Determination of Actual soil erosion risk with change in land use/land cover in Isiukhu river catchment, Kakamega County, Kenya

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Abstract- Determination of soil erosion risk with change in land use/land cover is significantly important for its ecological, social and economic impacts. Soil erosion in study area depends on both environmental and anthropogenic factors. To measure such factors, revised universal soil loss equation (RUSLE) model in ArcGIS 10.3 has been employed in the study area. In this study, potential soil erosion risk ($RUSLE_{potential}$) determined by environmental factors i.e. rainfall erosivity factor (R), soil erodibility factor (K) and slope length and slope steepness factor (LS) has been calculated. Land use/land cover factor (C) for 1990, 2000, 2010 and 2015 has been computed to measure its change with time. Soil erosion control factor (P) has been computed. Combining $RUSLE_{potential}$ with C factor and P factor resulted in actual soil erosion risk ($RUSLE_{actual}$) for four different years.

The results showed that spatial distribution of potential soil erosion risk had a weighted mean (RUSLEweighted mean) of 63 t/ha/y with only 7.3% meeting soil erosion tolerance limit of 12 t ha-1y-1. The LULC changed with time, in 1990 weighted mean of C factor was 0.051 and in 2015 was 0.344. The actual soil erosion risk changed with time, in 1990 weighted mean ($RUSLE_{weightedmean}$) was 7.2 t/ha/y and 85% of the catchment was within tolerance limit, and in 2015 weighted mean ($RUSLE_{weighted\ mean}$) was 32 t/ha/y and 3% of the catchment was within tolerance limit.The study concludes that actualsoil erosion riskin Isiukhu river catchment was influenced bychange in Land use/land cover. 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 land degradation.

Index Terms- GIS, Isiukhu river catchment, Land use/land cover change, RUSLE, Actual soil erosion risk.

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 [1]. The intensity of erosion processes depends on soil properties, topography and vegetation cover. The author in [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 [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 [4]. Farmers' knowledge on soil erosion hazards is very crucial in sustaining Kenya's agricultural production [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 [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 [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 [7, 8]. Technologies to counteract fertility constraints are rarely implemented, as they do not consider system diversity or farm-specific characteristics [9].

Soil erosion in study area depends on both environmental and anthropogenic factors. To measure such factors, revised universal

soil loss equation (RUSLE) model in ArcGIS 10.3 has been employed in the study area. According to the author in [10], the process for determining soil erosion 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.

It is with the foregoing in mind that this research sought to fulfill its objective of determining soil erosion risk with change in land use/land cover in Isiukhu river catchment. The study employed RUSLE model in ArcGIS 10.3 in determining soil erosion risk.

II. Study Details, MATERIALANDMETHODS

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(Figure 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.

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.

Computation of Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) was calculated from equation (1) [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 equation (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)

LS factor was calculated from equation (3) [12]

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

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

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

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.

Computation of Cover management (C) factor for 1990, 2000, 2010 and 2015

For this study, C factors for 1990, 2000, 2010 and 2015 were generated from the Land use/land cover shapefile map of the Isiukhu study area. Kenya soil database from world soil information of international soil reference and information centre (ISRIC) was used to produce the soil shapefile for the study area. The land use/land cover 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 land use map feature. The land use/land cover map attribute table of the soil map of study area of each year (1990, 2000, 2010 and 2015) was edited with adding a new field of C factor values under the Edit menu at attribute view. Then under conversion in spatial analyst the feature (Isiukhu land use shapefile) using C factor as the field it was converted to Raster. The C factor used for different land use composition was tabulated

