

Assessment of Soil Loss in a Typical Ungauged Dam Catchment using RUSLE Model (Maruba Dam, Kenya)

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Abstract

Soil erosion is a serious land degradation problem which nations all over the world are struggling with. It has affected many river catchments most of which are very dynamic and have become quite vulnerable due to human influence. As such, the functionality of the ecosystem has been largely compromised. Soil erosion has been reported as an expensive problem to remedy and therefore numerous of efforts have shifted to its prevention. This has called for estimation of soil loss which has been adequately achieved by use erosion models over the past. One such model is the Revised Universal Soil Loss Equation (RUSLE) which has been applied at catchment level. Maruba dam catchment has become very unhealthy due to the unsustainable modifications of the terrain. This is evident at the rate at which the dam is losing its storage capacity due to sedimentation. The current situation in the dam formed the basis for this study. Information on soil loss within the catchment is missing and as such decision makers do not have a basis for initiating soil and water conservation plans. The methodological framework for this study was the use of RUSLE model integrated in a GIS framework. The parameters of the model were derived using GIS and RS tools. The study revealed that soil loss ranged between 0 and 29 t ha⁻¹ yr⁻¹ and this explains why the dam is silting up at a fast rate. With this set of information on soil loss, the health of the catchment would be adequately restored and this would save the dam from unwarranted sedimentation.

Keywords: Soil erosion, catchment, RUSLE, sedimentation, GIS

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1. Introduction

Soil erosion is a serious land degradation problem which extends all over the world, (Girmay *et al.*, 2020). It is a more complex phenomenon due to the various natural processes which are involved, (Onyando *et al.*, 2005). Ideally, soil erosion is a three phase phenomenon which involves detachment, transport and deposition of soil particles (Merritt *et al.*, 2003; Benavidez *et al.*, 2018). Soil loss due to the effect of water has been identified the worst form of land degradation especially in third world countries, (Sujatha & Sridhar, 2018; Beyene, 2019). Water erosion is evident on the surface of land where widespread loss of soil has been noted, (Gitas *et al.*, 2009). This process has been accelerated by human activities where soil loss has exceeded the rate of soil formation within a given area, (Wolka *et al.*, 2015). Besides, climate change plays a significant role in acceleration of soil loss. This loss of soil has had adverse effects on all natural ecosystems and has since compromised their functionality, (Panagos *et al.*, 2015).

Soil erosion impacts are worst pronounced in developing countries because farmers rely mostly on intrinsic properties of lands and they are unable to restore the fertility of soils due to the cost of inputs. In the Kenyan situation for instance, agriculture remains an important driver of the economy, (Onyando *et al.*, 2005) but this would be possible if the soils are of good quality, (Fleitmann *et al.*, 2007). However, about 75 % of the Kenyan soils are reported to be environmentally fragile, (Fwamba *et al.*, 2017). This has been attributed to soil erosion which has led to severe degradation of agricultural lands thereby reducing the country's capacity to produce and increasing the occurrence of some natural hazards, (Biamah, 1997). Dregne (1990) reported that more than 20 % of Kenyan land has been subjected to permanent soil loss by water erosion. This is an indication that soil erosion is a serious environmental threat to the Kenyan soils as statistics show that soil loss in the country is way beyond the permissible annual rates of between 2.2 and 10 t ha⁻¹ yr⁻¹, (Angima *et al.*, 2003).

Land degradation assessment in developing countries has been constrained by lack of data and finances to facilitate assessment efforts, (Hammad, 2009). This makes it hard for the implementation of conservation plans especially in high erosion risk watersheds, (Beyene, 2019). On the other hand, soil erosion experiences a high spatial and temporal variation (Onyando *et al.*, 2005) and therefore it is very useful to obtain correct information at the point

of occurrence in order to facilitate planning for conservation measures, (Pandey *et al.*, 2015; Wolka *et al.*, 2015). Further, soil erosion process is complicated by the interplay between physical and hydrological factors (Onyando *et al.*, 2005) and as result, soil conservation practices and consistent estimates for soil erosion rates in watersheds remain a big challenge for any soil erosion study. Thus, soil loss and even sediment yield have been better estimated with the use of hydrological models which have comprehensive geospatial sets of data especially on both biophysical as well as hydrological factors which cause soil erosion, (Benavidez *et al.*, 2018; Woldemariam & Harka, 2020). As such reasonable estimates are obtained with soil erosion models, (Onyando *et al.*, 2005).

The sustenance of the ecology and economic development calls for prediction of the spatial variation and magnitude of soil erosion in order to plan for appropriate conservation measures, (Gelagay & Minale, 2016; Sujatha & Sridhar, 2018). Further, soil erosion has been pronounced as global hazard and therefore a relevant approach is required for the estimation of the spatial extend of soil erosion, (Wolka *et al.*, 2015). All over the world, scientists have applied related approaches and even models through which soil erosion has been estimated and related processes studied, (Wolka *et al.*, 2015). These approaches differ in terms of complexity, process, data requirements and application. A model is chosen on the basis of the study objectives, characteristics of the catchment, data availability and efficiency of the model.

