EROSION MAPPING USING REVISED UNIVERSAL SOIL LOSS EQUATION MODEL AND GEOGRAPHIC INFORMATION SYSTEM: A CASE STUDY OF OKITIPUPA, NIGERIA

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ABSTRACT

There is critical need to assess soil erosion and its spatial distribution in Okitipupa town so as to achieve sustainable land use and comprehensive soil conservation. Soil erosion vulnerability mapping of Okitipupa town provides an insight into which areas should be first conserved based on the severity level of soil loss. This research integrates Geographic Information System, Remote Sensing technologies and Revised Universal Soil Loss Equation model for erosion assessment and vulnerability mapping. Vulnerability to erosion was classified into five classes: very low, low, moderate, high and very high. The very low vulnerable areas covers an area of 735.55km^2, low covers an area of 30.72km^2, moderate covers an area of 3.17km^2, high covers an area of 0.73km^2, very high covers an area of 0.14km^2.

INTRODUCTION

During storm events, rainfall intensity can exceed the infiltration capacity of the soil and the excess water would form a runoff directed downslope (Toy, *et al*, 2002). The runoff would cause sheet erosion, which is more or less spatially uniform removal of soil, or rill erosion which occurs in small closely related channel called rills. Erosion act on land and inhabitants in many ways by changing the soil properties, bringing the both economic and social consequences to the population. Erosion related consequences in local, regional and national scales can be derived from physical and chemical changes in the soil properties, causing a reduction in crop yields and requirements of increased efforts to maintain the agricultural productivity (Toy *et al*, 2002). In Africa, it is estimated that the decrease in production due to soil erosion is 2 - 40% with an average of 8.2% for the whole continent (Eswaran *et al*, 2001). An average of 19% of the reservoir storage in Africa is silted (Jebari *et al*, 2010). Okitipupa lies on a topographically flat terrain with fine-medium grained sand and silt/clay contents. These characteristics along with low permeability make the soil vulnerable to erosion (Obasi, 2013). Geographic information system (GIS) have emerged as a powerful tool for handling spatial information and interact well with erosion models to provide robust problem solving capabilities useful for effective decision making. Erosion model often require moderate to high amount of spatial data, which can be effectively handled through GIS. The aim of this study is to model of soil erosion vulnerability in Okitipupa using GIS and Remote Sensing technologies integrated with RUSLE model. The result of this study serves as a guide for ground survey that needs to be undertaken in areas that show high risk to soil erosion in order to provide soil conservation management solutions.

METHODOLOGY
Data
Rainfall
Rainfall data was acquired from Nigerian Meteorological Agency (NIMET) for the period of 30 years. The precipitation data is for year 1986 to 2015. The rainfall data was averaged for the 30 years to estimate the average annual rainfall over the area.

Soil
Soil data was acquired from the Harmonised World Soil Database (HWSD) viewer of the Food and Agriculture Organisation (FAO). The data was pre-processed to a format that can be used for the analysis using Arc-GIS. The data was digitised and then converted to a raster format.

Landsat
Landsat 8 satellite imagery for Okitipupa was acquired from the United States Geological Survey (USGS) Agency. The acquisition date of the landsat data is 4th January, 2017. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9

Shuttle Radar Topography Mission (SRTM)
Shuttle Radar Topography Mission (SRTM) satellite imagery was acquired from the United States Geological Survey (USGS) Agency to model the slope length and slope steepness factor. The Shuttle Radar Topography Mission (SRTM) is an international research effort that obtained digital elevation models on a near-global scale to generate the most complete high-resolution digital topographic database of earth.

METHODOLOGY
Soil erosion modeling using revised universal soil loss equation (RUSLE)
The Revised Universal Soil Loss Equation (USLE) is an empirically based soil erosion model developed by Wischmeier and Smith (1978). The soil loss (A) due to water erosion per unit area per year (Mg ha^{-1} yr^{-1}) was quantified using USLE following equation:

$$A = R \times K \times L \times S \times C \times P. \quad (1)$$

Where A is the average annual soil loss due to water erosion, R the rainfall and runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K the soil erodibility factor (Mg h MJ^{-1} mm^{-1}), L the slope-length factor (dimensionless), S the slope steepness factor (dimensionless), C the cover and management practice factor (dimensionless),and P the support practice (dimensionless).

