Abstract
Soil erosion will have impact in the land productivity, water resource and watershed as a whole. The loss of top soil leads to land degradation and for an agrarian area like Jhimruk which also known as “The rice bowl of Nepal”, it would be a huge consequence on the land productivity. Therefore, it is essential to know the spatial distribution of the areas susceptible to the degradation and assess the erosion potential to plan effective mitigation measures. The Revised Universal Soil Loss Equation (RUSLE) model was used in a Geographic Information System (GIS) to estimate the soil loss of the Jhimruk watershed, Lumbini Province, Nepal. This research aimed to calculate the erosional soil loss status of the local governments lying inside the watershed. For this, remote sensing data obtained from various sources were used to generate the factor maps to calculate the soil loss through RUSLE. A 13-year mean annual precipitation data from the 8 meteorological stations in and around the watershed were used. The mean annual soil loss of the watershed was found to be 13.4 tons per hectare per year (t/ha/yr). However, the soil loss was calculated to be as high as 182 t/ha/yr. 68.82% of the total area of the watershed lie under very low erosion class and thus, have low conservation priority. On the other hand 7.73% of the total area of the watershed lie under extremely high erosion class and, thus, have a high conservation priority class. The mean erosion rate from the barren land was found to be highest (23.179 t/ha/yr) followed by agricultural (21.40 t/ha/yr) and forest area had the lowest erosion rate, i.e., 7.90 t/ha/yr.

Keywords  Land cover · Soil erosion · Land degradation · Jhimruk watershed

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

Land degradation and freshwater deterioration by soil erosion are major environmental and economic problems faced worldwide, especially in developing countries (Pimentel and Kounang 1998; Sidle et al. 2006). In Nepal, the situation is even worse because two-thirds of the country’s total area is geologically fragile making the country highly vulnerable to different forms of mass movement and soil erosion on mountain slopes and flooding and siltation in the low-land area. Due to soil erosion, topsoil loss has been lost as high as 87 tons per hectare per year (t/ha/yr) on sloping terraces (Kaini 2018). It is estimated that about 1.7 m of topsoil is lost each year due to soil erosion (Gautam 1993). Poor land management not only impact on food production but also on biodiversity loss, carbon loss and disaster resilience. Nepal
will have to face the greatest challenges if better land regulation and improved farming technologies are not put in place.

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

Nepalese economy which is based on agriculture is mostly rainfall dependent. It faces vagaries of monsoon in larger parts of country without irrigation facilities. In mountainous regions, farmers largely rely on rain fed agriculture. The mountainous regions are characterized by a climate with no or insufficient rainfall to sustain agricultural production (Chalise et al. 2019). Most of the rainfall water through torrential downpours is lost as run-off, eroding significant quantities or precious top soil in the mountain watersheds (Kalpana 2006). To manage watershed activities for sustainability of land and water resources, simulation and optimization models would be required for significant representation of processes and quantification impacts of management strategies in natural watersheds (Tripathi and Ogbazghi 2016). In other words, to protect the land from further degradation and make the mitigation measures effective, it is essential to know the spatial distribution of the areas susceptible to degradation and to assess erosion hazard severity. The combined use of Remote Sensing (RS), Geographic Information System (GIS) and erosion models have been shown to be an effective approach for estimating the severity and spatial different soil resources and land use conditions for soil conservation planning (Chalise et al. 2018).

Soil erosion modeling is able to consider many of the complex interactions that influence rate of erosion by simulating erosion processes in the watershed. Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. The models are designed for specific set of conditions of particular area. The Universal Soil Loss Equation (USLE) is an empirical model assessing long-term averages of sheet and rill erosion (Wischmeier and Smith 1978). Morgan, Morgan and Finney (MMF) model, a semi-empirical model having strong physical base used to assess soil loss (Morgan et al. 1984). The USLE and its modified version such as MUSLE (Williams 1975) and RUSLE (Renard et al. 1991) have been widely used to various scale and regions. RUSLE has been used widely to estimate soil erosion loss, assess soil erosion risk and to support conservation and development plans (Millward and Mersey 1999). The soil loss estimation employing these models indicates the severity of soil erosion under the present land use practices. In the present study, the Revised Soil Loss Equation (RUSLE) was selected to be applied in Jhimruk watershed for predicting the average annual soil loss within the watershed, because of its simplicity and lower data requirements. The main reason for choosing RUSLE is that it predicts the benefits of different management practices by predicting the amounts of sediment that may be trapped in sediment ponds, and determining maintenance schedules for different controls.

