Investigation and Computation of the Soil Erodibility Factor in Karubanda watershed located in Ngoma, Huye and Mbazi Sectors of Huye District, Southern Province of Rwanda using USLE Nomograph (K-factor) Equation

F. Uwisunzimana[1], F.X. Naramabuye[1], O. Munyaneza[2], D. Uwizeyimana[3], S. Uwingabire[4]

[1]University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine. School of Agriculture Engineering and Environment Management, (UR-CAVM), Busogo, Post Box: 210 Musanze.

[2]University of Rwanda, School of Engineering, Department of Civil Engineering P.O. Box 3900, Kigali, Rwanda

[3]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O. Box 29053, 00625 Nairobi, Kenya

[4] Sokoine University of Agriculture, P. O. Box 3000, Chuo Kikuu, Morogoro -Tanzania

Abstract: ***Soil erodiblity signifies the level of resistance of soil to rainfall and runoff erosivity, Soil physico-chemical properties such as SOM (Soil Organic Matter), soil texture, soil structure and soil permeability are key master control of soil erodibility. The present study was conducted to examine the prospective range of soil erodibility in mentioned watershed. Watershed delineation was done using Arc GIS 10.5 software and shape file of Digital Elevation Model (DEM) of Huye District. Systematic soil profiling was performed in order to assess the number of soil horizons that affect permeability of soil. A total of 25 Soil samples were taken on grid of 81 ha within Karubanda watershed covering an area of 1998 ha. The Soil samples were analyzed for soil texture, soil organic carbon, soil structure, and permeability in the University of Rwanda Laboratory of soil and Plant analysis, Wischmeier model was used to determine soil erodibility of Karubanda watershed. The results show moderate range of soil erodibility, the figure show that the soil erodibility ranges from 0.3 to 0.7Mg h MJ^{-1}mm^{-1}.The mean is 0.454Mg h MJ^{-1}mm^{-1} and standard deviation is 0.16 of soil erodibility in entire watershed, Coefficient of Variation(CV) was 35% , thus ,soil erodilility variation is moderate in Karubanda Watershed .Nyakagezi sub watershed was reached maximum value of soil erodibility 0.7 Mg h MJ^{-1}mm^{-1},while Karubanda sub-watershed revealed low value of soil erodibility with 0.3 Mg h MJ^{-1}mm^{-1}, land use master plan, agronomic techniques like soil conservation practices (forestation, hedgerow, contouring, strip cropping and application of organic matter)as well as mechanical techniques (terraces and waterway) at Karubanda watershed are needed to reduce the degree of susceptibility of soil which are being eroded specifically in critical area of Nyakagezi sub watershed.***

Keywords: Nomograph,soil erodibility, soil susceptibility, Rwanda, watershed conservation

1. Introduction

Soil erosion is defined as soil detachment, transportation and deposition of dislodge soil particles in landscape (Balasubramanian, 2017). It is tremendous threat of soil and environment in the world (Morgan, 2005) and influenced by five erosive factors that includes rainfall erosivity, soil erodibility, cover management, topographical and support practice(panagos, 2015). Soil water erosion interrupt normal condition of ecological services includes crop production, drinking water and nutrient, carbon stock, drainage system, habit for variety of organisms and biodiversity (panagos, 2015).

Two third agricultural land in the world are not affected by soil erosion while one third of world's agricultural land were undermined by erosion (pimentel, 1995), the prediction of soil loss show that South America and Africa have high value of soil loss 3.53 and 3.51 Mg ha^{-1} yr^{-1}, followed by Asia with the value of 3.47 Mg ha^{-1}yr^{-1} while north America, Europe and Oceania represent low value of soil loss 2.23, 0.92 and 0.9 Mg ha^{-1} yr^{-1} respectively (Borrelli, 2018) in Rwanda, estimated mean soil erosion rate is 250 t·ha^{-1}·y^{-1} (Karamage, 2016).

The soil texture, soil structure, soil organic carbon and soil permeability are considered as tremendous key variable parameters that determining ability of soil resist to raindrop, runoff and other water flow aggressive ((Wieschmeier, 1978).

