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Estimation of Spatial Distribution of Potential Soil Erosion Risk in Isiukhu River Catchment, Kakamega County, Kenya

Wekulo Saidi Fwamba, Prof. Samuel.S. China, Dr. Edward.N.Masibayi
Department of Disaster preparedness and Engineering Management
Masinde Muliro University of Science and Technology
P.O. Box 190 – 50100, Kakamega, Kenya

***Abstract* — An assessment of potential soil erosion risk is essential in soil conservation and environmental management. Potential soil erosion risk is the benchmark from which land use/land cover management and soil erosion control support practices are based on control of soil loss and thus affects agricultural production. Potential soil erosion risk is based on environmental factors which include: rainfall erosivity, soil erodibility, slope length and slope steepness. Isiukhu river catchment and its environs have experienced fatal landslides leading to loss of lives and property. The spatial variation of rainfall erosivity (R) factor, soil erodibility (K) factor, slope length and slope steepness (LS) factor were determined in ArcGIS 10.3 environment. The spatial distribution of potential soil erosion risk was determined by applying revised universal soil loss equation (RUSLE) model in ArcGIS 10.3. The spatial variation of soil erosion risk showed that 0-12 t ha-1 y-1 covered an area of 5,000ha (7.3%), 13-25 t ha-1 y-1 covered an area of 12,000ha (17.6%), 26-69 t ha-1 y-1 covered an area of 19,882ha (29.1%), 70-106 t ha-1 y-1 covered an area of 19,807ha (29%), 107-125 t ha-1 y-1 covered an area of 10,245ha (15%) and 126-128 t ha-1 y-1 covered an area of 1,366ha (2%). From these results, only 7.3% of the catchment is within soil loss tolerance limit (12tha-1y-1). This could be due to degradation of natural cover within the catchment. Deforestation as a result of farming activities and settlement in the catchment forest could have led to exposure of ground to surface run-off. The high rate of soil erosion could be reduced by controlling encroachment on the forest, proper land use/land cover through multiple-cropping**

Keywords* — *Potential Soil Erosion Risk; Environmental Factors;Lland use; RUSLE; GIS

I. INTRODUCTION

Globally soil erosion is one of the global environmental problems resulting in both on-site and off-site effects on catchments. Soil erosion, defined as the detachment, transportation and deposition of soil particles by wind or water, is a natural process driven by physical factors, as in [1]. The intensity of erosion processes depends on soil properties, topography and vegetation cover. Reference [2] stated that soil erosion leads to environmental degradation that is a precursor to disaster risks such as landslides, loss of soil fertility and infrastructure destruction The economic implications of soil erosion are more serious in developing countries because of lack of capacity to cope with it and also to replace lost nutrients. These countries also have high population growth which leads to intensified use of already stressed resources and expansion of production to marginal and fragile lands. Such processes aggravate erosion and productivity declines, resulting in a population-poverty-land degradation cycle, as in [3].

In Kenya, agriculture is the backbone of the country’s economy. Good soils lead to increased agricultural production. Studies carried out on soil erosion risk in Kenya show that more than 75% of Kenya’s soil is fragile environmentally. Soil erosion in Kenya leads to land degradation that lowers its capability to produce and increases its vulnerability to disaster hazards, as in [4]. Farmers’ knowledge on soil erosion hazards is very crucial in sustaining Kenya’s agricultural production, as in [5] The anthropogenic pressure on land in Kenya is essentially reflected in the land cover, where land use change and -intensity and cultivation practices, such as tillage and implementation of conservation strategies, determine the vulnerability to erosion, as in [6].

Isiukhu River has its source in Nandi escarpment, Nandi forest on the boundary of Nandi and Kakamega Counties. It combines with river Lusumu before draining in river Nzoia in Mumias Sub-County. Isiukhu river catchment has had a lot of environmental challenges emanating from deforestation and improper conservation measures, as in [7]. Mono-cropping of maize and sugarcane on majority of the farms in the catchment poses serious environmental challenges including landslides that occurred at Khuvasali village in August 2007 killing 12 people, injuring100 and displacing 49 families and another one at Chepng’abai hills in May 2016 that killed one mother and her four children, as in [7; 8]. Technologies to counteract fertility constraints are rarely implemented, as they do not consider system diversity or farm-specific characteristics, as in [9].