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

Materials and methods

Study area

In this study, Jhimruk watershed situated in Pyuthan, Gulmi and Arghakhanchi district is considered. Jhimruk watershed lies in the West Rapti River accounting 915 km² area of Rapti Basin. The river mainly covers Pyuthan District with the altitude of the basin reaching a height of 3200 m. The watershed primarily lies in the Sub-Himalaya (Siwaliks) in the south and Lesser Himalaya zone in the north (Pathak et al. 2008). These two zones are separated with each other by the Main Boundary Thrust (MBT). The Siwalik rocks are basically consisting of sedimentary rocks (mudstone, sandstone and conglomerate), while the Lesser Himalayan rocks are basically the low grade metamorphic rocks (e.g., Slate, phylite, schists, garnet-schists, metasandstone and quartzite) (Rijal et al. 2022). The combination of rock types makes the zone susceptible to folding, faulting and thrusting. Generally, the range exhibits very rugged terrain with deeply dissected gullies and steep slopes. The watershed contains sub-tropical and warm temperature climates, determined by elevation. The fertile alluvial soil of the watershed makes it suitable to paddy plantation, giving the area its nickname, “The Rice Bowl of Nepal”. The study area has three dominant types of lithologies: the Proterozoic A lithology consisting mainly of slates, shales, siltstones, sandstones and graphite schists in the lower part of the watershed; the Proterozoic B lithology...
comprising of phyllites, amphibolites and metasandstones; and, the Proterozoic C lithologies that consists of major carbonate band (Thapa et al. 2020).

The catchment area of the basin is diverse because of the difference in altitude, climate, geology, biological and land use conditions. Jhimruk River carries important value since the water from the river is used for agricultural purposes as well a 12 megawatt (MW) hydroelectric plant is being installed on the river since 1994. Figure 1 shows the map of the research area.

**Data collection**

Table 1 represents the data used for soil erosion modeling (to produce the respective factor maps) and the source from where it is taken. The temporal satellite data of Sentinal-2 of 10 m resolution acquired on October 21, 2018 was used for LULC mapping. The image was geometrically corrected. 13-year hydro-meteorological data were taken from the Department of Hydrology and Meteorology (DHM), from 8 meteorological stations lying within and nearby the watershed. The soil parameters were taken from Food and
Agricultural Organization (FAO), Digital Soil Map of the World (DSMW) to calculate the K factor. A Digital Elevation Model (DEM) of 30 m resolution from ASTER was used to calculate the LS factor. Figure 2 shows the methodological framework used for conducting this research.

**The revised Universal Soil Loss Equation (RUSLE)**

The revised Universal Soil Loss Equation (RUSLE), developed in 1987 by the Natural Resource Conservation Society NRCS which predicts the rill and inter-rill erosion was used for estimating the soil erosion rate in Jhimruk watershed. The model was designed to calculate the mean annual soil loss for ground slopes where flow convergence or divergence can be neglected such as planar slopes. RUSLE is found to be efficient to estimate the water-induced rill and sheet soil erosion but the disadvantage is that it is not able to predict the soil loss caused by gully erosion (Bastola et al. 2019). USLE and RUSLE models have been quite largely used in Nepal to predict the soil loss at watershed scales. RUSLE quantifies soil erosion as a product of six factors illustrating rainfall erosivity (R), soil erodibility (K), Slope length (L), Slope steepness (S), cover and management practice (C) and conservation practices (P). The equation is given as:

\[
A = R \times K \times LS \times C \times P, \tag{1}
\]

where \( A \) is the total soil loss in t/ha/yr, \( R \) is the rain energy factor for the time period, \( K \) is the soil erodibility factor, \( LS \) is the length-slope factor, \( C \) is the degree of soil cover factor, and \( P \) is the conservation practices factor (for agricultural tillage and crop rotation operations, not generally applicable for construction site calculation).

