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Integration of RUSLE Model with Remote Sensing and GIS Tools for Soil Loss Estimation in the Kubanni Drainage Basin, Zaria, Nigeria

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Abstract

The prevalence of unwholesome land use practices and population pressure exacerbates soil loss which is worsening the problem of sedimentation of the Kubanni dam. This study was conducted at the Kubanni drainage basin covering a spatial area of 56.7 Km^2 in Samaru, Zaria, Nigeria to estimate annual soil loss using the RUSLE model. Satellite images of Landsat OLI for December 2014, 2016, 2018, February, July and November 2022; soil data, rainfall data from 2010 to 2022, and DEM of 30-meter resolution were utilized for the study. All factors of the RUSLE model were calculated for the basin using assembled data. The erosivity (R-factor) was discovered to be 553.437 $\text{MJ}\cdot\text{mm}\cdot\text{ha}^{-1}\cdot\text{h}^{-1}\cdot\text{yr}^{-1}$. The average erodibility (K-factor) value was 0.1 $\text{Mg}\cdot\text{h}\cdot\text{h}\cdot\text{ha}^{-1}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1}\cdot\text{yr}^{-1}$. The Slope Length and Steepness factor (LS-factor) in the basin ranged between 0% and 13.47%. The Crop Management Factor (C-factor) values were obtained from a rescaling of the NDVI values derived for the study area and ranged from 0.26 to 0.55. Support practice (P-factors) were computed from the prevalent tillage practice in the basin and ranged from 0.27 to 0.40. The soil loss amount for the Kubanni basin was found to be 28441.482 $\text{tons}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$, while the annual soil loss for the entire Kubanni drainage basin was found to be 49780.257 $\text{tons}\cdot\text{yr}^{-1}$. The study has demonstrated the viability of coupling RUSLE model and Remote Sensing and Geographic Information System (GIS) techniques for the estimation of soil loss in the Kubanni drainage basin.

Keywords

Soil Loss, Watershed, Erosivity (R-Factor), Erodibility (K-Factor), Cover Management Factor (C-Factor), Slope Length and Steepness Factor (LS-Factor), Support Practice Factor (P-Factor)

1. Introduction

Soil erosion from fluvial processes causes soil removal and sediment generation which engenders sedimentation of water courses and dams. It is a natural process that exacerbates land degradation, loss of soil fertility, and siltation of impoundment reservoirs, thereby diminishing crop yield, depreciating the safety and storage capacity of the dams and compounding soil conservation and environmental management problems (Anees et al., 2018; Wang et al., 2018). Despite its uniqueness as a physical feature of geomorphologic and hydrologic significance, the drainage basin is beset with environmental challenges such as soil loss. Horton (1932), recognized the drainage basin as a fundamental geomorphological unit which is frequently used as the primary landscape unit for hydrological, water supply and ecological investigations and for land management activities. The watershed plays a dominant role in the development of landforms and therefore, the study of drainage basin has a great significance in geomorphological studies (Rahaman et al., 2015). Given its disposition as a fluvial cum geomorphologic entity, the drainage basin is thus a fundamental unit upon which soil loss investigations can be based. Soil erosion assessment for sustainable development of watershed is a world-wide concern for landuse planners (Balasubramani et al., 2015). The impact of rainfall on a drainage basin triggers processes which result in channel erosion and soil loss. The abuse of the drainage basin/watershed landscape by anthropogenic interference promotes degradation which aggravates soil erosion and soil loss, thereby accelerating sedimentation of water courses and impoundment reservoirs. Soil loss is facilitated by the composite influences of climatic and physiographic factors. The climatic factors which affect soil loss include rainfall intensity, rainfall duration, rainfall distribution and direction of prevailing wind in a drainage basin. In the same vein, the physiographic factors which influence surface runoff are size, shape, slope of drainage basin, land use and soil type. Since watershed forms a natural boundary to focus on all the effects of downhill runoff such as soil loss and sediment yield, a systematic assessment of soil erosion within the watershed would provide reliable information to draw strategies for sustainable development of watershed resources (Balasubramani, et al., 2015). Drainage basin studies which aim at ensuring sustainable management and development of drainage basin resources have attracted the attention of researchers (Yildirim & Erkal, 2013; Kamaludin et al., 2013; De Carvalho et al., 2014; Kumar et al., 2014; Biswas & Pani, 2015; Ezenwa et al., 2022a; Ezenwa et al., 2022b; Ahmad et al., 2024). Many models and methods have been employed to assess soil erosion in watersheds (Ezenwa et al., 2023). These models vary from simple to complex and differ in their need for data input and their ability to predict soil erosion by water (Chadli, 2016). For instance, the work of Iguisi (1996) on soil loss investigations using USLE model focused on only two sub basins of the Kubanni drainage basin near Zaria, Nigeria, whereas the Kubanni drainage basin is made up of four sub basins namely: Goruba, Maigamo, Tukurwa and Malmo sub basins (Ezenwa et al., 2022a; Ezenwa et al., 2022b; Ezenwa et al., 2023). The curiosity therefore is whether the findings of Iguisi (1996) can be extrapolated to represent soil loss profile of the entire Kubanni basin. The idea of using Iguisi (1996) soil loss findings as being representative enough for the entire Kubanni drainage basin is alien to the culture of empiricism of scientific investigations. Thus, in line with the requirements of a scientific inquiry which is empiricism, it is important to investigate soil loss profile of the entire Kubanni basin as a precursor to effective management of the resources incumbent in the Kubanni drainage basin. Besides, the utilization of a more recent data to investigate soil loss in the basin will provide a more up to date soil loss status of the Kubanni drainage basin. Although significant success has been recorded in the geospatial implementation of the RUSLE model for soil loss estimation in other study areas in Nigeria (Fagbohun et al., 2016; Thlakma et al., 2018; Olorunfemi et al., 2020), the applicability and viability or otherwise of RUSLE model cannot be ascertained for the Kubanni drainage basin as there is no empirical study to arrive at that judgement. This study will therefore resolve the curiosity and uncertainty surrounding the applicability and viability or otherwise of utilizing geospatial tools in the implementation of RUSLE model for soil loss estimation in the Kubanni drainage basin.

1.1. Study Objective

The goal of this study is to estimate the amount of annual soil loss in the Kubanni drainage basin using the RUSLE model. The achievement of this goal entails determining in GIS environment the Erosivity factor (R-Factor), erodibility factor (K-Factor), Cover Management Factor (C-Factor), slope length and steepness factor (LS-Factor), and Support Practice Factor (P-Factor) for the Kubanni drainage basin.

