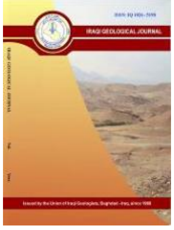
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Environmental Threat of Soil Erosion in the Gwang Khola Watershed, Chure Region of Nepal

Basanta K. Neupane[1, 2], Umesh K. Mandal[3], Ayad M. F. Al-Quraishi[4]*, Mehmet Ozdemir[5], Raju Rai[2]

[1] Department of Geography, Patan Multiple Campus, Tribhuvan University, Kathmandu 44600, Nepal
[2] Nepal Geographical Society, Kathmandu 44600, Nepal (Orchid id: 0000-0001-9001-0162)
[3] Central Department of Geography, Tribhuvan University, Kathmandu 44600, Nepal
[4] Petroleum and Mining Engineering Department, Faculty of Engineering, Tishk International University, Erbil 44001, Kurdistan Region, Iraq. (Orchid id: 0000-0001-7732-129X)
[5] Dentistry Department, Faculty of Dentistry, Tishk International University, Erbil 44001, Kurdistan Region, Iraq
* **Correspondence**: ayad.alquraishi@tiu.edu.iq; ayad.alquraishi@gmail.com

Received:
15 November 2022
Accepted:
17 April 2023

Published:
31 May 2023

Abstract

Chure, also known as the foothills of the Himalayas that extends from east to west of Nepal, is an essential region due to the hotspot of biological diversity and various natural resources, including recharge groundwater for the Tarai region of the country. However, the Chure region has a high rate of soil erosion due to human activities and natural processes, a severe issue in the Chure region. This study looked at soil erosion in the Gwang Khola watershed in the Chure region. We used the Revised Universal Soil Loss Equation (RUSLE) model to measure soil loss by soil erosion. The results showed that about 547,992.9 tons of soil were lost annually in the Gwang Khola watershed. The results indicated that 5,259.87 hectares of the land area were in a very low-risk zone for soil erosion. Similarly, 317.79 hectares of land had a moderate risk of soil degradation, while 13.59 hectares of forest area posed a high threat. The extreme-risk erosion area was situated above 1,250 m. In contrast, the moderate and the low-risk regions of soil erosion had a lower elevation range of 950 m to 1,250 m and 650 m to 950 m, respectively. The findings of this study may aid planners and policymakers in preventing soil erosion and protecting the ecosystem in this watershed and those with similar circumstances.

Keywords: Soil erosion; Soil loss estimation; RUSLE; Gwang Khola watershed; Chure Region

1. Introduction

Soil erosion is a serious issue due to its impacts on various aspects, including humans, the environment, and ecosystems (Guerra et al., 2020; Hossini et al., 2022). Mainly soil erosion is responsible for losses of crop productivity, pollution of land and water resources, and loss of agricultural productivity (Chalise et al., 2019; Bag et al., 2022). Soil erosion is a multi-step geological process that begins with soil separation, continues with soil transport, and concludes with soil redeposition (Mhaske et al., 2021; Al-Quraishi, 2003). It is deteriorating due to natural and human activities (Lewis and Nyamulinda, 1996; Zhao et al., 2005). In recent years, human-caused degradation has been continuously rising in the Chure region of Nepal. The Chure region is an essential region between the mid-hill in the north and the Tarai in the south. The region is ecologically and geologically fragile, structurally weak, and highly soil loss-prone (Bhandari et al., 2016).

DOI: 10.46717/igj.56.1E.14ms-2023-5-24

The anthropogenic activities, such as collecting pebbles, sand, and stones imported from outside the country and cutting trees are rapidly increasing in this region, which suorts accelerating soil erosion in the Chure region (Pokhrel, 2013). Moreover, urbanization processes such as road construction, mining, deforestation, and overgrazing are also responsible for losing soil in this region (Ghimire, 2017). Migration in the Tarai region from hills and mountains for better livelihood was also a significant cause of the degrading of Chure ecosystems and environment, where people used to go Chure region to collect various natural resources (Bishwokarma et al., 2019; Singh, 2017).

The geological and physiographic characteristics of the Chure region are comparatively weak due to its fragile landscape, young landscape, and vulnerable topography (Gyawali and Tamrakar, 2018; Singh, 2017). In the monsoon season, there is intense rainfall, which leads to a high amount of soil loss in the Chure area (Tiruwa et al., 2021). A study has analyzed that 1.7 mm of fertile topsoil is lost annually due to soil erosion in the Chure region (Singh, 2017). The topsoil is used to wash off from Nepal to the Bay of Bengal every year by 240 million cubic meters (Mandal et al., 2015). A study based on RUSLE modeling has found that the Koshi River transports a high amount of soil in Nepal.

The region was also identified as erosion prone area of Nepal (Uddin et al., 2016; Yigez et al., 2021). The biophysical environment of this region has been rapidly damaged over the last 32 years (Chalise et al., 2018). The Tarai region, which is crucial for food production and human survival, is also negatively impacted by soil erosion in the Chure region (Ghimire et al., 2019). The soil characteristics of the Gwang Khola watershed have yet to be the subject of any investigation. In this regard, this study was conducted in the Gwang Khola watershed of the Chure region. Still, there needs to be more information about soil erosion and how it might affect the environment in this area. Because of this, the RUSLE model was used to estimate the average amount of soil lost each year in this research study area.

2. Materials and Methods

2.1. Study Area

The Chure region is a continuous terrain that extends from the east to the west of Nepal, with elevations of around 120 m to about 2,000 m. The region covers about 17679 km^2 (13% of the country) (Singh, 2017). There are 164 river system watersheds within the Chure region. This study has selected the Gwang Khola watershed, which lies in the eastern part of the Chure region. Geographically, it is located between 27° 13' to 27° 29' N and 85° 82' to 86° 13' E (Fig. 1). The watershed covers about 94 km^2 of Chure region with latitude ranging from 453 to 1651 m asl. It is a perennial river where tributaries, including the Gaumati Khola, Gadauli Khola, and Phiting Khola, are the major tributaries of Gwang Khola.