The change of land use due to Land shortage in Rwanda is extremely high where household use only 0.6ha, consequently, overexploitation of available land cause variation of key parameters of soil erodibility includes soil organic carbon, change of soil structure and reduction of soil permeability (Twagiramungu, 2006).

The acceptable range of soil susceptibility value to erosion (soil erodibility K) is ranging from 0.02 up to 0.7,the increase of K value imply that soil is great susceptible to soil erosion by water (Lance, 2014) this implies that soil characterized by low organic carbon and low level of aggregate stability is susceptible to soil erosion and has high value of soil erodility.

The value of variable soil properties such as soil texture, structure, organic carbon and permeability give image of resistance from soil mass for being eroded.(Kim, 2014). This is because weight ,placement and the bonds formed between soil particles influence stability of soil particle (Shahangian, 2011). For instance, the clay soil has low soil erodibility (K factor) because clay is more resistant to detachment due to its reactive surface(Kim, 2014). Moreover, the change of environment in natural system enhance aggregation or dispersion of soil particles, for instance, decline of land cover causes reduction of long chain of organic complexants such as humic substance which influence soil structure formation (Klumpp, 2004).

Karubanda watershed has no exception in term of land use and environment change that affecting physico-chemical properties of soil because Urbanization of Huye city is expended in side of Karubanda watershed, furthermore exponential increase of population linked by land shortage affect available vegetation cover and put Karubanda watershed at risk of being degraded,(Dominique, 2012)

Different methods are available for estimating soil erodibility using empirical nomograph developed by Wischmeier et al (1971), field measurement method(FM), this requires field measurement of variable parameters like soil texture, soil structure, soil organic carbon and permeability. Method of soil erodibility determination using Digital Soil Map (DSM) and Land Information System (LIS) (Xihua Yang, 2018). Fuzzy Logic based program FUZKBAS given by Tarri et al (1998) is used to approximate K distribution by combining decimal logarithm of geometric mean particle size (Dg), the organic matter and clay fraction (Rosewell, 1992). USLE nomograph (Wischmeier et al., 1971) is mostly used to estimate soil erodibility (K-Factor) of tropical soils (Hailu Kendie Addisa, 2015).

Soil erodibility determination using Digital Soil Map(DSM) and Land Information System (LIS) is used in large spatial scale, this method is challenged by lack of updated soil properties from field measurement in order to validate model(Xihua Yang, 2018).

This research was aimed to determine soil erodibility in Karubanda watershed by using empirical USLE nomograph developed by wischmeier et al.(1971) through land surveying and soil laboratory analysis in order to have accurate and updated data of soil properties, in addition to that, I did not find other research that has been conducted through collecting data by land surveying and soil laboratory analysis in order to compute value of soil erodibility in southern province of Rwanda precisely in Karubanda watershed. The paramount role of the research is to warn different stakeholders include urban planners and other watershed users about the range of inherent capacity of Karubanda watershed to resist to erosion and to promote Karubanda watershed management programme through restoration and conservation of available natural resources.

2. Methods and Materials

Karubanda watershed is located in southern province of Rwanda precisely in Huye District, there is 156 km distance from Huye District and Kigali capital city of Rwanda, the total area of Karubanda watershed is 1998ha, Geographical coordinate of Karubanda Watershed is ranging between 2^{o} 33’00” and 2^{o}36’30” South and between 29^{o} 41’30” and 29^{o} 44’30 East. The topography of Karubanda watershed characterized by gentle and steep mounts; It is area of mountains with altitude ranging from 1609 to 1890 m above sea level (HABARUREMA, 1997), In general, Rwanda is characterized by two climatic condition including tropical climate and temperate climate due to its high altitudes and its placement in globe terrestrial, Karubanda watershed is classified in tropical climate where the rainfall in that region ranging from 1000-1400 mm, and temperature is ranging from 16 to 24^{o} c and wind is general around 1-3m/s (Twagiramungu, 2006).

