Vol. 51, No. 3, pp 171-180, 2023
Indian Journal of Soil Conservation
https://iaswc.com/ijsc-2023.html

Soil erosion assessment in the hilly terrain of Arunachal Pradesh, India through integrated approach of RUSLE and geospatial technology

S. Ramachandran[1,4], R.K. Jena[2,*], P. Ray[5], Shelton Padua[3], A.J. Borah[1] and S.K. Ray[1]

[1]ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Jorhat, Assam; [2]ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha; [3]ICAR-Central Marine Fisheries Research Institute, Kochi, Kerala; [4]ICAR-Indian Institute of Horticultural Research, Bagaluru, Karnataka; [5]ICAR-Indian Agricultural Research Institute, New Delhi.

**Corresponding author:*
E-mail: roomeshjena@gmail.com (R.K. Jena)

ARTICLE INFO

DOI: 10.59797/ijsc.v51.i3.133

Article history:
Received : March, 2021
Revised : June, 2023
Accepted : July, 2023

Key words:
Geo-spatial technique
Landform
Spatial assessment
Soil erosion

ABSTRACT

Soil erosion is a major challenge in the north-eastern Himalayan region, due to the fragile nature of the soil and ecosystem, high intensity of rainfall and faulty agricultural processes. To understand and asses the causes, measure the impact of soil erosion and find suitable correction measures, a study was undertaken at Diyun block, Changlang district of Arunachal Pradesh. For this study, the RUSLE method was used and thematic layers were extracted using remote sensing and soil data in the GIS environment. The block was divided into six broad landforms, *viz.,* low amplitudinal hills (LAH), inter-hill valley, upper piedmont, lower piedmont, upland and floodplain. Under these landforms, soil series were identified *viz.,* Shillongphar, Dimapur and Kamayakapur, Balupathar, Shayambhasti and Deba block, Modoi and Udaipur, respectively. It was observed that LAH (Shillongphar series), the inter-hill valley (Dimapur and Kamayakapur series) and the upper piedmont (Balupathar series) are more prone to erosion. However, soil erosion in floodplain (Udaipur series) was eroded extremely severe, which is located near to the river side. The area under soil loss falling in category of the severe to extremely severe class was 6450.16 ha (29.71% of TGA), whereas the soil losses of block follow under very slight category was of 11733 ha (54.06 % of TGA), extremely severe 3369 ha (15.52% of TGA), severe 1632 ha (7.52% of TGA), very severe 1448 ha (6.67% of TGA), slight 1218 ha (5.61% of TGA), moderate 893 ha (4.12% of TGA) and moderately severe 680 ha (3.14% of TGA). The soil erosion was found to be higher near to the 1st and 2nd order streams, where soil conservation measures are necessary to check soil erosion. It has been proven that the use of geospatial technologies in combination with RUSLE is a comprehensive approach which helps in the spatial assessment of soil erosion for better resource planning.

1. INTRODUCTION

Soil erosion is a major global concern due to its association with natural resources and the terrestrial ecosystem, which totally depends on the livelihood of the people (Mitra *et al*., 1998). Although it is a natural phenomenon, it cannot be avoided due to the natural environment, also associated with increasing the population and a subsistence-based rural economy. It is a major cause of soil quality deterioration, land degradation, environmental problems and affects crop production and natural resource quality (Lal, 2001). The erosion in India is due to the complex nature of landform formation, land fragmentation, geological formation, climatic conditions and human activities. Especially in the north eastern part of India, erosion caused due to variation in topography, land use-land cover changes, mining, construction, faulty agricultural practices, *jhum* cultivation and high intensity rainfall are the main reasons for soil erosion (Bai *et al*., 2008). The study reported that 33% of soil is getting eroded on the globe (Pimentel *et al*., 1995). In Asia, about 663 M ha of total land area is affected by soil erosion which is highest when compare to other continent (Rao *et al*., 2016), an average range of soil losses is 30-40 t ha^{-1}yr^{-1} have been reported from the various agro-ecosystems in Asia, Africa and South America. In India, about 6.6 billion tonnes of soil reported to be lost annually (Pimentel, 2006), the average yearly soil loss is roughly 15.2 t ha (Singh *et al*., 1990). Through this erosion, the loss of key nutrient is about 74 M t yr^{-1} (Reddy, 2003 and CSWCRTI) on which every year, 0.8 M t of nitrogen, 1.8 M t of phosphorus, and 26.3 M t of potassium are lost. Among the different regions in India, Himalayas were reported to exhibit very high soil erosion rates (Swarnkar *et al*., 2018), especially in steeply sloping region, the average rate of soil loss is more than 20 t $ha^{-1}yr^{-1}$ with a higher limit of 80 t $ha^{-1}yr^{-1}$ (Samra *et al*., 2002; Sudhishri *et al.,* 2014). In NEH region, about 77% of areas are under hilly terrain (Choudhury *et al*., 2016), which encourages the loss of significant amount soil and nutrients due to annual rainfall in the form of run-off. The erosion is a serious hazard in this region due to this nature (Angima *et al*., 2003; Sharma, 2010) like steep-sloping topography, fragile geology, undulating and rugged terrain, and high intensity of rainfall are more vulnerable to soil erosion. Furthermore, cultivation of *jhum* has accelerated soil loss. The total loss amounts to ~669.35 M t with an average rate of 90.9 t $ha^{-1}yr^{-1}$ (Singh, 1999). This may have a significant impact on biodiversity, river discharge, crop productivity, soil quality and flood frequency. It has resulted in large tracts of unproductive area, thereby impacting the socio-economic conditions of the rural population (Das *et al*., 2018). Moreover, Arunachal Pradesh, the largest mountainous state of India having 96% forest and 4% agricultural land with diversity in soils, is located in the northeastern part of the Himalayan region (Maji *et al*., 2010) receives high amount of rainfall, tectonically originated steep mountain, frequent action of deforestation, low land holding, heavy discharge rivers and unscientific cultivation are the reason for erosion. Hence, there is an urgent need for quantitative assessment of the degree and amount of soil erosion so that a suitable management approach can be developed to minimize the erosion.

The quantification of soil loss is an efficient way to monitor soil loss. In general, the loss can be quantified by geospatial technology (GIS) at the regional, sub-watershed and sub-basin scale (Gelagy and Minale, 2016). But at farm level, monitoring, analyzing and management of natural resources can be done by the latest technology of remote sensing data and GIS (Prasanna kumar *et al*., 2012). Several studies were conducted around the world on these aspects using various models. But, in this model, the integrated approach of satellite data, DEM and GIS can be efficaciously used for mapping soil erosion on space and time scale (Kouli *et al*., 2009). The model can be fit in to different empirical formulas to quantify soil loss, like universal soil loss equation (USLE) and revised universal soil loss equation (RUSLE) which were used for estimating soil loss, especially in watersheds or basins. Among these, the USLE model developed by Wischmeier and Smith (1978) is extensively used worldwide because of its simplicity. But, RUSLE estimates soil loss on a small scale as well as gives spatial distribution of soil erosion (Renard *et al*., 1997; Youe-Qing *et al*., 2008) and it's very useful to identify the spatial class of soil erosion at landscape level (Shinde *et al*., 2010). Moreover, RUSLE is an integration of technology and has become more reliable for estimation of soil loss for large areas (Pradeep *et al*., 2015).

