SOIL SCIENCE ANNUAL
2024, 75(2), 189538

https://doi.org/10.37501/soilsa/189538

Revisiting the questioned reliability of the revised universal soil loss equation (RUSLE) for soil erosion prediction in the tropics

Enya A. Akpa[1,2], Sunday E. Obalum[1,3*], Charles A. Igwe[1]

[1] Department of Soil Science, University of Nigeria, Nsukka, Nigeria
[2] Department of Soil Science, University of Calabar, Calabar, Nigeria
[3] Department of Soil and Environmental Management, Prince Abubakar Audu University, Anyigba, Kogi State, Nigeria

* Corresponding author: Sunday E. Obalum, sunday.obalum@unn.edu.ng; +2348039688755, ORCID iD: http://orcid.org/0000-0002-6857-6773

Received: 2023-06-04
Accepted: 2024-06-01
Published online: 2024-06-01
Associated editor: Zsofia Bakacsi

Keywords:

Rill erosion
Rainfall erosivity
Potential soil loss
Reliable erosion predictions

Abstract

Soil erosion is one of the greatest environmental degradation challenges the tropical region and the world in general are facing. Tropical soils are less erodible than those of the temperate region, but climatic erosivity is higher in the tropical region due to high erosive power of rain than those of the temperate region. In the past and present, physical processes of soil erosion and soil erosion control have been assessed using the revised universal soil loss equation (RUSLE) model. This review aims at revisiting the questioned reliability of the RUSLE for soil erosion prediction in the tropics. The RUSLE model estimates the long-term average annual soil loss (A) by multiplying out factors of rainfall erosivity (R) and soil erodibility (K), slope length and slope steepness factors (LS), land cover and management factor (C) and the soil conservation or prevention practices factor (P). The RUSLE model is not as data demanding and so more often used than any other tool available. It is also characterized by high degree of flexibility, data accessibility and suitability in computer program. As a drawback, the development of the model is site-specific and often criticized as being a mere temperate-based empirical erosion model which cannot be applied in tropical soil erosion predictions. However, amongst all other soil erosion prediction tools, the model is dependable and reliable in the tropics especially now that it combines with remote sensing (RS), digital elevation model (DEM) and geographical information system (GIS) to estimate annual soil loss (on a pixel-by-pixel basis) and spatial distribution of the soil erosion.

1. Introduction

Soil erosion is the wearing away of the land surface by rain or irrigation water, wind, ice or other natural or anthropogenic agents that abrade, detach, and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere including such processes as gravitational creep and the so-called tillage erosion (SSSA, 2008). Soil erosion is a natural process involving the detachment, movement and deposition of soil or rock caused by the dynamic activity of erosive agents, such as water, ice (glaciers), snow, air (wind), plants, animals, and humans (Apollo et al., 2018). The hydro-meteorological event that induces movement of gross amount of soil material from a higher area to a lower deposition location due to raindrop impact, overland flow or wind is triggered by soil erosion (Okenmuo et al., 2023).

Soil erosion by water is more extensive and its effect is greater than that of wind erosion. It is the most significant global environmental problems we face today which threatens human life due to the severity of its ecological effects, and the scale on which it is going on (Hellden and Tottrup, 2008; Toy, 2002). Soil erosion affects ecosystem services and increases sediment content in rivers and catchment area, agricultural productivity, recreational activities, water quality and quantity, and biodiversity (Panagos et al., 2015). It is caused by natural processes (geologic) but can also be human-induced (accelerated). Accelerated erosion can be 10–1000 times more damaging than geologic erosion (Brady and Weil, 2007), and it creates negative impacts on agriculture and the environment, including loss of life and property, decline in soil fertility, loss of nutrients for plant growth among others.

Globally, soil erosion leads to severe soil loss especially under conditions of unstable soil aggregates (Xu et al., 2012). The severe soil loss (>11 t ha^{-1} yr^{-1}) from erosion cuts across about 70% of the world's agricultural land (Sartori et al., 2019). Also, it has been estimated that, about 80–85% of agricultural land suffers soil erosion problems and six billion hectares of fertile land are being lost annually due to water erosion and other land degrading factors (Comino-Rodrigo et al., 2015; Ganasri and Ramesh, 2016). Some other records show that, of about million hectares of agriculturally productive lands, 45% are significantly eroded, 23.2% hectares are seriously eroded and 3.3% hectares can no longer sustain productivity, with an estimated soil loss of 2 billion m^2 topsoil per annum (Bedadi, 2004).

Soil erosion rates are greater than soil formation rates, posing threat to sustainable agriculture in developing countries, especially when small farms are located in marginal lands, fine-textured soils, and steep slopes (Pimentel, 2006). The rate from cultivated land ranges from 22 t ha^{-1} yr^{-1} to 100 t ha^{-1} yr^{-1} and causes a 15–30% reduction in crop productivity (Morgan, 2005). Furthermore, if land use is not considered, it is realistic to expect approximately a 1.7% change in soil erosion for every 1% change in total precipitation under climate change (Nearing et al., 2004).

Many researchers have shown that soil erosion is more serious in the tropics than the temperate due to erosive nature of tropical rains (Mulengera and Payton, 1998). Regions in the tropical climate zones suffer the greatest rainfall-related soil erosion. This causes excessive soil loss rate of 2–3 t ha^{-1} yr^{-1} due to unsustainable exploitation of land resources on agricultural lands, 40–400 t ha^{-1} yr^{-1} and bare soil areas, 120–460 t ha^{-1} yr^{-1}. One of the prime agents of soil erosion is a rainfall parameter referred to as rainfall erosivity. In recent studies, there are predicted increases of rainfall erosivity by 17% in the United States, 18% in Europe, and universally 30–66% (Panagos et al., 2017). Analysis shows that mean annual rainfall erosivities for countries in the tropics are more than double the global average of about 2,190 MJ mm ha^{-1} hr^{-1} yr^{-1} (Panagos et al., 2017). For instance, countries in the tropics, that is, South America (particularly Brazil, Columbia and Peru), South Eastern Asia (Cambodia, Indonesia, Malaysia, the Philippines and Bangladesh), the Carribean and Western and Central Africa have mean annual rainfall erosivities greater than 5,000 MJ mm ha^{-1} hr^{-1} yr^{-1}. This is unlike cold and dry regions, that is, Canada, the Russian Federation, Northern Europe, Northern Africa and the Middle East having lowest mean annual rainfall erosivity (Panagos et al., 2017). The severity of rainfall causing soil erosion in the tropics cannot be overemphasized. The resulting loss of the topsoil ultimately leads to ecological collapse, causing mass starvation and complete disintegration of soil quality.

To predict soil loss from water erosion, the Universal Soil Loss Equation (USLE) developed in the 1960s and 1970s and later updated to Revised Universal Soil Loss Equation (RUSLE) is often the most widely used due to its simple, transparent, robust model structure and compatibility with geospatial platforms (Merritt et al., 2003; Thomas et al., 2017). The RUSLE model has proven to be a useful tool in many developing nations where there have been major constraints in establishing long-term experiments, as number of changes are now incorporated (Renard et al., 1991). These changes include; revisions of erosivity factor R values, development of a seasonally variable soil erodibility factor K, modifications to the slope length and slope steepness (LS) to account for the susceptibility of soils to rill erosion, and a new procedure for computing the crop management factor C value through the multiplication of various sub-factor values. The emergence of RUSLE has enabled the study of soil erosion, especially for conservation purposes, with effective and acceptable levels of accuracy (Balasubramani et al., 2015) which represent the spatial heterogeneity of soil erosion that is rather feasible with reasonable costs and with better accuracy in larger areas (Angima et al. 2003). The RUSLE model proves to be very effective in predicting the rate of soil erosion, but the accuracy of such prediction could only be assured with the help of numerical data derived from monitoring stations and previous studies (Handique et al., 2023).

However, many authors criticize the misuse of the RUSLE model outside of the United States of America (USA) where it was developed (Manaouch et al., 2020). Despite its widespread use, Majhi et al. (2021) documented that, often there are discrepancies in the methods used to compute it and in the values of the five individual factors that comprise the model. They examined these aspects using the raft of USLE-based studies undertaken in India over the last few decades, reviewing a total of 100 investigations in this respect. Almost all the studies had either over- or underestimated at least one of the five factors, thereby possibly misrepresenting the actual soil loss occurring from an examined area. The most worrisome is that the studies failed to document their methods succinctly or in sufficient detail to ascertain their abilities (Majhi et al., 2021).

Similarly, Kinnell (2017) and Marques et al. (2019) identified that results generated from the RUSLE are frequently unrealistic because of the methods used to estimate some factors of the equation, which were empirically developed in the United States, and may not be applicable under different conditions. Also, Wang et al. (2013) noted that the RUSLE model estimates the average annual soil loss and suited for a given soil type at specific geo-locations other than the United States where it was developed. The model does not provide prediction on a short-term basis, which tends to over-predict small annual soil losses and under-predict large annual soil losses (Kinnell, 2010). This is besides its being widely criticized (Hudson, 1993), on the premises that empirical equation cannot be generally applicable. The update of USLE to RUSLE with its software RUSLE 1 and 2 lends credence to this criticism.

Extensive reviews of RUSLE soil erosion models of varying complexities have been done, with such reviews focussing on input requirements and applications (Aksoy and Kavvas, 2005; Merritt et al., 2003) and the use of different types of soil erosion models in particular places (Mello et al., 2016). In view of this, the present review titled “Revisiting the questioned reliability of the revised universal soil loss equation (RUSLE) for soil erosion prediction in the tropics” was carried out, so as to enhance the dependence, use and reliability of the model to land users in agriculture and soil conservationists in the tropics.

