Soil Loss and Erosion Potential Estimation of Jhimruk Watershed, Nepal

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Abstract

The Revised Universal Soil Loss Equation (RUSLE) model was used in a Geographic Information System (GIS) to estimate the soil loss of the Jhimruk Watershed, Lumbini Province, Nepal. This research also aimed to calculate the erosional soil loss status of the local governments lying inside the watershed. For this, remote sensing data obtained from various sources were used to generate the factor maps to calculate the soil loss through RUSLE. A 13 year mean annual precipitation data from the 8 meteorological stations in and around the watershed was used to calculate the rainfall erosivity (R) factor. For the soil erodibility factor (K), the soil map of the watershed was clipped from the digital soil map of the world provided by FAO. Aster Digital Elevation Model of 30m resolution was used for the generation of LS factor map. For the computation of C-factor, the landcover map of the watershed produced in Arc GIS 10.2.1 through supervised classification of the Sentinel imagery of 10m resolution was used. The values were assigned based on the literatures in the case of C and P factors. The mean annual soil loss of the watershed was found to be 13.4 tons per hectare per year (t/ha/yr.). However, the soil loss was calculated to be as high as 182 t/ha/yr. 68.82% of the total area of the watershed lie under very low erosion class and thus have low conservation priority whereas 7.73 % of the total area lie under extremely high erosion class and thus have a conservation priority class of 1. The mean erosion rate from the barren land was found to be highest (23.179 t/ha/yr.) followed by agricultural (21.40 t/ha/yr.) and forest area had the lowest erosion rate i.e. 7.90 t/ha/yr.

1. Introduction

In developing countries, soil degradation by accelerated water and wind-induced erosion is a serious problem and will remain so during the 21st century as well. Soil erosion is a complex phenomenon that involves various natural processes: detachment, transport and subsequently deposition (Jain et al., 2001). The process erodes top soil by the natural physical forces of water wind or through forces associated with farming activities such as tillage (Sahu et al., 2017). In recent years, anthropogenic activities including mining, deforestation, construction, agricultural pesticides and malpractices, overstocking and overgrazing, etc., are rapidly accelerating the soil erosion (Gautam et al., 2013; Singh et al., 2016). These activities mainly cause two sets of problems: (i) on-site and (ii) off-site problems. On-site problems include loss of agricultural land productivity, soil quality, water-holding capacity, nutrient loss, etc., and off-site problems include movement of sediment, which causes flooding and the silting up of reservoirs and rivers beds (Singh et al., 2016). The resulting effects of on-site problems may pose serious threat to the environment and livelihood as it reduces the soil fertility and crop production simultaneously (Pimentel, 2006; Pimentel & Burgess, 2013).

Land degradation and freshwater deterioration by soil erosion are major environmental and economic problems faced worldwide, especially in developing countries (Pimentel & Kounang, 1998; Sidle et al., 2006). In Nepal, the situation is even worse because two-thirds of the country's total area is geologically fragile where soil erosion is exceedingly high. Due to soil erosion, topsoil loss has been lost as high as 87 t/ha/yr. on sloping terraces (Kaini, 2018). It is estimated that about 1.7 mm of topsoil is lost each year

due to soil erosion (Gautam, 1993). When the top soil is lost, the land is degraded which resulted into poor land management. Poor land management not only impact on food production but also on biodiversity loss, carbon loss and disaster resilience. Nepal will have to face the greatest challenges if better land regulation and improved farming technologies are not put in place.

Because of Nepal's highly rugged mountainous topography, active tectonics and highly concentrated monsoon precipitation, the country is naturally highly vulnerable to different forms of mass-movement and soil erosion on mountain slopes and flooding and siltation in the low-land area. Generally, when farmland is ploughed and tilled, the exposed topsoil is often blown away by wind or washed away by rain. Erosion due to faulty practices in crop production, for example, has resulted in the loss of millions of tons of topsoil every year, which ultimately reduce soil fertility and degrade land. Unscientific farming in the hills (steep slope) is one of the causes of soil erosion in Nepal. About 80% of the nation's land is covered by mountains and thus, shifting cultivation and unnecessary tillage practices lead to land degradation and damage the ground vegetation and natural ecosystems.

