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Soil Erosion Modelling On Yanze Watershed, Kigali, Rwanda

Irankunda Moise * Jean De Dieu Bazimenyera*Abias Maniragaba,

Department of Environmental and development studies, Faculty of Environmental studies, University of Lay Adventists of Kigali (UNILAK), Kigali, Rwanda

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ABSTRACT

Soil erosion involves detachment and transport of soil particles from top soil layers, degrading soil quality and reducing the productivity of affected lands, Soil eroded from the upland catchment causes depletion of fertile agricultural land and the resulting sediment deposited at the river networks creates river morphological change and reservoir sediment problems.

To achieve the goal of this research, using Geographical Information System (GIS) ;the Universal Soil Loss Equation (USLE) and digital elevation model (DEM) of the watershed was used to generate topographic factor (LS) factors; The soil survey data were used to develop the erodibility factor (K) ; The value of cover management (C) factor and support practice (P) factor were collected from literature and digitized land use land cover map of the study area, the rainfall runoff erosivity (R) was derived from rainfall data. Those factors were calculated from local data collected from Rwanda Land Use Management Authority (RMLUA) and Meteo Rwanda.

The objectives of this study was to identify the hotspot of soil erosion in Yanze watershed ; to analyze the spatial distribution of soil erosion within Yanze watershed ; to quantify the soil erosion rate in Yanze watershed and to propose the land management practices that can reduce the soil erosion in identified hotspot of soil erosion Yanze watershed. This research combines USLE and computer capabilities of Using GIS specifically ArcGIS 10.5.to store USLE factors ; and calculation of soil loss by multiplying six mentioned above factor , USLE factors as individual digital layer and multiplied together to create soil erosion potential map, the results indicate the average annual soil loss (A) within the watershed is about 5798.72445 m^3/ha/ year which is high compared to the values of potential soil loss vary from 4.3 to 1,819.7 m^3 ha-1 year-1 in the Yangou watershed (China) and 6 to 1200 t/ha/year in Urualla watershed (Nigeria) .

This is highly dependent on rainfall runoff erosivity (R) value which ranges between (105 to 110.64) MJ/ha.mm/h with the highest value being in the upper part of delineated watershed and lowest value in its lowest part, hence it could be better if the implementation of land husbandry measures put in place in order to reduce high risk of soil erosion.

Keywords: Geographical Information system, soil and Universal Soil Loss Equation (USLE).

I. INTRODUCTION

In China due to fragmentized terrain and physiognomy of typical loess landform, long term anthropogenic influences, and inherent vulnerability, soil erosion is a serious problem in the Loess Plateau of China. There is a critical need to assess soil erosion and spatial distribution for achieving sustainable land use and comprehensive soil conservation management. Taking the Yangou watershed as a case and using the Landsat Thematic Map per image (land use map), Digital Elevation Model (DEM), soil maps, and precipitation data, the study integrated the revised universal soil loss equation (RUSLE) with GIS technology to estimate soil loss and its spatial distribution. The benefits of soil conservation of land use types were analyzed and the measures for future soil conservation planning were discussed. The results show that silt covered land and terrace have high benefits of soil conservation, indicating that building check dam, producing silt covered land for farming, and converting sloped farmland to terrace are effective ways to control soil erosion in the Yangou watershed (Qing Tang et al, 2014).

In Nigeria Soil erosion represents a natural risk which produces material and human losses annually. The assessment and mapping of erosion prone areas are essential for soil watershed management. The objective was to apply RUSLE model to determine the amount of soil loss in Urualla watershed of Imo, Nigeria. Land use and land cover map was obtained from Google earth satellite image; ground control point data was collected from GeoSmart Survey, Imo State, Nigeria; 25-year sannual rainfall data was obtained from NIMET; soil map was generated from Onyekanne et al. (2012) soil data.

The various components of RUSLE were integrated into the ArcGIS 10.2.1 to estimate the annual soil loss in the area. The soil loss in the area ranged from6 to 1200 t/ha/year while the mean annual soil loss is 36 t/ha/yr. The erosion map obtained shows that in the study area, 25.9% has medium erosion rate of 10-15 t/ha/yr; 33.6% has moderately high erosion rate of 15-25 t/ha/yr; 16.4% has high rate of 25-50 t/ha/yr while 14.7% has a rate greater than 50 t/ha/yr. The study shows that GIS presents simple and low-cost tools for assessing erosion potential and risk in a watershed (B.U. Dike, 2018)

Rwanda, land of thousands of hills, is small land locked country located in central Africa characterized by its mountainous topography. Soil erosion forms a prominent threat to the agricultural development of Rwanda, in which steep slopes prevail and the ever-increasing population pressurize smallholder family farms. As one of the most basic natural resources, land relates to almost all the human activities directly or indirectly and is crucial for sustaining livelihoods in Rwanda and world in general. However, land degradation is one of the major and widespread environmental threats both in past and present years. Furthermore, soil erosion is regarded as the most serious form of land degradation around the world, especially in developing countries like Rwanda. The percentage of land that has been reported as protected against soil erosion in Nyarugenge district is (74.1 %) Kicukiro is reported to have the lowest percentage (38.3%) and Gakenke the highest (94.5 %) among all districts (NISR, 2016).

Universal Soil Loss Equation (USLE) and revised Universal soil loss equation (RUSLE) are the most popular empirically based models used globally for erosion prediction and control and has been tested in many agricultural watersheds in the world. The main reason why empirical regression equations are still widely used for soil erosion and sediment yield pre-dictions is their simplicity, which makes them applicable even if only a limited amount of input data is available.

Remote sensing and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. For this reason, use of these techniques have been widely adopted and currently there are several studies that show the potential of remote sensing technique integrated with GIS in soil erosion mapping (Reshma Parveen, 2012).

Every factor within the USLE is calculated by GIS, which is obtained from meteorological stations, land use maps from (orthophotos, Google earth and Earth explorer), soil data and results of other relevant studies.There are several factors included in this model, such as rainfall erosivity, soil erodibility, slope length and steepness factor, cover management factor, and conservation practice factor. Yanze watershed passes in boundary of Jali and Kanyinya sectors located in Nyarugenge and Gasabo districts, Kigali city of Rwanda, the activities around the area; its slope steepness and low land covers accelerates soil erosion.

II. MATERIALS AND METHODS

2.0. Introduction

This chapter describes the study area, data sources and tools, software, basic concepts, the procedure of the USLE model and how six parameters is estimated, based on the rainfall events, DEM, soil type map, and land cover map.

