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Research Article

GIS and Remote Sensing Supported Soil Erosion Assessment of Kamala River Watershed, Sindhuli, Nepal

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Abstract

This study analysed the situation of water-induced soil erosion in Kamala River watershed of Sindhuli, Nepal covering 23,194.33 hectares of land, extending from 85°58'11.6"E to 86°18'16.8"E longitude and 26°56'45.9"N to 27°5'44.4"N latitude. Revised universal soil loss equation was applied in GIS environment using the satellite-based data, field measurements, surveys and lab analysis. R factor predicted from the average annual precipitation. K factor based on the soil texture and organic carbon content. LS factors derived from the DEM of 20m resolution. C factor derived from the NDVI value extracted from Landsat 8 OLI imagery of the pre-monsoon season. P factor assigned according to the land cover of the study area. The study explored the massive diversity of erosion rates even within the narrow span of a landscape in the Churia range of the Himalayan foothills. As predisposed by the diversity of terrain and vegetation cover, and aggravated further by the dominance of silts in the texture of soils, soil erosion rate has been found to vary and noticeably occur in higher ranges of severity. Overall, total potential of soil loss in the watershed was 1.460 million tons/ year, out of which only 0.297 million tons of soil was estimated to be actually eroded from the watershed in the existing conditions. Conservation measures are advisable in the areas having severe soil loss. The resulting soil erosion rate map can be a guideline for developing sustainable land management strategy in the concerned and similar lower foothills of Himalayan mountain landscapes.

Keywords: GIS; remote sensing; RUSLE; soil erosion

Introduction

Land degradation is a global problem causing a decline in the productive capacity of the land. The degradation receives a wide area of concern due to its significant negative impacts on production. This, in fact, is the main reason for the dramatic decrease of prime agricultural lands where only 3% of the global surface is left in the category of prime or class I (Eswaran*et al.*, 2001). Land degradation remains a major threat to the provision of environmental services and the ability of smallholder farmers to meet the growing demand for food. Understanding patterns of land degradation is, therefore, a central starting point for designing any sustainable land management strategies. However, land degradation is a complex process both in time and space making its quantification difficult.

Land degradation is a major challenge of Nepal. Over the past few years, mid-hills of Nepal have been a focus of research in regard to sedimentation, runoff and soil erosion (Ghimire *et al.*, 2013). Both the natural conditions and human activities have contributed to the degradation of

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land. Predominantly, in Nepal, soil erosion is more related to natural forces; however, it is also connected with how the lands are being cultivated and how they are managed (Shrestha et al., 2004). Land degradation may occur through different physical, chemical and biological processes which are directly or indirectly aggravated further by anthropogenic activities. Similarly, Soil erosion is a prominent environmental concern in the mountainous ecosystems (Nyssen*et al.,* 2009). It is widely experienced fact that water-induced soil erosion is a major challenge in the mountainous slopes of Nepal.

Therefore, this study aimed at exploring a scenario of water-induced soil erosion in the Kamala River watershed, using geospatial technology to spatially predict the scenario of soil loss by deploying Revised Universal Soil Loss Equation (RUSLE). RUSLE in combination with Remote Sensing and GIS can make the prediction of the spatial distribution of soil erosion more practicable and economical with available resources (Lu *et al.,* 2004; Millward and Mersey, 1999).

Materials and Methods

Study Area

Kamala River watershed is located in Churia physiographic region, which is a fragile and vulnerable landscape in terms of soil erosion (Fig. 1). The total area of the watershed is 23,194.33 hectares extending from 85° 58' 11.6"E to 86° 18' 16.8"E longitude and 26° 56' 45.9"N to 27° 5' 44.4"N latitude.The location of the watershed is geologically fragile. Moreover, land covers as well their statistic also shown on the Table 1 and Fig 2.

