Assessment of Soil Erosion Hotspots by RUSLE Model using Remote Sensing and GIS in Morogoro Region, Tanzania

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Abstract

Soil erosion is a significant constraint on soil productivity and agricultural endeavors in Sub-Saharan Africa, including Tanzania. The districts of Mvomero, Morogoro urban, and Morogoro rural heavily rely on agriculture, making the preservation of key water bodies like Mindu Dam crucial. The dam and its catchment areas currently face threats from siltation, necessitating effective land and water resource management. Sustainable land management practices are imperative to prevent soil degradation and erosion, and identifying soil erosion hotspots is essential for resource prioritization. This study employs GIS-based analysis using the Revised Universal Soil Erosion (RUSLE) Model to assess potential water-induced soil loss risks in the mentioned districts. The analysis reveals spatial trends and distribution of soil erosion risks due to rainfall. Soil loss magnitudes range from very slight (<2 tons/ha/year) to very severe/catastrophic (>100 ton/ha/year), with mountainous regions being prone to high erosion hotspots. Mvomero district stands out, with 42.8% of its land potentially susceptible to unacceptable soil losses (>5 tons/ha/year) for tropical and/or shallow highland soils without appropriate support and conservation practices during land use, particularly agriculture. Similarly, both Morogoro urban and rural areas face potential risks of unacceptable soil loss (>5 ton/ha/year), affecting 35% and 38% of their respective land areas. Implementation of support and conservation measures is essential, especially for agricultural activities. The study highlights spatial variability of soil erosion severity, necessitating tailored management strategies in the three districts based on identified erosion hazards.

Keywords: Soil erosion hotspot, RUSLE, land management, acceptable soil loss

Introduction

Soil erosion is one of the major threats to the World's Soil Resources which affects agricultural productivity (Devatha *et al.,* 2015; Food and Agriculture Organization (FAO)(2015)). Water-induced soil erosion emerges as the most significant factor impeding soil productivity and agricultural development in various regions across Africa, particularly in the humid and sub-humid zones of Sub-Saharan Africa, including Tanzania. Human activities, notably agriculture, play a crucial role in accelerating water-induced soil erosion, making it the primary cause of soil degradation globally (Borrelli *et al.,* 2017) In most of the Sub-Saharan Africa region soil degradation potentially undermines efforts towards sustainable agricultural production and so poses a major threat to the future of agriculture (Obalum *et al.,* 2012). All the adverse impacts of soil erosion on agronomic productivity and environmental quality scientific causes. Respectively are due to a decline in land quality and deposition of sediments and have been designated on-site effect and off-site effect, respectively (Stavi & Lal, 2015). Soil erosion control is one option to increase crop productivity while controlling river and lake sedimentation. Considering the agriculture sector, most rural cultivable lands have been degraded by either water or wind disintegration. In cultivable rural land, the disintegration of the soils leads to the expulsion of the ripe topsoil, hence clearing out the subsoil and staying with fewer agricultural benefits. Soil erosion is altered by biophysical components as well as anthropogenic impacts.

Based on the findings from various studies, soil erosion exhibits varying degrees of severity and distribution, particularly in mountainous areas (Wassie, 2020). The intensity of soil erosion is influenced by factors such as land use practices, lithology, vegetation cover, soil type, and management policies (Evdoxia et al., 2014; Panagos *et al.,* 2015; Yin *et al.,* 2022). In Tanzania, soil erosion poses a serious challenge across multiple sectors, including agriculture, transportation, and the environment (Ligonja & Shrestha, 2015; Mulengera *et al.,* 2009). However, there is a lack of sufficient information and management strategies to address this issue effectively. Water-induced soil erosion is particularly prevalent in mountainous regions, leading to reduced productivity and increased poverty (Liu *et al.,* 2012). Unsuitable land practices, such as cultivating on steep slopes without conservation measures and bushfires, contribute significantly to soil erosion (Kimaro *et al.,* 2008; Stavi & Lal, 2015). Studies focusing on the Uluguru Mountains have reported alarmingly high soil losses from arable lands. Between 1966 and 1970, the average annual soil erosion in this region was estimated at 312 t/ha (Temple & Rapp, 1972) and in 2008 the rates mean soil loss ranged between 91 and 258 t/ha/year (Kimaro *et al.,* 2008). The Uluguru Mountains are an essential part of the Eastern Arc Mountains of Kenya and Tanzania, representing a crucial area for global biological conservation. Addressing soil erosion in Tanzania requires comprehensive strategies that consider the specific pre-determinant factors, including intrinsic soil properties, erosive nature of rainfall, and geomorphic position (Moore, 1979; Stone *et al.,* 1985; Temple & Rapp, 1972). By understanding the factors driving soil erosion and implementing appropriate land management practices, sustainable solutions can be developed to preserve the productivity and ecological integrity of Tanzania's landscapes.

