



Spatial assessment of soil erosion in a hilly watershed of Western Nepal

Devraj Chalise^{1,2}  · Lalit Kumar¹ · Chandeshwar Prasad Shrivastav³ · Sushil Lamichhane¹

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Abstract

Soil erosion is a serious problem mankind is facing today as it has been continuously degrading the quality and standard of lives across the globe. Being a hilly country with undulating topography with steeper slopes accompanied with heavy rainfall, Nepal is predisposed to natural hazards including soil erosion. This paper attempts to model the soil erosion rate in the Aringale Khola Watershed of middle hills of Nepal with the judicious use of geographic information system (GIS) and revised universal soil loss equation (RUSLE) techniques. RUSLE was used in ArcGIS environment, taking rainfall-runoff (*R*), soil erodibility (*K*), topography (*LS*), crop management (*C*) and conservation support practice (*P*) factors as primary inputs. A total of nine soil erosion classes were observed; soil erosion rates ranging from 0.03 to 100.33 t/ha/year with a mean soil rate of 11.17 t/ha/year. GIS analysis depicted that 36.93% (1256.28 ha) of the total watershed area fell in the severe erosion classes whereas the remaining 63.07% (2145.56 ha) were less severe. A major part of the watershed, particularly areas with higher elevations and steep slopes, are degraded and needs urgent conservation measures. This study is a first attempt to model soil erosion distribution in the Aringale Khola Watershed and has very good potential to be used for soil erosion prediction in similar watersheds in the middle hills of Nepal.

Keywords GIS · Land management · RUSLE · Soil conservation · Soil erosion

Introduction

Soil erosion is a most severe environmental issue mankind has faced in the modern era (Atreya et al. 2006; Nigel and Rughooputh 2013). It is also a regular process associated with the evolution of topography (Lu et al. 2003). It is the most serious concern of environment as it deteriorates agricultural productivity and also harms the natural environment (Wijesekera and Samarakoon 2001). At a worldwide scale, soil erosion has been established as a main source of land and soil degradation, which accounts for 70–90% of total land degradation (Teshahunegn et al. 2014). Many developing nations are facing serious ecological degradation that is

brought by mass deforestation, regarding this Nepal is no exception (Awasthi et al. 2002).

Nepal, a mountainous country with very active tectonics, wide range of reliefs starting from 60 m in the south to 8848 m in the north and much concentrated rainfall in the months of June–September, is prone to different natural hazards such as landslides and soil erosion (Chalise and Khanal 1997). Soil erosion is a leading environmental concern in the hilly ecosystems (Nyssen et al. 2009). Deleterious effects of soil erosion have been identified to be major problems for the sustainability of natural resources as it is losing fertile topsoil which hinders attaining food surplus for ever increasing world population (Morgan 2009; Teshahunegn et al. 2014). Over the last few decades, Nepalese mid hills have been at the center of research regarding soil erosion, sedimentation and runoff (Ghimire et al. 2013). Continuous soil erosion may result in reduced nutrient and water holding capacity of soil, inhibition of vegetation growth and loss of top fertile soil (Mohammad and Adam 2010; Vásquez-Méndez et al. 2010; Zhou et al. 2006). In a hilly country such as Nepal, loss of soil is considerably more from landslides (Fort et al. 2010). Soil erosion in the Himalayan region is borne by landslide,

✉ Devraj Chalise
dchalise@myune.edu.au

¹ School of Environmental and Rural Science, University of New England, Armidale, NSW 2351, Australia

² Nepal Agricultural Research Council, Kathmandu, Nepal

³ Department of Soil Science and Agri-Engineering, Agriculture and Forestry University, Chitwan, Nepal

deforestation, overgrazing and mudslides (Shrestha 1997). Although erosion is more related to natural forces in Nepal, it is also associated with how farmers are cultivating their lands and how they are managing them (Shrestha et al. 2004). In the middle hills, cultivating crops is common in marginal lands of gentle to steep slopes formed by landslides (Higaki et al. 2005). There has been severe decline in soil fertility where cultivated and grazing lands are abandoned due to continuous soil erosion (Partap and Watson 1994).

Several soil erosion prediction models have been developed worldwide but the most adopted ones are Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) (Prasannakumar et al. 2011). Although empirical (Wang et al. 2003), RUSLE integrated with RS and GIS can make spatial prediction and distribution of soil erosion much achievable and cheaper with available resources (Lu et al. 2004; Millward and Mersey 1999). RUSLE not only can calculate soil loss of ungauged watersheds but can also express spatial diversity of erosion too (Yue-Qing et al. 2008).

This paper, thus, aims to document, measure and map soil erosion risks in the Aringale Khola Watershed of Nepal with the integrated use of RUSLE and GIS techniques. It is a typical watershed of middle hills that includes grasslands, open and dense forests, cultivated lands, rugged and sloping uncultivated hills, and residential areas. It provides a range of ecological and environmental benefits, however, traditional agricultural practices coupled with steep slopes and high rainfall have resulted in the areas being severely eroded. The condition will be more severe if urgent conservation measures are not undertaken. The general RUSLE

framework has been utilized, integrating spatial distribution of rainfall (R), soil erodibility (K), topography (LS), crop management (C) and conservation support practice (P) factors (Renard et al. 1997). Information collected from fieldwork and findings of this study will be helpful to planners and decision makers in understanding the erosion processes and developing suitable policies to reduce them.

