# Soil Erosion Analysis Using GIS and RS in Makawanpur District, Nepal

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## ABSTRACT

Although soil erosion is a common phenomenon and a serious hazard in many areas of the Makawanpur district, it is still challenging to estimate and assess the amount of soil erosion. This study investigates the distribution of soil erosion in the Makawanpur district using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS). RUSLE model parameters were collected from various sources. Topography, rainfall, soil characteristics, and soil conservation techniques were considered in the study, among many other erosion factors. These variables were multiplied to determine the average soil loss. Based on the severity of the erosion, the final results of soil erosion rates were divided into six classes. Very serious class accounts for 11.31% of the land (>80 t h-1 yr-1), followed by severe which is 9.76% of the land with erosion rate rates ranging from (40-80 t h-1 yr-1), very high is 17.41% of the land with rates ranging from (20-40 t h-1 yr-1), followed by 16.38% of the land ranging from(10-20 t h-1 yr-1), and 9.32% of the land ranging from (5-10 t h-1 yr-1) and 35.83% of the land ranging from (0-5 t h-1 yr-1), fall under, moderate, low and very low severity zones respectively. The GIS-based soil erosion model is found to be a cost-effective method to estimate soil erosion as well as to identify priority areas for sustainable land management practices.

**Key Words: Soil erosion, GIS, RUSLE, sustainable land management.**

## INTRODUCTION

Land degradation, sedimentation, and ecological degradation tend to increase because of inappropriate land use and management practices (Römkensetal., 2011; Uddin *et al., 2016*). Soil erosion is contributing to changing basin hydrology and inundation (Nibhanupudi&HK, 2012; Uddin *et al., 2016*) in the transboundary Himalayan River basins, and problems compounded by social, economic, and political changes (Uddin *et al., 2016*).

In Nepal, the water erodes approximately 45.5% of the ground in steeper places (Thapa, 2020). Mid-hills of Nepal have been the focus of studies on sedimentation, runoff, and soil erosion for the past few years (Ghimire *et al., 2013;* Sah & Lamichhane, 2019). The degradation of land is a result of both natural and human-made factors. In Nepal, soil erosion is more closely related to natural forces, but it is also affected by how the land is managed and farmed (Shrestha *et al., 2004;* Sah &Lamichhane, 2019). Land degradation can be caused by a variety of physical, chemical, and biological processes that are either directly or indirectly exacerbated by anthropogenic activities. Similarly, in mountainous habitats, soil erosion is a significant environmental hazard (Nyssen *et al., 2009;* Sah&Lamichhane, 2019). It is a well-known fact that soil erosion brought on by water poses a significant problem on Nepal's mountain slopes (Sah &Lamichhane, 2019).

Soil erosion is one of the main issues affecting the viability and sustainability of upland agriculture. Five factors, namely rainfall erosivity, soil erodibility, topography, surface coverage, and support practices generally have an impact on surface water flow and soil erosion (Renard *et al., 1997*; Koirala *et al., 2019*). Because there is a limited amount of arable land, soil erosion limits the amount and quality of arable land to grow food. Water quality will be reduced, and freshwater bodies will become eutrophicated as a result of the transferred sediments (Pimentel, 2006; Koirala *et al., 2019*). On the one hand, speeding up soil erosion results in starvation, drought, and flooding. On the other hand, excessive silt dumped into rivers affects reservoirs and dams, which raises the expense of maintaining them and eventually renders them useless (Samaras &Koutitas, 2014, Koirala et al., 2019). Recently, land use patterns have changed because of urbanization and population migration triggering land degradation and soil erosion in many places (Chalise *et al., 2019*) (. A watershed loses soil due to erosion, and it is challenging to assess this loss since it results from a complex interaction of many hydro-geological processes (Singh *et al., 2008*; Parveen & Kumar, 2012).