Urbanization of Huye city is mainly taking place in Karubanda watershed Karubanda watershed is located in three sectors Ngoma, Huye and Mbazi of Huye District in Southern province of Rwanda, the concerned watershed has five main land uses including, urban building, crop land mixed with sprawl settlement, forest area and swamp, Butare airfield. the sedimental parent material is dominant which induce poor soil due to strong weathering mainly influenced by high rainfall, (MIDMAR, 2015).

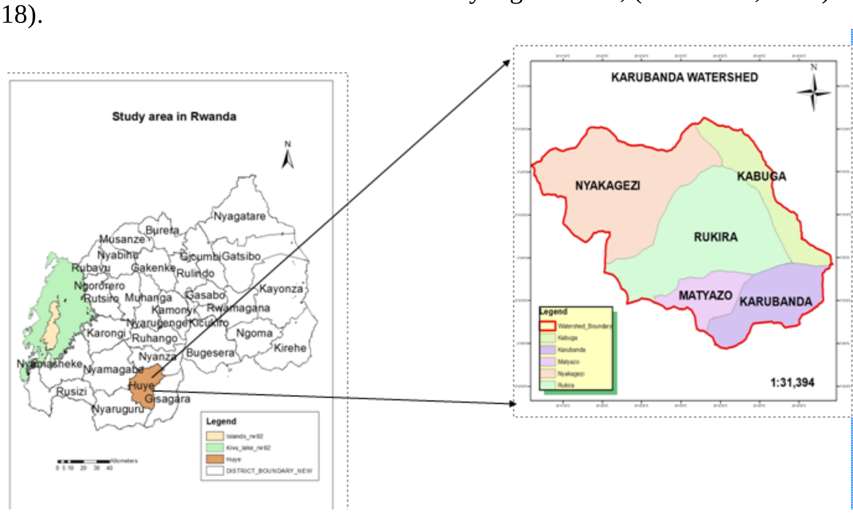

Figure 1: Localisation of Karubanda Watershed

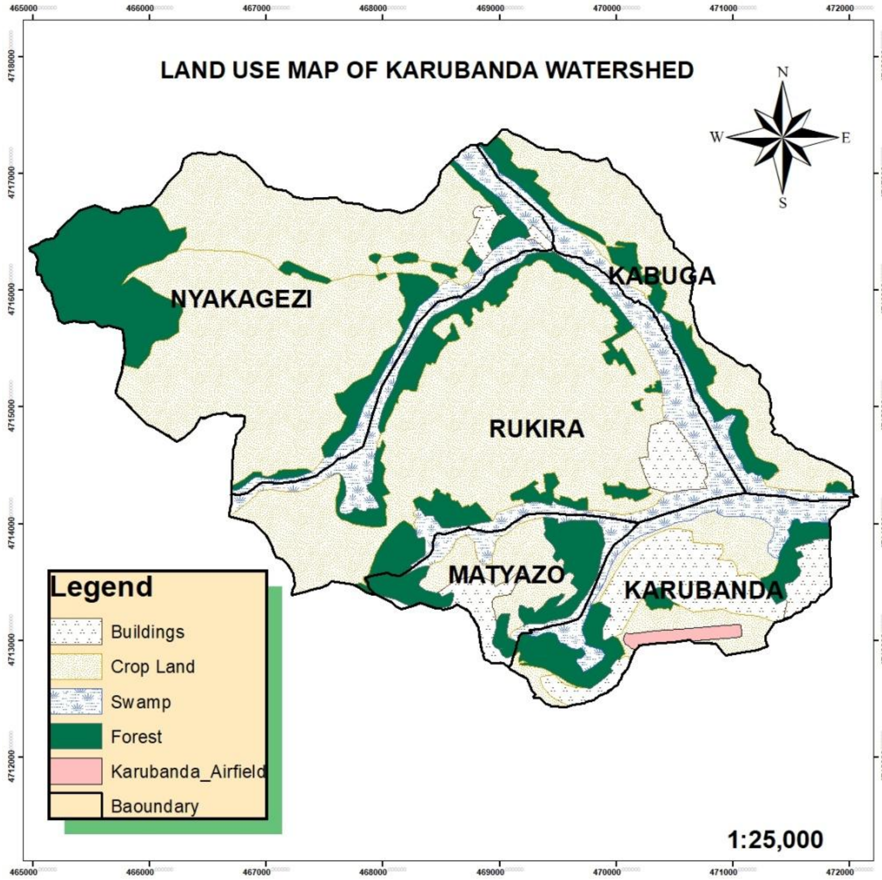

Figure 2: Karubanda Watershed land use

2.2 Experimental Design

Karubanda Watershed was delineated by using Arc GIS 10.5 software and Digital Elevation Model(DEM) of Huye District,Outlet points have taken by GPS from each sub watershed and main outlet of Karubanda watershed at MUNYAZI river, after delineation of Karubanda watershed which cover almost 1998 ha, systematic soil sampling have been followed, whole Karubanda watershed were stratified into 25 grids where one grid cover (900x 900) m, each grid has soil sample. this implies that the number of grids which corresponded by number of soil profile and samples are equal 19980000 m^2 /810000m^2 = 25 soil samples which were analyzed in order to get the value of physico-chemical parameters used in soil erodibility computation include soil texture, soil structure and soil organic carbon and permeability parameters

