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Using GIS Techniques to Model RUSLE's 'K' Factor for River Nzoia Basin in Kenya

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Abstract

RUSLE is a model used to estimate mean annual soil loss. The model is a predictive tool used to evaluate land use and land cover options. Soil Erodibility (K) Factor is a measure of the predisposition of soil particles to detachment and conveyance by rainfall and surface runoff. The study sought to model soil erodibility (K) factor for river Nzoia basin, western Kenya. Geographical Information System (GIS) techniques were used to generate spatial representation of soil erodibility in the basin. The soil erodibility in river Nzoia basin was classified into: Low (0-0.09); Moderate (0.09-0.13); High (0.13-0.19) and Severe (0.19-0.13) levels. The upper and parts of the middle river Nzoia basin with low and moderate erodibility levels are mainly defined by forestland. These areas experience minimal soil erosion due to dense vegetation cover. Areas with high and severe erodibility levels are defined by land use that is primarily characterized by agricultural activities that tend to leave the soil surface bare. These areas experience high soil erosion due to rainfall and surface runoff. Therefore, to attain environmental restoration of river Nzoia basin, there is need to employ resources for conservation programmes in the areas with high and severe erodibility levels.

Keywords: River Nzoia; GIS; Model; erodibility; K-Factor

Introduction

River Nzoia basin is in western Kenya and originates from Mt Elgon, Cheranganyi Hills and Nandi escapments. According to Ssegan [1], the economy of the basin is largely rural-based and more than 90% of the population earns its living from agricultural activities. The basin is also of great economic importance especially in such sectors as agriculture, tourism, fishing, forestry, mining and transport. However, the basin is experiencing degradation due to high levels of soil erosion resulting from surface runoff during rainfall events [2].

Soil erodibility (K) factor is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. As a result, the factor may be referred to as the rate of soil loss per rainfall erosion index unit plot. The unit plot is 22.1m long, has a 9% slope, and is continuously in a clean-tilled fallow condition with tillage performed upslope and downslope [3]. The factor is a quantitative value which is experimentally determined taking into consideration the soil texture, soil structure, the organic matter content and the permeability [4]. In practical terms, the soil erodibility factor is the average long-term soil and soil-profile response to the erosive powers of rainstorms. Thus, it is a lumped parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes. It can be determined on the basis of nomograms with due considerations of the granular-metric fractions of 0.002-0.1mm, 0.1-2mm, the organic matter content, the soil's structure and permeability. Zhang et al. [5] observe that, determination of the soil erodibility involves assigning values that correspond to the soil types contained within the study area. A calculating relation was developed by Renard et al. [6] as expressed in Equatio

$$K = 0.0034 + 0.0405 * Exp\left[-0.5\left(\frac{\log D_g + 1.659}{0.7101} \right)^2 \right] \tag{1}$$

Where,

D_g - Geometric mean weight diameter of the primary soil particles (mm), see Equation 2.

$$D_g = Exp\left[\Sigma f_i * \ln\left(\frac{d_i}{2} + \frac{d_{i-1}}{2} \right) \right] \tag{2}$$

Where,

d_i - Maximum diameters of the particle size class i

d_{i-1} - Minimum diameters of the particle size class i

f_i - Sub-unitary percentage of the particle size class i

Information required for determination of the K factor can be obtained from the soil taxonomy map. For each of the soil textural classes, the mean percentage of silt, clay and sand can be derived from the texture triangle, and these values can be used to calculate the geometric mean particle diameter (mm) as recorded by Shirazi & Boersma [7].

The information required for the determination of the K factor can be obtained from the soil taxonomy map. At the basin scale, soil reconnaissance survey can provide information required for generation of composite maps of soil mapping units that can be used for the determination of K values. For each of the soil textural classes, the mean percentage of silt, clay and sand can be derived from the texture triangle (Figure 1). These values can be used to calculate the geometric mean particle diameter Dg [mm]. Shirazi and Boersma [7] used the proportions of clay, silt and sand to obtain the geometric mean of particle diameter D_g[mm] and its geometric standard deviation (σ).

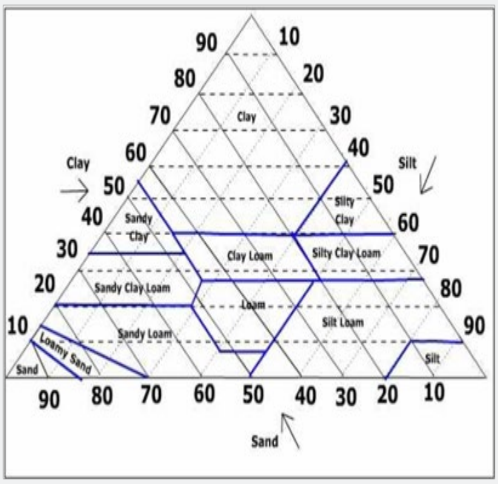

Figure 1: Soil Texture triangle [7].