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

**Fig. 2** Methodological framework for soil erosion modeling
Development of model database for RUSLE

Rainfall erosivity factor (R)

The rainfall erosivity factor (R) quantifies the effect of rainfall impact at a particular location and also describes the run-off amount and rate of the rain (Men et al. 2008). To calculate the rainfall erosivity of Jhimruk watershed, 13-year mean annual rainfall data were taken from eight different meteorological stations of that area. Since, only one meteorological station was located inside the watershed, other stations were taken as reference stations. The rainfall map was then produced by kriging method in ArcGIS 10.2.1 and then rainfall erosivity was calculated by using the formula given by (El-Swaify 1997):

$$R = 38.5 + 0.35 \times P,$$

where \( R \) is the mean rainfall erosivity factor, \( P \) is the mean annual rainfall calculated in mm.

Soil erodibility factor (K)

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

$$K = F_{csand} \times F_{st-cl} \times F_{orge} \times F_{hisand} \times 0.1317,$$

where \( F_{csand} \) is the sand factor, \( F_{st-cl} \) is the silt-clay factor, \( F_{orge} \) is the organic carbon content factor and \( F_{hisand} \) is the high sand content factor.

$$F_{csand} = \left[ 0.2 + 0.3\exp\left( -0.0565AN \left( 1 - \frac{SIL}{100} \right) \right) \right],$$

$$F_{st-cl} = \left[ \frac{SIL}{CLA + SIL} \right]^{0.3},$$

$$F_{orge} = \left[ 1.0 - \frac{0.25C}{C + \exp(3.72 - 2.95C)} \right],$$

$$F_{hisand} = \left[ 1.0 - \frac{0.70SN1}{SN1 + \exp(-5.41 + 22.9 \times SN1)} \right].$$

where \( SAN, SIL \) and \( CLA \) are percent sand, silt and clay, respectively; \( C \) is the organic carbon content and \( SN1 \) is sand content subtracted from 1 and divided by 100. \( F_{csand} \) gives low soil erodibility factor for soil with coarse sand and high values for soil with little sand content whereas \( F_{st-cl} \) gives low soil erodibility factor with high clay to silt ratio, \( F_{orge} \) is the factor that reduces soil erodibility for soil with high organic content and \( F_{hisand} \) is the factor that reduces soil erodibility for soil with extremely high sand content.

Topographic factor (LS)

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

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

$$L = \left( \frac{\lambda}{22.13} \right)^{m},$$

where \( L \) is the slope length factor, \( \lambda \) is the slope length, and \( m \) is slope length exponent calculated as follows:

$$m = \frac{F}{1 + F'},$$

where \( F \) is the ratio of rill erosion to inter-rill erosion, and \( F' \) is the slope angle (°).

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

where \( \beta \) is the slope angle (°).

In ArcGIS 10.2.1, \( m \) was calculated as,

$$L = \frac{\text{flow}_{acc} + 625}{25^{(m+2)} \times 22.13^{m}}.$$

For slope gradient factor,
The cover management factor (C) represents the ratio of soil loss from land with specific vegetation to the corresponding soil loss from a continuous fallow (Morgan 2005). It is used to reflect the effect of cropping and other management practices on erosion rates. Vegetation cover is also important for the erosion control. Here, the land use and land cover map of the Jhimruk watershed produced in ArcGIS 10.2.1 through supervised classification was used to prepare the C factor map. First the raster map was converted to polygon and the attributes with the same landuse types were merged in ArcGIS. From this, 5 types of landuse were obtained (Table 2). The values were assigned based on the study of (Erencin et al. 2000). The values of C factor range from 0 to 1 where higher values indicate no cover effect and soil loss as compared to that of the barren land. Whereas, the lower values of C represent the strong cover effect which has the effect to control the erosion.

**Table 2**  
| Land use     | C factor |
|--------------|----------|
| Forest       | 0.03     |
| Agricultural land | 0.21   |
| Barren land  | 0.45     |
| Water body   | 0.00     |
| Built-up     | 0.00     |

\[
S = Con(\tan(Slope \times 0.01745) < 0.09),
(10.8 \times \sin(Slope \times 0.0145) + 0.03),
(16.8 \times \sin(Slope \times 0.01745) - 0.5),
\]

\[
LS = L \times S.
\]

**Cover management factor (C)**

The cover management factor (C) represents the ratio of soil loss from land with specific vegetation to the corresponding soil loss from a continuous fallow (Morgan 2005). It is used to reflect the effect of cropping and other management practices on erosion rates. Vegetation cover is also important for the erosion control. Here, the land use and land cover map of the Jhimruk watershed produced in ArcGIS 10.2.1 through supervised classification was used to prepare the C factor map. First the raster map was converted to polygon and the attributes with the same landuse types were merged in ArcGIS. From this, 5 types of landuse were obtained (Table 2). The values were assigned based on the study of (Erencin et al. 2000). The values of C factor range from 0 to 1 where higher values indicate no cover effect and soil loss as compared to that of the barren land. Whereas, the lower values of C represent the strong cover effect which has the effect to control the erosion.