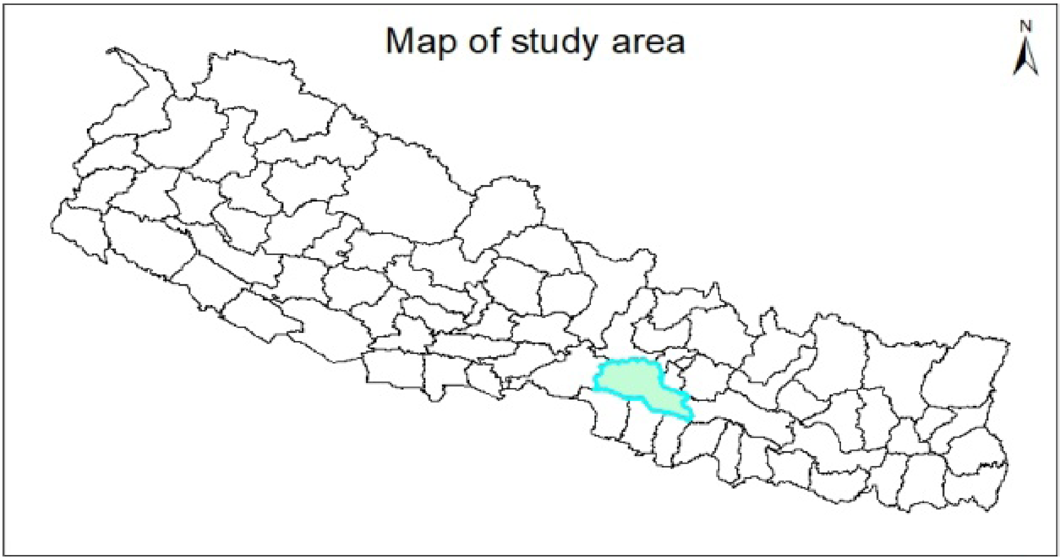
Remote sensing and GIS techniques have become valuable tools, especially for assessing erosional scales due to the amount of data needed and the greater area coverage (Parveen & Kumar, 2012). Several empirical models based on geomorphologic factors have been established in the past to measure sediment production for monitoring soil erosion from the watershed (Misra *et al., 1984*). Numerous models, including the Sediment Yield Index approach put forth by Bali and Karale (1977) and the Universal Soil Loss Equation (USLE) provided by Wischmeier and Smith (1978), are widely employed for the prioritization of watersheds (Dabrale *et al., 2008*). The data input varies greatly for the empirical (USLE/RUSLE) prediction of soil erosion. Based on field data collected from tiny land sites or small catchments in the US that shared similar meteorological, geographic, and geographical properties, the Revised Universal Soil Loss Equation (RUSLE) was developed. The RUSLE represents the effects of raindrops on climate, soil, topography, and land use on rill and inter-rill soil erosion (Thapa, 2020). This method is frequently used in order to evaluate soil erosion loss and risk. It serves as a reference for creating conservation plans and preventing erosion in various land-cover types, including croplands, rangelands, and disturbed forest lands (Thapa, 2020).

Soil erosion was not a huge concern until the middle of the 20th century. The Himalayan region, in general, and Nepal in particular, have suddenly shownsigns of major worry regarding soil erosion, deforestation, and desertification since the 1960s (Prajapati, 2010). This study uses the RUSLE model and GIS to quantify and understand the spatial distribution of soil erosion in the Makawanpur district of Nepal. However, the model is applicable only in the prediction of sheet erosion and rill erosion. The rate of gully erosion is not estimated by the model. This is an attempt to use a GIS application to estimate soil erosion using the RUSLE model. This research establishes a baseline for soil erosion in Makawanpur and contributes toward filling a data gap.

## METHODOLOGY

### *Study area*

In Nepal's Bagmati Province, the Makawanpur district spans in an area of 2418 square kilometers between latitudes 27°10' N and 27°40' N and 84°41' E and 85°31' E (Fig. 1). The district occupies 1.65% of Nepal's total land area and ranges from 166 meters to 2584 meters above sea level, Fig.1. A 66 km wide Mahabharata range in the district's north accounts for 41 percent of the district, while theChure (Silwalik) hills in the south account for 59 percent of the district (Subedi et al., 2019).