2. RUSLE: An Overview

The RUSLE, as an empirical erosion model, is a recognized standard method to calculate the average risk of erosion on arable land (Wischmeier and Smith, 1978). The RUSLE model is an update of the USLE developed in the 1990s and published by the US Department of Agriculture, that included new rainfall erosivity maps for the United States of America and improvements to the method of calculating the different USLE factors (Renard et al., 1997). The RUSLE model takes better into account some runoff channeled into rills and gullies, changes in soil erodibility due to freeze-thaw and soil moisture, a method for calculating cover and management factors, changes to how the influence of topography is incorporated into the model, and updated values for conservation practices (Renard and Freimund, 1994). The basic structure of the RUSLE model retains the multiplicative form of the USLE, and has process-based auxiliary components such as calculating time-variable soil erodibility, plant growth, residue management, residue decomposition and soil surface roughness as a function of physical and biological processes. The RUSLE model was designed to have updated values for was designed to have (R), new relationships for the topographical components (*L* and *S* factors) which include ratios of rill and inter-rill erosion, consideration of seasonality of the K-factor and additional P factors for rangelands and subsurface drainage, among other improvements (Alewell et al., 2019).

To quantify soil erosion, many empirical models have been developed in the past. Examples include soil erosion models such as the Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2009) and EROSION 2D/3D (Schindewolf and Schmidt, 2012). But the USELE model (Wischmeier and Smith, 1978) updated to RUSLE model is mostly applied around the world (Masha et al., 2021) for predicting soil loss from water erosion at varying scales (Ligonja and Shrestha, 2013; Lal, 2001). The limitations encountered in the RUSLE model are many. One, it permits only for limited interactions and inter-relationships between the basic multiplicative factors (Pruski and Nearing, 2002). The model also fails to take the effects of gully erosion and dispersive soils into account (Rowlands, 2019) and does not predict sediment pathways from hill slopes to water bodies (Cohen et al., 2005). The equation designated for its expression is as stated thus:

$$A = RKLSCP \quad (1)$$

where A is the predicted soil loss expressed in Mg ha^{-1} yr^{-1}, R is rainfall-runoff erosivity factor expressed in MJ mm h^{-1} ha^{-1} yr^{-1}, K is the soil erodibility factor expressed in Mg h MJ^{-1} mm^{-1}, LS are the slope length and slope steepness factors and are dimensionless, C is the land cover and management factor and is dimensionless, and P is the soil conservation or prevention practices factor and is dimensionless.

2.1. RUSLE factors and their applications

2.1.1. Predicted soil loss, A

This is the long-term average annual soil loss estimated by Change to multiplying out the rainfall erosivity factor (R), the soil erodibility factor (K), the topographic factors (L and S) and the cropping and support management factors (C and P). This is the amount which is compared to the “tolerable soil loss” limits.

2.1.2. Rainfall erosivity factor, *R*

The rainfall erosivity factor, *R*, measures the erosive force in a particular region caused by runoff (Karthick et al., 2017). The *R* is an important climatic factor for predicting soil loss and one of the physical factors affecting the magnitude of soil erosion which cause regional variations in water erosion potential (Wang et al., 2017; Leek and Olsen, 2000). The *R* is the potential of rain to cause erosion in an exposed and unprotected soil surface, whose physical definition is the product of total kinetic energy of the storm rainfall and the maximum rainfall intensity over a continuous 30-minute period during the rainstorm (EI_{30}) (Wischmeier and Smith, 1978). The *EI*, being acombination of energy and intensity, which is used to derive *R* has been proposed for modifications (Blanco-Canqui and Lal, 2008). These authors indicated that, *EI* for rain intensities up to 35 mm/h yields results by 12% less for tropical regions and overestimates soil loss for rain intensities ≤ 63.5 mm h^{-1}. Average annual value of *R* is determined from historical weather records which is the average annual sum of the erosivity of individual storms *R*, based on the following equation (Renard et al., 1997):

$$R = EI_{30} = EI_{max30} \quad (2)$$

where *E* is the kinetic energy (MJ ha^{-1} mm^{-1}) and I_{30} is the rainfall intensity (mm h^{-1}). The kinetic energy can be obtained from the following expression:

$$E = 0.119 + 0.087log10I \quad (3)$$

Many methods are considered appropriate for calculating the annual rainfall erosivity factor (Parveen and Kumar, 2012). For example, using data from field measurements, Odura-Afriye (1996) calculated the R factor based on the Fournier Index described as a climatic index, Cp (Eq. 4). He stated that values above 60 show severe to extremely severe erosion risk in average climatic conditions (Table 1). The formula follows thus:

$$Cp = \frac{P^2max}{P} \quad (4)$$

where Cp is the Fournier Index (mm); Pmax is rainfall amount in the wettest month; and P is annual precipitation (mm).

Similarly, Renard and Freimund (1994) proposed the use of monthly and mean annual rainfall in environments to be included with available long-term rainfall data in the modi-

Table 1
Classes of rainfall erosion risk, fournier indexes and soil losses

Class No	Erosion Risk Class	Fournier Index Cp	Soil Loss (t ha^{-1} yr^{-1})
1	Very Low	<20	<5
2	Low	21–40	12–50
3	Moderate	41–60	50–100
4	Severe	61–80	50–100
5	Very Severe	81–100	100–200
6	Extremely Severe	100	>200

Source: Odura-Afriye (1996)

fied Fournier index, F. This modification which is similar to the equation of Odura-Afriye (1996) was later advanced by Sauerborn et al. (1999) thus (Eq. 5):.

$$F = \sum_{i=1}^{12} \frac{P^i}{P} \tag{5}$$

where F is Modified Fournier index; P is mean annual rainfall depth, mm; and P^i is mean rainfall amount in mm for month i.

The equation was applied by Pradhan et al. (2011) to correlate soil erosion with landslide events in Malaysia. Kouli et al. (2009) applied it in Crete watershed of Greece to estimate the modified Fournier index (MFI) for 35 rainfall gauge stations. They determined the *R* on the basis of the estimated MFI using the kriging interpolation method. Five classes of the *R* factor were established ranging from low to high erosivity. Their studies showed high erosivity with high R values (3020–3687 MJ mm ha^{-1} yr^{-1}) to medium to high erosivity (2353–3019 MJ mm ha^{-1} yr^{-1}) in the Crete watershed area (Jahun et al., 2015).

Additionally, Fu et al. (2006) developed an equivalent *R* factor (R_{eq}) in the Inland Pacific Northwest (IPNW) region in the USA, in which they related the R_{eq} factor linearly with the local annual precipitation P_r, mm as shown in Eq. (6):

$$R_{eq} = -823.8 + 5.21\, P_r \tag{6}$$

where R_{eq} is equivalent R factor for unique climatic condition; and P_r is annual precipitation (mm).

Estimating the *R* using GIS is now in use which has been applied by Teshome (2015). He estimated the value of *R* in Shafe watershed of Ethiopia and arrived at 54.04 and 29.31 for the upland and lowland respectively and converted the values to a surface grid of 30 m cell size using ArcGIS taking *R* Factor as the value for cell. The equation follows thus:

$$R = -8.12 + (0.562 \times P) \tag{7}$$

where R is rainfall erosivity factor; and P is mean annual precipitation (mm).

For situations where climate stations are extremely sparse, the estimation of *R* factor poses a challenge. For example, in watershed assessment of erosion risk in Mexico, sparse climate data were observed (Millward and Mersey, 1999). The *R* factor was determined using observed historical rainfall data as well as application of several different formulas conditional to the prevailing conditions of the area (Jahun et al., 2015). Now, an improved technique of obtaining rainfall data using remote rainfall stations interpolated from kriging and inverse distance is often used to determine *R* factor. This is done in IDRISI using an algorithm INTERPOL to estimate the R factor. The EI_{30} measurement and results of their analysis have been shown to be improved by this technique (Jahun et al., 2015).

2.1.3. Soil erodibility factor, *K*

The soil erodibility factor, *K*, relates to the average long–term soil and soil profile response to the erosive power associated with rainfall and runoff. It represents the rate of soil loss per unit of rainfall erosion index for a specific soil (Belasri and Lakhouili, 2016). It is an index which quantifies the relative susceptibility of the soil to rill and inter-rill (sheet) erosion and is an inherent soil characteristic which cannot be readily controlled. The *K* Factor is the soil loss per erosion index unit for a specified soil measured on a standard plot, 22.1 m long, with uniform 9% (5.16°) slope, in continuous tilled fallow (Panagos et al., 2014). The *K* value indicates a strong effect of soil properties on soil erosion and ranges from 0.02 for the least erodible soils to 0.64 for the most erodible ones.

Soil properties affecting *K* Factor include soil texture, organic matter content, structure, and saturated hydraulic conductivity. Soils high in clay have low *K* values because they resist detachment. Coarse-textured soils (such as sandy soils) also have low *K* values because of reduced runoff. Medium-textured soils (such as fine sandy loams) have moderate *K* values because they are moderately susceptible to detachment and runoff. Soils having high silt content are the most erodible of all soils as they are easily detached; tend to crust, and produce high rates of runoff. Determination of *K* factor is based on extensive field research.

The *K* Factor is calculated with the use of USLE nomograph's equation of Wischmeier et al. (1971):

$$K = \frac{[2.1 \text{x}\, 10^{-4}(12-a)\, M^{1.14} + 3.25(b-2) + 3.3 \text{ x } 10^{-3}(c-3)]}{100} \tag{8}$$

where M is the particle size parameter, given by M = (% silt + % very fine sand) × (100 – % clay), *a* is the % organic matter, b is the soil structure class (1 = very fine granular; 2 = fine granular; 3 = medium or coarse granular; 4 = blocky, platy, or massive), and c is the soil profile permeability (saturated hydraulic conductivity) class [1 = rapid (150 mm/h); 2 = moderate to rapid (50–150 mm/h); 3 = moderate (12–50 mm/h); 4 = slow to moderate (5–15 mm/h); 5 = slow (1–5 mm/h); 6 = very slow (<1 mm/h)].