Materials and methods

Study area

The study area covers a hilly watershed, Aringale Khola Watershed, located at Dhanwang and Rim Village Development Committees (VDC) of Salyan district, Nepal. The area of the watershed is 3401.84 ha (34.01 km²) and lies between 28°13'50" and 28°16'36" north latitudes and 82°17'33" and 82°24'11" east longitudes (Fig. 1).

Aringale Khola flows in between Dhanwang and Rim VDCs and ultimately drains down to Sharada River. The watershed encompasses open and dense forests, cultivated lands, stream banks, bare lands and built-up areas. It was chosen as the research area as it is a typical catchment of the district and the diversity in land use and terrain landscape in the watershed can be a representative work in the study of soil erosion for the middle hills of Nepal.

Of the five distinct physiographic regions, the Aringale Khola Watershed covers Siwalik Hills (987–1500 m) and Middle Mountains (1500–2109 m) (Joshi et al. 2003;

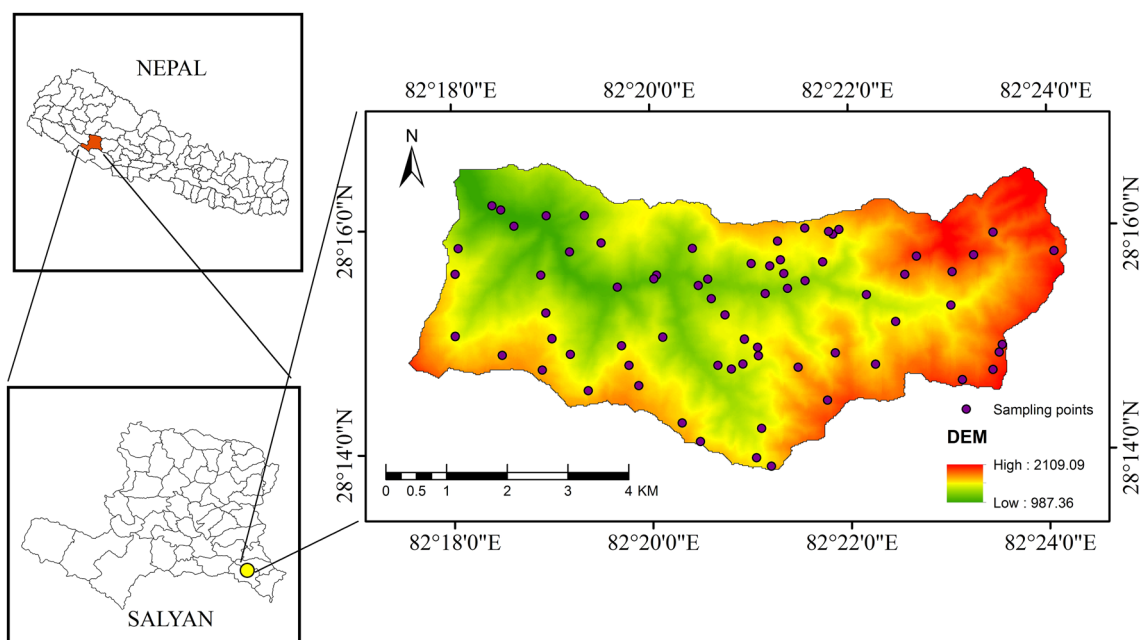


Fig. 1 Study area with digital elevation model showing soil sampling locations

Karkee 2004; Shrestha and Aryal 2011). The climate of the catchment differs, subtropical (Elevation: 987–2000 m) and temperate (Elevation: 2000–2109 m) with maximum temperature of 38 °C and minimum of 7 °C in normal years. Average, maximum and minimum precipitation recorded are 872.6 mm, 1161.4 mm and 633 mm for last 11 years. The majority of the catchment area is hilly with more of forests and less agricultural lands. Major agricultural crops grown in the area include maize, rice and millet.

Soil loss estimation method

Many soil erosion models have been proposed in the last 40 years at the regional and international levels (Farhan et al. 2013). Some of the models are Universal Soil Loss Equation (USLE), Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil loss Equation (MUSLE), Water Erosion Prediction Model (WEPP) (Farhan et al. 2013) and Morgan, Morgan and Finney (MMF) (Tesfahunegn et al. 2014). USLE is one of the most powerful and popular tools for assessing rill and sheet erosion (Renard et al. 1991). However, it demands intensive data and computation is also tedious (Farhan et al. 2013). RUSLE, therefore, emerged as an alternative to USLE (Renard et al. 1994, 1997). Unlike USLE, RUSLE can also be used in modeling erosion in rangelands, forests and disturbed areas including non-agricultural fields such as construction places (Karaburun 2010).

Using the following equation, RUSLE was used to calculate average soil loss in the study area (Renard et al. 1997).

$$A = R \times K \times LS \times C \times P,$$

where A is the average annual soil loss from the research area, R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, LS is the combined slope length and slope steepness factor (also called topographic factors), C is the cover-management factor and P is the conservation support practice factor. Measurement units are A (t/ha/year), R (MJ mm/ha/h/year) and K (t h ha/ha/MJ/mm) whereas LS , C and P are unitless. A conceptual framework for the estimation of soil erosion for the catchment is presented in Fig. 2.