The study area lies in the subtropical region, and tropical deciduous forests are found in this watershed. The Sal (*Shorea robusta*) is the dominant vegetation in this region. The lower part of the study area is the valley-type landscape and a built-up area with a dense population. The Gwang Khola watershed lies in the Chure region, which is humid with tropical climatic conditions. This region's annual winter temperatures settle between 15 °C to 22 °C, but summer is hot. Summer temperatures reach 36 °C, and maximum rainfall occurs during this time. The annual rainfall was recorded at 1,963 mm in the watershed.

2.2. Data Source and Analysis

Used 30m resolution DEM, extracted from USGS Earth-Explorer (EE) environment, distortions are eliminated by using Shuttle Radar Topographic Mission (SRTM). Nepalese coordinate system of central meridian 84^0 E of spheroid called Everest 1830 was used for the two-dimensional representation of the study area as it lies in the Sindhuli district. A land use land cover (LULC) map was prepared using a supervised classification method, adopting the maximum likelihood classifier algorithm and digitization technique. The Normalized Difference Vegetation Index (NDVI) calculation was carried out for the red and near-infrared multispectral band. Using the Spatial Analyst Tool in ArcGIS, the drainage basin was delineated in ArcGIS using a flow direction raster using a hydrology tool. The Landsat satellite image was used, and digital soil data for the year 2020 were obtained from Topographical Survey and Land Use Management Division (TSLUMD), Survey Department, Nepal. The image processing was performed in ERDAS Imagine software to achieve a higher level of accuracy. The Government of Nepal's Department of Hydrology and Meteorology provided data on precipitation. Likewise, soil information was acquired from Nepal's Department of Survey. Employed ERDAS Imagine tools for image processing and categorization and used the ERDAS software for image processing, including sub-setting, image extraction, restoration, atmospheric correction, and radiometric correction.

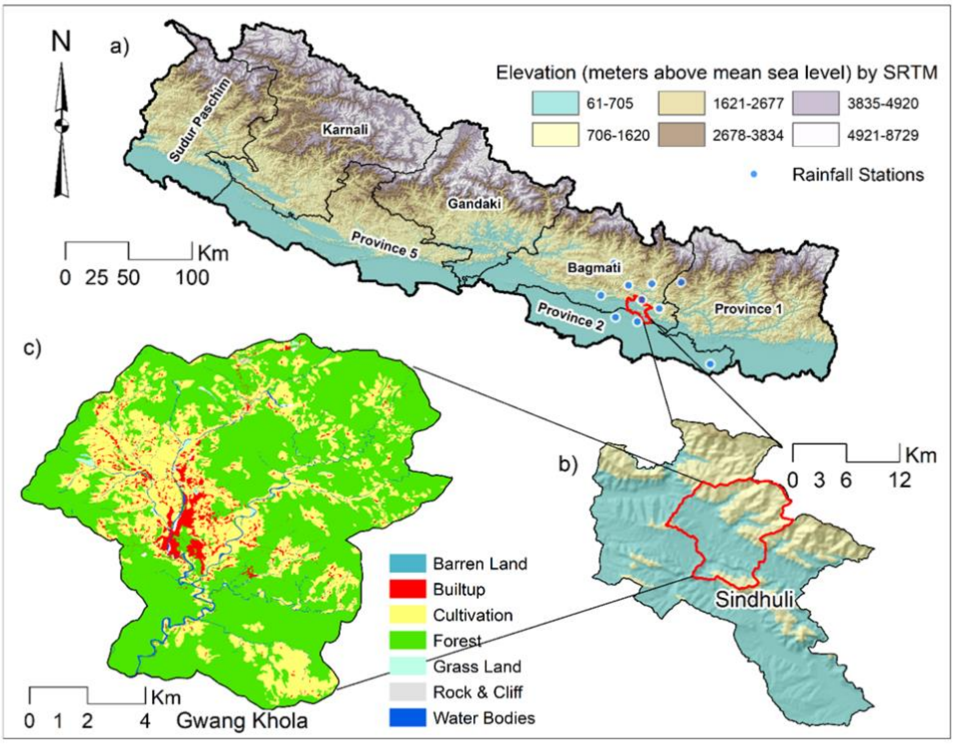


Fig. 1. The study area's location map and LULC classes.

2.3. The Revised Universal Soil Loss Equation (RUSLE)

The RUSLE modeling is an effective model for the interaction of complex soil components that influence rates of soil erosion. It simulates erosion processes in the watershed or other erosion-affected areas (Zhang et al., 1996). This study uses the RUSLE model to estimate soil loss in the study area. Among the various erosion modeling, RUSLE is very common and widely used, and the results are very reliable, which is the empirical-based erosion model. This model has five fundamental factors (Fig. 2), such as R × K × LS × C × P, which estimate soil loss by erosion (Benavidez et al., 2018). The erosion model includes the following factors (Equation 1).