Reference [10] stated that potential soil erosion risk expresses the inherent susceptibility of bare soil to erosion as it would be without any protective cover of vegetation. This way it provides information on the worst possible situation that might occur. Reference [11] stated that the process for determining erosion potential must involve identifying the factors that control the risk of erosion, use parameters for which data are available for the particular region, can be adjusted easily as more/better information becomes available, and is a method that has been vetted in the published literature. A number of models have been developed to predict soil erosion risk at various scales from individual fields to entire drainage basins. Each model requires specific information in order to predict soil erosion risk. This information is not available for Isiukhu river catchment.

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It is with the foregoing in mind that this research sought to fulfill its objective of estimating the spatial variation of potential soil erosion risk. The study employed RUSLE model in ArcGIS 10.3 in determining spatial variation of potential soil erosion risk..

II. MATERIALS AND METHODS

Study site

Isiukhu river catchment lies in Kakamega County, Western region of Kenya Its geographical coordinates are: 0° 15' 0" – 0o 25' 0" North and 34° 40' 0" - 34° 55' 0" East (Fig. 1). The study area covers an area of approximately 683.0 Km^2 (68,300ha) with an approximate population of 373,600. The altitudes of the study area range from 1,317 metres above sea level to 2,144 metres above sea level. There are two main ecological zones in the catchment namely; the Upper Medium (UM) and the Lower Medium (LM). The Upper Medium in which Nandi escarpment lies covers the Central and Northern parts of the county such as Lurambi, Malava, Shinyalu and Ikolomani that practise intensive maize, beans and horticultural production mainly on small scale; and Lugari and Likuyani where large scale farming is practiced. The second ecological zone, the Lower Medium (LM), covers a major portion of the southern part of the county which includes Mumias, Matungu and Butere and Khwisero. In this zone, the main economic activity is sugarcane and maize production with some farmers practicing sweet potatoes, tea, ground nuts and cassava production.

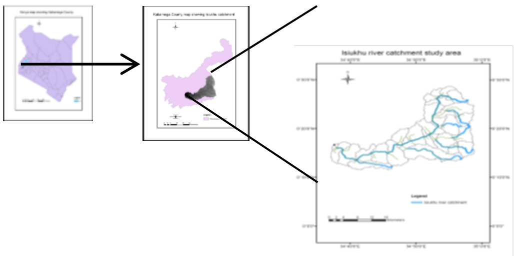

Fig. 1: Location of the study site

Data collection and processing

Meteorological data—monthly and annual precipitation data from available rainfall stations serving Isiukhu river catchment – Malava forest, Mundoli, Kakamega Met. Station, Mumias sugar, Bukura ATC and Alupe KALRO. Soil and Terrain (SOTER) map - vector data set from international soil reference and information centre (ISRIC) world soil information for Kenya soil DataBase set (KENSOTER). Digital Elevation Model (DEM) of 30m resolution—reference data set from Kakamega County Survey Office, based on the photogrammetric workout in the form of a Triangulated Irregular Network (TIN) having a vertical accuracy to the tens of centimeters. Fig. 2 shows data collection and processing.

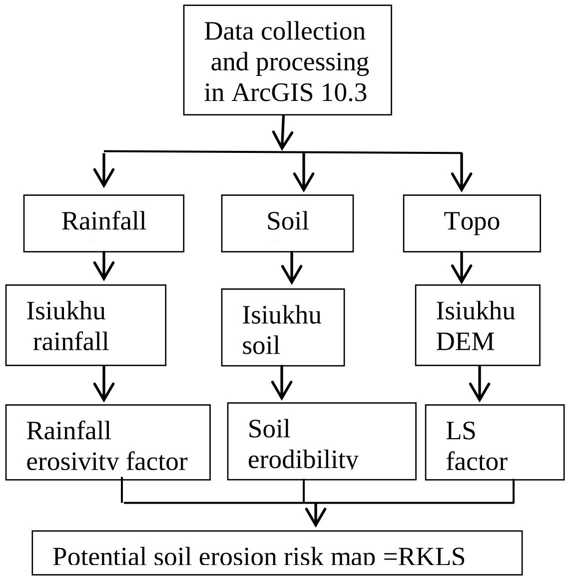

Fig. 2: Methodology flow chart

Computation of Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) was calculated from (1), as in [11]

$$F_M = \sum_{i=1}^{12} \frac{P_i^2}{P} \qquad (1)$$

where: F_M = Modified Fournier Index, P_i = the monthly average amount of precipitation for month i (mm), and P = the average annual quantity of precipitation (mm).