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2.1. Study area description

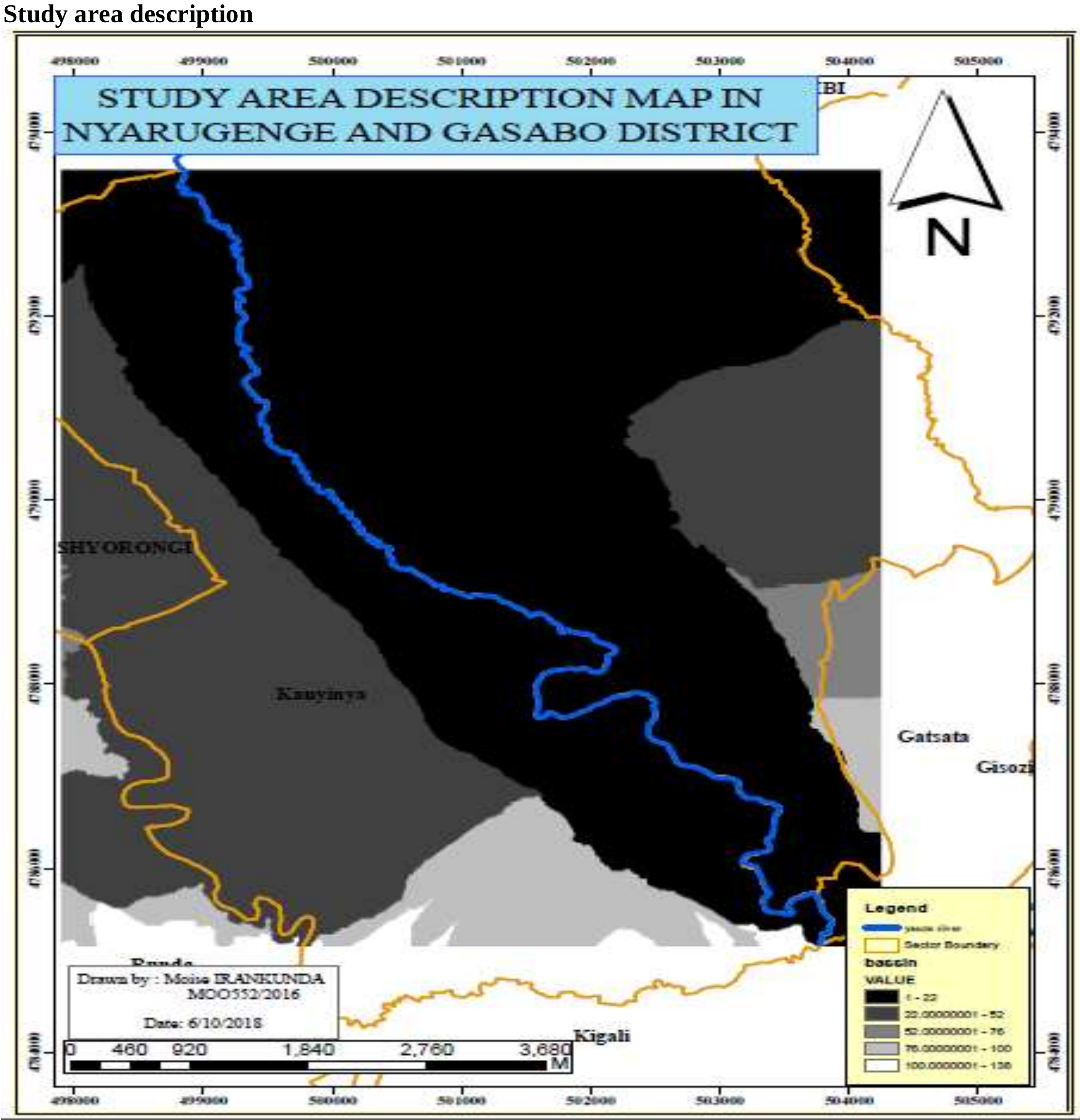

Figure 1: Map of Yanze Watershed

The study area is in Gasabo and Nyarugenge districts, the delineated area covers some part of shyorongi, Kanyinya, Gatsata and Jali sectors

2.2. Data sources and tools

2.2.1. Data sources

The quantitative evaluation of soil erosion on the Yanze watershed using GIS techniques is based on rain fall data, digital Elevation Model (DEM), land cover map, and Ortho photographic images. Those will be obtained from meteorological institutes, national land center of the country as summarized below

Table 1:Data used and sources

Data used	Data source	Usage
Orthophotos 2009	Rwanda Land Use Management Authority	To display the image of the study area for visualization and digitizing existing land use.
DEM (Digital Elevation Model) 10 m resolution.	Rwanda Land Use Management Authority	The DEM data will be added to ArcGIS 10.5 to delineate watershed and calculate flow length and slope steepness.
Rain fall data	Kigali city Meteorological Station	To calculate R factor of the study area.
Google earth Image.	Downloaded	To see current land uses and compare with orthophotos.

2.2.2. The Digital elevation model (DEM)

Digital elevation model (DEM) is the digital file consisting of terrain elevation for ground positions at regularly spaced horizontal intervals. In other word, digital elevation model (DEM) data are digital representations of cartographic information. The DEM data was added to ArcGIS 10.5 to delineate watershed, to calculate the flow length and slope steepness.

2.2.3 Land use/ Land cover description of study area

The land use types in Yanze watershed region can be classified as agricultural lands, forest, bare land, pasture, residential and built up areas. Residential (and built up area) lands are the most common land use type across this area that covers 38% of the total study area. Land use map was obtained through field survey, visualization, digitization of Google earth and satellite images.

Table 2: Existing land use type and percentage

Type of land use	Area (Ha)	% of Area (Ha)
Agricultural	801.45	37%
Bare soil	141.91	7%
Barren rock	55.57	3%
Forest	170.81	8%
Pasture	161.44	7%
Residential	825.01	38%
Grand Total	2156.19	100%

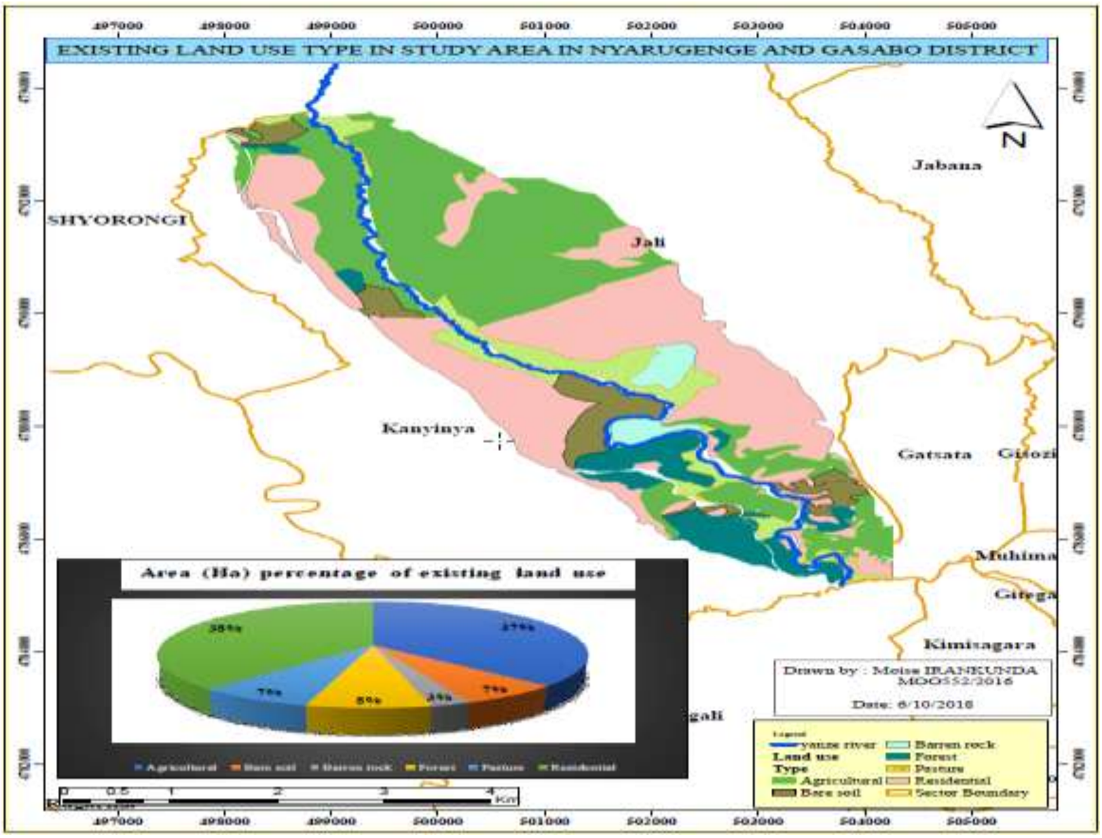

Figure 2: Existing land use type in study area

2.2.4. Land use, Crop factor (C) and conservative practice (P)

Table 3: C and P factor

Land use	C factor	P factor
Agriculture	0.128	0.92
Residential	0.030	1.00
Bare soil	0.60	1.00
Barren rock	0.5	1.00
Forest	0.01	1.00
Pasture	0.02	1.00
Average	1.288	5.92