In this study, Fall's equation (5) was used in ArcGIS 10.3 environment to compute P factor values

$$P = (Fac) * 0.45249^{0.6} + (0.01745 * Slope\_degree) \quad (5)$$

where; P is practice factor; Fac = Study area DEM flow accumulation; Slope_degree = Study area DEM slope in degrees. As the first step, the elevation value was modified by filling the sinks in the grid. This is done to avoid the problem of discontinuous flow when water is trapped in a cell, which is surrounded by cells with higher elevation. This was done by using the Fill tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS. Then, Flow direction was generated from the Fill grid. The Flow direction tool takes a terrain surface and identifies the down-slope direction for each cell. This grid shows the on surface water flow direction from one cell to one of the eight neighboring cells. This was done by using the Flow direction tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS

III. RESULTS OR FINDINGS

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 (Figure 1)

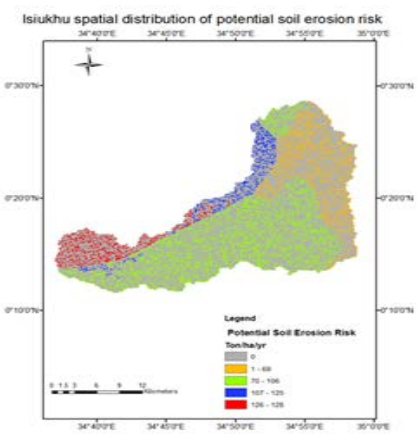

Figure 1: Spatial distribution of potential soil erosion risk map

Based on spatial distribution, Isiukhu river catchment potential soil erosion risk was classified in six classes (Table 1). 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 1: Spatial distribution of potential soil erosion risk

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 (Figure 2.4)

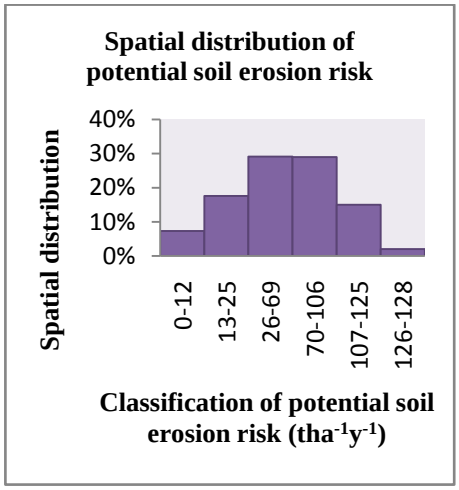

Figure 2: Spatial distribution of potential soil erosion risk

Determination of actual soil erosion risk ($RUSLE_{actual}$) using C factor of 1990

To determine actual soil erosion risk for 1990 ($RUSLE_{1990}$), R, K, LS and P factor maps were overlaid with C factor map of 1990 in ArcGIS 10.3 i.e. $RUSLE_{1990}$= $RKLSC_{1990}P$

The spatial distribution of the actual soil erosion risk showed that 0-6 t/ha/y covered 11%, 7-7 t/ha/y covered 44%, 11-12 t/ha/y covered 29% and 13-13 t/ha/y covered 17% (Figure 4.20). The results indicated that there were five classes of actual soil erosion risk in 1990 with minimum of 0 t/ha/y and maximum of 13 t/ha/y. The mean was 2 t/ha/y indicating standard deviation of 4 (Figure 11). These results showed that in 1990, more than 85% of Isiukhu river catchment had soil erosion risk within tolerance limit 12t/ha/y for Kenyan soils (Thomas, 1997). Compared with potential soil erosion risk which had more than 93% above soil erosion tolerance limit, land use/land cover in 1990 of C factor 0.002 to 0.1 played a great role in reducing soil erosion risk.