Soil erosion management can be effectively facilitated through the utilization of simulation and modeling techniques. Modeling serves as a valuable tool for assessing soil erosion scenarios, enabling the precise selection of appropriate soil erosion control measures (Moehansyah *et al.,* 2004). These soil erosion models essentially function as virtual laboratories, amalgamating data, observations, and insights from various fields to promote environmental sustainability (Pijl *et al.,* 2020). In light of the aforementioned literature, the Revised Universal Soil Loss Equation (RUSLE) emerges as a fitting model for this study specific conditions, making it the model of choice for this present study. The RUSLE model, as developed by Wischmeier and Smith in 1978, operates as an empirical framework that integrates influential factors in soil erosion to predict average annual soil loss in metric tons per hectare. In order to mitigate both on- and off-site repercussions of soil erosion, the implementation of conservation measures becomes imperative. The successful execution of conservation programs necessitates the targeted allocation of resources to priority action areas. Hence, the fundamental objective of this study is to ascertain the extent, severity, and spatial distribution of soil loss, with the ultimate goal of providing crucial insights for effective land management within the study area. The resulting spatial erosion maps, encompassing erosion severity levels and erosion tolerance thresholds, hold significant potential as valuable inputs for devising strategies pertaining to land planning and management within the study region.

Material and Methods

Description of the Study area

Mvomero, Morogoro urban and rural Districts are located between two latitudes 5°30’00’’S and 8°00’00’’S and between two longitudes 37°00’0’’E and 39°00’0’’E (Fig. 1). The average rainfall ranges from 400 mm to 1300 mm per annum. The mean temperature of the area per annum ranges from 18°C to 31°C during the hotter seasons. The dominant land use pattern includes arable land used for crop cultivation (about 52% of total land area for Morogoro DC, 22% of total land area for Morogoro MC and 27% of total land area for Mvomero DC), land used for grazing (about 7% of total land area for Morogoro DC, about

0.5% of total land area for Morogoro MC and about 0% of total land area for Mvomero DC) and forest cover (about 25% of total land area for Morogoro DC, about 0% of total land area for Morogoro MC and about 17% of total land area for Mvomero DC) (Tanzania NBS, 2022b). Soils in the study districts vary according to topographical and ecological zones. In the mountainous and hilly areas, the common type of soils found are mainly oxisols which are generally low in nitrogen and phosphorus. Valley and low lands are generally characterized by alluvial soils which are fertile in nature. Sandy and clay soils are common in woodlands and grasslands. Soil condition in the study districts favors production of various crops like maize, paddy, beans, cassava, spices, sweet and Irish potatoes, amaranths, vegetables and sugarcane (Tanzania NBS, 2022a).

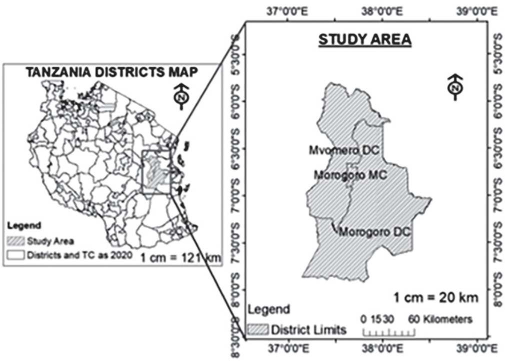


Figure 1: Study area Maps (Source: shapefiles 2020 from Tanzania Bureau of statistics website)