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where: A= Annual average soil loss (T $ha^{-1}yr^{-1}$), R= Rainfall erosivity factor (MJ mm h^{-1} yr^{-1}), K= Soil erodibility factor (T $ha^{-1}yr^{-1}$ MJ^{-1} mm^{-1}), C= Cover-management factor (dimensionless), LS= Slope length and slope steepness factor (dimensionless), P= Suort practices factor (dimensionless)

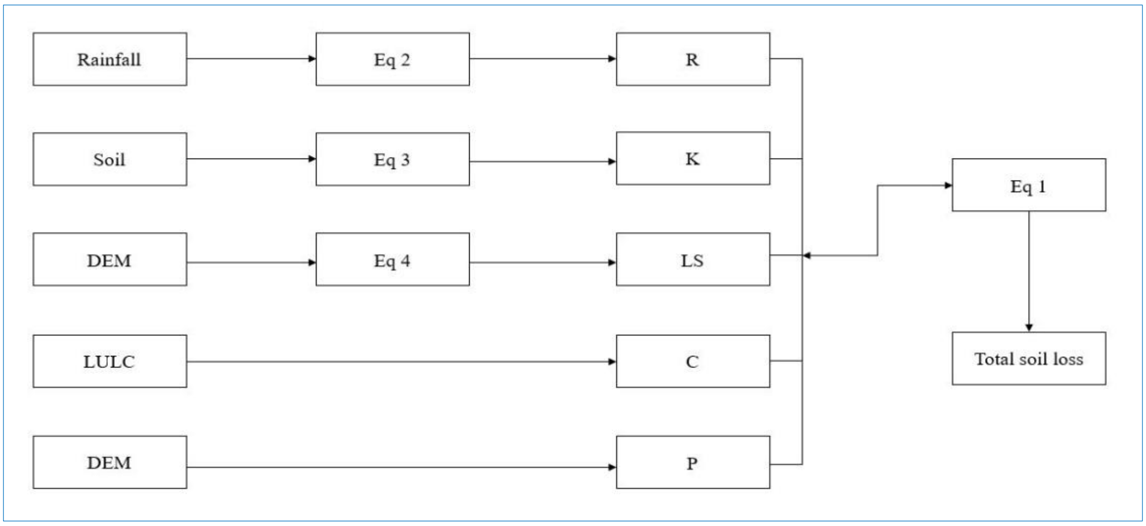


Fig. 2. Overall methodological framework for RUSLE modeling in GIS environment.

2.3.1. RUSLE development

A. Rainfall runoff erosivity factor (R)

Rainfall is the primary cause of erosion, which has a positive relationship with soil erosion. Most studies have been done by calculating E I30, the most accepted and usable source for calculating the rainfall erosivity factor. This study used 30 years (1988-2018) of monthly rainfall data from ten different meteorological stations in the study area.

$$R = 578.8 - 1.219 \times P + 0.005105 \times P \quad (2)$$

Where: R= Rainfall runoff erosivity factor (R), P= Mean annual rainfall (mm).

When P > 850 mm is usually accepted, most researchers working in the same climatic zone used this equation for the mountainous tropical and Siwalic climates (Mandal, 2017). Also, they used this formula for calculating the R factor in this study.

B. Soil erodibility factor (K)

The soil erodibility factor (K) is related to soil organic matter and mechanical components. The soil erodibility factor K is measured under the standard unit of plot condition, representing soil susceptibility to erosion and the amount and rate of runoff. Therefore, the best estimation of soil erodibility is to perform a direct measurement on field plots (Bonilla and Johnson, 2012). The Gwang Khola watershed has three main types of soil textures. Most of the area is covered by loamy skeletal, while only a small area is covered by sandy soil. The Gwang Khola watershed has metamorphic and quartzite rocks with big boulders that are cracked so that the soils are unstable. There is a steep slope with degraded forest. Used LRMP’s data for calculating the soil erodibility factor. The soil data, such as sand%, silt%, clay%, organic content%, and soil texture were extracted from a digital soil database provided by Topographical Survey and Land Use Management Division (TSLUMD), survey department, Nepal. Those soil data were obtained from a detailed soil survey in 2020 and a systematic examination in the laboratory by TSLUMD. The calculation was done in Microsoft Excel using the equation provided by Koirala et al. (2019).

$$K = Fcsand \times Fsi\text{-}cl \times Fhisand \times 01317 \quad (3)$$

$$\mathrm{Fcsand} = \left[0.2 + 0.3\exp\left(-0.0256\,\mathrm{SAN}\left(1 - \frac{SIL}{100}\right)\right)\right]$$

$$\mathrm{Fsi-cl} = \left[\frac{SIL}{CLA + SIL}\right]^{0.3}$$

$$\mathrm{Forgc} = 1 - \left[\frac{0.25\,ORG}{ORG + \exp(3.72\ -\ 2.95\ \mathrm{ORG})}\right]$$

$$\mathrm{Fhisand} = 1 - \left[\frac{0.70\left(1-\frac{SAN}{100}\right)}{\left(1-\frac{SAN}{100}\right) + \exp(-5.51\ +\ 22.9\left(1-\frac{SAN}{100}\right)}\right]$$

Where CLA, SIL, SAN, and ORG represent % clay, silt, sand, and organic carbon content, respectively. ‘Fcsand’ is a notation for low soil erodibility factor for soil which has coarse sand and high erodibility value for soil with little sand content, ‘Fsi-cl’ stands for low erodibility factor having high clay to silt ratio, ‘Forgc’ influenced for the reduction of soil erodibility of soil having high organic content, and ‘Fhisand’ controlled for the removal of soil erodibility of soil having high sand content.

C. Slope length and slope steepness factor (LS)

Topography is a leading cause of soil loss and LS factors. It describes the effects of topographic variation on soil erosion. The topographical factor plays the most significant influence on the soil erosion process. Slope length and slope steepness have a noticeable impact on soil loss. The s-factor is used to calculate the effect of slope steepness, and the LS-factor is used to calculate the impact of slope length in the RUSLE model (Schmidt et al., 2019). The product of the LS factor was calculated in the topographical factor grid using the given equation (Bekele and Gemi, 2020); the calculation of LS has presented in Equation 4.

$$LS\ =\ (Flow\ Accumulation\ \times\ Cell\ size\ /\ 22.13)0.4\ \times\ (Sin\ slope\ /\ 0.0896)^{1.3} \qquad (4)$$

D. Cover management factor (C)

This factor is primarily linked with people's consciousness and the land's surface. The cover management factor is vital in controlling soil erosion on farmland and depends upon the topographical condition and land cover (Bag et al., 2022). The C factor is also related to farmer behavior, crops, and management practices, affecting soil loss from the fallow areas (Prasuhn, 2012). The study categorized different land use Table 1, where the cover management factor (C) value for each LULC was assigned according to Thapa (2020). The C values range from 0 to 1, where lower C shows the minimum soil erosion with solid coverage. In comparison, a higher C means an uncovered surface and a higher possibility of soil erosion.

