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A review on assessment of soil loss through erosion using revised universal soil loss equation (RUSLE) model

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Abstract
Land is the most essential natural resource which is crucial in sustaining livelihoods in most of the countries. Soil erosion is one of the world environmental problems, the world is facing in 21st century affecting human society. According to the World Health Organization, an estimated 10 million hectares of agricultural land are degraded and rendered unusable owing to soil erosion, which reduces food supply for the 3.7 billion malnourished people. As a result, many nations now consider it vital to estimate soil erosion loss and evaluate soil erosion risk prior to implementing soil conservation techniques. However, it is challenging to estimate soil loss due to the intricacy of the erosion process. Moreover, management of catchment regions has become very difficult for decision-makers without adequate information on soil loss. It is now simple to assess soil loss due to the availability of soil erosion models. In order to take this complexity into account in soil erosion research, numerous models have been created. An easy and comprehensive methodology for evaluating soil erosion is provided by empirical models like RUSLE. Remote sensing and geographic information systems (GIS) are both well integrated by the RUSLE paradigm. This paper gives a broad summary of the RUSLE model's developmental milestones for assessing soil loss. According to the review, various equations have been created by scientists to model the five elements of the RUSLE model. It was also observed that when developing such equations, the various changes that represent the soil erosion process were taken into account.

Keywords: Erosion model, remote sensing, RUSLE, soil erosion

1. Introduction

In nature, land is the most crucial natural resource for sustaining livelihoods for all living beings. Almost all the human activities are performed to land resources, either directly or indirectly (Jiang *et al*. 2014) [31]. Land maintains numerous varieties of ecosystem services and therefore remains perilous for the survival of humanity (Raj *et al*., 2019) [53]. Land considered as a highly dynamic and complex medium consisting insufficient organic matter, erosion, landslides, and pollution are all potential degradation hazards of land resources (Gianinetto *et al*. 2019) [25]. A report depicted approximately 2 billion hectares of land are already being degraded, accounting to 12 to 15 tonnes of soil per hectare every year (Biggelaar *et al*. 2003) [12]. It is also reported that soil erosion accounts for 25% of total land degradation in Europe, 18% in Asia, 16% in Africa, and 5% in North America (Oldeman *et al*. 1992) [51]. The soil erosion process is both natural and dynamic triggered by various agents such as water and wind that results into degradation of the top soil. Soil erosion is widely defined as the process of detachment and transportation of soil particles from one place to another and the cumulative result of accelerated changes in agricultural practices and intensification, land degradation and climate change. Anthropogenic activities considered as land use-land cover alteration, overgrazing, deforestation, mining, improper agricultural practices, and construction practices speed up the pace of soil erosion (Kouli *et al*., 2009, John *et al* 2021) [38, 32]. The continuous and widespread soil erosion requires accurate and timely estimation has become critical for many countries. The scientist have been working since many years on soil erosion research for a long time, and much effort has gone into understanding the process of soil erosion and estimating the rate of soil erosion and soil loss at both the catchment scale and the plot scale (Fu *et al*., 2005) [21].

The earliest assessment of the area affected by the land degradation in India was made by the National Commission on Agriculture at 148 M ha, followed by 175 M ha by the Ministry of Agriculture (Soil and Water Conservation Division).

The NBSS&LUP estimates projected an area of 187 M ha as degraded lands in 1994 following GLASOD methodology (Oldeman, 1992) [51], and revised it to 147 Mha in 2004.
The efficiency of soil erosion research is determined by the model selection, which is based on the objectives, catchment characteristics, and data availability (Keesstra *et al*., 2014) [34]. The remarkable advancements in the assessment of land degradation in India using remote sensing technology, from mere interpretation of satellite imagery [Arya *et al*., 2009: Arya *et al*., 2011: Bhandari *et al*., 2012: Gandhi *et al*., 2015] [5, 4, 11, 23] to the application of complex statistical analysis. Remote sensing has traditionally been utilised in soil erosion research by interpreting aerial photos to locate erosion features and acquire model input data (Stephens *et al*., 1985) [66]. Satellite data became more available to researchers since the advent of Landsat-1 in 1972 and thereby development of soil erosion models.