Many studies have demonstrated variations of *K* factor among different soil. For instance, the *K* factor determination based on reference value for various types of soil in Indonesia (Table 2) shows *K* value as high 0.47 t ha^{-1} MJ mm for alluvial soils (easiest to erode) and *K* value as low 0.11 t ha^{-1} MJ mm for Regosol soils (the most difficult to erode) (Harliando et al., 2023).

In Ethiopia, Teshome (2015) evaluated *K* value and obtained the mean *K* factor value of 0.118 t ha^{-1} MJ mm which was high in the north and central parts as compared to the southern margin of the study area (Table 3). Accordingly, the *K* factor is considered to indicate very high erodibility when greater than 0.066 t ha^{-1} MJ mm. The study equally shows that the soils differ in their properties. Silt had the highest value in the lowland (64.9%) compared to the upland (26.4%) and midland (43.7%).

Table 2
RUSLE K factor value for some types of soils in Indonesia

ID	Soil type	K value (t ha^{-1} MJ mm)
1	Latosol red	0.12
2	Latosol red yellow	0.26
3	Latosol	0.31
4	Latosol brown	0.23
5	Regosol	0.11
6	Lithosol	0.29
7	Grumosol	0.20
8	Alluvial	0.47

Source: Harliando et al. (2023)

Very fine sand recorded the highest in the midland (26%) compared to the upland and lowland (12.5%, and 12.2%, respectively). Clay recorded the highest in the upland (60.1%) compared to the midland (30.3%) and lowland (13.8%). Furthermore, the organic matter had the highest value in the upland (2.1%) compared to the midland (0.94%) and lowland (1.1%). In terms of their permeability classes, the upland had the highest value of 5 which rated slow compared to the midland, slow to moderate, value of 4 and lowland, moderate to rapid, value of 2. However, their standard deviation expresses lowland had the highest value of 23.30, followed by the upland, 21.88 with the lowest value was recorded in the midland, 17.50.

2.1.4. Slope length and slope steepness factors, *LS*

The factors *L* and *S* are usually evaluated together in the erosion prediction. The combined *LS* factor in RUSLE represents the ratio of soil loss on a given slope length and steepness. The slope length, *L*, is defined as the horizontal distance from the origin of overland flow to the point where the slope gradient decreases enough that deposition begins or where the runoff becomes concentrated in a defined channel. The slope steepness, *S*, reflects the influence of slope gradient on erosion. The factors *L* and *S* in RUSLE are based on the equation by Presbitero (2003):

$$LS = (I22.13^{-1})^m\,(65.41 \sin^2 q + 4.56 \sin q + 0.0654) \tag{9}$$

where L is the slope length; S is slope steepness; q is the slope angle (°); m is equivalent to 0.5 for S > 5%, 0.4 for 3% < S ≤ 5%, 0.3 for 1% < S ≤3% and 0.2 for S ≤ 1% slope gradient; and m is the exponent in RUSLE defined as:

$$m = \frac{b}{(l + b)} \tag{10}$$

where m is a variable length-slope exponent, b is a function of slope, and l is the slope length. The b is moderately susceptible for rill and inter-rill erosion, i.e.,

$$b = (\sin q/0.0896)/3(\sin q)^{0.8} + 0.56 \tag{11}$$

The b is a factor that varies with slope gradient and q is the slope angle (°) for slopes 1–30°. In RUSLE, where the slopes are shorter than 4.6, m is calculated as:

$$S = 3.0\,(\sin q)^{0.8} + 0.56 \tag{12}$$

The *LS* factors are more reliable if measured directly in the field or obtained through contour maps or Digital Elevation Models (DEM). The *L* and *S* Factors are estimated by ArcGIS 10.8 and the DEM with a resolution (grid cell) of 30 m by 30 m, which is available from USGS Earth explorer (Tilahun and Desta, 2023). The DEM applied to calculate *LS* factors downloaded using 90 m resolution from ASTER DEM website was used to produce *LS* map in Dudhawa Catchment where the slopes of the DEM in percentage were generated using surface analysis under the spatial analyst function and as shown in Eq. 13, to compute *LS* factors (Alka et al., 2017).

$$LS = \left([\text{flow accumulation}] \times \frac{\text{cell size}}{23.13}\right)^{0.6} \times |[\text{Slope}] \times \times \left(\frac{0.01745}{0.0896}\right)^{1.3} \times 1.4 \tag{13}$$

where *LS* is Slope length and steepness factors.

2.1.5. Land cover and management factor, *C*

The *C* factor represents the crop and cover management factor which accounts for the effect of cropping and management practices on erosion rates (Renard et al., 1997). The *C* factor

Table 3
Soil properties and their respective mean erodibility factor values

Soil characteristics	Upland (Summit)	Midland	Lowland
% very fine sand	12.5	26	21.2
% silt	26.4	43.7	64.9
% clay	61.2	30.3	13.8
% Organic matter	2.1	0.94	1.1
Structure	4	4	3
Permeability class	5	4	2
K value (t ha^{-1} MJ mm)	0.14	0.13	0.08
Standard deviation (σ)	21.88	17.50	23.30

Source: Teshome (2015)

gives information on the degree of soil protection by vegetation cover, which is a relevant component of soil protection against water erosion (Brahim et al., 2020).

The *C* factor is quite difficult to obtain and must be determined empirically from plot data. This factor varies according to vegetation cover and could range from 0.001 for well-covered soils up to 1 as the maximum value in terms of efficiency of erosion processes for completely bare soils. The *C* factor is derived using empirical equations based on the measurements of many variables related to ground covers taken in sample plots or from weighted average soil loss ratios (SLRs) that are determined from successions of sub-factors like earlier land-use, canopy cover, surface cover and surface roughness (Renard et al., 1991). An optimization performed using reference values for soil erosion from land use-land cover (LULC) study in Indonesia showed that RUSLE parameters affected the calculated value of soil erosion, serving as a reference for soil erosion in tropical climate regions of Indonesia (Harliando et al., 2023).

Researchers often apply remote sensing techniques in the estimation of *C* to produce land use/cover classification from satellite. For instance, Yitayew et al. (1999) estimated the C factor to be 0.0013 by applying GIS technique to abridge erosion estimation in the Walnut Gulch experimental watershed in Arizona. Additionally, Li et al. (2009) mapped soil erosion risk in the Brazilian Amazonia by estimating the surface cover on the fraction images from spectral mixture analysis (SMA) of Landsat ETM + image, and *C* factor was estimated on the fact that availability of vegetation cover reduces soil loss. The technique of normalized difference vegetation index (NDVI) has been very useful to obtain the *C* factor in soil erosion prediction. Kouli et al. (2009) applied this technique in Northwestern Crete, Greece. They showed that the predicted slope values for the arable land were affected by crop type and management practices and therefore derived *C* factor from the NDVI values using Eq. 14 as proposed by Van der Knijff et al. (2000).

$$C = \exp\left[\alpha\left(\frac{\mathrm{NDVI}}{\beta - \mathrm{NDVI}}\right)\right] \tag{14}$$

where *C* is the land cover and management factor, α is 2 and β is 1, and NDVI is the normalized difference vegetation index.

2.1.6. Soil conservation or prevention practices factor, *P*

The *P* factor is the ratio of soil loss with a given support practice to the corresponding loss without the practice provided row crops are planted up and down the slope (Renard, 1997; Brady and Weil, 2007). The *P* factor is an anthropogenic factor that translates soil erosion practices into the effect of soil and water conservation measures in estimating erosion (Moussi et al., 2023). The use of contour tillage and strip-cropping at different slope gradient (Table 4) has been applied for estimating *P* values (Foster and Highfill, 1983). The equation for estimating P (Eq. 15) is as follows:

$$P = P_c \times P_s \times P_t \tag{15}$$

where P_c is contouring factor for a given field slope; P_s is strip cropping factor; and P_t is terrace sedimentation factor.

Nowadays, empirical equation approach is used to determine the conservation practices factor, *P*. In China, Fu et al. (2006) used the Wenner method proposed by Lufafa et al. (2003) to derive the P factor values. The slope required was easily extracted from available DEM and used to derive *P* factor values in environments without conservation and management practices, thus:

$$P = 0.2 + 0.03 \times S \tag{16}$$

where S is the slope grade (%).

2.2. RUSLE model versions

The RUSLE model has been developed into software; RUSLE versions 1 and 2 by USDA-Agricultural Research Service (ARS) to ease estimation of annual soil loss. The RUSLE version 1 was released on Jan. 19, 2001 by USDA-ARS to integrate the individual factors and multiply values to compute annual erosion and for calculations of a time – varying erodibility (K), a time-varying C, and a time-varying P. The RUSLE 2 was released on May 20, 2008 to replace RUSLE 1 to handle event-based erosion prediction (Foster et al., 2002). This was due to lapses in RUSLE 1 whereby the time-varying numbers for calculation of the average annual value for each factor were thrown away in version one ‘paper’.