2.2.5. Tools and Software

GPS or Global Positioning Systems are computer systems that use satellites in orbit around the globe to provide exact longitudinal and latitudinal position of the user ; Computers: for data storage and processing such as data interpolation and conversion ; ArcGIS software as the processing engine and a vital component of an operational GIS. It is made up of integrated collections of computer programs that implement geographic processing functions. In this research,ArcGIS has been applied to analyze the amount of soil loss in the study area in combination universal soil loss equation (USLE).

2.3. Methodology

2.3.1. Universal soil loss equation (USLE)

The Universal Soil Loss Equation (USLE) as conventional model of soil erosion that takes into account climate characteristics, soil properties, topography, surface conditions, and human activities; has been used after considering the following factors:

The equation is A = R* K *L* S* C* P

Where:

A = average soil loss (e.g., tons/acre/year)
R = rainfall runoff erosivity factor (derived from the energy in an average rainfall)
K = soil erodibility factor (average soil loss in tons/acre/year at a standard slope length and steepness)
L = slope length factor
S = slope steepness factor
C = crop management factor (effect of crop management factors on soil erosion)
P = support practice factor (determined by contouring, strip cropping, terracing, and subsurface drainage)

Universal soil loss equation analysis in GIS

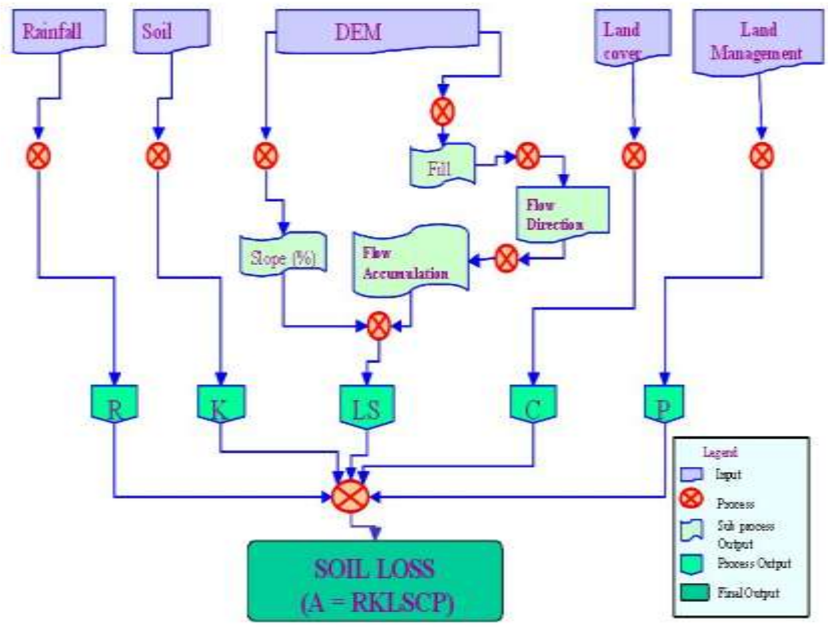

Figure 3: Flowchart showing analysis of soil loss based on GIS application

2.3.2. Triangulated Irregular Network

A Triangulated Irregular Network (TIN) data model is ideal for representing surfaces, for example, terrain (Ann et la, 2007). Data are represented in the form of a series of non-overlapping triangles drawn between irregularly spaced points. In the case of a terrain model, each triangle represents an area of constant slope or gradient. Due to their capability of mapping irregularly spaced data, TINs can model surfaces that vary sharply in some areas more accurately that a raster where data is more variable, more points can be added to represent the increased variability and fewer points are required where the surface is less variable.

2.3.3 Soil conservation model (Source: MINAGRI, 2007)

Table 4: Proposed conservation model

Slope categories	Proposed conserved model
0 – 6	Agriculture, residential
6 – 16	Soil bund, pasture, residential
16 – 40	Pasture, bench terraces

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40 – 60	Narrow cut, terraces, agriculture, pasture
>60	Forest, pasture

III. RESULTS AND DISCUSSION

The combined use of GIS and erosion models has been integrated to estimate the magnitude and spatial distribution of erosion of the study area. Five different erosion risk factors including rainfall erosivity, slope length and steepness, land cover management, soil erodibility and soil conservation were determined. The results of modeling these factors are shown and discussed below.

3.1. Watershed delineation

Watershed has been delineated using hydrological modelling techniques technology under spatial analysis and modelling tools in ArcGIS.