Plotting Fm index values in mm (Y - axis) against rainfall station altitudes in metres (X – axis) generated (2) which was used in ArcGIS 10.3 to compute rainfall erosivity factor (R) map.

$$Y = -0.0144X + 194.29 \qquad (2)$$

where: Y = Modified Fournier Index in mm, X = Study area DEM

Computation of soil erodibility factor (K)

For this study, K factor was generated from the soil shapefile map of the Isiukhu study area. Kenya soil database was used to produce the soil shapefile for the study area. The soil map was overlaid in ArcGiS. It was given spatial reference which was the same as the study area (WGS 1984 UTM Zone 37N). The study area was then clipped from the rest of the soil map feature and attribute table of the study area was edited for K factor before it was changed to raster file to give K factor map and its values.

Computation of slope length and slope steepness factor (LS)

- Equation (3), was used to calculate LS factor as in [12]

- $$LS = \left(\frac{x}{22.13}\right)^m (0.065 + 0.045s + 0.065s^2) \qquad (3)$$

where: x – Slope length (m), s – Slope gradient (%)

The values of x and s were derived from study area Digital Elevation Model (DEM). To calculate the x value, Flow Accumulation was derived from the DEM after conducting Fill and Flow Direction processes in ArcGIS 10.3.

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Hence x=Flow accumulation *cell value as in (4). Equation (4) was applied in ArcGIS 10.3 to generate LS factor map

$$LS = \left(\frac{Flowaccumulation \times cellvalue}{22.13} \right)^m (0.065 + 0.045s + 0.065s^2) \quad (4)$$

Computation of spatial distribution of potential soil erosion risk map ($RUSLE_{potential}$)

Spatial variation of potential soil erosion risk map was generated by overlaying rainfall erosivity factor (R) map, soil erodibility factor map and LS factor map in ArcGIS 10.3 (Fig. 3).

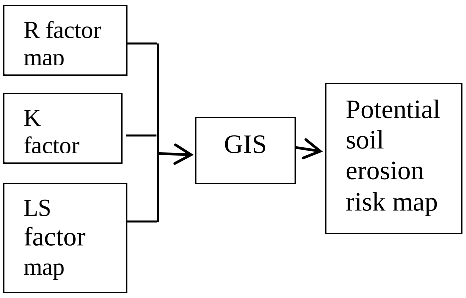

Fig. 3: Computation of potential soil erosion risk map

III. RESULTS AND DISCUSSIONS

Rainfall erosivity factor (R) values ranged from 163 $MJmmha^{-1}h^{-1}yr^{-1}$ to 175 $MJmmha^{-1}h^{-1}y^{-1}$ with mean of 171 $MJmmha^{-1}h^{-1}yr^{-1}$ and standard deviation of 1.9 (Fig. 4)

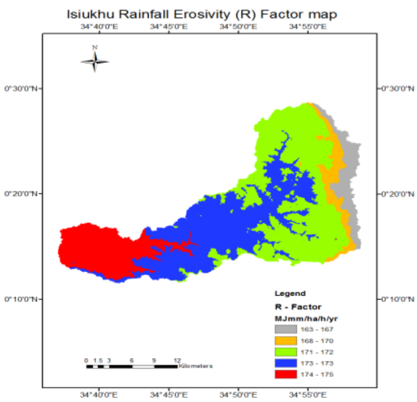

Fig. 4: Isiukhu river catchment R factor map

The spatial distribution of rainfall erosivity factor showed that 30% had 171-172 $MJmmha^{-1}h^{-1}yr^{-1}$, 50% had 173 $MJmmha^{-1}h^{-1}yr^{-1}$ 10% had 174-175 $MJmmha^{-1}h^{-1}yr^{-1}$ (Table 1). From these results, areas such as Mundoli, Kakamega and Mumias with high rainfall, their R factor values are higher than the mean. Since the greater the intensity and duration of the rain storm, the higher the erosivity (R) Factor, it means erosion potential is area specific.