Rainfall and Runoff Factor (R Factor)
Rainfall and Runoff erosivity factor, R factor, represents the effect of energy and intensity of rainfall (Kunta and Carosio, 2007). It is the long-term annual average of the product of event rainfall kinetic energy in MJ ha^{-1} and the maximum rainfall intensity in 30 minutes in mm per hour (Weischmeier and Smith 1978; Renard and Freidmund 1994). The most suitable expression of the erosivity of rainfall is an index based on kinetic energy of the rain.

$R = 0.5 \times P\pi r^2$ (in US unit) and $R = 0.5 \times P \times 1.73$ (in Metric unit) (2)

R - value was determined with equation 2 as it has been found to work well in tropical regions. Hence each grid cells of mean annual rainfall were calculated to get the R –value using ArcGIS software. The mean annual precipitation surface was used to calculate the R factor using the spatial analyst module of the ArcGIS software.

Soil Erodibility Factor (*K*)

The K factor is a soil erodibility factor. The soil-erodibility factor K is a measure of the intrisic susceptibility of given soil to soil erosion. It is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Specifically, soil erodibility is a function of particle size distribution, organic matter content, structure and permeability (Renard et al. 1997). The soil erodibility factor (*K*) was calculated using five characteristics for each soil type. The characteristics determined for each soil type included soil particle size distribution, soil structure, organic matter content and permeability (i.e. duration and degree of waterlogging). The erodibility value of each soil class can be calculated using an equation recommended by Wischmeier and Smith (1978).

$$100\,k = 2.1\,(\%\,silt\ \times (100 - \%clay)^{1.142}(10^{-4})(12 - \%organic\ matter)) + 3.23\,(b - 2) + 2.5(c - 3) \quad (3)$$

here b is the soil structure code used in soil classification (very fine grnular, 1; fine granular, 2; medium or coarse granular, 3; slow to moderate, 4; slow, 5; very low, 6). The raster map of the k factor was produced according to a digital soil map and the erodibility value of each soil type.

Slope Length and Slope Steepness Factors (*LS)*

The topographic factor consists of two sub-factors: a slope gradient factor and a slope length factor. The LS factor, which reflect the topographic erosion susceptibility on a given site, were computed together from the digital elevation model (DEM). A DEM was built through digitizing the contours of a topographic map of the study site. The slope length and slope gradient factors (shown below) were calculated using the filled DEM and entered into the equation below to produce the topographic factor grid, following:

$$4LS = (\frac{L}{22})^{0.5} r(0.065 + 0.045S + 0.0065S^2) \quad (4)$$

Where : $L = \frac{L}{22.13} m$, in which m is length of slope (in m), m is 0.5 if the slope is > 5%, 0.4 if between 3% and 5%, 0.3 if between 1% and 3% and 0.2 if below 1% and L is the slope length factor; $S = (0.43 + 0.30s + 0.043s^2)/6.613$, where s is the gradient (%), and S is the slope gradient factor.

Cover and Management Factor *(C)*

The cover and management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). Land use types in the site were assigned C factor values based on their percentage canopy cover, fall height and ground cover. The land use map of Okitipupa was used for analyzing the *C*-value. A cover and management factor *(C)* was determined for each land use and land cover type from values for similar land cover types given by Wischmeier & Smith (1978). After changing the coverage grid, a corresponding *C*- value was assigned to each land use classes using reclass method in ArcINFO 9 as given by Wischmeier and Smith, 1978.

Support Practice Factor (*P*)

The management support practice factor (*P*) is a measure of the effectiveness of land management practices aimed at reducing soil loss within the catchment. Such practices include contour ploughing, strip cropping, terracing, etc. (May and Place, 2005). *P* values ranges from 0 to 1, whereby the value 0 represents a very good manmade erosion resistance facility and the value 1 represent no manmade resistance erosion facility. Information on the support practices or *P* factor values in the site was collected through field observation.