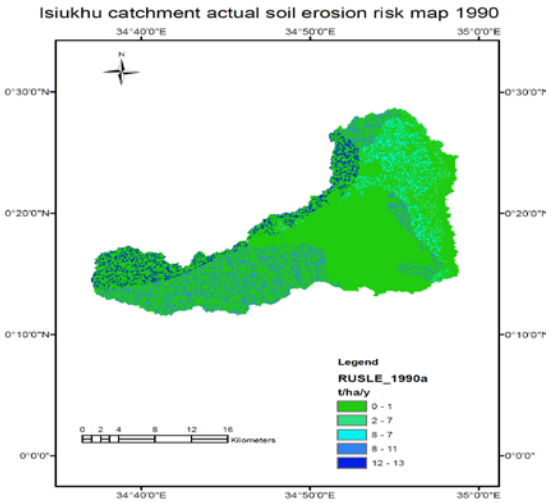

Figure 3: Isiukhu catchment actual soil erosion risk map 1990

Spatial distribution of actual soil erosion risk 1990 for Isiukhu catchment showed 0-1 t/ha/y covered 7,513 ha (11%), 2-7 t/ha/y covered 28,686ha (42%), 8-9 t/ha/y covered 683ha (1%), 10-11 t/ha/y covered 19,807ha (29%) and 12-13 t/ha/y covered 11,611ha (17%) (Table 8). The weighted mean ($RUSLE_{weightedmean}$) for Isiukhu river catchment for 1990 was 7.2 t/ha/y with standard deviation of 3.994. Therefore in 1990, the weighted mean for soil erosion risk ($RUSLE_{weightedmean}$) was below tolerance limit of 12 t/ha/y).

Table 2: Spatial distribution of actual soil erosion risk 1990

erosion rates (t ha^{-1} y^{-1})	Mid-point (x)	Area (ha) (c)	cx	% spatial distribution
0-1	0.5	7,513	3,756.5	11
2-7	4.5	28,686	129,087	42
8-9	8.5	683	5,805.5	01
10-11	10.5	19,807	207,973.5	29
12-13	12.5	11,611	145,137.5	17
Total		68,300	491,760	100
Weighted mean for 1990			$RUSLE_{Wtdmean1990}$ =7.2	

Estimation of Isiukhu catchment actual soil erosion risk using C factor of 2000

To determine actual soil erosion risk for 2000 ($RUSLE_{2000}$), R, K, LS and P factor maps were overlaid with C factor map of 2000 in ArcGIS 10.3 i.e. $RUSLE_{2000}$= $RKLSC_{2000}P$

The spatial distribution of the actual soil erosion risk showed that 0-2 t/ha/y covered 6%, 3-13 t/ha/y covered 20%, 14-20t/ha/y covered 27%, 21-23 t/ha/y covered 21 and 24-26 t/ha/y covered 26% (Figure 4.22). There were five classes of actual soil erosion risk in 2000 with minimum of 0 t/ha/y and maximum of 26 t/ha/y. The mean was 4 t/ha/y with standard deviation of 8 (Figure 4.23). These results showed that in 2000, 74% of Isiukhu catchment was having medium to high soil erosion risk (14-26 t/ha/y). Compared with actual soil erosion risk of 1990 which had more than 85% within soil erosion tolerance limit, land use/land cover in 2000 of C factor 0.003 to 0.2 had increased soil erosion risk by about 10% indicating worse land use/land cover management