Table 1: Spatial distribution of R factor

Classification of R Factor $MJmmha^{-1}h^{-1}y^{-1}$	Area (ha)	Spatial distribution of R Factor (%)
163-167	3,415	5
168-170	3,415	5
171-172	20,490	30
173-173	34,150	50
174-175	6,830	10
Total	68,300	100

Soil erodibilty factor (K) map showed that there were nine K factor classes with minimum of 0.4 t h MJ^{-1} mm^{-1} along Nandi escarpment, maximum of 0.73 t h $MJ^{-1}mm^{-1}$ in the lower catchment areas, mean of 0.58 t h MJ^{-1} mm^{-1} and standard deviation of 0.11 (Fig. 5).

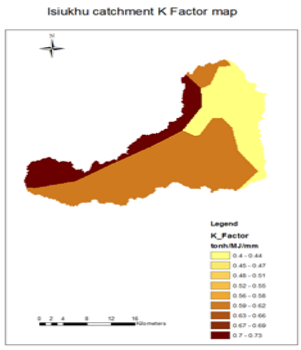

Fig. 5: Isiukhu river cathment K factor map

Majority of Isiukhu river catchment has K Factor of 0.59-0.62 $thMJ^{-1}$ mm^{-1} (60%) which is clayey (Sandy clay, silty clay and clay) soils (Table 2). Therefore 60% of the catchment is above mean erodibility (K) factor value of 58 t h MJ^{-1} mm^{-1}. Although there is no information on the variation of K with time and season in the study area, the difference in time and location, as well as in management practices would contribute to observed differences in K. The K-factors for tropical soils usually increase when soils are cultivated and vary with soil type, season of the year, and cultural practices, as in [13].

Table 2: Spatial distribution of K factor

Classification of K Factor $TonhMJ^{-1}mm^{-1}$	Area (Ha)	Spatial distribution of K Factor (%)
0.4-0.44	3,420	5
0.45-0.47	3,420	5
0.48-0.51	3,420	5
0.52-0.55	3,420	5
0.56-0.58	3,420	5
0.59-0.62	41,000	60
0.63-0.66	3,420	5
0.67-0.69	3,420	5
0.70-0.73	3,420	5
Total	68,300	100

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LS factor map showed that LS values ranged from 0 to 1, with the mean of 0.29 and the standard deviation was 0.45 (Figure 6). From the results, the highest elevation was 2,144m and the lowest was 1,317m giving steepness of 827m. The slope length had a minimum of 139m and a maximum of 16,891m. The slopes along Nandi escarpment (source of Isiukhu river) was 246% and decreased to 5% (exit of Isiukhu river). This indicated that there was steep rise from the exit to the source of the river.

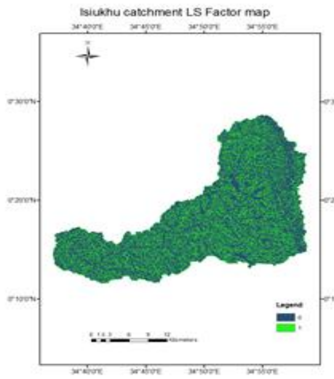

Fig. 6: Isiukhu river catchment LS factor map

Spatial distribution of potential soil erosion risk ($RUSLE_{potential}$)

The spatial distribution of potential soil erosion risk showed that minimum potential soil erosion risk was 1 t ha^{-1} y^{-1}, the maximum is128 ton ha^{-1} y^{-1}, the mean was 29 t ha^{-1} y^{-1} and the standard deviation was 46 (Fig. 7)

