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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 $ha^{-1}yr^{-1}$. 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 ^{o} 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).

$$\mathrm{SL} = R \times K \times \mathrm{LS} \times C \times P \qquad (1)$$

where SL is the mean annual soil erosion rate (t ha^{-1} yr^{-1}), R is the rainfall erosivity factor that accounts for the aggressiveness of rainfall (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility factor (t ha h MJ^{-1} 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.

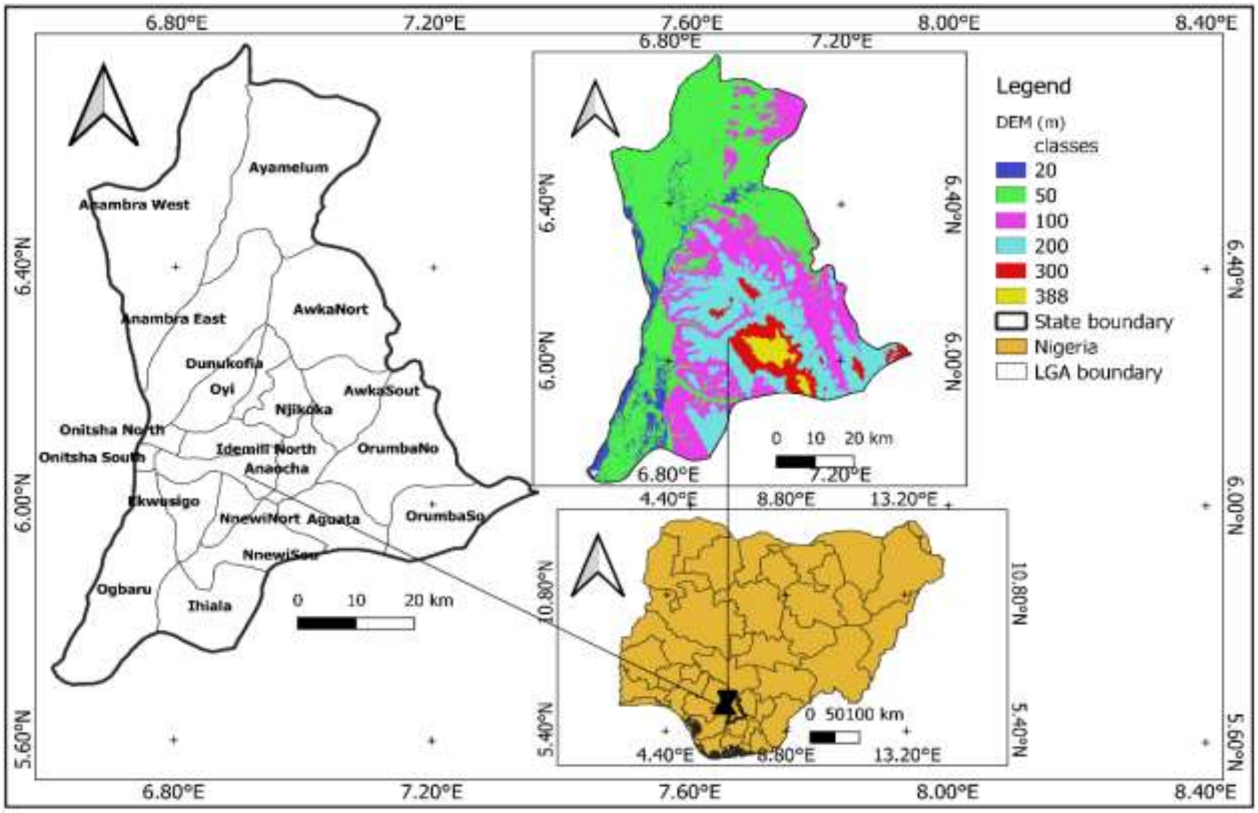

Figure 1: *Map of Nigeria Showing Anambra State*

(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).

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

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).

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

where

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

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

$$f_{orgC} = 1 - \frac{0.25 \times orgC}{orgC + \exp\left[3.72 - 2.95 orgC\right]} \tag{6}$$

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

where K is the soil erodibility in t ha h(MJ ha mm)$^{-1}$, f_{csand} is the fraction of coarse sand, $f_{cl\text{-}si}$ 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.

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

where LS is a dimensionless factor representing slope length and steepness, m is the parameter of slope varying from o.2 to 0.5 depending on steepness, and s is the slope in percent.

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

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.

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

where $A_{i,j-\text{in}}$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 interill erosion on a landscape, thus:

$$m = \frac{\beta}{\beta+1} \tag{11}$$

where

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

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 Mitasova 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 $ha^{-1}yr^{-1}$ (WS), 28.54 t $ha^{-1}yr^{-1}$ (MB), 14.87 t $ha^{-1}yr^{-1}$ (DG), and 27.76 t $ha^{-1}yr^{-1}$ (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.