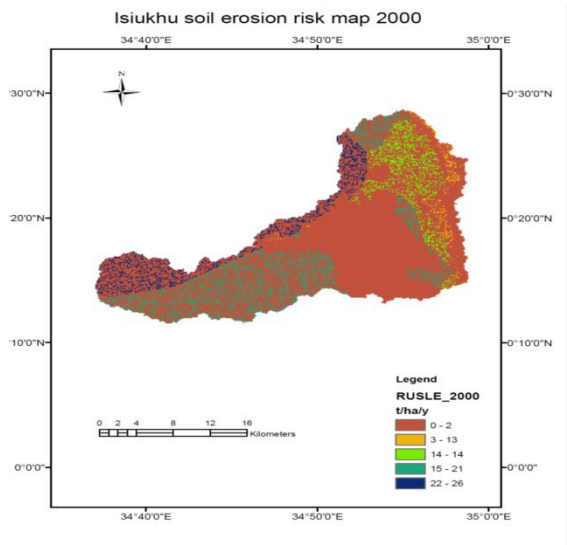

Figure 4: Soil erosion risk map 2000

Spatial distribution of actual soil erosion risk 2000 for Isiukhu catchment showed 0-2 t/ha/y covered 4,098ha (6%), 3-13 t/ha/y covered 16,392ha (20%), 14-20 t/ha/y covered 18,441ha (27%), 21-23 t/ha/y covered 14,343ha (21%) and 24-26 t/ha/y covered 17,758ha (26%) (Table 4.13).The weighted mean (RUSLEweighted mean) for Isiukhu river catchment for 2000 was 17.69 t/ha/y with standard deviation of 6.682. Therefore in 2000, the weighted mean for soil erosion risk ($RUSLE_{weightedmean}$) was above tolerance limit of 12 t/ha/y) by 5.69 t/ha/y. compared with 1990, soil erosion risk was higher by 10.49 t/ha/y (17.69-7.2).

Table 3: Spatial distribution of actual soil erosion risk 2000

erosion rates ($t\ ha^{-1}\ y^{-1}$)	mid-point (x)	Area (ha) c	cx	% spatial distribution
0-2	1	4,098	4,098	06
3-13	8	16,392	131,136	20
14-20	17	18,441	313,497	27
21-23	22	14,343	315,546	21
24-26	25	17,758	443,950	26
Total		**68,300**	**1,208,227**	**100**
Weighted mean for 2000			$RUSLE_{Wtdmean\,2000}$ =17.69	

Estimation of Isiukhu catchment actual soil erosion risk using C factor of 2010

To determine actual soil erosion risk for 2010 ($RUSLE_{2010}$), R, K, LS and P factor maps were overlaid with C factor map of 2010 in ArcGIS 10.3 i.e. $RUSLE_{2010}$= $RKLSC_{2010}P$

The spatial distribution of the actual soil erosion risk showed that 0-26 t/ha/y covered 2%, 27-41 t/ha/y covered 52%, 42-42 t/ha/y covered 28%, 43-48 t/ha/y covered 1% and 49-51 t/ha/y covered 17% (Figure 4.24). There were five classes of actual soil erosion risk in 2010 with minimum of 0 t/ha/y and maximum of 51 t/ha/y. The mean was 8 t/ha/y with standard deviation of 16 (Figure 13). These results showed that in 2010, 98% of Isiukhu river catchment was having high to very high soil erosion risk (27-51 t/ha/y). Compared with actual soil erosion risk of 2000 which had 74% of medium to high, land use/land cover in 2000 of C factor 0.03 to 0.3 had increased soil erosion risk by about 20% indicating worse land use/land cover management.

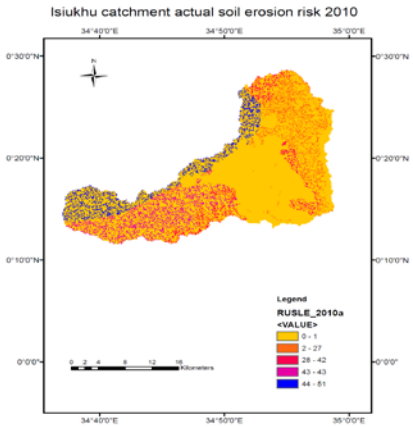

Figure 5: Soil erosion risk map 2010

Spatial distribution of actual soil erosion risk 2010 for Isiukhu catchment showed 0-1 t/ha/y covered 1,366ha (2%), 2-27 t/ha/y covered 35,516ha (52%), 28-42 t/ha/y covered 19,124ha (28%), 43-43t/ha/y covered 683ha (1%) and 44-51 t/ha/y covered 11,611ha (17%) (Table 10). The weighted mean ($RUSLE_{weightedmean}$) for Isiukhu river catchment for 2010 was 25.855 t/ha/y with standard deviation of 13.635. Therefore in 2010, the weighted mean for soil erosion risk ($RUSLE_{weightedmean}$) was above tolerance limit of 12 t/ha/y) by 13.855 t/ha/y. compared with 2000, soil erosion risk was higher by 8.165 t/ha/y (25.855-17.69).