RESULT AND DISCUSSION

Rainfall-runoff erosivity factor (*R*)

The average precipitation was calculated for the 30 years period. The average precipitation in Okitipupa for the 30 years period is 126.9mm. When fitted into equation 2, the R factor was calculated as 109.8. This indicates that the amount of rainfall and runoff within 1986 to 2015 in Okitipupa were high enough to cause flood. High rainfall causes localised rivers to overflow their banks and drainage system becomes filled up thereby causing increased surface runoff which leads to flooding.

Soil erodibility factor (*K*)

Figure 1 shows the spatial distribution map of *K* factor for each soil type. The *K* factor was calculated using the formula in equation 3. Table 1 shows the *K* factor for each soil type in Okitipupa. The erodibility of the various soil types determines the ease with which rainfall and runoff detach soil particles. A higher erodibility factor indicates that the soil particles are easily eroded. A low erodibility factor indicates that the driving force required detaching soil particles would be higher since the soil particles are compacted together. High soil erodibility causes quick detaching of soil particles.

Table 1: Shows the K factor for each soil type in Okitipupa:

SOIL TYPE	K FACTOR
Dystric Nitosols	0.07
Dystric Regosols	0.08
Gleysols	0.03

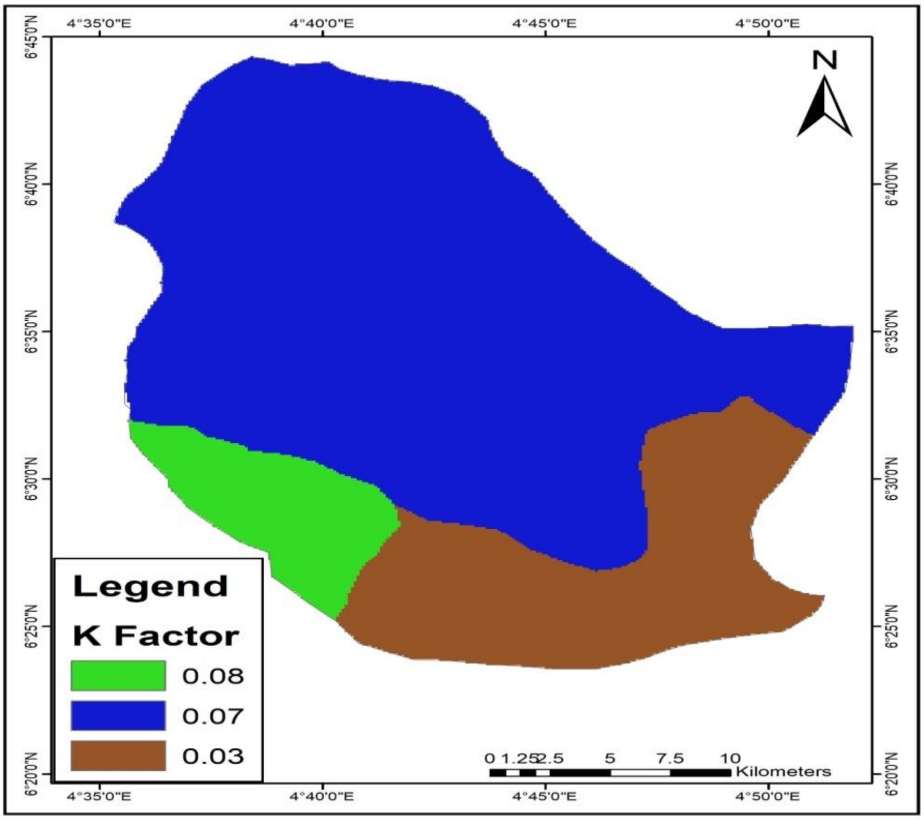

Figure 1: Map of K factor

Topography factor (*LS*)

Figure 2 shows the map LS factor. The LS factor ranges from 0 to 366.055. The LS factor indicates the slope length and slope steepness. High LS factor shows that such areas have steep slopes and long slope lengths. Steep slopes increase the speed of surface runoff. Increased surface runoff speed over a long distance would cause more soil particles to be detached over a wider area. This implies areas with lower LS factor in Okitipupa have lesser soil erosion effect while areas with high LS factor in Okitipupa experiences more adverse effects of soil erosion. The LS factor was higher around hilly areas.