The present study aims to document, measure and map soil erosion risk in the Diyun block, Changalang district of Arunachal Pradesh. It is covered with low amplitudinal hills and a low lying flood-prone area located under the foothills of the Himalaya. The crops include agricultural cropland, agricultural plantation, mixed forest, fallow land, char land, homestead plantation, residential areas, shifting cultivation, tea garden and sand bar along with the heavily flowing Noa Dihing river. The area is rich in ecological and environmental benefits, even though, due to its traditional farming, rivers and deforestation coupled with its topography and torrential rainfall have resulted in the areas being severely eroded. Keeping this view, the present study is aimed to estimate soil loss in a large scale area in Diyun block, Changlang district, Arunachal Pradesh.

2. MATERIALS AND METHODS

Study Area

The present study was undertaken in Diyun block, Changlang district of Arunachal Pradesh, Northeast India, and positioned in the south-eastern part of the state, having a geographical area of 217 km^2. It extends from 27°24'45" to 27°41'08"N latitude and 95°48'45" to 96°15'43"E longitude (Fig. 1). Lohit district of Arunacha Pradesh in the north, Bordumsa block in the west and south and Mio block of Changlang district on the eastern side. The elevation of the study area varies between 160 m amsl in the north-western part to about 240 m amsl in the north-western area. The climate of the Diyun block, Chnaglang district, is mainly cold, wet and humid and largely controlled by amplitudinal hills and valley plains. Study areas fall under a heavy rainfall belt and the annual average rainfall is 3800 mm to

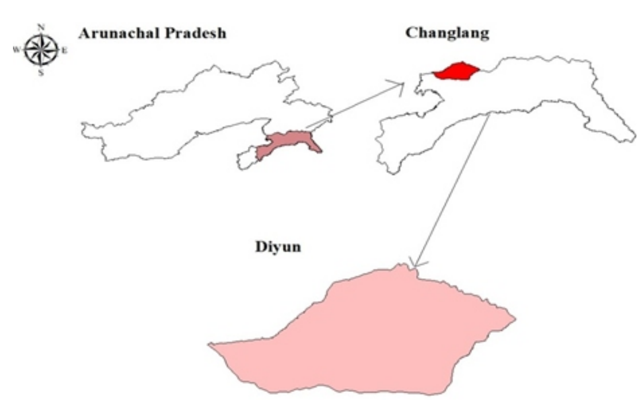


Fig. 1. Location map of Diyun block, Changlang district of Arunachal Pradesh

4866 mm. The monsoon sets in April-Oct and scanty in the dry winter months from Nov to Feb and the cold season prevails from Nov to Feb. Soil texture varies from sandy-loam to clay-loam in nature. Soil was generally shallow and well drained on top of hills, brown to reddish in colour and comparatively coarse in structure. In the middle portion of the slope, it is loamy and well developed, having a slightly deeper structure. At lower levels, soil ranges from loamy to clay loam. The study area having three distinct geological formations, such as the Disang and Barail groups of rocks, constitutes consolidated formations and this unit occupies nearly 80% of the area. The semi-consolidated formation of the area is represented by the Dihing and Namsang groups and is exposed in the Manabum anticline. The unconsolidated formation is comprised by recent alluvium consisting of gravel, sand, silt, clay, etc. Alluvium is exposed in the north-eastern part of the district around Miao-Bordumsa area.

Data Acquisition and Preparation

Digital data of IRS P6 (Resourcesat-2) LISS IV sensor with a spatial resolution of 5.8 m acquired from National Remote Sensing Centre (NRSC), Hyderabad was used to prepare land use/land cover map through visual image interpretation techniques. DEM (10 m spatial resolution) was generated from Cartosat 1 data sets and the same was used to develop slope (degree), flow direction and flow accumulation thematic rasters. The details of the digital data have been shown in Table 1. Images were processed in GIS software version Arc-GIS 10.3 to generate the digital coverage of input parameters of the erosion model. Toposheets at scale 1:50,000 was used to delineate the study area boundary and outline the natural drainage for DEM manipulation. Field survey was carried out for the collection of other necessary information.

RUSLE Parameter Estimation

The RUSLE quantifies soil erosion using five factors of eq. 1 (Wischmier and Smith, 1978; Renard *et al*., 1997).

Table: 1
Details of the digital data used

Satellite	Sensor	Date of pass	Path	Row
Resourcesat-2	LISS-IV	02-Jan-2015	114	52
		02-Jan-2015	114	52
		02-Jan-2015	114	52
Cartosat-1	PAN-A/F	03-Jan-2008	623	271
		03-Jan-2008	623	271
		03-Jan-2008	623	270
		03-Jan-2008	623	270
		23-Dec-2007	624	270
		23-Dec-2007	624	270
		23-Dec-2007	624	271
		23-Dec-2007	624	271

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

Where, A is the average annual soil loss per unit area (t $ha^{-1}yr^{-1}$), R is the rainfall and runoff factor (MJ mm $ha^{-1}yr^{-1}$), K is the soil erodibility factor (t ha $MJ^{-1}mm^{-1}$), LS is the topography factor, C is the cover and management factor and P is the support practice factor.

Rainfall Erosivity Factor (R)

The R-factor represents the input that drives the sheet and rill erosion process, and differences in the R-values represent differences in erosivity of the climate (Renard *et al.,* 1991). It depends on the amount and the intensity of rainfall (Jayasekara *et al.,* 2018).In the present study, seventeen years (2003-2019) monthly rainfall data was downloaded from CHRS (Centre for Hydrometeorology and Remote Sensing) (www.chrs.web.uci.edu) from which the rainfall erosivity factor (R) was estimated. The rainfall erosivity factor is the erosivity of rainfall events and is defined as the product of two rainstorm characteristics: kinetic energy (E) and the maximum 30-minute intensity (I) (Wischmeier, 1959). The raster layer of R-value was generated by using the eq. 2 (Dutta *et al*., 2014) in Arc-GIS 10.3.

$$R = 79 + 0.363\,X \qquad ...(2)$$

Where, X = Mean annual rainfall (mm).

Soil Erodibility Factor (K)

The K-factor represents both susceptibility of soil to erosion and the rate of runoff. The surface soil information from 65 points under land resource inventory of Diyun block, Changlang district, Arunachal Pradesh at 1:10,000 scale was used for calculation of the K-factor. Wischmeier and Smith (1978) used different soil properties to estimate K-values and presented a monograph for this purpose. However, in the present study modified methodology proposed by Auerswald *et al*. (2014) was used to calculate the K-factor following eq's. 3 to 8.