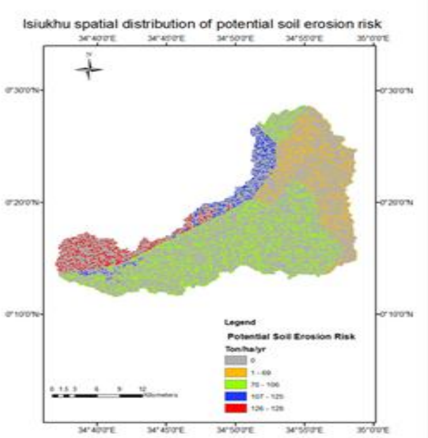

Fig. 7: Spatial distribution of potential soil erosion risk map

Based on spatial distribution, Isiukhu river catchment potential soil erosion risk was classified in six classes (Table 3). 0-12 t ha^{-1} y^{-1} covered an area of 5,000ha (7.3%), 13-25 t ha^{-1} y^{-1} covered an area of 12,000ha (17.6%), 26-69 t ha^{-1} y^{-1} covered an area of 19,882ha (29.1%), 70-106 t ha^{-1} y^{-1} covered an area of 19,807ha (29%), 107-125 t ha^{-1} y^{-1} covered an area of 10,245ha (15%) and 126-128 t ha^{-1} y^{-1} covered an area of 1,366ha (2%).

Table 3: Spatial distribution of potential RUSLE

Classification of potential soils erosion risk (t ha^{-1} y^{-1})	Area coverage (ha) (c)	Percent spatial distribution
0 - 12	5,000	7.3
13 - 25	12,000	17.6
26 - 69	19,882	29.1
70 - 106	19,807	29
107 - 125	10,245	15
126 - 128	1,366	2
Total	68,300	100

In comparison with standard soil loss tolerance limit, only 7.3% (0-12 t ha^{-1} y^{-1}) of Isiukhu river catchment had allowable potential soil erosion risk (Bergsma 1986 and Thomas 1997). Above 90% of the catchment had 13-128 t ha^{-1} y^{-1} which was above soil erosion tolerance limit (Fig. 8)

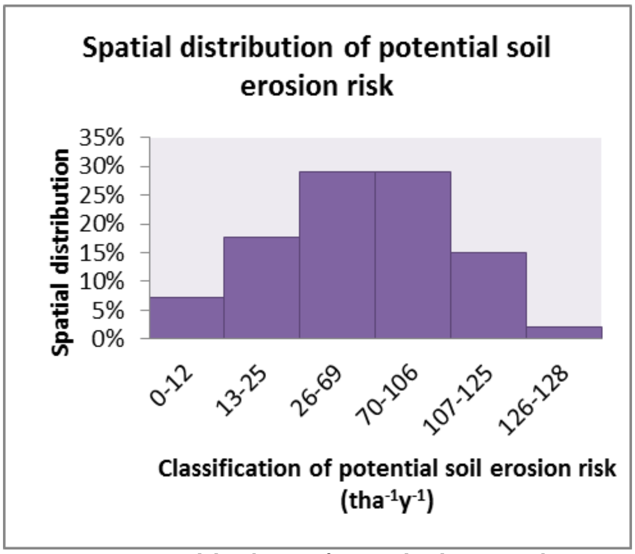

Fig. 8: Spatial distribution of potential soil erosion risk

IV. CONCLUSIONS

The spatial distribution of potential soil erosion risk using RUSLE model in ArcGIS 10.3 with its environmental factors which include rainfall erosivity (R), soil erodibility (K), slope length and slope steepness (LS) are studied. The results of Isiukhu river catchment suggest that spatial distribution of potential soil erosion risk varies with rainfall erosivity, soil erodibility, slope length and slope steepness of a given site. Soil texture, land use/land cover and slope of an area are highest determinants of soil loss through erosion. The lowest class (0-12$tha^{-1}y^{-1}$) of soil loss covering 7.3% of the catchment was where there is intensive forest cover along Nandi hills while about 93% 0f the catchment with intensive farming activities had soil loss above tolerance limit (13-128$tha^{-1}y^{-1}$). The study discourages indiscriminate felling of trees, mono-cropping, over grazing, ploughing up and down the slope and other anthropogenic activities that expose ground surface for high surface run-off. The study recommends an-all inclusive approach to environmental management that would encourage afforestation, proper land use/land cover and implementation of soil erosion control support practices to mitigate. Further studies are needed on spatial distribution of potential soil erosion with a DEM of higher resolution than 30m, soil texture analysis and rainfall data analysis using a different method other than Modified Fournier Index.

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