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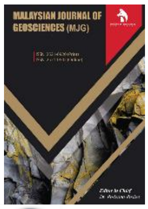

RESEARCH ARTICLE

ASSESSING SOIL EROSION IN MANDAKINI RIVER WATERSHED: A SUB-WATERSHED SCALE ANALYSIS USING RUSLE MODEL AND GEOSPATIAL TOOLS

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ABSTRACT

Watershed are adversely affected by delectable land use land cover changes over the last two decades and these changes witnessed the soil loss in watershed. Soil weathering processes are induced by various factors like aggressive rainfall, hilly topography, land use land cover changes, less vegetation. Most of the watershed of Himalayan Rivers are being affected due to soil loss. The Mandakini River Watershed of Garhwal Himalaya, Uttarakhand has been affected by these soil accelerating components. The remote sensing and GIS can plays a vital role in identification of erosion vulnerable area for estimation of soil loss using revised universal soil loss equation (RUSLE) it provides an erosion scenario on sub-watershed scale. The RUSLE factors (R, K, LS, C and P) acquired using satellite based product and spatial technology. The rainfall map prepared from IMD gridded rainfall data, K-factor map retrieved from NBSS & LUP, Sentinel data and ALOSPALSAR DEM utilized for estimation of LS, C and P factors. All factors integrated in ArcGIS environment and soil loss map for year 2022 were prepared and categorized into 23 sub-watershed. This study classify the sub-watersheds based on various soil classes. Soil loss classified on five major classes where, out of 23 sub-watersheds (SW02, SW12, and SW23) classified in very high erosion category, five sub-watershed classified into high erosion class, two at moderate soil erosion class, and rest of thirteen sub-watersheds falls under less erosion risk. This study can helpful for policy makers and planners to take action for mitigation of natural resources.

KEYWORDS

RUSLE; ALOSPALSAR DEM; Mandakini River Watershed; soil loss

1. INTRODUCTION

Soil is the most fundamental resource on earth, which is basis of all terrestrial life. Soil plays a multi-functionality role in global climate change, repository for industrial waste and a vital resource of food and fodder (Chaudhary and Kumar. 2018). The soil degradation is natural process that ensures stability among diverse ecosystem functionaries and this process is accelerated by key factors such as land use change, heavy rainfall, steep topography (Abdulkareem et al., 2021). Predicting soil erosion and its associated environmental, social, and economic impacts at the sub-watershed level, facilitating the implementation of sustainable conservation measures (Zhang et al., 2009). Various mathematical equations are used to quantify the soil loss in watershed. The empirical based model such as Revised universal soil loss equation (RUSLE) based on observed data and relationship among various factors affecting soil (rainfall, soil type, land use pattern, topography) is widely for quantifying soil erosion (Zhang et al., 2009). Wind and water are two major factor that are responsible for soil loss (Mishra et al., 2018).

The worldwide erosion rate ranges from 0.5 to 350 Mg ha-1 yr-1, where water erosion (56%) and wind erosion (28%) affects the total degraded land worldwide (Oldman 1994). In India, soil erosion and land degradation affects an estimated 147 million hectare (Mha) of land, about 94 million hectares are getting eroded by water, 16 million hectares are dealing with acidification, 14 million hectares are underwater due to flooding, 9 million hectares are getting blown away by wind, 6 million hectares are becoming salty, and 7 million hectares are facing a mix of different problems (Bhattacharyya et al., 2015). One of the main reason of land deterioration in hilly region, is water induced erosion (Mandal and Sharda, 2011). In agricultural land, tillage erosion is one the cause of erosion in hilly areas (Naik et al., 2014). The Uttarakhand state have serious water erosion problem due to heavy rainfall, weak geological formation, deforestation, active seismicity and rapid urbanization (Mahapatra et al., 2018).

A group researcher estimated soil erosion in Mandakini River basin using USLE and GCM (global circulation model) and suggested that major area of basin experienced soil loss ranges 5-20 t/ha/yr that current year (Khare et al., 2017). The RUSLE model is a practical soil erosion model that is straightforward to grasp conceptually, requires minimal resources, and operates with readily accessible input data. Kumar and Hole quantify erosion rate in Uttrakahnd state with help of RUSLE model and estimated total soil loss rate of Alaknanda basin was 22.90 Mt/yr later, Singh and Kansal applied RUSLE model in Alaknanda basin, and classifying basin into 12 sub-watersheds (SW), where Mandakini basin falls in moderate erosion category with mean soil loss of 14.69 M t/year (Kumar and Hole, 2021; Singh and Kansal, 2023). There have been limited efforts to simultaneously assess both soil loss rates and qualitative evaluations in the river basins of Uttarakhand. The RUSLE model output is based on the data resolution and equations that were incorporated as inputs for the model.