Table 1: Land covers statistics

Land cover class	Area (Hectare)
Agriculture area	6423.61
Barren area	602.07
Forest	15116.64
Grassland	454.34
Shrubland	172.87
Water body	424.80
Total	23194.33

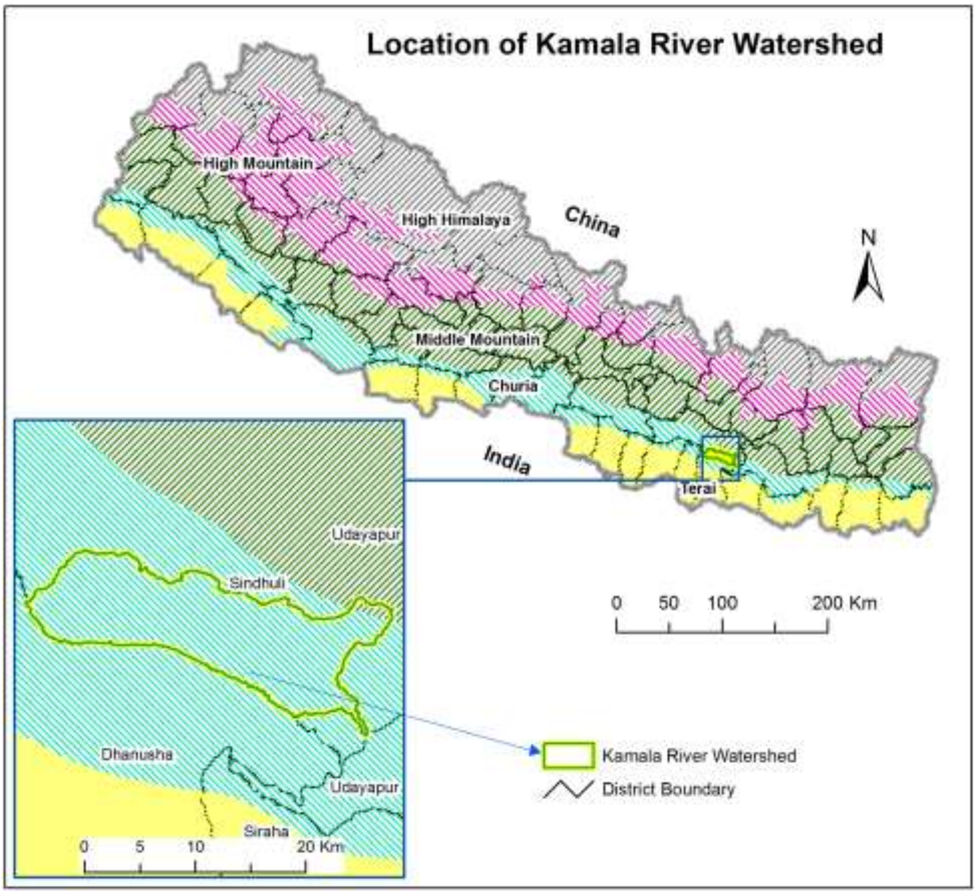

Fig.1: Location map of Kamala river watershed

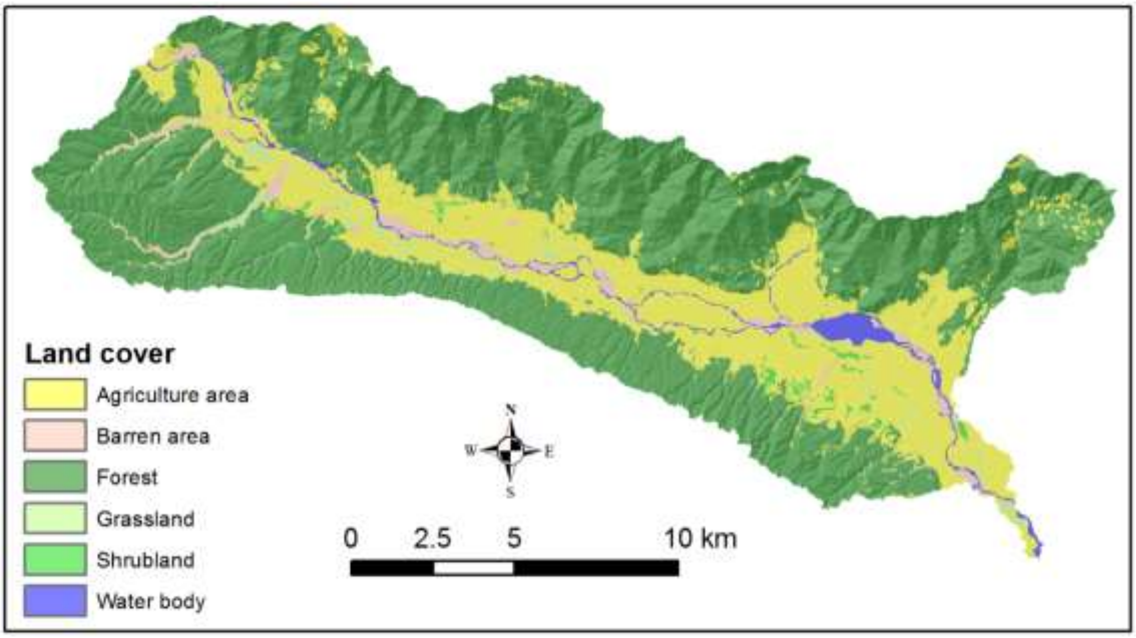

Fig. 2: Land Cover map of Kamala river watershed

Soil Loss Estimation

Revised universal soil loss equation was used for the estimation of the rate of annual soil loss from the Kamala River watershed. The analysis was performed in GIS environment using spatial-overlay of data in raster structure.

According to Revised Universal Soil Loss Equation average annual soil loss rate is calculated as follows:

A = R x K x LS x C x P (Wischmeier and Smith, 1978)

Where;

A = Average annual soil loss rate ($t^{-1}ha^{-1}yr^{-1}$)

R = Rainfall factor (MJ mm $ha^{-1}hr^{-1}yr^{-1}$)

K = Soil erodibility (ton hr ha $ha^{-1}MJ^{-1}mm^{-1}$)

L = Slope length factor (dimensionless)

S = Slope steepness factor (dimensionless)

C = Crop management factor (dimensionless)

P = Support practice factor (dimensionless)

Rainfall erosivity i.e. R factor was derived from the long-term annual average of the precipitation. R is the product of storm kinetic energy and maximum 30 – minute intensity. Rainfall erosivity estimation using rainfall data with long-time intervals have been attempted by several workers for different regions of the world. Using the long-term average of WorldClim data, erosivity was calculated using the following expression given by Parveen and Kumar (2012).

R = 79+0.363*P

Where, P=annual precipitation, mm.

Soil erodibility i.e. K factor was derived from the texture and organic matter content of the soil (Wischmeier and Smith, 1978; Renard*et al.,* 1997). Soil sampling was carried out randomly and laboratory analysis was conducted to test the texture and organic matter content of the soil. Based on the K value calculated using the following expression and the location of the soil samples captured using GPS, the soil erodibility of the entire catchment was predicted using stable semi-variogram of ordinary kriging method.