1.2. The Study Area

The study site is situated in the Kubanni drainage basin in Zaria and occupies an area of landscape defined by Latitudes 11˚05′30″ N to 11˚10′30″ N and Longitudes 7˚35′15″ to 7˚38′45″E. Taking its source from Kampaji Hill in Shika, near Zaria, Kubanni river dissects the study site and flows in a southeast direction through Ahmadu Bello University Main Campus, Samaru to empty into an impoundment reservoir—the Kubanni dam. The map of the study area is shown in (**Figure 1**).

Geologically, Zaria is underlain by differential pre-cambrian basement complex formation which comprises igneous and metamorphic rocks (Wright & Mc Curry, 1970). The study site which is the upper Kubanni is developed on the old granite while the downstream of the dam, the channel is incised into superficial materials and deeply weathered gneiss (Ololobou, 1982). With the summits of the residual hills of Kufena and Kampaji at 820 m and 708 m respectively above sea level, the Kubanni drainage basin which is our study area is characteristically enmeshed between these two prominent landmark features (Iguisi, 1996). The drainage system of the Kubanni river traces four tributaries upstream of the Kubanni impoundment reservoir which is located at Ahmadu Bello University main campus, Samaru, Zaria. The Kubanni drainage basin landscape and its network is shown in **Figure 1**. From the perspective of geomorphology, Zaria landscape is characterized by thorough and deep chemical weathering which has developed thick lateritic regolith of varying degrees of induration (Bello, 1973). The study area is characterized by strong seasonality in rainfall and temperature distributions (Oladipo, 1985). Seasonality in climatic conditions is caused by the oscillation over the study area of two air masses, the Maritime Tropical Air Mass (MTS) and the Continental Tropical Air Mass (CTS). The natural vegetation of the study area belongs to the northern Guinea savanna type which has been altered by human activities such as deforestation, construction, overgrazing, amongst others (Aminu & Jaiyeoba, 2015). The dominant tree species found in the Zaria region are the *Isoberlinia doka, Terminalia avicennioides, Stereospermum kunthianum, Nauclea latifolia, Annona senegalensis and Dichrostachys cinerea* (Jackson, 1970). Most of the soils have a sandy loam texture (Jaiyeoba, 1995). The soil of the Kubanni drainage basin – our study area is mainly sandy-clayey-loam with poor infiltration capacity because of the high clay content (Iguisi, 1997).

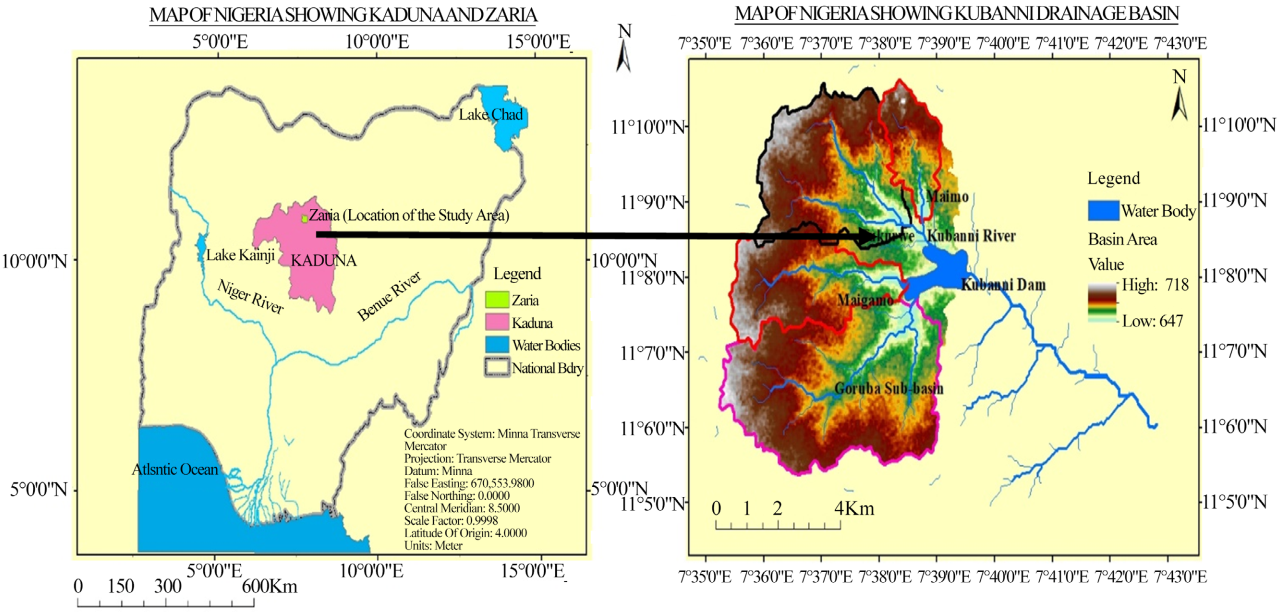

Figure 1. Kubanni drainage basin in Zaria Kaduna State, Nigeria.

2. Study Methods

The data utilized for soil loss estimation in the Kubanni drainge basin were obtained from both primary and secondary sources. Rainfall data of 13 years' period (2010-2022) were obtained from the Institute of Agricultural Research, Ahmadu Bello University, Zaria. Soil data for the study was obtained from results of laboratory test conducted on soil samples obtained from the study site. The soil samples were obtained with soil auger at intervals of 1000 meters in the study area. The secondary data were obtained from: 1) Landsat OLI images (189/82) of December

2014, December 2016, December 2018, February, July and November 2022. 2) Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with a spatial resolution of 30 m. The data were processed using the maximum likelihood classification technique of supervised image classification. The average soil loss (A) in the Kubanni drainage basin per unit area per year (ton·ha^{-1}·yr^{-1}) was quantified using the RUSLE model in GIS environment. The RUSLE is a model devised by (Wischmeier & Smith, 1978) is expressed as follows:

$$A = R \times K \times LS \times C \times P \tag{1}$$

where, A is the computed average soil loss over a period selected for R, usually on yearly basis (ton·ha^{-1}·yr^{-1}); R is the rainfall-runoff erosivity factor (MJ·mm·ha^{-1}·h^{-1}·yr^{-1}); K is the soil erodibility factor (Mg·h·MJ^{-1}·mm^{-1}); LS is the slope length (L) and slope gradient (S) factor (dimensionless); C is the crop management factor (dimensionless, ranging between 0 and 0.5); and P is the support practice factor (dimensionless, ranging between 0 and 1). The quantitative evaluation of soil loss by RUSLE is based on its component factors corresponding to each of the parameters of the equation. In this study, GIS plays a major role in the preparation of the thematic layers related to the estimation of the soil loss in the Kubanni drainage basin.