In this study a combine approach of RUSLE and geospatial technique are incorporate to quantify the soil erosion in Mandakini River watershed on sub-watershed (SW) scale. A total 23 SWs extracted from Mandakini River watershed and analyzed for soil erosion in basin. This study includes specific objectives: (1) To extract the sub-watersheds from Mandakini River watershed in GIS environment (2) To conduct the RUSLE model in

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basin (3) To prioritize sub-watersheds on basis and ranking SWs on least to most susceptible to soil erosional class. The result of this study would be recommended for soil conservation methods to better management of natural resource.

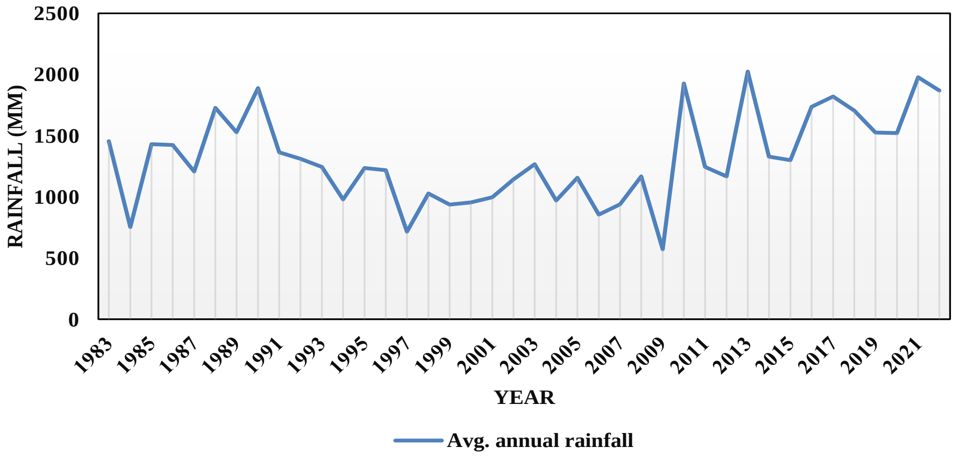


Figure 2: Average annual precipitation (1983-2022)

2. Description of Study Area

The Mandakini River is a significant tributary of the Alakananda River, which rises from the Chorabari Glacier close to Kedarnath in the Indian state of Uttarakhand. The watershed is located in Uttrakhand's Rudraprayag district with an area comprises of 1645 km^2 (approx.). The mean annual precipitation of the watershed is ranges 1000 –2000 mm (Figure 2). The maximum amount of rainfall is typically observed during the monsoon month. The terrain is steep and young, with little troughs dividing sharp to extremely steep slopes. The study area is situated between 78° 50' 0"E and 79° 20' 0"E longitude and between 30° 10' 0"N and 30° 50' 0"N latitude (Figure 1)