For silt + very fine sand <70%, $K1 = 2.77 \times 10^{-6} \times M^{1.14}$ ...(3)

For silt + very fine sand > 70%, $K1 = 1.75 \times 10^{-6} \times M^{1.14} + 0.0024\,(\%\,silt + \%\,very\ fine\ sand) + 0.16$ ...(4)

For organic matter < 4%, $K2 = 100 - clay$ ...(5)

For organic matter > 4%, $K2 = 0.8$ ...(6)

For $K1 \times K2 > 0.2$, $K3 = 2.77 \times 10^{-6} \times M^{1.14}\,(12\text{-}a) + 0.043\,(b\text{-}2) + 0.033\,(c\text{-}3)$ ...(7)

For $K1 \times K2 < 0.2$, $K3 = 0.091\text{-}0.34 \times K1 \times K2 + 1.79 \times (K1 \times K2)^2 + 0.24 \times K1 \times K2 \times b + 0.033\,(c\text{-}3)$ ...(8)

Where, M = Percent silt * (100-percent clay); a = percent organic matter; b = the soil structure code used in soil classification; c = the profile permeability code. For computing *K*-factor, the database was generated in the field study. The study area has textural variations from loamy sand to clay loam. The soil structure was estimated from field observation and the textural data generated after laboratory analysis (Piper, 1966) was used to assess the permeability. Then the numerical codes were assigned for both the characteristics (Sinha and Joshi, 2012) and *K*-factor was calculated. The *K*-factor map was generated in Arc-GIS using Thiessen polygons method considering 65 data points.

Topographic Factor (LS)

The topographic factor represents a ratio of soil loss under given condition to that at a site with the "standard" slope steepness of 9% and slope length of 22.6 m. The topographical factor constitutes two factors which are slope length (L) and slope steepness (S) (Ganasri and Ramesh, 2016). The LS factor can be estimated from several available relationships (Wischmeier and Smith, 1978; Moore and Burch, 1986a and 1986b; McCool *et al*., 1987 and 1989; Moore and Wilson, 1992; Desmet and Govers, 1996). Among these, units' stream power theory is best suited for integration with the GIS and which is calculated using eq. 9:

$$LS = (A/22.13)^{n}\,(Sin\,B/0.0896)^{m} \qquad ...(9)$$

Where, *A* is the up-slope contributing factor, *B* is the slope gradient in degrees. RUSLE uses both the factors, *L* and *S* and are combined to give the topographic factor *LS* (Jha and Paudel, 2010). The precision with which it can be estimated depends on the resolution of the DEM (Simms *et al*., 2003). The combined topography (*LS*) factor was computed rather than the individual slope length and slope angle because the slope length factor was replaced by up slope contributing area (Moore and Burch, 1986a; Mitasova *et al*., 1996; Desmet and Govers, 1996). The LS factor for RUSLE was computed using the eq. 5 and the raster calculator in Arc-GIS 10.3 version (ESRI, 2010) was used to build an expression for estimating *LS*, based on flow accumulation and slope steepness (Mitasova and Mitas, 1999).

$$LS = ([Flow\ Accumulation] \times Cell\ size/22.13)0.6\ (Sin\ ([Slope\ of\ DEM] \times 0.01745)/0.0896)\ 1.3 \times 1.4 \qquad ...(10)$$

Crop Management Factor (C)

The *C*-factor is used to reflect the effect of cropping and management practices on erosion rates. The *C*-factor measures the effects of all interrelated cover and management variables (Renard *et al*., 1997). Vegetation cover can be estimated using vegetation indices derived from satellite images. Vegetation indices allow us to delineate the distribution of vegetation and soil based on the characteristic reflectance patterns of green vegetation. The normalized difference vegetation index (NDVI), one of the vegetation indices, measures the amount of green vegetation. The spectral reflectance difference between near infrared (NIR) and red is used to calculate NDVI (Ahmet, 2010). The formula can be expressed as (Jensen, 2000):

$$NDVI = (NIR - Red) / (NIR + Red) \qquad ...(11)$$

Many scholars' uses NDVI for Cover Management (C) factor calculation because The C factor values vary between 0 and 1 based on types of land covers. Since NDVI values have correlation with *C*-factor (De Jong *et al.,* 1999; Ahmet, 2010; Van der Knijff *et al.,* 1999) for this study LISS IV image was used in Arc-GIS to derive NDVI and for calculating the *C*-factor eq. 12 developed by Van der Knijff *et al.* (1999) was used.

$$Cvk = e^{\left(-\alpha\frac{NDVI}{\beta - NDVI}\right)} \qquad ...(12)$$

Where, α and β parameters that determine the shape of the NDVI-C curve, in the present study values 1 and 2 have been used for α and β parameters, respectively as these values are the best representatives for the eq.12.

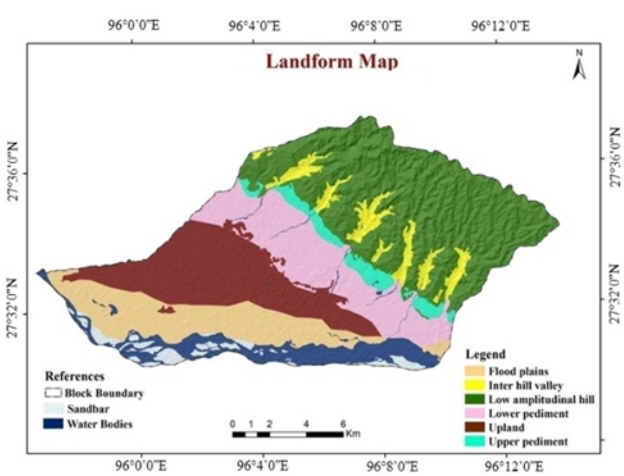
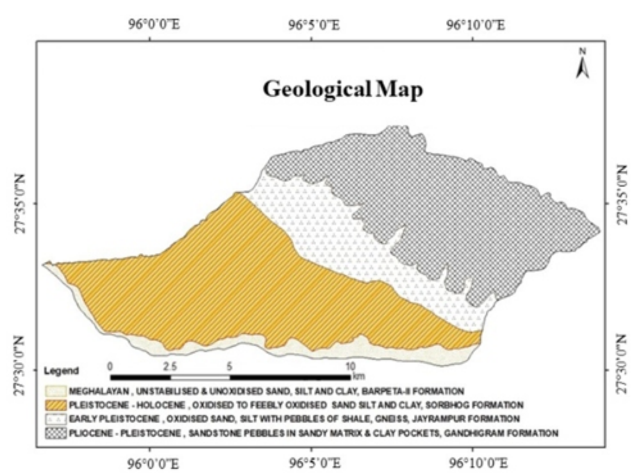


Fig. 2. Landform of Diyun block, Changlang district of Arunachal Pradesh



Source: Geological Survey of India

Fig. 3. Geological map of Diyun block, Changlang district of Arunachal Pradesh

P-factor

The *P*-factor reflects the impact of support practices and the average annual erosion rate (IWR, 2002), the erosion control practice factor is the ratio of soil loss using the specific practice compared with the soil loss using up and down hill culture (Kirkby and Morgan, 1980). The numerical value of *P*-factor is always between 0 and 1 according to the management of agricultural land. The *P*-factor value near to 0 indicates good conservation practice, and the value near to 1 indicates poor conservation practice (El Jazouli *et al.,* 2017)*, P*-factors have been developed to reflect conservation practices on rangeland. The practices require estimates of surface roughness and runoff reduction. Some of the practice values are also slope-dependent (Renard *et al.,* 1991). For calculating the *P*-factor the LU/LC is generated from LISS IV, using visual interpretation through digitization process, eleven type classification of land cover was generated, for assigning ranks (Jena *et al*., 2018) values were used, the assigning values were as shown in Table 2.