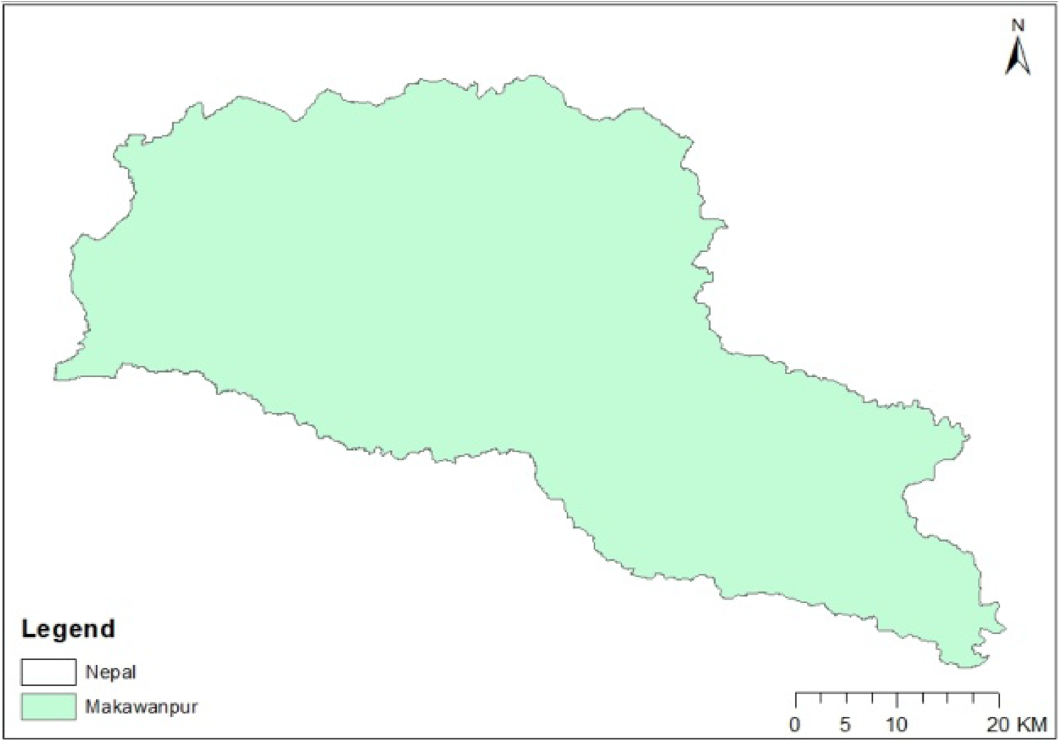



*Figure 1: Map of the study area*

### *Data Collection*

The assessment of soil erosion is based on the regional features of the location, including topography, land use, soil quality, and climate. The information utilized in this study is gathered from a variety of sources to create maps of these qualities (Jazouli *et al., 2017*). The study used various spatial datasets acquired from different sources. The datasets and their respective sources are shown in Table 1.

*Table 1: Data sets used for the RUSLE model*

| Date Set | Factor | Data Sources |
|---|---|---|
| DEM | LS, P | Earth Explorer (usgs.gov) |
| Soil Map | K | www.fao.org/geonetwork |
| Land Cover Map | C | ICIMOD (Land cover Map of Nepal - 2010 |
| Rainfall Map | R | https://worldclim.org/ |

***Methods:***

The RUSLE model was used in the GIS platform in this study, Fig. 2. The RUSLE was designed to compute the mean annual soil loss for ground slopes where flow convergence/ divergence can be neglected, i.e., planar slopes, common in agricultural lands. The RUSLE is expressed by an equation 1.