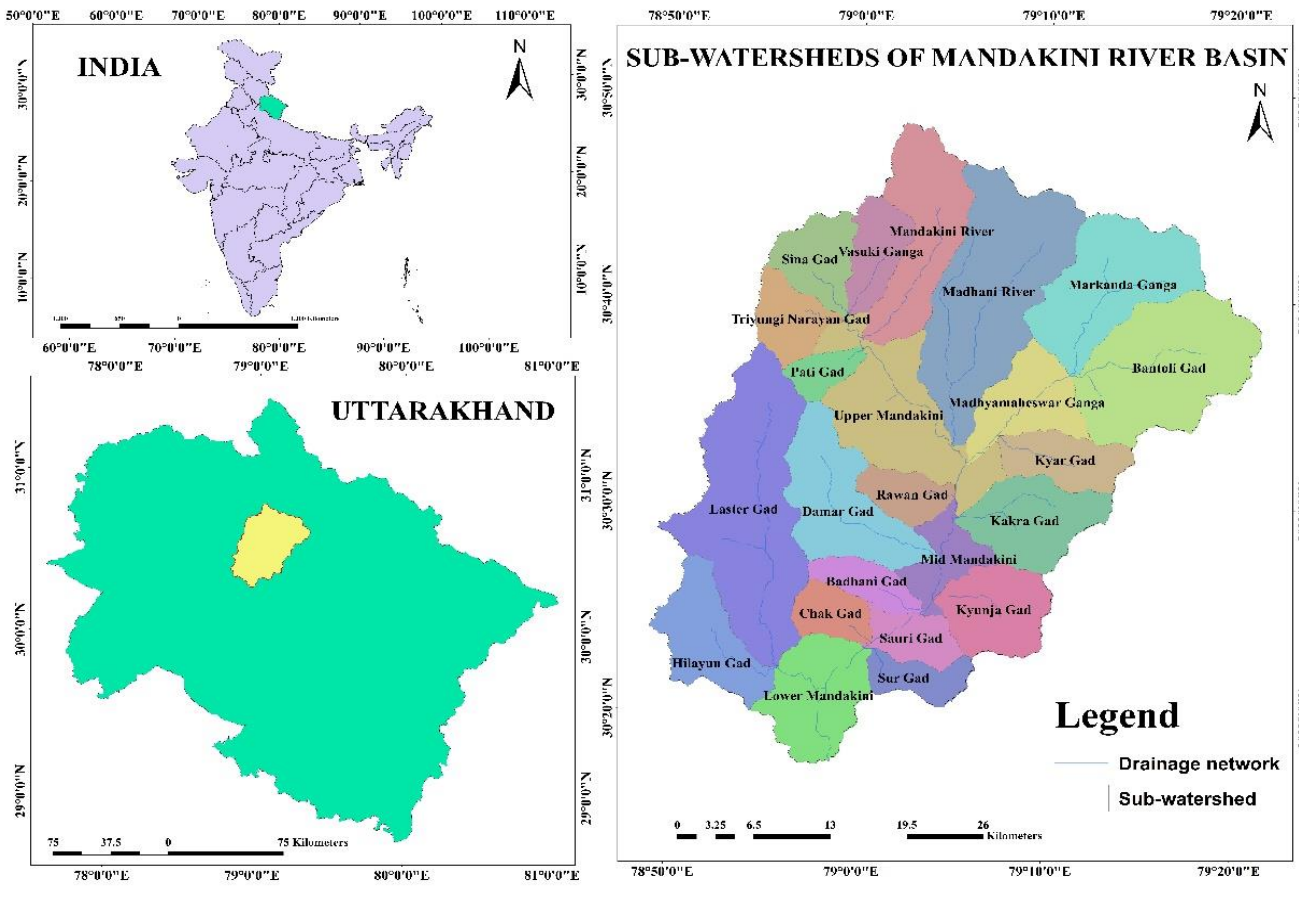


Figure 1: Location map of study area

3. Methodology and Data Used

The sub-watersheds are extracted from DEM data which has been downloaded from https://search.asf.alaska.edu with tile number ALPSRP235820600 and ALPSRP235820590 of ALOS PALSAR DEM (Radiometric terrain corrected) having a resolution of 12.5 m. The SWs has been delineated using Arc-hydro tool in ArcGis 10.6.1 environment. To calculate various factors of RUSLE ancillary data like the rainfall data downloaded from Indian Meteorological Department (IMD), Pune (Pai et al., 2014) https://www.imdpune.gov.in/cmpg/Griddata/Rainfall_25_NetCDF.html. The soil map have been collected from National Bureau of Soil Survey and land use planning (NBSS & LUP) and values of K-factor are taken from existing literature. The DEM of study area has been extracted from ALOSPALSAR satellite data and LS factor has been calculated using the same. C factor have been generated from Landsat OLI imagery for the year 2021 and P factor values generated from existing literature. The methodology followed in the present study is shown in Figure 3. Using a raster calculator tool, all the variables were combined, and a final soil risk map for the watershed created and on the basis of soil loss values the prioritization of SWs has been done.