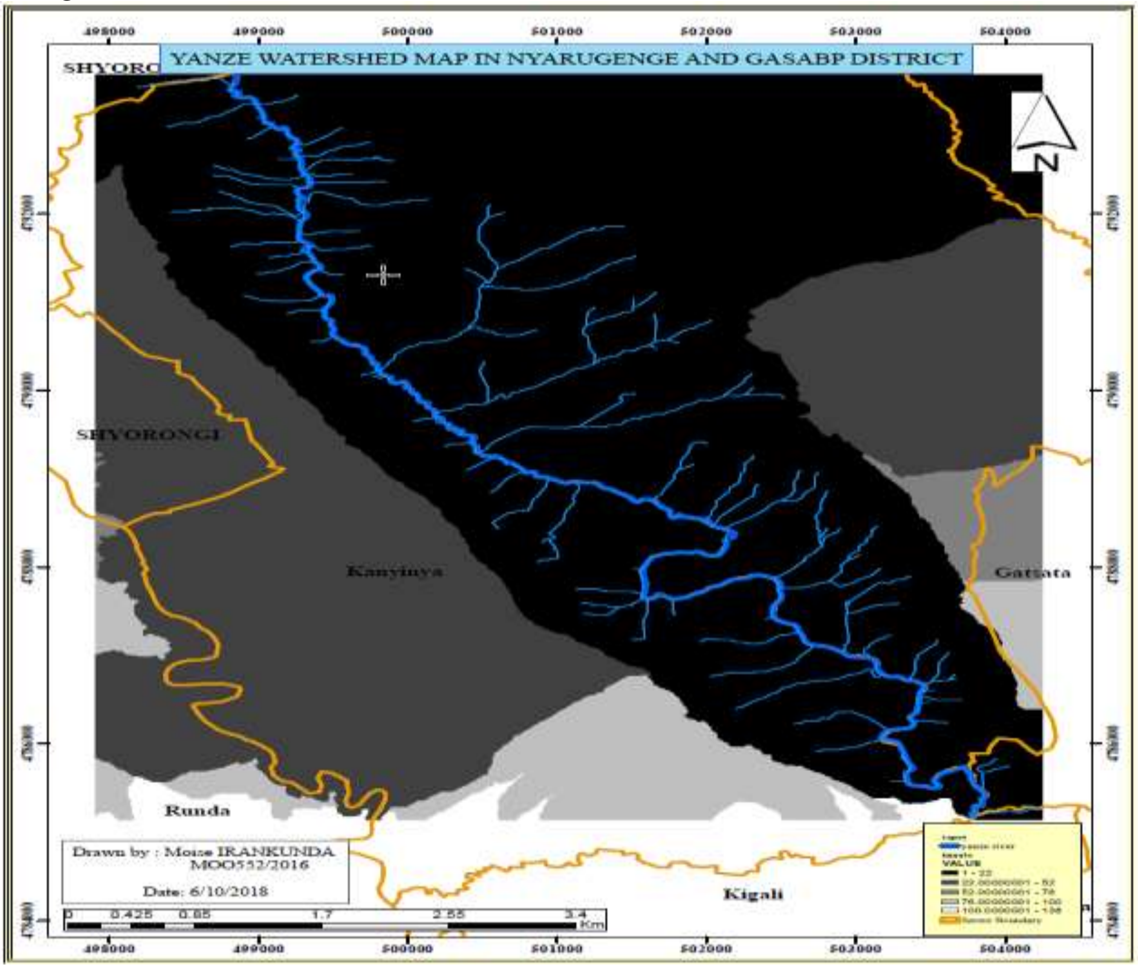

Figure 4: Yanze watershed map

3.2. Estimating rainfall erosivity R factor

Rainfall erosivity R factor R= 79+0.363P, where P is the mean annual rainfall (mm). This value was determined based on the Thiessen polygon; this later was determined using GIS tools where the Thiessen polygon was made based on the national rainfall shape file data. Using interpolation technique mean annual rain fall was established using kriging method. According to rainfall erosivity (R-factor) map below the value ranges from (105.93 to 110.64) MJ/ha/h/yr.