Nepalese economy even though based on agriculture faces vagaries of monsoon in larger parts of country without irrigation facilities. In mountainous regions, farmers largely rely on rain fed agriculture. The mountainous regions are characterized by a climate with no or insufficient rainfall to sustain agricultural production. Most of the rainfall water through torrential downpours is lost as run-off, eroding significant quantities or precious top soil in the mountain watersheds (Kalpana, 2006). In order to manage watershed activities for sustainability of land and water resources, simulation and optimization models would be required for significant representation of processes and quantification impacts of management strategies in natural watersheds (Tripathi & Ogbazghi, 2016). In other words, to protect the land from further degradation and make the mitigation measures effective, it is essential to know the spatial distribution of the areas susceptible to degradation and to assess erosion hazard severity. The combined use of Remote Sensing (RS), Geographic Information System (GIS) and erosion models have been shown to be an effective approach for estimating the severity and spatial different soil resources and land use conditions for soil conservation planning (Chalise et al., 2018).

Hydrologic models are important in addressing a range of problems related to water resources assessment, development, and management activities. However, many users may not be able to take use of modeling efforts in management decision due to lack of synergy of site-specific modeling options and their applications. Soil erosion modelling is able to consider many of the complex interactions that influence rate of erosion by simulating erosion processes in the watershed. Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. The models are designed for specific set of conditions of particular area. The Universal Soil Loss Equation (USLE) is an empirical model assessing long term averages of sheet and rill erosion (Wischmeir & Smith, 1978). Morgan, Morgan and Finney (MMF) model, a semi-empirical model having strong physical base used to assess soil loss (Morgan et al., 1984). The USLE and its modified version such as MUSLE (Williams, 1975) and RUSLE (Renard et al., 1991) have been widely used to various scale and regions. The soil loss estimation employing these models indicates the severity of soil erosion under the present

land use practices. In the present study, the Revised Soil Loss Equation (RUSLE) was selected to be applied in Jhimruk watershed for predicting the average annual soil loss within the watershed, because of its simplicity and lower data requirements. The main reason for choosing RUSLE is that it predicts the benefits of different management practices by predicting the amounts of sediment that may be trapped in sediment ponds, and determining maintenance schedules for different controls.

The current study also tries to answers the questions on the erosional soil loss status of the Jhimruk watershed and the local governments associated with it such as Municipalities and Rural Municipalities. The main objective of this research was to estimate the annual soil loss of the watershed as well as to develop a potential soil erosion map of the watershed and associated local bodies.

2. Materials And Methods

2.1. Study Area:

In this study, Jhimruk watershed situated in Pyuthan District is considered. Jhimruk watershed lies in the West Rapti River accounting 915 km² of the 4500 km² area of Rapti Basin. The river mainly covers Pyuthan District with the altitude of the basin reaching a height of 3200 m. The Jhimruk River originates in Gaumukhi and flows along the Mahabharat range until it merges into the Madi River and later downstream into the West Rapti River. The ArkhaKhola and Lung Khola are upper tributaries to the Jhimruk. The watershed contains sub-tropical and warm temperature climates, determined by elevation. The fertile alluvial soil of the watershed makes it suitable to paddy plantation, giving the area its nickname, “The Rice Bowl of Nepal”. In the northern part of the watershed, the Mahabharat Range comprised of metamorphic rock, such as slate, sandstone and limestone. The combination of rock types makes the zone susceptible to folding, faulting and thrusting.

The catchment area of the basin is diverse because of the difference in altitude, climate, geology, biological and land use conditions. Jhimruk River carries important value since the water from the river is used for agricultural purposes as well a 12 megawatt (MW) hydroelectric plant is being installed on the river since 1994.

2.2. Data collection:

Table 1 represents the data used for soil erosion modelling and the source from where it is taken.

Table 1: Data used for soil erosion modelling

Factor	Input data	Data source
Rainfall erosivity factor (R)	Mean Annual Precipitation data	DHM, Government of Nepal
Soil erodibility factor (K)	Digital soil map of Nepal	DSMW, FAO
Slope length and steepness factor (LS)	ASTER 30m Digital Elevation data	USGS Earth Explorer
Land cover management Factor (C)	LULC map from Sentinel 2 A(10m resolution) imagery	USGS Earth Explorer
Support Practice factor (P)	Slope percentage from ASTER 30m DEM data	USGS Earth Explorer

