Chapter 5

Soil Erosion Estimation Using RUSLE Method

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A. Soil Erosion

Nowadays, the urbanization activity and population increase has caused natural resources such as soil and land to depleting time by time. Many development projects have changed the morphology and land function, which in turn caused many environmental problems. One of them is known as soil erosion. Soil erosion or soil loss is a phenomenon in which many the soil properties experienced serious degradation due to external forces. The erosion phenomenon is deeply affected by several factors, such as rainfall (errosivity/R factor), soil type (erodibility/K factor), topography (slope and steepness/LS factor), control practices (P factor), and vegetation cover (C factor). For a long period, many scientists have been studying the soil ero-

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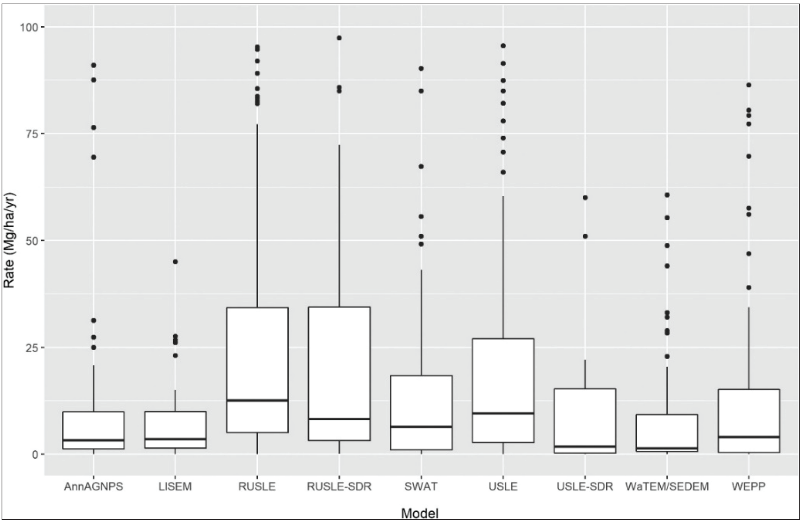
sion process, the causes, and its impacts in the socio-environmental field (Bennett & Chapline, 1928). They also have determined that this phenomenon is mainly caused by water, hill slope, and minor catchment (Turnbull et al., 2010). A few years later, the method to calculate erosion become more advanced since the existence of Geographic Information System (GIS) software as a device to create a model simulation for larger catchment and more complex surface run-off. The Digital Elevation Model (DEM) generation, watershed delineation, and morphometric parameters extraction can be obtained using ArcHydro and morphometric toolbox in GIS.

There are several methods to predict soil erosion, for example Erosion Potential Model (EPM) (Gavrilovic, 1962), Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978), and the revision of USLE method known as Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991). RUSLE is regarded as one of the most



Source: Borrelli et al. (2021)

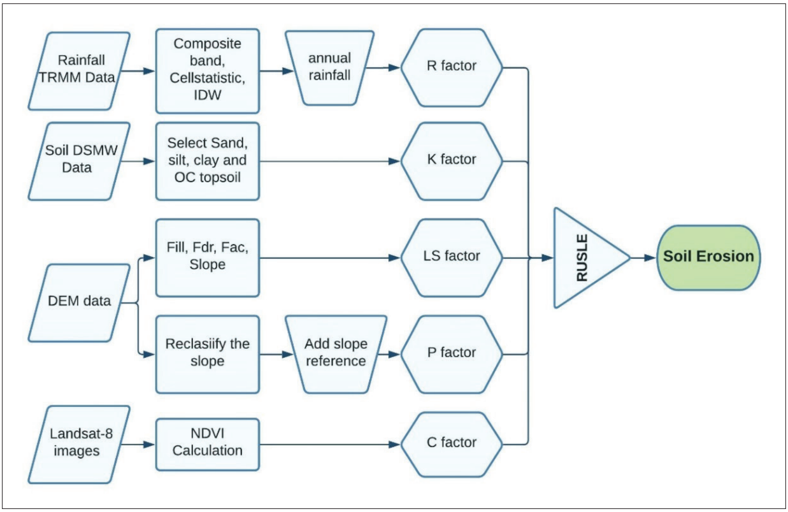
Figure 5.1 Comparison of the RUSLE and Eight Soil Erosion Prediction Most Commonly Used Models Based on the GASEMT Database popular methods in the world based on Global Applications of Soil Erosion Modelling Tracker (GASEMT) database (Figure 5.1). Another methods are Water Erosion Prediction Project (Flanagan and Nearing, 1995), Pan-European Soil Erosion Risk Assessment (Kirkby et al., 2004), and Soil Water Assessment Tool or SWAT (Moriasi et al., 2012). The RUSLE is a model that can appropriately produce accurate results and easier to apply in some specific areas, such as mountainous tropical watershed (Millward & Mersey, 1999), in Mediterranian area Tunisia (Gaubi et al., 2017; Kefi et al., 2012), in Algeria (Benkadja et al., 2015), and in Morocco (Chadli, 2016). The calculation using RUSLE model mainly focused on rainfall or errosivity factor as the main variable and most important factor of erosion problem. Since the the RUSLE method using satellite images without in-situ field, the results will be depends on the quality and resolution of satellite images. Therefore to assess the accuracy, the result should be compared and validated with reliable field data and published literatures.