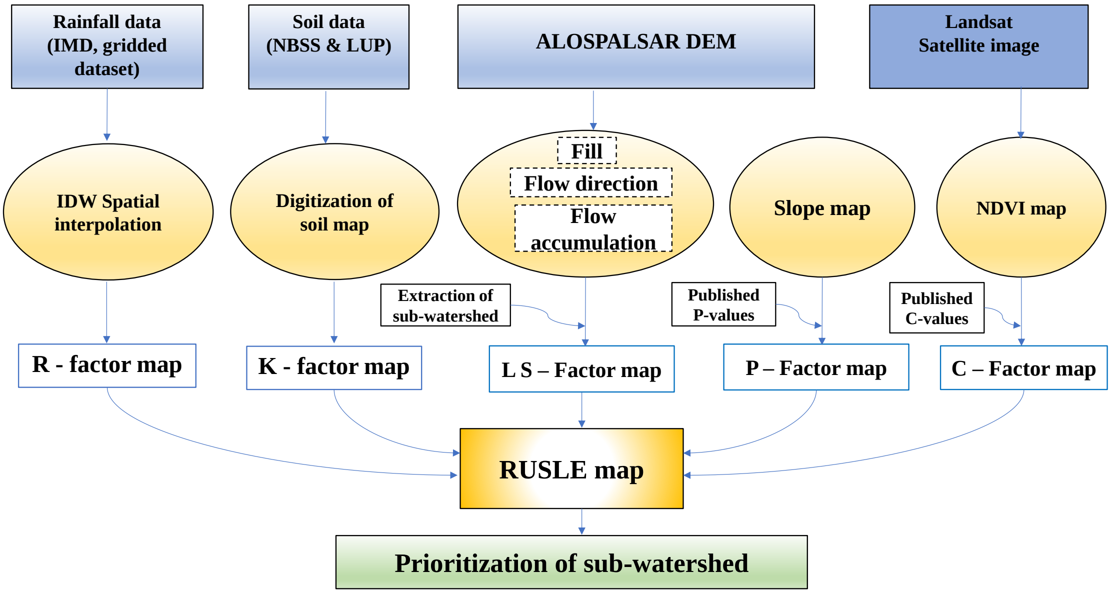


Figure 3: Methodology adopted for the study

4. Results and Discussion

4.1 Rainfall Erosivity Factor (R)

This factor specifies the erosive potential of raindrops, which arises from their capacity to dislodge soil through significant impact force and kinetic energy (Wischmeier and Smith). The annual rainfall data for Mandakini River watershed has been extracted from IMD, PUNE ($0.25^o * 0.25^o$) gridded datasets. A group researcher proposed R-factor (MJ mm ha^{-1} h^{-1} $year^{-1}$) equation for India, the following equation as below (Babu et al., 1978):

$$R = 22.8 + 0.64 * AAP \quad (1)$$

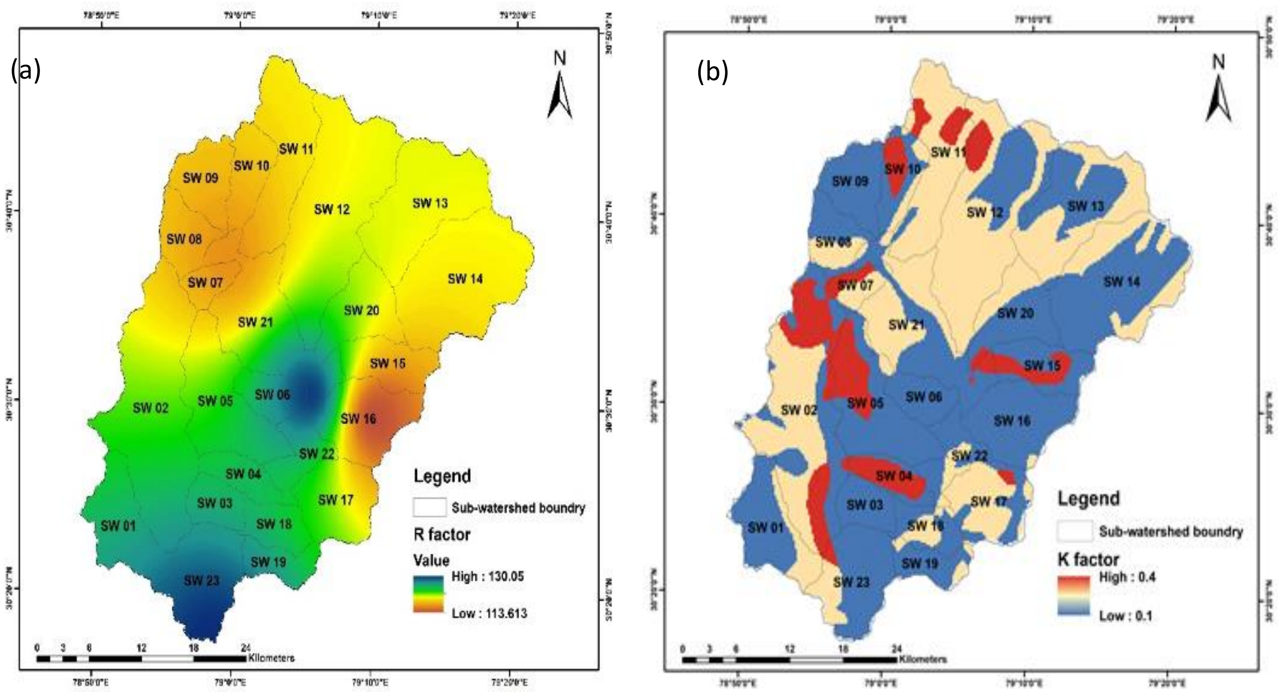
Where, AAP is average annual precipitation in mm.

4.2 Soil Erodibility Factor (K)

This factor designates the susceptibility of soil to get erode (Chaudhary and Kumar 2018). The role of soil or surface material depends on its particle-size distribution, organic matter content, structure, and permeability. Based on the soil codes and soil types in the study area, the soil is categorized into five primary groups. The various classes of soil and the corresponding K values are provided in Table 1.