$K = 27.66 \times m^{1.14} \times 10\text{-}8 \times (12 – a)$

Where:

K = Soil erodibility factor (ton hr ha $ha^{-1}MJ^{-1}mm^{-1}$)

m = (Silt% + Fine Sand %) × (100 − clay %).

a = % organic matter.

Slope length and steepness factors i.e. LS factors were calculated from the digital elevation of 20-metre spatial resolution using the following expression proposed byWischmeier and Smith(1978) and Modified further by Moore and Wilson (1992).

$LS = [\text{flow acc*cellsize}/22.13]^{0.4} * [(\sin(\text{slope}*3.14/180))/0.0896]^{1.3}$

Cover management factor C was derived using the following expression on the normalized difference vegetation index (NDVI) of Landsat 8 OLI imagery of pre-monsoon season which was assumed to provide effective vegetation cover to protect from monsoon rainfall (Karaburun, 2010).

C = 0.431 – 0.805 × NDVI

Support practice factor i.e. P was derived from the land use and support practice parameters of the area. Values of P were derived based on literature according to land use and related support practices issues like bench terrace, sloping lands etc. Most of the cultivated and barren lands are in the bench terraces, whereas the forests are in natural slopes of the terrain. Values were adjusted accordingly.Land use data was derived by classification of Landsat 8 OLI Imagery, and the accuracy was further enhanced by the visual interpretation overlaid on high-resolution satellite imagery of Google earth.

Table 2: P factor values

Land use	P Factor value
Built-up	1
Barren land	1
Cultivated land	0.5
Forest	1

Mean annual soil loss was worked out by multiplying all these factors. For calculating potential soil loss, only R, K, and LS factors were multiplied. For calculating actual estimated soil loss, C and P factors were also multiplied in the expression (Table 2).

Raster data structure based spatial overlay was carried in ArcGIS 10.4.1 platform using raster calculator tool for the analysis.