**Conservation support-practices factor (P)**

Support practices like terrace, contour methods are the important factor to control the soil erosion. The P factor indicates the rate of soil loss according to the various cultivated lands on the earth. It also indicates the impact management through the control of run-off, with specific reference on how the management practices (e.g., contour tillage, strip cropping, and terraces) reduces and alters the pattern, direction and speed of the run-off (Renard et al. 1991). P factor can be computed through different methods of field observation and visual interpretations. The value of support practice factor given by (Shin 1999) was used for the computation. The contour farmland is taken into consideration as agricultural support practice factor in Jhimruk watershed as the farming practice is in sloppy agriculture land by the construction of terraces in most of the areas. The P value ranges from 0 to 1, where the value 0 represents a very good anthropogenic erosion resistance facility and the value 1 represents non-anthropogenic resistance erosion facility. Table 3 shows the P factor values for different slopes for contour farming in the Jhimruk watershed.

Figure 3 shows the spatial distribution of the factor maps used in RULSE and the soil erosion of the Jhimruk watershed.

**Results**

To determine the spatial distribution of average annual soil loss in Jhimruk watershed, the RUSLE parameters were estimated and multiplied in the specified 100 m*100 m cells to estimate the average annual soil loss as shown in the methodological framework (Fig. 2). The R value ranges between 996.39 and 2200 MJ/ha.mm/h. The average annual soil loss from the Jhimruk watershed is computed as 13.5 t/ha/yr with the highest soil loss amounting to 182 t/ha/yr.

The priority classes for soil losses in the study area were regrouped into eight classes (Uddin et al. 2016) as shown in Table 4. The priority class was ranked from very low to extremely high (Fig. 4).

The mean erosion rate of Jhimruk watershed at Sandhikharka Municipality was found to be highest, i.e., 18.601 t/ha/yr. The soil loss of the watershed lying in this Municipality was calculated to be 11,160.6 tons per year. Figures 5 and 6 show the soil erosion occur due to changes in landcover and by slope.

Table 5 represents the soil erosion rate and total soil loss of the Jhimruk watershed lying at various local governments of Argakhanchi, Gulmi and Pyuthan districts of Nepal.

In this study, the highest mean soil erosion rate was found in the Sandhikharka Municipality which was 18.601 t/ha/yr. However, the total soil loss was observed highest in Naubahini Rural Municipality that was 236,629.8 t/yr.

**Rainfall erosivity factor (R)**

The rainfall erosivity factor (R) was generated using the equations as mentioned in Eq. (2). The spatial distribution

\[
S = Con(\tan(Slope \times 0.01745) < 0.09),
(10.8 \times \sin(Slope \times 0.0145) + 0.03),
(16.8 \times \sin(Slope \times 0.01745) - 0.5),
\]

**Table 3**  
| Slope (%)          | Contouring |
|-------------------|------------|
| 0–7               | 0.55       |
| 7–11.3            | 0.6        |
| 11.3–17.6         | 0.8        |
| 17.6–26.8         | 0.95       |
| > 26.8            | 1          |

\[
LS = L \times S.
\]
Fig. 3 Spatial distribution of the factor maps used in RUSLE (a–e) and Soil erosion map of Jhimruk watershed (f)
Soil erodibility factor (K)

The soil map of DSMW was used to generate the soil erodibility factor map. The soil map of Jhimruk watershed was clipped from DSMW in Arc GIS environment and converted the raster into polygon where four types of soil were found. The attributes of the same types of soil were merged and fraction of sand, silt and clay were tabulated from FAO data portal for each characteristics soil type. The erodibility value was calculated by using the equation mentioned in the methods section. The K factor for each type of soil is given in the table and the K value ranged from 0.017 to 0.02001. The South-Western region of the watershed had higher K factor indicating higher soil loss rate.