Table 4
Values of soil conservation practices (P) factor for contour and strip-cropping at different slopes and the terrace subfactor at different terrace intervals

Land slope (%)	Contour P factor	Strip crop P factor	Terrace internal (m)	Terrace factor	
				Closed outlets	Open outlets
1–2	0.60	0.30	33	0.5	0.7
3–8	0.50	0.25	33–43	0.6	0.8
9–12	0.60	0.30	44–54	0.7	0.8
13–16	0.70	0.35	55–68	0.8	0.9
17–20	0.80	0.40	69–89	0.9	0.9
21–25	0.90	0.45	90	1.0	1.0

Source: Foster and Highfill (1983)

The RUSLE 2 is widely used and enhanced computer software, the newest in the family of RUSLE models which provides acceptable estimates of average annual rill and inter-rill erosion from a wide range of land uses, soil and climatic conditions (Foster et al., 2002). The RUSLE version 2 is an upgrade of the text-based RUSLE DOS version 1 which uses computer model containing both empirical and process-based science in a windows environment that predicts rill and inter-rill erosion by rainfall and runoff. The RUSLE 2 uses a complete integration procedure to multiply daily factor values and adds those values to compute annual erosion. It is flexible and customizable to particular user preferences, allowing a choice of units between the U.S. customary units and SI (metric) units. It is a key part of the emerging ARS Modular Soil Erosion System (MOSES).

2.3. Soil loss and soil loss tolerance, T

Soil loss refers to the amount of sediment that reaches the end of a specified area on a hillslope that is experiencing net loss of soil by water erosion. Soil loss is the most important index for establishing soil loss tolerance (T). Research carried out in cultivated lands and watershed reported different T values compared to the permissible rate of annual soil loss. For example, in a cultivated land, 42 t ha^{-1} y^{-1} was reported as the annual soil loss as estimated by the RUSLE model (Hurni, 1985). Montgomery (2007) observed that this estimated annual soil loss from the cultivated land was excessive when related to the permissible rate of annual soil loss of 11.2 t ha^{-1} y^{-1}. Lal (1998) reported similarly low annual soil losses in relation to slope length under conventional tillage as 9.59 t ha^{-1} for 60 m long slope, 9.88 t ha^{-1} for 50 m, 6.84 t ha^{-1} for 40 m, 5.69 t ha^{-1} for 30 m, 1.27 t ha^{-1} for 20 m and 2.19 t ha^{-1} for 10 m slopes in Ibadan, southwestern Nigeria. The slope length *(*L) and erosion (Y) relationship fitted a polynomial function:

$$Y = c + aL + bL^2 \quad (17)$$

where a, b and c depend on soil, slope, rainfall regime, and management practices.

In Ethiopia, Zerihun et al. (2018) estimated total soil loss to be 1,399,210 t yr^{-1} from a watershed with a mean annual soil loss of 32.84 t $ha^{-1}yr^{-1}$, and used the estimation to classify the severity of soil erosion at 27 sub-watershed into seven severity classes low (below 10), moderate (10–20), high (20–30), very high (30–35), severe (35–40), very severe (40–45) and extremely severe (above 45), with all values in t ha^{-1} yr^{-1}. The soil erosion rate varied from 0.08 to greater than 500 t ha^{-1} yr^{-1}.

Whether by estimation using USLE or by field plot measurements, soil loss or soil erosion from the coarse-textured soils exceed a tolerance (T) limit of about 2 t ha^{-1} yr^{-1} for tropical soils. The T values range from 1 t ha^{-1} yr^{-1} for the most fragile soils to 5 t ha^{-1} yr^{-1} for soils that can sustain more erosion without losing significant productive potential. It has been shown, however, that soil loss from bare tropical soils with very poor aggregation and tilled up and down the slope could be up to 59 t ha^{-1}. y^{-1} (Obi et al., 1989). Soil loss above 2 t ha^{-1} yr^{-1} will lead to degeneration of soil reserves and soil fertility as well as accelerated silting of dams and estuaries. The tolerable soil erosion rates all over the world are between 0.1 mm yr^{-1} and 1 mm yr^{-1} (Li et al., 2009), translating into 1.3 and 13 t ha^{-1} yr^{-1}, respectively, assuming a soil bulk density of 1.3 t m^{-3}. The wide range suggests that the value varies from one region to another. Below are some countries with different soil loss rates (Table 5).

2.4. RUSLE and soil loss tolerance, T

While working to protect soils from excessive erosion and soil productivity degradation and determine when they have been stretched beyond their limits, Hays and Clark (1941) proposed the concept of soil loss tolerance (T). They quantified the T value of the Fayette silt loam and considered topsoil depth as a reference. Soil loss tolerance (T) is a widely used concept for assessing potential risks of soil loss (Xingwu et al., 2012) by soil erosion and a criterion for assessing the effectiveness of soil and water conservation projects (Duan et al., 2012).

Many scholars defined T in different contexts (Li et al., 2009). The definition proposed by Wischmeier and Smith (1978)

Table 5
Soil loss rates in some parts of the country

Country	Soil loss (t/ha/yr)	Author(s)
United Kingdom	0.05–44.4	Rickson, 2014
Arkosa watershed, India	<1 – >6	Pradhan, 2011
Caribbean, Brazil, Central Africa and South East Asia	>11	Panagos et al., 2017
United States of America and Europe	17	Primentel, 2006
Asia, South America and Africa	30–40	Primentel, 2006
Bangladesh	14.25–61.42	Azad, 2001
Ekiti, Southwestern Nigeria	0–889	Olurunfemi et al., 2020
Imo, Southeastern Nigeria	6–1200	Dike et al., 2018
Obibia watershed, Southeastern Nigeria	0–543	Okenmuo and Ewemoje, 2022
Katsina, Northern Nigeria	0.6–4185.12	Adediji et al., 2010
Jos, Northern Nigeria	0–10	Ugese et al., 2022

remains the most widely used and the recommended soil loss tolerance (SLT) value is 11.2 t ha^{-1} yr^{-1}. This value is the acceptable limit of soil erosion which is the amount of soil loss which the soil can withstand without degrading its long-term productivity based on the assumption that the rates of soil erosion and soil formation are equal. In the USA, this SLT value of 11.2 t ha^{-1} yr^{-1} is the upper limit of T (Renard et al., 1997). For major soils in the humid and sub-humid tropics with long weathering history, however, *T* is less than 2 t ha^{-1} yr^{-1} (Igwe, 1999).

As a criterion for assessing erosion rates, the determination of T value is one of the most important aspects of soil and water conservation projects (Hays and Clark, 1941). For a specific soil, SLT is denoted by the T value which is the average annual soil loss that permits current production levels to be sustained economically and indefinitely or the maximum annual amount of soils which can be removed before the long-term natural soil productivity is adversely affected (Wischmeier and Smith, 1978). Hence, an acceptable or tolerable level of soil erosion is one that maintains the delivery of ecosystem goods (such as the provision of food and fibre) and services without degrading the soil's capacity to deliver these services in the future (Li et al., 2009). The RUSLE predicted soil loss (A) is the amount which is compared to the "tolerable soil loss" limits (Wischmeier and Smith, 1978).

In the 1980s, following intensive studies of the long-term effects of soil erosion on soil productivity (Foster et al., 1981), scientists realized that the key question for determining T values was "how much soil loss is tolerable without damaging their productivity?" To address this question, Skidmore (1982) developed a mathematical equation for SLT based on soil depth:

$$T(x, y, t) = \frac{(T_1 + T_2)}{2} - (T_1 - T_2)/2\cos\left(\frac{\pi(Z - Z_1)}{(Z_2 - Z_1)}\right) \quad (18)$$

where T (x, y, t) is the T value at point (x, y); T_1 is the lower limit of T; T_2 is the upper limit of T; Z is the present soil depth, Z_1 is the minimum allowable soil depth, and Z_2 is the optimum soil depth. The SLT function between the points (T_1 Z_1) and (T_2, Z_2) is sinusoidal and dependent upon soil depth, and $(T_2–T_1) / 2$ is the amplitude. The period is represented by the cosine argument from 0° to 180° for values of Z between Z_1 and Z_2. However, soil thickness cannot completely express the soil productivity level, as equivalent soil thicknesses do not mean identical soil productivities.

The equation of Skidmore (1982) was applied on approximated SLT limit to consider the estimated values of potential erosion hazard units and develop SLT limit for central eastern Nigeria (Igwe, 1999). In his study, the SLT limit values ranged between 1.16 t ha^{-1} yr^{-1} in the very slight and 1.30 t ha^{-1} yr^{-1} in the potential erosion hazard classes, values of which were within the range obtained in similar environments. According to him, these values were mere estimations obtained by adopting extensive crop management and soil conservation practices such as cover cropping, mulching and reduced or no tillage to reduce the soil loss. An assigned T value is not used in any erosion prediction equations, but is the target value used to determine whether a management system is sustainable or not.

2.5. RUSLE, remote sensing (RS) and geographic information system (GIS)

Over the last decades, the improvement of GIS technologies allowed the application of the USLE model to compute sediment yield spatially (Marques et al., 2019). The GIS and RS are evolving most effective tools for analyzing spatially distributed information in a vast area nowadays. The use of the USLE model integrated to GIS and RS is a more effective tool than the time-consuming conventional methods for assessing soil loss vulnerability in a basin's scale (Bera, 2017). In recent years, GIS and RS are often used to assess and map water erosion effects, and this has increasingly exposed the advantages of spatialization methods for assessing and mapping soil erosion over large areas and setting up scenarios for rehabilitation (Belasri and Lakhouili, 2016).

The RS and GIS are figuring more important tools and appropriate techniques for decision making to support and operate planning of combating or assessing soil erosion at larger scales (Srinivasan et al., 2019). These techniques have been widely adopted in many studies that show the potential of RS techniques integrated with GIS in soil erosion mapping (Parveen and Kumar, 2012). Soil erosion losses have been evaluated in different regions by utilizing RS and GIS techniques as well as using the empirical soil erosion model (Belayneh et al., 2019; Tadesse and Tefera, 2021). All around the world, RS and GIS techniques have been used to estimate soil erosion by incorporating topographic features with land use and soil characteristics (Star et al. 1997; Wondrade, 2023).