2.1. Rainfall Erosivity (R-Factor)

The R-factor is the total storm energy (E) times the maximum 30-min intensity (I_{30}) denoted as EI usually expressed as the rainfall erosion index (Renard et al., 1997). The R-factor is usually computed in accordance with (Wischmeier & Smith, 1978). Rainfall intensity for a particular increment of rainfall event (i_r) is usually computed using the relation:

$$i_r = \frac{\Delta V_r}{\Delta t_r} \tag{2}$$

where Δt_r is duration of the increment over which rainfall intensity is usually considered to be constant in hours (h), ΔV_r equals depth of rain falling (mm) during the increment. Rainfall energy per unit depth of rainfall e_r is usually computed using the relation:

$$e_r = 0.29\left[1 - 0.72\exp\left(-0.05 i_r\right)\right] \tag{3}$$

where e_r has units of megajoules per hectare per millimeter of rain (MJ·ha^{-1}·mm^{-1}), and i_r is rainfall intensity (mm·h^{-1}) (Brown & Foster, 1987). The total storm kinetic energy (E) was computed using the relation:

$$E = \sum_{r=1}^{m} e_r \Delta V_r \tag{4}$$

where e_r is the rainfall energy per unit depth of rainfall per unit area in megajoules per hectare per millimeter (MJ·ha^{-1}·mm^{-1}), and ΔV_r is the depth of rainfall in millimeters (mm) for the rth increment of the storm (Brown & Foster, 1987). The average annual rainfall and runoff erosivity factor (R) (MJ·ha^{-1}·mm^{-1}·yr^{-1}) is the average of the (EI) computed values. The R-Factor is mathematically defined as:

$$R=\frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)_k\,(I_{30})_k\right]_j \tag{5}$$

where E is the total storm kinetic energy (MJ·ha^{-1}), I_{30} is the maximum 30 min rainfall intensity (mm·ha^{-1}), j is the index of the number of years used to obtain the average, k is an index of the number of storms in each year, n is the number of years used to obtain the average (R) and m is the number of storms in each year (Renard & Freidmund, 1994). At the study site, daily rainfall totals for 13 years (2010-2022) were collected by the Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria without in-situ rain gages. A relationship which was developed by (Roose, 1976) was applied to determine the R-factor. Thus, the R-factor for the Kubanni drainage basin landscape was computed using the relation:

$$R=\left(0.5\pm0.05\right)P \tag{6}$$

where (P) is average annual rainfall records in millimeters. This R-factor value was then integrated into the RUSLE model in GIS domain to estimate annual soil loss for the Kubanni drainage basin catchment.

2.2. Soil Erodibility (K-Factor)

Soil Erodibility K-factor was obtained using relevant soil properties in accordance with the procedure outlined by El-Swaify and Dangler (1976) for tropical soils. The procedure uses the benchmark of percent-modified silt (0.002 - 0.1 mm), percent modified sand (0.1 - 2 mm), base saturation, percent unstable aggregates, and percent very fine sand. The units of the determined K-factor was quoted in ton acre h [hundreds of acre ft tonf in]$^{-1}$. The result was therefore divided by 7.59 to obtain the equivalent value in SI units of Mg h MJ^{-1}·mm^{-1} (Renard et al., 1997). The values obtained from the measured soil properties were used to determine K-factor using the following equation:

$$\begin{aligned}K=&-0.03970+0.00311X_1+0.00043X_2+0.00185X_3\\&+0.00258X_4+0.00823X_5\end{aligned} \tag{7}$$

where X_1 is percent unstable aggregates < 0.250 mm, X_2 is the product of the percent of silt (0.002 - 0.01 mm) and sand (0.1 - 2 mm) present in the sample, X_3 is percent base saturation of the soil, X_4 is percent silt present (0.002 - 0.050 mm), and X_5 is percent sand in the soil (0.1 - 2 mm). The percent organic carbon (OC) was determined following the modified Walkley-Black method, a procedure described in extant literature (Anderson & Ingram, 1993). The Cation Exchange Capacity (CEC) was determined following the ammonium saturation method which is a procedures described by (Anderson & Ingram, 1993). Percentage sand, silt and clay content in the soil and particle size distribution were determined by the Bouyoucas hydrometer method (Bouyoucos, 1962). The K-factor values were subsequently divided by 7.59 to obtain the equivalent value in SI units of Mg·h·MJ^{-1}·mm^{-1} (Renard et al., 1997).

2.3. Slope Length and Steepness (LS-Factor)

The LS-factor is one of the factor in the RUSLE model which compiles the influence of topography on soil loss RUSLE model. The combined slope length and slope steepness factors in RUSLE represent the ratio of soil loss on a given slope length and steepness to soil loss from a slope that has a slope length of 72.6 feet and a steepness of 9% where all other conditions are the same (McCool et al., 1987). The LS-factor for the Kubanni drainage basin was extracted from DEM with ArcHydro tool within ArcGIS 10.1 environment. The GIS operation returned raster derivatives such as flow direction, flow accumulation and slope map which were used as input data for the generation of LS-factor raster map. The LS-factor for the Kubanni drainage basin landscape was computed in line with Morgan (2005). The computation of the LS-factor followed the relation:

$$LS = \left(\frac{x}{22.13}\right)^n \left(0.065 + 0.045S + 0.0065S^2\right) \tag{8}$$

where x is the slope length (m) and s is the slope gradient in percent and n is the slope length exponent. The value of n was varied in accordance with the steepness of the slope. Values were assigned to represent slope length exponent in commensurate measure to the degree of steepness of a given slope as indicated by (Wischmeier & Smith, 1978). The map algebra which is a function of the Spatial Analyst tool in ArcGIS 10.1 was used in the implementation of the formula for the LS-factor computation.

2.4. Cover Management Factor (C-Factor)

The C-factor which represents the effect of plants, ground cover, soil biomass, and soil disturbing activities on erosion (Renard et al., 1997) expresses the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled, continuous fallow condition (Wischmeier & Smith, 1978; Risse et al., 1993). The C-factor for the Kubanni drainage basin was obtained from Landsat image scenes of the study area. The C-factor values of the land use classes were extracted from the Landsat satellite images using the relation for the NDVI which is expressed by the relationship:

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{9}$$

where NIR is surface spectral reflectance in the near infrared band and RED is surface spectral in the infrared band. In accordance with Durigon et al. (2014), the extraction of C-factor for the Kubanni basin landscape was based on NDVI rescaling method suitable for application in tropical regions. Thus, Durigon et al. (2014) proposed the relation below which was adopted for the determination of C-factor in our study area.

$$C_D = \frac{-\text{NDVI} + 1}{2} \tag{10}$$

A C-factor raster map of the study area was created from GIS operations integrating the C-factor values and classified raster images of the Kubanni drainage basin. The raster images were classified using maximum likelihood classification technique and depicting five land use classes.