Table 4; Spatial distribution of actual soil erosion risk 2010

erosion rates ($t\ ha^{-1}\ y^{-1}$)	mid-point (x)	Area (ha) (c)	cx	% spatial distribution
0-1	0.5	1,366	683	02
2-27	14.5	35,516	514,982	52
28-42	35	19,124	669,340	28
43-43	43	683	29,369	01
44-51	47.5	11,611	551,522.5	17
Total		68,300	1,765,896.5	100
Weighted mean for 2010			$RUSLE_{Wtdmean\,2010}$ =25.86	

Estimation of Isiukhu catchment actual soil erosion risk using C factor of 2015

To determine soil erosion risk for 2015 ($RUSLE_{2015}$), R, K, LS and P factor maps were overlaid with C factor map of 2015 in ArcGIS 10.3 i.e. $RUSLE_{2015}$= $RKLSC_{2015}P$

The spatial distribution of the actual soil erosion risk showed that 0-3 t/ha/y covered 2%, 4-34 t/ha/y covered 5%, 35-52 t/ha/y covered 45%, 53-53 t/ha/y covered 21% and 54-64 t/ha/y covered 27%. (Figure 4.26). There were five classes of actual soil erosion risk in 2015 with minimum of 0 t/ha/y and maximum of 64 t/ha/y. The mean was 11 t/ha/y with standard deviation of 21 (Figure 14). These results showed that in 2015, over 98% of Isiukhu river catchment was having high to very high soil erosion risk (35-64 t/ha/y). Compared with actual soil erosion risk of 2010 land use/land cover in 2015 of C factor 0.02 to 0.5 had increased soil erosion risk by over 20% indicating worse land use/land cover management

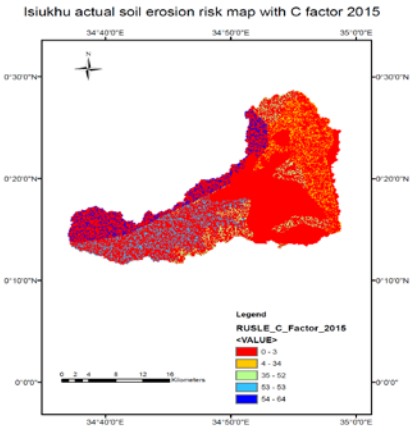

Figure 6: Soil erosion risk map 2015

Spatial distribution of actual soil erosion risk 2015 for Isiukhu catchment showed 0-12 t/ha/y covered 10,245ha (15%), 13-34 t/ha/y covered 26,637ha (39%), 35-51 t/ha/y covered 19,124ha (28%), 52-53t/ha/y covered 683ha (1%) and 54-64 t/ha/y covered 11,611ha (17%) (Table 12).The weighted mean ($RUSLE_{weighted\ mean}$) for Isiukhu river catchment for 2015 was 32.660t/ha/y with standard deviation of 16.931. Therefore in 2015, the weighted mean for soil erosion risk ($RUSLE_{weightedmean}$) was above tolerance limit of 12 t/ha/y) by 20.660 t/ha/y. compared with 2010, soil erosion risk was higher by 6.805 t/ha/y (32.660-25.855).

IV. CONCLUSIONS

This study has shown that by integrating RUSLE model factors in ArcGIS 10.3, it makes it possible to investigate both environmental and management factors independently. Catchment approach was applied to the study area to monitor the effects of anthropogenic pressure as a precursor to soil erosion risk. A digital elevation model ofhigher resolution can be used to compare precision before executing the model for determination of soil erosion risk.

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