Several studies have shown that the combination of RUSLE and GIS gives useful information in soil erosion predictions (Wang et al., 2016; Uddin et al., 2018). The RUSLE model and GIS were combined to estimate and map water erosion in abandoned quarries in a Moroccan semi-arid zone (Aouichaty et al., 2022). The GIS has augmented the RUSLE model and permitted its effective and accurate application with appreciable advancement (Balasubramani et al., 2015).

The RUSLE model has also been used to predict soil erosion by combining and extracting some parameters of this model with Google Earth Engine (Wang and Zhao, 2020). Because of the ease of use of the RUSLE model, all its parameters can be manipulated and integrated into GIS allowing for a better analysis (Medjani et al., 2023). The RUSLE input parameters are now developed using RS as well as information received from the field and, afterward, integrated in a GIS context where GIS software are used to create the different RUSLE factor maps in a digital GIS environment (Ketema et al., 2024).

To assess annual mean soil loss and delineate erosion hazards, the RUSLE model together with RS and GIS have been used (Teshome, 2015). The combination of RS and GIS techniques with soil erosion models, such as RUSLE, was also found to be an effective approach for estimating the magnitude and spatial distribution of erosion by other researchers (Jahun et al., 2015). Such a combination is the best available practical erosion prediction approach that can be easily applied at the local or regional level using parameters such as slope, aspect, etc. derived from DEM and LULC from satellite images.

The RUSLE model and GIS have been adapted to empirical / statistical data by using standard GIS software. Required input data are usually available and easy to obtain (Wischmeier and Smith, 1978). The RUSLE model has been very useful when combined with GIS dataset with the following input data required as GIS datasets: average annual precipitation (raster dataset), digital soil map with information regarding the topsoil layer, Digital Elevation Model (DEM), digital land use data about land use classes and objects that inhibit erosion (barriers), and data on crops. Once provided with this set of data, the RUSLE model links erosion-influence factors including climatic erosity (R) factor, soil erodibility (*K*) factor, slope length and slope steepness (*LS*) factor, land cover and management (*C*) factor, and soil conservation practices (*P*) factor.. By multiplying these factors, the mean relative soil loss in tons per hectare per year is calculated. The calculation can be based on GIS grid cells or polygons such as crop fields.

The RUSLE model and GIS data have been combined to produce a map of soil erosion risk at a 30 m resolution pixel level with predicted factors (Jun et al., 2019). Landsat 8 satellite images were used to obtain the spatial distribution of four types of soil erosion by carrying out ground-truth checking of the RUSLE which indicated some differences between the spatial distribution and class of soil erosion derived from the RUSLE and the actual situation (Jun et al., 2019). The GIS-RUSLE model was also used to capture the input data to generate spatial average of annual total soil loss A (t ha^{-1} yr^{-1}) which was used to model soil erosion in Rwanda (Byizigiro et al., 2020). Also, Fayas et al. (2019) and Panagos et al. (2015) combined RUSLE model and GIS to evaluate the maximum average annual soil erosion in the Kelani River watershed in Sri Lanka and erosion-prone areas of the European Union, respectively. They obtained the mean soil loss rates of 103.7 $t·ha^{-1}·yr^{-1}$ and 2.46 $t·ha^{-1}·yr^{-1}$, respectively. The RUSLE model has been adopted to estimate soil erosion in the semi-arid Andipatti Watershed of Tamil Nadu, India, where all layers were prepared in GIS platform using various data sources and data preparation methods.

Around the world today, the integration of the RUSLE model with geospatial modeling, GIS, and satellite imagery data could be said to have led to its widespread use in assessing soil erosion on a regional scale in a cost-effective and accurate manner (Wang et al., 2003; Atoma et al., 2020).

3. Revisiting the questioned reliability of RUSLE in the tropics

There are indications that the RUSLE model, though developed to predict water erosion in temperate climates, is easier to adapt to tropical climates than other existing models (Angima et al., 2003). Yet, there are concerns about RUSLE model applicability in tropical regions with different climatic considerations, land uses, and soil types (Cohen et al., 2005). This is despite the fact that the model is a capable tool for improving soil erosion predictions with global applicability. The RUSLE model was first applied on a global scale for estimating the global soil erosion potential despite the various limitations related to applying the RUSLE model (Yang et al., 2003; Ito, 2007). The RUSLE model represents an upgrading to cope with data sensitivities due to unique environmental conditions including the tropical environment (Lu et al., 2004). With its attributes of simplified structure and ease of incorporating parameters, the RUSLE model has been applied by many researchers to evaluate the most vulnerable zones of soil erosion. Moreover, the model can be utilized to identify the potential sources of sediments, estimate the volume of the sediments (Eniyew et al., 2021), and, more frequently, estimate potential soil erosion hazard with a map developed to display the distribution of the hazard (Rahman et al., 2009).

The RUSLE model provides international applicability and comparability of the results and methods, as the method has been adapted to and applied in many world regions (Wischmeier and Smith, 1978). At present, the RUSLE model is by far the most widely applied soil erosion prediction model globally (Risse et al., 1993), essentially because it seems to meet the prediction need better than any other tool available.

The RUSLE model has been useful to estimate the amount of sediment leaving a landscape that may cause off-site damages such as sedimentation in a road ditch. In this case, the slope length is the distance from the origin of overland flow through depositional overland flow areas to the first "concentrated flow" area that collects the overland flow to the point that the runoff can no longer be considered an overland flow.

Several studies carried out in different parts of the world using RUSLE model justify its use and reliability in regions of diverse climatic conditions and varying soil properties (Adediji et al., 2010). The major reasons for RUSLE type modelling being widely used or reliable throughout the world include its high degree of flexibility and data accessibility, a parsimonious parametrization, extensive scientific literature base, and comparability of results allowing to adapt the model to nearly every kind of condition and region of the world (Alewell et al., 2019). Additionally, the RUSLE model is most precise and widely used since some of the other models (e.g., Water Erosion Prediction Project, WEPP) are difficult for most users to use. Some records also show that RUSLE estimates better the maximum rate of soil erosion observed near river channels and over the hilly region with annual average soil erosion.

About 109 countries have used RUSLE model because of its reliability during the last 40 years with the largest number of publications found in the United States of America (274 papers), followed by China (218 papers), Brazil (88), Italy (87), India (67), Spain (66) Australia (50) and Turkey (43) (Alewell et al., 2019). In an analysis per continent, 519 papers (33% of the total) have study sites in 32 countries of Asia (Alewell et al., 2019).

Similarly, the percentage of the total number of studies using the RUSLE model to estimate soil loss by water showed Europe to have 373 publications (24%) in 31 countries; Northern America, 341 publications (22%) in 13 countries; Asia (33%); Africa, 146 publications (9%) in 21 countries; South America, 123 publications (8%); and Oceania, 54 publications (4%) (Alewell et al., 2019). The meta-analysis showed also a wide use of the RUSLE model in East-Southern Asia (South Korea, Malaysia, Thailand and Indonesia), East and West Africa (Ethiopia, Kenya, Nigeria) and the Mediterranean (Italy, Spain, Greece, Portugal, Morocco, Tunisia, Algeria) (Alewell et al., 2019).

Though, the RUSLE model is used more in North America than any other region of the world, there have specific cases of its adoption and application in other tropical envirionments including Southwestern Nigeria (Adediji et al., 2010), Southeastern Nigeria (Igwe et al., 1999) and Milewa Catchments, Kenya (Odongo, 2006). The RUSLE model is a very effective tool to quantitatively assess average soil loss in a watershed. For example, using three-year field data in central Kenyan highland, the RUSLE model was able to pinpoint site-specific erosion hazards associated with each overland flow segment in the catchment for different cropping patterns and management practices (Angima et al., 2003). Also, the model has been used to assess the soil erosion in the El Kharroub River watershed over the baseline period 2000–2020 and two future periods 2021–2030 and 2031–2050 (Ammari et al., 2023). The RUSLE model can characterize areas with severe or extreme risk to guide the rating of soil erosion and setting of priority of management of potentially affected areas (Ammari et al., 2023).

The RUSLE model was developed to meet the multiple needs and conditions of modelled systems. This model has, for more than four decades, proven its technology to be valuable as a conservation-planning guide in the US, providing farmers and conservation planners with a tool to estimate rates of soil erosion for different cropping systems and land managements (Renard et al., 1997). A globally applicable version of the model together with data on environmental factors from Earth System Models (ESMs) can provide the possibility for future studies to accurately estimate soil erosion rates for the past, current and future time periods.

4. Conclusions

- Worldwide, soil erosion is one of the greatest environmental issues threatening human existence with its impact resting heavily on agricultural sustainability.
- In the tropics, soil erosion by water is in the increase causing excessive rate of soil loss due to unsustainable exploitation of land resources. The topsoils are severely lost in almost every rainfall event, and these losses imply increased soil compaction and depletion of nutrients for plant growth.
- The revised universal soil loss equation (RUSLE) model is widely applied to predict soil erosion. The RUSLE is very flexible and customizable to user preference with the ability to estimate rates of soil erosion for different cropping systems and land managements in the country of its use.
- A globally applicable version of the RUSLE model together with data of GIS as well as data on environmental factors from Earth System Models (ESMs) has provided the possibility to accurately estimate soil erosion rates for the past, current and future time periods.
- Many countries have used RUSLE model because of its model structure simplicity and ease of incorporating factors.
- With these features and attributes of the RUSLE model, it is now recognized to be more useful and reliable in estimating soil erosion by water in the tropics, applicability of which is increasingly being demonstrated.