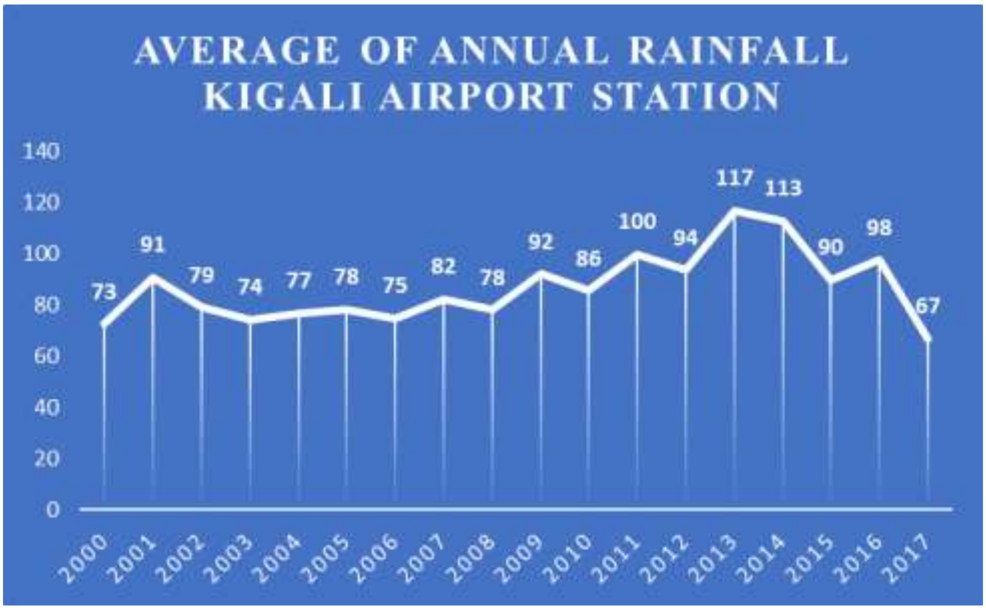

Figure 5: Average of annual rainfall Kigali Airport station

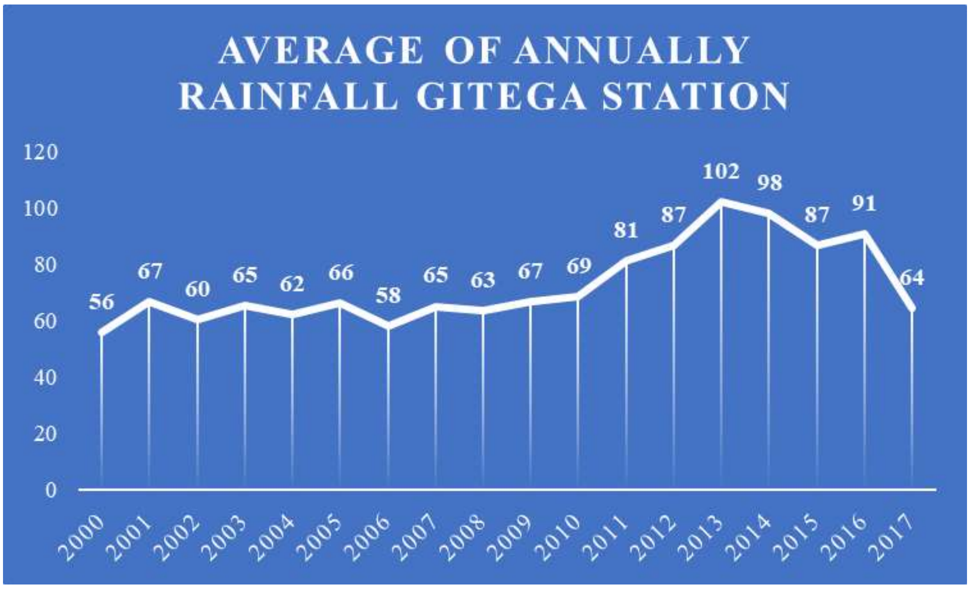

Figure 6: Average of annual rainfall Kigali Gitega station

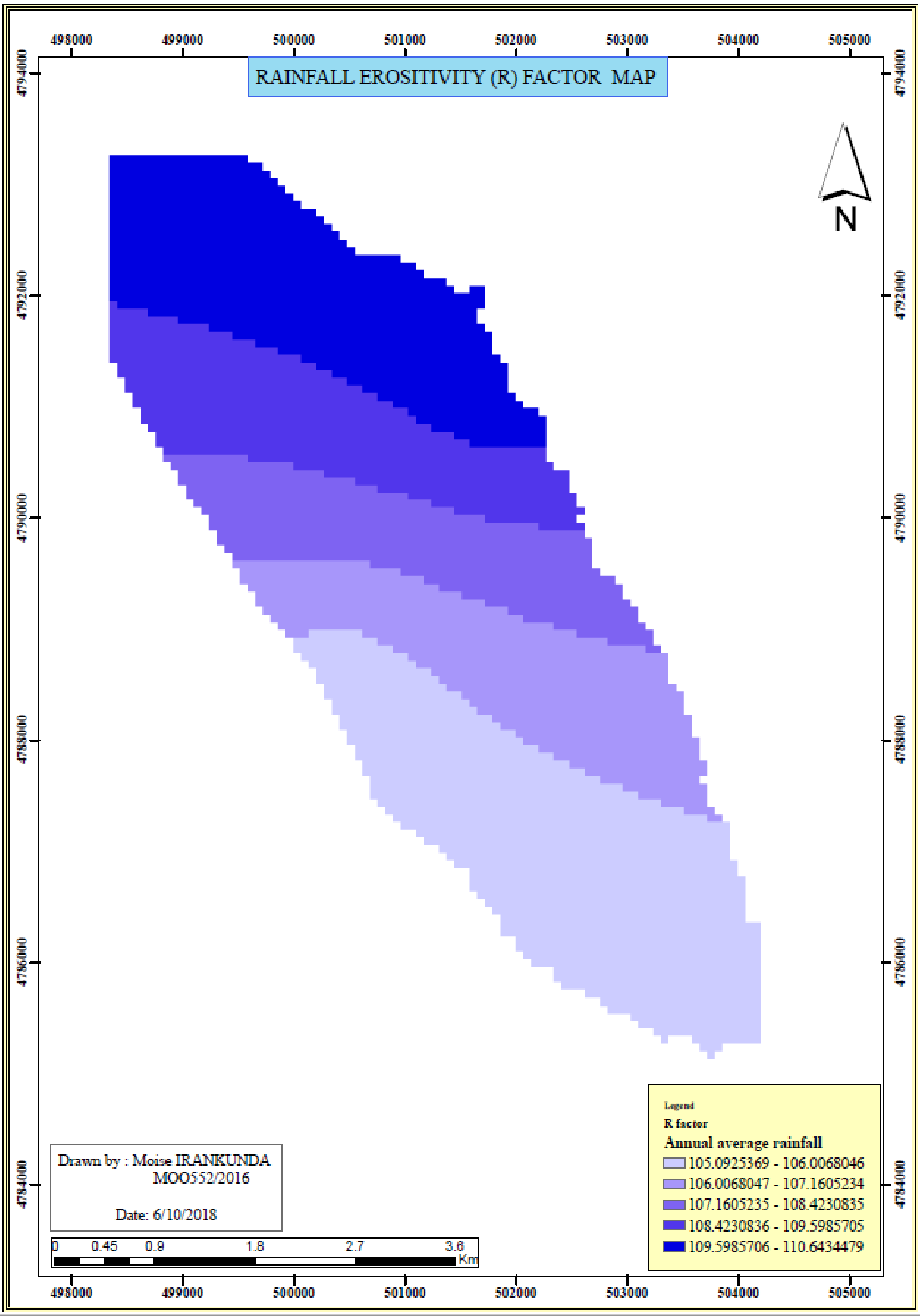

Figure 7: Rainfall erosivity (R-factor) map

Table 5: Rain fall erosivity (R factor) and coverage

R factor	Area (ha)	Area (in %)
105.092-106.0068	504.85	22.47223521
106.0068-107.16	367.78	16.37087979
107.06-108.42	315.44	14.04108522
108.42-109.598	374.64	16.6762369
109.598-110.64	683.84	30.43956289

In modelling the rainfall erosivity, it can be seen that the minimum rainfall in the study area is 105.092 ha and the maximum is 110.64 ha. The maximum rainfall is ranging between 109.598 and 110.64 which cover an area of 683.84 ha in north of our study area, while the minimum ranges between 107.06 and 108.42 which covers an area of 504.85 ha in the south of our study area therefore the higher intensity of rainfall the higher erosion potential.

3.3 Estimating soil erodibility K factor

As we have seen in chapter 2, soil erodibility K factor depends on physical and biochemical soil properties, it ranges between 0 and 1 it can be estimated using pedotransfer function. In this study 1 was used as K factor.

3.4 Determination of topographic factor (LS)

The slope length L represents the effect of slope length on erosion, and slope steepness S reflects the influence of slope gradient on erosion. For this study L is the Flow length and S is the slope steepness which is given in meters and degrees respectively.

Basically, topographic factor (LS) were estimated from 10m resolution DEM of delineated area, with incorporation of Digital Elevation Model (DEM) into GIS, the slope gradient S and slope length L was determined using geoprocessing analysis under spatial analysis.

Moore and Burch (1985) equation:

$LS = (Slope\ Length/22.13)^{0.4} * (0.01745\ Sin\ □/0.0896)^{1.4} * 1.4$; where Slope length is flow accumulation *cell resolution (DEM) and □ is "Slope in Degree".

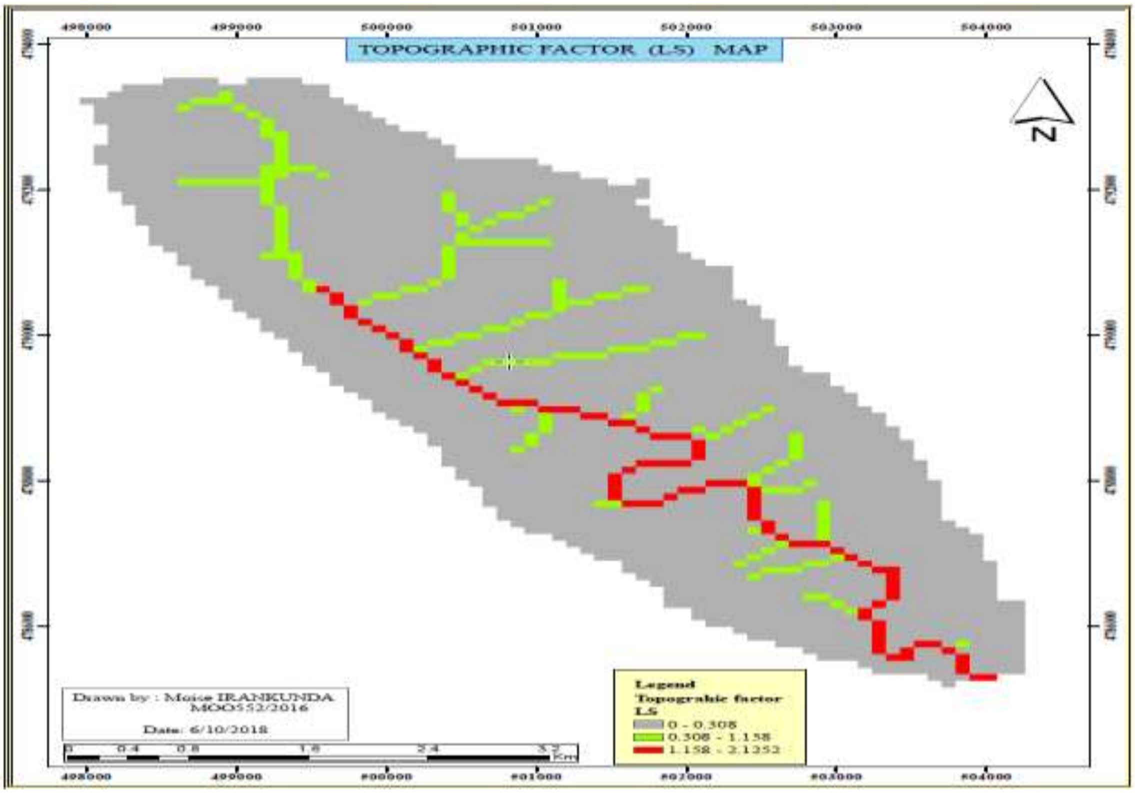

Figure 8: Topographic factor (LS) map

The estimated LS values based on flow length, is varying between 0 and 2.1251 as presented in above map. This later shown that slope angle was very low and also slope length this might have an impact on soil losses production.