B. Methodology

The methodology for calculating soil erosion comprises the following:

1. DEM Generating from ALOS PALSAR with 12.5 m spatial resolution, obtained from Alaska Satellite Facility (ASF).
2. Collecting five soil erosion factors; R factor from rainfall data, K factor from Digital Soil Map of the World (DSMW) data, C factor from Landsat-8 satellite image, and P factor from DEM and references data.
3. Calculate soil erosion RUSLE model using raster calculator in ArcGIS software.
4. Morphometric parameters of the watershed extract using Archydro and morphometric toolbox.

Figure 5.2 shows the flow chart of soil erosion estimation using the RUSLE method in ArcGIS software. Some additional toolboxes used in this study are include Conversion to raster or polygon, Map reclassification, Composite bands, Cell statistics, and Inverse Distance Weighting (IDW).



Source: Author

Figure 5.2 Flowchart of the Soil Erosion Estimation Using the RUSLE Method

1. Soil Erosion Estimation

The RUSLE method can be expressed using the following equation:

$$A = R \times K \times LS \times P \times C \text{.......................(1)}$$

Where: A = Average soil loss (ton/ha/yr)

R = Rainfall erosivity factor (MJ mm/ha/hr/yr)

K = Soil erodibility factor (ton ha hr MJ/ha/mm)

LS = Topography factor (Slope length and steepness)

P = Conservation/anti erosive factor

C = Land cover management factor

1) Errosivity Factor (R)

Errosivity or R factor related to the rainfall energy. The longer the duration of rainfall, the higher the potency of erosion. The high-resolution annual rainfall data can be obtained from Climatic Research Unit data (Harris et al., 2020) then processed using composite band and cell statistics tools. The interpolation rainfall distribution is calculated using Inverse Distance Weighting (IDW) tools. The R factor can be obtained from rainfall data using Hurni's empirical equation (Hurni, 1985):

$$R = -8.12 + 0.562 \times P \qquad (2)$$

Where: P = annual rainfall (mm/year^{-1})

2) Errodibility Factor (K)

The soil erodibility or K factor is related to the lithology and soil quality that responds to the erosion. The K value ranges between 0 and 1, the smallest value indicates the soil is most susceptible to erosion. There are four elements that affected the K factor in this formula: soil structure and texture, the organic content, soil coarse fragments, and its permeability (Williams, 1995). K factor is calculated using the following equation:

$$K_{RUSLE} = f_{csand} \times f_{cl-silt} \times f_{organic} \times f_{hisand} \qquad (3)$$

Where : f_{csand} = coarse-sand contents factor
$f_{cl-silt}$ = clay to silt ratios factor
$f_{organic}$ = organic carbon content factor
f_{hisand} = sand contents factor

3) Length and Steepness Factor (LS)

The length and steepness (LS) factor are related to the topographic factor. The watershed with high LS will have high soil erosion. This study calculates LS using the equation from Moore and Burch (Moore & Burch, 1986):

$$LS = \left(\frac{Slope\ Length}{22.13}\right)^{0.4} \times \left(\frac{0.01745\ \sin(\theta)}{0.0896}\right)^{1.3} \times 1.6 \quad \text{........(4)}$$

Where: Slope length = flow accumulation multiply cell size (using GIS technique)

θ = slope degree

4) Cover Management Factor (C)

The C factor is related to land cover management. Vegetation has the great potency to protect the soil from erosion, control the energy of rainfall, and reduce the speed of rainfall and run-off, which can be known based on Normalized Difference Vegetation Index (NDVI) value. Bare land has zero NDVI, while vegetation has a value more than 0. The C factor can be estimated using Colman equation (Colman et al., 2018) while depends on NDVI value.

$$C\ factor = 0.1\left(\frac{-NDVI+1}{2}\right) \quad \text{........ (5)}$$

$$NDVI = \frac{NIR-IR}{NIR+IR} \quad \text{........(6)}$$

Near Infra-Red (NIR) for band 5 and Infra-Red (IR) for band 4 in Landsat image-8. NDVI is a dimensionless indicator and the value ranges from the minimum (-1.0) to the maximum (1.0). The NDVI with a negative value is for water, 0-0.1 value is for soil, and those with the value more than 0.1 is for vegetation.