Table 1. Cover Management Factor (C)

Land use land cover	C-factor
Built-up Area	0
Water Body	0
Barren land	0.45
Cultivation land	0.21
Forest	0.03
Grassland	0.01

Source: (Thapa, 2020)

E. suort practice factor (P)

This model uses the bare plot with till up and down the slope as a reference condition (Panagos et al., 2015). The suort practices (P) factor was derived from LRMP data, the Land Resource Maing Project (LRMP) has broadly classified cultivated land based on the physiography of Nepal. Therefore, we assigned 0.2 to 1 P-value according to land-use type for this research. The study area lies in the Chure region, consisting of level and sloing terrace farming practices. As a method of conservation farming suort practice, terrace construction resembles contour farming. This study assigned values per the contouring method (Koirala et al., 2019). The slope percentage was reclassified as per the value (Table 2) and then converted to raster in ArcGIS.

Table 2. suort practice factor (P)

Slope %	Contouring (P)
0 – 7	0.55
7 - 11.3	0.6
11.3 - 17.6	0.8
17.6 - 26.8	0.95
> 26.8	1

Source: Koirala et al., 2019

3. Results and Discussion

3.1. RUSLE Factors Analyses

3.1.1. R factor

The most significant factor in soil erosion is precipitation in the form of rain. The findings of this study indicated that the R factor in the study region varied anywhere from 920 to 1445 MJ mm. ha^{-1} year^{-1}, with the highest value being located in the northern part of the watershed and the lowest value situated in the southern part of the watershed (Fig. 3a).

3.1.2. K factor

In the watershed, it has been found that there are three main kinds of textures. The vast majority of the area is covered by sandy soil. In contrast, only a tiny portion of the region is covered by loamy skeletal soil (Fig. 3b). According to our study's findings, the K factor range in this particular study region is between 0.35 and 0.41 T ha MJ^{-1} mm^{-1}. The values of K are found to be at their highest in the study area's northern and southern parts, while they are at their lowest in the area's central region. As a result of the increased K value, the watershed is significantly more susceptible to the occurrence of soil erosion.

3.1.3. LS factor

Throughout the study area, the LS factor values exhibited a spatial distribution ranging from 0 to 20.467. The study identified a low-value range in the central portion of the region, but there were some high-value sites in the northeastern half of the area. A wide variety of LS variables also had high values in the southwestern part. The majority of the low values characterize the watershed's central and northern portions. High LS factors have only been found in a few places, mainly in the northeastern and southern parts of the watershed (Fig. 3c).

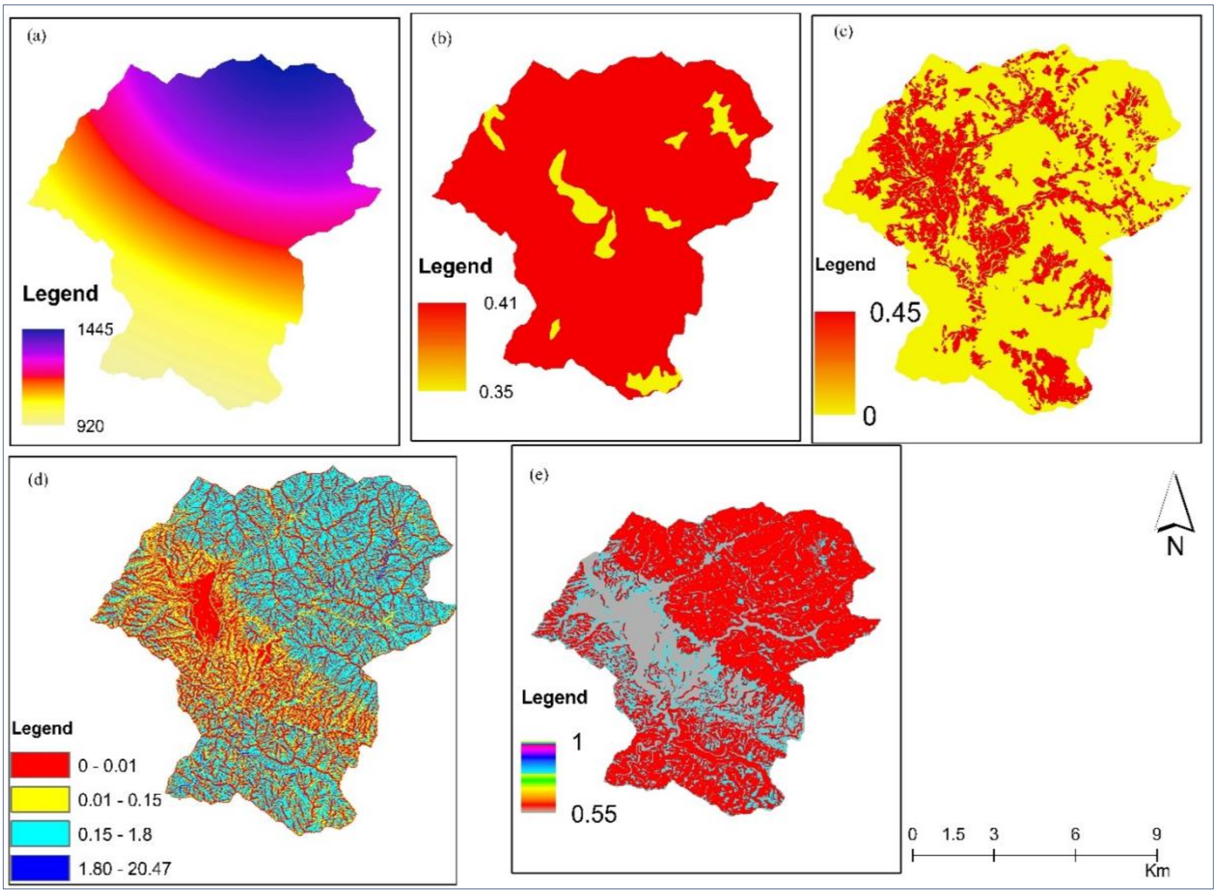


Fig. 3. RUSLE factors maps; (a) R, (b) K, (c) C, (d) LS, and (e) P.