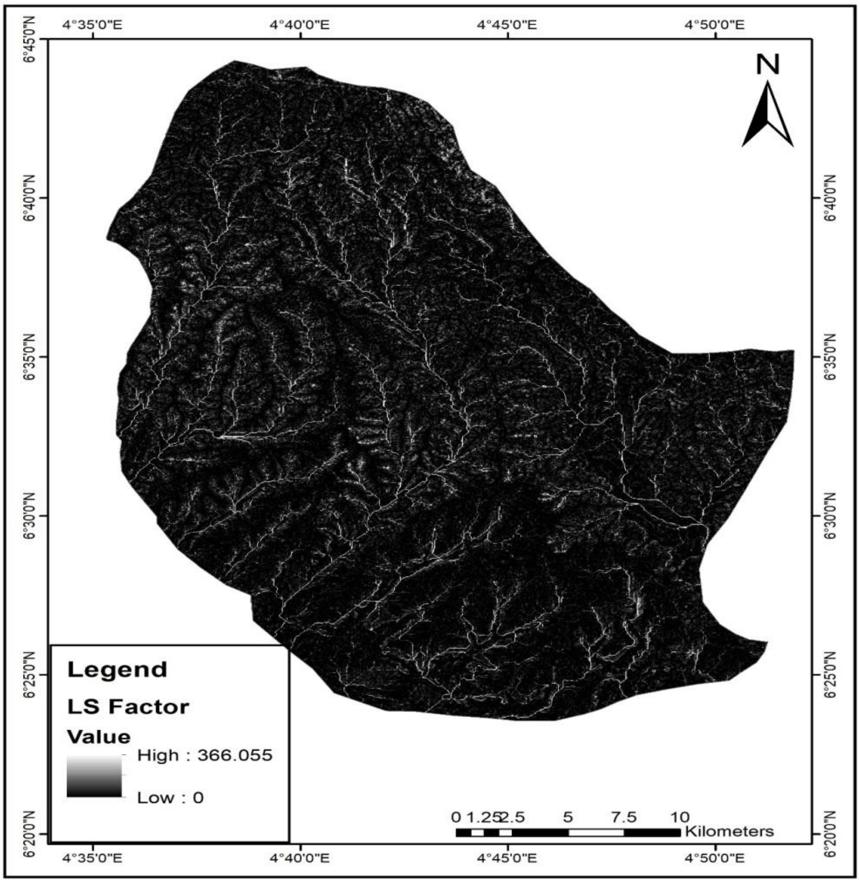

Figure 2: Map showing LS factor

Cover management factor *(C)*

Figure 3 shows the map of C factor. The generated C factor ranges between 0.36 and 0.37. The *C* factor is used to indicate the effect of vegetation cover on soil erodibility. Vegetation protects the soil from direct contact with rainfall. Thick vegetation reduces the speed of rain drops on the soil causing less detachment of soil particles. The *C* factor was higher in areas with bare and exposed surfaces. Vegetation areas have moderate *C* factor values. Built up and water body has the lowest *C* factor values. This shows that soil erosion were lesser in built-up and vegetative areas and higher in bare and exposed surfaces.

