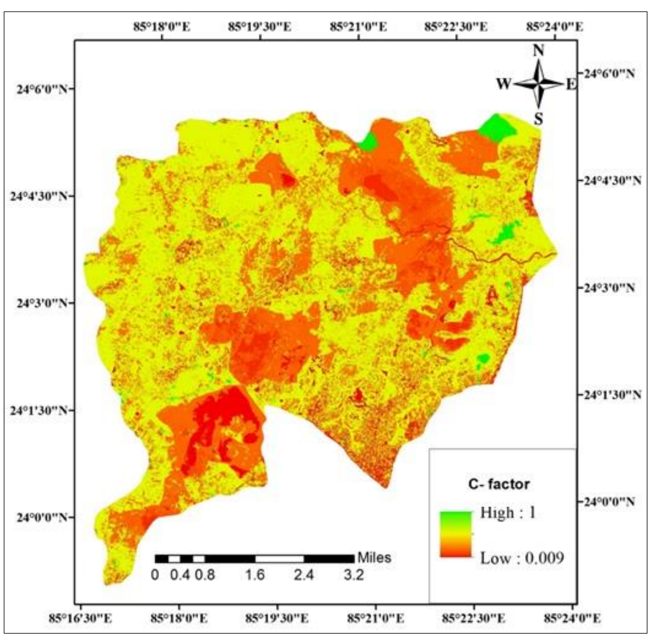

Fig 5: Cover and management (C) map of the Nagwan watershed

Conservation / Support practice (P) factor

The P-factor represents a ratio of erosion occurring in a field treated with conservation measures to another referenced plot without treatment. These conservation practices dominantly affect erosion by improving the flow path, grade, direction of surface runoff and reducing the amount rate of runoff. Therefore, conservation/support practice factor is based on the soil conservation practices already available in a particular area. In the study area, no major conservation practices are presently followed. Table 6 and Figure 6 shows the value of conservation/support practice factor according to the different landuse patterns in the Nagwan watershed.

Table 6: C and P factors for different land use in Nagwan watershed

Land use	C value	P value
Agriculture	0.42	1
Barren land	1	1
Built up land	0.024	1
Dense forest	0.004	0.8
Open forest	0.09	0.8
Grass land	0.12	1
Scrub	0.014	1
Water bodies	0.009	1

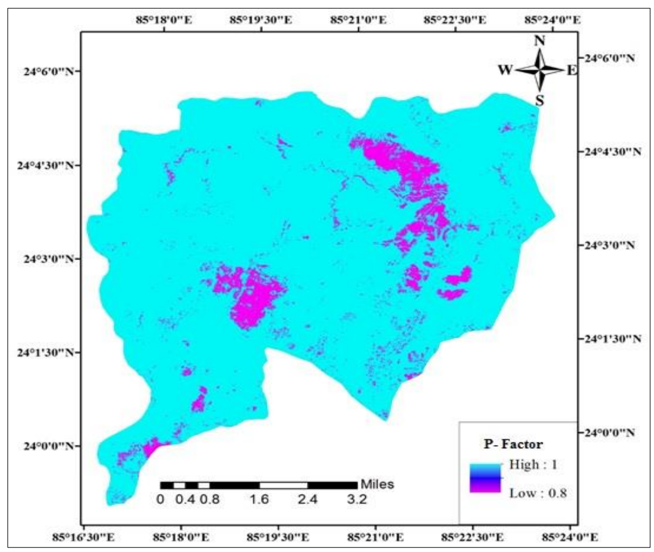

Fig 6: Conservation/support practice (P) factor map of the Nagwan watershed

Soil loss estimation for Nagwan watershed

The different factors such as R, K, L, S, C and P factor are calculated individually for the watershed and combined further USLE formula, resulting in a single number (Figure 7).The soil loss map of study area was also generated by integrating the all erosion factor in a raster calculator of ArcGIS (Figure 8). The average annual soil loss prediction was accounted as 12.39 tones ha^{-1}year^{-1} with standard deviation of 49.95.

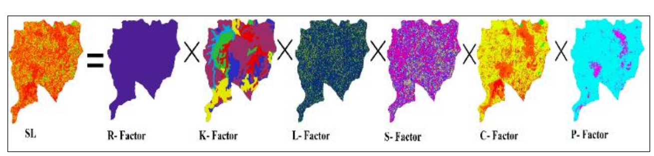

Fig 7: Different factors involve in computation of USLE

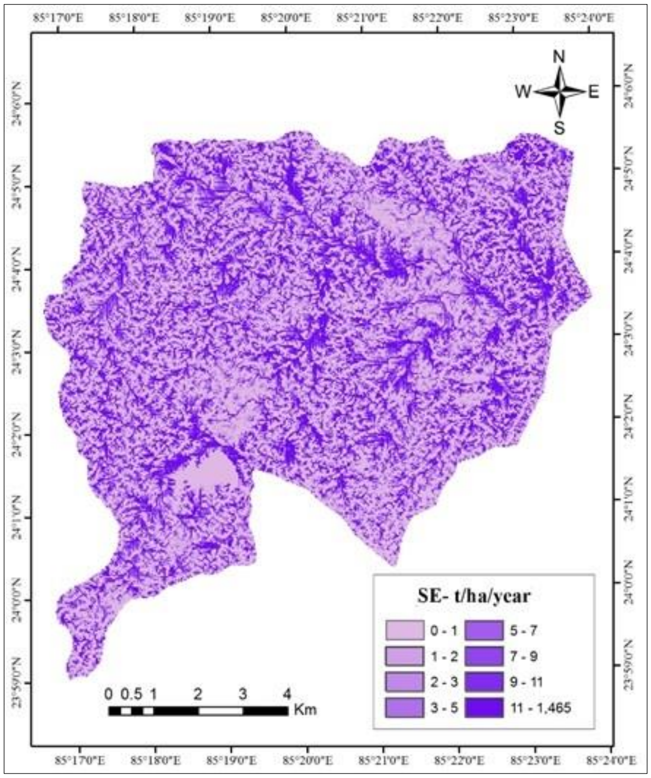

Fig 8: Annual soil loss map of the Nagwan watershed

Conclusion

The assessment of soil erosion is indeed essential for strategizing conservation planning, erosion control and management of the environment. The estimation of soil erosion using USLE is considered an effective method because it includes most the factors which directly influence soil erosion in any particular region. The identification of erosion prone areas and quantitative estimation of rate of soil loss helps in adopting suitable conservation practices. The estimation of rate of soil erosion losses with significant precision are of extreme importance for designing and constructional purpose in soil and water conservation measures. The spatial analysis of soil erosion provides a new hope in dealing with soil erosion losses in most effective and efficient manner. The major threat to sustainable agriculture can be reduces by adopting suitable conservation measures.

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