Data sources

In this research, RUSLE was used in ArcGIS environment to compute the rate of annual soil loss. Land use and land cover information for the whole study area was extracted from Landsat 8 Operational Land Imager (OLI) of November 8, 2016. For calculating rainfall erosivity, 11 years (2006–2016) rainfall data were obtained from Department of Hydrology and Meteorology, Ministry of Environment, Kathmandu, Nepal. NDVI values were produced and drawn

from Landsat8 OLI images for the determination of C value. Other data sources used were soil data from the field and table of support practices factor. Soil samples were collected from different parts of the watershed covering different land uses, slope and aspects and analyzed for soil organic matter (SOM) and soil texture. The LS factor map was produced with the help of a DEM. Land use/land cover value gives P value which is obtained from tabulated value and field observation (Table 1).

Calculation of RUSLE parameters

Rainfall-runoff erosivity factor (R)

Rainfall is a key parameter in governing erosion processes of a landscape (Bahrawi et al. 2016). It not only estimates the impacts of rainfall but also rates and volume of runoff water that comes with it (Prasannakumar et al. 2011). Monthly average precipitation data were taken from 44 different stations from adjoining Arghakhanchi, Baglung, Banke, Bardiya, Dailekh, Dang, Gulmi, Jajarkot, Kapilbastu, Myagdi, Pyuthan, Rolpa, Rukum, Salyan and Surkhet districts for the last 11 years (2006–2016). These average precipitation data were interpolated in ArcGIS using ordinary Kriging tool to obtain a representative rainfall distribution map and subsequent R factor map for the Aringale Khola Watershed. The R factor was calculated using the following equation (Harper 1987):

$$R = 38.5 + 0.35 r,$$

where r is yearly precipitation in mm.

Soil erodibility factor (K)

The K factor indicates soil's inherent susceptibility to soil loss by different forms of soil erosion (Abdo and Salloum 2017; Prasannakumar et al. 2011). For a specific soil, it is the rate of erosion per erosion index unit measured in a standard plot; standard plot here means the plot of 22.6 m length having a uniform slope of 9% (Ganasri and Ramesh 2016; Uddin et al. 2016). The soil characteristics influencing erodibility are infiltration capacity and structural ability. The higher the infiltration, the lesser is the runoff and lesser will be the soil erosion. Stable soil has a capacity to resist the beating action of rain and minimizes the soil erosion.

Generally, clayey and sandy soils have low K values since clayey soils are tolerant to separation and the sandy soils have high infiltration capacity. On the other hand, silt soils crust and detach readily thereby having very high K values (Ganasri and Ramesh 2016). The K factor varies from 0 to 1, where 0 indicates least susceptible soil to erosion and 1 indicates soil highly susceptible to erosion (Farhan et al. 2013).