2. Mechanism of soil erosion

Soil erosion refers to a natural geomorphic activity that occurs on the surface of the land and is both endogenic and exogenic. It is more common and widely dispersed than other geomorphic processes. Anthropogenic disturbances and poor land management increases the process of soil erosion (Malleswara Rao, 2005) [41]. The process of soil erosion comprises three main stages. These three phases are detachability, transportability, and deposition by various factors of soil erosion (Jain *et al*. 2001) [28]. The soil particles break down during the detachment phase as a result of stresses brought on by tillage, wind shear, raindrop impact, and other factors (Malleswara Rao *et al*. 2005; Sahu *et al*. 2017) [41, 60]. Among the other agents of soil erosion, water-induced soil erosion is considered to be the most severe one (Thlakma *et al*. 2018) [68].

3. Soil erosion modelling

Soil erosion modelling is a complex dynamic process that exposes subsurface soil, causes siltation in reservoirs or natural streams, and detaches, transports, and accumulates fertile surface soil across a large area (Verma *et al*. 1995) [70]. Some of the soil erosion models employed by researchers are listed in table 1. Modelling soil erosion is necessary for the following three reasons *viz*. Prediction tool for assessing soil loss for conservation planning, project planning, soil erosion inventories, and the creation of laws; Predicting where and when erosion will occur using physical-based mathematical models and to be utilised as a tool for determining research priorities by helping to understand processes and how they interact (Jasrotia *et al*. 2002) [29]. Mathematical expressions are used in soil erosion models to relate key variables and processes that take place on the surface of the land (Jetten *et al*. 2003) [30]. Soil erosion models have been generally divided into three groups *viz*. based on the physical processes that need to be simulated, the algorithms that characterise those processes, and the model's reliance on data (Merritt *et al*. 2003) [43].

3.1 Physical model

By offering answers to basic physics equations, physical models are recognised to be able to explain the process of soil erosion within a watershed (Roshani *et al*. 2013) [59]. These models are based on a particular class of differential equations known as the continuity equation, which is sometimes hypothesised as the law of conservation of matter through space and time (Mitasova *et al*. 2013) [45]. However, physical models are complex, require huge amounts of data and difficult for modelling larger catchments (Malleswara Rao *et al*. 2005) [41]. Some of the physical model for assessing soil erosion includes European Soil Erosion Model (EUROSEM), Water Erosion Prediction Project model (WEPP), Griffith University Erosion System Template model (GUEST), Productivity, Erosion and Runoff, Functions to Evaluate Conservation Techniques model (PERFECT) and Areal Nonpoint Source Watershed Environment Response Simulation model (ANSWERS).

3.2 Empirical Models

These models have the benefit of being very easy to use and make use of inductive reasoning, past experiences, and experimental results (Merritt *et al*. 2003) [43]. To simulate the amount of detached soil, empirical models link the characteristics that may be assessed scientifically, like basin area and slope gradient. The fact that empirical models require less data and fewer computations makes them widely applicable (Asadi *et al*. 2017) [6]. Common examples of empirical models include Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), Revised Universal Soil Loss Equation (RUSLE), Sediment Delivery Ratio (SDR), Sediment Delivery Distributed (SEDD) and Agricultural Nonpoint Pollution Source (AGNPS).

3.3 Conceptual Models

This model outlines the main processes that control the movement of water and sediment between various reservoirs (Merritt *et al*. 2003) [43]. However, when it comes to interpreting physical processes including sediment production and soil erosion, the parameters utilised in conceptual models pose a constrained range of application (Sujatha and Sridhar, 2018) [67]. Common examples of conceptual models include Large Scale Catchment (LASCAM) and Chemical Runoff and Erosion from the Agricultural Management Systems (CREAMS).

Table 1: Soil erosion models

Models		References
MUSLE	Modified Universal Soil Loss Equation	Williams (1975) [72]
USLE	Universal Soil Loss Equation	Wischmeier and Smith (1978) [73]
CREAMS	Chemical Runoff and Erosion from Agriculture Management Systems	Knisel (1980) [36]
ANSWERS	Areal Nonpoint Source Watershed Environment Response System	Beasley and Huggins (1982) [8]
WEPP	Water Erosion Prediction Project	Lane and Nearing (1989) [40]
DUSLE	Differentiated Universal Soil Loss Equation	Flacke *et al*. (1990) [20]
KINEROS	Kinematic Erosion Simulation	Woolhiser *et al*. (1990) [74]
RUSLE	Revised Universal Soil Loss Equation	Renard *et al*. (1991) [56]
EROSION2D	Erosion- 2D	Schmidt (1991) [61]