2.5. Support Practice Factor (P-Factor)

The support practice factor embodies all the soil erosion management attributes prevalent in the Kubanni drainage basin landscape. It represents the effects of those practices such as contouring, strip cropping, terracing, etc. that contribute to the prevention of soil from eroding by reducing the rate of water runoff (Parveen & Kumar, 2012). The P-factor for the landscape of the study area was determined cognizant of the prevalence of strip cropping farming practice in the Kubanni basin landscape and slope (Shin, 1999). The flowchart of the RUSLE model implementation in GIS environment is shown in Figure 2.

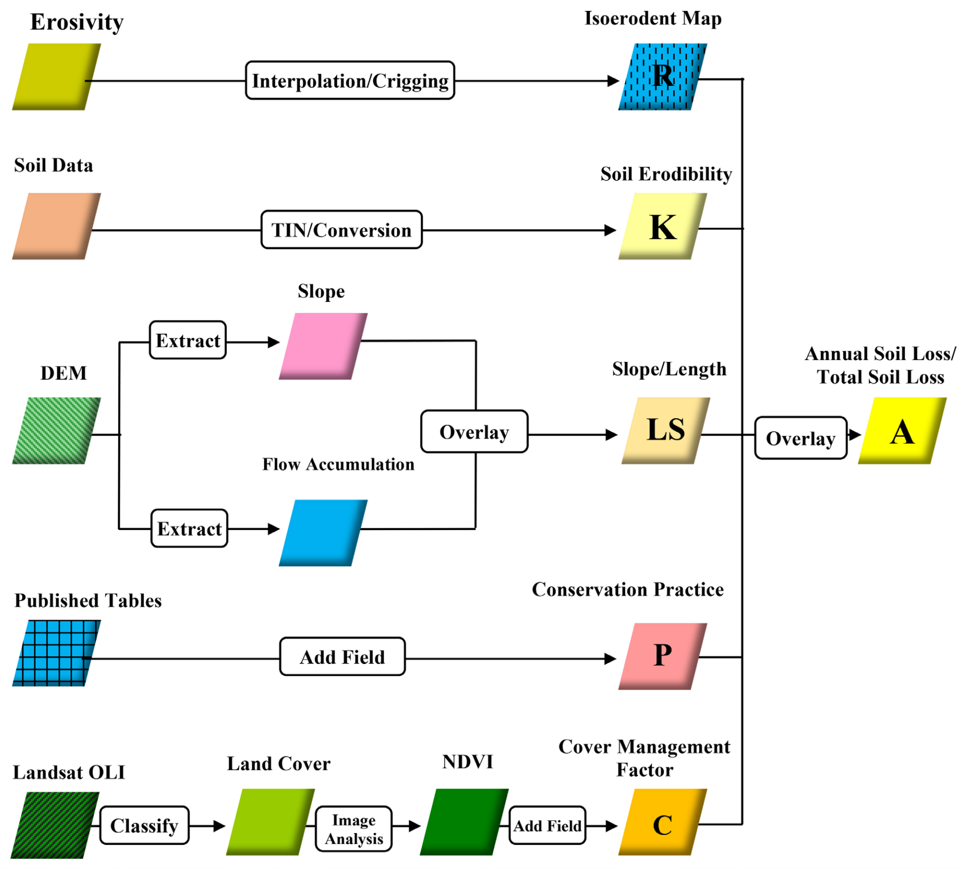

Figure 2. Flowchart for the implementation of RUSLE model for soil loss estimation.

3. Results and Discussion

3.1. Rainfall Erosivity (R-Factor)

The average annual rainfall distribution of the Kubanni drainage basin over a period of 13 years is shown in Figure 3. The pattern of rainfall distribution in the basin is reflective of the pattern of distribution of R-factor across the basin landscape. The R-factor values for the Kubanni drainage basin varies between 599.253 MJ·mm·ha^{-1}·h^{-1}·yr^{-1} and 507.62 MJ·mm·ha^{-1}·h^{-1}·yr^{-1} while the average R-factor value was 553.437 MJ·mm·ha^{-1}·h^{-1}·yr^{-1}. It is evident from **Figure 3** that the highest erosivity value was recorded in the central stretch of the basin running from the North of the Kubanni drainage basin to the Southwestern part. This indicates that the central part of the basin can be characterized as the area of high rainfall compared to the downstream area where the Kubanni dam is located. Such variation has implications in the estimation of soil erosion as the rate of soil loss increases with increase in rainfall amounts and increase in basin slope steepness. Thus, rate of soil erosion on the upstream district contribute the highest amount of annual soil loss in the basin. Although the erosivity values of the Kubanni drainage basin was found to be less than the global average of 2190 MJ·mm·ha^{-1}·h^{-1}·yr^{-1} (Panagos et al., 2017), the amount of soil loss contributed by R-factor is significant. The studies of Ahmad et al. (2024) reported R-factor values ranging from 560.93 MJ·mm·ha^{-1}·h^{-1}·yr^{-1} to 342.68 MJ·mm·ha^{-1}·h^{-1}·yr^{-1}. Despite reporting R-factor values which are higher than that of this study, Ahmad et al. (2024) collaborated the notion that R-factor plays a key role in soil loss and sedimentation of water courses as well as reservoirs. The output R-factor map (Isoerodent Map) of the Kubanni drainage basin is shown in **Figure 3**.

3.2. Soil Erodibility (K-Factor)

The K-factor of the Kubanni drainage basin is depicted on a K-factor map shown in **Figure 4**. As can be seen in **Figure 4**, the K-factor values for the Kubanni drainage basin varied from 0.07 Mg·ha·h·ha^{-1}·MJ^{-1}·mm^{-1} (0.535 ton acre h [hundreds of acre ft tonf in]$^{-1}$) to 0.13 Mg·h·h·ha^{-1}·MJ^{-1}·mm^{-1} (1.0 ton acre h [hundreds of acre ft tonf in]$^{-1}$). A comparison of the K-factor value of the Kubanni drainage basin *vs-a-vis* the K-factor values reported by Angima et al. (2003) reveals some similarity. The shared similarity between the K-factor values derived for this study and that of Angima et al. (2003) is attributable to the fact that the determination of K-factor for tropical soils incorporate input data such as unstable soil aggregates, modified silt, sand, and the corresponding base saturation (El-Swaify & Dangler, 1976). The derived K-factor values for this study also coincides with the benchmark values of (Wischmeier & Smith, 1978) K-nomograph which is 0.018 Mg·h·h·ha^{-1}·MJ^{-1}·mm^{-1} (0.14 ton acre h [hundreds of acre ft tonf in]$^{-1}$). The K-factor values of the K nomograph is applicable to tropical soils that have kaolinite as the dominant clay mineral (Wischmeier & Smith, 1978). The average K-factor value for the Kubanni drainage basin was found to be 0.1 Mg·h·h·ha^{-1}·MJ^{-1}·mm^{-1}·yr^{-1}. The results of this study is indicative of the dominance of sandy loam soil in the Kubanni basin. The sandy loam soil falls under HSG A. Parts of the Kubanni basin is equally prevalent with loam soil, although sandy loam soil has preponderance over other soil types in the drainage basin.