3.5 Determination of cover management (C) and Conservative practice (P)

Table 6: C factor values and coverages

C-factor	Coverage(ha)	Area (%)
0.01 - 0.01	170.7998	7.92
0.01 – 0.029	161.533	7.49
0.029 – 0.128	824.53	38.25
0.128 – 0.600	998.803	46.33

Table 7: P factor values and coverage

Conservative practice	Coverage (ha)	Area (%)
0.92 – 0.92	801.065	37.158
0.92 - 1	1354.754	62.842

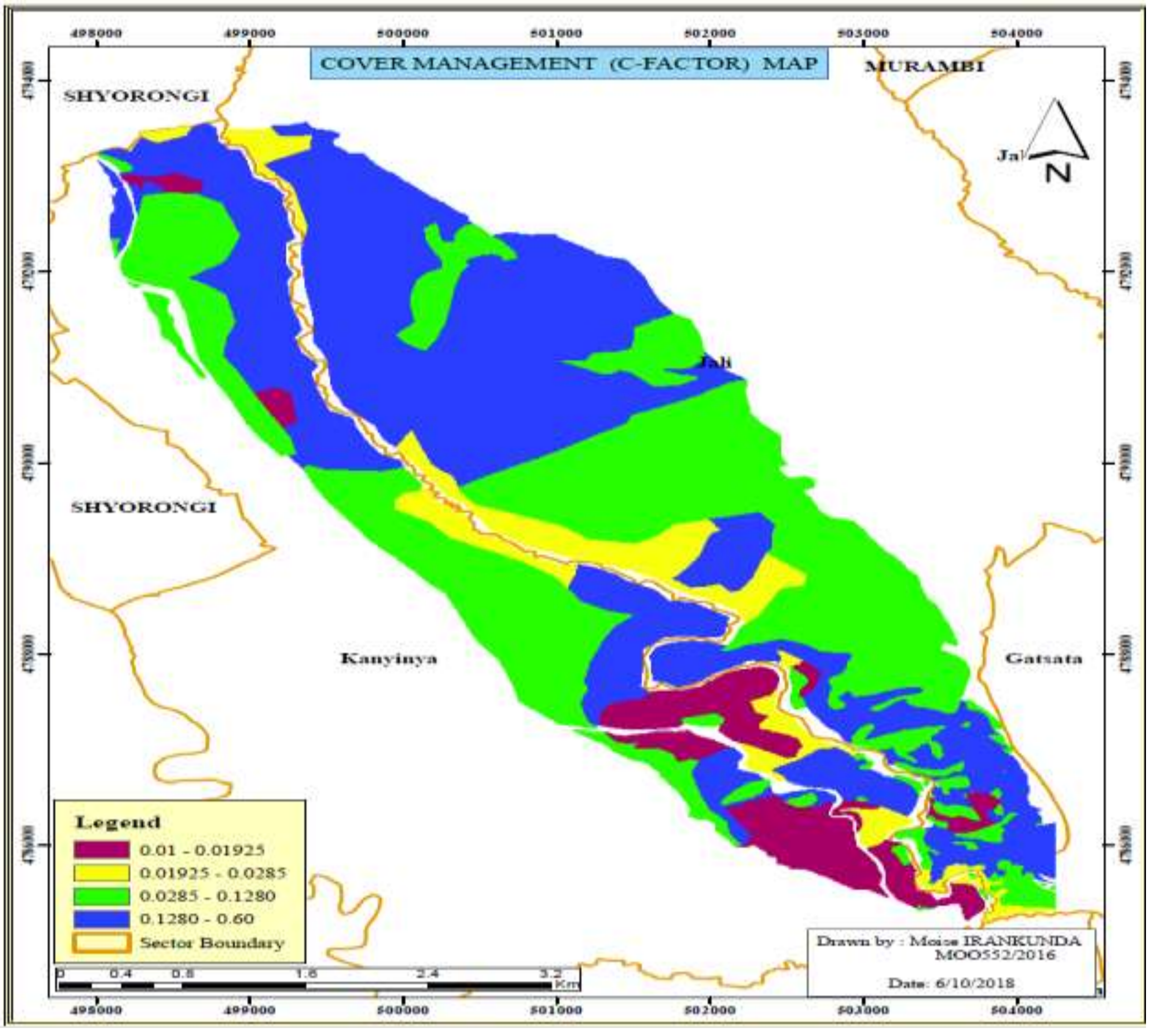

Figure 9: Cover management (C-factor) map

International Journal of Advances in Engineering and Management (IJAEM)
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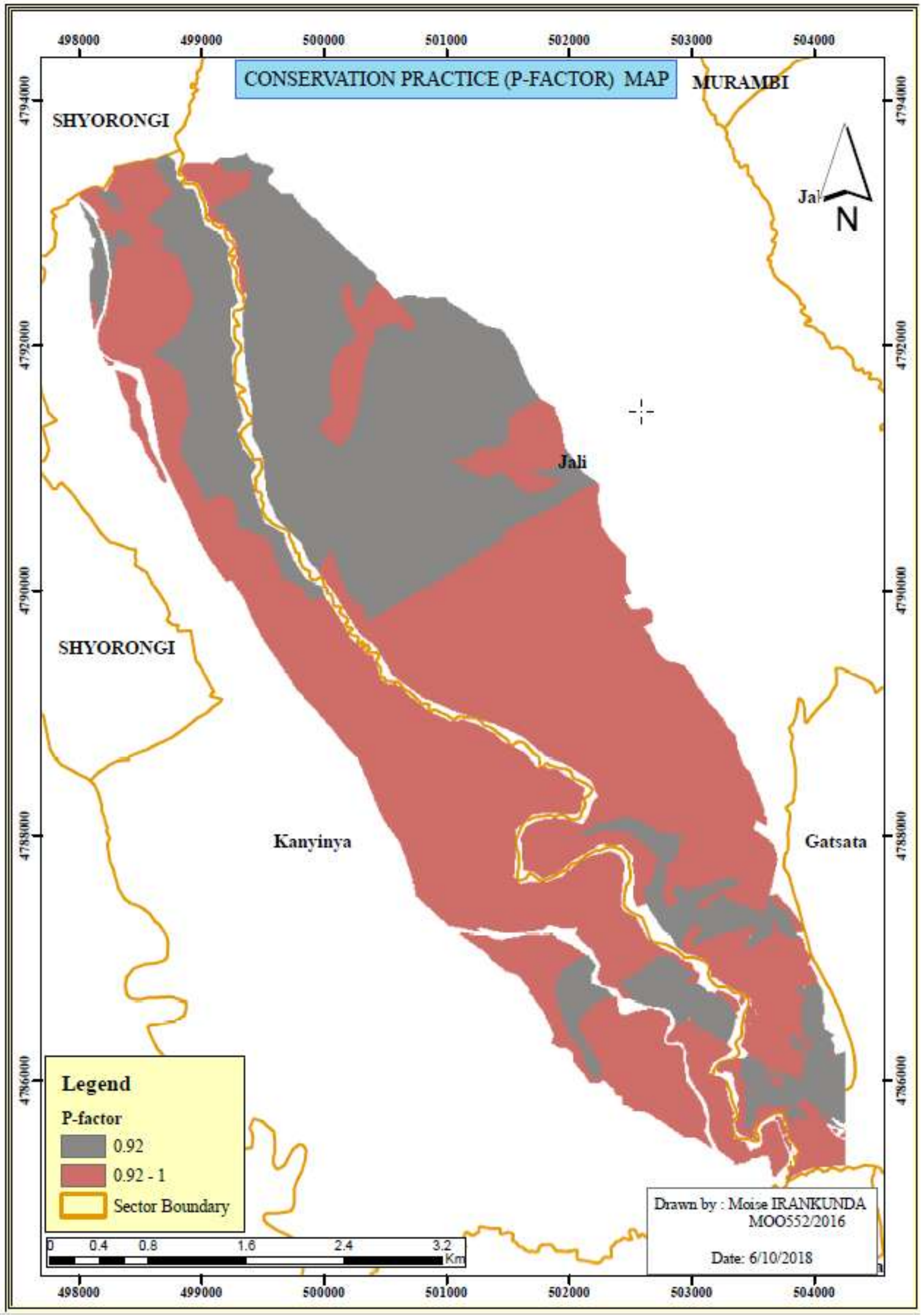

Figure 10: conservation practice (P-factor) map

International Journal of Advances in Engineering and Management (IJAEM)
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Based on land cover management factor as modeled and the results were shown in figure 13 (as it ranges from 0.01 to 0.60). the results as seen in the table indicated that 0.01 covers 7.92%, 0.01-0.029 covers 7.49%, 0.029-0.128 covers 38.28% and 0.128-0.600 covers 46.33 of the total area, the vegetation cover has impact in the erosion by intercepting the rainfall thus reducing the rainfall velocity and increasing infiltration. About conservation practice it was observed that 62.842% of the total area was occupied by class 0.92- 1 factor.