Soils with a fine texture, characterized by a high clay content, demonstrate resistance to particle detachment, resulting in low K factors ranging from 0.05 to 0.15. On the other hand, coarse-textured soils like sandy soils also exhibit low K values between 0.05 and 0.2 due to their high capacity for infiltration, leading to minimal runoff despite their vulnerability to particle detachment. Medium-textured soils, exemplified by silt loam, display moderate K values of around 0.25, as they possess a moderate susceptibility to particle detachment, resulting in runoff at moderate rates. Soils containing a significant amount of silt are highly prone to erosion, consequently having high K values typically falling between 0.25 and 0.4, with an average value of 0.325 assigned. In cases of very severe soil erosion, a K value of 0.4 is considered (Khare et al., 2017).

The soil map was produced for the study area using geospatial methods followed by the preparation of the K factor map of Mandakini River basin (Figure 4 b). The major area of basin falls under shallow and moderate shallow soil (46.22 % and 37.30 %) followed by soil on fluvial valleys (6.26%), soil on cliffs (2.80 %) was calculated in ArcGIS 10.6.1 version.



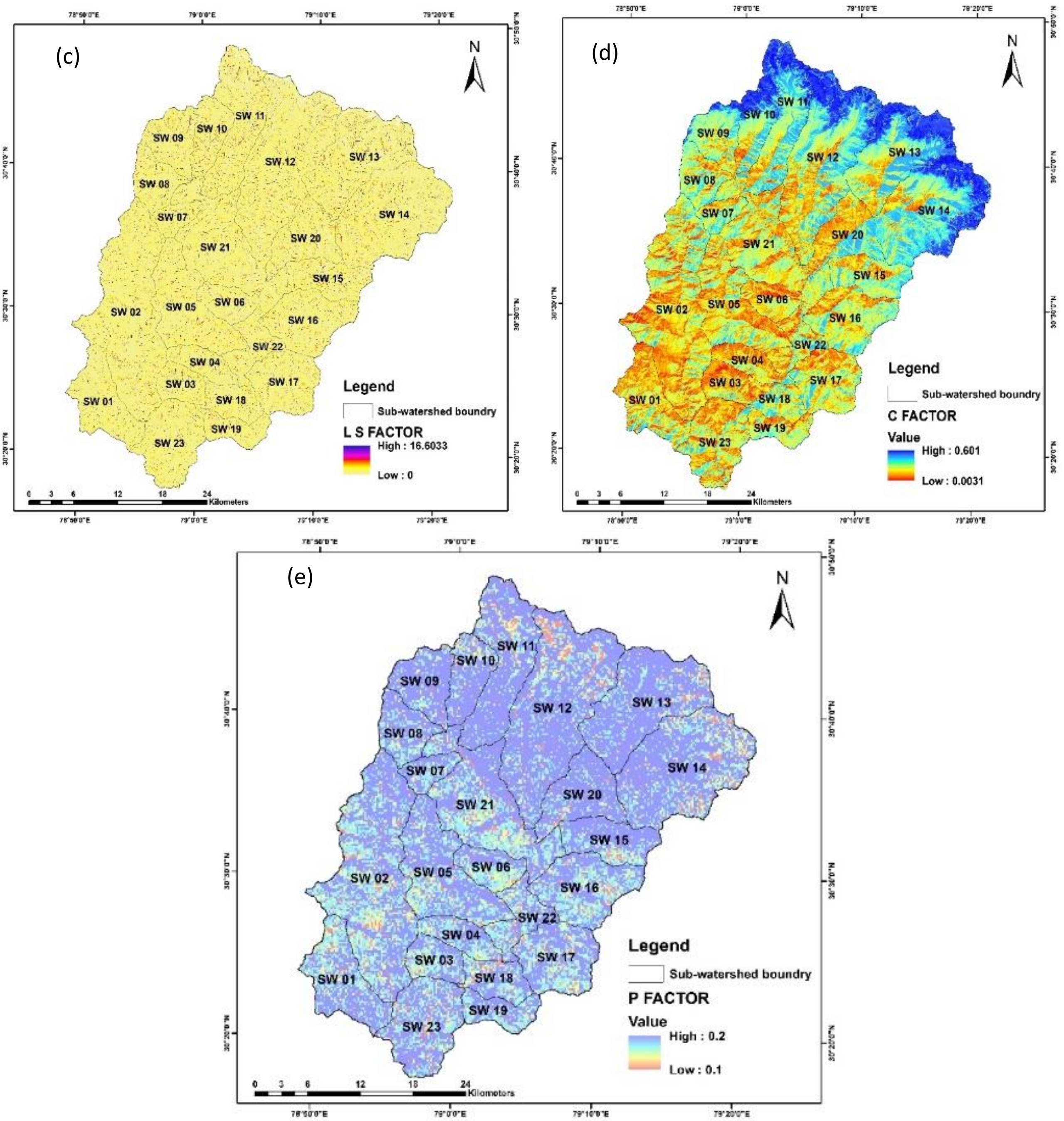


Figure 4: Factors integrating for RUSLE model (a) R factor (b) K factor (c) LS factor (d) C factor (e) P factor