Data Collection and Analysis procedure

The Revised Universal Soil Loss Equation (RUSLE) model integrated with GIS has been used to estimate soil loss in the Mvomero, Morogoro Rural (DC) and Urban (MC) districts. The RUSLE model (Wischmeier & Smith, 1978) is an empirical model that combines factors influencing soil erosion in predicting average annual soil loss in tonnes per hectare. The manual/conventional use of the model in predicting can be expensive resource wise and in terms of money. Integration of this model with GIS and Remote sensing tools has enabled the estimation of the soil loss much easier. The use of Digital Elevation Models has enabled the quick computation of terrain characteristics of an area; satellite images are useful in computing land cover characteristics of even a large area in a short time. Based on the above facts, it is now easier than before to evaluate the predicted potential losses of the soil and plan for mitigation measures using the RUSLE model integrated into GIS and Remote Sensing tools. Below is a used RUSLE model to indicate annual soil loss (A), $A=R*K*S*C*P$ ....(1)

Where; A: is Annual soil loss in tonnes per hectares (t/ha-y); R: is annual rainfall erosivity index (MJ-mm/ha-h-y); K: is soil erodibility factor (t-ha-h/ha-MJ-mm); L: is slope length factor, dimensionless; S: is slope steepness factor, dimensionless; C: is cover and soil management factor, dimensionless, P: is support practice factor, dimensionless. The data used in document for the study area, were collected from different credible open resources as follwow: Bouandary shapefile of 2019 (source: TNBS), Rainfall data of 2012-2022 (source: NASA Power website), Soil Map shapefiles 2020 (Source:FAO soil portal 2020, Soil texture data, 2019(source: International Soil Reference and Information Centre (ISRIC), Tanzania DEM SRTM 30M (Source: The Regional Centre for Mapping of Resources for Development (RCMRD) and NDVI 2022 (Source: Earth USGS Platform), a conceptual framework to this study is represented in figure 2 (the chart flow is top to down)

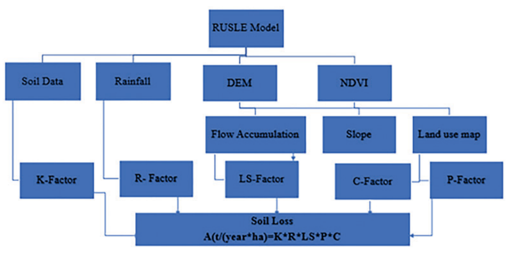
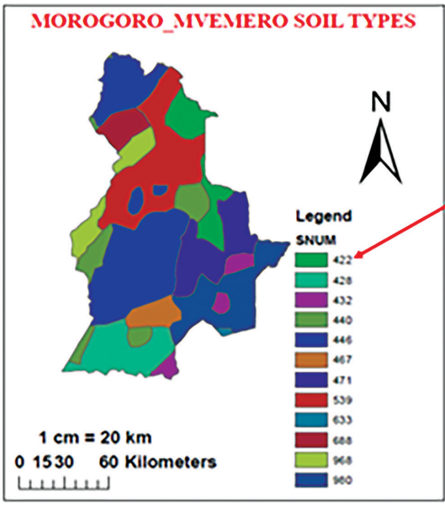


Figure 2: Conceptual framework of soil loss analysis by RUSLE model (Flow is top to down)

Computation of the RUSLE Factors

Rainfall erosivity factor R (MJ (MJ mm ha^{-1} h^{-1} year^{-1})

Rainfall erosivity is the potential ability for rainfall to cause soil loss. In order to avoid calculating Annual Rainfall Erosivity Index solely from rainfall amounts, and due to limited time resources to conduct field experiments for determination of rainfall erosivity (it would have required several years of field work), rainfall erosivity dataset (GIS files) developed by (Panagos *et al.,* 2012) was used. The generation of this Rainfall Erosivity dataset by (Panagos *et al.,* 2012) involved the following steps:



OBJECTID	MUID	SEQN	SNAM	SOIL TYPES
302		422	Af40-2b-422	SANDY_CLAY_LOAM
307		428	Ao65-1-2a-428	SANDY_LOAM
310		432	Ao68-1-2a-432	SANDY_LOAM
314		440	Bc14-2bc-440	LOAM
318		446	Bc18-c-446	LOAM
334		467	Bk25-2a-467	LOAM
338		471	Bk28-2b-471	LOAM
396		539	Fo77-2b-539	SANDY_CLAY_LOAM
472		633	Gp6-2-3a-633	CLAY_LOAM
512		688	Je51-2-3a-688	CLAY_LOAM
732		969	Vp51-3a-969	CLAY
739		980	We8-1-2a-980	SANDY_CLAY_LOAM

Figure 3: Soil SEQN with their soil textures distribution in the study area
(***Source:*** FAO, 2022)

a) the collection of high-temporal resolution rainfall data; b) the calculation of the erosivity factor (R-factor) for each rainfall station; c) the normalization of R-factor values calculated with rainfall data collected at different time steps (1 min to 60 min), and d) the spatial interpolation of the R-factor points values.