Hydrology Analysis

The Cartosat 1 DEM (10 m) of the study area was given fill operation to generate a completely smooth raster surface. This fill layer was used for deriving flow direction and flow accumulation layer. Then flow accumulation and flow direction layer were used as inputs in conditional tool to generate conditional flow accumulation layer where in a value of 1 indicate cells representing a stream and null value indicate no stream cells. The conditional flow accumulation and flow direction layers were used as inputs to generate stream order (Strahler stream order) and converted to feature class. The feature layer showed up to 9th order of streams, which were reduced up to 3rd order of streams by giving query in the definition queries.

Spatial Assessment of Soil Erosion Using Geostatistics and GIS

The computed values of *R, K, C* and *P* were converted to 10×10 m grid to maintain uniform cell size at par with spatial resolution of Cartosat-1 DEM. The LS factor map was already in 10×10 m grid format as it was derived from the 10 m DEM. The generated rasters of RUSLE factors were integrated in GIS to estimate the soil loss of Diyun block in a spatial domain (Fig. 4). The RUSLE was applied through raster calculator and all the factor layers were multiplied to derive the soil erosion map. The soil erosion map thus generated in GIS indicates the spatial distribution of soil loss in terms of t ha^{-1}yr^{-1}. Average soil loss per pixel was calculated as the product of each pixel value multiplied by pixel area.

3. RESULTS AND DISCUSSION

The erosion assessment map has been prepared by using the RUSLE factors like rainfall erosivity factor (*R*), soil erodibility factor (*K*), slope length and steepness factor (*LS*), cover and management factor (*C*) and erosion control practice factor (*P*).

The rainfall erosivity factor (*R*-factor) is varied between 350.7 to 406.9 MJ mm ha^{-1}yr^{-1} in the block. Low *R*-values were observed in the northern and eastern part of the block whereas it gradually increases towards southwest direction

Table: 2
Erosion control practice factor (P) values used in assessing soil erosion

S.No.	Erosion control practice	*P*-factor value
1	Agriculture, crop land	0.5
2	Current shifting cultivation	1.0
3	Terrace cultivation	0.5
4	Plantations	0.8
5	Scrub land	1.0
6	Land with open scrub	1.0
7	Wasteland	1.0
8	Built up	1.0
9	Evergreen forest	1.0
10	Deciduous forest	1.0
11	Scrub forest	1.0
12	Dense scrub forest	1.0
13	Water bodies	1.0

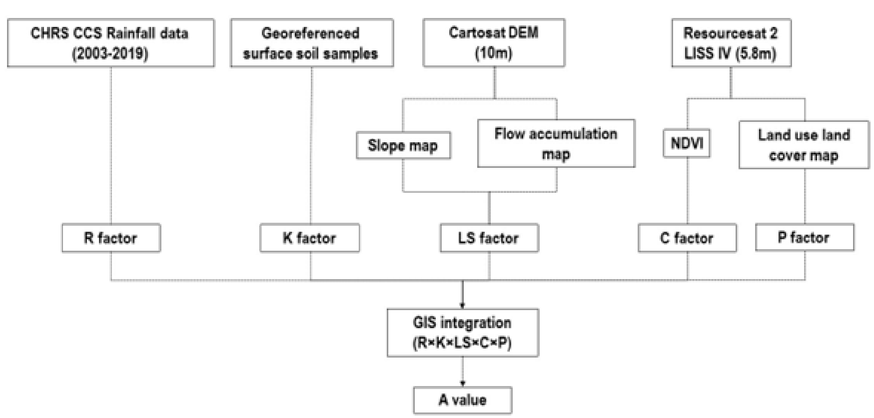


Fig. 4. Flow chart of methodology for soil loss assessment

(Fig. 5a). The soil erodibility (*K*-factor) reported to vary from 0.18 to 0.89 t ha $MJ^{-1}mm^{-1}$ in the block. The low *K*-factor (0.18-0.28) values were observed in inter hill valley and villages are, Haripur I, II and II, Dimapur and Kamayakapur (Kamayakapur series), which occupies 4.19% of TGA of the study area. The soils are mostly sandy loam and loam. Whereas, highest *K*-factor was obtained in floodplain (Udaipur series) ranged from 0.38-0.89 t ha MJ^{-1} mm^{-1} covered 13.63% TGA. The villages under this series are, Jyotipur, Dumba Mossang, Innao Khamati, Udaipur, Modai Dweep and Innao sangmai. The soils were silty loam and clay loam in texture. In low amplitude hill landform (Shilongphar series), the soils are clay loam and sandy clay loam in texture having *K*-values ranged from 0.18-0.36 which expanded over 34.97% of the study area. Whereas, lower piedmont villages area Innao Pathar, Sompoi-I, Madhupur I and II, Srirampur, Gautompur, Shantipur ,Matripur and Deba black (Deba block), and part of inter hill valleys (Dimapur series) had K-values ranging from 0.35-0.63 t ha $MJ^{-1}mm^{-1}$. The other series of the block had *K*-values ranging from 0.18 to 0.77 (Table 3).The erodibility is calculated based on relationship between its texture and organic carbon (Stone and Hillborn, 2000) and percentage organic matter reduce the erosion susceptibility (Behera, 2015). Based on *K*-factor range, raster layer was classified into 4 classes *i.e.* <0.2, 0.2-0.3, 0.3-0.5 and >0.5, It was found that maximum area was under >0.5 class which was 35.5% of TGA followed by 0.3-0.5 (26.6% of TGA), 0.2-0.3 (24.3% of TGA) and <0.2 classes (13.6% of TGA) (Fig.5b).

The LS ranged from 0.5 to 5 in the block. The LS map of the study area was classified into three classes, *i.e.* <1, 1-3 and >3 (Fig.5c).

The lower LS factor values of <1 have been mostly noticed in the valley plains as well as on the upland and lower piedmont covering 52.9% of TGA. The lower LS value was observed in Debablack, Modoi and Shyambhasti (upland) and Udaipur series. The LS factor values of 1.0-3.0 were observed within the landforms of valley plains, upland and lower piedmont where the slope was higher, covering 13.64% of TGA, which was interspersed with the other two LS factors of the study area. The highest LS factor values (>3.0) were observed in 33.42% of TGA where the slope was varying from strongly sloping to moderately steep (15-25%). This has been observed in Shillongphar, Kamayakapur, Dimapur and Balupathar series. Yildirim (2012) and Ozsoy *et al*. (2012) developed the topography with slopes in different conditions and their relationship.