A= R* K* LS * C *P .....Equation 1

Where,

A = Soil loss (ton/ha/yr.), R = Rainfall Erosivity (MJ mm /ha/yr.) K = Soil Erodibility Factor (T/MJ/mm), LS = Length-Slope Steepness Factor (Dimensionless), C = Land Cover Management Factor (Dimensionless), P = Conservation Practice Factor (Dimensionless)

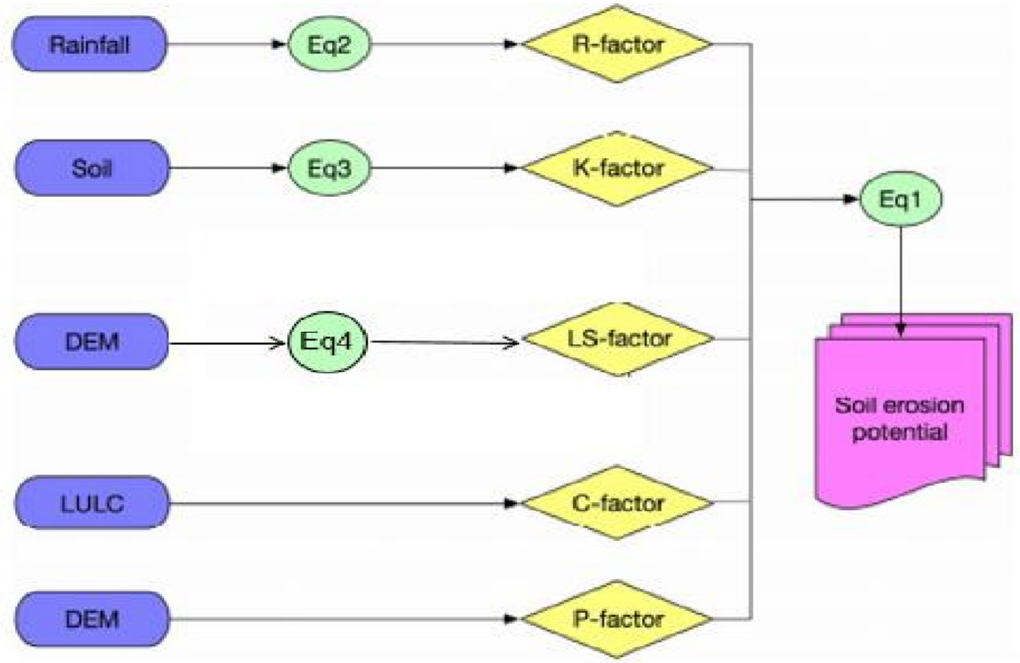



*Figure 2: The general framework to compute RUSLE parameters*

## Computation of RUSLE Parameters

### *Rainfall Erosivity Factor (R)*

The rainfall erosivity factor (R), which accounts for rainfall amount and intensity, describes how erosive rainfall is in a certain region and illustrates how rainfall intensity affects soil erosion. The R-factor measures the impact of rainfall on erosion in MJ mm ha−1 h−1 year−1, and it is designed to represent the input that drives the sheet and rill erosion processes through climatic factors. It is generally determined as a function of the volume, intensity, and duration of the rainfall (Karamage *et al., 2016*).

In this study, the rainfall data was downloaded from https://worldclim.org/ at 1 km x 1 km resolution, which was resampled to 30 m using the resample tool in ArcMap 10.5. The equation integrated to generate the R- factor is given by (Morgan, 1985; Koirala *et al., 2019*; Dahal, 2020) in equation 2 and is calculated using a raster calculator in ArcMap 10.5.

R=38.5+0.35P ……................ Equation2

Where, R=Rainfall erosivity factor, P=Mean Annual Rainfall (mm)

### *Soil Erodibility Factor (K)*

The soil erodibility factor is a measurement of the susceptibility of soil particles to be separated and transported by rainfall. The soil erodibility factor (K), a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoffprovides a quantitative description of the inherent erodibility of a certain soil type. The primary soil characteristics that affect the K factor are soil texture, organic matter, soil structure, and soil profile permeability (Koirala *et al., 2019*). "The soil erodibility factor map was created using a soil map provided by FAO. This soil map was restricted to the specific study area, and the pixels within the study area were determined based on the soil code. The FAO soil map has been utilized to conduct numerous studies on soil erosion." (Koirala *et al., 2019*). Equation 3 for estimating K value is given by Wiliams' (Williams, 1995; Wawer *et al., 2005*).