2.3. The revised Universal Soil Loss Equation (RUSLE):

The revised Universal Soil Loss Equation (RUSLE), developed in 1987 by the Natural Resource Conservation Society NRCS which predicts the rill and inter-rill erosion was used for estimating the soil erosion rate in Jhimruk watershed. The equation is given as:

$$A = (R) (K) (LS) (C) (P) \dots\dots\dots (i)$$

Where,

A = total soil loss, in tons per hectare per year

R = rain energy factor for the time period

K = the soil erodibility factor

LS = the length-slope factor

C = the degree of soil cover factor

P = conservation practices factor (for agricultural tillage and crop rotation operations, not generally applicable for construction site calculation)

2.3.1. Development of model database for RUSLE

a. Rainfall erosivity Factor (R)

The rainfall erosivity factor quantifies the effect of rainfall impact at a particular location and also describes the runoff amount and rate of the rain (Men et al., 2008). To calculate the rainfall erosivity of Jhimruk watershed, 13 year mean annual rainfall data was taken from eight different meteorological stations of that area. Since, only one meteorological station was located inside the watershed, other stations were taken as reference stations. The rainfall map was then produced by kriging method in Arc GIS and then rainfall erosivity was calculated by using the formula given by (El-Swaify, 1997):

$$R = 38.5 + 0.35 * P \dots\dots\dots (ii)$$

Where,

R = Mean Rainfall Erosivity Factor (R)

P = Mean Annual Rainfall (mm)

b. Soil Erodibility Factor (K)

Soil erodibility (K) factor represents the susceptibility of soil or surface material to erosion, transportability of the sediment and the amount and rate of runoff due to rainfall. The main soil properties that affect the K factor are soil texture, organic matter, soil structure and permeability of the soil profile. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard unit plot of 22.13 m long slope length with 9% slope gradient (Ganasri & Ramesh, 2016). The original equation given by the Wischmeir and Smith (1978) requires the soil structure and soil permeability values which were absent in the DSMW data. So, the equation provided by Sharpley and Williams (1990) was used for the estimation. The equation is given as:

$$K = F_{csand} * F_{si-cl} * F_{orgc} * F_{hisand} * 0.1317$$

Where,

$$F_{csand} = [0.2 + 0.3 * e^{-0.056SAN} (1 - \frac{SIL}{100})]$$

$$F_{si-cl} = [\frac{SIL}{CLA + SIL}]^{0.8}$$

$$F_{orgc} = [1.0 - \frac{0.25C}{C + e^{3.72 - 2.95 * C}}]$$

$$F_{hisand} = [1.0 - \frac{0.70SN1}{SN1 + e^{-5.41 + 22.9 * SN1}}]$$

Where,

SAN, SIL and CLA are percent sand, silt and clay respectively; c is the organic carbon content and SN1 is sand content subtracted from 1 and divided by 100

F_{csand} : It gives low soil erodibility factor for soil with coarse sand and high values for soil with little sand content.

F_{si-cl} : It gives low soil erodibility factor with high clay to silt ratio

F_{orgc} : It is the factor that reduce soil erodibility for soil with high organic content

F_{hisand} : It is the factor that reduces soil erodibility for soil with extremely high sand content

c. Topographic Factor (LS)

The (LS) factor is the ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9% slope under otherwise identical conditions (Wischmeir & Smith, 1978). LS factor takes into the rill erosion. The topographic factor also known as Slope Length and Steepness Factor (LS) was prepared from two sub-factors: a slope length factor (L) and a slope gradient factor (S). For this an ASTER Digital Elevation Model (DEM) of 30*30 m resolution of the Jhimruk watershed was used. The LS factor is very important to estimate the soil loss as it helps in calculating the transport capacity of overland flow (Morgan et al., 1984). The 'L' represents the effect of slope length on erosion whereas the 'S' represents the effect of the slope steepness on erosion. There is greater soil loss in areas with greater soil steepness than that with the slope length (Koirala et al., 2019). The LS factor represents the effect of topography, hill slope length and steepness on soil erosion.