Soil Erodibility Factor K

Soil erodibility factor (K) represents the inherent susceptibility of the soil material to erosion. The erodibility factor really depends on the textural class of the soil and the fraction of soil organic carbon.

Here digital soil data Map of the world were used to find the soil type Map in the study area, these data are found at https://www.fao.org/soils-portal, after downloading these data, the shapefile was added in ArcGIS, and by geoprocessing clipping of the Tanzania soil types by overlapping Tanzania district shapefile, and the same procedure was repeated to get soil types map in the study area.

The soil textures (types) of Mvemero, Morogoro DC, and MC districts, are obtained by comparing SNUM on soil Map and SEQN (Sequence number) in Figure 3. SNUM: is a sequential code unique for each soil mapping unit which links the first level of soil information to the expansion data file.

The zones with high erodibility value are those which have high proportion value of silt and low proportion value of organic carbon content in the soil. Organic carbon enhances soil aggregate stability and hence resistance to detachment and transport by water. Soils with high clay content faces detachment difficulties (detachment limited erosion) and areas with large amount of sand faces transport limited erosion (Ganasri & Ramesh, 2016).

$K = 2.459 * 10^{-5}\ Mn + 1.333 * 10^{-4}$ ....(3)

Where, Mn = Silt%(Silt%+Sand%)

To use the above formula, there is to join the excel sheet with the attribute table of Mvomero Morogoro MC and DC soil textures map. This has to consider DMSOI for both map and excel sheet. After, field calculator is applied to get the corresponding values for *Mn* and *K* factor respectively.

Now we have to classify our map using through properties using *K* factor and convert the shapefile into raster. The soil erodibility, ***K***

values are in t –ha –h/ha –MJ – mm, Map of Mvomero, Morogoro Urban and Rural districts is shown in Figure 5.

Slope length and Slope steepness factor (LS)

Slope length and steepness factor were computed by using the Digital Elevation Model of Tanzania where the study area was clipped. LS factor is the topographic factor that integrates the steepness and length of the slope as a single indicator. The Steepness sub-factor indicates the effect of the slope angle on the speed of the runoff, generally the higher the chances of erosion. The slope length sub-factor indicates the distance of the slope where the surface flow is expected. The digital elevation model of Tanzania gets to extract the study area by mask, create fill DEM through spatial analysis tool and hydrology, Slope of the area was computed followed by flow direction, flow accumulation, and finally the LS was computed using Raster calculator in spatial analyst toolbar. The result is the map indicating the LS values on the whole map of Mvemero, Morogoro Urban and Rural Districts.

*LS=Power(FlowAccummulation*Cell Resolution/22.1,0.4)*power (Sin(Slop*0.01745)/0.09,1.4) * 1.4*................(4)

The formula above has been used to get *LS* factor using a raster calculator by passing to spatial analysis tool, map algebra. The cell resolution used was 30M

Cover Factor (C)

Factor *C* in the soil loss equation is the ratio of soil loss from land covered land under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier & Smith, 1978). The factor has no unit of measurement as it is a ratio of two associated features measured in the same scale. This is an important factor as it explains the impact of having different types of vegetation on soil loss due to water (Ligonja & Shrestha, 2015; Martine Hagai, 2019). In this study, there is a use of NDVI prepared in ArcGIS from landsat8 2022 (landsat8 are obtained from Earth USGS Platform),

$$NDVI = \frac{B5 - B4}{B5 + B4} \text{ Or } NDVI = \frac{NIR - RED}{NIR + RED} \quad (5)$$

Where *NIR:* surface spectral reflectance in the near-infrared

NDVI map is used to get C factor for the study area, and the formula is as follows

$$C = 0.1\left(\frac{-NDVI + 1}{2}\right)$$, by (Almagro *et al.,* 2019),

Where *C* is the RUSLE area vegetation cover factor

NDVI: Normalized Difference Vegetation Index of the area.