The *C*-factor (cover and management factor) in the study area comprises forest, scrub land, fallow land, waste land, homestead plantation, plantation and agricultural land, which are important to developing and planning the erosion studies (Srinivasan *et al*., 2019; Jena *et al*., 2018). The *C*-values of the block ranged from 0.0002 to 1.7. The *C*-factor of <0.005 was mainly observed in forest mainly located on the northern side of the block, which was 14.10% of TGA. The area under value 0.005-0.05 was located sporadically in all the landforms occupied an area of 27.88% of TGA. However, 0.05-0.5 covered maximum area of the block *i.e.* 48.92% of TGA, which was majorly under agricultural practices. The *C*-value >0.5 was observed in water bodies of the block (9.09% of TGA) (Fig.5d). The results revealed that the high percentage of vegetation cover reduce the soil erosion (Renard *et al*., 2011). In addition, land cover is an important factor in soil losses, which is very sensitive in addition to relief (Chatterjee *et al.,* 2014).

The conservation practice factor (*P*-factor) in the Diyun block ranged from 0.5 to 1.0 (Fig.5e). The lowest values (<0.5) were observed in sporadic distribution of upper and lower piedmont, upland, inter hill valley and floodplain regions where agricultural practices were mainly confined and coverage were found in Balupather series (upper piedmont landform comprise villages are Balupathar and Sampoi-II), kamayakapur, Dimapur, Debablack, Modoi and Shyambasthi series (upland landform comprise villages are Kamachi Deori, Rajendra Nagar, Avoipur, Diyun, Dumpathar, Dumpa Singpho, Innao Ahom, Innao, Kumchaikha, Shyambhasti and Modoi) and Udaipur soil series covering an area of 33.75% of TGA. The highest values (0.5-1.0) were observed

Table: 3
Soil series wise *K*-factor values and their spatial extent

Series	Range of *K*-factor	Area (ha)	% of TGA
Balupathar	0.18-0.40	693	3.19
Deba block	0.35-0.63	3269	15.06
Dimapur	0.61	108	0.50
Kamayakapur	0.18-0.28	909	4.19
Modai	0.63-0.71	2704	12.46
Udaipur 1	0.51-0.77	2554	11.77
Shillong phar	0.18-0.36	7588	34.97
Shyambasti	0.36-0.573	918	4.23
Udaipur 2	0.38-0.89	2957	13.63
Total		21703	100

Table: 4
Status of soil loss in Diyun block, Changlang district of Arunachal Pradesh

Soil loss (t $ha^{-1}yr^{-1}$)	Area (ha)	% of TGA
Very slight (<5)	11733	54.06
Slight (5-10)	1218	5.61
Moderate (10-15)	893	4.12
Moderately severe (15-20)	680	3.14
Severe (20-40)	1632	7.52
Very severe (40-80)	1448	6.67
Extremely severe (>80)	3369	15.52
Water bodies	727	3.35
Total	21703	100.00

mainly in low amplitudinal hill region of the block, which covers an area of 62.25% of TGA. Adoption of suitable cultivation measures like, afforestation, silviculture, and terrace cultivation will help to reduce the top soil loss due to water erosion.

Spatial Assessment of Soil Erosion

The soil erosion can be assessed spatially by computing the raster of *R, K, LS, C* and *P*-factors in GIS. Seven soil erosion classes, namely very slight (<5.0 t $ha^{-1}yr^{-1}$), slight (5.0-10.0 t $ha^{-1}yr^{-1}$), moderate (10.1-15.0 t $ha^{-1}yr^{-1}$), moder-

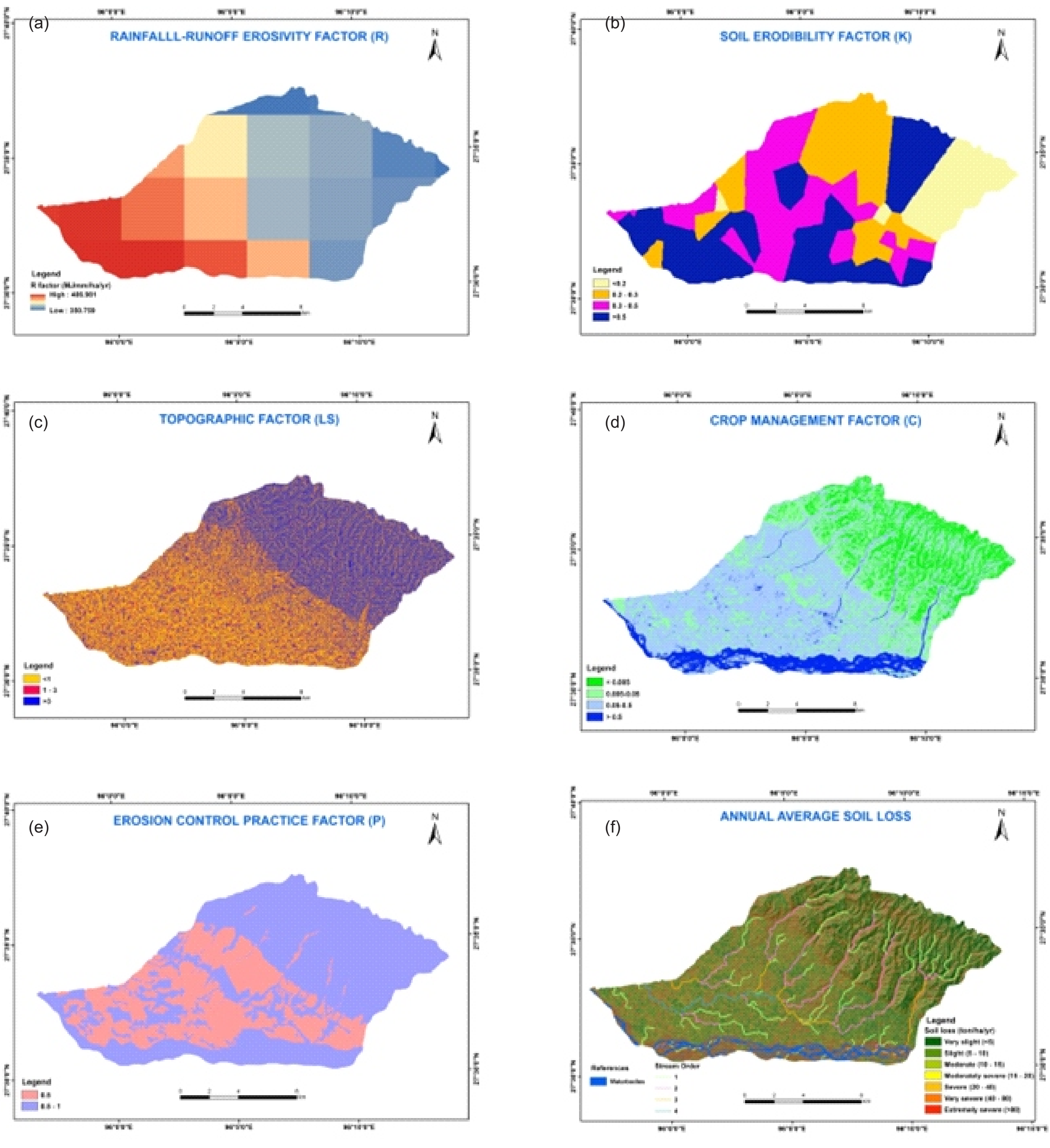


Fig. 5. Spatial variability maps of (a) R, (b) K, (c) LS, (d) C, (e) P factors and (f) soil loss for Diyun block, Changlang district of Arunachal Pradesh