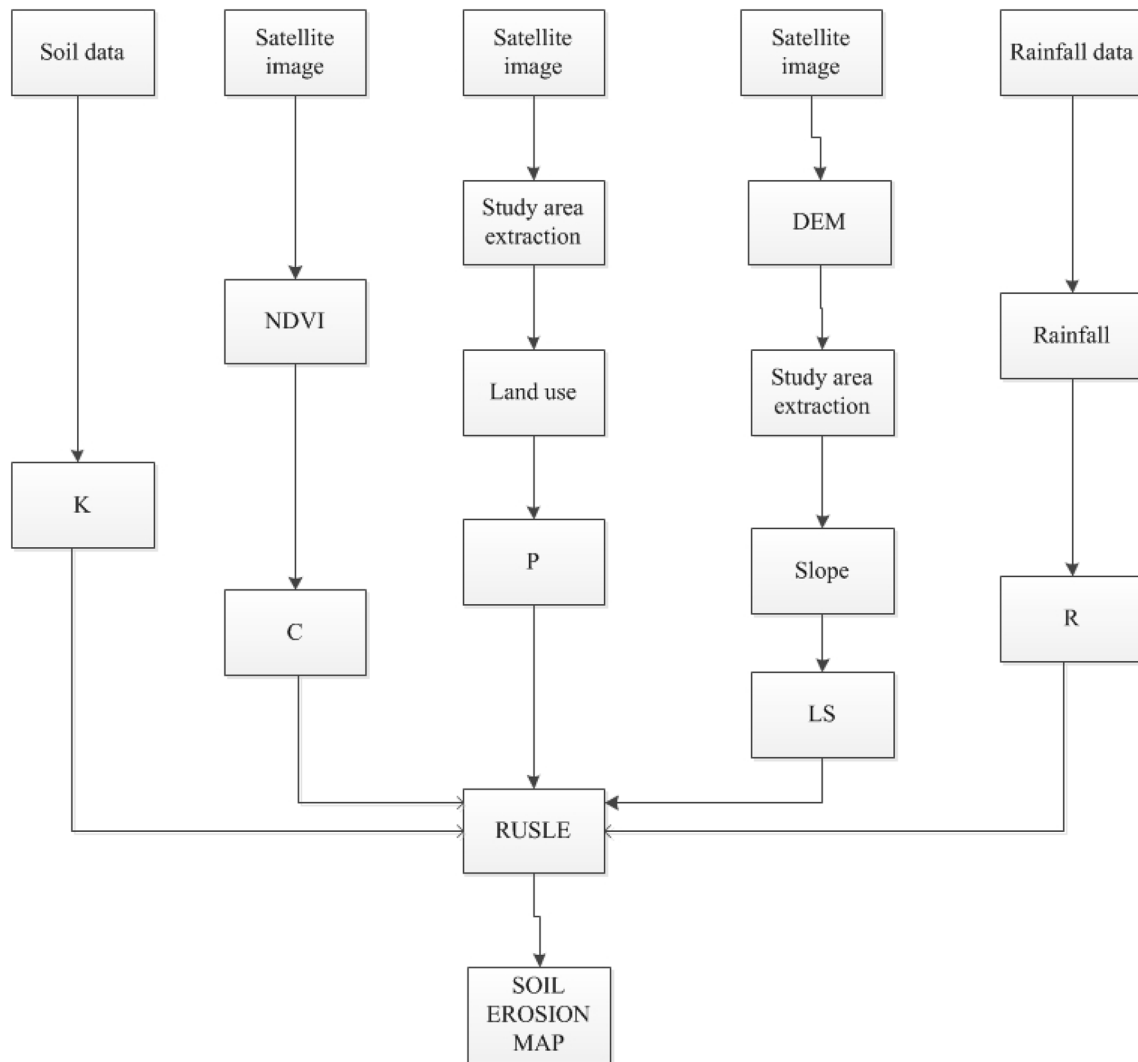


Fig. 2 Flow diagram for the soil erosion estimation

Table 1 Data input, sources and equations used in RUSLE calculation

Factor	Input	Source	Equations employed
<i>R</i>	Precipitation data (2006–2016)	Department of Hydrology and Meteorology, Kathmandu, Nepal	$R = 38.5 + 0.35 r$ (where r is annual rainfall in mm) (Harper 1987)
<i>K</i>	Soil texture and SOM values from laboratory analysis	Field work	$K = 27.66 \times m^{1.14} \times 10^{(-8)} \times (12 - a) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3)$ (where $m = (\text{silt \%} + \text{sand \%}) \times (100 - \text{clay \%})$, $a = \text{SOM \%}$, $b = \text{structure code}$ and $c = \text{permeability code}$) (Renard et al. 1997)
<i>LS</i>	DEM (20 m)	Nepal Agricultural Research Council, Kathmandu, Nepal	$L = (\text{cell size}/22.13)^m$, where m ranges from 0.2 to 0.5 (Wischmeier and Smith 1978) $S = 0.0138 + 0.0097 s + 0.00138 s^2$ where $s = \text{slope in \%}$ (Ligonja and Shrestha 2015; Wall et al. 2002)
<i>C</i>	NDVI from Landsat 8 OLI	USGS Earth Explorer	$C = 0.431 - 0.805 \times \text{NDVI}$ (De Jong 1994)
<i>P</i>	Land use map from Landsat 8 OLI	USGS Earth Explorer	Literature review

Soil sample points were determined according to land uses, slope and aspects. A total of 71 soil samples were gathered from the field covering various soil types over the study area (Fig. 1). Soil texture and SOM were analyzed by hydrometer (Bouyoucos 1962) and chromic acid titration method (Walkley and Black 1934), respectively. Ordinary kriging technique was used for the interpolation of the soil K values for the entire study area. In this study, the K factor for the research area was calculated using the relationship between soil texture and SOM using the following equation given by Renard et al. (1997).

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

where $m = (100 - \text{clay}\%) \times (\text{sand} \% \text{ silt}\%)$, $a = \text{SOM}\%$, $b =$ soil structure: (1) very structured, (2) fairly structured, (3) slightly structured, and (4) solid, $c =$ profile permeability: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow, and (6) very slow.

Topographic factor (LS)

Slope length (L) and steepness (S) are the topographic factors and they represent the effects of slope length and steepness on soil erosion, particularly on rill and sheet erosion (Simms et al. 2003). They represent the soil loss under a particular condition to that lost in a standard plot of 22.6 m length and 9% slope (Ganasri and Ramesh 2016; Yang 2015). Soil erosion increases with increase in L factor due to more collection of water overflow in downslope whereas the S factor increases erosion by increasing runoff velocity and runoff erosivity (Prasannakumar et al. 2011). In this study, the L factor is calculated using the following equation given by Wischmeier and Smith (1978).

$$L = (\text{cell size}/22.13)^m,$$

where cell size = grid cell size (20 m for this study), $m = 0.2$ to 0.5 (0.2 for slopes less than 1%, 0.3 for 1–3%, 0.4 for 3–4.5% and 0.5 for slopes exceeding 4.5%) (Wischmeier and Smith 1978).

The S factor is calculated using the following equation (Ligonja and Shrestha 2015; Wall et al. 2002).

$$S = 0.0138 + 0.0097s + 0.00138 s^2,$$

where s is the slope in percent.

Crop management factor (C)

The C factor is considered the second most influential element after relief in determining the rate, volume and extent of soil erosion (Farhan et al. 2013). It represents the effects of agricultural cropping and associated management

practices on the severity of soil erosion (Renard et al. 1997). It is the ratio of soil loss from a cultivated land to soil loss from plowed and bare land under identical rainfall, slope-gradient and edaphic conditions (Dabral et al. 2008). The C factor signifies the effects of cultivation on soil loss since incidence of soil erosion is less when there is enough vegetal cover on the soil (Prasannakumar et al. 2011). The value of C varies from 1 to 9/10 (root crops), 1/100 (grassland), 1/1000 (forest) and 1 (bare soil), (Farhan et al. 2013).