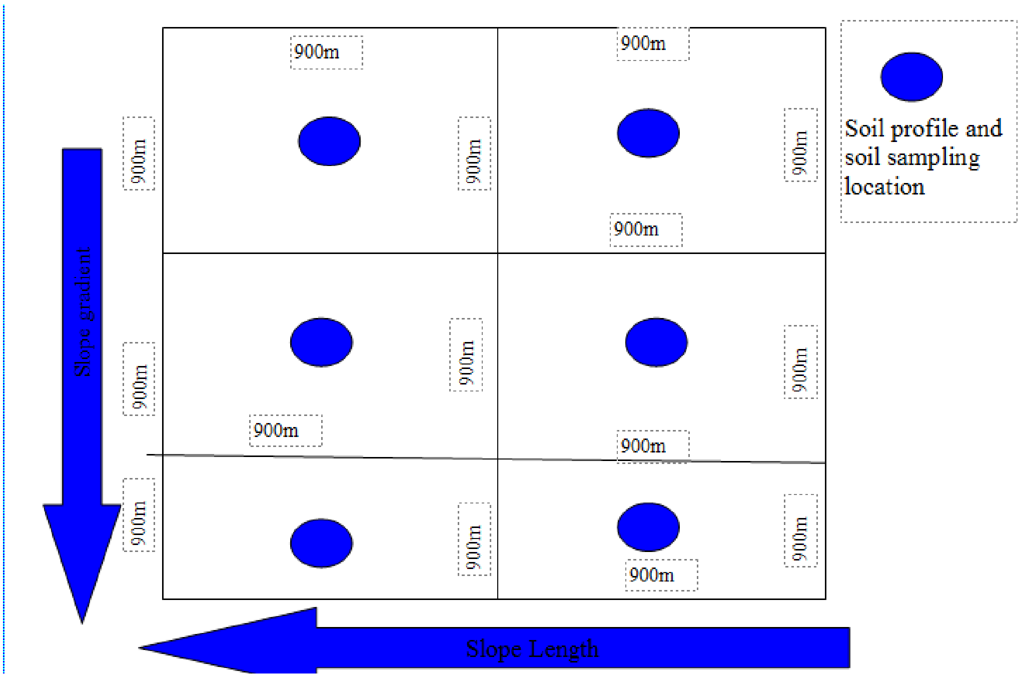

Figure 3: Soil Sampling Design in Karubanda watershed

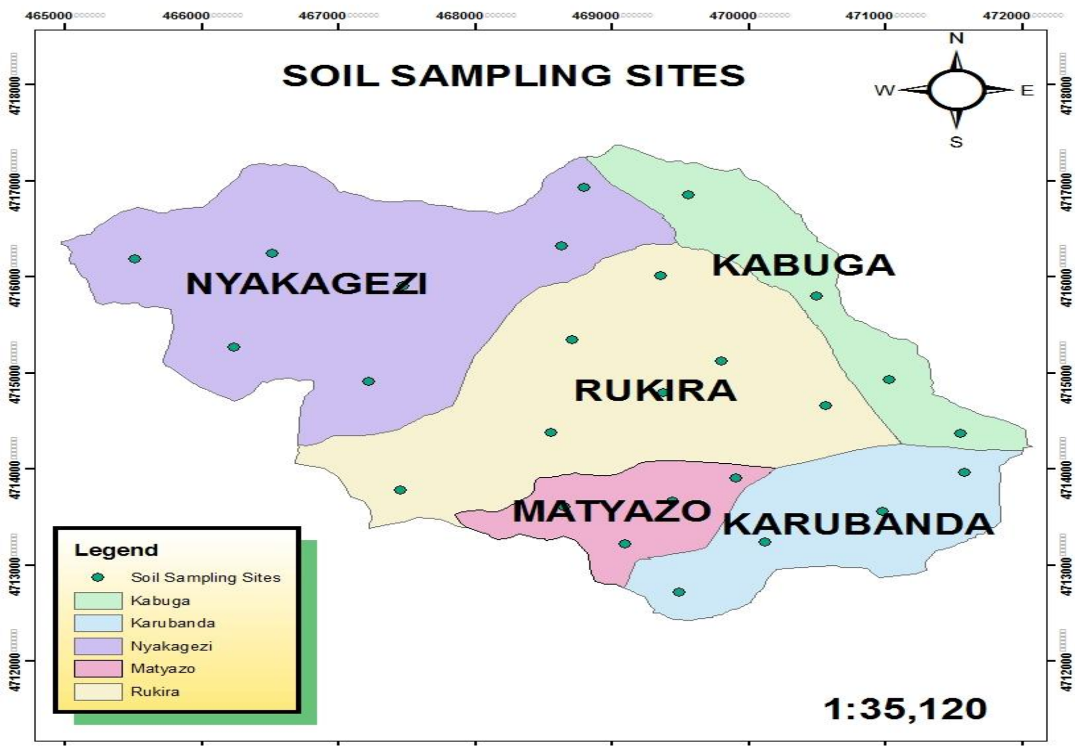

Figure 4: Location of soil sampling sites in Karubanda watershed map

2.3 Method of Data collection

2.3.1 Soil texture analysis

the Robinson's pipette method is selected way for analyzing soil texture classes (Olmstead, 1930), after reading the value of soil texture classes (clay, silt and sandy), United States Department of Agriculture had developed soil texture triangle was performed in order to know available soil types in each sub watershed

Figure 5