$$K = f_{csand} * f_{cl-si} * f_{orgic} * f_{hisand} \quad \text{..... Equation 3}$$

Where,

$$f_{csand} = \lfloor 0.2 + 0.3 * exp\left(-0.0256 * m_{sand} * \left(1 - \frac{m_{silt}}{100}\right)\right)\rfloor \quad \text{..... Equation 3a}$$

$$f_{cl-si} = \left(\frac{m_{slit}}{m_c + m_{slit}}\right)^{0.3} \quad \text{..... Equation 3b}$$

$$f_{orgic} = \left(1 - \frac{0.25 * orgic}{orgic + exp\ exp\ (3.72 - 2.95 * orgic)}\right) \quad \text{..... Equation 3c}$$

$$f_{hisand} = \left(1 - \frac{0.7\left(1 - \frac{m_{sand}}{100}\right)}{\left(1 - \frac{m_{sand}}{100}\right) + exp\ (-5.51 + 22.9 * \left(\frac{m_{sand}}{100}\right)}\right) \quad \text{..... Equation 3d}$$

where, $msand$, $mslit$and $mc$are % sand, silt and clay, respectively; $orgic$isthe organic carbon content.

Fcsand=it gives a low soil erodibility factor for soil with coarse sand and a high value for soil with little sand content.

Fsi-cl=it gives a low soil erodibility factor with a high clay to silt ratio.

Forgc =it is the fact or that reduces soil erodibility for soil with high organic content.

Fhisand =it is the factor that reduces soil erodibility for soil with extremely high sand content

### *Slope Length and Slope Steepness (LS)*

The slope gradient factor (S) and slope-length factor (L), which are calculated from the DEM, are combined to form the topographic factor-Slope Length and Steepness (LS) (Dahal, 2020). The amount of vegetation present and the size of the soil particles both have an impact on how much soil is lost due to the slope. It describes the impact of topography, particularly the length of hill slopes, on erosion (Dahal, 2020).

With the incorporation of Digital Elevation Models (DEM) into GIS, the slope gradient (S) and slope length (L) were determined accurately. The Digital Elevation Model (DEM) resolution determines how well it may be estimated (Parveen & Kumar, 2012). Here, the study's flow accumulation and slope gradient were mapped using the Shuttle Radar Topography Mission (SRTM) downloaded from Earth Explorer(usgs.gov)at a 30m resolution. Then by using spatial analyst tool – map algebra- raster calculator in ArcMap, slope length and steepness (LS)factor was calculated, and map based on equation 4 as defined in Desalegn et al., (2018).

LS=pow [(flow accumulation) *cell size/22.1,0.6]*pow[sin (slope) *0.01745/0.09,1.3]…Equation4

***Cropping-Management Factor (C)***

The C factor takes into account how cropping and management techniques affect soil erosion rates in agricultural fields as well as how ground coverings and vegetation might reduce soil erosion in forested areas (Renard *et al., 1997*; Karamage *et al., 2016*). It is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow. The kind of vegetation, growth stage, and cover percentage are the key determinants of the C factor. The C-factor continues to be the most crucial element in lowering the danger of erosion. According to the situation, the primary variables directly influencing whether human action would cause erosion to increase, or decrease are plant cover and agricultural methods (Jazouli *et al., 2017*). The C factor lowers the estimated amount of lost soil based on how effectively vegetation prevents soil particle separation and movement. The less soil surface erosion there is, the denser the vegetation is. Overgrazed lands result in the most severe surface erosion, while multistoried forests have the lowest levels of topsoil erosion (Prajapati, 2010).

Land Use/Land Cover (LULC) produced by the ICIMOD was used for preparing a C-factor map using ArcMap 10.5. From this, eight types of land use were obtained (Table 2). For each land use type, C values were assigned through reference (Panagosetala *et al., 2015*; Koirala *et al., 2019*). The C factor ranges from 0 to approximately 1, where higher values indicate no cover effect and soil loss comparable to that from a tilled bare fallow, while lower C means a very strong cover effect resulting in no erosion (Erencin, 2000; Koirala *et al., 2019*).