3.6. Computation of soil losses

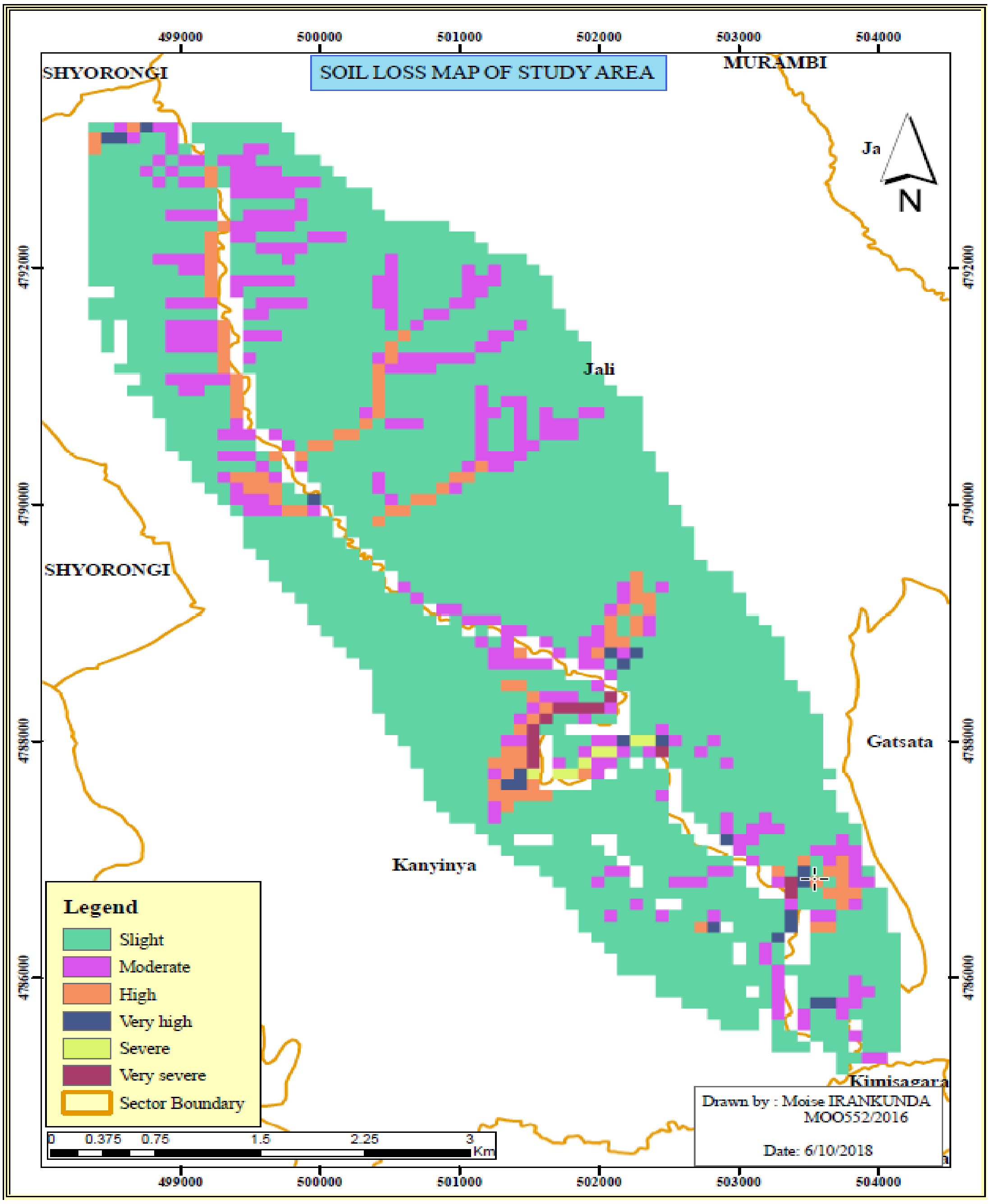

Figure 11: soil losses (A) map

Table 8: Soil losses description

s/n	Soil loss zone	Range (ton/ha/year)	Average	Area (ha)	Area (%)	Volume(m3)
1	Slight	0 - 2	1	1685.036	82.01	1685.036
2	Moderate	2 - 7	4.5	247.54	12.05	1113.93
3	High	7 - 15	11	87.096	4.24	958.056
4	Very high	15 - 26	20.5	17.1039	0.83	350.62995
5	Severe	26 - 99	62.5	6.829	0.33	426.8125
6	Very Severe	>99	114	11.09	0.54	1264.26
Total				**2054.6949**	**100**	**5798.72445**

The main goal of this study was to test the USLE model in the study area. All USLE parameters determined for the study area were either in spatial format and/or in numerical format. The spatial map and other factors were integrated and analyzed in ArcGIS module. The annual soil loss map obtained was grouped in the following scales of priority: Slight (0 to 2 ton/ha/year), Moderate (2 to 7 ton/ha/year), High (7 to 15 ton/ha/year), Very high (15 to 26 ton/ha/year), Severe (26 to 99 ton/ha/year) and Very severe (>99 ton/ha/year).

It has been observed the most eroded land was located in the following figure soil losses was high at downstream compared to upstream this was caused by the increase of slope length at downstream as well as accumulation of soil lost toward downstream. The highest value per ha was found in upstream according to the following figure this might be caused by steepness and land use land cover which was not proportional to slope categories.