OPUS	Advanced Simulation Model for Nonpoint Source Pollution Transport	Ferreira and Smith (1992) [19]
PEPP	Process-Oriented Erosion Prognosis Program	Schramm (1994) [62]
LISEM	Limburg Soil Erosion Model	De Roo *et al*. (1994) [14]

4. RUSLE model of soil erosion

In 1954, USLE was developed for field crops as an empirical model where the main purpose was to imitate sheet and rill erosion that associated with overland flow in agricultural areas (Merritt *et al*. 2003) [43]. The RUSLE model is an advance developed version of USLE used for better assessment of soil depletion assessment and it may be utilized in natural settings (Renard *et al*. 1997) [55]. The scientists worked as that aspects and having extensive knowledge in soil erosion issues developed the model (Angima, 2003) [2]. Revised Universal Soil Loss Equation (RUSLE) is preferred over traditional physical models due to its simplicity in terms of usage (Ayinla and Jona, 2018) [7], fewer computations and data involved (Merritt *et al*., 2003, Efthimiou and Karavitis, 2014, Asadi *et al*., 2017) [43, 15, 6], wide area coverage, and less expensive and time consuming (Malleswara Rao *et al*., 2005) [41]. RUSLE model computes average annual soil loss (A) by using five important input factors *viz*. rainfall erosivity (R), soil erodibility (K), slope length and slope steepness (LS), cover management (C), and support practice (P). The equation and the input factors are described in the following.

$$A = R \times K \times LS \times C \times P$$

Where, A is the mean annual soil loss in t $ha^{-1}\ yr^{-1}$, R is the rainfall erosivity (MJ $mmha^{-1}yr^{-1}$), K is the soil erodibility factor (t ha h ha^{-1} $MJ^{-1}mm^{-1}$), LS is the slope length and slope steepness factor (dimensionless), C is the cover management factor (dimensionless), and P is the support practice factor (dimensionless). The methodology for computing annual soil loss is represented schematically in figure 1.