ately severe (15.1-20.0 t $ha^{-1}yr^{-1}$), severe (20.1-40.0 t $ha^{-1}yr^{-1}$), very severe (40.1-80.0 t $ha^{-1}yr^{-1}$) and extremely severe (>80.0 t $ha^{-1}yr^{-1}$) were identified in the block (Fig.5f). authors have followed similar classification system in defining the soil loss classes in India (Challa *et al*., 2001; Sahoo *et al*., 2005; Reddy *et al*., 2013 and 2016; Jena *et al*., 2018; Srinivasan *et al*., 2019). From the study, the analysed data showed that, very slight (<5.0 t $ha^{-1}yr^{-1}$) was the dominant soil loss class covered maximum area under the study *i.e.* 54.06 % of TGA followed by extremely severe (>80 t $ha^{-1}yr^{-1}$), Severe (20.1-40.0 t $ha^{-1}yr^{-1}$), very severe (40.1-80.0 t $ha^{-1}yr^{-1}$), slight (5.0-10.0 t $ha^{-1}yr^{-1}$), moderate (10.1-15.0 t $ha^{-1}yr^{-1}$) and moderately severe (15.1-20.0 t $ha^{-1}yr^{-1}$). Extremely severe (>80.0 t $ha^{-1}yr^{-1}$) soil loss was noticed in the extreme northern and southern parts of the block where elevation is relatively high and in the river side regions. The extremely severe soil loss was observed on very steep areas, covering an area of 15.52% of TGA (Table 4). There was no trend in the soil loss in a particular direction but, the movement of soil loss is north to south and south west direction due to complexity in the topography. Especially in the north-west direction, the loss was due to sharp slopes and sparse density of vegetation. The maximum soil loss was found near the 1st and 2nd order streams where the slope is high (Fig.5f). On the steep slopes, soil gets detached easily at the time of rainfall and gets transported with the runoff, leading to excessive soil erosion in this region.

The RUSLE model has been used to predict soil erosion rates in Shivalik and the mountainous landscape of Himalaya by several researchers (Kumar and Kushwaha, 2013; Kalambukattu and Kumar, 2017). However, in Diyun block of Changlang district, Arunachal Pradesh, the major causes of erosion are natural causes like water erosion, topography, fragile nature and immature geology (Singh *et al*., 2019) and anthropogenic activities like deforestation, poor agricultural management practices and shifting cultivation. Among activities, deforestation and poor agricultural management practices are the major anthropogenic reasons for soil erosion in this region. Hence, there is scientific information required to develop site-specific conservation strategies and plan to preserve soil's production potential, sustain productivity, *in-situ* rainwater harvesting, minimize soil erosion, flood downstream, harvest and recycle inevitable runoff and ensure environmental security (Handbook of Agriculture, 2009). Therefore, the soil erosion can be identified from its distribution in the entire area. Among this erosion, the contribution of cultivated land is little. But the situation will persist; it may lead to physical, chemical and biological soil degradation and thereby render the cultivable land unfit for cultivation. The soil erosion may increase in future due to increasing human activities in the area in the form of cleaning forest to bring more area under traditional shifting cultivation. So the combination of both engineering and non-engineering measures for soil conservation can thwart soil erosion in this region (Sudhishri and Dass, 2012). Thus, the estimated soil loss of the study area through the RUSLE model would be of immense help to adopt site-specific suitable conservation measures to minimize the severity of soil erosion. This study was in conformity with different workers with similar methodology to identify the erosion like, Vanlalchhuanga *et al*. (2023) in Mahadevpur block, Namsai district, Arunachal Pradesh and Srinivasan, R *et al.* (2019) in Ganjam block, Odisa to find erosion risk classes and Biswajit Das *et al.* (2018) in Tirap district, Arunachal Pradesh was reported soil loss by RUSLE under GIS frame work in crop wise, on which highest soil loss was in agricultural land use (5.54 t $ha^{-1}yr^{-1}$).

4. CONCLUSIONS

The result from the study showed that about 30% of the area in the study area is subject to severe to extremely severe soil erosion risk and the landforms, *viz.,* low amplitudinal hill, inter hill valley, upper piedmont and floodplain which are identified in this study are susceptible to erosion risk. It was observed that the erosion occurring in the study area is mostly near 1st and 2nd order streams present. Therefore, these landforms are needed to adopt suitable engineering and non-engineering measures for sustainable soil and water conservation. The information obtained from this study can be helpful for the planners, managers and policy-makers to develop site-specific agronomic and mechanical soil and water conservation strategies, particularly in high erosion risk areas, to minimize soil loss and preserve soils for sustained productivity.

ACKNOWLEDGEMENTS

The authors are very much thankful to the Director, ICAR-NBSS&LUP, Nagpur for providing all logistics support to conduct this study.

REFERENCES

Ahmet K. 2010. Estimation of *C*-factor for soil erosion modeling using NDVI in Buyukcekmece watershed. *Ozean J. Appl. Sci.,* 3(1): 77-85.

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K. and Weesies, G.A. 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agric. Ecosys. Environ.,* 97: 295-308.

Auerswald, K., Fiener, P., Martin, W. and Elhaus, D. 2014. Use and misuse of the K-factor equation in soil erosion modeling: An alternative equation for determining USLE nomograph soil erodibility values. *Catena,* 118: 220-225.

Bai, Z.G., Dent, D.L., Olsson, L. and Schaepman, M.E. 2008. Proxy global assessment of land degradation. *Soil Use Manage,* 24: 223-234.

Behera, S.K., 2015. *Estimation of soil erosion and sediment yield on ONG Catchment, Odisha, India.* MSc Thesis. National Institute of Technology, Rourkela, Department of Civil Engineering, India.

Biswajit Das., Paul, A., Bordoloi, R., Tripathi, O.P. and Pandey, P. 2018. Soil erosion risk assessment of hilly terrain through integrated approach of RUSLE and geospatial technology: A case study of Tirap district, Arunachal Pradesh. *Modeling Earth Syst. Environ.,* 4(1): 373-381.