3.1.4. C factor

The C-factors are essential to effective crop management and are the fundamental components of this strategy. Because of the many factors at play, it is subject to change. It varies depending on several factors, such as the amount of rainfall, the methods used in agriculture, the different crops, etc. However, the study assumed there was a yearly variation since there is very little farming during the dry season (March to May) and very little precipitation after December. When there is no crop coverage on the land, we have assigned a C value of zero; when there is more crop coverage on the land, we have allocated a lower C value. We have assigned C values ranging from zero to one in this model. It was determined that the C factor for the built-up and agricultural areas should be 0.13 and 0.21, respectively. Because the C value was high in the research area, no soil erosion problems could be seen. The extensive forest cover made most of the land less susceptible to damage. Most of the area that makes up this watershed has C factor values of either 0 or very close to 0. This result revealed that the majority of the area is comprised of soils and land that are adequately preserved.

3.1.5. P factor

The P factor (Fig. 3e) shows how runoff has managed the landscape, the concentration of runoff, and the speed of runoff, all of which are caused by runoff on the soil. This shows how runoff can cause erosion. This is done by runoff on the soil. One of three practices, contouring, strip croing, or terracing, can help stop soil erosion by making the land more stable. The cultivation method used in this research area is considered when figuring out the letter P, which stands for the suort practice component. Within the scope of this investigation, the P-value ranged anywhere from 0.55 to 1. A number of 0 indicates well-managed conservation practices, while a value of 1 indicates bad or poor conservation behavior. The range of possible values for the P factor is 0 to 1. There needs to be more field data available on the conservation methods implemented in the Gwang Khola watershed. Therefore, it is difficult to comment on how effective they are. Thus, the value of the P factor was determined to be 0.55 to 1 by the researcher since most of the watershed was covered by forest.

3.2 Potential Soil Erosion at Gwang Khola Watershed

The possible rate of soil loss in the Gwang Khola watershed has been calculated by multiplying the different five-factor maps in ArcGIS. This was done to account for future erosion (R, K, LS, C, and P). In the watersheds of Mahesh Khola, the Basin of Bagmati, and Kulekhani, RUSLE has been used to figure out how much soil is being lost and how the erosion in these areas is changing (Ban et al., 2016; Bastola et al., 2019; Mandal et al., 2015). To estimate the watershed's typical annual soil loss, these factors are first established for the RUSLE parameters, then multiplied in the cells that are 90 m by 90 m (Fig. 4). Within the Gwang Khola watershed, researchers determined that the yearly soil loss rate might range from 0 to 731 ton ha^{-1}.

The average soil loss rate has been calculated by 5.46 tons ha^{-1}yr^{-1} in the study area. The average soil loss rate of the water body and built-up area is the lowest, and cultivated land performed the highest soil loss. The average soil erosion rate of the cultivated land has been calculated as 15.76 tons ha^{-1}yr^{-1}. Annually, 547,992.9 tons of soil losses have been estimated in the watershed. Overall, most of the area has been found under low levels of soil erosion in the study area.

Some existing studies have been conducted within the country at various spatial scales. Ban et al. (2016) conducted a study in the Kulekhani watershed. Their study calculated 52.54 tons of ha^{-1}yr^{-1}soil erosion in the Kulekhani watershed. Likewise, Bastola et al., (2019) and Koirala et al. (2019) estimated 25 tons of ha^{-1}yr^{-1} soil loss in Nepal. Similarly, Chalise et al. (2018) also conducted a study on soil erosion in various physiographic regions of the country, which found that the middle mountains have a maximum mean annual soil loss of 38.39 tons ha^{-1}. Likewise, a total of 32.46 tons ha^{-1} yr^{-1} soil loss was found in the high Mountain. However, the Chure region was calculated with low erosion potential (6.9 tons ha^{-1}yr^{-1}). The estimated soil loss is observed to vary between the previous studies and the present investigation in the Chure region. It could be due to the spatial scales of the study area, topography, and various factors taking on modeling. The high soil loss depends upon its topography, heavy and intensive rainfall, fragile rock, and agricultural practices (Chalise et al., 2018; Koirala et al., 2019). Mountain's areas have a relatively high chance of soil erosion with unmanaged farming practices, poor management, and a high amount of abandoned land (Han and Song, 2019).

As a result, this hypothesis was checked against the current state of soil loss in the Chure region. We compared the data with the estimated levels of soil loss at watersheds with topographical features comparable to ours. The northeastern part of the study area was found to be the most at risk, according to the results of this study. Both the central and western halves of the research area exhibit spatial patterns of soil erosion that are very comparable to one another. The soil erosion in the northern portion of the study area was typically the worst, while the soil erosion in the western parts of the study area was usually the best. Most areas that comprised the research area were at a low risk of soil erosion, whereas only a small number of the sites were at a high risk of soil erosion.