The slope gradient and slope length factors were calculated from the Dem and combined result in the topographical factor grid using the relation given by (Gao et al., 2012).

$$L = \left(\frac{\lambda}{22.13} \right)^m \quad \text{(iii)}$$

Where, L= slope length factor, λ = slope length (m), m= slope-length exponent

$$m = \frac{F}{1+F} \quad \text{(iv)}$$

$$F = \frac{\sin \beta / 0.0896}{3(\sin \beta)^{0.8} + 0.56} \quad \text{(v)}$$

Where, F= Ratio of rill erosion to interrill erosion, β = slope angle ($^{\circ}$)

In ArcGIS, L was calculated as,

$$L = \frac{(flow_{acc} + 625)^{(m+1)} - flow_{acc}^{(m+1)}}{25^{(m+2)} + 22.13^m} \quad \text{(vi)}$$

For slope gradient factor,

$$S = \text{Con} ((\text{Tan} (\text{Slope} * 0.01745) < 0.09), (10.8 * \text{Sin} (\text{Slope} * 0.01745) + 0.03), (16.8 * \text{Sin} (\text{Slope} * 0.01745) - 0.5)), \dots\dots\dots (\text{vii})$$

$$\text{Final, LS} = L * S \dots\dots\dots (\text{viii})$$

d. Cover management factor (C):

The cover management factor (C) represents the ratio of soil loss from land with specific vegetation to the corresponding soil loss from a continuous fallow (Morgan, 2005). It is used to reflect the effect of cropping and other management practices on erosion rates. Vegetation cover is also important factor for the erosion control. Here, the land use and land cover map of the Jhimruk watershed produced in Arc GIS 10.2.1 through supervised classification was used to prepare the C- factor map. The values were assigned based on the study of (Erencia et al., 2000). The values of c-factor ranges from 0 to 1 where higher values indicate no cover effect and soil loss as compared to that of the barren land. Whereas, the lower values of c represents the strong cover effect which has the effect to control the erosion.

e. Conservation support-practices factor (P)

Support practices like terrace, contour methods are the important factor to control the soil erosion. The P factor indicates the rate of soil loss according to the various cultivated lands on the earth. The value of support practice factor given by (Shin, 1999) was used for the computation. The contour farmland is taken into consideration as agricultural support practice factor in Jhimruk watershed.

3. Results And Discussion

To determine the spatial distribution of average annual soil loss in Jhimruk watershed, the RUSLE parameters were estimated and multiplied in the specified 100m*100m cells to estimate the average annual soil loss as shown in fig.2. The R value ranges between 996.39 to 2200 MJ/ha.mm/h. The average annual soil loss from the Jhimruk watershed is computed as 13.5 t/ha/yr with the highest soil loss amounting to 182 t/ha/yr. The priority classes for soil losses in the study area were regrouped into eight classes (Uddin et al., 2016) as shown in Table 2.

Table 2: Area under different erosion classes of soil erosion in Jhimruk watershed

Erosion rate (Tons/ha/yr.)	Erosion class	Area(Km ²)	Area (%)	Conservation priority
0-0.5	Very low	599.7	65.54	8
0.5-1	Low	2.54	0.27	7
1-2	Low medium	4.72	0.51	6
2-5	Medium	11.11	1.21	5
5-10	High medium	17.06	1.86	4
10-20	High	44.45	4.85	3
20-50	Very high	154.65	16.90	2
>50	Extremely high	73	7.97	1

a. Rainfall Erosivity Factor (R)

The rainfall erosivity factor was generated using the equations as mentioned in equation (ii). The spatial distribution of this factor is as shown in Fig.3. The results showed that the R value ranges between 996.39 to 2200 MJ/ha.mm/h. The rainfall erosivity increases with the increase in slope as mentioned in the study of (Assouline & Ben-Hur, 2006). The slope of Jhimruk watershed ranged up to 80 degrees with most of the areas ranging in between 20-50 degrees. The erosivity was found to be higher in most of the parts of the watershed which might be due to the lack of meteorological stations inside the watershed. Although the rainfall data was collected from 8 different meteorological stations, only one station lied inside the watershed. And rainfall erosivity influences the rate of soil erosion too. Soil erosion due to water takes place in slopy areas when the rain falls on the soils with less vegetation and low cover management (Lal, 2001). A long term rainfall data is also required for the correct estimation of the R-factor.

b. Soil Erodibility Factor (K)

The soil map of DSMW was used to generate the soil erodibility factor map. The soil map of Jhimruk watershed was clipped from DSMW in Arc GIS environment and converted the raster into polygon where four types of soil were found. The attributes of the same types of soil were merged and fraction of sand, silt and clay were tabulated from FAO data portal for each characteristics soil type. The erodibility value was calculated by using the equation mentioned in the methods section. The K-factor for each type of soil is given in the table and the K value ranged from 0.017 to 0.020011. Soil erodibility factor (K) is dependent on the soil type of the area. The soil erodibility factor 'K' depends upon the soil texture, organic matter, soil structure and permeability of the soil profile (Ganasri & Ramesh, 2016; Koirala et al., 2019).