Challa, O., Kurothe, R.S. and Gajbhiye, K.S. 2001. *Soil erosion in Maharashtra.* NBSS Publ. No. 82. NBSS&LUP (ICAR), Nagpur, Maharashtra, 51p.

Chatterjee, S., Krishna, A.P. and Sharma, A.P. 2014. Geospatial assessment of soil erosion vulnerability at watershed level in some sections of the Upper Subarnarekha river basin, Jharkhand, India. *Environ. Earth Sci.,* 71(1): 357-374.

Choudhury, B.U., Fiyaz, A.R., Mohapatra, K.P. and Ngachan, S. 2016. Impact of land uses, agro-physical variables and altitudinal gradient of soil organic carbon concentration of north-eastern Himalayan region of India. *Land Deg. Dev.,* 27: 1163-1174.

CSWCRTI Vision. 2030. Central Soil and Water Conservation Research and Training Institute, Dehradun, 2011, pp 1-46.

De Jong, S.M., Paracchini, M.L., Bertolo, F., Folving, S., Megier, J. and De Roo, A.P.J. 1999. Regional assessment of soil erosion using the distributed model SEMMED and remotely sensed data. *Catena,* 37 (3-4): 291-308.

Desmet, P.J. and Govers, G. 1996. A GIS-procedure for the automated calculation of the USLE LS-factor on topographically complex landscape units. *J. Soil Water Cons.,* 51: 427-433.

Dutta, D., Bandopadhyay, S., Baruah, U., Sarkar, Dipak, Singh, S.K., Maji, A.K. and Dhyani, B.L. 2014. *Soil erosion in Meghalaya.* NBSS Publ. No. 160, NBSS&LUP (ICAR), Nagpur, India. 29 p.

El Jazouli, A., Barakat, A., Ghafiri, A., Moutaki, S.E., Ettaqy, A. and Khellouk, R. 2017. Soil erosion modeled with USLE, GIS, and RS: A case study of Ikkour watershed in Middle Atlas (Morocco). *Geosci. Lett.,* 4: 25, doi.org/10.1186/s40562-017-0091-6.

Ganasri, B.P. and Ramesh, H. 2016. Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. *Geosci. Front.,* 7: 953-961.

Gelagay, H.S., Minale, A.S. 2016. Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. *Int. Soil Water Cons. Res.,* 4: 126-136, dx.doi.org/10.1016/j.iswcr.2016.01.002.

Handbook of Agriculture. 2009. Handbook of Agriculture, 6th Edition, Directorate of Information and Publications of Agriculture, Indian Council of Agricultural Research, New Delhi-12.

IWR.2002. *RUSLE Factors,* http://www.iwr.msu.edu/rusle/factors.htm.

Jayasekara, M.J.P.T., Kadupitiya, H.K. and Vitharana, U.W.A. 2018. Mapping of soil erosion hazard zones of Sri Lanka. *Trop. Agric. Res.,* 29(2): 135-146.

Jena, R.K., Padua, S., Ray, P., Ramachandran, S., Bandyopadhyay, S., Deb Roy, P., Reddy, G.P.Obi, Singh, S.K. and Ray, S.K. 2018. Assessment of soil erosion in sub- tropical ecosystem of Meghalaya, India using remote sensing, GIS and RUSLE. *Indian J. Soil Cons.,* 46(3): 273-282.

Jensen, J.R. 2000. *Remote Sensing of the Environment: An Earth Resource Perspective.* Prentice Hall, New Jersey.

Jha, M.K. and Paudel, R.C. 2010. Erosion predictions by empirical models in a mountainous watershed in Nepal. *J. Spat. Hydrol.,* 10(1): 89-102.

Kalambukattu, J. and Kumar, S. 2017. Modelling soil erosion risk in a mountainous watershed of mid-himalaya by integrating RUSLE model with GIS. *Eurasian J. Soil Sci.,* 6(2): 92-105.

Kirkby, M.J. and Morgan, R.P.C. 1980. *Soil erosion.* A Wiley- Interscience Publication, Great Britain, 45p.

Kouli, M., Soupios, P. and Vallianatos, F. 2009. Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ. Geol.,* 57(3): 483-497.

Kumar, S. and Kushwaha, S.P.S. 2013. Modeling soil erosion risk based on RUSLE-3D using GIS in a Shivalik sub-watershed. *J. Earth Syst. Sci.,* 122(2): 389-398.

Lal, R. 2001. Soil degradation by erosion. *Land Deg. Dev.,* 12: 519-539.

Maji, A.K., Reddy, G.P.O. and Sarkar, D. 2010. *Degraded and wastelands of India: Status and spatial distribution.* Directorate of Information and Publications of Agriculture, ICAR, New Delhi.

McCool, D.K., Foster, G.R., Mutchler, C.K. and Meyer, L.D. 1987. Revised slope steepness factor for the universal soil loss equation. *Trans. Am. Soc. Agric. Eng.,* 30(5): 1387-1396.

McCool, D.K., Foster, G.R., Mutchler, C.K. and Meyer, L.D. 1989. Revised slope length factor for the universal soil loss equation. *Trans. Am. Soc. Agric. Eng.,* 32(5): 1571-1576.

Mitasova, H. and Mitas, L. 1999. *Modeling soil detachment with RUSLE 3D using GIS.* Geographic modeling systems laboratory, university of illinois at urbana-champaign, http://Skagit.meas.ncsu.edu/-helena/gmslab/erosion/usle.html.

Mitasova, H., Hofierka, J., Zlocha, M. and Iverson, R. 1996. Modeling topographic potential for erosion and deposition using GIS. *Int. J. Geo. Infor. Sci.,* 10(5): 629-641.

Mitra, B, Scott, H.D., Dixon, J.C. and McKimmey, J.M. 1998. Applications of fuzzy logic to the prediction of soil erosion in a large watershed. *Geoderma,* 86(3-4): 183-209.

Moore, I. and Burch, G. 1986a. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Sci. Soc. Am. J.,* 50: 1294-1298.

Moore, I. and Burch, G. 1986b. Modeling erosion and deposition topographic effects. *Trans. Am. Soc. Agric. Eng.,* 29(5): 1624-1630.

Moore, I. and Wilson, J.P. 1992. Length slope factor for the revised universal soil loss equation: simplified method of solution. *J. Soil Water Cons.,* 47(4): 423-428.

Ozsoy, G., Aksoy, E., Dirim, M.S. and Tumsavas, Z. 2012. Determination of soil erosion risk in the Mustafakemalpasa river Basin, Turkey, using the revised universal soil loss equation, geographic information system, and remote sensing. *Environ. Manag.,* 50(4): 679-694.

Pimentel, D. 2006. Soil erosion: a food and environmental threat. *Environ. Dev. Sust.,* doi:10.1007/s10668-005-1262-8.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M. and Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Sci.,* 267(5201): 1117-1123.

Piper, C.S. 1966. Soil and Plant Analysis. University of Adelaide, Australia.