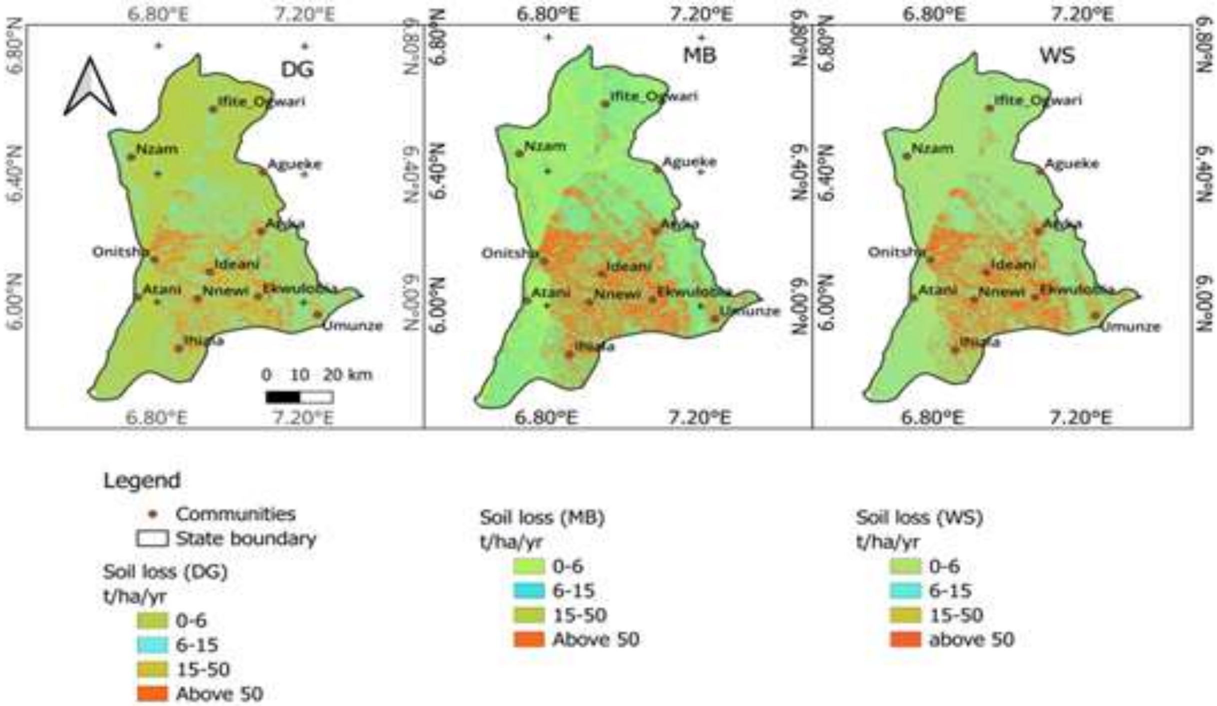

Figure 2: *Estimated Soil Loss in Anambra State*

(Source: Authors' Illustration)

The LGAs where soil loss was above 40 t $ha^{-1}yr^{-1}$ 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 t $ha^{-1}yr^{-1}$ 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 t $ha^{-1}yr^{-1}$ while areas with gullies can be high reaching 1000 t $ha^{-1}yr^{-1}$. 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 t $ha^{-1}yr^{-1}$. The DG method underestimated all the areas as none of the LGA had soil loss up to 40 t $ha^{-1}yr^{-1}$. 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-value = 0.0003/0.002). The null hypothesis for the test between the WS and the MB method at 0.05 confidence level (p-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 $ha^{-1}yr^{-1}$ 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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REFERENCES

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, 7(3), 203–225. https://doi.org/10.1016/j.iswcr.2019.05.004

Andreoli, R. (2018). Modeling erosion risk using the RUSLE equation. QGIS and Applications in Water and Risks, 4, 245–282. https://doi.org/10.1002/9781119476726.ch8

Benavidez, R., Jackson, B., Maxwell, D., & Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R) USLE): With a view to increasing its global applicability and improving soil loss estimates. Hydrology and Earth System Sciences, 22(11), 6059–6086. https://doi.org/10.5194/hess-22-6059-2018

CHIRPS. (2022). Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) daily rainfall data (2022nd ed.) [Map]. USGS. https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_DAILY

Desmet, P. J. J., & Govers, G. (1996). A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation, 51(5), 427–433. https://www.researchgate.net/publication/233425999_A_GIS_procedure_for_automatically_calculating_the_USLE_LS_factor_on_topographically_complex_landscape_units

Desmet, P. J. J., & Govers, G. (1997). Comment on'Modelling topographic potential for erosion and deposition using GIS'. International Journal of Geographical Information Science, 11(6), 603–610. https://doi.org/10.1080/136588197242211