Soil texture triangle is used to classify the texture class of a soil. Sides of the triangle are scaled for the percentages of sand, silt, and clay. Clay percentages are read from left to right across the triangle (dashed lines). Silt is read from the upper right to lower left (light, dotted lines). Sand from lower right towards the upper left portion of the triangle (bold, solid lines). Boundaries of the soil texture classes are highlighted in blue. The intersection of the three sizes on the triangle gives the texture class. For instance, consider a soil with 20% clay, 60% silt, and 20% sand it falls in the "silt loam" class. As argued by Wischmeier et al. [4], when data on soil permeability, structure, and organic matter are available, Equation 3 can be applied to determine K- factor.

$$100K = 2.1*10^{-4}*M^{1.14}*(12-OM)+3.25(S-2)+2.5(p-3) \quad (3)$$

Where,

M-[%very fine sand+%silt]×[100- %clay]

OM-Percentage of organic matter

S-Code according to the soil structure (very fine granular=1, fine granular=2, coarse granular=3, lattice/massive=4), and

P-Code according to the permeability/drainage class (fast=1, fast to moderately fast=2, moderately fast=3, moderately fast to slow=4, slow=5, very slow=6)

Methodology

Basic data to estimate the erodibility (K) factor values and soil hydrological parameters (texture, hydraulic conductivity, soil moisture, soil depth) were obtained from the soil map for river Nzoia basin. The soil map was obtained from FAO (http://www.fao.org) i.e. Kenya Soil and Terrain (KENSOTER) database. The soil map shape file was added as a layer into ArcGIS 10.1 and its attribute table edited with additional new field of K values generating K-Factors for various soil layers. Figure 2 shows the schematic diagram used to generate the soil erodibility (K) factor.

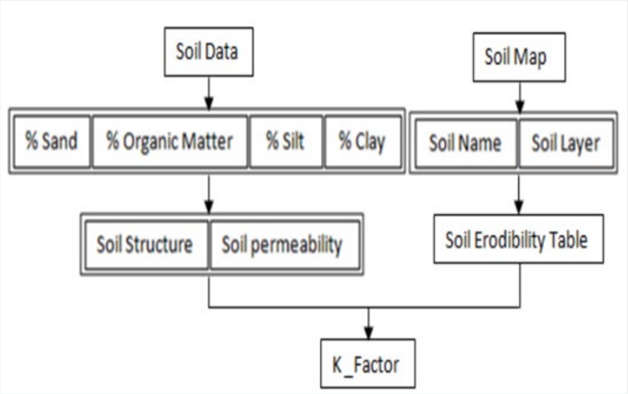

Figure 2: Schematic diagram for generation of K-Factor.

Results and Discussion

Soil erodibility K value map was generated to show spatial distribution of erodibility (Figure 3). The study revealed that K-factor value range was 0.00 to 0.31ton $ha^{-1}MJ^{-1}mm^{-1}$.

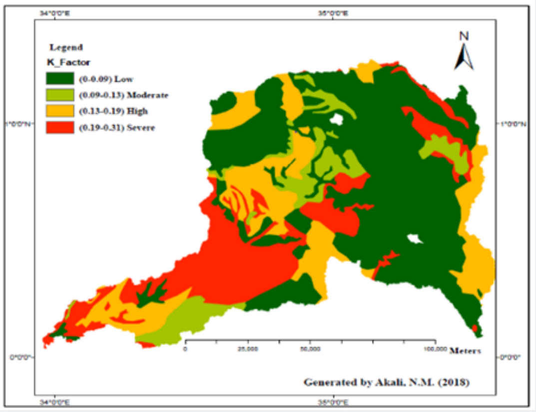

Figure 3: River Nzoia basin soil erodibility (K) factor.

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The erodibility factor was classified into: Low (0-0.09); Moderate (0.09-0.13); High (0.13-0.19) and Severe (0.19-0.31) levels. Areas spanning Soy, Leseru, Eldoret, Kaptalelia, Kitale, Ainabukoi and Cherenganyi with erodibility factor between 0.0 and 0.13 are at a low to moderate soil erosion risk. These areasare mainly characterized by heavy vegetation cover. Regions covering, Khachonge, Kipkaren, Sang'alo, Mumias, Buhuyi had erodibility (K) factor (0.19-0.31) that reflects severe predicted soil losses due to water erosion.The high values of K-Factor could be as a result of the highly silty nature of the soils from the affected areas. Silty soils lack cohesion as their particles are loose therefore require little drag force to be transported by the force of moving water.

Most erodible soils are silts and fine grain sands. High erodibility of silty soils is due to small size and weight of the grains and to their low cohesion. As a consequence, sandy and silty grains are easily detached and transported by overland flow. In addition, anthropogenic activities, mainly agricultural, pre-dispose these areas to high soil erosion risk. The low erodibility factor value could be attributed to the more clay content present in the soils in most parts of the basin. They provide higher binding and inter binding forces that increases cohesion of soil particles. As well, there is the presence of land cover which helps in resisting detachability of the soil by water.

Conclusion

Soil erodibility factor (K) in the Revised Universal Soil Loss Equation (RUSLE) significantly correlates with soil loss. It is a fundamental factor in soil erosion hazard modeling and prediction. In this study, soil erodibility (K) factor was classified into: Low; Moderate; High and Severe levels. Its range was between 0.00 and 0.305ton $ha^{-1}MJ^{-1}mm^{-1}$. Mean factor was estimated to be 0.13ton $ha^{-1}MJ^{-1}mm^{-1}$. The upper river Nzoia basin has a low soil erodibility factor (K) ranging from 0 to 0.13ton $ha^{-1}MJ^{-1}mm^{-1}$. This was attributed to the land cover that is majorly forestland. Area spanning middle up to the lower basin has a high K-factor with a range of 0.13 to 0.305ton $ha^{-1}MJ^{-1}mm^{-1}$. The high K-factor is associated to the land use that is primarily characterized by agricultural activities that tend to leave the soil surface bare. This area is likely to experience high soil erosion due to rainfall and surface runoff. Therefore, it is in priority for soil conservation programmes.

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