Table 1: K factor classes for various types of soils of Mandakini River basin (Khare et al., 2016)

S.NO	Soil codes	Erosion rate	Soil type	K value
1.	8,12,14,15,18,19,20,27,28,29,30,32,33,35,36,37,40,41,42,45,46	Moderate erosion	Soil on side slopes/ Moderate shallow	0.15
2.	9,48,49	Very very severe erosion	Soil at cliffs	0.40
3.	1,2,38,39, 43,44,47	Slight erosion	Soil on fluvial valleys	0.10
4.	3,4,5,6,16,17,22,31	Very severe erosion	Soil on side slopes/ Very shallow	0.325
5.	7,10,11,13,21,23,24,25,26,34	Severe erosion	Soil on side slopes/ Shallow	0.25

4.3 Slope length and steepness Factor (LS)

It represents the combined influence of both slope length (L) and slope steepness (S) on the rate of soil erosion. (Singh and Kansal, 2023). The LS factor was calculated by utilizing a "flow accumulation" raster, which provides information on the total count of pixels contributing to the flow into a particular cell. Using the flow accumulation matrix, along with the dimensions of individual pixels and pixel slopes, the LS factor was calculated within a GIS-based environment through the application of a raster calculator by multiplying L factor and S factor (Figure 4 c). This computation follows a specific equation for determining the LS factor as follows (Moore and Burch, 1986):

$$LS = (Flow\ accumulation \times \llbracket 22.13) \rrbracket \hat{} 0.5 \times (sinslope / \llbracket 0.0896) \rrbracket \hat{} 1.4 \qquad (2)$$

Where, "flow accumulation" represents the accumulated duplicate-slope contributing area for a specific cell, "cell size" denotes the dimensions of a grid cell (which, in this case, are 12.5 meters by 12.5 meters), and "slope" refers to the slope percentage of the cell.

The L and S factors were calculated by Raster Calculator tool in ArcGIS. Then, the LS factor raster layer was further generated by multiplying L factor and S fact

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4.4 Cover management Factor (C)

The C factor serves to assess the effects of surface cover, roughness, the presence of soil biomass, and activities that disturb the soil on the rate of soil erosion in a given location (Singh et al., 2023). This factor regulates how changes in Land Use and Land Cover (LULC) affect the rate of soil erosion or soil loss in response to the energy and impact of raindrops on the land or soil surface. (Sujatha and Sridhar, 2018). The C-value varies from 0.0 to 1.0. A C-value approaching 1.0 indicates an increased susceptibility of the soil to erosion.

In this study, we estimated the C-factor using the Landsat 9 OLI (2022) satellite imagery and adopting the following equations as follows (Durigon et al., 2014):

$$C = (-NDVI + 1)/2 \quad (3)$$

Where, using raster calculator tool the NDVI map prepared further, C factor map prepared using above equation shown in figure 4 (d).

4.5 Cover management Factor (P)

This factor express the effect of surface management practice that apply to reduce the soil loss through erosion processes like terracing, contour ploughing, strip cropping. The P value ranges from 0-1 where, 0 denotes highest effectiveness of conservation practice and 1, shows no support practice The DEM data has been converted into slope (degree) further, on basis of terraces value classified slope into five category shown in table 2 (Shin 1999).

The P factor map rescaled to 30m resolution using GIS tools (Figure 4 e).

Table 2: Conservation practice factor values according to slope (Shin, 1999)

S.NO	Slope (%)	Contour	Strip cropping	Terracing
1	0 - 7	0.55	0.27	0.10
2	7 - 11.3	0.60	0.30	0.12
3	11.3 - 17.6	0.80	0.40	0.16
4	17.6 - 26.8	0.90	0.45	0.18
5	> 26.8	1.00	0.50	0.20