Results and Discussion

Potential soil loss was predicted range up to as high as 4329 t $ha^{-1}yr^{-1}$, whereas, the highest rate of actual estimated soil erosion was only up to 1127 t $ha^{-1}yr^{-1}$ (Figure 4; Figure 5) offset by the presence of cover factor and management factors in the watershed. Erosion was observed in all 10 categories.

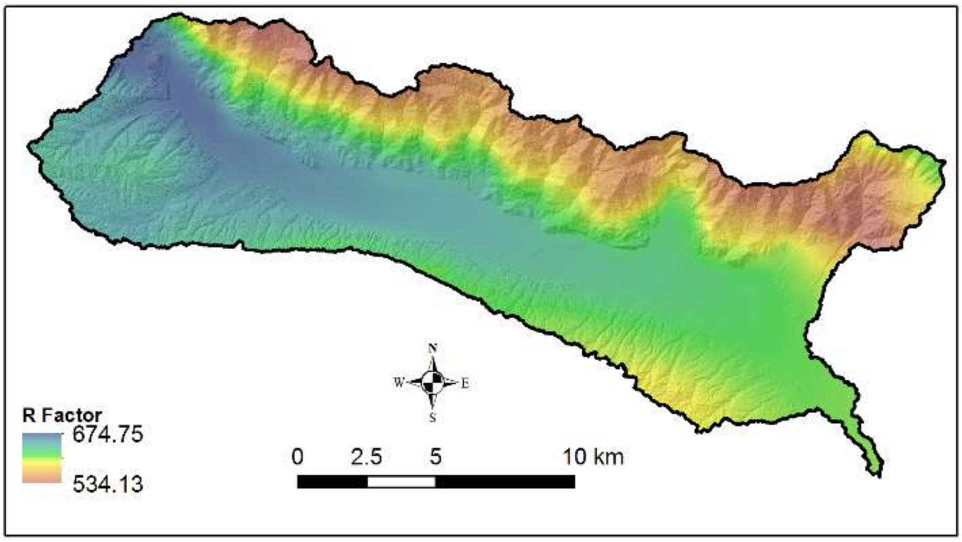

Fig.3:R fac tor of RUSLE

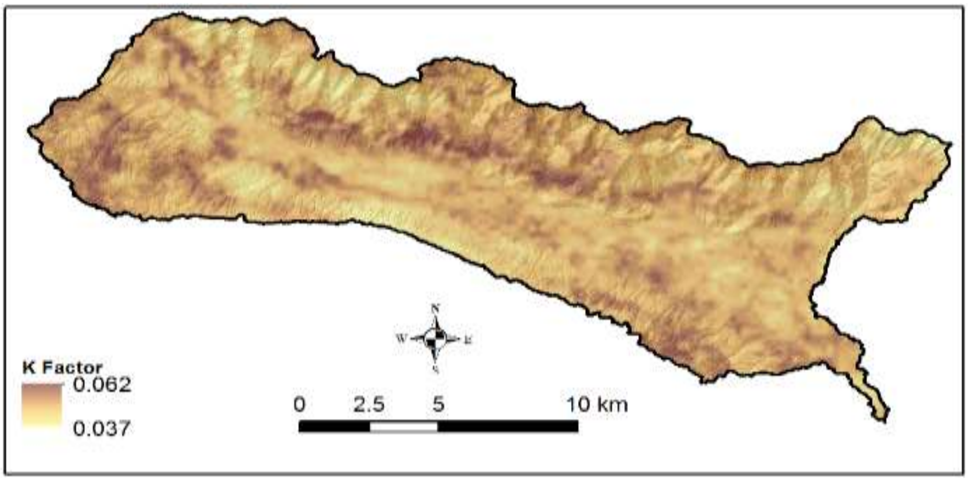

Fig. 4: K factor of RUSLE

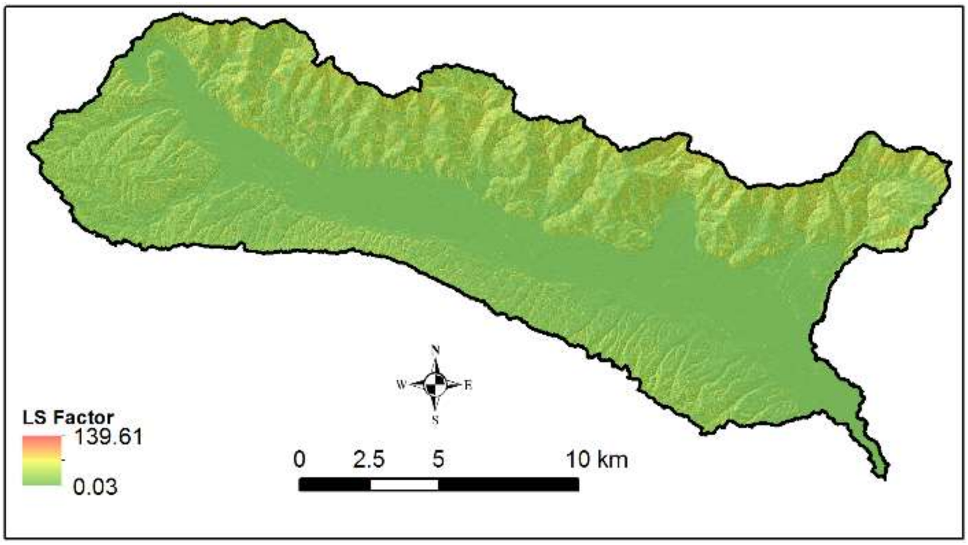

Fig.5:LS factor of RUSLE

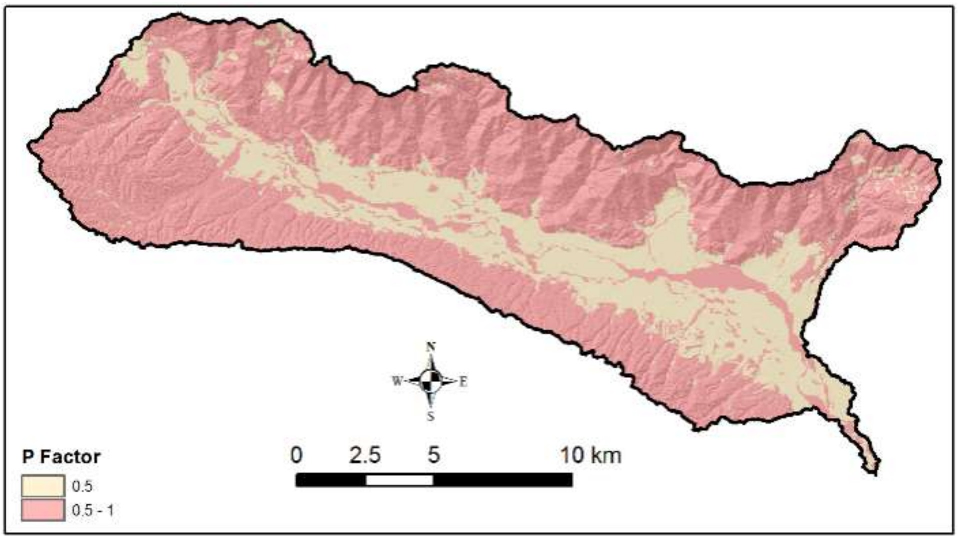

Fig.6: P factor of RUSLE

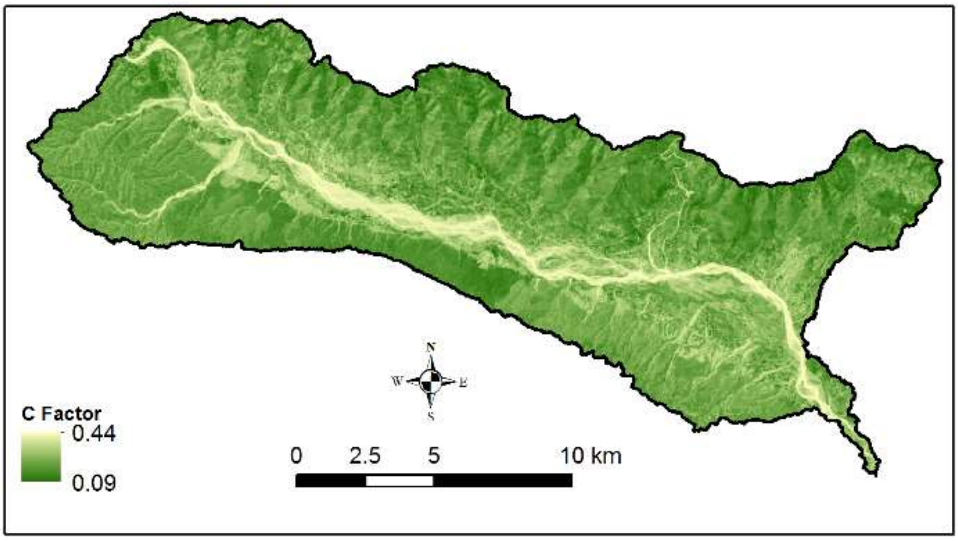

Fig.7:C factor of RUSLE

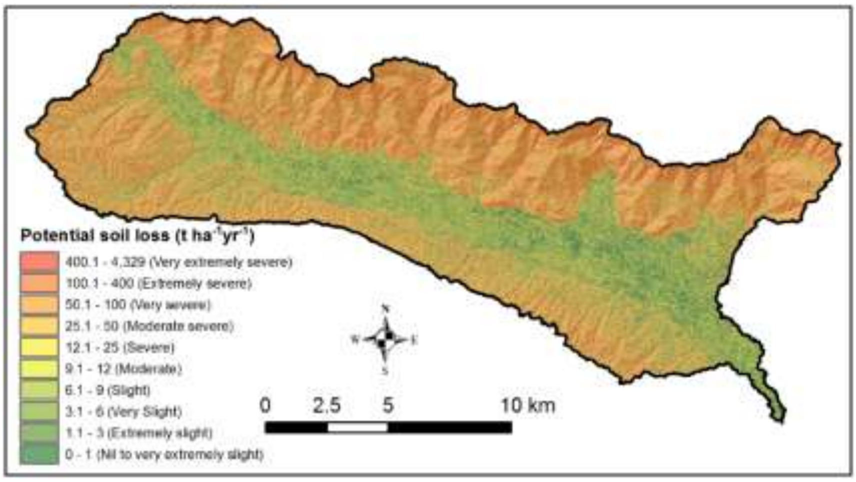