3.3. Slope Length and Steepness (LS-Factor)

The LS-factor of the Kubanni drainage basin which was obtained from the DEM of the study area is summarized in **Table 1**. As shown in **Table 1**, the study found that the slope of the Kubanni drainage basin ranged from 0% to 13.47%. The LS value was estimated using slope contributing area approaches and it ranged from 0 to 49.4 which correspond to the topography factor of the study area as depicted in the LS-factor map for the Kubanni drainage basin shown in **Figure 5**. The distribution of the slope values as evident in **Table 1** is in perfect agreement with (Wischmeier & Smith, 1978). The LS-factor map is shown in **Figure 5**.

3.4. Cover Management Factor (C-Factor)

The values of C-factor for the Kubanni drainage basin was found to range from 0.26 to 0.55 as shown in **Table 2**. It is evident from **Table 2** that the C-factor values for built up area, water body, vegetation, farmland and bare land were discovered to be 0.41, 0.55, 0.26, 0.35 and 0.40 respectively. The finding of this study with respect to C-factor differed with previous studies especially with respect to the land use class of water. The reasons for the variation between the C-factors of this study and that of Hlaing et al. (2008) are accounted for by the differences in the selected land use classes of the two study areas. While the land use classes for this study were built up area, water body, vegetation, farmland and bare land as evident in **Table 2**; that of Hlaing et al. (2008) were closed forest type (0.048), opened forest type (0.08), scrub land (0.35), grass land (0.64), agriculture land (0.45) water body (0.00). Secondly, the C-factor derived in Hlaing et al. (2008) were generalized C-factor values for specified crop that does not account for crop rotations or climate and annual rainfall distribution for the different agricultural regions of the study area. A C-factor raster map of the study area was created from GIS operations integrating the C-factor values of the Kubanni drainage basin. The C-factor map is shown in **Figure 6**.

3.5. Support Practice Factor (P-Factor)

The P-factor values for the Kubanni drainage basin is shown in **Table 3**. From **Table 3**, is it evident that the P-factor values varied from 0 to 1; where 0 represents very good manmade erosion resistance facility and 1 represents non manmade erosion resistance facility. The steepness parameters of the Kubanni drainage basin slope map were categorized into defined intervals of five discreet classes. The GIS operation for support practice factor returned a P-factor raster map. The generated P-factor map is shown in **Figure 7**.

3.6. RUSLE Model Implementation

The quantification of soil loss for the Kubanni drainage basin in a GIS environment returned an outcome quoted in tons per hectare per year as shown in **Table 4**. From **Table 4**, the amount of soil loss for the Kubanni basin was found to be 28441.482 tons·ha^{-1}·yr^{-1}, while the total annual soil loss for the entire Kubanni drainage basin was found to be 49780.257 tons·yr^{-1}. The results of this study are in contrast to the findings of Iguisi (1996) whose study in the Kubanni basin reported soil loss values which ranged from about 0.44 to 2.72 mt/ha/yr to about

1.71 to 12.79 mt/ha/yr in sub basins 1 and 2 respectively. While the result of this study is representative of the entire Kubanni basin, that of Iguisi (1996) was representative of two sub basins which are but only a portion of the entire drainage basin, and therefore could partly account for the contrast in the findings of the two soil loss investigations. Furthermore, the differences in the methodological approaches in the two studies could also be accountable for the differences in the outcomes. While Iguisi (1996) adopted the USLE model in his study, this study adopted the coupling of RUSLE model and GIS as a study technique. A further comparison of the findings of this study with that of Amah et al. (2020) reveals a dissimilarity. With their findings of soil loss of 1373.79 tons·yr^{-1} for Edda-Afikpo mesas in the lower Cross River watersheds of Nigeria, Amah et al. (2020) compares contrastingly with the findings of this study. The reasons for this dissimilarity of findings could be linked to the differences in the C-factors and K-factors of the two studies. While the C-factor and K-factor of this study stood at ranges of 026 - 0.55 and 0.535054 - 1 respectively, the C-factor and K-factor of Amah et al. (2020) stood at ranges of 0 - 0.45 and 0.027 - 0.3 respectively. The findings of this study also contrasted with the findings of Ugese et al. (2022) who despite the coupling of RUSLE model with RS and GIS techniques to investigate soil loss in a study area located in Jos East Local Government Area of Plateau State, Nigeria, reported soil loss which ranged from a tolerable amount of 10 tons·ha^{-1}·yr^{-1} to a moderate amount of 20 - 50 tons·ha^{-1}·yr^{-1} to a critical soil loss amount of >50 tons·ha^{-1}·yr^{-1}. The contrast in the findings of this study and that of Ugese et al. (2022) can be attributed to the differences in the R-factors and K-factors of the two studies. While the R-factor and K-factor of this study stood at ranges of 507.62 - 599.253 and 0.535054 - 1 respectively, the R-factor and K-factor of Ugese et al. (2022) stood at ranges of 42.9312 - 44.2963 and 0.216 - 0.245 respectively. Overall, The GIS based estimation of soil loss in the Kubanni drainage basin using RUSLE model returned a soil loss map which is shown in **Figure 8**.

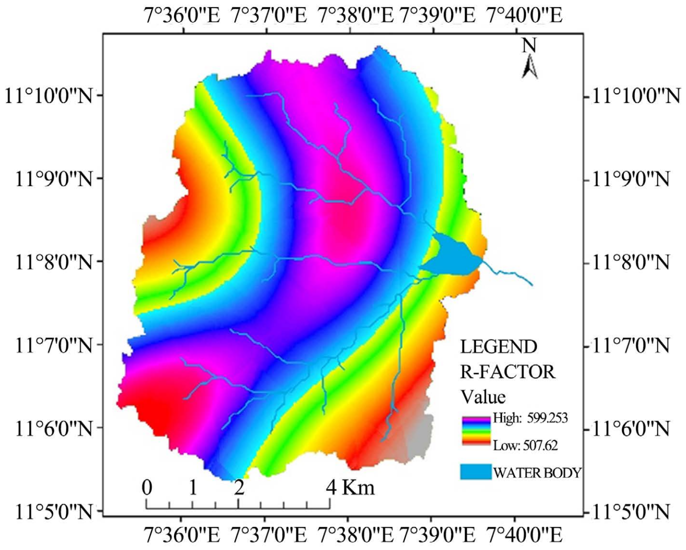

Figure 3. Isoerodent map of Kubanni basin.