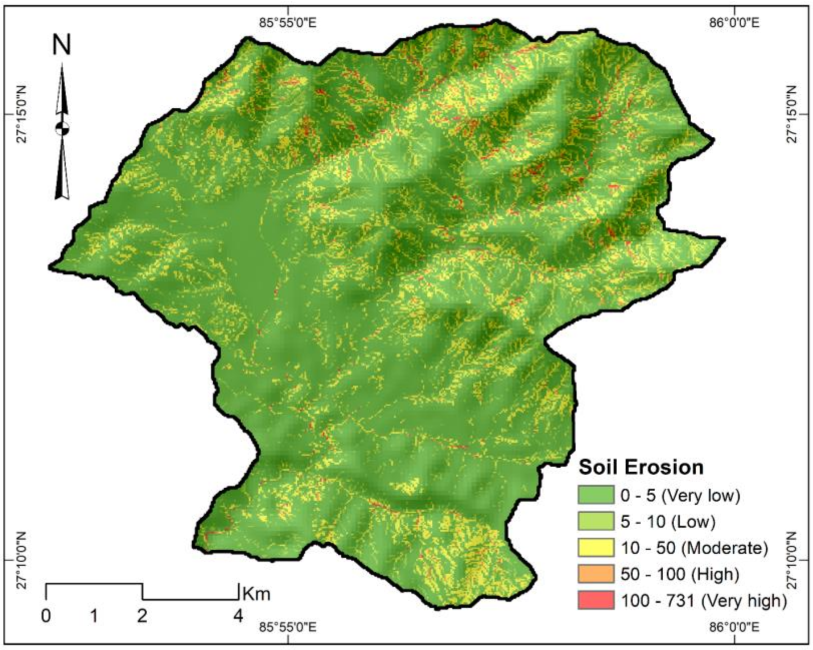


Fig. 4. Annual average soil loss (ton ha^{-1} yr^{-1}) in the study area.

A total of seven major types of land use land cover have been observed in the watershed (Table 3). The cultivated land is the dominant cover in the middle of the study area, and the rest is covered by forest. 64.71% of the land is covered by forest and 29.19% by cultivated land. The built-up area represents nearly 4% of the study area, while the water body was covered by 1.75 % and barren land by 0.01 %, respectively. Increasing soil loss in the Chure region is a serious cause of land degradation and has resulted in a serious challenge for disasters and environmental property loss (Bhandari et al., 2015; Al-Quraishi et al., 2004). Mainly, it degraded the Chure region's topsoil, increasing the bed level of the river in the Tarai plains area and the flood.

In this study area, most of the portion was covered by forest, which covers 5259.87 hectares. Study shows that vegetation-covered areas were very low-risk in terms of soil erosion in the Chure region. Likewise, 317.79 hectares of land are at medium risk, while 13.59 hectares of forest area are at high risk of soil degradation. Similarly, a total of 2,848.68 hectares of land is under-cultivated land. The Soil erosion rate was high, mainly in arable land. During the cultivation period, the soil detaches from each other, and due to unmanaged farming, the soil is eroded, and the soil erosion is more in the cultivated area (Basyal, 2020; Nyawade et al., 2019). Likewise, 863.55 hectares of land are at moderate risk, and 159.3 hectares of land are at high risk. This study shows that a large amount of soil is washed away from the cultivable land of the Chure region every year.

Table 3. The risk level of LULC (ha) as observed in the Gwang Khola watershed, 2020

Level/LULC	Water bodies	Built up	Rock	Forest	Barren land	Grassland	Cultivation land	Total
Very low	173.16	363.87	7.02	4,477.5	4.32	32.40	1,556.01	6,614.28
Low			0.09	782.37	1.17	0.09	269.82	1,053.54
Moderate			2.25	317.79	1.44	0.09	863.55	1,185.12
High			4.59	10.8	0.09		120.33	135.81
Very high			2.34	2.79			38.97	44.10
Total	173.16	363.87	16.29	5,591.25	7.02	32.58	2,848.68	9,032.85

Soil erosion is very low in barren land and grasslands. Overall, the Gwang Khola watershed is at low risk for soil erosion. Out of the total land area of the catchment area, only 1.99% of the land is at high risk of soil erosion. Similarly, 13.12% of the land is at medium risk. Much of the land in this study area was at very low risk of soil erosion. 84.88% of the land was in a low-risk area in this study area. Many factors have been playing an essential role in soil erosion. The predominant factors in soil erosion include slope gradient, the cover of vegetation, and human activity on the land (Sun et al., 2014). This might be the case with the Gwang Khola watershed; most areas are covered with forests and have low erosion rates. Aropriate land use plans might be essential in controlling soil erosion (Chalise et al., 2018; Ghimire et al., 2019; Koirala et al., 2019; Mandal, 2017).

Geographical location and topographic factors play a crucial role in soil erosion (Neupane and Dhakal, 2017). Steep slopes topography usually has a high bulk density. The Chure region of Nepal has a fragile structure, but there is no steep slope on the hill. Dense vegetation cover helps to save the soil of the Gwang Khola watershed. In this study area, there were some higher points, and they had a steep slope, and the higher bulk density affects the air, water, and plant nutrients, increasing soil erosion. Gully and Rill's erosion is a primary surface erosion, and they play a crucial role in surface erosion (Knapen and Poesen, 2010; Li et al., 2009). During the Gwang Khola watershed field observations, we found a lot of that type of erosion in cultivated land. The primary factor of surface erosion (Rill and gully) is a deficiency in forest areas. Comparatively, soil loss was found to be very low in forest areas, and surface erosion is higher on steep slopes and highly elevated areas.

Various factors determine the soil erosion level, albeit topography and altitude are closely correlated with altitude (Yisehak et al., 2013). Most of the erosion-prone areas in this study area are found above 1250 m. The extreme risk erosion area was situated above 1250 m. In contrast, the moderate and the low-risk regions of soil erosion have a lower elevation range of 950 m to 1250 m and 650 to 950 m, respectively. It is interesting to note that elevation below 650 m has very low soil erosion in this watershed. This study area is a part of the Kamala River basin. This river basin is considered one of the most flood-prone areas of the Chure region (Neupane and Dhakal, 2017). The Chure region receives a tremendous amount and intensity of rainfall during the monsoon season and experiences a massive deterioration of soil (Bashyal, 2020; Karna et al., 2020). Such geological and biophysical components have been made highly fragile and sensitive in the study area.

