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IMPACT OF THE LS-FACTOR ESTIMATION METHODS ON MEAN ANNUAL SOIL LOSS

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Abstract

Soil erosion was assessed in Anambra State using three different LS factor estimation methods. It showed that soil loss from the LS factor based on the slope in percent gives a good result with little underestimation with a PBIAS of -9.04 % while that based on slopes in radians performed best with a slight overestimation with a PBIAS of 2.81 %. The one based on degrees' slope performed the least with a high underestimation with a PBIAS of -46.43 %. The result from field measurement yielded 27.76 t ha⁻¹yr⁻¹. The coefficient of variations was 241.47 %, 192.01 %, and 157.97 %, respectively, for slope in percent, radians and degree. Soil erosion is a highly variable phenomenon which was reflected by the high coefficient of variations. It shows that modelling soil erosion in the State with the LS factor estimation based on slopes in radians and percent yields better results. We believe this finding will be useful to authorities and scientists interested in soil erosion studies in the State. It is recommended that a similar study be extended to other terrains with moderate slopes.

Keywords

Soil Erosion, Soil Loss, LS-Factor, RUSLE, Nigeria, Slope

1. Introduction

Soil erosion by water is a principal cause of soil degradation in the humid tropics. It distorts soil fertility by washing away the rich topsoils and contributing to water pollution. The USLE model which was revised (RUSLE) is widely used for assessing erosion (Renard et al., 1997; Wischmeier & Smith, 1978).

It has become the most widely used model for soil erosion studies (Benavidez et al., 2018; Alewell et al., 2019). Other revised versions are RUSLE1 and RUSLE2. Its use has been extended to larger scales such as watersheds, a region, or the globe (Naipal et al., 2015; Panagos

et al., 2015). Its extension to a larger scale is associated with greater uncertainties. Also, its output is affected by the method employed to estimate the factors used in the model. One such factor that is very critical to the output of the model is the topographic (LS) factor. Some scholars argued that methods employing slope in percent are better for estimating the LS factor in moderate to very steep areas (Nakil & Khire, 2016). Others argue that the methods using slope in radians or degrees are more suited for regions with complex topography (Moore & Burch, 1986b; Andreoli, 2018; Demet & Govers, 1996; Benavidez et al., 2018). They contend that it accounts for the convergence and divergence of flows (Andreoli, 2018).

On this account, the study tested the effect of three (3) LS estimation methods each based on slopes in percent, radians, and degrees to understand their effect on mean annual soil loss in the area. The output of each was compared with the output from field measurement. This allowed us to understand the best-performing method for estimating the LS factor for the region. The study is necessary to guide scientists and stakeholders in the planning and management of soil erosion in Anambra State. Also, to the authors' best knowledge, this gap is yet to be filled in the area despite being a State highly ravaged by soil erosion.

2. Materials and Methods

The study covers Anambra State Nigeria. The location is shown in Figure 1. It has an Aw climate with much rain in the summer (June- Oct). Its rainy season spans 7 to 8 months.

The study used open source data comprising CHIRPS daily rainfall data at 0.05 ° resolution (2021-2022) (CHIRPS, 2022), soil data was obtained from Innovative Solutions for Decision Agriculture at 30 m resolution (iSDASoil, 2022), the Digital Elevation Model (DEM) data were obtained from ~~obtained from~~ the USGS Earthexplorer website (NASA, 2022; USGS, 2023). The landcover data were obtained from the ESRI website (Karra et al., 2021). It has 10 m spatial resolution. The data were used to estimate the five (5) key factors of the RUSLE model (eq. 1).

$$SL = R \times K \times LS \times C \times P \quad (1)$$

where SL is the mean annual soil erosion rate ($t \text{ ha}^{-1} \text{ yr}^{-1}$), R is the rainfall erosivity factor that accounts for the aggressiveness of rainfall ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$), K is the soil erodibility factor ($t \text{ ha h MJ}^{-1} \text{ mm}^{-1}$), LS is the topographic factor representing slope length and steepness, C is the cover management factor, and P is the conservation practices factor.