Soil can be composed of different types of sediments including sand, silt, clay, and organic matter and have their respective eroding rates. In the drier areas, the organic matter takes longer time to decompose and hence soil takes longer time to develop.

c. Topographic Factor (LS)

The slope map and Flow accumulation map was produced from ASTER DEM at 30m resolution following the equations (iii), (iv) and (v). The LS value of the watershed ranged from 0.029 to 18.638. Topographic factor represents the influence of slope length and slope steepness on the erosion process (Ganasri & Ramesh, 2016). The LS factor was calculated by considering the flow accumulation and slope in percentage as the inputs. LS factor ranged from zero to 18.3 based on these input. The LS factor tells us about the impact on soil erosion due to the topographic features like slope length and steepness (Koirala et al., 2019). LS factor increases with the increase in hill slope length and steepness.

d. Cover Management Factor (C)

The land cover map of the watershed was used to generate the cover management factor. The C-value ranged from 0-0.449. The value indicates the percentage of the erosive capacity as compared to the bare fallow area. The highest value indicates the higher rate of erosion occurs in those areas as compared with the bare land. The water bodies and settlement areas in the watershed have obtained higher values of the c-factor. The land use and land cover information helps to understand the land utilization aspects of agricultural land, barren land, water bodies, forests and settlements which are very essential for the erosion estimation.

e. Support Practice Factor (P)

The P factor was generated from slope map produced from the DEM. At first, the slope was classified into 5 range values based on Table 2 (Shin, 1999) and the P values were assigned assuming the contouring as the major agricultural practices on the slopes. The value ranged from 0.55 to 1 where higher value indicates the absence of support practice and hence the erosion becomes maximum. Support practice (P) factor shows the activity that people follow to slow down the rate of erosion. For instance, terrace farming on hillsides and contour farming on flatter areas. It shows how people's decisions affect their sustainability. Figure (3) shows the support practice factor of Jhimruk watershed where most of the parts have the P-factor near to 1 indicating quite low support in the conservation activity. It might also be due to because the P- factor values were assigned according to the cultivating methods and slope (Shin, 1999) and might not have correctly predicted for this specific region.

Potential Soil erosion Rate of Jhimruk Watershed

The potential soil erosion rate of the watershed has been produced in Arc GIS by multiplying the factor maps. The RUSLE parameters were estimated and then multiplied in the specified 100m * 100m cells to estimate the average annual soil loss of the watershed as shown in figure 4. It has been found that the erosion ranges from zero tons per hectare per year to 182 t/ha/yr. in Jhimruk watershed. The mean erosion rate of the watershed was calculated as 13.4 t/ha/yr. The mean soil erosion rate of the bare land was highest followed by Agriculture and built up (Settlement). The mean erosion rate of the bare land was calculated as 23.179 tons per hectare per year.

Rapti River basin is considered as one of the most flood prone area of Nepal and several villages in the lower part of West Rapti River along the Nepal-India border gets inundated due to monsoon floods every year (Talchabhadel & sharma, 2014). Soil erosion is also one of the major cause of the flooding. The hills receive greater amount and intensity of rainfall and experience frequent earthquake waves. Such biophysical conditions make watersheds of those regions extremely fragile and sensitive ecological environment to human disturbance (Shrestha et al., 2008).

Although there are many factors that affect the water erosion, vegetation cover, slope gradient and land use play the most important role as mentioned by (Uddin et al., 2016). This might be the case with Jhimruk that most of the areas are covered with forest and agricultural land have few erosion rates. Effect landuse planning might be an important factor to control the erosion rates. Several studies have also shown that Mid-Hills of Nepal have variable erosion rates which is because of the heterogeneity in the rainfall distribution, soil characteristics, and topography (Chalise et al., 2018; Uddin et al., 2016).

Erosion also has an association with the cultivation practices adopted by the farmers as well as its management (Shrestha et al., 2004). In this case, contour farming method is taken into consideration for the whole watershed. Topographic factors such as slope length and steepness, vegetation cover factors contribute in the soil loss of the mountainous watershed (King et al., 2005; Zhou et al., 2008). Areas with high erosion risk need to be applied soil conservation measures such as implementation of the bioengineering measures. Areas located in steep slopes usually have higher bulk density (Khalil et al., 2020). And the higher bulk density affect the circulation of air, water and plant nutrients and the root systems and hence increases the soil erosion. Rill erosion is a significant process of surface erosion and hence it is necessary to take it into account (Higaki et al., 2005). The field observations of this study concluded that less soil erosion was seen in areas with vegetation cover and the surface erosion is slight on gentle slopes.