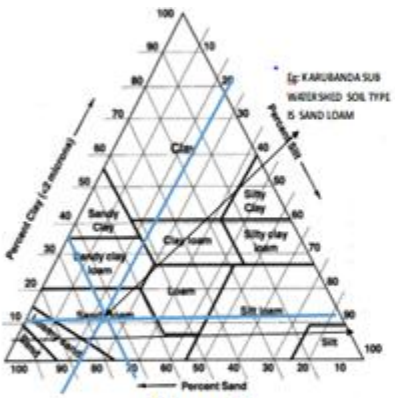

Figure 6

Soil texture triangle before plotting the Soil texture triangle after plotting the value. Value of soil texture classes of soil texture classes of one sub watershed

Karubanda watershed has represented three dominant soil types include **loam sandy, Sandy loam, and sandy**.

Table 1: Percentage of soil texture classes and corresponded soil types

Sub-watershed	Sand %	Silt %	Clay %	Silt + fine sand %	Soil texture
KARUBANDA	68.5	21.1	10.3	89.7	Sandy loam
KABUGA	76.1	15	8.9	91.1	Sandy soil
NYAKAGEZI	77	17	6	94	Sandy soil
MATYAZO	69	19	12	88	Loam sand
RUKIRA	76	18	6	94	Sandy soil