Soil erosion models have been categorized as physical, conceptual and empirical and this has been on the basis of the physical simulation process as well as data requirements, (Merritt *et al.*, 2003; Sujatha & Sridhar, 2018). Whereas physical models are sophisticated and suited in numerous environmental applications, they are quite complex and data demanding, (Sujatha & Sridhar, 2018). On the other hand, parameters involved in conceptual models have limited scope when it comes to interpreting physical processes, (Sujatha & Sridhar, 2018). Physical soil erosion processes are better modeled using temporal data such as rainfall data with high resolution, infiltration rates in addition to saturated hydraulic conductivity. However, when such data is not available empirical models are preferred especially on regional scales and in preliminary assessment, (Sujatha & Sridhar, 2018). Empirical models have been widely used as opposed to physical models because they require minimum amounts data and they are easy to apply in estimation of annual soil loss at both regional and global levels, (Efthimiou *et al.*, 2014).

The USLE (Universal Soil Loss Equation) is one such empirical model which has been widely accepted and applied to estimate soil loss on an annual basis, (Wischmeier & Smith, 1978). It is described as simple and robust in addition to representing a standard approach. In the event that there are no measurements available, the USLE serves as the most efficient method for soil loss assessment, (Efthimiou *et al.*, 2014). Renard *et al.* (1991) developed the Revised Universal Soil Loss Equation (RUSLE) model which has the capability of incorporating additional research where an elaborate understanding of soil erosion process was developed. However, the basic form of the USLE equation remained the same with only a few modifications in some soil erosion factors changing, (Efthimiou *et al.*, 2014).

Soil erosion is a disturbing problem within Maruba dam catchment and its consequences are so severe. However, there have been no studies which aim to quantify soil erosion rates within the catchment. There is need to have specific information on soil erosion within the catchment in order to inform decision making with regards to Maruba dam reservoir which is heavily silted. The purpose of this study was to predict the rates of soil loss within Maruba dam catchment using RUSLE and GIS following which high erosion risk areas were to be identified and a soil loss intensity map developed. The choice of the RUSLE model was informed by its widespread use, documentation, ease with which data is extrapolated, capability of quantifying soil erosion factors and that of producing a net estimate of soil loss and finally modeling soil loss over a particular area, (Depountis *et al.*, 2018; Thlakma *et al.*, 2018).

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in Maruba dam reservoir catchment, in Machakos County, Kenya (figure 1). Maruba dam reservoir serves as the key source of water for Machakos town and its environment and it is operated by the Machakos Water and Sewerage Company. The town has a projected population of about 210,000 and the water demand has been estimated at 8000 m³/day. The dam was built in 1950s and has a height of 17 m in addition to a design yield of about 4000 m³/day. The storage capacity of the dam has reduced over years due to buildup of sediment to nearly 2000 m³/day.

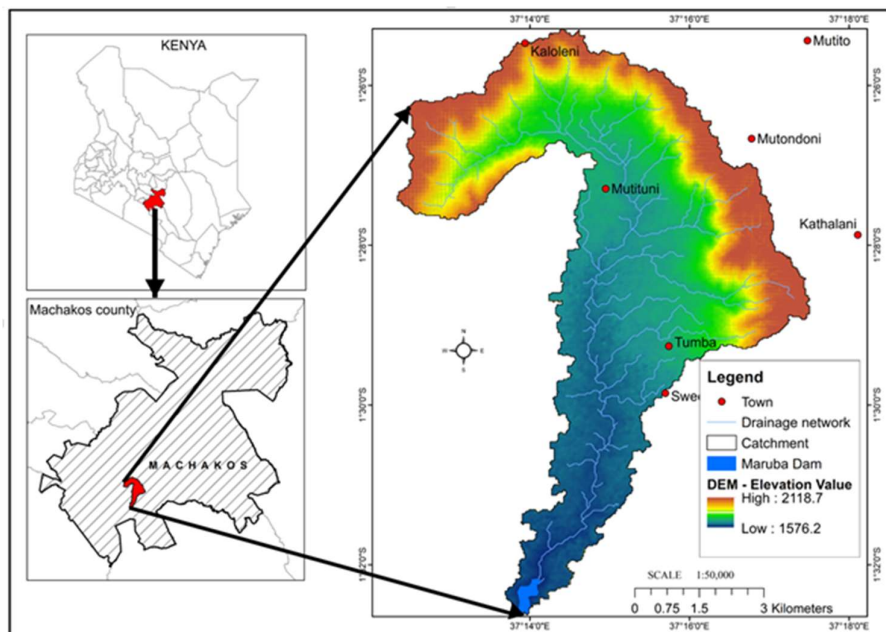


Figure 1: Location of the study area

2.2. Data Collection

The methodology adopted for this study was an integration of the revised universal soil loss equation (RUSLE) and geographical information system (GIS) spatial analysis environment, (Angima *et al.*, 2003; Kidane *et al.*, 2019; Rellini *et al.*, 2019). The model utilizes several parameters which were obtained from different sources, (Table 1). Reconnaissance survey indicated that Maruba dam catchment has suffered rapid land use and land cover changes for the last few decades. Therefore, the methodological framework for this study was critical in estimating the loss of soil due to this rapid change in Maruba dam catchment. The model parameters were estimated based on the following data sets: rainfall, digital elevation models (DEM), soil properties, and soil data, (Rellini *et al.*, 2019).