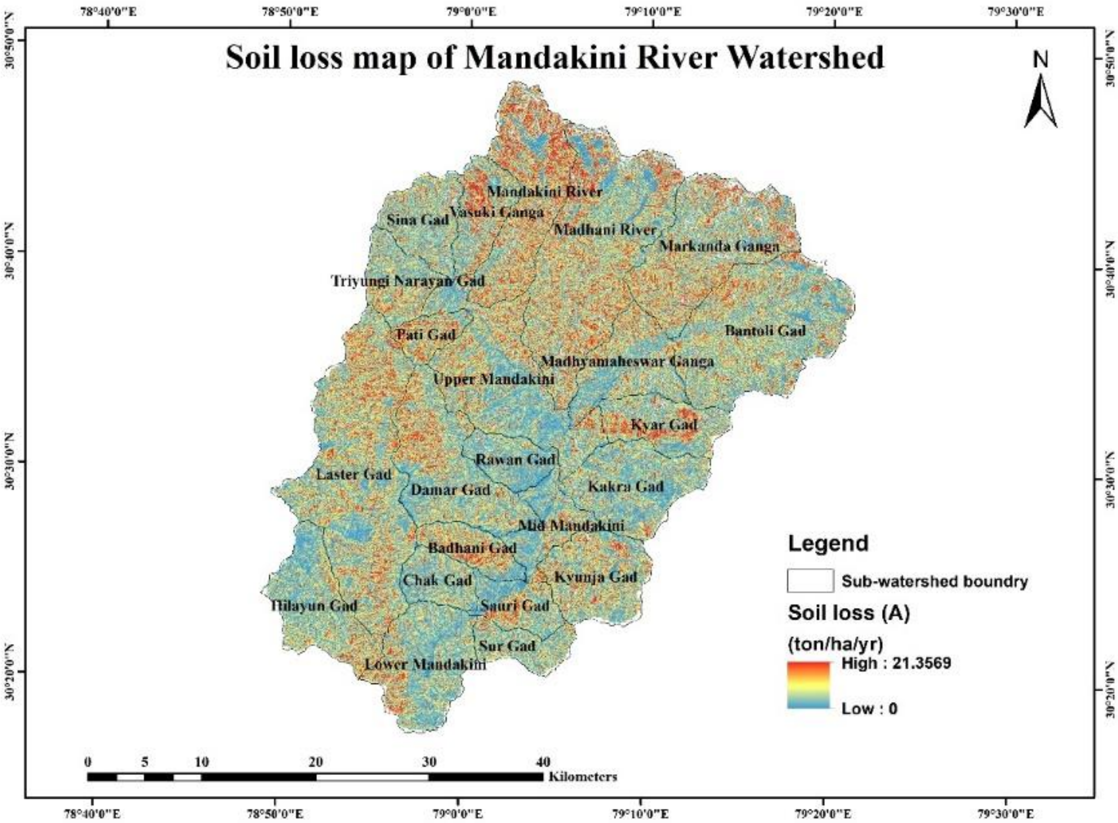

Figure 5: Soil loss map of Mandakini River watershed

4.6 Soil loss (A) estimation and sub-watershed prioritization

The factors (K, LS, R, C and P) integrated in ArcGIS using raster calculator tool for estimating soil erosion map of Mandakini River watershed. The major soil erosion classes are five (very low, low, moderate, high and very high) adopted from (Singh and Kansal, 2023). The annual soil loss in Mandakini River watershed is 21.35 t/ha/yr with a mean rate of 9.13 t/ha/yr. Soil erosion rates differed across various sub-basins in this study, as shown in Fig. 05, and these variations were influenced by factors such as agricultural techniques, population density, soil type, erosion susceptibility, local climate, and topographical features.

The soil loss tolerance limit for river basins are <11.2 t/ha/yr, the erosion rate should not higher than this value as this erosion loss limit based on the assumption that this rate of erosion equals soil formation (Sharda and Mandal, 2021). Singh and Kansal applied RUSLE model on Alaknanda basin, the Mandakini River watershed lying in moderate erosion class with soil loss of 14.69 t/ha/yr (Singh and Kansal, 2023). This study classify the sub-watersheds based on the severity of soil erosion in particular sub-watershed (Figure 6). It was observed that nine sub-watershed falls into low erosion category (SW04, SW07, SW09, SW10, SW14, SW15, SW17, SW18, SW19) with 27.06% of total watershed area. The SW01 and SW05 classified into moderate erosion class, covering 9.85% of area and resulting a mean soil loss of 8.89 million tons per year. On the other hand, sub-watersheds SW11, SW13, SW20, SW21, and SW22 has been found high erosion class with mean soil loss of 14.25 t/ha/yr.

The sub-watershed named Mandakini River, Markanda Ganga, Madhyamaheswar Ganga, Upper Mandakini, Madhani River, Laster Gad Mid-Mandakini and Lower Mandakini are lies in flow path of major tributaries of Mandakini River, these SW are comes in very high to high erosion class of prioritization as these SW are affected by river flow so, most of the landslide are reported on these SW (Merritt et al., 2003; Demirci and Karaburun, 2012). It require immediate attention to combat soil loss in these SW.