4. Conclusions

According to the findings of this study, the Gwang Khola watershed could suffer a potential loss. The rate of soil loss in the Gwang Khola watershed varies from close to 0 t ha^{-1} $year^{-1}$ to 731 t ha^{-1} $year^{-1}$. The watershed experienced a mean soil loss rate of 5.46 t ha^{-1} $year^{-1}$, according to the calculations. The Chure region is a lifeline of Nepal but the environmental threat was increasing in trend due to soil erosion. It is a major challenge in the Gwang Khola watershed of the Chure region in Nepal. Climate change, extreme environmental events, deforestation, construction, and topography has helped soil erosion in the Chure region. These results increased landslides and floods, loss of fertile topsoil, decreased agricultural production, and affected the ecosystems, the area is vulnerable due to soil erosion. This finding could help policymakers, land-use planners, municipal governments, and other stakeholders figure out how to save and manage soil. This study may be helpful to other people who have been directly or indirectly involved in the land management process. Even though people can take steps toward improved management, the projected amount of soil loss is relatively manageable. Sustainable land resource management is required to overcome the problems of deteriorating environmental conditions, uncontrolled development, and loss of prime agricultural lands. Nepal's local government may need help planning how to use land in a way that is good for the environment in the

Gwang Khola watershed. The spatial distribution of soil erosion maing could help the decision-makers and the soil conservation planning.

Acknowledgement

The authors would like to acknowledge all the suort received from the people of the Gwang Khola watershed and the Central Department of Geography for providing permission to publish it.

References

Al-Quraishi, A.M.F., Hu, G.D. and Chen, J.G., 2004. Land degradation detection, mapping and monitoring in the northwestern part of Hebei Province, China, using RS and GIS technologies. Map Asia Conference 2004, Beijing, 26-29 August 2004.

Al-Quraishi, A.M.F., 2003. Soil Erosion Risk Prediction with RS and GIS for the Northwestern Part of Hebei Province, China. Journal of Alied Sciences, 3(10), 659–669.

Bag, R., Mondal, I., Dehbozorgi, M., Bank, S.P., Das, D.N., Bandyopadhyay, J., Pham, Q.B., Al-Quraishi, A.M.F., Nguyen, X.C., 2022. Modelling and maing of soil erosion susceptibility using machine learning in a tropical hot sub-humid environment. Journal of Cleaner Production, 364, 132428.

Ban, J.K., Yu, I., Jeong, S., 2016. Estimation of Soil Erosion Using RUSLE Model and GIS Techniques for Conservation Planning from Kulekhani Reservoir Catchment, Nepal. Journal of Korean Society of Hazard Mitigation, 16(3), 323–330.

Basyal, S., 2020. Management of degraded Chure hills through soil conservation practices - A case study of Hariwan municipality-1, Sarlahi district, M. Sc Thesis.

Bastola, S., Seong, Y.J., Lee, S.H., Shin, Y., Jung, Y., 2019. Assessment of Soil Erosion Loss by Using RUSLE and GIS in the Bagmati Basin of Nepal. Journal of the Korean GEO-environmental Society, [online] 20(3), 5–14.

Bekele, B., Gemi, Y., 2020. Soil erosion risk and sediment yield assessment with universal soil loss equation and GIS: in Dijo watershed, Rift valley Basin of Ethiopia. Modeling Earth Systems and Environment, 7(1), 273–291.

Benavidez, R., Jackson, B., Maxwell, D., Norton, K., 2018. A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global alicability and improving soil loss estimates. Hydrology and Earth System Sciences, 22(11), 6059–6086.

Bhandari, K.P., Aryal, J., Darnsawasdi, R., 2014. A geospatial aroach to assessing soil erosion in a watershed by integrating socio-economic determinants and the RUSLE model. Natural Hazards, 75(1), 321–342.

Bhandari, P., KC., M., Shrestha, S., Aryal, A., Shrestha, U.B., 2016. Assessments of ecosystem service indicators and stakeholder’s willingness to pay for selected ecosystem services in the Chure region of Nepal. Alied Geography, 69, 25–34.

Bishwokarma, D., Thing, S.J., Paudel, N.S., 2019. Political Ecology of the Chure Region in Nepal. Journal of Forest and Livelihood, 14(1), 84–96.

Bonilla, C.A., Johnson, O.I., 2012. Soil erodibility maing and its correlation with soil properties in Central Chile. Geoderma, 189-190, 116–123.

Chalise, D., Kumar, L., Shriwastav, C.P., Lamichhane, S., 2018. Spatial assessment of soil erosion in a hilly watershed of Western Nepal. Environmental Earth Sciences, 77(19). doi:10.1007/s12665-018-7842-3.

Chalise, D., Kumar, L. and Kristiansen, P., 2019. Land Degradation by Soil Erosion in Nepal: A Review. Soil Systems, 3(1), 12.

Ghimire, M., 2017. Historical Land Covers Change in the Chure-Tarai Landscape in the Last Six Decades: Drivers and Environmental Consequences. Springer Geography.109–147. doi:10.1007/978-981-10-2890-8_5.

Ghimire, P., Bhatta, B., Pokhrel, B., Kafle, G., Paudel, P., 2019. Soil organic carbon stocks under different land uses in Chure region of Makawanpur district, Nepal. SAARC Journal of Agriculture, 16(2), 13–23.

Guerra, C.A., Rosa, I.M.D., Valentini, E., Wolf, F., Filioni, F., Karger, D.N., Nguyen Xuan, A., Mathieu, J., Lavelle, P., Eisenhauer, N., 2020. Global vulnerability of soil ecosystems to erosion. Landscape Ecology, 35(4), 823–842.