Table 1: Table of datasets and their sources

S. No.	Types of data	Sources of Data	Description
1.	Rainfall data	Kenya meteorological department	Average annual rainfall for 30 years (1990 – 2019)
2.	Soil data	Field collection and laboratory determination	Soil samples analyzed for texture, structure, organic matter and permeability
3.	Digital Elevation Models (DEM)	RCMRD (Regional Centre for Mapping of Resources for Development)	SRTM 30m resolution
4.	Satellite images	USGS (https://earthexplorer.usgs.gov)	Landsat 8 OLI/TIR of November 2020 with a resolution of 30m

2.3 Estimation of Soil Loss

The procedure for estimating soil loss using RUSLE model involves implementing the empirically developed formula in raster based spatial analysis, (Kidane *et al.*, 2019; Rellini *et al.*, 2019). Here, each parameter was calculated using a grid-based criterion after which the model values were multiplied in a raster calculator and the outcome was total soil loss per grid cell, (Renard *et al.*, 1991). The input factors for the RUSLE model are represented as shown in equation (1).

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where, A = spatial average of soil loss computed over a selected period of time ($t \text{ ha}^{-1} \text{ yr}^{-1}$), R = rainfall-runoff erosivity factor ($\text{MJ mm t ha}^{-1} \text{ y}^{-1}$), K = soil erodibility factor ($\text{t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$), LS = slope length steepness factor (dimensionless parameter), C = cover management factor (dimensionless parameter ranging between 0 and 1.5), P = erosion control (conservation support) practices factor ranging between 0 and 1. The methodological framework for this study is schematically represented by figure 2 below:

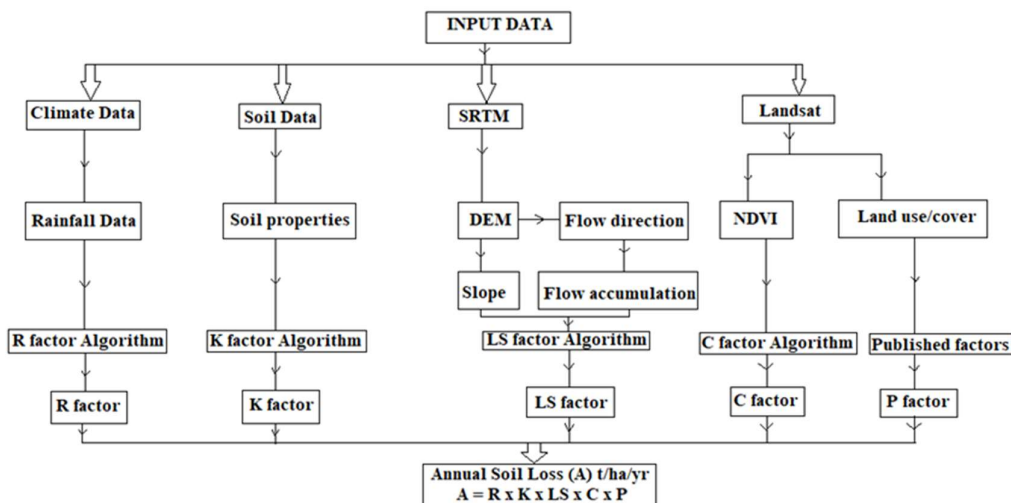


Figure 2: Flow chart of RUSLE methodology

2.3.1. Estimation of the RUSLE factors

Rainfall Erosivity Factor (R)

Rainfall is a critical factor in water erosion processes and its erosive power is defined by rainfall erosivity, (Conforti *et al.*, 2016). R factor therefore measures the erosive force possessed by rainfall of specific intensity, (Thlakma *et al.*, 2018). In simple terms, it is a measure of how aggressive the rainfall is, (Kidane *et al.*, 2019). The R factor takes into account the combined effect duration, magnitude and intensity of each rainfall storm, (Wischmeier & Smith, 1978; Renard *et al.*, 1997; Kidane *et al.*, 2019). R factor may be calculated on storm basis or even a series of storms where the cumulative erosivity effect for a particular period of time is accounted for, (Thlakma *et al.*, 2018). For this study, rainfall data for 30 years (1999 to 2019) for three stations was collected from the Kenya Meteorological Department, Nairobi, Kenya. Continuous raster grids based on 30 year average annual rainfall data were created using geospatial interpolation techniques in geographic information system framework, (Kidane *et al.*, 2019). After the development of rainfall grids, equation ... was used to calculate the rainfall factor in ArcGIS raster calculator. Equation (2) was developed by Kassam *et al.* (1992) for calculation of R factor for Kenyan situation.

$$R = 117.6 (1.00105^{MAR}) \text{ for } < 2000 \text{ mm} \quad (2)$$

Where MAR = mean annual rainfall (mm).