The result of soil particle size distribution at Karubanda watershed show that the soil texture classes dominant are Loam sand and sand soil, justification of findings on soil texture classes are the result of (Fidele Karamage, 2017) where has been shown that the southern province of Rwanda is dominated by Sand clay loam and sand soil, the same result when extraction of Rwanda soil map is done from Africa Soil Information Services(AFSIS), the findings on soil texture of Karubanda watershed give idea of watershed management like other tropical sandy soil due to its wide range of limiting factor of agriculture use includes poor physical attribute , water stress due to low water holding capacity and nutrientt deficiency, further more environment is prone to degradation risk, the proper management of Karubanda watershed according to its soil texture is to enhance reforestation, agroforestry and shifting cultivation (Bell, 2005)

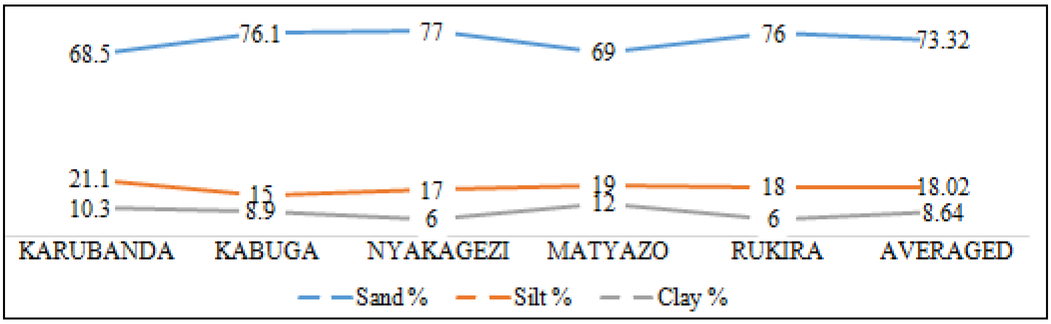

Figure 7: The value of Soil texture classes in Karubanda watershed

2.3.2. Soil organic Carbon analysis

Walkey–Black wet dichromate oxidation method was used in determining soil organic carbon and corresponded total organic matter by multiply common factor 1.724 (Nelson and Somers, 1982).

Soil organic carbon is uneven distributed across slope gradient in all sub watershed of Karubanda watershed where coefficient of variation of soil organic carbon in four sub watershed are exceeding 15% except Kabuga, the variability of soil organic carbon across slope gradient in Karubanda watershed is explained by the exponential reduce of land cover in four sub watershed, recently was covered by forest and vegetation. general the value of soil organic carbon in whole Karubanda watershed has no significant variability where the mean value is (2.22±0.17) and coefficient of variation is equal 8% in five sub watershed ,the soil organic carbon of Karubanda watershed is good to keep soil aggregate stable where is ranging from1.9-2.6% (Patrick1, 2014)

Table 2: The value of soil organic matter in Karubanda Watershed

Sub-watershed	Soil Organic Carbon	Organic Matter
KARUBANDA	2.6	4.4
KABUGA	1.9	3.2
NYAKAGEZI	1.9	3.2
MATYAZO	2.2	3.7
RUKIRA	2.5	4.3

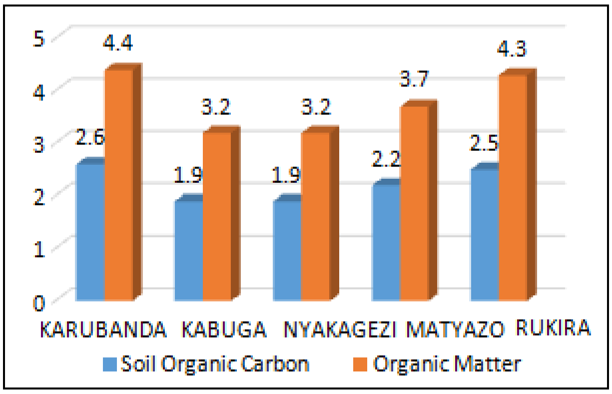

Figure 8: The value of soil organic matter in different sub watershed of Karubanda

2.3.3. Soil structure identification

The soil structures determination in Karubanda watershed has been conducted based on visual field assessment (Mancada, 2014)where they refer to the size and shape of aggregates and wet sieving method based on mean weight Diameter (LI-jiang-tao, 2007).