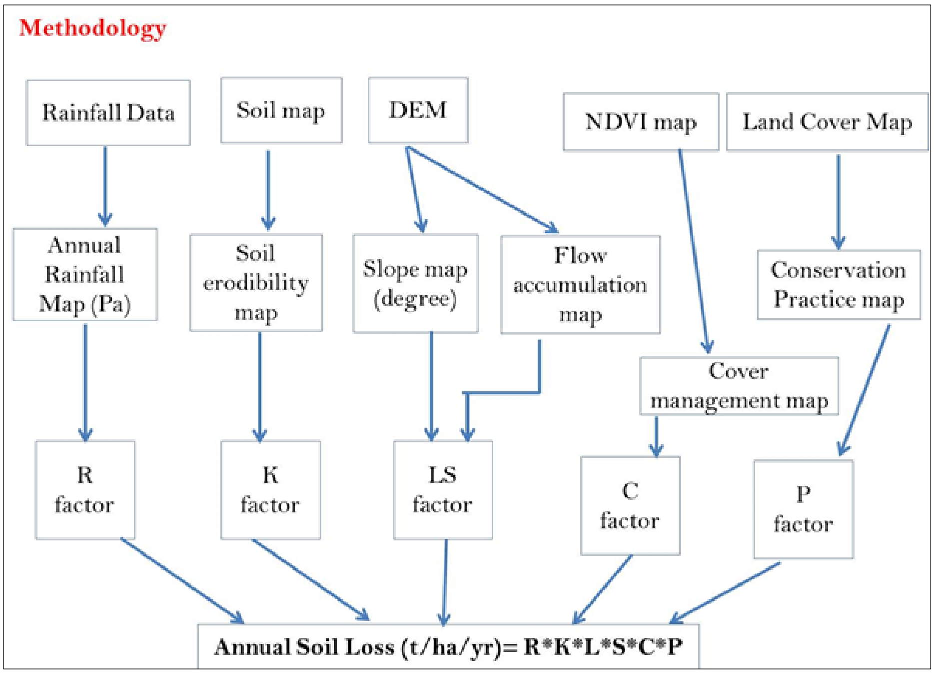

Fig 1: Schematic representation for computing annual soil loss

4.1 Rainfall erosivity (R) factor

The R factor indicated the erosive power of a specified rainfall. Wischmeier and Smith (1978) [73] established a correlation between rainfall depth and rainfall erosivity. The volume and rate of runoff most likely to be brought on by rain are represented by the rainfall-runoff erosivity factor (R), which measures the influence of precipitation. It provides a quantitative analysis of how much soil erosion is caused by rainfall (Wischmeier and Smith 1978) [73]. Rainfall erosivity within the RUSLE is often calculated using the EI_{30} measurement (Renard *et al*. 1997) [55]. Here, EI_{30} refers to the product of total energy E, (MJ ha^{-1}) and maximum intensity I, (mmh^{-1}) of rainfall in 30 minutes. The amount of soil loss is proportional to the product of the total storm's energy and the storm's maximum intensity in a time of 30 minute (Renard *et al*. 1997) [55]. Different researchers have developed equations from where the *R* factor has been derived and applied in different regions (Table 2).

Table 2: R factor developed for RUSLE soil erosion model

Equation	Area of application	References
$R = 0.55MAR - 24.7$	Ethiopia and Egypt	Hurni, 1985 [27]
$R = 79 + 0.363MAR$	Entire India	Singh *et al*. 1981 [64]
$R = 50 + 0.389$ MSR	Entire India	Singh and Phadke, 2006 [65]
$R = 0.5MAR$	Ivory Coast and Burkina Faso	Roose, 1975; Morgan, 1986 [58, 48]
R = 117.6 (1.00105^{MAR}) for <2000mm	Kenya	Kassam *et al*. 1992 [33]
R = 0.38 + 0.35MAR	&ailand	Harper, 1987 [26]

4.2 Soil erodibility (K) factor

The K factor quantifies how easily soil will erode. The K factor can be simply stated as the soil's innate vulnerability to erosion (Farhan *et al*. 2013) [18]. The K factor depends on various biological and chemical aspects of the soil, including its mineralogy, particle size, permeability, and presence of organic matter (Wischmeier and Smith 1978) [73]. Soil detachability shows direct proportion with the size of particles while soil transportability shows indirect proportion with its particle size (Schwab *et al*. 2002) [63]. Some of the different K factor algorithms developed based on suitability and requirement are summarised in Table 3.

Table 3: Different *K* factor equations developed

Equation	References
$K = 27.66m^{1.14} * (12\text{-}a) + 0.0043\ (b\text{-}2) + 0.0033\ (c\text{-}3)$ *K*= soil erodibility factor (t hr− 1ha− 1MJ mm), *m*= (silt %+ sand %) × (100 − clay %) *a* = percent organic matter, *b* = soil structure code: (1) very structured or particulate, (2) fairly structured, (3) slightly structured, and (4) solid, *c* = soil profile permeability code: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow, and (6) very slow Soil organic matter is derived by the following equation: SOM= 1.72 ∗OC [99], where, SOM= soil organic matter, OC= soil percentage organic carbon content	Wischmeir and Smith, 1978 [73]
$K = 311.63\text{-}4.48 * (SG\% + S\%) + 613.4 + 6.45 * EC$ Where SG = coarse sand content (%), *S* = sand content (%), EC = electrical conductivity	Merzoul, 1985 [44]
$K = -0.03970 + 0.00311A_1 + 0.00043A_2 + 0.00185A_3 + 0.00258A_4 - 0.00823A_5$ Where, A_1 = % unstable aggregates less than 0.250mm; A_2 = product of % silt (0.002–0.01 mm) and % sand (0.1–2 mm); A_3 = % base saturation of the soil; A_4 = % silt (0.002–0.050 mm); A_5 = % sand (0.1–2mm); Units for *K*: $Mg\ h\ MJ^{-1} mm^{-1}$	El-Swaify and Dangler, 1976 [16]

4.3 LS factor

The LS factor considers both the steepness (S), which increases runoff velocity, and the slope length (L), which helps to increase the land surface affected by runoff. Two independent algorithms were used to calculate this factor, one for a slope up to a 20 percent gradient and another for a steeper slope (Arnoldus 1980) [3]. The slope length is the horizontal distance between the point of overland flow to the point at which either deposition starts or runoff concentrates in a specific channel, depending on which happens first (Wischmeier and Smith 1978) [73]. The raster calculator in ArcMap can be used to calculate the LS factor for RUSLE and create an equation for calculating LS based on flow accumulation and slope steepness (Anamika *et al*. 2013) [1]. The digital elevation model is a crucial input component for the RUSLE model where the change of topographic features on a specific terrain is quantitatively represented (Phinzi and Ngetar, 2019) [52]. Some of the LS equation developed by researcher is tabulated below (Table 4).