Support practice factor (P)

According to (Wischmeier and Smith, 1978), generally, when so ever sloping soil is to be cultivated and uncovered to erosive rains, the protection offered by sod or close-growing crops in the land needs to be supported by practices that will slow the runoff water, and thus reduce the amount of soil it can carry. Support practices include contour farming, strip cropping, intercropping, and other practices that will decrease slope angle and runoff speed. By definition, factor *P* in the RUSLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope cultivation (Wischmeier & Smith, 1978). Due to a lack of information on local indicative *P* values, the *P* values used in this study were obtained from the literature. The value used in this study was 1 as there are no significant support practices followed by farmers in the region.

Soil Erosion Risk Hotspot Characterization

The resultant soil erosion hazard map from RUSLE model was reclassified to obtain two maps: The map on soil erosion risk was classified after (Morgan *et al.,* 2004) in which a total of seven classes were produced (note: class six and seven were later merged in the final map) and indicators for those classes can be identified in the field using the simple guide provided in Table 2.

The second map is based on acceptable soil loss proposed for tropics countries as recommended in the research findings by (Hudson, 1986; Lal, 1983). Tolerable (acceptable) soil loss is the maximum level of soil erosion that will permit a high level of

Table 2: Soil erosion risk classes and indicators for appraisal in the field

Class	Erosion Rate (Ton/Ha)	Indicators
Very slight	<2	No evidence of compaction or crusting of the soil; no wash marks or scour features; no splash pedestals or exposure of tree roots; over 70% plant cover (ground and canopy)
Slight	2 - 5	Some crusting of soil surface; localized wash but no or minor scouring; rills every 50 -100 m; small splash pedestals, 1 – 5 mm depth, where stones or exposed trees protect underlying soil, occupying not more than 10% of the area; soil level slightly higher on upslope or windward sides of plants and boulders; 30 – 70% plant cover
Moderate	5 - 10	Wash marks; discontinuous rills spaced every 20–50m; splash pedestals and exposed tree roots mark level of former surface, soil mounds protected by vegetation, all to depths of 5–10mm and occupying not more than 10% of the area; slight to moderate surface crusting; 30–70% plant cover; slight risk of pollution problems downstream if slopes discharge straight into water courses.
High	10 - 50	Connected and continuous network of rills every 5–10m or gullies spaced every 50–100 m; tree root exposure, splash pedestals and soil mounds to depths of 10–50mm occupying not more than 10% of the area; crusting of the surface over large areas; less than 30% plant cover; danger of pollution and sedimentation problems downstream.
Severe	50 - 100	Continuous network of rills every 2–5 m or gullies every 20m; tree root exposure, splash pedestals and soil mounds to depths of 50–100mm covering more than 10% of the area; splays of coarse material; bare soil; siltation of water bodies; damage to roads by erosion and sedimentation.
Very severe	100 - 500	Continuous network of channels with gullies every 5–10m; surrounding soil heavily crusted; severe siltation, pollution and eutrophication problems; bare soil.
Catastrophic	>500	Extensive network of rills and gullies; large gullies (>100m^2) every 20 m; most of original soil surface removed; severe damage from erosion and sedimentation on-site and downstream.

Source: Morgan *et al.,* 2004

crop productivity to be sustained economically through fertility maintenance for a period not less than 20 – 25 years (Morgan, 2005). For the case of Tropical and mountainous soils/shallow soils the recommended acceptable soil loss is 0 – 5 ton/Ha/Year (Hudson, 1986; Lal, 2001).