Acknowledgements

Acknowledged is the Vice Chancellor, University of Calabar, Calabar, Prof. Florence Banku Obi for granting me study leave and Tertiary Education Trust Fund sponsorship to undergo a PhD study in the University of Nigeria, Nsukka.

References

Adediji, A., Tukur, A., Adepoju, K., 2010. Assessment of revised universal soil loss equation (RUSLE) in Katsina Area, Katsina State of Nigeria using remote sensing (RS) and geographic information system (GIS). Iranica Journal of Energy and Environment 1(3), 255–264.

Alewell, C., Borrelli, P., Meusburger, K., Panagos, P., 2019. Using the USLE: Chances, challenges and limitations of soil erosion modelling. International Soil and Water Conservation Research 3(7), 203–225. https://doi.org/10.1016/j.iswcr.2019.05.004

Alka, S., Triambak, B., Manish, K.S., Ishtiyaq, A., Mukesh, K.V., 2017. Soil Erosion Modeling using Rusle and GIS on Dudhawa Catchment. International Journal of Applied Environmental Sciences 12(6), 1147–1158. https://www.ripublication.com

Aksoy, H., Kavvas, M.L., 2005. A review of hillslope and watershed scale erosion and sediment transport models. Catena 64(2–3), 247–271. http://doi.org/10.1016/j.catena.2005.08.008

Ammari, Z., Mili, E., Essahlaoui, A., El Hafyani, M., Essahlaoui, N., Boufala, M., Ouallali, A., Berrad, F., Aassoumi, H., 2023. Mapping and Predicting of Water Erosion using RUSLE in the Mediterranean context: CASE OF El kharroub watershed (Western Rif, Northern Morocco). ARPN Journal of Engineering and Applied Sciences 18(6), 1819–6608.

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K., Weesies, G.A., 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. Agriculture Ecosystems Environment 97, 295–308. https://doi.org/10.1016/S0167–8809(03)00011-2

Aouichaty, N., Bouslihim, Y., Hilali, S., Zouhri, A., Koulali, Y., 2022. Estimation of water erosion in abandoned quarries sites using the combination of RUSLE model and geostatistical method. Scientific African 16, 2468–2276. https://doi.org/10.1016/j.sciaf.2022.e01153

Apollo, M., Andreychouk, V., Bhattarai, S.S., 2018. Short-Term Impacts of Livestock Grazing on Vegetation and Track Formation in a High Mountain Environment: A Case Study from the Himalayan Miyar Valley (India). Sustainability 10(4), 951. https://doi.org/10.3390/su10040951

Atoma, H., Suryabhagavan, K.V., Balakrishnan, M., 2020. Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia. Sustainable Water Resources Management 6. https://doi.org/10.1007/s40899-020-00365-z

Azad, A.K., 2001. A study on the prediction of sediment yield from the hilly catchment of Chittagong Hill tracts. Bangladesh University of Engineering and Technology. lib.buet.ac.bd.8080/xmlui/handle/123456789/250

Bedadi, B., 2004. Evaluation of Soil Erosion in the Harerge Region of Ethiopia using Soil Loss Models, Rainfall Simulation and Field Trials. Research report. University of Pretoria: Pretoria. https://hdl.handle.net/2263/26929

Balasubramani, K., Mohan, V., Kumaraswamy, K., Saravanabavan, V., 2015. Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (rusle) model through GIS Model. Earth Systems and Environment 1, 10. https://doi.org/10.5194/isprsannals-II-2-W2-207-201

Belasri, A., Lakhouili, A., 2016. Estimation of Soil Erosion Risk Using the Universal Soil Loss Equation (USLE) and Geo-Information Technology in Oued El Makhazine Watershed, Morocco. Journal of Geographic Information System 8, 98–107. http://dx.doi.org/10.4236/jgis.20

Belayneh, M., Yirgu, T., Tsegave, D., 2019. Potential soil erosion estimation and area prioritization for better conservation planning in Gumara watershed using RUSLE and GIS techniques. Environmental System Research 8, 20. https://doi.org/10.11186/s40068–019-0149-x

Bera, A., 2017. Estimation of Soil loss by USLE Model using GIS and Remote Sensing techniques: A case study of Muhuri River Basin, Tripura, India. Eurasian Journal of Soil Science 6(3), 206–215 https://doi.org/10.18393/ejss.288350

Blanco-Canqui, H., Lal, R., 2008. Principles of Soil Conservation and Management. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-8709-7

Brady, N.C., Weil, R.R., 2007. The Nature and Properties of soils. 14th Edition, Prentice Hall, Upper Saddle River, N. J.

Brahim, B., Meshram, S.G., Abdallah, D., Larbi, B., Drisss, S., Khalid, M., Mohamed, K.K., 2020. Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). Arabian Journal of Geosciences 13, 1153. https://doi.org/10.1007/s12517-020-06079-y

Byizigiro, R.V., Rwanyiziri, G., Mugabowindekwe, M., Kagoyire, C., Biryabarema, M., 2020. Estimation of Soil Erosion Using RUSLE Model and GIS: The Case of Satinskyi Catchment, Western Rwanda. Rwanda Journal of Engineering, Science, Technology and Environment 3(1), 14–33. https://doi.org/10.4314/rjeste.v3i1.2S

Cohen, M.J., Shepherd, K.D., Walsh, M.G., 2005. Empirical reformulation of the universal soil loss equation for erosion risk assessment in a tropical watershed. Geoderma 124 (3–4), 235–252. https://doi.org/10.1016/j.geoderma.2004.05.003

Comino-Rodrigo, J., Brings, C., Lassu, T., Iserloh, T., Senciales, J.M., Martínez, J.F. Murillo, J.D., Ruiz S., Seeger, M., Ries, J.B., 2015. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth 6(3), 823–837. https://doi.org/10.5194/se-6-823-2015

Dike, B.U., Alakwem, O.P., Nwoke, H.U., Nwakwasi, N.N., 2018. Potential soil loss rates in Urualla, Nigeria using RUSLE. Global Journal of Science Frontier Research: H Environment & Earth Science 18(H2), 43–48. Retrieved from journalofscience.org/index.php/GJSR/article/view/2291

Duan, X.W., Xie, Y., Liu, B.Y., Liu, G., Feng, Y. J., Gao, X. F., 2012. Soil loss tolerance in the black soil region of Northeast China. Journal of Geographical Sciences 22(4), 737–751. https://doi.org/10.1007/S11442-012-0959-5

Eniyew, S., Teshome, M., Sisay, E., Bezabin, T., 2021. Integrating RUSLE model with remote sensing and GIS for evaluation soil erosion in Telkwonz watershed, Northwestern Ethiopia. Remote Sensing Applications: Society and Environment 24. https://doi.org/10.1016/j.rsase.2021.100623

Fayas, C.M., Abeysingha, N.S., Nirmanee, K.G.S., Samaratunga, D., Mallawatantri, A., 2019. Soil loss estimation using rusle model to prioritize erosion control in KELANI river basin in Sri Lanka. International Soil and Water Conservation Research 7(2), 130–137. https://doi.org/10.1016/j.iswcr.2019.01.003

Foster, G.R., Highfill, R.E., 1983. "Effects of terraces on soil loss: USLEP factor values for terraces," Journal of Soil Water Conservation 38, 48–51.

Foster, G.R., Meyer, L.D., Onstad, C.A., 2002. An erosion equation derived from basic erosion principles. Transactions of the American Society of Agricultural Engineers 20, 678–682. https://doi:org/10:13031720133562

Foster, G.R., Moldenhauer, W.C., Wischmeier, W.H., 1981. Transferability of U.S. technology for prediction and control of erosion in the tropics. In Soil Erosion and Conservation in the Tropics; ASA: Madison, WI, USA, pp. 135–149.

Fu, G., Chen, S., McCool, D.K., 2006. Modeling the Impacts of no-till practice on Soil Erosion and Sediment Yield with RUSLE, SEDD, and ArcView GIS. Soil and Tillage Research 85, 38–49. https://doi:org/10:1016/j.still.2004.11.009

Ganasri, B.P., Ramesh, H., 2016. Assessment of soil erosion by RUSLE model using remote sensing and GIS – a case study of nethravathi basin Geoscience Frontiers 7(6), 953–961. https://doi.org/10.1016/j.gsf.2015.10.007

Handique, A., Dey, P., Patnaik, S.K., 2023. Application of Revised Universal Soil Loss Equation (RUSLE) model for the estimation of soil erosion and prioritization of erosion-prone areas in Majuli Island, Assam, India. Journal of Applied and Natural Science 15(4), 1667–1678. https://doi.org/10.31018/jans.v15i4.5176

Harliando, D.P., Saputri, H.I., Setyawan, C., Khidzir, A., Susanto, S., Zaki, M.K., 2023. RUSLE CP factor optimization for soil erosion modeling in tropical watershed of Indonesia. In: Saputro A.D. et al. (Eds.), ICOSEAT 2022, ABSR 26 (pp. 275–280). https://doi.org/10.2991/978-94-6463-086-2_35

Hays, O.E., Clark, N., 1941. Cropping system that helps control erosion. USA: University of Wisconsin, Bulletin No. 452.

Hellden, U., Tottrup, C., 2008. Regional desertification: A global synthesis. https://doi.org/10.1016/j.iswcr.2019.05.004

Hudson, N.W., 1993. Field measurement of soil erosion and runoff. FAO Soils Bulletin 68, 139.

Hurni, H., 1985. Erosion Productivity Conservation Systems in Ethiopia. 4th ISCO Conference, Venezuala 654–674.