Table 4 Area under different erosion classes of soil erosion in Jhimruk watershed on the basis of (Uddin et al. 2016)

| Erosion rate (Tons/ha/yr.) | Erosion class | Area (Km²) | Area (%) | Conservation priority |
|---------------------------|---------------|------------|----------|-----------------------|
| 0–0.5                     | Very low      | 599.7      | 65.54    | 8                     |
| 0.5–1                     | Low           | 2.54       | 0.27     | 7                     |
| 1–2                       | Low medium    | 4.72       | 0.51     | 6                     |
| 2–5                       | Medium        | 11.11      | 1.21     | 5                     |
| 5–10                      | High medium   | 17.06      | 1.86     | 4                     |
| 10–20                     | High          | 44.45      | 4.85     | 3                     |
| 20–50                     | Very high     | 154.65     | 16.90    | 2                     |
| > 50                      | Extremely high| 73         | 7.97     | 1                     |

Table 5 Soil erosion of Jhimruk watershed by Local Governments

| Local Governments | Area (Km²) | Mean erosion rate (t/ha/yr) | Total soil loss (t/yr.) |
|-------------------|------------|-----------------------------|-------------------------|
| Gaumukhi RM       | 138        | 14.125                      | 1,94,925                |
| Bhumikasthan RM   | 80         | 14.844                      | 118,752                 |
| Madane RM         | 41         | 12.752                      | 52,283.2                |
| Malarani RM       | 41         | 11.804                      | 48,396.4                |
| Mallarani RM      | 80         | 14.165                      | 113,320                 |
| Naubahini RM      | 209        | 11.322                      | 236,629.8               |
| Jhimruk RM        | 107        | 14.796                      | 158,317.2               |
| Sandikharka M     | 6          | 18.601                      | 11,160.6                |
| Pyuthan M         | 116        | 12.818                      | 148,688.8               |
| Airawati RM       | 89         | 14.926                      | 132,841.4               |
| Mandavi RM        | 8          | 15.566                      | 12,452.8                |

Fig. 4 Soil erosion severity class map of Jhimruk watershed

Fig. 5 Soil erosion by slope
Topographic factor (LS)

The slope map and Flow accumulation map was produced from ASTER DEM at 30 m resolution following the Eq. (8–13). The LS value of the watershed ranged from 0.029 to 18.638. LS factor increases with the increase in hill slope length and steepness.

Cover management factor (C)

The land cover map of the watershed was used to generate the cover management factor. The C value ranged from 0 to 0.449. The value indicates the percentage of the erosive capacity as compared to the bare fallow area. The highest value indicates the higher rate of erosion occurs in those areas as compared with the bare land.

Support practice factor (P)

The support practice factor (P) was generated from slope map produced from the DEM. At first, the slope was classified into 5 range values based on Table 4 (Shin 1999) and the P values were assigned assuming the contouring as the major agricultural practices on the slopes. The value ranged from 0.55 to 1 where higher value indicates the absence of support practice and hence the erosion becomes maximum. The P factor shows the activity that people follow to slow down the rate of erosion. For instance, terrace farming on hillsides and contour farming on flatter areas. It shows how people’s decisions affect their sustainability.

Potential soil erosion rate of Jhimruk watershed

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

Discussion

The rainfall erosivity increases with the increase in slope as mentioned in the study of (Assouline and Ben-Hur 2006). The slope of Jhimruk watershed ranged up to 80 degrees with most of the areas ranging in between 20 and 50 degrees. The erosivity was found to be higher in most of the parts of the watershed which might be due to the lack of meteorological stations inside the watershed. Although the rainfall data was collected from 8 different meteorological stations, only one station lied inside the watershed. And rainfall erosivity influences the rate of soil erosion too. Soil erosion due to water takes place in slopy areas when the rain falls on the soils with less vegetation and low cover management (Lal 2001). A long-term rainfall data are also required for the correct estimation of the R factor. Soil erodibility factor (K) is dependent on the soil type of the area. The soil erodibility factor ‘K’ depends upon the soil texture, organic matter, soil structure and permeability of the soil profile (Ganasri and Ramesh 2016; Koirala et al. 2019). Soil can be composed of different types of sediments including sand, silt, clay, and organic matter and have their respective eroding rates. In the drier areas, the organic matter takes longer time to decompose and hence soil takes longer time to develop. Topographic factor represents the influence of slope length and slope steepness on the erosion process (Ganasri and Ramesh 2016). The LS factor was calculated by considering the flow accumulation and slope in percentage as the inputs. LS factor ranged from zero to 18.3 based on these input. The LS factor tells us about the impact on soil erosion due to the topographic features like slope length and steepness (Koirala et al. 2019). LS factor increases with the increase in hill slope length and steepness. The water bodies and settlement areas in the watershed have obtained higher values of the
C factor. The land use and land cover information helps to understand the land utilization aspects of agricultural land, barren land, water bodies, forests and settlements which are very essential for the erosion estimation.