Soil Erodibility Factor (K)

The soil erodibility factor (K) measures the inherent susceptibility of soil or even surface material to erosion, (Ayalew, 2015; Ganasri & Ramesh, 2016; Koirala *et al.*, 2019). The K factor is influenced by the soils' physical and chemical soil properties and which have been reported to experience spatial variation, (Conforti *et al.*, 2016). The main soil parameters which affect the K factor include soil texture, soil structure, organic matter content and permeability, (Wischmeier & Smith, 1978; Koirala *et al.*, 2019). Hence, different types of soils have varying degrees of natural resistance and susceptibility to erosion depending on the soil's properties, (Thlakma *et al.*, 2018). Soil erodibility is described as the resistance to either detachment or transport of soil particles. Therefore, K factor values reflect the rate at which soil is lost per rainfall erosivity indices, (Gansri & Ramesh, 2016; Koirala *et al.*, 2019). For this particular study, soil erodibility factors were calculated using the equation (3) developed by (Wischmeier and Smith, 1978). The equation is based on soil texture, particle size distribution, soil structure, organic matter content and permeability.

$$K = 27.66m^{1.14} * 10^{-8} * (12 - a) + 0.0043(b - 2) + 0.0033(c - 3) \quad (3)$$

Where, K = Soil erodibility factor (ton·hr⁻¹·ha⁻¹·MJ·mm), m = (Silt % + Sand %) × (100 - clay %), a = percent organic matter, b = soil structure code: 1) very structured or particulate, 2) fairly structured, 3) slightly structured, and 4) solid, c = soil profile permeability code: 1) rapid, 2) moderate to rapid, 3) moderate, 4) moderate to slow, 5) slow, 6) very slow.

The calculation of K factor values was based on analyzed data on soil properties where samples were collected between 0 - 20 cm depth. The soil samples were a representative the numerous soil types and the varying degree

of land degradation conditions within the catchment area, (Conforti *et al.*, 2016; Olaniya *et al.*, 2020). Geo-referencing of the sampling points was achieved with the use of a global positioning system (GPS) receiver which had a precision of 3m. Laboratory analysis for determination of soil texture, organic carbon and hydraulic conductivity were determined using standard procedures. The K factor values were interpolated in GIS framework following which the spatial distribution of soil erodibility was derived.

Ganasri and Ramesh (2016) noted the following with regards to soil types and K factor values: Clay soils are associated with low values of soil erodibility because they are quite resistant to detaching forces. Likewise, sandy soils have low soil erodibility values because they have high rates of infiltration and reduced levels of runoff and as such sandy particles resist transportability. On the other hand, silt loams have moderate to relatively high soil erodibility values since silt particles suffer moderate detachment, infiltration and transport. Silt soils are reported to have the very high K values because they crust very readily thereby producing very high rates of runoff and quantities as well.

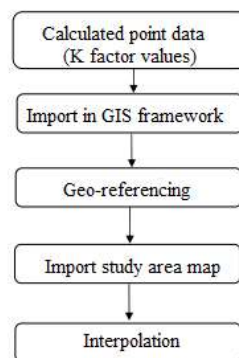


Figure 3: Derivation of the K factor Map

Topographic Factor (LS)

The topographic factor (LS) depicts the topographic effects on erosion and it includes steepness and length of slope which influence the speed of surface runoff, (Conforti *et al.*, 2016; Koirala *et al.*, 2019). The two sub-factors are critical in soil erosion modeling because they aid in calculation of the transport capacity of overland flow, (Ganasri & Ramesh, 2015; Conforti *et al.*, 2016) and they are determined from DEM, (Koirala *et al.*, 2019). The sub-factors L and S capture the contribution of slope length and slope gradient on erosion respectively, (Renard *et al.*, 1997). The slope length (L) accounts for the slope length effect on soil erosion and it is defined as the distance from the point where overland flow begins to the point where surface gradient reduces to an extent that deposition of erosion material begins or surface runoff water finds its way in a channel which is well defined, (Ganasri & Ramesh, 2015; Koirala *et al.*, 2019; Tessema *et al.*, 2020). As a consequence, the amount of soil lost per given unit area increases with slope length, (Tessema *et al.*, 2020).

On the other hand, slope steepness (S) accounts for slope steepness effects on soil erosion, (Ganasri & Ramesh, 2015; Koirala *et al.*, 2019). Erosion effects are more pronounced with increase in slope steepness as compared to increase in slope, (Koirala *et al.*, 2019). This means soil is lost more in highly sloping areas and the worst form of it occurs in slope gradient varying from 10 to 25 percent, (Ganasri & Ramesh, 2015). Thus, the LS factor is an expression of topographical effects on soil erosion and as such the factor is noted to increase with increase in both sub-factors, (Koirala *et al.*, 2019).