Igwe, C.A., 1999. Land use and soil conservation strategies for potentially highly erodible soils of central eastern Nigeria. Land Degredation and Development 10, 425–434. https://doi.org/10.1002/(1099-145X(199909/10)10:5<425: AID-LDR338>3.0.CO;2-5

Igwe, C.A., Akamigbo, F.O.R., Mbagwu, J.S.C., 1999. Application of SLEMSA and USLE Erosion Models for Potential Erosion Hazard Mapping in Southeastern Nigeria. International Agrophysics 13, 41–48.

Ito, A., 2007. Simulated impacts of climate and land-cover change on soil erosion and implication for the carbon cycle, 1901 to 2100, Geophysical Research Letters 34(9). https://doi.org/10.1029/2007GL029342

Jahun, B.G., Ibrahim, R., Dlamini, N.S., Musa, S.M., 2015. Review of Soil Erosion Assessment using RUSLE Model and GIS. Journal of Biology, Agriculture and Healthcare. ISSN 2224–3208.

Jun, W., Qian, H., Ping, Z. Qinghua, G., 2019. Test of the RUSLE and Key Influencing Factors Using GIS and Probability Methods: A Case Study in Nanling National Nature Reserve, South China. Advances in Civil Engineering. https://doi.org/10.1155/2019/7129639

Karthick, P., Lakshumanan, C., Ramki, P., 2017. Estimation of soil erosion vulnerability in Perambalur Taluk, Tamilnadu using revised universal soil loss equation model (RUSLE) and geo information technology. International Research Journal of Earth Sciences 5(8), 8–14

Ketema, T., Chimdesa, C., Eshetu, M., Gosa, R., Abagaja, D., Getachew, G., 2024. Soil Erosion Mapping and Severity Analysis Based on RUSLE Model on Welmel Catchments of Ganale-Dewa River Basin Bale Lowland South Eastern Ethiopia. East African Scholars Journal of Agriculture and Life Sciences 7(3), 2617–7277. https://doi.org/10.36349/easjals.2024.v07i03.001

Kinnell, P.I.A., 2017. A comparison of the abilities of the USLE-M, RUSLE 2 and WEPP to model event erosion from bare fallow areas. Science of the Total Environment 596–597, 32–42. https://doi.org/10.1016/j.scitotenv.2017.04.046

Kinnell, P.I.A., 2010. Event Soil Loss, Runoff and the Universal Soil Loss Equation Family of models: A Review. Journal of Hydrology 385, 384–397. https://doi.org/10.1016/j.jhydrol.2010.01.024

Kouli, M., Soupios, P., Vallianatos, F., 2009. Soil Erosion Prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environmental Earth Sciences 57(3), 483–497. https://doi.org/1007/s00254-008-1318-9

Lal, R., 1998. Soil degradative effects of slope length and tillage methods on Alfisols in western Nigeria. III. Soil physical properties. Land Degradation and Development 8(4), 325–342. https://doi.org/10.1002/(SICI)1099-145X(199712)8:4<325::AID-LDR265>3.0.CO;2-N

Lal, R., 2001. Soil degradation by erosion. Land Degradation and Development 12, 519–539. https://doi.org/10.1002/ldr.472

Leek, R., Olsen, P., 2000. Modelling climatic erosivity as a factor of soil erosion in Denmark: Changes and temporal trends. Soil use and management 16(1), 61–65. https://doi.org/10.1111/1.1475-2743.2000.tb00175.x

Li, L., Du S., Wu L., Liu., G., 2009. An overview of soil loss tolerance. Catena 78(2), 93–99. https.//doi.org/10.1016/j.catena.2009.03.00

Ligonja, P.J., Shrestha, R.P., 2013. Soil erosion assessment in Kondoa eroded area in Tanzania using universal soil loss equation, geographic information systems and socioeconomic approach, Land Degradation and Development 26(4), 367–379. https://doi.org/10.1002/ldr.2215

Lu, D., Li, G., Valladares, G.S., Batistella, M., 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazona: using RUSLE, remote sensing and GIS. Land Degradation and development 15(5), 499–512. https://doi.org/10.1002/ldr.634

Lufafa, A., Tenywa, M., Isabirye, M., Majaliwa, M., Woomer, P., 2003. Prediction of Soil erosion in a Lake Victoria Basin Catchment using a GIS-based Universal Soil Loss Model. Agricultural Systems 76(3), 883–894.

Masha, M., Yirgu, T., Debele, M., 2021. Impacts of land cover and greenness change on soil loss and erosion risk in Damota area districts, Southern Ethiopia. Applied and Environmenta Soil Science, 1–14. https://doi.org/10.1155/2021/9148138

Majhi, A., Shaw, R., Mallick, K., Patel, P.P., 2021. Towards improved USLE-based soil erosion modelling in India: A review of prevalent pitfalls and implementation of exemplar methods. Earth-Science Reviews 221, 103786. Advance online publication. https://doi.org/10.1016/j.earscirev.2021.103786

Manaouch, M., Zouagui, A., Fenjiro, I., 2020. A review of soil erosion modeling by R/USLE in Morocco: Achievements and limits. E3S Web of Conferences 234. https://doi.org/10.1051/e3sconf/202123400067

Marques, V.S., Ceddia, M.B., Antunes, M.A.H., Carvalho, D.F., Anache, J.A.A., Rodrigues, D.B.B., Oliveira, P.T.S., 2019. USLE K-Factor Method Selection for a Tropical Catchment. Sustainability 11, 1840. http://dx.doi.org/10.3390/su11071840

Medjani, F., Derradji, T., Zahi, F., Djidel, M., Labar, S., Bouchagoura, L., 2023. Assessment of soil erosion by Universal Soil Loss Equation model based on Geographic Information System data: a case study of the Mafragh watershed, north-eastern Algeria. Scientific African 21, 2468–2276. https://doi.org/10.1016/j.sciaf.2023.e01782

Mello, C.R., Norton, L.D., Pinto, L.C., Beskow, S., Curi, N., 2016. Agricultural watershed modeling: a review for hydrology and soil erosion processes. Ciecia and Agrotechnologia 40(1), 7–25. https://doi.org/10.1590/S1413-70542016000100001

Merritt, W.S., Letcher, R.A., Jakeman, A.J., 2003. A review of erosion and sediment transport models. Environmental Modelling and Software 18(8–9), 761–799. https://doi.org/10.1016/51364-8152(03)00078-1

Millward, A.A., Mersey, J.E., 1999. Adapting the RUSLE to Model Soil Erosion Potential in a Mountainous Tropical Watershed. Catena 38(2), 109–129. https://doi.org/10.1016/s0341-8162(99)00067-3

Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences 104(33), 13268–13272. https://doi.org/10.1073/pnas.0611508104

Morgan, R.P.C., 2005. Soil erosion and conservation. 3rd ed. Carlton: Blackwell Publishing, Oxford. https://doi.org/10.1111/j.1365-2389.2005.0756f.x.

Moussi, R., Bengamra, S., Bouziane, H., Nouayti, A., Benzougagh, B., 2023. Quantification of soil erosion by USLE model in the Oued Za watershed (northeastern Morocco). 2458–7184.

Mulengera, M.K., Payton, R.W., 1998. Estimating the USLE-Soil erodibility factor in the developing tropical countries. A case study in Tazania. Uhandisi Journal 22.

Nearing, M., Pruski, F., O'Neal, M., 2004. Expected Climate Change impacts on Soil Erosion Rates: A Review. Journal of Soil and Water Conservation 59, 43–60.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2009. Soil and Water Assessment Tool Theoretical Documentation Version 2009. Soil and Water Research Laboratory, Agricultural Research Service, US Department of Agriculture, Temple.

Obi, M.E., Salako, F.K., Lal, R., 1989. Relative susceptibility of some Southeastern Nigeria soils to erosion Catena 16, https://doi.org/10.1016/034-8162(89)90009x

Odongo, V.O., 2006. Evaluating the Topographic indicator of soil susceptibility to runoff and factor in the Universal Soil Loss Equation Using GIS erosion, validation at several levels, In: Catena Techniques for Malewa Catchment, Nawasha, Kenya 47(2), 133–149.

Oduro-Afriye, K., 1996. Rainfall erosivity map for Ghana. Geoderma 74(1–2), 161–166. https://doi.org/10.1016/js0016–7061(96)00054-7

Okenmuo, F.C., Ewemoje, T.A., 2022. Estimation of soil water erosion using RUSLE, GIS, and remote sensing in Obibia River watershed, Anambra, Nigeria. DYSONA-Applied Science 4(1), 6–14. https://doi.org/10.30493/DAS.2022.349144

Okenmuo, F.C., Ibeh, K.G., Obalum, S.E., 2023. The menace of widespread gully erosion in southeastern Nigeria: litho-anthropogenic history and management and policy issues. In: E. C. Igwe, I. Uko & A. O. Onunwa (Eds.), Valedictorian Festschrift in Honour of Professor Peter Chinedum Nnabude 61–79, Cadventures Press, Umunya, Anambra State, Nigeria.