Figure 3 shows the support practice factor of Jhimruk watershed where most of the parts have the P factor near to 1 indicating quite low support in the conservation activity. It might also due to because the P- factor values were assigned according to the cultivating methods and slope (Shin 1999) and might not have correctly predicted for this specific region. Rapti River basin is considered as one of the most flood prone area of Nepal and several villages in the lower part of West Rapti River along the Nepal–India border gets inundated due to monsoon floods every year (Talchabhadel and Sharma 2014). Soil erosion is also one of the major causes of the flooding. The hills receive greater amount and intensity of rainfall and experience frequent earthquake waves. Such biophysical conditions make watersheds of those regions extremely fragile and sensitive ecological environment to human disturbance (Shrestha et al. 2008)

Although there are many factors that affect the water erosion, vegetation cover, slope gradient and land use play the most important role as mentioned by (Uddin et al. 2016). This might be the case with Jhimruk that most of the areas are covered with forest and agricultural land have few erosion rates. Effective landuse planning might be an important factor to control the erosion rates. Several studies have also shown that mid-hills of Nepal have variable erosion rates which is because of the heterogeneity in the rainfall distribution, soil characteristics, and topography (Chalise et al. 2018; Uddin et al. 2016). The youngest geological formation in the mid-hills and the sloping nature has higher erosion rates than the plain areas (Koirala et al. 2019; Uddin et al. 2016).

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

It is very essential to access the accuracy of the estimated soil loss from the models through field-based measurements (Jha and Paudel 2010). But due to the limitation of the resources and the study area being large, the field-based measurement is not possible. Since Jhimruk watershed has not been gauged for soil erosion therefore it was verified with the erosion status of mid-hill regions of Nepal. The obtained results were compared with the estimated erosion levels at watershed having similar geographical features as well as with national scale to get an overall perspective. The RUSLE-derived mean erosion rates for different types of land cover classes were within the range given by (Koirala et al. 2019; Uddin et al. 2016). The study conducted by (Chalise et al. 2018) has found the soil loss rate of 11 t/ha/yr for Aringalekhola watershed in Salyan district having the similar geographical conditions and physical features as Jhimruk watershed. The study showed that 68.82% of the watershed lies under very low erosion class with soil loss ranging between 0 and 5 t/ha/yr whereas, 7.73% of the watershed falls under extremely high erosion class. The high erosion class of the watershed might be attributed to the high rainfall, steep slopes, agricultural practices and fragile rocks (Chalise et al. 2018; Koirala et al. 2019; Pandey et al. 2009).

Mountainous areas have relatively increased level of soil erosion which is also due to the poor management and abandoned cultivation of terraced paddy fields (Chen et al. 2011). Rising temperatures have an indirect impact on soil erosion (Nearing et al. 2004). There occur changes in vegetation cover and soil moisture along with the change in temperature. So, change in the climate will also have an impact in the soil erosion of that place.

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

The results obtained were compared with the estimated erosion levels at watershed scale, national scale as well as physiographic region and different land cover classes, mostly relating to mid-hill areas in Nepal having similar characteristics. Much better results could have been obtained if the field-based measurements of the soil data could have been taken for the watershed. Also, experimental plots and iterative process for soil loss estimation could help to refine the model improve the results. Further studies can take into consideration of these things in order to get more accurate and specific results.

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

**Conclusion**

The results of the soil erosion map that was produced with the RUSLE model showed that the soil erosion rate of Jhimruk watershed was found to ranging from 0 to 182 t/ha/yr with most of the areas lying under low erosion risk. This might be due to the conservation practices value that is assigned for the area and also there are other factors like slope, cover management and soil type. Although, most of the areas fall under low erosion risk, there are some of the areas which have greater soil loss up to 182.11 tons/ha/yr. Categorizing the soil loss of the watershed on the basis of the local governments, Sandikharka Municipality had the highest soil erosion rate (18.601), whereas Naubahini Rural Municipality had the lowest erosion rate of 11.322 t/ha/yr. It is necessary to design and implement erosion control practices in the erosion prone areas. The results obtained from the study can assist in the prioritization of the areas prone to soil erosion and develop effective conservation measures.