Table 4: Some LS factor equation developed.

Equation	Reference
$LS = (\text{Flow Accumulation} * (\text{cell size}/22.31))^{0.4} * (\sin(\text{slope})/0.0896)^{1.3}$, Where, LS = topographic factor Cell size = grid size	Moore and Burch, 1986 [47]
$LS = (\text{Flow accumulation} * \text{grid size}/22.13)^{0.4} * (\sin(\text{slope}) * 0.1745/0.09)^{1.4}$, Where, Flow accumulation = raster of flow accumulated to each cell Grid size = cell size Sin (slope) = sin of the slope degree value	Mitasova *et al*. 1996 [46]
$LS = (QaM/22.13)^y \times (0.065 + 0.045\ S_g + 0.0065\ S^2{}_g)$, Where, LS = topographical factor Q_a = flow accumulation grid S_g = grid slope in percentage *M*= grid size (vertical length × horizontal length) *y* = a constant, which depends on the slope gradient 0.5 for $S_g \geq 4.5\%$; 0.4 for $3 \leq S_g < 4.5\%$; 0.3 for $1 \leq S_g < 3\%$; 0.2 for $S_g < 1\%$	Wischmeier and Smith, 1978 [73]

4.4 Cover Management Factor (C)

The influence of vegetation and management on soil erosion rates is reflected in the cover management factor (Renard *et al*. 1997) [55]. It is the ratio of soil loss caused by a particular crop to soil loss caused by uninterrupted bare land. Vegetation type, growth stage, and Percentage cover all have a significant impact on it (Mallick *et al*. 2014) [42]. The amount of soil surface protection provided by a crop affects how quickly soil erodes. The energy of raindrops is dissipated by vegetation cover before they hit the soil surface, protecting it from the impact of the raindrops (Ghosal and Bhattacharya, 2020) [24]. Depending on the types of land cover, the C factor can have values between 0 and 1. The normal range for bare soils is 1, for root and tuber crops 1 to 0.01, for grasslands and cover plants 0.01 and for forests 0.001 (Rao 1981) [54]. Numerous techniques have been developed by researchers for calculating the C factor based on the normalised difference vegetation index (NDVI) for the RUSLE model assessment of soil loss (Table 5).

Table 5: C factor equation for RUSLE model assessment of soil loss

Equation	Reference
$C = 0.1((-\text{NDVI} + 1)/2)$, Where, C = land cover factor	Durigon *et al*. 2014
$C = 0.431 - 0.805 \times \text{NDVI}$	De Jong, 1994 [13]
$C = \exp(-\alpha(\text{NDVI}/(\beta - \text{NDVI})))$, Where α and β defines the NDVI curve	Knijff *et al*. 2000 [35]

4.5 Support Practice Factor (P)

The influence of support practices and the average annual rate of erosion are both included in the support practice (P) factor (Renard *et al*. 2011) [55]. The P factor is the ratio of the soil loss on farmland sites with a particular support technique to the comparable loss with upslope and downslope tillage (Merritt *et al*. 2003) [43]. The P factor takes into account any farming technique used to minimise soil erosion caused by water flow. The most popular support practices include using contours, terraces, strip crop and cross-slope farming (Renard *et al*. 1997) [55]. P factor values typically fall between 0 and 1. A score of 1 represents lands with no support practises (particularly grasslands and barren lands), while readings that are close to 0 represent lands with a specific support practise (Koirala *et al*. 2019) [37]. By changing the flow pattern, gradients, or direction of surface runoff and by lowering runoff amounts and rates, the support practise effectively has an impact on soil erosion (Renard *et al*. 1997) [55]. By taking into account various support practises, including contouring, terracing, and strip cropping, Wischmeier and Smith were able to calculate various P factor values is presented in table 6.