5) Control Practices Factor (P)

The P factor is the ratio of soil loss with specific support practice. The control practices can reduce the potential of erosion by reducing the amount and velocity of run-off, modifying the flow pattern and direction of surface run-off (Renard et al., 1991). The value ranges of P factor are between 0 and 1. The various farming practices like crop rotation, contour farming, and shelterbelts can reduce soil erosion. In estimating the P factor, there are at least two assumptions. First, P factor can predicted by assuming the three-parameter of soil control are known: contouring, strip-cropping, and terracing, all of them refer to slope grades and their corresponding P factor values (Shin, 1999) as shown in Table 5.1. The second is P factor assumed as 1 for all watersheds in arid land area (Gaubi et al., 2017).

Table 5.1 P Factor Values based on the Slope Classes

Slope (%)	Conservation Support Practices (P factor)		
	Contouring	Strip Cropping	Terracing
0–0.7	0.55	0.27	0.10
7–11.3	0.60	0.30	0.12
11.3–17.6	0.80	0.40	0.16
17.6–26.8	0.90	0.45	0.18
>26.8	1	0.50	0.20

Source: Shin (1999)

2. Watershed Morphometric Parameter

Morphometric parameters have an important role in the hydrologic behavior of the watersheds (Elfeki et al., 2017). The morphometric parameters of the watershed include area, perimeter, elevation, watershed length, slope, stream order, infiltration number, bifurcation ratio, drainage texture, and drainage density. The morphometric parameters were calculated using several equations, like Horton-Strahler equations (Horton, 1945; Strahler, 1964).

1) The Drainage density (D) of the watershed is obtained by stream length divided by the area of the watershed, mainly in km/km2 units. The area with mountainous relief and impermeable subsurface have a high value of drainage density, and the area with low relief and permeable subsurface material has a low value of drainage density.
2) The drainage texture (Dt) is a parameter that depends on rainfall, soil type, vegetation, relief, and infiltration number. Dt has been classified into five groups: very fine (>8), fine (6–8), moderate (4–6), coarse (2–4), and very coarse (<2) (Smith, 1950).
3) Infiltration number is the output part of drainage density and stream frequency.
4) The bifurcation ratio (Rb) is the ratio between the number of streams of an order to the next order in a drainage network. High Rb values indicates the watershed controlled drainage pattern structurally, while the low values indicate less structural disturbance in drainage pattern.
5) Elongation ratio is defined as the ratio between the length of the watershed with its diameter (Schumm, 1956). The area with low relief and few structural influences has Re value close to 1.0, and the area with high relief and much steeper has values ranging from 0.8 to 0.6 (Strahler, 1964).

Table 5.2 The Morphometric Parameters of the Watershed with its Equation and References

Morphometric Parameters	Equation	References
Elevation (m)	H	GIS software
Watershed Area (km2)	A	GIS software
Watershed Perimeter (km)	P	GIS software
Longest Flow Path (km)	Lf	GIS software
Basin Length (km)	Bl	GIS software
Drainage Density (km/km2)	Dd = Lu/A	Horton (1945)
Drainage Texture	Dt = Dd * Fd	Smith (1950)

Morphometric Parameters	Equation	References
Bifurcation Ratio	Rb = Nu/(Nu+1)	Schumm (1956)
Infiltration Number	NF	Horton (1945)
Relief Ratio	Rr = R/L	Schumm (1956)
Elongation Ratio	Re =	Schumm (1956)
Circularity Ratio	Rc	
Compactness Coefficient	Cc =	Strahler (1964)

C. Conclusions

The RUSLE model has been proven as potential method for estimating soil erosion that supported by GIS software and satellite images data. Five natural factors were used as input for calculate soil loss. The area with high or severe risk needs further attention for mitigation purposes. This area has correlation with high and steep slope. This study can provide useful information of the soil erosion risk map and morphometric parameters and also can help land decision-makers to manage sustainable water resource and evaluate risk assessment of the watershed.

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