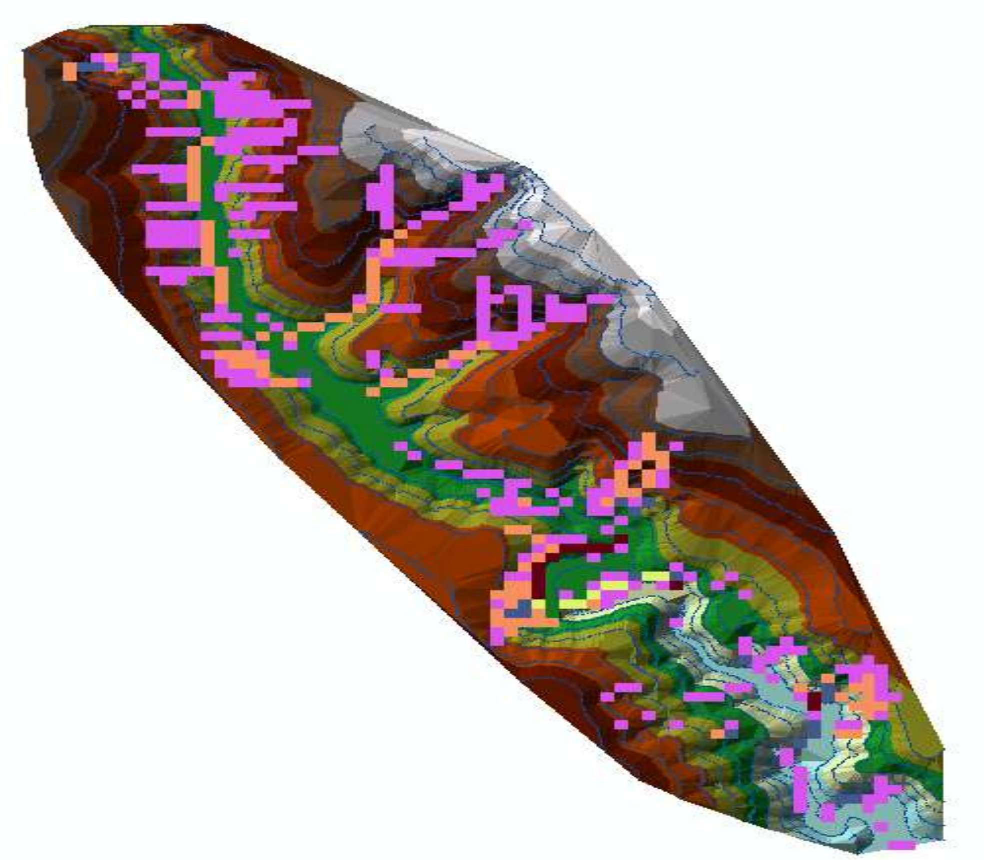

Figure 12: TIN overlaid with soil losses map

3.7 Establishment of conservation model

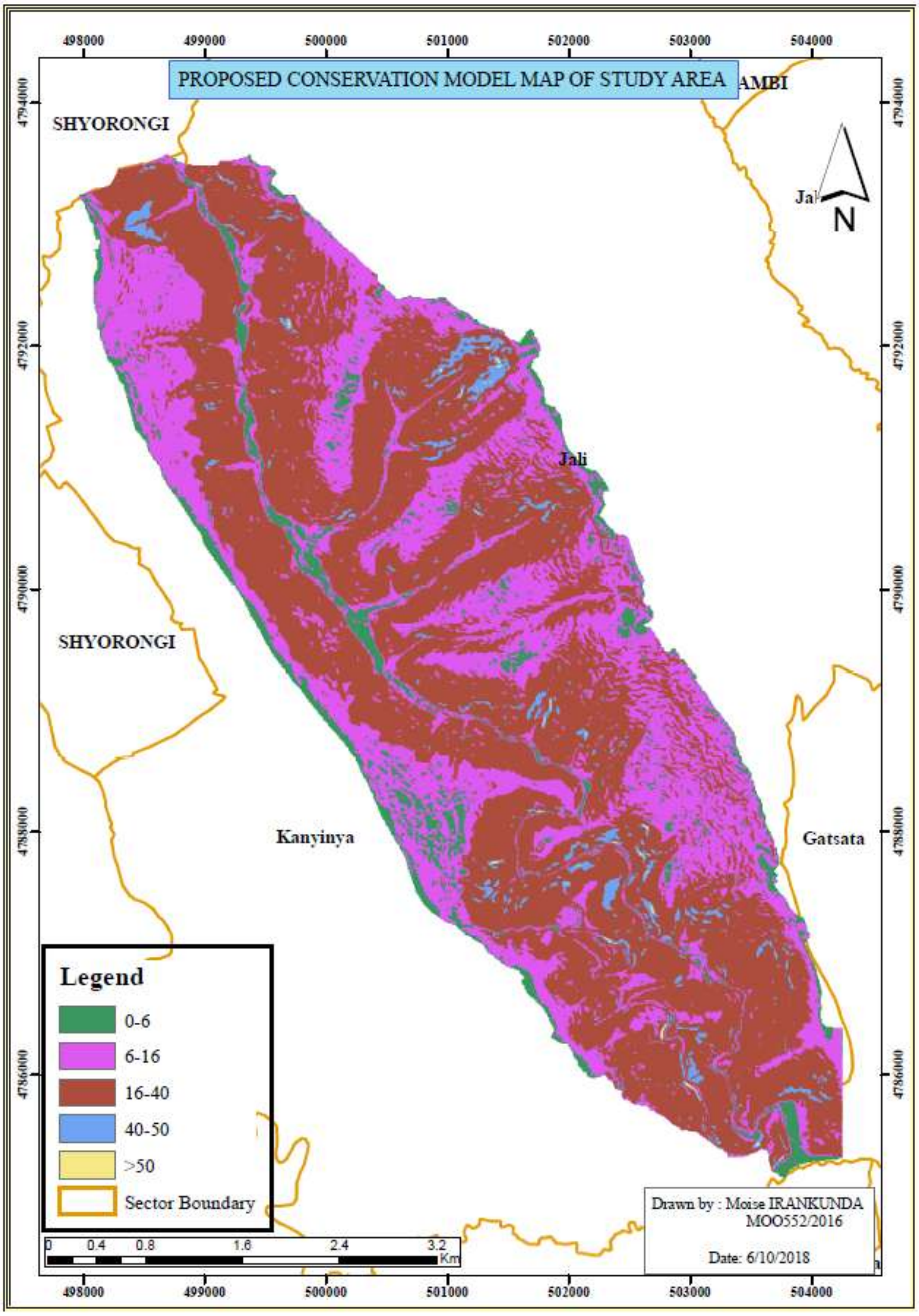

Figure 13: Site development plan map

Table 9: Site development plan

Slope categories	Area (ha)	Area (%)	Proposed conserved model	Suitability model
0 - 6	747.46	32.18	Agriculture, residential	Class 1
6 - 16	1362.87	58.68	Soil bund, pasture, residential	Class 2
16 - 40	154	6.63	Pasture, bench terraces	Class 3
40 - 50	56.58	2.44	Narrow cut, terraces, agriculture, pasture	Class 4
>50	1.78	0.08	Forest, pasture	Class 5

IV. CONCLUSION AND RECOMMENDATIONS

The study conducted in Yanze watershed located in Nyarugenge and Gasabo districts categorized into five different erosion risk classes. The spatial map and other factors were integrated and analyzed in ArcGIS module. The annual soil loss map obtained was grouped in the following scales of priority: Slight (0 to 2 ton/ha/year), Moderate (2 to 7 ton/ha/year), High (7 to 15 ton/ha/year), Very high (15 to 26 ton/ha/year), Severe (26 to 99 ton/ha/year) and Very severe (>99 ton/ha/year).

Figure 11 shows annual erosion map of the study area, helpful in identification of areas vulnerable to soil erosion in table 8 shows the spatial distribution of different erosion classes in the study area. The total annual soil loss was 5798.72445 m^3/ha/ year; this value is very high compared to The values of potential soil loss vary from 4.3 to 1,819.7 m^3 ha-1 year-1 in the Yangou watershed (China) and 6 to 1200 t/ha/year in Urualla watershed, hence it could be better if the implementation of land husbandry measures put in place.In order to control soil loss. It is recommended that land husbandry where agriculture was at slope 0 to 6 without any physical soil conservation measures and occupying 747.46 ha and 6 to 16 with engineering measures such as soil bund, bench terraces and narrow cut terraces occupying 1575.23 ha. Residential will be recommended to slope 0 to 6 and also to 6 to 16 with appropriate drainage and landscape planning. On the slope higher 50 nothing recommended except biological measures, this area occupied 1.78 ha

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