*Table 2: Land use factor*

| Land Use | Factor |
|---|---|
| Forest | 0.03 |
| Shrub Land | 0.03 |
| Grassland | 0.01 |
| Agricultural Land | 0.21 |
| Barren Land | 0.45 |
| Water Body | 0.00 |
| Snow Glacier | 0.00 |
| Build-Up | 0.00 |

### *Conservation Practice Factor (P)*

The P-factor indicates the rate of soil loss according to the various cultivated lands on the earth. It is the impact of tillage and contouring techniques on soil erosion. The P factor is the comparison between the soil loss caused by a certain support practice and the matching loss caused by uphill and downhill slope culture. According to the management of agricultural land, the P-numerical factor's value is always between 0 and 1. Good conservation practices are indicated by a P-factor value close to 0, and bad conservation practices are indicated by a number close to 1 (Jazouli *et al., 2017*). There are - contour, cropping, and terrace. Itis an important factor that can control erosion. Table 3 shows the value of the support practice factor according to the cultivating methods and slope (Shin, 1999; Sheikh *et al., 2011*). In the study area, contouring was used.

*Table 3: Support practice factor according to the types of cultivation and slope*

| Slope (%) | Contouring | Strip Cropping | Terracing |
|---|---|---|---|
| 0.0s-7.0 | 0.55 | 0.27 | 0.10 |
| 7.0-11.3 | 0.60 | 0.30 | 0.12 |
| 11.3-17.6 | 0.80 | 0.40 | 0.16 |
| 17.6-26.8 | 0.90 | 0.45 | 0.18 |
| 26.8 > | 1.00 | 0.50 | 0.20 |

## RESULTS

### *RUSLE- parameter values*

The results showed that the Rainfall Erosivity Factor (R) value ranges between 443.25 and 871.15 MJ mm ha−1 h−1 yr−1, Fig. 3(a). Soil Erodibility Factor (K) values ranged from 0.065 to 0.297, Fig. 3(b). The topographic factor (LS) value for the entire region rearranged from 0 to 1267.88, Fig. 3(c). The value of the Cover Management Factor (C) ranged between 0 and 0.45. The value indicates the percentage erosive capacity in comparison with bare fallow area. The highest value of 0.45 indicates that 45% of erosion occurs in the area in comparison with the bare fallow land, Fig. 3(d).

The Support Practice Factor (P) value ranged from 0.55 to 1, where a higher value indicates there is no support practice such that erosion is at its maximum due to the absence of any practice, Fig. 3(e).. The total soil erosion of the Makawanpur is shown in Figure 3(f), categorized into six different classes.

*Table 4: Calculated value of K-factor*

| Soil Unit Symbol | ms (sand % top soil) | mslit (silt % top soil | me (clay % to soil) | Origc (Oc % top soil) | Fcsand | Fcl-si | Forgc | Fhisand | K |
|---|---|---|---|---|---|---|---|---|---|
| BD | 32.7 | 30.3 | 37.1 | 3.28 | 0.367 | 0.786 | 0.75 | 0.3 | 0.06 |
| JE | 70.8 | 12.8 | 16.5 | 1.15 | 0.262 | 0.78 | 0.88 | 0.44 | 0.07 |
| RD | 82.1 | 6.7 | 11.3 | 0.27 | 0.242 | 0.743 | 0.99 | 1.65 | 0.29 |

***Potential Factor Map and Soil Erosion Map***

A potential soil erosion map of Makawanpur district was prepared by multiplying all five different factor maps in ArcMap using a raster calculator. The study area was classified into six classes, indicating the majority of the area, i.e., 35.83% of the area falls under low severity (0-5 ton/ha/yr), followed by very high severity of 17.41% of the total area having a rate of erosion of 5-10 ton/ha/yr. Similarly, 9.32% is the least area under moderate severity (5-10 ton/ha/yr) as shown in table 5.