Fig.8: Potential soil erosion

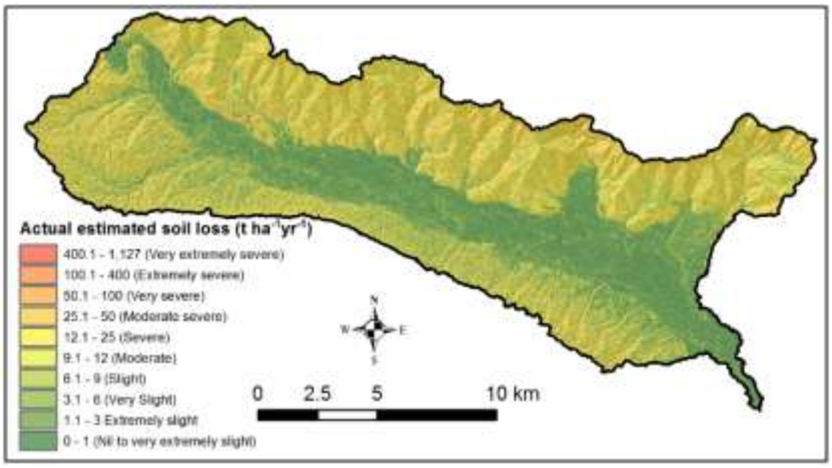

Fig. 9: Actual estimated soil erosion

Highest actual estimated erosion was observed in '*Severe*' category occurring in 6667.6 ha of land closely followed by nil in 6333.7 hectares. Area under 'Moderately severe' category is also significant which amounts to 3674.6 hectares.