Gyawali, P., Tamrakar, N.K., 2018. Landslide susceptibility assessment of the Chure Khola Catchment area of the Siwalik region, Central Nepal. Journal of Nepal Geological Society, 56(1), 19–30.

Hossini, H., Karimi, H., Mustafa, Y.T., Al-Quraishi, A.M.F., 2022. Role of Effective Factors on Soil Erosion and Land Degradation: A Review. Earth and Environmental Sciences Library, .221–235.

Han, Z., Song, W., 2019. Spatiotemporal variations in cropland abandonment in the Guizhou–Guangxi karst mountain area, China. Journal of Cleaner Production, 238, 117888.

Karna, B.K., Shrestha, S., Koirala, H.L., 2020. Geo-Information Modeling of Soil Erosion for Sustainable Agriculture Land Management in Sambhunath Municipality. Journal on Geoinformatics, Nepal, 20(1), 47–57.

Knapen, A., Poesen, J., 2009. Soil erosion resistance effects on rill and gully initiation points and dimensions. Earth Surface Processes and Landforms, 217-228.

Koirala, P., Thakuri, S., Joshi, S., Chauhan, R. (2019). Estimation of Soil Erosion in Nepal Using a RUSLE Modeling and Geospatial Tool. Geosciences, 9(4), 147.

Lewis, L.A., Nyamulinda, V., 1996. The critical role of human activities in land degradation in Rwanda. Land Degradation and Development (United Kingdom).

Li, M., Yao, W., Ding, W., Yang, J., Chen, J., 2009. Effect of grass coverage on sediment yield in the hillslope-gully side erosion system. Journal of Geographical Sciences, 19(3), 321–330.

Mandal, U.K. 2017. Geo-information-Based Soil Erosion Modeling for Sustainable Agriculture Development in Khadokhola Watershed, Nepal. In: Li, A., Deng, W., Zhao, W. (eds) Land Cover Change and Its Eco-environmental Responses in Nepal. Springer Geography. Springer, Singapore.

Mandal, U.K., Dutta, S., Nazma, M., Ali, M.S., Sharifee, N., Ahmed, A., 2015. Spatial Soil Erosion Modeling for Sustainable Agriculture Development Using Remote Sensing and GIS Technology. Dhaka University Journal of Biological Sciences, 24(2), 177–189.

Mhaske, S.N., Pathak, K., Dash, S.S., Nayak, D.B., 2021. Assessment and management of soil erosion in the hilltop mining dominated catchment using GIS integrated RUSLE model. Journal of Environmental Management, 294, 112987.

Neupane, M. and Dhakal, S., 2017. Climatic Variability and Land Use Change in Kamala Watershed, Sindhuli District, Nepal. Climate, 5(1), 11.

Nyawade, S.O., Gachene, C.K.K., Karanja, N.N., Gitari, H.I., Schulte-Geldermann, E., Parker, M.L., 2019. Controlling soil erosion in smallholder potato farming systems using legume intercrops. Geoderma Regional, 17, e00225.

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., Montanarella, L., 2015. Estimating the soil erosion cover-management factor at the European scale. Land Use Policy, 48, 38–50.

Pokhrel, P., 2013. Chure forestry conservation and management plan: A case study of Arghakhanchi district, Nepal. Journal of Geography and Regional Planning, 6(5), 172–183.

Prasuhn, V., 2012. On-farm effects of tillage and crops on soil erosion measured over 10 years in Switzerland. Soil and Tillage Research, 120, 137–146.

Schmidt, S., Tresch, S. and Meusburger, K., 2019. Modification of the RUSLE slope length and steepness factor (LS-factor) based on rainfall experiments at steep alpine grasslands. MethodsX, 6, 219–229.

Singh, B.K., 2017. Land Tenure and Conservation in Chure. Journal of Forest and Livelihood, 15(1), 87–102.

Sun, W., Shao, Q., Liu, J., Zhai, J., 2014. Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China. CATENA, 121, 151–16.

Thapa, P., 2020. Spatial estimation of soil erosion using RUSLE modeling: a case study of Dolakha district, Nepal. Environmental Systems Research, 9(1).

Tiruwa, D.B., Khanal, B.R., Lamichhane, S., Acharya, B.S., 2021. Soil erosion estimation using Geographic Information System (GIS) and Revised Universal Soil Loss Equation (RUSLE) in the Siwalik Hills of Nawalparasi, Nepal. Journal of Water and Climate Change. 12 (5), 1958–1974.

Uddin, K., Murthy, M.S.R., Wahid, S.M., Matin, M.A., 2016. Estimation of Soil Erosion Dynamics in the Koshi Basin Using GIS and Remote Sensing to Assess Priority Areas for Conservation. PLOS ONE, 11(3), e0150494.

Yigez, B., Xiong, D., Zhang, B., Yuan, Y., Baig, M.A., Dahal, N.M., Guadie, A., Zhao, W., Wu, Y., 2021. Spatial distribution of soil erosion and sediment yield in the Koshi River Basin, Nepal: a case study of Triyuga watershed. Journal of Soils and Sediments, 21(12), 3888–3905.

Yisehak, K., Belay, D., Taye, T., Janssens, G.P.J., 2013. Impact of soil erosion associated factors on available feed resources for free-ranging cattle at three altitude regions: Measurements and perceptions. Journal of Arid Environments, 98, 70–78

Zhang, L., O'Neill, A.L., Lacey, S., 1996. Modelling aroaches to the prediction of soil erosion in catchments. Environmental Software, 11(1-3), 123–133.

Zhao, W.Z., Xiao, H.L., Liu, Z.M., Li, J., 2005. Soil degradation and restoration as affected by land use change in the semiarid Bashang area, northern China. CATENA, 59(2), 173–186.