Olorunfemi, I.E., Komolafe, A.A., Fasinmirin, J.T., Olufayo, A.A., Akande, S.O., 2020. A GIS–based assessment of the potential soil erosion and flood hazard zones in Ekiti State, Southwestern Nigeria using integrated RUSLE and HAND models. Catena 194. https://doi.org/10.1016/j.catena.2020.104725

Panagos, P., Borrelli, P., Meusburger, K., 2015. A new European slope length and Steepness factor (LS-factor) for modeling soil erosion by water. Journal of Geosciences 5, 117–126. https://doi.org/10.1016/j.envsci.2015.12.013

Panagos, P., Ballabio, C., Meusburger, K., Spinoni, J., Alewell, C., Borrelli, P., 2017. Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets. Journal of Hydrology 548, 251–262. https://doi.org/10.1016/j.jhydrol.2017.03.0106

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C., 2014. Soil erodibility in Europe: A high-resolution dataset based on LUCAS. Science of the Total Environment 189–200. https://doi.org/10.1016/j.scitotenv.2014.02.010

Parveen, R., Kumar, U., 2012. Integrated approach of universal soil loss equation (USLE) and geographical information system (GIS) for soil loss risk assessment in upper south Koel Basin, Jharkhand. Journal of Geographic Information System 4(6), 588–596. http://doi.org/10.4236/jgis.2012.46061

Pimentel, D., 2006. Soil erosion: a food and environmental threat. Environment, Development and Sustainability 8(1), 119–137. http://doi.org/10.1007/S10668-005-1262-8

Pradhan, B., Chaudhari, A., Adinarayana, J., Buchroithner, M.F., 2011. Soil Erosion Assessment and its correlation with landslide events using Remote Sensing Data and GIS: A case study at Penang Island, Malaysia. Environmental Monitoring and Assessment 184(2), 715–727. https://doi.org/10.1007/s10661–011-1996-8

Presbitero, A.L., 2003. Soil Erosion Studies on Steep Slopes of Humid-Tropic Philippines. Australian School of Environmental Studies; Nathan Campus, Griffith University. https://doi.org/10.25904/1912/3182

Pruski, F.F., Nearing, M.A., 2002. Runoff and soil loss responses to changes in precipitation: a computer simulation study. Journal of Soil and Water Conservation 57(1), 7–16.

Rahman, M.R., Shi, Z.H., Chongfa, C., 2009. Soil erosion hazard evaluation—An integrated use of remote sensing, GIS and statistical approaches with biophysical parameters towards management strategies. Ecological Modelling 220(13–14), 1724–1734. https://doi.org/10.1016/j.ecolmodel.2009.04.004

Renard, K.G., Freimund, J.R., 1994. Using Monthly Precipitation Data to Estimate the R Factor in the Revised USLE. Journal of Hydrology 157(1), 287–306. https://doi.org/10.1016/0022-1694(94)90110-4

Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P., 1991. RUSLE: Revised Universal Soil Loss Equation. Journal of Soil and Water Conservation 46(1), 30–33. https://doi.org/10.1201/9780203739358-5

Renard, K.G., Foster, G.R., Yoder, D.C., 1997. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). USDA Agriculture Handbook 703, pp. 382

Rickson, R.J., 2014. Can control of soil erosion mitigate water pollution by sediments? Science of the Total Environment 468–469, 1187–1197. https://doi.org/10.1016/j.scitotenv.2013.05.057

Risse, L.M., Nearing, M.A., Nicks A.D., Laflen, J.M., 1993. Error assessment in the universal soil loss equation. Soil Science Society of America Journal 57(3), 825. https://doi.org/10.2136/sssaj1993.03615995005700030032x

Rowlands, L., 2019. Erosion and Sediment Control-WSUD During the Construction Phase of Land Development. Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Elsevier Inc.: Cambridge, USA 45, 163–176. https://doi.org/10.1016/B978-0-12-812843-5.00008-3

Star, J.L., Estes, J.E., McGwire, K.C., 1997. Integration of geographic information systems and remote sensing. New York (NY): Cambridge University Press.

Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L., Panagos, P., 2019. A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. Land Use Policy 86, 299–312. https://doi.org/10.1016/j.landusepol.2019.05.014

Sauerborn, P., Klein, A., Botschek, J., Skowronek, A., 1999. Future Rainfall Erosivity Derived from Large-scale Climate Models-Methods and Scenarios for a humid region. Geoderma 93(3–4), 269–276. https://doi.org/10.1016/S0016-7061(99)00068-3

Schindewolf, M., Schmidt, J., 2012. EROSION 2D/3D soil erosion model using a small-scale rainfall simulator and upstream runoff simulation. Catena 91, 47–55. https://doi.org/10.1016/j.catena.2011.01.007

Skidmore, E.L., 1982. Soil loss tolerance. ASA Special Publications. https://doi.org/10.2134/asaspecpub45.c8

Soil Science Society of America, 2008. Glossary of Soil Science terms. ASA-CSSA-SSSA

Srinivasan, R., Singh, S.K., Nayak, D.C., Hegde, R., Ramesh, M., 2019. Estimation of soil loss by USLE Model using Remote Sensing and GIS Techniques – A Case study of Coastal Odisha, India. Eurasian Journal of Soil Science 8(4), 321–328. https://doi.org/10.18393/ejss.598120

Tadesse, T.B., Tefera, S.A., 2021. Comparing potential risk of soil erosion using RUSLE and MCDA techniques in central Ethiopia. Modeling Earth System and Environment 7(3), 1713–1725. https://doi.org/10.1007/s40808-020-00881-z

Teshome, Y.B., 2015. An assessment of spatial analysis of erosion risk in Shafe watershed, Western Hills of Lake Abaya, South western Ethiopia. International Journal of Physical and Human Geography 3(1), 16–30.

Tilahun, A., Desta, H., 2023. Soil erosion modeling and sediment transport index analysis using USLE and GIS techniques in Ada'a watershed, Awash River Basin, Ethiopia. Geoscience Letters 10, 57. https://doi.org/10.1186/s40562-023-00311-9

Thomas, J., Joseph, S., Thrivikramji, K.P., 2017. Assessment of soil erosion in a tropical mountain river basin of the Southern Western Ghats, India using RUSLE and GIS, Geoscience Frontiers 9(3), 893–906. https://doi.org/10.1016/j.gsf.2017.05.011

Toy, T.J., 2002. Soil Erosion: Processes, Prediction, Measurement, and Control. John Wiley & Sons. p. 1. ISBN 978-0-471-38369-7.

Uddin, K., Abdul Matin, M., Maharjan, S., 2018. Assessment of Land Cover Change and its Impact on Changes in Soil Erosion Risk in Nepal. Sustainability (10)12, 4715–4726. https://doi.org/10.3390/su10124715

Ugese, A.A., Ajiboye, J.O., Ibrahim, E.S., Gajere, E.N., Itse, A., Shaba, H.A., 2022. Soil loss estimation using remote sensing and RUSLE model in Koromi-Federe catchment area of Jos-East LGA, Plateau State, Nigeria. Geomatics 2(4), 499–517. https://doi.org/10.3390/geomatics2040027

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 2000. Soil Erosion Risk Assessment in Europe: European Soil Bureau Joint Research Centre, European Commission.

Wang, B., Zheng, F., Romkens, M.J.M., Darboux, F., 2013. Soil erodibility for water erosion: a perspective and Chinese experience. Geomorphomlogy 187, 1–10. https://doi.org/10.1016/j.geomorph.2013.01.018

Wang, G., Gertner, G.Z., Fang, S., Anderson, A.B., 2003. Mapping multiple variables for predicting soil loss by Geo-statistical methods with TM images and a slope map. Photogrammetric Engineering and Remote Sensing 69, 889–898. https://doi.org/10.14358/PERS.69.8.889

Wang, H., Zhao, H., 2020. Dynamic Changes of Soil Erosion in the Taohe River Basin using the RUSLE Model and Google Earth Engine. Water 12(5), 1293. https://doi.org/10.3390/w12051293

Wang, R., Zhang, S., Yang, J., Pu, L., Yang, C., Yu, L., Chang, L., Bu, K., 2016. Integrated Use of GCM, RS, and GIS for the Assessment of Hillslope and Gully Erosion in the Mushi River Sub-Catchment, Northeast China. Sustainability (8)4, 317. https://doi.org/10.3390/su8040317

Wang, Y., Tan, S., Liu, B., Yang, Y., 2017. Estimating rainfall erosivity by incorporating seasonal variations in parameters into the Richardson model. Journal of Geographical Sciences 27, 275–296. https://doi.org/10.1007/s11442-017-1376-6

Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses – a guide to conservation planning. Agriculture Handbook No. 537, USDA, Washington.

Wischmeier, W.H., Johnson, C.B., Cross, B.V., 1971. A soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation 26, 189–193.

Wondrade, N., 2023. Integrated use of GIS, RS and USLE model for LULC change analysis and soil erosion risk mapping in the Lake Hawassa Watershed, Southern Ethiopia, Geocarto International 38(1), 2210106. https://doi.org/10.1080/10106049.2023.2210106

Xingwu, D., Xiaoning, S., Yanbo L., Li, R., Detai, F., 2012. A new method to calculate soil loss tolerance for sustainable soil productivity in farmland Agronomy for Sustainable Development 37, 2. https://doi.org/10.1007/s13593-016-0409-3

Xu, L., Xu, X., Meng, X., 2012. Risk assessment of soil erosion in different rainfall scenarios by RUSLE model coupled with Information Diffusion Model: A case study of Bohai Rim, China. Catena 100, 74–82. https://doi.org/10.1016/j.catena.2012.08.012

Yang, D.W., Kanae, S., Oki, T., Koike, T., Musiake, K., 2003. Global potential soil erosion with reference to land use and climate changes, Hydrological Processes 17(14), 2913–2928. https://doi.org/10.1002/hyp.1441

Yitayew, M., Pokrzywka, S.J., Renard, K.G., 1999. Using GIS for Facilitating Erosion Estimation. Applied Engineering in Agriculture 15(4), 295–302. https://doi.org/10.13031/2013.5780

Zerihun, M., Mohammedyasin, M.S., Sewnet, D., Adem, A.A., Lakew, M., 2018. Assessment of soil erosion using RUSLE, GIS and remote sensing in NW Ethiopia, Geoderma Regional 12, 83–90. https://doi.org/10.16/j.geodrs.2018.01.002