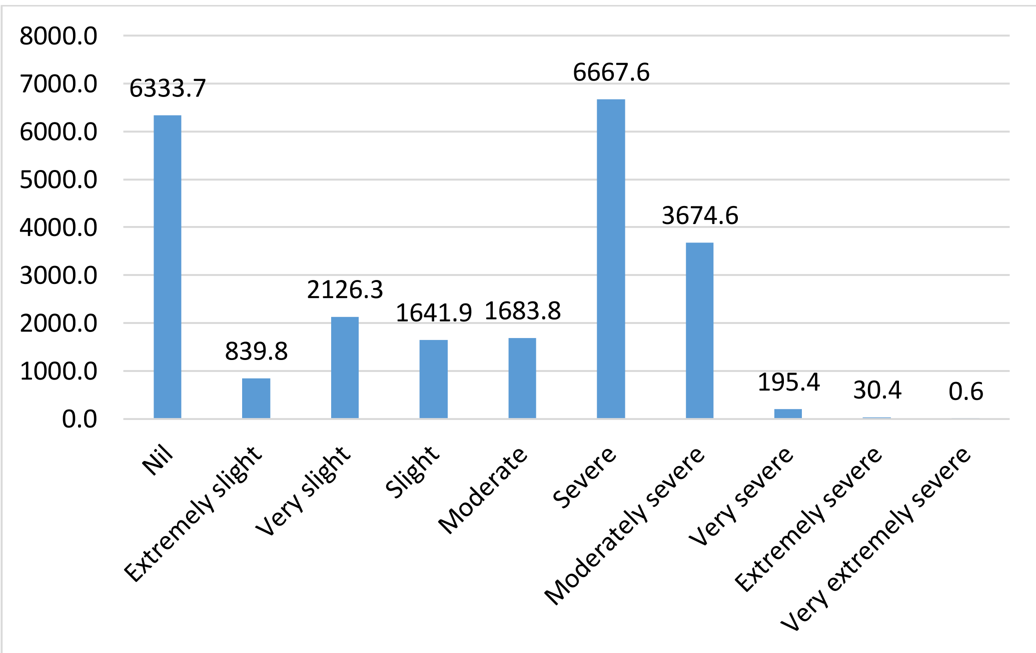

Fig.10: Area (hectares) of the occurrence of actual estimated soil erosion rate statistics

Table 3: Potential and estimated actual soil loss rate according to land cover

Land cover	Potential soil loss rate (t ha^{-1} yr^{-1})					Estimated Actual soil loss rate (t ha^{-1} yr^{-1})				Difference in mean soil loss rate
	Area (Ha)	MIN	MAX	MEAN	STD	MIN	MAX	MEAN	STD	
Agriculture area	6423.61	0.71	2041.72	21.62	35.50	0.04	312.35	2.76	4.51	18.86
Barren area	602.07	0.80	1874.90	17.41	36.68	0.16	459.60	5.21	10.47	12.19
Forest	15116.64	0.68	4328.07	85.51	65.65	0.08	1127.11	17.95	14.06	67.55
Grassland	454.34	0.74	2160.95	30.40	46.53	0.13	718.38	7.86	12.07	22.54
Shrubland	172.87	0.77	1640.36	27.42	39.29	0.10	458.00	6.64	9.50	20.78

Table 4: Total annual soil loss from different land covers in Kamala river watershed

Land cover	Potential soil loss (t year^{-1})	Estimated actual soil loss (t year^{-1})	Difference (Potential – actual)
Agriculture area	138875.90	17718.51	121157.39
Barren area	10481.85	3139.70	7342.15
Forest	1292575.08	271408.27	1021166.81
Grassland	13810.64	3572.01	10238.63
Shrubland	4739.34	1147.59	3591.75
Total	1,460,482.80	296,986.08	1,163,496.72

Comparing the potential and actual estimated soil erosion rate according to different land cover categories, highest difference in soil loss was under the forest cover, amounting to 67.55 t ha^{-1}yr^{-1}. Lowest difference was observed in barren area (67.55 t ha^{-1}yr^{-1}).

Total potential of soil loss in the watershed was calculated to be 1.460 million tons per year, out of which only 0.297 million tons of soil was estimated to be actually eroded from the watershed in the given scenario of vegetation cover and the level of conservation management practices. The Table 4 mentioned depicts the scenario according to different land cover categories.

Conclusion

The study explored the massive diversity of erosion rates even within the narrow span of a landscape in the Churia range of the Himalayan foothills. As predisposed by the diversity of terrain and vegetation cover, and aggravated further by the dominance of silts in the texture of soils, soil erosion rate has been found to vary and noticeably occur in higher ranges of severity. Overall, total potential of soil loss in the watershed was calculated to be 1.460 million tons per year, out of which only 0.297 million tons of soil was estimated to be actually eroded from the watershed in the given scenario of vegetation cover and the level of conservation management practices. Conservation measures are advisable in the areas with higher severity rates of loss of soils. The resulting soil erosion rate map can be a guideline for developing sustainable land management strategy in the concerned and similar lower foothills of Himalayan mountain landscapes.

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