During field survey and field soil surveying of Karubanda watershed, in all considered sub watershed, soil structure and permeability have been assessed on the spot, below are the result ((Vermont, Stormwater technique guidance, 1983) and (Rosewell CJ, 2002),there are four classes of soil structure and six soil permeability classes

Table 3: The range of variability of aggregate size, permeability and their corresponded soil structure code and permeability class (Rosewell CJ, 2002)

soil structure	Soil structure code(S)	soil permeability range	permeability class (P)
Ped or aggregated soil particles <1 mm as diameter	1	Water movement in soil is rapid , >130 mm /h	1
Ped or aggregated soil particles 1–2 mm as diameter	2	Water movement in soil ismoderate or rapid 60–130 mm/ h	2
Ped or aggregated soil particles 2–10 mm as diameter;	3	Water movement in soil ismoderate, 20–60 mm/ h	3
Blocky, platy and massive ped or aggregated soil particles mass	4	Water movement in soil isslow to moderate, 5–20 mm /h	4
		Water movement in soil isslow, 1–5 mm /h	5
		Water movement in soil isvery slow, <1 mm/ h	6

Table 4: The soil structure code of each sub watershed in Karubanda watershed

Sub-watershed	(S)
Rukira	1
KARUBANDA	2
KABUGA	1
NYAKAGEZI	1
MATYAZO	2

Table 5: The value of all required Parameters for USLE Nomograph Simulation

S- watershed	Soil texture	SOC%	OM%	(S)	(P)
KARUBANDA	Loam sandy	2.6	4.4	2	2
KABUGA	Sandy soil	1.9	3,2	1	1
NYAKAGEZI	Sandy soil	1.9	3.2	1	1
MATYAZO	Loam sandy	2.2	3.7	2	2
RUKIRA	Sandy soil	2.5	4,3	1	1

2.4 USLE Nomograph

3.2.2 Erodibility of soil (K-factor) in Karubanda watershed was calculated by using empirical model so called USLE nomograph , below model was firstly developed by Wisch meier et al.(1971) , $K = 2.73X\ 10^{-6}\ M^{1.14}(12 - OM) + 3.25X\ 10^{-2}(S - 2) + 2.5^{-2}\ (P - 3)$M:is texture from fifteen centimeter of soil surface is calculated as $M = [(100 - AC) * (L + FS)]$ where Ac is clay (%) (<0.002mm), Lis silt % (0.002-0.05mm), FS: is very fine sand %,OM :is organic matter content % **S**: code of soil structure while **P**:is classes or code of soil permeability , all required parameters for soil erodibility calculation have been gathered from field survey and laboratory analysis. Substitution of above available data derived from laboratory analysis and Karubanda watershed field survey within model developed by Wischmeier and al (1971) lead to the value of all sub-watersheds soil erodibility in Karubanda Watershed.

$$K = 2.73X\ 10^{-6}\ M^{1.14}(12 - OM) + 3.25X\ 10^{-2}(S - 2) + 2.5^{-2}(P - 3)$$

Table 6: key required parameters for USLE nomograph(K-factor) equation and corresponded result

S- watershed	Soil texture	SOC%	OM%	(S)	(P)	Kfactor(Mg h $MJ^{-1}mm^{-1}$)
KARUBANDA	Loam sandy	2.6	4.4	2	2	0,3
KABUGA	Sandy soil	1.9	3,2	1	1	0.52
NYAKAGEZI	Sandy soil	1.9	3.2	1	1	0.7
MATYAZO	Loam sandy	2.2	3.7	2	2	0.42
RUKIRA	Sandy soil	2.5	4,3	1	1	0.33