*Table 5: Potential soil erosion of Makawanpur district*

| Class | Rate of Erosion (ton/ha/yr) | Area (Sq Km) | %of Area | Level of Severity |
|---|---|---|---|---|
| 1 | 0–5 | 862.52 | 35.83 | Low |
| 2 | 5–10 | 224.34 | 9.32 | Moderate |
| 3 | 10–20 | 394.14 | 16.38 | High |
| 4 | 20–40 | 418.96 | 17.41 | Very High |
| 5 | 40–80 | 234.84 | 9.76 | Serve |
| 6 | >80 | 272.15 | 11.31 | Very Severe |

The potential soil erosion rate map of Makawanpur is generated using different sources (Table 1) for the RUSLE model using ArcMap 10.5 software. The maps are provided in the Figure 3.

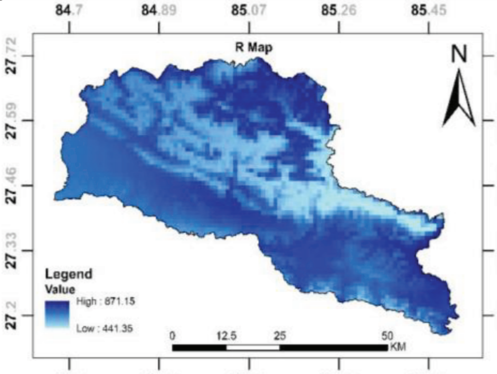



*Fig 3a : R factor map of Makawanpur district*

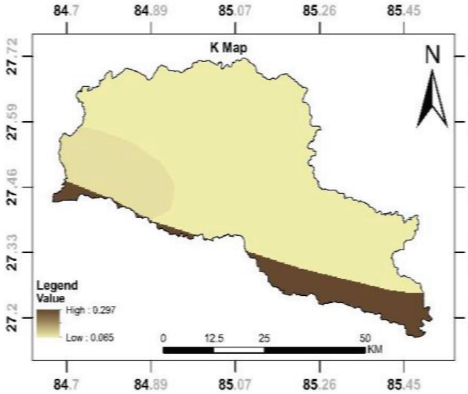



*Fig 3b : K factor map of Makawanpur district*

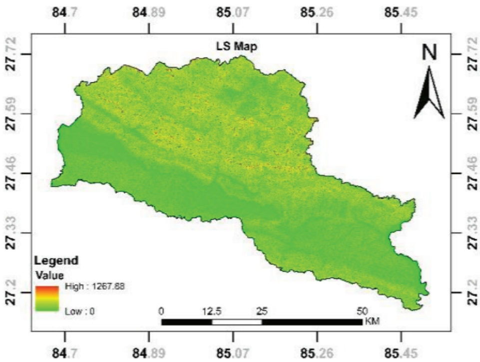



*Fig 3c : LS factor map of Makawanpur district*

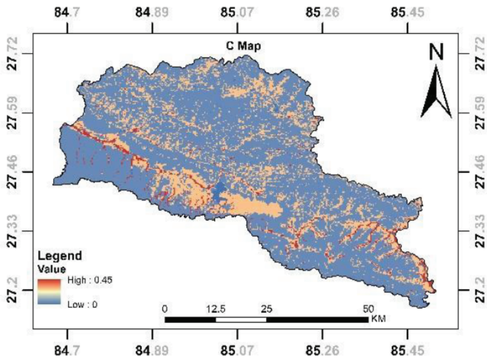



*Fig 3d : C factor map of Makawanpur district*

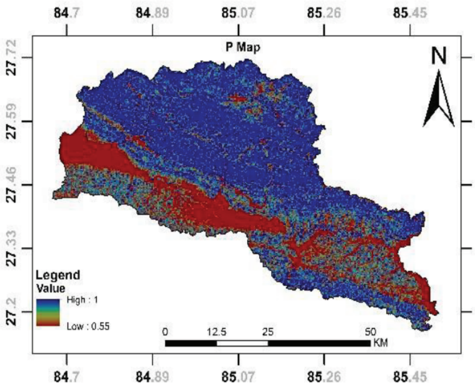



*Fig 3e : P factor map of Makawanpur district*

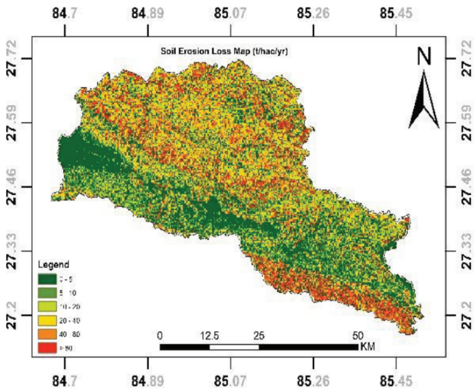



*Fig 3f : Erosion map of Makawanpur district*

*Figure 3: Erosion map of Makawanpur showing its factor*

## DISCUSSION

The estimation of soil erosion is critical for land planning for its conservation. However, there is limited studies to spatial estimation of soil erosion using universal models in the Makawanpurdistrict. Among other, the RUSLE is an empirical-based modeling approach that predicts the long-term average annual rate of soil erosion on slopes using five factors (Dahal, 2020). The RUSLE modeling helps to develop a spatial assessment of the erosion vulnerability of a specified location with the help of remotely sensed data. A similar model has been usedfor the area having similar geographical and topographical features (Devatha et al., 2015; Dahal, 2020). This study used a modeling approach–the RUSLE based method–to develop a detailed spatial assessment of the distribution of erosion risk across the Makawanpur district using remotely-sensed data and automated analysis of land cover and slope gradient.