It is very essential to access the accuracy of the estimated soil loss from the models through field based measurements (Jha & Paudel, 2010). But due to the limitation of the resources and the study area being large the field based measurement is not possible. Since Jhimruk watershed has not been gauged for soil erosion therefore it was verified with the erosion status of mid-hill regions of Nepal. The obtained results were compared with the estimated erosion levels at watershed having similar geographical features as well as with national scale to get an overall perspective. The RUSLE derived mean erosion rates for different types of land cover classes were within the range given by (Koirala et al., 2019; Uddin et al.,

2016). The study conducted by (Chalise et al., 2018) has found the soil loss rate of 11 t/ha/yr. for Aringalekhola watershed in Salyan district having the similar geographical conditions and physical features as Jhimruk watershed. The study showed that 68.82 % of the watershed lies under very low erosion class with soil loss ranging between 0-5 t/ha/yr whereas, 7.73 % of the watershed falls under extremely high erosion class. The high erosion class of the watershed might be attributed to the high rainfall, steep slopes, agricultural practices and fragile rocks (Chalise et al., 2018; Koirala et al., 2019; Pandey et al., 2009). Mountainous areas have relatively increased level of soil erosion which is also due to the poor management and abandoned cultivation of terraced paddy fields (Chen et al., 2011). Rising temperatures have an indirect impact on soil erosion (Nearing et al., 2004). There occur changes in vegetation cover and soil moisture along with the change in temperature. So, change in the climate will also have an impact in the soil erosion of that place.

As per the report published by USAID (2018), unsustainable farming and limestone mining in Luplung village of the watershed contributed to soil erosion which weakened the terrain on fragile slopes. The occurrences of landslides have become more frequent after that. The poor design of the road infrastructures has also intensified the disasters like landslides and soil erosion in several areas of the watershed. The erosion of the soil also affects the natural habitat of the aquatic and terrestrial species. The haphazard road construction in the name of development in rural areas of the country which run without the proper environmental impact assessment intensify the soil erosion rates and also reduces the soil fertility. These erosion and landslides can result in river cutting and downstream flooding. Not only these, there are incidences of drying up of springs and other water resources due to the road construction (Gurung et al., 2019).

Much better results could have been obtained if the field based measurements of the soil data could have been taken for the watershed. Also, experimental plots and iterative process for soil loss estimation could help to refine the model improve the results. Further studies can take into consideration of these things in order to get more accurate and specific results.

It has been said that plants take 100 years to grow as a tree but it takes about 1000 years to be a fertile soil which is very true as the decomposition process takes a long time. Once, the soil is lost it affects the whole soil cycle and ultimately affects the productivity of the land. Estimation of soil loss will help to understand about the prioritization of erosion prone areas and ultimately the effective management plan for the watershed.

Conclusion

The results of the soil erosion map that was produced with the RUSLE model showed that the soil erosion rate of Jhimruk watershed was found to be ranging from 0- 182 t/ha/yr. with most of the areas lying under low erosion risk. This might be due to the conservation practices value that is assigned for the area and also there are other factors like slope, cover management and soil type. Although, most of the areas fall under low erosion risk, there are some of the areas which have greater soil loss up to 182.11

tons/ha/yr. Categorizing the soil loss of the watershed on the basis of the local governments, Sandikharkha Municipality had the highest soil erosion rate (18.601), whereas Naubahini Rural Municipality had the lowest erosion rate of 11.322 t/ha/yr. It is necessary to design and implement erosion control practices in the erosion prone areas. The results obtained from the study can assist in the prioritization of the areas prone to soil erosion and develop effective conservation measures.

Declarations

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Conflict of interest

None of the author has conflict of issue.

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Figures

Figure 1

Map of the study area: Jhimruk watershed, Nepal

Figure 2

Methodological framework for soil erosion modelling

Figure (a)

Figure (b)

Figure (c)

Figure (d)

(e)

(f)

Figure 3

(a-e), Spatial distribution of the factor maps used in RUSLE, (f) Soil erosion map of Jhimruk watershed

Figure 4

Soil loss map of Jhimruk watershed

Figure 5

Soil erosion by slope

Figure 6

Soil erosion by landcover