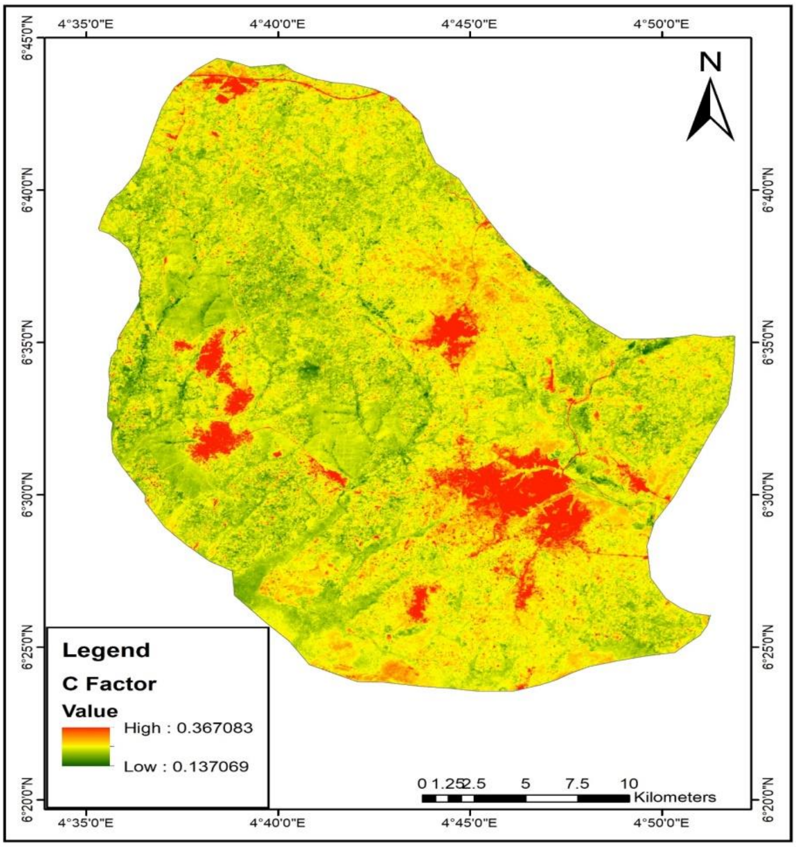

Figure 3: Map of C factor

Conservation practice factor (*P*)

Soil conservation methods reduce the effect of soil erosion in areas where they have been practiced. Where there are no soil conservation practices, the soils are exposed to soil erosion. The *P* factor value for Okitipupa was set at 1 since there are no specified management practices used in the Local Government Area. This indicates that the soils in Okitipupa are left bare and exposed to all factors causing soil erosion.

Soil loss

Figure 4 shows the amount of soil loss in tonnes per hectares per year in Okitipupa. The soil loss ranges from 0 to 14.7282ha/ton/yr. Soil erosion activities are scattered across Okitipupa. Okitipupa covers an area of 770.31 km^2. Figure shows the soil erosion risk map for Okitipupa. The risk was classified into five; very low, low, moderate, high and very high. The very low covers an area of 735.55km^2, low covers an area of 30.72km^2, moderate covers an area of 3.17km^2, high covers an area of 0.73km^2, and very high covers an area of 0.14km^2.