Other research studies having similar geographic characteristics also used the same method (Prasannakumar et al., 2012; Dahal, 2020). In an erosion model, proper consideration of R-factor, LS-factor, K-factor, P-factor, and C-factor should minimize the uncertainties. The LS-factor with a maximum slope in the study area was used as the original RUSLE formulations (McCool et al., 1989; Dahal, 2020). According to many research results, Nepal is vulnerable to soil erosion hazards due to five factors-high annual precipitations, the soil characteristics, mainly texture and steep slopes' land cover' and soil conservation practices along the slopes. Its total soil erosion is comparatively higher than in other countries in the world (Koirala et al., 2019).

## CONCLUSION

Soil erosion is a global issue with a major impact on sloppy and agricultural lands. The study contributes to the spatial distribution of soil erosion which will be useful for policy-level conservation and management planning processes by land use planners and decision-makers. The result is based on the model RUSLE that ArcMap processed (Koirala *et al., 2019*).

The severity assessment of soil erosion is based on the GIS-based RUSLE equation, considering rainfall, soil, DEM, land use, and land cover. The soil erosion rate was categorized into six classes based on its severity, and 11.31 % of the regions were found under extreme risk (> 80 t h-1 yr-1), 35.83 % of the areas remained in a low-risk zone. This shows the area with high elevation, along with prompt rainfall, is susceptible to soil erosion. The predicted severity can provide a basis for conservation and planning processes for the decision-makers. The regions with high to very severe soil erosion warrant special priority and control measures. While this model is based on vulnerability zone mapping and prediction employing remote sensing and GIS-based research, such studies are recommended for conservation and future model refinement. The estimation of potential soil erosion in the Makawanpurdistrict by the RUSLE model was used, in which five factors were determined with the help of GIS and various factors like annual rainfall, soil data, DEM, and land use. The soil erosion rates of Makawanpur district were classified into six different classes based on the rate of erosion that is found in a specific location, in which 35.83% of the area falls under low severity (0-5t h-1 yr-1), 9.32%, 16.38%, 17.41%, 9.76%and 11.31% falls under moderate severity (5-10 ton/ha/yr), high severity (10-20 t h-1 yr-1), very high (20-40 t h-1 yr-1), severe (40-80 t h-1 yr-1) and high severity (>80 t h-1 yr-1) respectively. The results showed that the areas with a steep slope, high intensity of rainfall, and bare land are most prone to erosion.

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