In this study, the topographic factor was computed from the slope and flow accumulation maps, (Karamage *et al.*, 2016). The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) for Kenya with a spatial resolution of 30 m was obtained from the Regional center for mapping of resources and development (RCMRD). The procedure in computing the LS factor involved filling DEM sink using the hydrology tool in ArcGIS after which flow direction and flow accumulation were generated, (Karamage *et al.*, 2016; Kogo *et al.*, 2020; Tessema *et al.*, 2020). DEM was also used to compute the surface slope after which the topographic factor was calculated using equation (4).

$$LS = \left(\frac{Q_a M}{22.13} \right)^y \times (0.065 + 0.045 \times S_g + 0.0065 \times S_g^2) \quad (4)$$

Where, LS = topographic factor, Q_a = flow accumulation grid, S_g = grid slope (%), M = grid size (vertical length x horizontal length), y = dimensionless exponent which depends on slope steepness and ranges from 0.2 to 0.5. Wischmeier and Smith (1978) proposed the values of y as follows: 0.5 for slopes greater than 4.5 %, 0.4 for slopes between 3 and 4.5 %, 0.3 for slopes between 1 and 3 % and 0.1 for slopes less than 1 %.

Land Cover Factor (C)

The land factor reflects the effect of soil cover on soil erosion, (Wischmeier & Smith, 1978; Renard *et al.*, 1997; Koirala *et al.*, 2019). It is related to land use and land cover changes, (Wischmeier & Smith, 1997). C factor represents the effect brought about on soil by soil disturbing activities, vegetation, sequence of crops and production level, (Thlakma *et al.*, 2018). Vegetation is ranked second after topography with regards to the risk of soil erosion, (Koirala *et al.*, 2019). Generally, vegetation intercepts rainfall thereby increasing the rates of infiltration in addition to absorbing the energy possessed by rainfall. The range of C factor values is between 0 and 1 with 0 indicating strong effect in land cover while 1 shows no effect at all.

C factor for the RUSLE model is computed from different sub-factors such as prior land use, surface cover, canopy cover, surface roughness and soil moisture, (Renard *et al.*, 1997). These sub-factors experience spatial and temporal variation and as such, remote sensed data serves as an important tool for assessing the C- factor. Hence, satellite imagery was used to prepare land use and land cover map. Normalized Difference Vegetation Index (NDVI) is an important indicator which helps in detection and interpretation of vegetation cover, (Kogo *et al.*, 2020). NDVI serves as an indicator for the vegetation vigor and health. Landsat 8 OLI/TIR of November 2020 with a resolution of 30m was downloaded from <https://earthexplorer.usgs.gov>. From these multispectral images, NDVI map was extracted. The C factor map for the study area was generated using equation 5 in a spatial analyst raster calculator.

Land use and land cover classification of the catchment area was done using supervised classification based on Maximum Likelihood Classifier algorithm. Here, six land use and land cover classes were identified and which were verified using ground truth, (Ayalew, 2015). A normalized difference vegetation index (NDVI) map for the catchment was produced. NDVI serves as an indicator for the vegetation vigor and health and it was incorporated in equation (5) following which the C-factor value map for the study area was generated.

$$C = 0.1 \left(\frac{-NDVI + 1}{2} \right) \quad (5)$$

Support Practices (P) Factor

Support practices (P) factor is an indication of the rate at which soil is lost from various farmlands, (Thomas *et al.*, 2018; Koirala *et al.*, 2019). P factors reflect the effects brought about by practices which reduce the magnitude and the rate of runoff water and thus reducing erosion amount, (Wischmeier and Smith, 1978; Ganasri & Ramesh, 2016). The factor gives an account of the specific conservation practices which aim to reduce the erosion potential of runoff water by the manner in which they influence drainage patterns, concentration of runoff, velocity of runoff and hydraulic forces subjected to the soil by runoff, (Ganasri & Ramesh, 2016; Kogo *et al.*, 2020). P factor values have a range of between 0 and 1, where a value of 0 shows that there is good facility which resists erosion while 1 shows that there is none, (Thomas *et al.*, 2018; Koirala *et al.*, 2019).

Support practice factor for this study was derived from land use and land cover map in conjunction with the Wischmeier and Smith (1978) methodology (table 2). This methodology involved assigning values to each of land use/land cover class on the basis of the slope after which a P factor map was derived in a GIS framework, (Ayalew, 2015; Kidane *et al.*, 2019; Kogo *et al.*, 2020).

Table 2: P factor values (Source: Wischmeier & Smith, 1978)

Land use	Percentage slope	P-factor
Agriculture (cultivated land)	0.00 – 5.00	0.10
	5.00 – 10.00	0.12
	10.00 – 20.00	0.14
	20.00 – 30.00	0.19
	30.00 – 50.00	0.25
	50.00 – 100.00	0.33
Other land use	All	1.00

2.3.2. Soil Loss Analysis

Processing of geospatial data sets was done in ArcGIS where five raster maps for rainfall erosivity, soil erodibility, topographic, land cover and support practice factors were produced, (Thomas *et al.*, 2018). The produced raster maps were then integrated within a geographic information system framework (ArcGIS 10.5) using raster operations and with the use of the RUSLE equation a composite map through which the annual rate of soil erosion could be predicted in t/ha/year was created, (Depountis *et al.*, 2018; Sujatha & Sridhar, 2018; Koirala *et al.*, 2019).