Egbueri, J. C., Igwe, O., & Ifediegwu, S. I. (2022). Erosion risk mapping of Anambra State in southeastern Nigeria: Soil loss estimation by RUSLE model and geoinformatics. Bulletin of Engineering Geology and the Environment, 81(3), 91. https://doi.org/10.1007/s10064-022-02589-z

iSDASoil. (2022). Innovative Solutions for Decision Agriculture (iSDA), 30 m resolution soil map of Africa. (2nd ed.) [Map]. https://www.isda-africa.com/isdasoil/developer/

Karra, K., Kontgis, C., Statman-Weil, Z., Mazzariello, J. C., Mathis, M., & Brumby, S. P. (2021). Global land use/land cover with Sentinel 2 and deep learning. 2021 IEEE

International Geoscience and Remote Sensing Symposium IGARSS, 4704–4707. https://doi.org/10.1109/IGARSS47720.2021.9553499

Koirala, P., Thakuri, S., Joshi, S., & Chauhan, R. (2019). Estimation of soil erosion in Nepal using a RUSLE modeling and geospatial tool. Geosciences, 9(4), 147. https://doi.org/10.3390/geosciences9040147

Merchán, L., Martínez-Graña, A. M., Alonso Rojo, P., & Criado, M. (2023). Water Erosion Risk Analysis in the Arribes del Duero Natural Park (Spain) Using RUSLE and GIS Techniques. Sustainability, 15(2), 1627. https://doi.org/10.3390/su15021627

Mitasova, H., Hofierka, J., Zlocha, M., & Iverson, L. R. (1996). Modelling topographic potential for erosion and deposition using GIS. International Journal of Geographical Information Systems, 10(5), 629–641. https://doi.org/10.1080/02693799608902101

Moisa, M. B., Negash, D. A., Merga, B. B., & Gemeda, D. O. (2021). Impact of land-use and land-cover change on soil erosion using the RUSLE model and the geographic information system: A case of Temeji watershed, Western Ethiopia. Journal of Water and Climate Change, 12(7), 3404–3420. https://doi.org/10.2166/wcc.2021.131

Moore, I. D., & Burch, G. J. (1986a). Modelling erosion and deposition: Topographic effects. Transactions of the ASAE, 29(6), 1624–1630. https://doi.org/10.13031/2013.30363

Moore, I. D., & Burch, G. J. (1986b). Physical basis of the length-slope factor in the universal soil loss equation. Soil Science Society of America Journal, 50(5), 1294–1298. https://doi.org/10.2136/sssaj1986.03615995005000050042x

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885–900. https://doi.org/10.13031/2013.23153

Naipal, V., Reick, C., Pongratz, J., & Van Oost, K. (2015). Improving the global applicability of the RUSLE model–adjustment of the topographical and rainfall erosivity factors. Geoscientific Model Development, 8(9), 2893–2913. https://doi.org/10.5194/gmd-8-2893-2015

Nakil, M., & Khire, M. (2016). Effect of slope steepness parameter computations on soil loss estimation: Review of methods using GIS. Geocarto International, 31(10), 1078–1093. https://doi.org/10.1080/10106049.2015.1120349

NASA. (2022). Shuttle Radar Topographic Mission (SRTM) 30 m Digital Elevation Model (DEM) [Tiff]. https://dwtkns.com/srtm30m/

Panagos, P., Borrelli, P., & Meusburger, K. (2015). A new European slope length and steepness factor (LS-Factor) for modeling soil erosion by water. Geosciences, 5(2), 117–126. https://doi.org/10.3390/geosciences5020117

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook, 703, 407. https://www.ars.usda.gov/arsuserfiles/64080530/rusle/ah_703.pdf

Roose, E. J. (1977). Use of the universal soil loss equation to predict erosion in West Africa. In Soil erosion: Prediction and control (Vol. 21, pp. 60–74). Soil Conservation Society of America Ankeny, IA. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_5/b_fdi_08-09/09135.pdf

Tsige, M. G., Malcherek, A., & Seleshi, Y. (2022). Improving the Modified Universal Soil Loss Equation by Physical Interpretation of Its Factors. Water, 14(9), 1450. https://doi.org/10.3390/w14091450

USGS. (2023). The United States Geological Survey (USGS) 30 m resolution Landsat 7 and 8 images [Map]. https://earthexplorer.usgs.gov/

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. Department of Agriculture, Science and Education Administration. https://www.researchgate.net/profile/Heriansyah-Putra-2/post/Which-formula-is-correct/attachment/59d64d4e79197b80779a6e2c/AS%3A487650378424321%401493276318482/download/USLE.pdf

Ziadat, F. M., & Taimeh, A. Y. (2013). Effect of rainfall intensity, slope, land use and antecedent soil moisture on soil erosion in an arid environment. Land Degradation & Development, 24(6), 582–590. https://doi.org/10.1002/ldr.2239