Landsat 8 OLI images of 30 m resolution just before monsoon season were acquired for different dates (March 16, April 1, April 17, May 1, and June 4 of 2017) and an NDVI composite map was prepared employing the following equation (Carlson and Ripley 1997).

$$\text{NDVI} = (\text{NIR} - R) / (\text{NIR} + R),$$

where NIR is the reflection in near infrared region of the electromagnetic spectrum and R is the reflection in the red region of the visible spectrum. In Landsat 8 image, band 5 is NIR and band 4 is red. The NDVI value ranges from -1.0 to $+1.0$, where greater values indicate more green vegetation and lesser values indicate no vegetation or bare land and water sources are given with negative NDVI (Jasinski 1990; Karaburun 2010; Upanoi and Tripathi 2003). To calculate C value, the following equation was used (De Jong 1994).

$$C = 0.431 - 0.805 \times \text{NDVI}.$$

Conservation support practice factor (P)

The P factor represents the consequences of protection measures, namely terracing and contouring that reduce incidence and occurrence of water runoff, consequently reducing soil erosion rates at a particular place (Yoon et al. 2009). It represents the proportion of eroded soil with particular support practice and eroded soil of row cultivation down and up the slope (Dabral et al. 2008; Prasannakumar et al. 2011). Landsat 8 OLI images were used to digitize the land use of the watershed area to delineate dense forest, open forest, stream bank, bare land, built-up area and agricultural land using Maximum Likelihood Classification in ArcGIS environment. Values of P factor were assigned according to land uses in vector format and converted to raster format to be used with the other factor layers. The P values were assigned as per Jung et al. (2004) and Tiruwa (2016).

Results and discussion

Land use land cover in the study area

Using Maximum Likelihood Classification in ArcMap, a land use map of the catchment was prepared (Fig. 3e). A total of six land use classes were observed in the

watershed, namely dense forest, open forest, stream bank, bare land and agricultural land with almost 72% of the area cover with forest and remaining area by other land uses (Table 4).

RUSLE parameters

Soil loss by erosion in the watershed area is more sensitive to precipitation in that area (Dabral et al. 2008). 11 year's average precipitation data obtained from 44 different stations around the watershed were interpolated in ArcGIS using ordinary kriging tool to generate average rainfall-runoff

erosivity map (Fig. 3a) and the R factor values were found in the range of 365.97–435.92.

Ordinary Kriging technique was used for the interpolation of the soil K values to prepare soil erodibility factor map of the watershed (Fig. 3b) and the K values were found in the range of 0.008 and 0.068. Clay, clay loam, loam and silt loam are the dominant soil textural classes and soils were well structured ranging from fairly structured to slightly structured. Soil profiles are moderately permeable and high in SOM (mean: 5.33%). The lower K values can be attributed to the presence of clay and loam particles in the soil exchange complex, presence of high amounts of SOM in