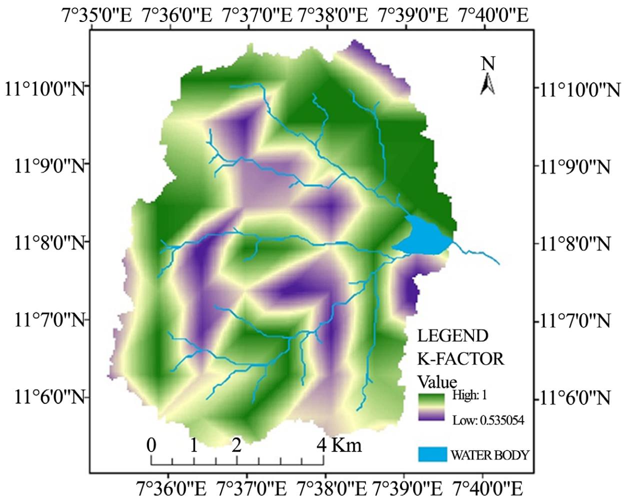

Figure 4. K-factor map of Kubanni basin.

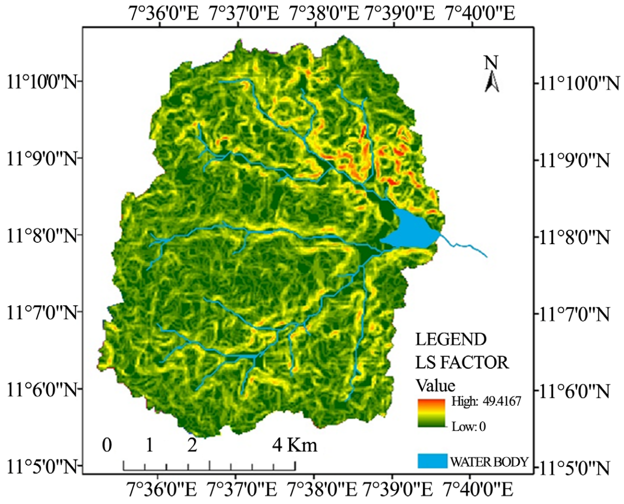

Figure 5. Slope map of Kubanni basin.

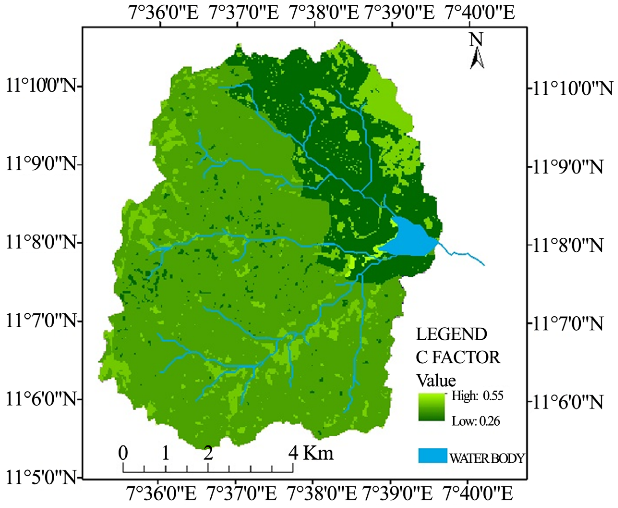

Figure 6. C-factor map of Kubanni basin.

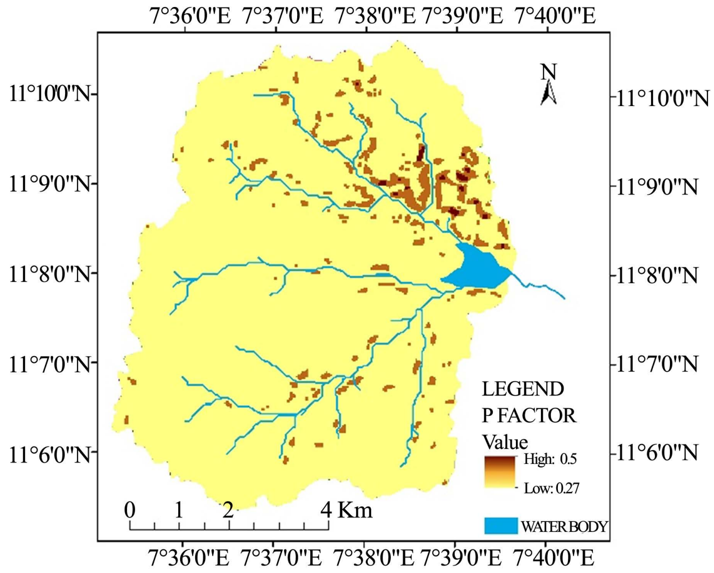

Figure 7. P-factor map of Kubanni basin.

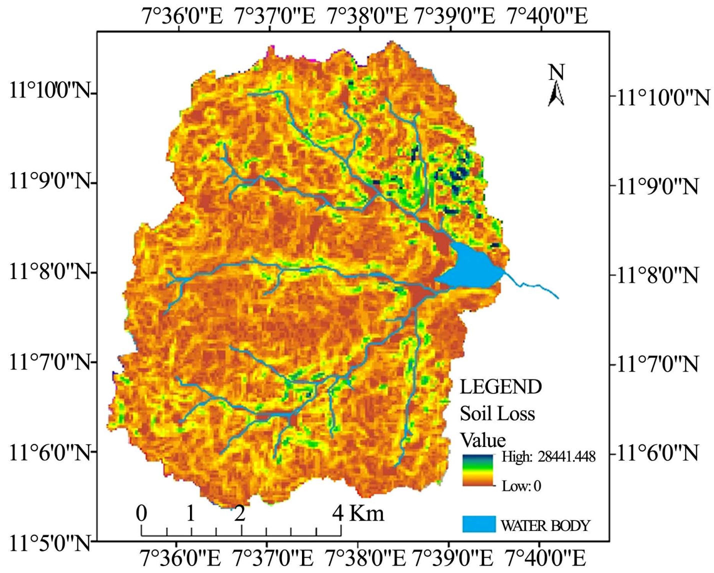

Figure 8. Soil loss map of Kubanni basin.

Table 1. Values for slope length exponent for LS-factor.

Slope Length Exponent (n)	Slope Gradient (%)
0.2	0 - 0.106
0.3	0.106 - 0.371
0.4	0.371 - 1.803
0.5	1.803 - 5.144
5 > n < 6	5.144 - 13.470

Source: Author's Field Survey, 2023.

Table 2. NDVI and C-factor for land use classes.

LULC Classes	NDVI	C-Factor
Built Up Area	0.19	0.41
Water Body	−0.1	0.55
Vegetation	0.48	0.26
Farmland	0.3	0.35
Bare Land	0.21	0.40

Source: Author's Field Survey, 2023.