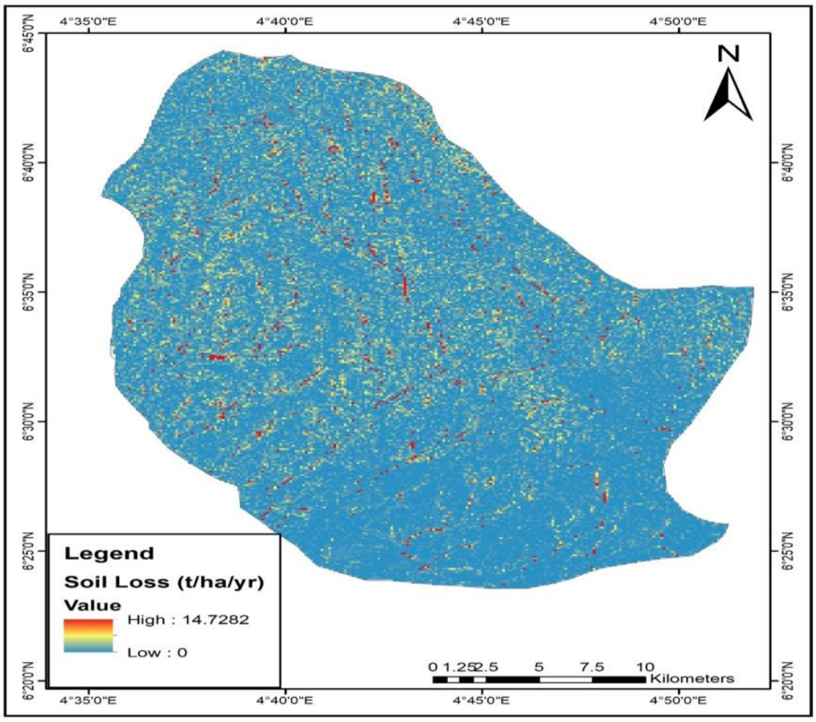

Figure 4: Soil Loss Map

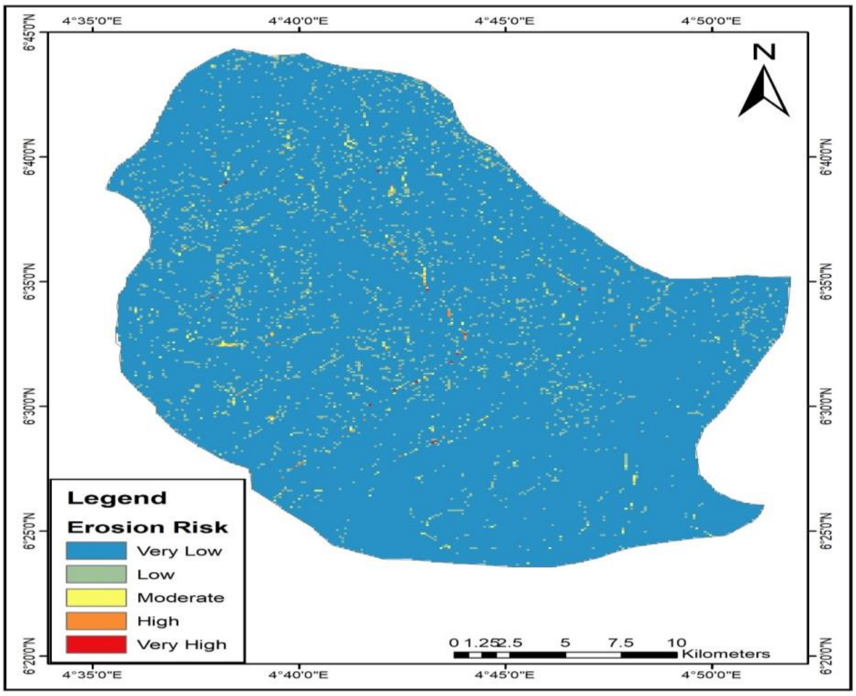

Figure 5: Erosion Risk Map

CONCLUSION

Soil erosion is a major challenge and problem in Okitipupa. Local communities are currently ill-equipped to combat the problem. The modeling of soil erosion vulnerability in Okitipupa provides an insight into which areas should be first conserved based on the severity level of

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soil loss. This study indicates that using GIS and Remote Sensing technologies integrated with RUSLE model for erosion vulnerability mapping resulted in the assessment of soil erosion in a considerably shorter time and at low cost for a large area. The result of this study serves a guide for ground survey to be undertaken in areas showing high risk of soil erosion to provide soil management solutions to mitigate the accelerating degradation soil in the area.

REFERENCES

Eswaran, H., Lai, R. and Reich, F.P. (2001). Land degradation: An overview response to land degradation.

Jebari, H., Berndtsson, R., Akissa, B. and Boufaroua, M. (2010). Spatial soil risk and reservoir siltation in semiarid Tunisia. *Hydrological Science Journal*, 55(1):121-137

Morgan, R. (1986) *Soil erosion and conservation*. JohnWiley and Sons. New York

Obasi, R.A.(2013). Vulnerability of soil erosion in Okitipupa area of Ondo State, south west Nigeria: A climatic problem. *The International Journal of Engineering and Science*, 2(3): 75-83.

Renard, K., Foster, G., Weesies, G., McDool, D., & Yoder, D. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. Agricultural Handbook 703, USDA-ARS.

Toy, T.J., Foster, G.R, and Renard, K.G (2002). *Soil erosion: processes, prediction, measurement and control*. John Wiley and sons, Inc., New York.

Wischmeier WH and Smith DD (1978). *Predicting rainfall erosion losses*. Agriculture handbook No. 537, USDA Science and Education Administration.