**Acknowledgements** This research was supported by Youth Alliance for Environment (YAE) through USAID PAANI project, which is gratefully acknowledged. We would also like to acknowledge the help and support from Central Department of Environmental Science (CDES) TU, Department of Hydrology and Meteorology, Government of Nepal (for providing the metrological data). We would also like to thank everyone who has been a part of this research.

**Declarations**

**Conflict of interest** None of the author has conflict of issue.

**Funding** This study was funded by Youth Alliance for Environment (YAE), Gairidhara, Kathmandu Nepal.

**References**

Assouline S, Ben-Hur M (2006) Effects of rainfall intensity and slope gradient on the dynamics of interrill erosion during soil surface sealing. CATENA 66:211–220

Chalise D, Kumar L, Shriwastav CP, Lamichhane S (2018) Spatial assessment of soil erosion in a hilly watershed of Western Nepal. Environ Earth Sci. https://doi.org/10.1007/s12665-018-7842-3

Chen L, Qian X, Shi Y (2011) Critical area identification of potential soil loss in a typical watershed of the three gorges reservoir region. Water Resour Manage 25(13):3445

El-Swaify SA (1997) Factors affecting soil erosion hazards and conservation needs for tropical steppelands. Soil Technol 11(1):3–16

Erençin Z, Shresta DP, Krol IB (2000) C-factor mapping using remote sensing and GIS. Case study Lom SakLom Kao Thail Geogr Inst Justus-Liebig- Univ Giess Intern Inst Aerosp Surv Earth Sci ITC Enschede Netherland.

Ganasi BP, Ramesh H (2016) Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravati Basin. Geosci Front 7(6):953–961

Gao GY, Fu BJ, Lu YH, Liu Y, Wang S, Zhou J (2012) Coupling the modified SCS-CN and RUSLE models to simulate hydrological effects of restoring vegetation in the Loess Plateau of China. Hydrol Earth Syst Sci 16(7):2347–2364

Gautam DR (1993) Environmental risk in Nepal: a general assessment. Tribhuvan Univ J 17:87–93

Gautam SK, Sharma D, Tripathi JK, Ahirwar S, Singh SK (2013) A study of the effectiveness of sewage treatment plants in Delhi region. Appl Water Sci 3(1):57–65

Gurung A, Adhikari S, Chauhan R, Thakuri S, Nakarmi S, Ghale S, Dongol BS, Rijal D (2019) Water crises in a water-rich country: case studies from rural watersheds of Nepal’s mid-hills. Water Policy 21(4):826–847

Higaki D, Karki KK, Gautam CS (2005) Soil erosion control measures on degraded sloping lands: a case study in Midlands of Nepal. Aquat Ecosyst Health Manage 8(3):243–249

Jain SK, Kumar S, Varghese J (2001) Estimation of soil erosion for a Himalayan watershed using GIS technique. Water Resour Manage 15(1):41–54

Jha M, Paudel R (2010). Erosion predictions by empirical models in a mountainous watershed in Nepal. J Spatial Hydrol 10.

Kaini BR (2018) Losing the land: soil erosion and degradation. The Himalayan Times, Kathmandu

Kalpana B (2006) Application of remote sensing and GIS to soil erosion assessment and spatial risk modeling in Himalayan watershed using hierarchical perspective: a case study in sitla-rao watershed. In 18th World Congress of Soil Science, July 9–15 - Philadelphia, Pennsylvania, USA.

Khalil MI, Fornara DA, Osborne B (2020) Simulation and validation of long-term changes in soil organic carbon under permanent grassland using the DNDC model. Geoderma 361:114014

King C, Baghdadi N, Lecomte V, Cerdan O (2005) The application of remote-sensing data to monitoring and modelling of soil erosion. CATENA 62(2):79–93

Koirala P, Thakuri S, Joshi S, Chauhan R (2019) Estimation of soil erosion in nepal using a RUSLE modeling and geospatial tool. Geosciences (Switzerland) 9(4):1–19