Results

RUSLE factors generated

Results of computed RUSLE model factors are presented in Figures 4, 5, 6 and 7 showing the spatial variability of rainfall erosivity, soil erodibility, slope length and steepness, and vegetation factor across the study area

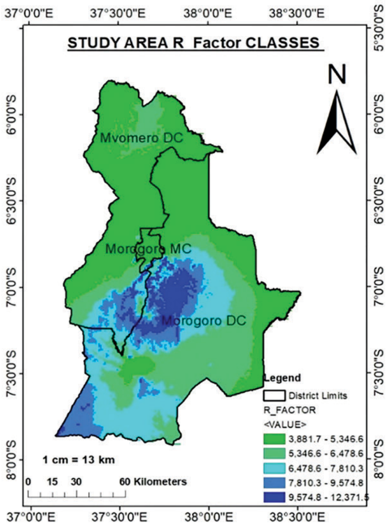


Figure 4: Rainfall erosivity factor Map for the study districts

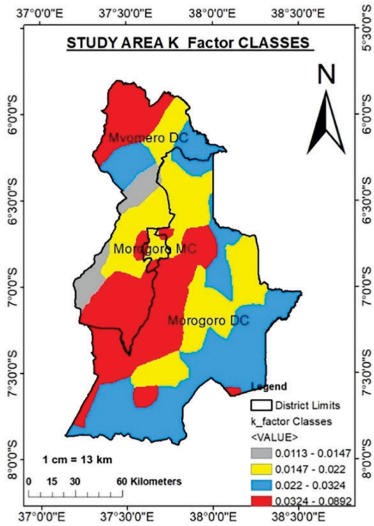


Figure 5: Soil Erodibility Map of study districts

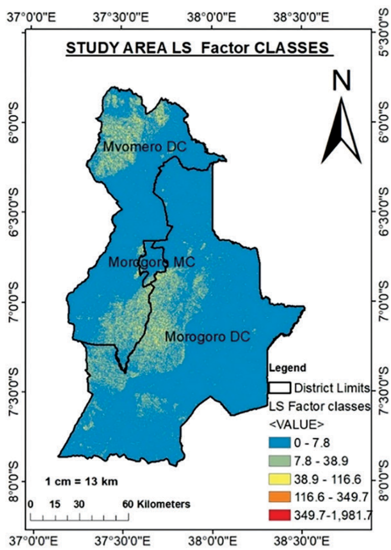


Figure 6: LS Map of study districts

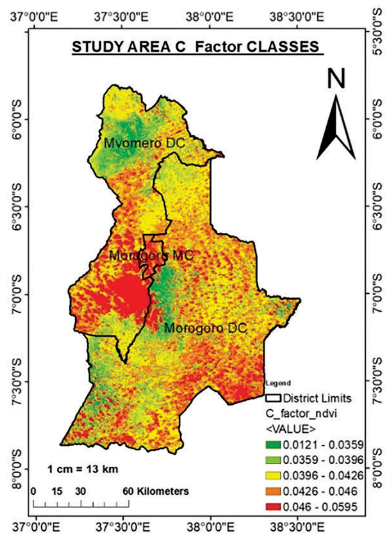


Figure 7: C-factor map of study districts

Predicted soil Erosion Severity and Soil Loss Tolerance Levels

The findings in Table 3 and Figure 8 show that Mvomero district has highest risk of soil erosion compared to other districts in the study area, with about 35.8%% of the district's land areas having erosion rate greater than 10 Tons/Ha/Year (Fig. 9), followed by Morogoro district (29%) and Morogoro municipality with only 24.3% of its total land having erosion rate greater than 10 Tons/Ha/Year. On the other hand, Morogoro municipality has the lowest erosion risks with 64.9% land area falling under Very slight to Slight erosion which has erosion magnitude of 0 – 5 Ton/Ha/Year which is also within the magnitude of tolerable (acceptable) soil loss. Wards having some of their land areas with Very Severe to Catastrophic Erosion Severity are presented in Table 4. Table 5 show the Tolerance limit classes and their corresponding area per District.