3. Results and Discussions

3.1 Rainfall Erosivity Factor

The rate of soil erosion in Maruba dam catchment is a little bit more sensitive to precipitation. This is evident due to the volumes of sediment impoundment in Maruba dam. The R factor value ranged from 251 to 254 MJ mm t ha⁻¹ yr⁻¹. The R factor map shown in figure 4 below shows the spatial distribution of the rainfall erosivity values. The R factor map show slight variation in R factor values since the catchment is quite small with an area of 49 km².

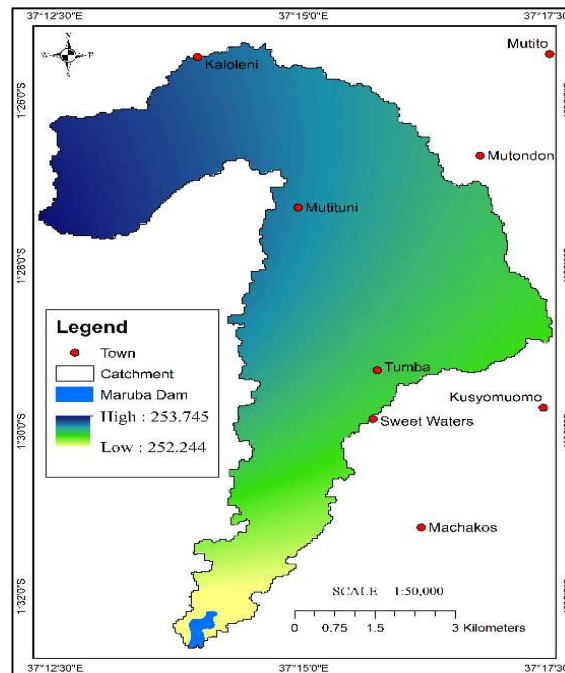


Figure 4: Rainfall Erosivity Factor Map

3.2. Soil Erodibility Factor

Soil erodibility measures a soil's resistance to erosive power possessed by rainfall energy and that of runoff. There exists a strong relation between mechanical composition of soils and organic matter content, (Ban *et al.*, 2016). Figure 4 below shows the spatial distribution of the K factors for entire catchment. Higher soil erodibility factors are indicative of easier detachment while low ones mean that the soil particles are compacted and therefore would require higher detaching forces, (Obiora-Okeke, 2019). The K values for this study range between 0.0026 and 0.0117 t ha h ha⁻¹ MJ⁻¹ mm⁻¹. The values are generally low which according to Ganasri & Ramesh (2016) such soils are associated with soils which have low permeability rates, low initial soil moisture content, etc., (Ganasri & Ramesh, 2016).

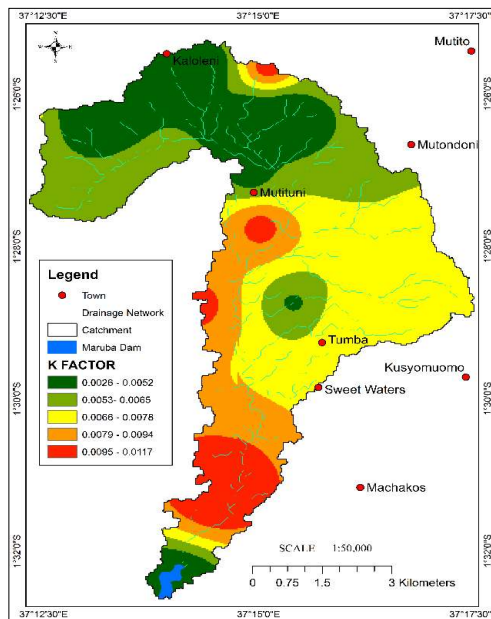


Figure 5: Soil Erodibility Map

3.3. Topographic Factor (LS)

The slope gradient of the catchment ranged from 0 to 50 %. The slope gradient was classified into six classes. Figure 6 shows that the topographic factor for the study area ranged from 0 - 384. Topographic characteristics of a catchment area have a strong influence on the spatial variation of soil loss and deposition. In this regard, the LS factor was noted to increase as flow accumulation and slope increased, (Ganasri & Ramesh, 2015). High values for LS factor indicate that such areas are characteristic of steep slopes and longer slope lengths. This means that the velocity of surface runoff increases with slope. On the other hand, increased velocity of surface runoff over a longer distance causes more detachment of soil particles. Figure 6 shows that the topographic factor was highest in hilly terrains and along gullies, (Wischmeier & Smith, 1978).