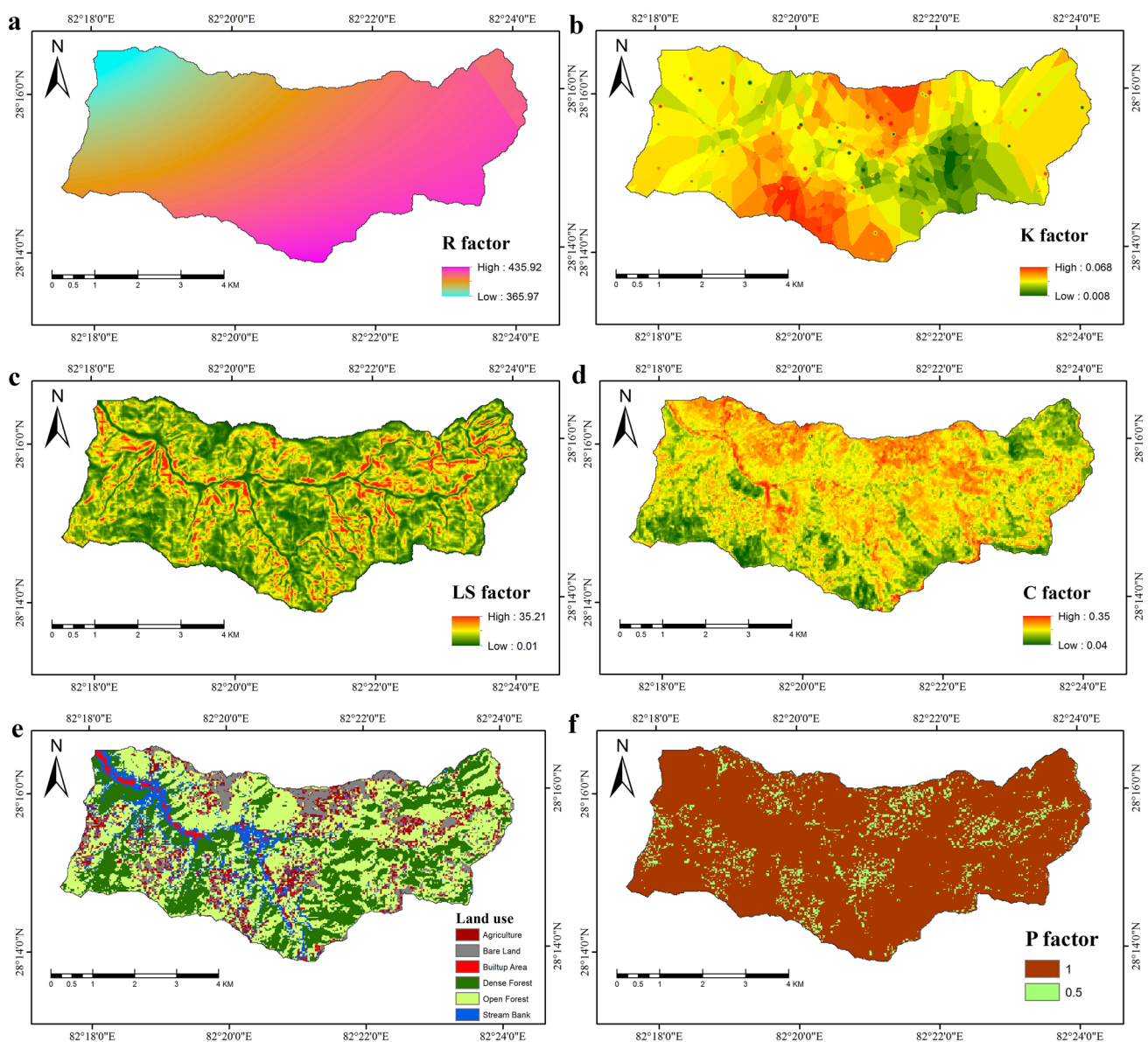


Fig. 3 Spatial distribution of **a** R factor, **b** K factor, **c** LS factor, **d** C factor, **e** land use land cover and **f** P factor

the soil and soils being quite well structured and moderately permeable.

Computation of topographic factors were done by calculating slope using a DEM of 20 m resolution. The slope-gradient of the study area was in the range from 0 to 160.32% and *LS* factor values were found between 0.01 and 35.21 (Fig. 3c).

An NDVI composite map was prepared using Landsat 8 OLI images of March 16, April 1, April 17, May 1 and June 4 of 2017. The calculated NDVI values were fed in ArcGIS environment to calculate crop management factor map. NDVI varied from 0.10 to 0.48 whereas values of *C* factor were in the range of 0.04 to 0.35 (Fig. 3d).

The *P* values were assigned as 1 for dense forest, open forest, stream bank, bare land and built up area whereas for agricultural land it was assigned as 0.5 (Jung et al. 2004; Tiruwa 2016). Only two classes of *P* factor were observed in the study area (Fig. 3f).

Soil erosion in the Aringale Khola watershed

Soil erosion map for the Aringale Khola Watershed area was then prepared in combination with GIS, RS and RUSLE. Spatial distribution map of *R*, *K*, *LS*, *C* and *P* factors were multiplied in raster calculator tool of ArcMap to generate soil erosion map of the watershed (Fig. 4). Soil erosion classes and severity were described as per guidelines given by Bahadur (2009) (Table 2). Altogether nine soil erosion classes were observed in the watershed area and a major

proportion (36.93%) of which is in severe in terms of soil erosion, losing approximately 12–100 tons of soil per hectare per year (Table 2).

Soil erosion as function of topography and land use

Spatial distribution of soil loss in the watershed (Fig. 4) clearly shows greater soil loss was occurring from the areas with steep slopes. Mean soil erosion rate varied from as low as 1.53 t/ha/year in the slopes of 0–25% to as high as 43.64 t/ha/year from the areas with slopes greater than 100 (Table 3). Owing to larger area (1296.86 ha), slope range of 50–75% lost a maximum of 18078.28 tons of soil per year.

Table 2 Soil erosion classes and severity in the watershed

Class	Soil loss (t/ha/year)	Area (ha)	Erosion severity	%
1	0–1	116.92	Nil to extremely slight	3.44
2	1–3	345.16	Extremely slight	10.15
3	3–6	605.28	Very slight	17.79
4	6–9	584.92	Slight	17.19
5	9–12	493.28	Moderate	14.50
6	12–25	988.84	Severe	29.07
7	25–50	253.24	Moderate severe	7.44
8	50–100	13.88	Very severe	0.41
9	100–400	0.32	Extremely severe	0.01