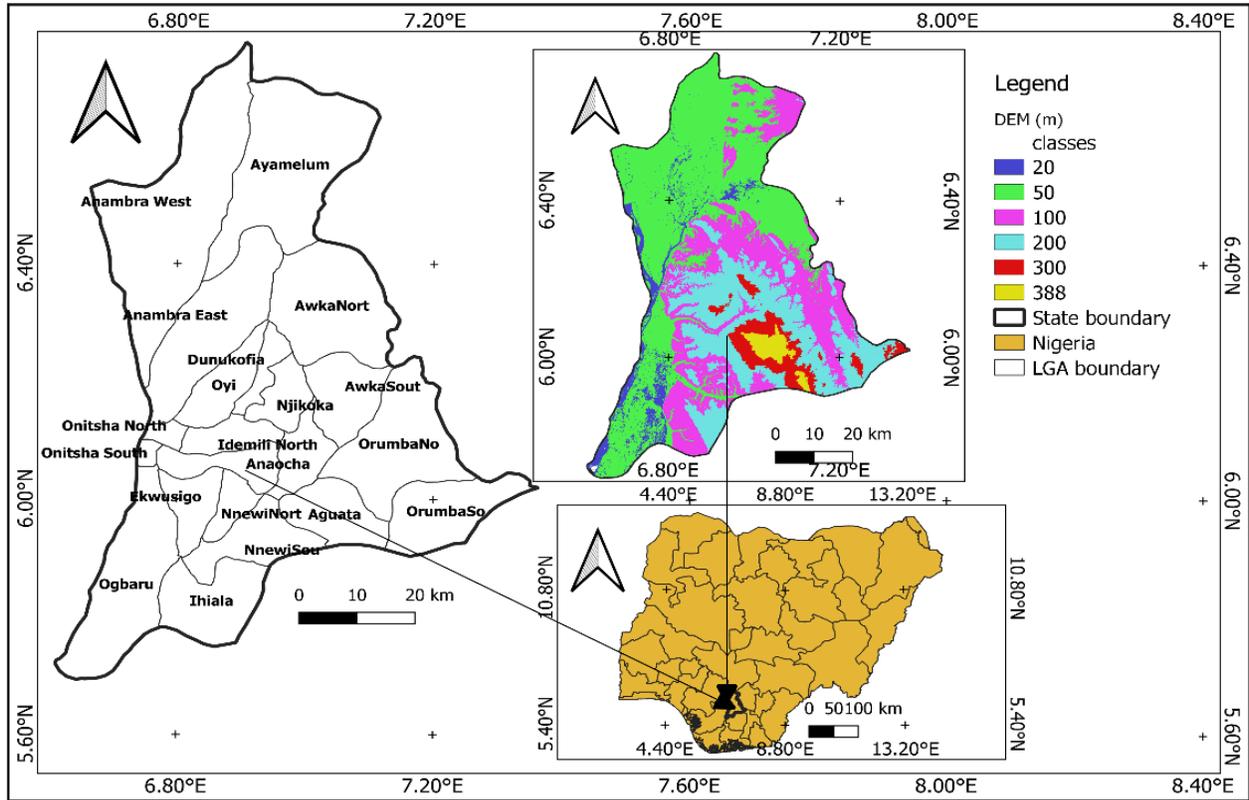


Figure 1: Map of Nigeria Showing Anambra State

(Source: Authors' Illustration)

The R factor describes the rain energy impact on soil loss. The higher the rain intensity and amount, the higher the erosion (Roose, 1977; Ziadat & Taimeh, 2013). The Roose (1977) method was used (eq. 2).

$$R = 0.05 \times AR \times a \quad (2)$$

where R is erosivity, AR is mean annual rainfall, a = 1.73

The K factor was estimated with a widely used method in the tropics (eq. 3) (Tsige et al., 2022).

$$K = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand} \quad (3)$$

where

$$f_{csand} = 0.2 + 0.3 \exp \left[-0.256 m_s \left(1 - \frac{m_{silt}}{100} \right) \right] \quad (4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c - m_{silt}} \right)^{0.3} \quad (5)$$

$$f_{orgC} = 1 - \frac{0.25 \times orgC}{orgC + \exp[3.72 - 2.95orgC]} \quad (6)$$

$$f_{hisand} = 1 - \frac{0.7 \left(1 - \frac{m_s}{100} \right)}{1 - \frac{m_s}{100} + \exp \left[-5.51 + 22.9 \left(1 - \frac{m_s}{100} \right) \right]} \quad (7)$$

where K is the soil erodibility in $t\ ha\ h(MJ\ ha\ mm)^{-1}$, f_{csand} is the fraction of coarse sand, f_{cl-si} is the fraction of clay minus silt, f_{orgC} is the fraction of organic carbon, and f_{hisand} is the fraction of fine sand.