Pradeep, G.S., Krishnan, M.V.N. and Vijith, H. 2015. Identification of critical soil erosion prone areas and annual average soil loss in anup land agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. *Arabian J. Geosci.,* 8(6): 3697-3711, dx. doi.org/10.1007/s12517-014-1460-5.

Prasannakumar, V.,Vijith, H., Abinod, S. and Geetha, N. 2012. Estimation of soil erosion risk with in a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. *Geosci. Front.,* 3(2): 209-215, http://dx.doi.org/10.1016/j.gsf.2011.11.003.

Rao, C.S., Gopinath, K.A., Prasad, J.V.N.S. and Singh, A.K. 2016. Climate resilient villages for sustainable food security in tropical India: Concept, process, technologies, institutions, and impacts. *Adv. Agron.,* 140: 101-214, doi:10.1016/bs.agron.2016.06.003.

Reddy, G.P.O., Kurothe, R.S., Sena, D.R., Harindranath, C.S., Niranjana, K.V., Naidu, L.G.K., Singh, S.K., Sarkar, D., Mishra, P.K. and Sharda, V.N. 2016. Assessment of soil erosion in tropical ecosystem of Goa, India using universal soil loss equation, geostatistics and GIS. *Indian J. Soil Cons.,* 44(1): 1-7.

Reddy, G.P.O., Sarkar, D., Prasad, J. and Ramamurthy, V. 2013. Geospatial modeling in assessment of biophysical resources for sustainable land resource management. *Trop. Ecol.,* 54: 227-238.

Reddy, V.R. 2003. Land degradation in India: Extent, costs and determinants. *Econ. Pol. Weekly,* 38(44): 4700-4713.

Renard, K.G., Foster, G.R., Weesies, G.A. and Porter, J.P. 1991. RUSLE-revised universal soil loss equation. *J. Soil Water Cons.,* 46(1): 30-33.

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

Renard, K.G., Yoder, D.C., Lightle, D.T. and Dabney, S.M. 2011. *Universal soil loss equation and revised universal soil loss equation.* In: Handbook of erosion modeling. Morgan, R.P.C., Nearing, M.A. (eds.). Blackwell Publishing Ltd. Oxford, England, pp 137-167.

Sahoo, A.K., Sarkar, D., Sah, K.D., Maji, A.K. and Dhyani, B.L. 2005. *Soil erosion of Bihar.* NBSS Pub.125, NBSS&LUP (ICAR), Nagpur, 49p.

Samra, J.S. 2002. Watershed management: A tool for sustainable production. In: Resource conservation and watershed management technology options and future strategies. Dhyani S.K., Tripathi, K.P., Singh, R., Raizada, A., Sharam, N.K., Mishra, A.S., Shrimali, S.S., Dhyani, B.L., Sharma, A.R. and Khola, O.P.S. (eds.). *Indian Association of Soil and Water Conservationists*, CSWCRTI, Dehradun, Uttaranchal, India, pp 1-10.

Sharma, A. 2010. Integrating terrain and vegetation indices for identifying potential soil erosion risk area. *Geospat. Inf. Sci.,* 13(3): 201-209.

Shinde, V., Tiwari, K.N. and Singh, M. 2010. Prioritization of micro watersheds on the basis of soil erosion hazard using remote sensing and geographic information system. *Int. J. Water Resour. Environ. Eng.,* 2(3): 130-136.

Simms, A.D. Woodroffe, C.D. and Jones, B.G. 2003. *Application of RUSLE for erosion management in a coastal catchment, southern NSW.* https://ro.uow.edu.au/scipapers/34/.

Singh, A.K., Kumar, S., Naithani, S. and George K.J. 2019. Soil erosion and sediment yield estimation using remote sensing data and GIS of watershed in north west himalayan region. *Indian J. Soil Cons.,* 47(3): 143-147.

Singh, G., Babu, R., Narain, P., Bhusan, L.S and Abrol, I.P. 1990. Soil erosion rates in India. *J. Soil Water Cons.,* 47(1): 97-99.

Singh, S. 1999. *A resource Atlas of Arunachal Pradesh, Government Publication.* Government of Arunachal Pradesh, Itanagar.

Sinha, D. and Joshi, V.U. 2012. Application of universal soil loss equation (USLE) to recently reclaimed Badlands along the Adula and Mahalungi rivers, Pravara basin, Maharashtra. *J. Geo. Soc. India,* 80: 341-350.

Srinivasan, R., Singh, S.K., Nayak, D.C., Hegde, R. and Ramesh, M. 2019. Estimation of soil loss by USLE model using remote sensing and GIS techniques - A case study of coastal Odisha, India. *Eurasian J. Soil Sci.,* 8(4): 321-328.

Stone, R.P. and Hilborn, D. 2000. *Universal soil loss equation (USLE).* Ministry of Agriculture, Food and Rural Affairs, Ontario.

Sudhishri, S. and Dass, A. 2012. Study on the impact and adoption of soil and water conservation technologies in Eastern ghats of India. *J. Agric. Eng.,* 49(1): 51-59.

Sudhishri, S., Kumar, A., Singh, J.K., Dass, A. and Nain, A.S. 2014. Erosion tolerance index under different land use units for sustainable resource conservation in a Himalayan watershed using remote sensing and geographic information system (GIS). *Afr. J. Agric. Res.,* 9(41): 3098-3110.

Swarnkar, S., Malini, A., Tripathi, S. and Sinha, R. 2018. Assessment of uncertainties in soil erosion and sediment yield estimates at ungauged basins: An application to the Garra river basin, India. Hydrol. *J. Earth Sys. Sci.,* 22(4): 2471-2485.

Van der Knijff, J.M., Jones, R.J.A. and Montanarella, L. 1999. Soil erosion risk assessment in Italy. *Eur. Soil Bureau.* EUR 19044 EN, 52p.

Vanlalchhuanga, Jena, R.K., Moharana, P.C., Kumar, N., Sharma, R.P., Das, B., Roy, P.D. and Ray, S.K. 2023. Modelling and mapping of soil erosion in the north-eastern frontier Himalayan ranges of India using remote sensing and GIS. *J. Soil Water Cons.,* 21(4): 345-353.

Wischmeier, W.H. 1959. A rainfall erosion index for a universal soil loss equation. *Proc. Soil Sci. Soc. Am. J.,* 23: 246-249.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses. Agriculture Handbook No. 537, United States Department of Agriculture, Washington, D.C.

Yildirim, U. 2012. Assessment of soil erosion at the Degirmen Creek watershed area, Afyonkarahisar, Turkey. *Proc. of ISEPP (International Symposium on Environmental Protection and Planning: Geographic Information Systems (GIS) and Remote Sensing (RS) Applications)*. 28-29th June 2011, İzmir, Turkey, pp 73-80.

Youe-Qing X., Xiao-Mei, S., Xiang-Bin, K., Jian, P. and Yun-Long, C. 2008. Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. *Environ. Monit. Assess.,* 141(1-3): 275-286.