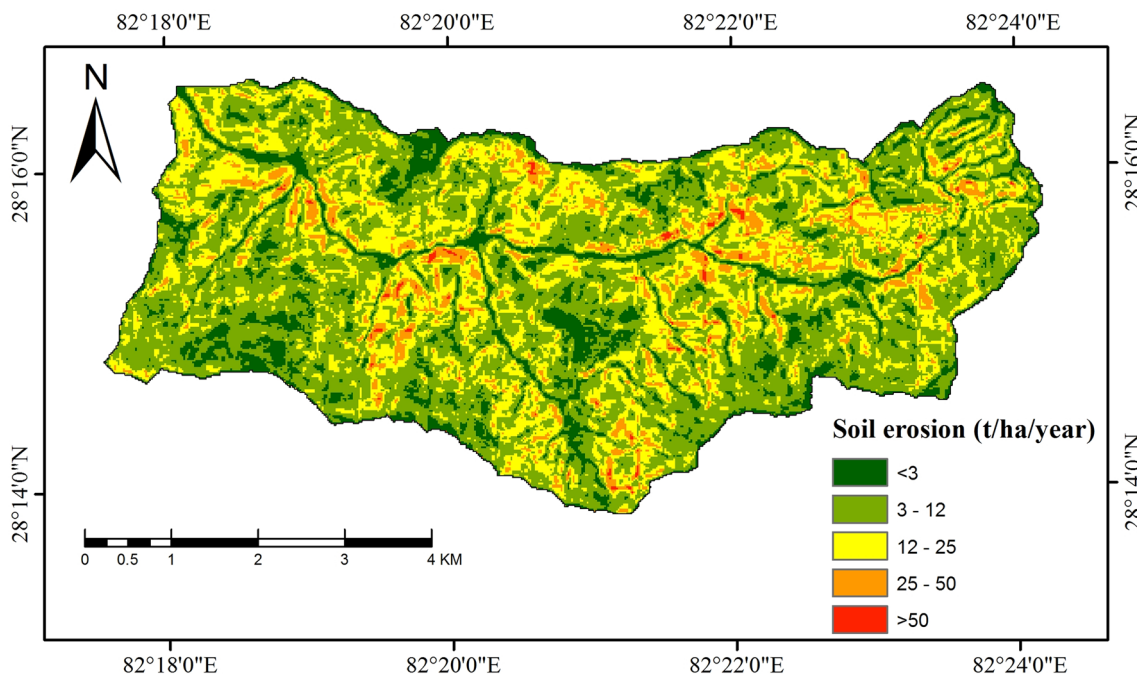


Fig. 4 Spatial distribution of soil erosion in the study area

In terms of land use land cover, dense and open forest occupying nearly 72% of the study area had the greatest contribution (79.49%) to gross soil erosion in the study area whereas that of agricultural land use was 3.98% only (Table 4). Majority of forest area is under steep slopes and at higher elevations as compared to agriculture and built up area which are under relatively less steep slope and at lower elevations. That may be reason for higher soil loss by forest land use as compared to other land uses. Terrace based agricultural practicing seemed to be effective in reducing soil erosion to greater extent in the study area. In a soil erosion study that used compound-specific stable isotope analysis in the Chitlang catchment located at central middle hills of Nepal have found the similar result with forest losing more soils as compared to agricultural areas having terraces (Upadhyay et al. 2018).

Soil loss across physiographic zones

Soil loss varies with the physiographic zones and elevations too. Contribution of Siwalik Hills and Middle Mountains to gross soil loss was almost equal. Calculated mean soil erosion rate for Siwalik Hills and Middle Mountains were 12.24 and 10.61 t/ha/year, respectively, whereas total soil loss for the Siwalik Hills and Middle Mountains are 19464.78 t/year 19220.86 t/year, respectively (Table 5). Occurrence of steep slopes and the presence of more erodible silt particles conferred higher soil loss in the Siwalik Hills than in the Middle Mountain regions with relatively gentle slopes having coarse textured sand particles.

Nepal is a country with significant diversity in topography and socio-economics (Karkee 2004). Five distinct physiographic regions prevail in the country namely Terai, Siwalik, Middle Mountains, High Mountains and High Himalayas; with the elevation ranging from 70 to 8848 m. The Middle Mountains, High Mountains and High Himalayas are categorized to have rugged and undulating topography with

Table 3 Variation of soil loss with slope (%)

Slope range (%)	Total area		Mean erosion rate (t/ha/year)	Total soil loss (t/year)	Contribution to gross soil loss (%)
	Ha	%			
0–25	350.02	10.29	1.53	535.54	1.38
25–50	1328.66	39.06	6.2	8237.72	21.29
50–75	1296.86	38.12	13.94	18078.28	46.72
75–100	375.30	11.03	25.63	9619.04	24.86
> 100	50.98	1.50	43.64	2224.94	5.75
Total	3401.84	100.00	18.18	38695.52	100.00

Table 4 Variation of soil loss with land use land cover

Land use	Area		Mean erosion rate (t/ha/year)	Total soil loss (t/year)	Contribution to gross soil loss (%)
	Ha	%			
Dense forest	921.1	27.08	13.32	12269.052	31.73
Open forest	1523.62	44.79	12.12	18466.27	47.76
Stream bank	295.82	8.70	10.57	3126.81	8.08
Bare land	296.66	8.72	9.43	2797.50	7.23
Builtup area	60.06	1.77	7.72	463.66	1.19
Agriculture	304.58	8.95	5.06	1541.17	3.98
Total	3401.84	100.00	9.70	38664.48	100

Table 5 Variation of soil loss with physiographic regions

Physiographic zone	Area		Mean erosion rate (t/ha/year)	Total soil loss (t/year)	Contribution to gross soil loss (%)
	Ha	%			
Siwalik hills (987–1500 m)	1590.26	46.75	12.24	19464.78	50.32
Middle mountains (1500–2109 m)	1811.58	53.25	10.61	19220.86	49.68
Total	3401.84	100.00	53.74	38685.65	100.00

much steeper slopes. There is no option but to cultivate on steeper slopes due to the lack of flat lands. The practice of tilling land many times before planting makes the land bare without crops; this loosens the soil which often gets washed with runoff during heavy rainfall in monsoon (Atreya et al. 2006).