The LS factor is estimated by a method using slope in percent (eq.8) (Wischmeier & Smith, 1978) herein denoted with WS, radians (eq. 9) (Moore & Burch, 1986a) herein denoted with MB, and degree (eq. 10) (Desmet & Govers, 1996; Panagos et al., 2015) denoted with DG.

$$LS = \left(\frac{\lambda}{22.13} \right)^m \times (0.065 + 0.045s + 0.0065s^2) \quad (8)$$

where LS is a dimensionless factor representing slope length and steepness, m is the parameter of slope varying from 0.2 to 0.5 depending on steepness, and s is the slope in percent.

$$LS = \left(\frac{\lambda}{22.13} \right)^m \times \left(\frac{\sin\beta}{0.0896} \right)^n \quad (9)$$

where $m = 0.4$ (ranges from 0.4-0.6), $n = 1.3$ (ranges from 1.22-1.3 depending on steepness). λ is flow accumulation multiplied by the cell size of the DEM, β is the slope in radians.

$$L_{i,j} = \frac{(A_{i,j-in} + D^2)^{m+1} - A_{i,j-in}^{m+1}}{D^{m+2} \times x_{i,j}^m \times 22.13^m} \quad (10)$$

where $A_{i,j-in}$ in metres square represents the grid cell's contributing area at its inlet (i,j). D is the area of the grid cell (m), $X_{i,j} = \sin a_{i,j} + \cos a_{i,j}$, and the $a_{i,j}$ is the aspect direction of the grid cell (i,j). m is associated with the ratio of rill to interrill erosion on a landscape, thus:

$$m = \frac{\beta}{\beta+1} \quad (11)$$

where

$$\beta = \frac{\frac{\sin \theta}{0.0896}}{[0.56+3 \times (\sin \theta)^{0.8}]} \quad (12)$$

θ is the slope gradient in degrees. m is between 0 and 1. It decreases as the ratio of rill to interrill decreases such that it is close to 0 as the ratio gets nearer to 0. According to Desmet & Govers (1997), this technique is suitable for complex topography, though it has been criticized by Mitsova et al (1996).

The C factor was estimated by value assignment from tables from existing research in a similar environment. Thus, shrub was assigned 0.015, agriculture 0.38, water 0.00, barren land 1.00, forest 0.08, and settlement 0.8 (Wischmeier & Smith, 1978; Koirala et al., 2019; Moisa et al., 2021; Egbueri et al., 2022; Merchán et al., 2023). The P factor was assigned 1 due to the unavailability of data on conservation practices in the area.

3. Results and Discussion

The estimated soil losses (Figure 2) with the LS methods were 25.25 t ha⁻¹yr⁻¹ (WS), 28.54 t ha⁻¹yr⁻¹ (MB), 14.87 t ha⁻¹yr⁻¹ (DG), and 27.76 t ha⁻¹yr⁻¹ (field). It shows that the PBIAS was -9.04 %, 2.81 %, and -46.43 %. Following, Moriasi et al. (2007) recommendation, all the models can be used for soil loss prediction, however, the WS and MB performed best and are recommended for soil loss prediction in the State.