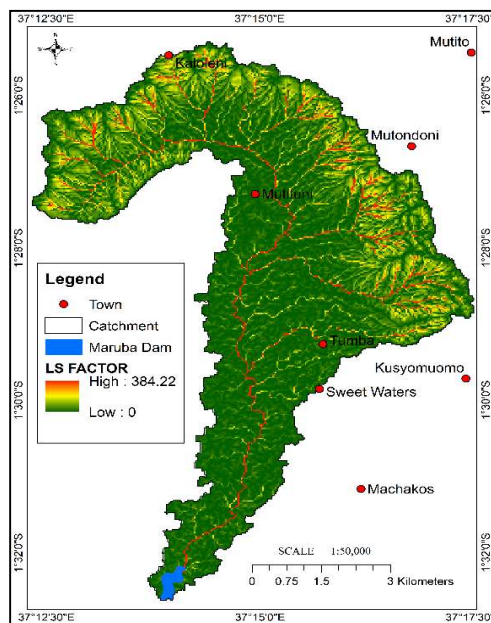


Figure 6: Topographic Factor Map

3.4. Land Cover Factor (C)

Land utilization factors such cropping patterns, forests, fallow lands, waste lands among others are better

understood if information regarding land use is made available as this necessitates planning for development and soil erosion studies, (Ganasri & Ramesh, 2015). In this regard, C factor is an indicator of land cover and vegetation management, (Wolka *et al.*, 2015) and its range is between 0 and 1. It is taken as the most important RUSLE factor with regards to reducing soil loss in highly sloping terrains. The factor indicates how effective vegetation cover is with regards to soil erodibility (Obiora-Okeke, 2019). Vegetation reduces the raindrop impact on soil hence reduced detachment of soil particles. Therefore, soil cover by cover plants, mulches, cover crops and crop residues have a protective effect on soils from wind and water erosion and cumulative result is enhanced infiltration and increased soil organic matter. However, land cover varies significantly depending on the forest type, agricultural activities and shrub land among others. Hence, areas which have high C factor values are indicative of rocky surfaces or open scrub land, (figure 7). According to figure 7, soil erosion is much less in built-up lands and vegetated areas and much higher in bare lands and exposed surfaces.

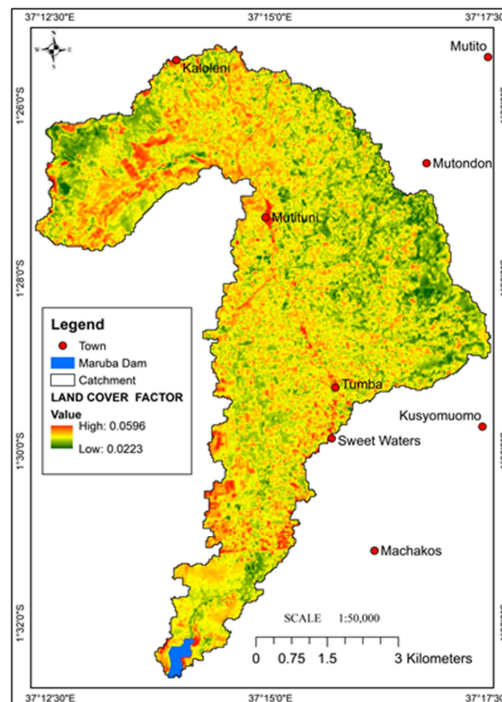


Figure 7: Land Cover Factor Map

3.5. Support Practices Factor (P)

Soil conservation practices slow down the process of soil erosion by reducing the amount and rate of runoff, (Obiora-Okeke, 2019; Rellini *et al.*, 2019; Kogo *et al.*, 2020). In places where no such practices have been put into place, the soils are very vulnerable to erosion, (Obiora-Okeke, 2019). P factor values ranges from 0 to 1, where a value that approaches 0 indicates some good conservation practice while a value that approaches 1 is indicative of poor or no conservation practice at all, (Rellini *et al.*, 2019). A combination of land use and land cover classes with slope was used to compute the P factor upon which the conservation factor map for the catchment was produced. The spatial distribution of the P factor is shown in figure 7 below. In steep slopes, agricultural activities are accompanied by soil conservation structures and that explains why the P factor appears to have a high value, (figure 7).