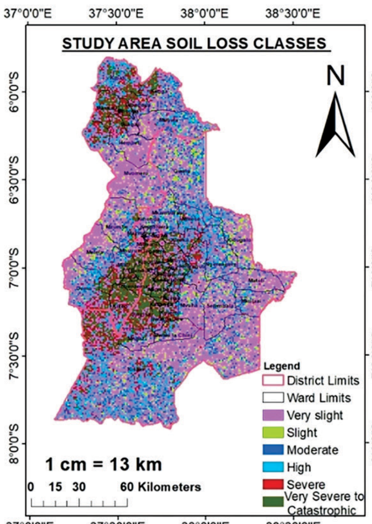


Figure 8: Soil erosion risk classes

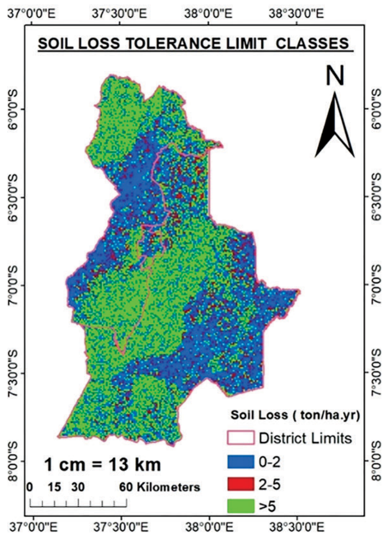


Figure 9: Soil Loss Tolerance Levels

Table 3: Soil loss class and their corresponding area per district

District	ID	Soil Loss (Ton/ha/yr)	Soil loss classes	Area (sqkm)	Area (Ha)	Proportions (%) within district
Morogoro MC	1	0 - 2	Very Slight	149.801	14,980.1	51.9%
	2	2 - 5	Slight	37.502	3,750.2	13.0%
	3	5-10	Moderate	31.001	3,100.1	10.7%
	4	10-50	High	29.757	2,975.7	10.3%
	5	50-100	Severe	15.722	1,572.2	5.5%
	6	>100	Very Severe to Catastrophic	24.618	2,461.8	8.5%
	TOTAL			**288.402**	**28,840.2**	**100.0%**
Mvemero DC	1	0 - 2	Very Slight	3,259.928	325,992.8	50.0%
	2	2 - 5	Slight	468.733	46,873.3	7.2%
	3	5-10	Moderate	454.756	45,475.6	7.0%
	4	10-50	High	834.115	83,411.5	12.8%
	5	50-100	Severe	486.751	48,675.1	7.5%
	6	>100	Very Severe to Catastrophic	1,012.025	101,202.5	15.5%
	TOTAL			**6,516.307**	**651,630.7**	**100.0%**
Morogoro DC	1	0 - 2	Very Slight	6,443.288	644,328.8	52%
	2	2 - 5	Slight	1,146.306	114,630.6	9%
	3	5-10	Moderate	1,065.433	106,543.3	9%
	4	10-50	High	1,902.480	190,248.0	15%
	5	50-100	Severe	621.571	62,157.1	5%
	6	>100	Very Severe to Catastrophic	1,138.409	113,840.9	9%
	TOTAL			**12,317.486**	**1,231,748.6**	**100%**
	Overall Total			19,122.195	1,912,219.50	

Table 4: Wards which are in Very Severe to Catastrophic Erosion Severity per District

District	Wards
Morogoro DC	Kiroka, Mtombozi, Tegetero, Singisu, Mkuyuni, Bwakila Juu, Kibogwa, Kolero, Tawa, Bungu, Kibungo Juu, Kasanga, Konde, Mngazi, Kisemu, Kisemu, Kisaki and Lundi
Morogoro Mc	Mlimani
Mvomero DC	Kibati, Mlali, Kanga, Bunduki, Biongoya, Langali, Mhonda, Tchenzema, Maskati, Kikeo, Sungaji, Doma, Mvemero

Table 5: Tolerance limit classes and their corresponding area per District

District	ID	Soil erosion/ Loss (Ton/ ha/yr)	Tolerance limit class	Area (sqkm)	Area (Ha)	Proportions (%) within district
Morogoro MC	1	0 – 2	Acceptable Soil Loss for Tropical Soils	149.8	14,979.2	51.9%
	2	2 - 5	Acceptance Soil Loss for Shallow Highland Soils and Edible Soils	37.5	3,746.8	13.0%
	3	>5	Unacceptable Soil Loss for Tropical Soils	101.1	10,109.3	35.1%
	TOTAL			**288.4**	**28,835.3**	**100.0%**
Mvemero DC	1	0 - 2	Acceptable Soil Loss for Tropical Soils	3,259.9	325,988.9	50.0%
	2	2 - 5	Acceptance Soil Loss for Shallow Highland Soils and Edible Solis	468.7	46,874.5	7.2%
	3	>5	Unacceptable Soil Loss for Tropical Soils	2,787.6	278,762.9	42.8%
	TOTAL			**6,516.3**	**651,626.4**	**100.0%**
Morogoro DC	1	0 - 2	Acceptable Soil Loss for Tropical Soils	6,443.2	644,322.4	52%
	2	2 - 5	Acceptance Soil Loss for Shallow Highland Soils and Edible Solis	1,146.3	114,625.3	9%
	3	>5	Unacceptable Soil Loss for Tropical Soils	4,728.0	472,802.3	38%
	TOTAL			**12,317.5**	**1,231,750.0**	**100%**
	Overall Total			19,122.12	1,912,211.73	