Lal R (2001) Soil degradation by erosion. Land Degrad Dev 12(6):519–539
Men M, Yu Z, Xu H (2008) Study on the spatial pattern of rainfall erosivity based on geostatistics in Hebei Province, China. Front Mech Eng China 2:281–289
Morgan RPC (2005) Soil Erosion and Conservation. Blackwell Publisher, Oxford
Morgan RPC, Morgan DDV, Finney HJ (1984) A predictive model for the assessment of soil erosion risk. J Agric Eng Res 30:245–253
Nearing M, Pruski F, O’Neal MR (2004) Expected climate change impacts on soil erosion rates: a review. J Soil Water Conserv 59:43–50
Pandey A, Mathur A, Mishra SK, Mal BC (2009) Soil erosion modeling of a Himalayan watershed using RS and GIS. Environ Earth Sci 59(2):399–410
Pathak D, Gajurel A, Shrestha G (2008) GIS-based landslide hazard mapping in Jhimruk River Basin, West Nepal. J Nepal Geol Soc 36:25.
Pimentel D (2006) Soil erosion: a food and environmental threat. Environ Dev Sustain 8(1):119–137
Pimentel D, Burgess M (2013) Soil erosion threatens food production. Agriculture 3:443–463
Pimentel D, Kounang N (1998) Ecology of soil erosion in ecosystems. Ecosystems 1(5):416–426
Renard KG, Foster GR, Weesies GA, Porter JP (1991) RUSLE: revised universal soil loss equation. J Soil Water Conserv 46(1):30–33
Rijal M, Pandit HP, Mishra BK (2022) SWAT-based runoff and sediment simulation in a small watershed of Nepalese river: a case study of Jhimruk watershed. Int J Hydrol Sci Technol 13:215–235
Sahu A, Baghel T, Sinha M, Ahmad I, Verma M (2017) Soil erosion modeling using RUSLE and GIS on dudhawa catchment. Int J Appl Environ Sci 12:1147–1158
Sharpley AN, Williams JR (1990) EPIC Erosion/Productivity Impact Calculator: 1. Model Documentation. USA Department of Agriculture Technical Bulletin No. 1768, USA Government Printing Office, Washington DC.
Shin KJ (1999) The soil loss analysis using GIS in watershed. A Master Thesis, Kangwon National University, Gangwon-do, Korea, p. 116.
Shrestha DP, Zinck JA, Van Ranst E (2004) Modelling land degradation in the Nepalese Himalaya. CATENA 57(2):135–156
Shrestha MB, Tamракar NK, Miyazaki T (2008) Morphometry and sediment dynamics of the churiya river area, siwalik range in Nepal. Boletín De Geología 30:35–48
Sidle RC, Ziegler AD, Negishi JN, Nik AR, Siew R, Turkelboom F (2006) Erosion processes in steep terrain—truths, myths, and uncertainties related to forest management in Southeast Asia. For Ecol Manage 224(1):199–225
Singh P, Gautam S, Singh S, Srivastava P (2016) Appraisal of surface and groundwater of the Subarnarekha River Basin, Jharkhand, India: using remote sensing, irrigation indices and statistical techniques.
Talchabhadel R, Sharma, R (2014) Real time data analysis of west rapti river basin of Nepal. J Geosci Environ Protect 2:1–7
Thapa B, Pant RR, Thakuri S, Pond G (2020) Assessment of spring water quality in Jhimruk River Watershed, Lesser Himalaya, Nepal. Environ Earth Sci. https://doi.org/10.1007/s12665-020-09252-4
Tripathi RP, Ogbazghi W (2016) Watershed management to enhance rainwater conservation and crop yields in semiarid environments—a case study at Hamelmalo Agricultural College, Anseba region of Eritrea. Agric Water Manag 168:1–10
Uddin K, Murthy MSR, Wahid SM, Matin MA (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
USAID (2018) Jhimruk khola watershed profile: status, challenges, and opportunities for improved water resource management. DAI Global LLC, Kathmandu
Williams JR (1975) Sediment-yield prediction with universal equation using runoff energy factor. Present and Prospective Technology for Predicting Sediment Yield and Sources ARS, WA: USDA.
Wischmeir WH, Smith DD (1978). Predicting rainfall erosion losses: a guide to conservation planning (No.537). Science and Education Administration, US Department of Agriculture USDA.
Zhou P, Luukkanen O, Tokola T, Nieminen J (2008) Effect of vegetation cover on soil erosion in a mountainous watershed. CATENA 75:319–325

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.