Table 3. Support practice factor according to the types of cultivation and slope.

Slope (%)	Contouring	Strip Cropping	Terracing
0.0 - 7.0	0.55	0.27	0.10
7.0 - 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	1.00	0.50	0.20

Source: Shin (1999).

Table 4. Soil loss profile of the Kubanni drainage basin.

Scale of Soil Loss	Spatial Extent	Quantity
Unit Soil Loss	Per Hectare	28441.482 tons·ha^{-1}·yr^{-1}
Total Soil Loss	Entire Basin	49780.257 tons·yr^{-1}

Source: Author's Field Survey, 2023.

4. Conclusion

The estimation of soil loss using RUSLE model in Idirisi Selva 12 GIS environment returned an annual soil loss amount of 28441.482 tons·ha^{-1}·yr^{-1} and a total soil loss generated on an annual scale was found to be 49780.257 tons·yr^{-1}. The result of this study satisfies the curiosity as to whether or not soil loss estimation using USLE model in parts of the Kubanni drainage basin could approximate the soil loss profile of the entire Kubanni drainage basin. Thus, the result of this study has laid to rest one of the curiosities for which this study was embarked. The assumption that the applicability of RUSLE model in a study area elsewhere automatically translates to RUSLE applicability in our study area without the support of any empirical study was incompetent and illogical. From the results of this scientific investigation on soil loss, it is safe to assert that the coupling of RUSLE model and GIS applications for soil loss quantification was found credible for our study area. The erosivity factor was derived based on case situation without in-situ rain gages. The support practice factor was obtained cognizant of the prevalence of strip cropping farming practice in the Kubanni basin landscape. The erodibility factor relied on the soil test results while cover management factor was obtained using NDVI rescaling approach. The running of the RUSLE model was carried out in Idrisi Selva 12 and the performance of the model and output were found credible. The application of RUSLE model in this study embodied improvements which accommodated expanded information of soil erodibility. The utilization of recent data and modern geospatial tools in this study renders its findings on soil loss germane and especially bequeath input data for drainage basin managers and conservationists. The study found the coupling of RUSLE model with RS and GIS techniques for soil loss investigations in our study area to be viable. Future studies of soil loss estimation in this same study area should incorporate rainfall data obtained from in-situ rain gages planted across the entire drainage basin.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Ahmad, W. S., Jamal, S., Taqi, M., El-Hamid, H. T. A., & Norboo, J. (2024). Estimation of Soil Erosion and Sediment Yield Concentrations in Dudhganga Watershed of Kashmir Valley Using RUSLE & SDR Model. *Environment, Development and Sustainability, 26,* 215-238. https://doi.org/10.1007/s10668-022-02705-9

Amah, J. I., Aghamelu, O. P., Omonona, O. V., & Onwe, I. M. (2020). A Study of the Dynamics of Soil Erosion Using Rusle2 Modelling and Geospatial Tool in Edda-Afikpo Mesas, South Eastern Nigeria. *Pakistan Journal of Geology, 4,* 56-71. https://doi.org/10.2478/pjg-2020-0007

Aminu, Z., & Jaiyeoba, I. A. (2015). An Assessment of Soil Degradation in Zaria Area, Kaduna State, Nigeria. *Ife Research Publications in Geography, 13,* 26-36.

Anderson, J. M., & Ingram, J. S. I. (1993). *Tropical Soil Biology and Fertility. A Handbook of Method* (2nd ed.). University of Oxford.

Anees, M. T., Abdullah, K., Nawawi, M. N. M., Norulaini, N. A. N., Syakir, M. I., & Omar, A. K. M. (2018). Soil Erosion Analysis by RUSLE and Sediment Yield Models Using Remote Sensing and GIS in Kelantan State, Peninsular Malaysia. *Soil Research, 56,* 356-372. https://doi.org/10.1071/sr17193

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

Balasubramani, K., Veena, M., 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. *Modeling Earth Systems and Environment, 1,* Article No. 10. https://doi.org/10.1007/s40808-015-0015-4

Bello, A. L. (1973). *The Morphology of an Erosional Scarp, South of the Ahmadu Bello University, Zaria*. Unpublished B.A. Dissertation, Dept. of Geography, Ahmadu Bello University.

Biswas, S. S., & Pani, P. (2015). Estimation of Soil Erosion Using RUSLE and GIS Techniques: A Case Study of Barakar River Basin, Jharkhand, India. *Modeling Earth Systems and Environment, 1,* Article No. 42. https://doi.org/10.1007/s40808-015-0040-3

Bouyoucos, G. J. (1962). Hydrometer Method Improved for Making Particle Size Analyses

of Soils. *Agronomy Journal, 54,* 464-465.
https://doi.org/10.2134/agronj1962.00021962005400050028x

Brown, L. C., & Foster, G. R. (1987). Storm Erosivity Using Idealized Intensity Distributions. *Transactions of the ASAE, 30,* 379-386.
https://doi.org/10.13031/2013.31957

Chadli, K. (2016). Estimation of Soil Loss Using RUSLE Model for Sebou Watershed (Morocco). *Modeling Earth Systems and Environment, 2,* Article No. 51.
https://doi.org/10.1007/s40808-016-0105-y

De Carvalho, D. F., Durigon, V. L., Antunes, M. A. H., Almeida, W. S. d., & Oliveira, P. T. S. d. (2014). Predicting Soil Erosion Using Rusle and NDVI Time Series from TM Landsat 5. *Pesquisa Agropecuária Brasileira, 49,* 215-224.
https://doi.org/10.1590/s0100-204x2014000300008

Durigon, V. L., Carvalho, D. F., Antunes, M. A. H., Oliveira, P. T. S., & Fernandes, M. M. (2014). NDVI Time Series for Monitoring RUSLE Cover Management Factor in a Tropical Watershed. *International Journal of Remote Sensing, 35,* 441-453.
https://doi.org/10.1080/01431161.2013.871081

El-Swaify, S. A., & Dangler, E. W. (1976). Erodibilities of Selected Tropical Soils in Relation to Structural and Hydrologic Parameters. In *Soil Erosion: Prediction and Control* (pp. 105-114). Soil Conservation Society of America.

Ezenwa, K. O., Iguisi, E. O., & Yelwa, S. A. (2023). Application of GIS-Based MUSLE Model Approach for Sediment Yield Estimation in the Kubanni Drainage Basin, Zaria, Nigeria. *Sahel Journal of Geography, Environment & Development, 4,* 22-33.