Table 6: P factor for contour ploughing developed by (Wischmeier and Smith 1978a, b) [73]

Land slope percentage (%)	P value	Maximum length (Feet)
1-2	0.6	400
3-5	0.5	300
6-8	0.5	200
9-12	0.6	120
13-16	0.7	80
17-20	0.8	60
21-25	0.9	50

5. Satellites and sensors used in erosion study

The satellites has been established to record frequently imaged by a vast number of earth observation on the earth surface where, many of these satellites that able to provide important information for assessing erosion. Satellite image sensors are classified as either sensing the reflection of sunlight in the visible and infrared parts of the electromagnetic spectrum and thermal infrared radiance (optical systems) or actively emitting microwave pulses and storing the received signal (imaging radars). For erosion studies, optical satellite systems have been most commonly employed. In the electromagnetic spectrum, the optical system encompasses the visible and near-infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR). Initially, Landsat satellites equipped with the Multispectral Scanner (MSS) featured four bands at 80-m resolution, but subsequent versions added the Thematic Mapper (TM) and Enhanced TM (ETM) sensors, providing greater resolution and more spectral bands. The SPOT family of satellites began collecting data in 1986, with the HRV-sensor (High Resolution Visible) having a 10 metre panchromatic mode and a three band 20-m resolution multispectral mode. The Indian Remote Sensing Satellites (IRS) consists of 1A, 1B, 1C, and 1D. IRS 1A and 1B contain two sensors called LISS-1 and LISS-2 (Linear Imaging and Self-Scanning Sensor), while IRS 1C and 1D have an identical 5.8-m resolution panchromatic camera (PAN) and a 23.5-m resolution multispectral sensor called LISS-3. Terra, TIROS, IKONOS, QuickBird and Sentinel also provide high-resolution image ranging from 0.61m (QuickBird) to 10 m (Sentinel). Sensors such as Advanced Very High Resolution Radiometer (AVHRR) have five bands with a resolution of 1.1 km and have been flown on a variety of platforms, such as Television Infrared Observation System (TIROS-N) and various National Oceanic and Atmospheric Administration (NOAA) satellites. Sentinel-2 is equipped with an optical payload that includes visible, near infrared, and shortwave infrared sensors with 13 spectral bands: four at 10 m, six at 20 m, and three at 60 m spatial resolution. The satellites and sensor properties employed in erosion assessment are summarised in Table 7.

Table 7: Overview of optical satellite sensors applied in erosion study

Satellite	Sensor	Spatial resolution (m)	Spectral bands	Spectral domain
Landsat-1,2,3	MSS	80	4	VNIR
Landsat-4,5	TM	30	6	VNIR, SWIR
Landsat-7	ETM	120	1	TIR
		15	1	VNIR
		30	6	VNIR, SWIR
SPOT-1,2,3	HRV	60	1	TIR
		10	1	VNIR
		20	3	VNIR
SPOT-4	HRVIR	10	1	VIS
		20	4	VNIR,SWIR
IRS-1A,1B	LISS-1	72.25	4	VNIR
	LISS-2	36.25	4	VNIR
IRS-1C,1D	PAN, LISS-3	5.8	1	VNIR
		23.5	3	VNIR
		70	1	SWIR
Terra	ASTER	15	3	VNIR
		30	6	SWIR
		90	5	TIR
NOAA/ TIROS	AVHRR	1.1	5	VNIR, SWIR, TIR

IKONOS	Panchromatic	1.0	1	VNIR
	Multispectral	4.0	4	VNIR
QuickBird	Panchromatic	0.61	1	VNIR
	Multispectral	2.44	4	VNIR
Sentinel-2A, 2B	MSI	10	2,3,4,8	VNIR
		20	5,6,7,8A,11,12	Red, SWIR
		60	1,9,10	Atmospheric correction

(Anton Vrieling, 2006; MSI overview, 2018) [71, 18]

6. Summary and Conclusions

Soil erosion leaves the impact on the ecosystem is particularly noticeable in emerging nations. The variability occurred in environmental conditions and the paucity of high-quality data make it difficult to assess soil erosion. The technology used to assess the soil loss may be conducted more effectively using the RUSLE model when it is used in a geospatial environment. The use of empirical hydrological models, such as RUSLE, along with remote sensing and GIS tools has expanded the utility of these models for locating areas those are more prone to soil erosion and assessing the best management strategies to stop it. Therefore, close coordination is needed between the remote sensing community and field-based erosion experts.

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