Amongst the different factors that contribute to soil erosion, rainfall and topography seemed the most dominant factors influencing erosion severity in the watershed. Nepalese hills are characterized by sloping and undulating terrains and a high concentration of rainfall in the months of June–September, thereby contributing substantial overland sediment flow. While farmers cannot control *R* and *LS* factors, the *K*, *C* and *P* factors can, however, be better controlled with good management practices to reduce their effects on soil erosion. Strategies to manage soil erosion include conservation based agricultural practices such as zero/minimum tillage, use of mulch/cover crop, contour farming, strip cropping, bunding, terracing and other bioengineering methods. These conservation measures are to be concentrated in the most vulnerable and prioritized areas (Nigel and Rughooputh 2013).

The presence of land cover in terms of crops, grasses and forests can significantly reduce the rate of soil erosion. Forests, both dense and open, occupying nearly 72% of the study area has many implications on soil erosion. Deforestation is a serious problem in the study area as it increases the rate of soil removal (Ghimire et al. 2013). In revealing the impacts of land use changes on soil erosion dynamics in Western Nepal, Chalise and Kumar (2018) found that a decrease of forest area by 12.58% during 1995 and 2015 increased soil erosion rate by 0.68 t/ha/year in three major watersheds of Western Nepal, namely Sarada, Rapti and Thuli Bheri.

Very few studies have been undertaken in the soil erosion modeling focusing on the middle hills of Nepal. In two of the soil erosion studies one using erosion plots and the other using Morgan, Morgan and Finney (MMF) model in the Likhu Khola basin of the middle hills and middle mountains, respectively, soil erosion rates were found up to 12.9 t/ha/year (middle hills) and 56 t/ha/year (middle mountains) (Shrestha 1997). In another soil erosion study that was undertaken in the Khajuri Stream catchment, average soil erosion rate in the area was found to be 64 t/ha/year (Ghimire et al. 2013). Annually, 1 mm, 2 mm and 7 mm of top soil was lost from forest and shrub land, agricultural land and bare land, respectively, due to sheet erosion whereas streambank erosion was responsible for washing out 160 mm thick soil every year in the Khajuri stream catchment (Ghimire et al. 2013). Soil profile of the study area is in the range of 50–70 m deep whereas the plow depth is normally top 15–30 cm soil where most of the humus horizons are located. Washing away of topsoil ranging from 1 to 160 mm will certainly reduce the crop production. The Koshi basin

of Nepal lost 42 million tonnes of soil in 2010; with the barren lands losing a maximum of 22 t/ha/year (Uddin et al. 2016). Looking at these figures, soil loss in the Aringale Khola Watershed seems quite high. Unlike the Aringale Khola Watershed extending only through Siwalik Hills and Middle Mountains, the Likhu Khola drainage basin, Koshi basin and Khajuri catchment cover significant areas of flat lands on Terai Plains. This may be the reason why the Likhu Khola drainage basin, Koshi basin and Khajuri catchment are losing soils at lower rates than the Aringale Khola Watershed. Most of the mountain agriculture is concentrated in the Siwalik Hills and Middle Mountains regions, making the area most vulnerable to soil erosion. The Aringale Khola Watershed, located at the center of the Siwalik Hills and Middle Mountains, where most of the mountain agriculture is concentrated, is a typical catchment of the middle hills of Nepal. So, the results from this study can be rapidly applied to similar watersheds in this region.

The Aringale Khola Watershed suffers from severe forms of soil erosion which is not only degrading the land quality but also declining the agricultural productivity in the vicinity. There is an urgent need to implement soil and water conservation activities focusing more on the most vulnerable areas (Uddin et al. 2016). Detailed field monitoring in combination with several other erosion estimation techniques can be employed based on these data to develop better policies in combating soil erosion in the watershed area. This is the first attempt at modeling soil erosion in the Aringale Khola Watershed with the integrated use of GIS and RUSLE. Although there are limitations, the results may be used as a useful guide to look at the erosion status in similar watersheds and plan for better land and water protection measures in the area.

Conclusion

Soil erosion is still the prime reason for land and soil degradation in Nepal and this study attempts to emphasize the soil erosion severity in the middle hills of Nepal. Several soil erosion models have been established and adopted for estimating soil erosion at micro and macro watershed levels so trying different models to compute soil loss at larger watershed scale is crucial for ecological land use and management. RUSLE, in conjunction with GIS, was used to assess the soil erosion rates in the Aringale Khola Watershed of Salyan district, Nepal. The measured soil erosion may not be comparable with the erosion rate of short term experimental results as RUSLE forecasts the soil loss in the long run, however, the computed soil erosion rates were also in the range of soil erosion rates obtained from erosion plots in another experiment conducted at Kapurkot, Salyan, Nepal (Chalise et al. 2017). Results show that the majority of watershed

(36.93%) is severely eroded, which shows the poor condition of watershed requiring desperate soil conservation actions to be adopted.

This method appears to be the best substitute for the field based soil estimation which takes substantial time and effort; which is not even practical for the larger watershed level (Uddin et al. 2016). The process of estimating and mapping different RUSLE parameters may be useful for other similar studies too. This study also confirms the effectiveness of GIS and RUSLE techniques in developing spatial distribution of soil erosion at watershed scale. Similarly estimated soil loss and their spatial distribution may be helpful to land use/land cover decision makers in broader planning and formulating soil and water conservation programs at the large watershed scale.

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