Ezenwa, K. O., Iguisi, E. O., Yakubu, Y. O., & Ismail, M. (2022a). A SCS-CN Technique for Geospatial Estimation of Runoff Peak Discharge in the Kubanni Drainage Basin, Zaria, Nigeria. *Fudma Journal of Sciences, 6,* 314-322.
https://doi.org/10.33003/fjs-2022-0601-901

Ezenwa, K. O., Iguisi, E. O., Yusuf, Y. O., & Isma'il, M. (2022b). Application of GIS-Based SCS-CN Method for Runoff Estimation in the Kubanni Drainage Basin, Zaria, Nigeria. *Journal of Geospatial Science and Technology, 3,* 1-12.
https://doi.org/10.54222/afrigist/jgst/v3i1.1

Fagbohun, B. J., Anifowose, A. Y. B., Odeyemi, C., Aladejana, O. O., & Aladeboyeje, A. I. (2016). GIS-Based Estimation of Soil Erosion Rates and Identification of Critical Areas in Anambra Sub-Basin, Nigeria. *Modeling Earth Systems and Environment, 2,* Article No. 159. https://doi.org/10.1007/s40808-016-0218-3

Hlaing, K. T., Haruyama, S., & Aye, M. M. (2008). Using Gis-Based Distributed Soil Loss Modeling and Morphometric Analysis to Prioritize Watershed for Soil Conservation in Bago River Basin of Lower Myanmar. *Frontiers of Earth Science in China, 2*, 465-478.
https://doi.org/10.1007/s11707-008-0048-3

Horton, R. E. (1932). Drainage Basin Characteristics. *Transactions of the American Geophysical Union, 13,* 350-361.

Iguisi, E. O. (1996). *Variations of Soil Loss in Two Sub-Basins Near Zaria, Nigeria*. PhD Thesis, Department of Geography, Ahmadu Bello University.

Iguisi, E. O. (1997). An Assessment of Current Level of Sedimentation of the Kubanni Dam. *Savannna, 18,* 17-28.

Jackson, G. (1970). Vegetation; Around the City and Nearby Villages of Zaria. In M. J. Morti-more (Ed.), *Zaria and Its Region* (p. 191). Occasional Paper No. 4, Department of Geography, Ahmadu Bello University.

Jaiyeoba, I. A. (1995). Changes in Soil Properties Related to Different Land Uses in Part of the Nigerian Semi-Arid Savannah. *Soil Use and Management, 11,* 84-89. https://doi.org/10.1111/j.1475-2743.1995.tb00501.x

Kamaludin, H., Lihan, T., Rahman, Z. A., Mustapha, M. A., Idris, W. M. R., & Rahim, S. A. (2013). Integration of Remote Sensing, RUSLE and GIS to Model Potential Soil Loss and Sediment Yield (SY). *Hydrology and Earth System Sciences, 10,* 4567-4596.

Kumar, K. M., Annadurai, R., & Ravichandran, P. T. (2014). Assessment of Soil Erosion Susceptibility in Kothagiri Taluk Using Revised Universal Soil Loss Equation (RUSLE) and Geo-Spatial Technology. *International Journal of Scientific and Research Publications, 4,* 1-13.

McCool, D. K., Brown, L. C., Foster, G. R., Mutchler, C. K., & Meyer, L. D. (1987). Revised Slope Steepness Factor for the Universal Soil Loss Equation. *Transactions of the ASAE, 30,* 1387-1396. https://doi.org/10.13031/2013.30576

Morgan, R. P. C. (2005). *Soil Erosion and Conservation* (3rd ed.). Blackwell Publishing Company.

Oladipo, E. O., & Mornu, M. E. (1985). Characteristics of Thunderstorm in Zaria, Nigeria. *Weather, 40*, 316-322. https://doi.org/10.1002/j.1477-8696.1985.tb03720.x

Ololobou, Y. P. S. (1982). *Some Aspects of River Channel Morphology in the Zaria Area of Northern Nigeria*. PhD Thesis, Dept. of Geography, Ahmadu Bello University.

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,* Article ID: 104725. https://doi.org/10.1016/j.catena.2020.104725

Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Jae Lim, K. et al. (2017). Global Rainfall Erosivity Assessment Based on High-Temporal Resolution Rainfall Records. *Scientific Reports, 7*, Article No. 4175. https://doi.org/10.1038/s41598-017-04282-8

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,* 588-596. https://doi.org/10.4236/jgis.2012.46061

Rahaman, S. A., Ajeez, S. A., Aruchamy, S., & Jegankumar, R. (2015). Prioritization of Sub Watershed Based on Morphometric Characteristics Using Fuzzy Analytical Hierarchy Process and Geographical Information System—A Study of Kallar Watershed, Tamil Nadu. *Aquatic Procedia, 4,* 1322-1330. https://doi.org/10.1016/j.aqpro.2015.02.172

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

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, No. 703, USDA-ARS.

Risse, L. M., Nearing, M. A., Laflen, J. M., & Nicks, A. D. (1993). Error Assessment in the Universal Soil Loss Equation. *Soil Science Society of America Journal, 57,* 825-833. https://doi.org/10.2136/sssaj1993.03615995005700030032x

Roose, E. J. (1976). *Use of the Universal Soil Loss Equation to Predict Erosion in West Africa*. Reprinted from Soil Erosion: Prediction and Control, Soil Conservation Society of America. http://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_5/b_fdi_08-09/09135.pdf

Shin, G. J. (1999). *The Analysis of Soil Erosion Analysis in Watershed Using GIS*. Ph.D.

Thesis, Department of Civil Engineering, Gang-Won National University.

Thlakma, S. R., Iguisi, E. O., Odunze, A. C., & Jeb, D. N. (2018). Assessment of Soil Erosion Risk in Mubi South Watershed, Adamawa State, Nigeria. *International Journal of Advanced Remote Sensing and GIS, 7,* 2518-2539. https://doi.org/10.23953/cloud.ijarsg.340

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,* 499-517. https://doi.org/10.3390/geomatics2040027

Wang, L., Qian, J., Qi, W., Li, S., & Chen, J. (2018). Changes in Soil Erosion and Sediment Transport Based on the RUSLE Model in Zhifanggou Watershed, China. *Proceedings of the International Association of Hydrological Sciences, 377,* 9-18. https://doi.org/10.5194/piahs-377-9-2018

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting Rainfall Erosion Losses. A Guide to Conservation Planning*. USDA-ARS Handbook No. 537, United States Government.

Wright, J. B. & Mc Curry, P. (1970). Geology and Geormorphology. In M. J. Moretimore (Ed.), *Zaria and Its Region* (5-12). Department of Geography, Ahmadu Bello University, Zaria.

Yildirim, Ü., & Erkal, T. (2013). Assessment of Soil Erosion in the Ihsaniye Watershed Area, Afyonkarahisar, Turkey. *Scientific Research and Essays, Academic Journals, 8,* 388-397.