Discussion of Results

A quantitative assessment of average annual soil loss for Morogoro DC, Morogoro MC and Mvomero DC is made with GIS based on well-known RUSLE equation considering rainfall erodibility, soil erodibility, land use and topographic dataset. The assessed average annual soil loss of in the three study districts was grouped into different six erosion severity classes as per Morgan *et al.,* 2004. The study has revealed the spatial distribution of the soil erosion severity classes across the study districts. Also, the soil loss tolerance levels have been generated for all study districts. The spatial pattern of classified soil erosion risk zones identifies wards with areas with high and severe erosion risks. For example, most of the wards identified to be more exposed to soil erosion risks are located in mountainous areas of the district. This may be due to those area having higher slope length and steepness factors coupled with vegetation clearance and high rainfall erosivity (Evdoxia *et al.,* 2014; Kimaro *et al.,* 2008; Panagos *et al.,* 2012, 2015; Yin *et al.,* 2022). These results are similar to previous studies which reported high soil erosion rates in the Uluguru (Kimaro, 2003; Kimaro *et al.,* 2008; Rapp, A., Berry & Temple, 1973). The current study has also established the spatial distribution of soil loss tolerance levels in the study district and these findings are quite useful for planning soil conservation Strategies (Di Stefano & Ferro, 2016). Soil loss tolerance is a criterion for establishing if a soil is potentially subjected to erosion risk and productivity loss. Furthermore, a study by (Mulengera *et al.,* 2009) reported high to very high soil erosion losses on agricultural lands in Uluguru Mountains (33 tons/ha/year) which fall within the area identified by the current study to be dominated by high erosion severity levels. Also, (Kimaro, 2003) reported soil losses ranging from 91 to 258 tons/ha/year from fields in the adjacent upper Morogoro river catchment which is comparable to some erosion severity rates in the current study. However the study by (Kimaro, 2003), covered a small area of the Uluguru Mountain (i.e the Northern Slopes of the Uluguru Mountain) as compared to the current study covering three districts (Mvomero DC, Morogoro DC and Morogoro MC). The results of this study covering a large area of Morogoro region will therefore provide useful information for decision makers and planners to take sustainable land use management and soil conservation measures in the Morogoro region. The information will guide the setting of soil conservation priorities in the study area which will eventually minimize costs by concentrating efforts on priority areas in the study area. Substantial conservation practices should be taken into account in these areas with unacceptable soil losses.

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Conclusions and Recommendations

This study showed that soil loss magnitudes range from Very slight (< 2 Tons/Ha/Year) to Very severe/Catastrophic (> 100 Ton/Ha/Year) with high erosion hotspots located on mountainous areas. Mvomero district has the highest proportion (42%) of land potentially susceptible to risks of unacceptable soil losses (> 5 Tons/Ha/ Year) for tropical soils/and or shallow highland soils if no support/conservation practices applied when undertaking a number of land uses including agriculture. On the other hand, Morogoro rural and urban have 38 % and 35% of the lands areas respectively has potential risk of experiencing unacceptable soil loss for tropical soils/and or shallow highland soils (>5 Ton/ Ha/Year) if no support/conservation practices applied when undertaking a number of land uses including agriculture. The study shows that soil erosion in the study area vary spatially in terms of the degree of severity at various scales and therefore different management strategies in the three districts should be prioritized according to varying degrees of erosion hazards established in this study. Furthermore, there is need of field investigation on the highlighted wards located in very severe to catastrophic area to match the physical area conditions with the appropriate soil conservation measures to put in place and quick implementation of identified soil conservation interventions to reduce impacts of soil erosion by water in the respective wards.

Conflicts of Interest

The authors wish to declare that they have no conflicts of interest to disclose related to this research.

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