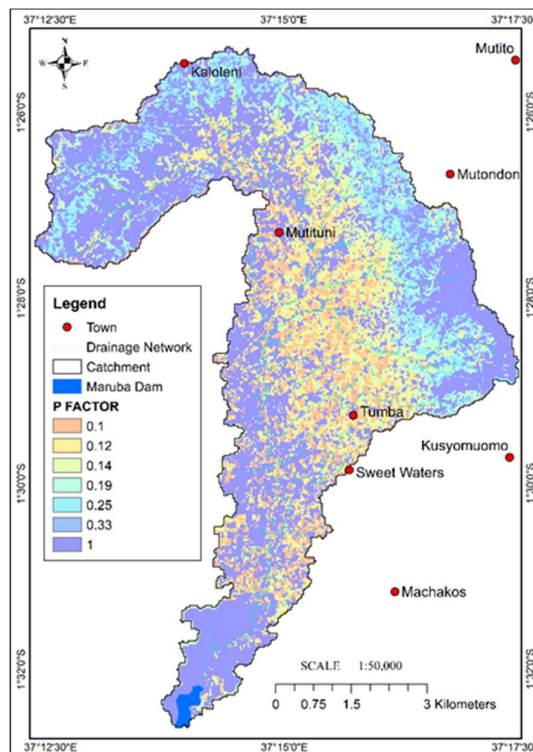


Figure 7: Support practices factor map

3.6. Spatial Distribution of Soil Loss

The RUSLE model predicts the amount soil loss on an annual basis as function five parameters: rainfall erosivity (R), soil erodibility (K), topographic factor (LS), land cover management (C), and support practice factor (P). The raster layers of each RUSLE factor were superimposed then multiplied in GIS environment after which soil erosion risk maps for the entire catchment were generated. The soil erosion maps were further subjected to classification where five classes were obtained. These included: slight (0 – 2), moderate (2 – 5), high (5 – 10), very high (10 – 15) and extreme (15 – 30) $t\ ha^{-1}\ yr^{-1}$ (table 3). The spatial distribution of soil loss for Maruba dam catchment is given by figure 8 below. According to the figure, the predicted average annual loss of soil ranges from 0 to 29 ton/ha/year. These statistics are indicative of the real existence soil erosion risk in the study area. The spatial distribution as well the soil erosion rates are closed associated with land use and the topography of the catchment. In this regard, soil erosion is prevalent in the highly sloping areas of the catchment. The high population density with the dam catchment piles enormous pressure on land and water resources. Therefore, the vulnerability of soil loss has increased and this requires immediate attention.

Differences in soil loss are brought about by variability of soil erosion contributing factors such as topographic factors, erosivity and erodibility and most importantly land use and land cover, (Kogo *et al.*, 2020). Table 3 shows that 90 % of the catchment experiences moderate soil loss. This shows that soil loss was within the soil loss tolerance of between 5 to 11 $t\ ha^{-1}\ yr^{-1}$, (Mati *et al.*, 2000). Hammad (2009) argued that soils which have depths of less than 100 cm, low content of organic matter (1 to 3 %) and low aggregate stability should be categorized using the lower limit of soil loss tolerance. The highlighted characteristics by Hammad (2009) apply to soils within Maruba dam catchment. Therefore, the risk of soil loss within the catchment is considered high. Further, the cumulative effect of soil erosion cannot be ignored given its extent over the entire catchment, (Kogo *et al.*, 2020).

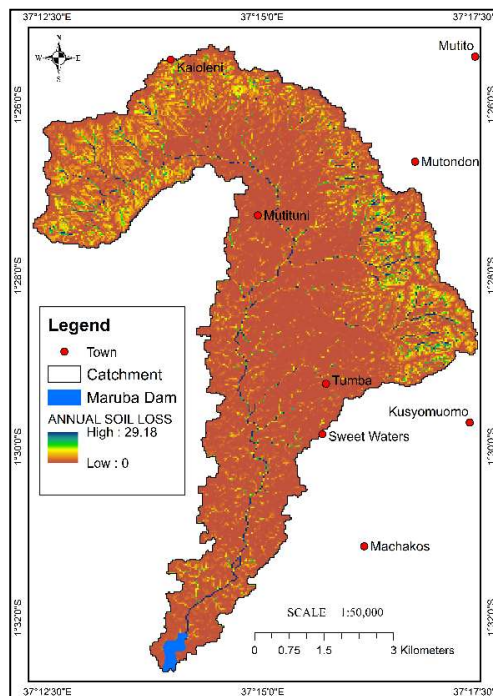


Figure 8: Spatial distribution of soil loss

Table 3: Soil loss classes

Erosion Categories	Numeric Range ($t\ ha^{-1}\ yr^{-1}$)	Soil Loss Proportions (%)
Very Low	0 - 2	78.52
Low	2 - 5	11.04
Moderate	5 - 10	8.28
High	10 - 15	2.14
Very High	15 - 20	0.02
Extremely High	20 - 30	0.01
		100

4. Conclusions

Evaluation of soil loss within catchments is an important discourse which would help in planning for prevention measures in order to foster sustainable use of land. The use of an empirical approach which comprised of the RUSLE model integrated with geographical information system was used to estimate the average annual loss of soil. The study singled geospatial techniques and remote sensing as key methodologies in the derivation of the RUSLE model factors at an appreciable cost and in a practical manner considering the constraints in data availability within the catchment. Through this methodology, vulnerable areas to soil loss within the catchment were identified. The study identified soil erosion as a major challenge in Maruba dam catchment ($0 - 29\ t\ ha^{-1}\ yr^{-1}$). The severity of soil erosion in dam catchment was brought to light by this study (table 3). The spatial distribution of soil erosion in the catchment area is strongly related to the use of land and topography. The health of the catchment was noted to be compromised by the undulating nature of the terrain in addition to the unsustainable land uses. Since land use and land cover is an important consideration in soil erosion studies, having the right information on land use changes and land cover features would be a good entry point for fast-tracking soil and water conservation measures. Consequently, establishing the slope length and slope steepness of the entire catchment would inform the design of various soil and water conservation structures. Soil erosion was found to be high in the catchment where different terrain modifications exist (figure 8). The health of the catchment may be improved by adopting effective ways of controlling soil erosion such as grass ways, adoption of conservation practices and use of soil conservation structures such as terraces and contours among others.

5. Recommendations

The predicted quantity of soil loss and its spatial variation is an important breakthrough in developing a comprehensive and a sustainable conservation plan for Maruba dam catchment. Priority should be given to areas which have high rates of soil loss especially around hilly terrains. Terrain modifications must be made sustainable as a way of restoring the health of the catchment in moderate erosion hazard areas.

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