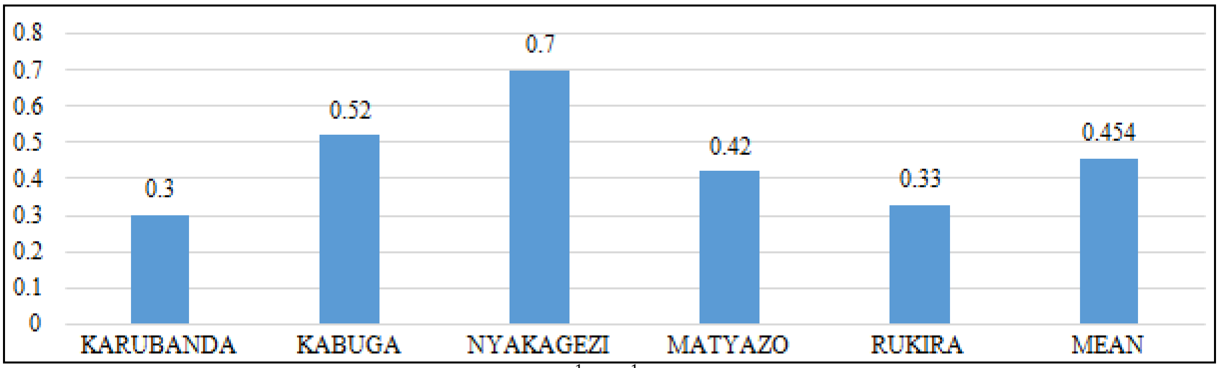

Figure 9: K factor (Mg h $MJ^{-1}mm^{-1}$) of Karubanda sub watershed

3. Results and Discussion

The increase of the value of soil erodibility is proportional with the degree of susceptibility of soil to erosion by rainfall and raindrop(wischmeier, 1971)(USDA, 1983), the highest value of soil erodibility in Nyakagezi sub watershed 0.7Mg h $MJ^{-1}mm^{-1}$ is direct coincided with intensive agriculture activities without fallow or shifting, population who are practicing agriculture with shortage of land lead to low organic carbon, disturbed soil structure and hard pan of cultivation layer , in addition to that Nyakagezi sub watershed is characterized by steeped mountains that could affecting negatively permeability of water, site of Nyakazi has sand soil texture, the lowest value of soil erodibility in Karubanda sub watershed 0.3Mg h $MJ^{-1}mm^{-1}$ is meaningful because is value of virginal soil because there is no agriculture activities has been done in that area except recent exponential growth of Huye city at Karubanda sub watershed which is ongoing, it was only covered by forest before Huye city expansion, thus high organic matter and gentle slope allow soil particles for not being dispersed (Klumpp, 2004), the entire Karubanda watershed have moderate soil erodibility with value of (0.394 Mg h $MJ^{-1}mm^{-1}$) which means that the soil of Karubanda watershed are susceptible to erosion depend on the level variability of other external factors of revised universal soil loss equation(RUSLE) include rainfall pattern, slope gradient and length, available land cover and the soil and land protection management through by agronomic techniques (restoration of forest and crop management like mulching), mechanical techniques For instance terraces and waterway installation in Karubanda watershed could increase soil organic matter in whole Karubanda watershed and reduce degree of susceptibility of soil of being eroded in Karubanda watershed specifically in in critical area Nyakagezi sub watershed. (Imani, 2014) urban planners and other watershed resources users could use the results of soil erodibility in Karubanda watershed as guidance in land use master plan.

3.1 Conclusion

Within the investigation,Universal Soil Loss Equation nomograph(K-Factor) equation was used to compute the value of (K-factor) soil erodibility in Karubanda watershed, the key variable parameters of equation have been achieved through land survey and laboratory analysis(Soil organic carbon, soil texture, Soil Structure, and Permeability), the results are in acceptable range of soil erodibility(Lance, 2014), regardless of present field condition and big field of soil sampling grid area, many soil Samples have taken in order to have composite soil sampling of grids. however, the up-dated values of key parameters were used in USLE Nomograph (K-factor) equation and representative value of soil erodibility in Karubanda Watershed characterized bylow variability 0.454 ± 0.16Mg h $MJ^{-1}mm^{-1}$, the users of this resultsare required to consider the level of variability of land use in Karubanda watershed depending on the purpose and intended use of the this results, the validation of soil erodility (K-factors) is required in long-term, urban planners and other watershed users need to consider the range of soil erodibility of Karubanda watershed during allocation of different activities and to promote Karubanda watershed management programme through restoration and conservation of available natural resources.

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