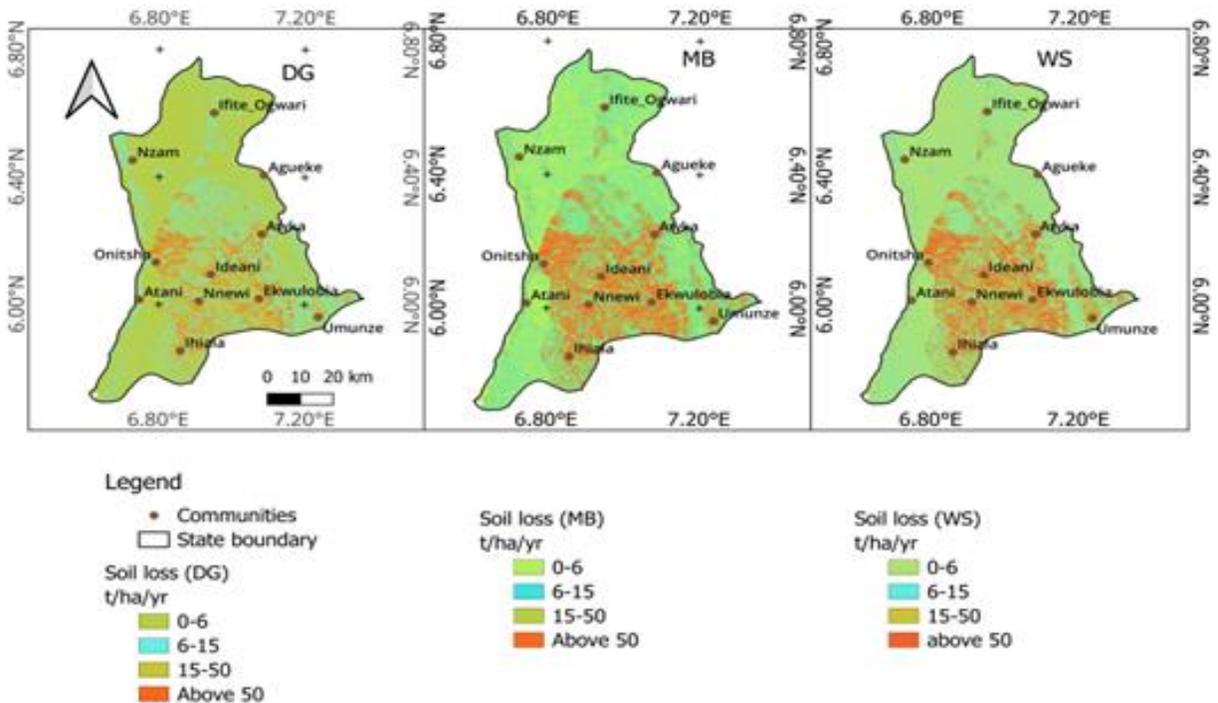


Figure 2: Estimated Soil Loss in Anambra State

(Source: Authors' Illustration)

The LGAs where soil loss was above $40 \text{ t ha}^{-1}\text{yr}^{-1}$ are Aguata, Anaocha, Awka South, Idemili North, Idemili South, Njikoka, Nnewi North and South, Onitsha North, and Oyi LGAs.

These are all areas with notable gullies in the State. This was confirmed via fieldwork. This showed that though, the model does not account for gullies, areas of extreme soil loss above $40 \text{ t ha}^{-1}\text{yr}^{-1}$ are also areas of intense gully erosion in the State. This is in line with Andreoli (2018) that sheet and rill erosion are theoretically within the range of 0 to $5 \text{ t ha}^{-1}\text{yr}^{-1}$ while areas with gullies can be high reaching $1000 \text{ t ha}^{-1}\text{yr}^{-1}$. Based on this, the MB model highlighted all the LGA where large gullies exist while the WS omitted Onitsha North as it had only $37.56 \text{ t ha}^{-1}\text{yr}^{-1}$. The DG method underestimated all the areas as none of the LGA had soil loss up to $40 \text{ t ha}^{-1}\text{yr}^{-1}$. Therefore, the three (3) different methods of estimating the LS method highlighted areas of high erosion risks but the DG method underestimated the extent of soil loss in the State. Also, t-test result showed that there is a significant difference between the estimated mean annual soil erosion rate loss using the WS or MB method and the DG method ($p\text{-value} = 0.0003/0.002$). The null hypothesis for the test between the WS and the MB method at 0.05 confidence level ($p\text{-value} = 0.23$) was not rejected due to insufficient evidence, unlike when the DG method is compared with

either WS or MB method. Thus, the MB and WS methods performed best in predicting soil erosion in Anambra State. Hence, in erosion studies over Anambra State, the WS or the MB method is recommended. Thus in line with the recommendation for its use (Benavidez et al. 2018; Desmet & Govers, 1996), it shows that the DG method is not very suitable for less complex terrains like Anambra State.

4. Conclusion

Soil erosion prediction using the RUSLE model was carried out in Anambra State, Nigeria using three (3) different methods of LS factor estimation. The result indicates that soil erosion is a severe problem of soil degradation in the area. Also, it shows that the mean annual soil erosion rate in the State was 25–29 t ha⁻¹yr⁻¹ with variations as erosion is severer in the central and southern parts than the northern and western parts. The DG method of LS estimation underperformed in predicting soil loss in the State, unlike the MB and WS methods. Therefore, soil erosion in the Anambra State is best estimated in the RUSLE model using the MB and WS methods of LS estimation. Thus, for moderate topographies like the Anambra State's terrain, the WS and MB methods of estimating the LS-factor perform better than the DG method in soil erosion modelling using the RUSLE model.

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