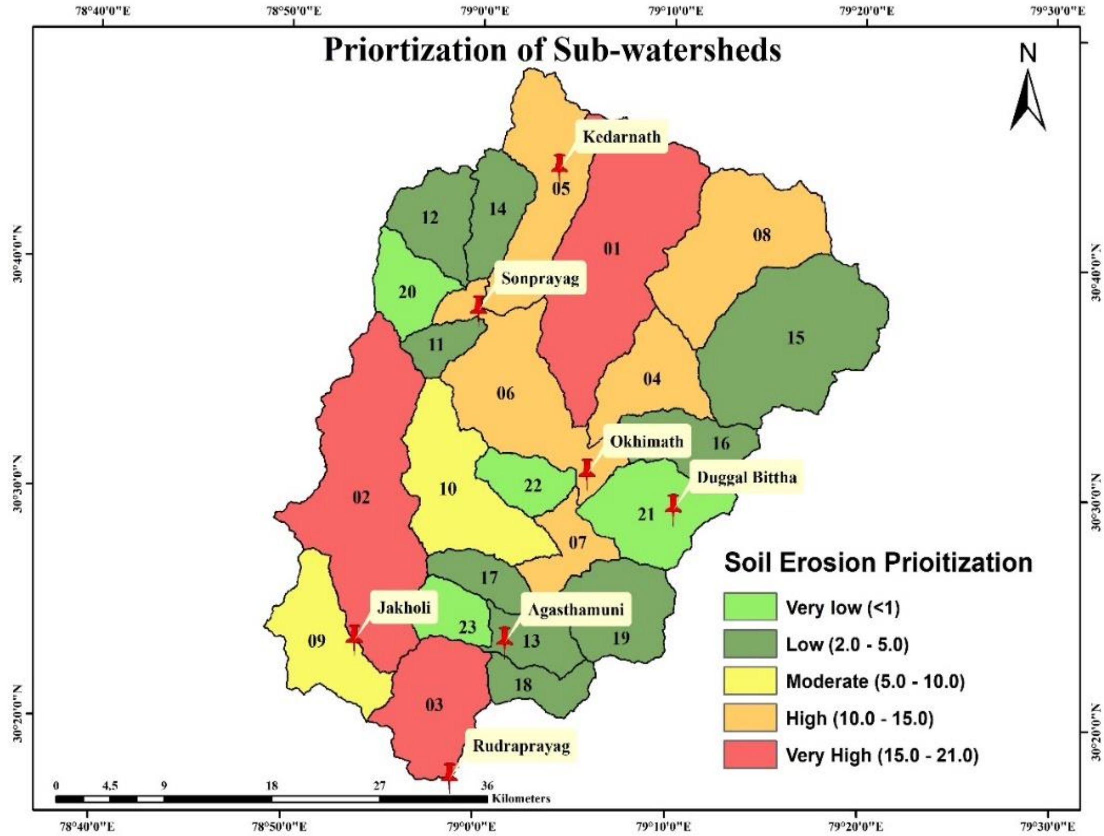

Figure 6: Priority ranking of the SW in relation to the severity of soil erosion from Mandakini River watershed.

5. Conclusion

RUSLE is considered an empirical model, and its utility is constrained by the potential disparities in modeled results and data sources used in the research. Nevertheless, it serves as a valuable tool for prioritizing sub-watersheds, when devising and executing interventions to mitigate soil erosion. Empirical models such as RUSLE are the most commonly employed model of soil erosion, primarily owing to their simplicity and the relatively low amount of data they necessitate when applied at the basin scale. The qualitative classifications of the sub-watershed make it easier for local authorities to comprehend areas prone to erosion. The sub-watersheds which are located along the river channels are majorly affected by the soil erosion. Overall, 37.13% of the area falls into low erosion category, with a mean soil loss of 4.0 t/ha/yr, 9.85% of lying in moderate erosion class, with average soil loss of 8.89 t/ha/yr and more than 50% of total area falls in high erosion category with mean soil loss of 16.94 t/ha/yr.

Among the 23 sub-watersheds, 08 exhibit mean soil erosion rates exceeding 10 t/ha/yr, highlighting the need for soil conservation efforts in erosion susceptible areas. In certain instances, the soil erosion rate surpasses the acceptable threshold, underscoring the requirement for robust and efficient soil conservation measures. Employing vegetative barriers, proper drainage channelization or drainage modification and contour bunding stands out as effective conservation approaches for safeguarding fallow land against soil loss and diminishing rain fed agriculture-induced soil erosion. In hilly regions such as Rudraprayag district (Uttarakahnd) characterized by steep slopes, various support methods, like stone-walling and geo-textiles, could prove beneficial for stabilizing slopes and managing erosion in impacted sub-basins. The utilization of cover management practices, including mulching, conservation farming, and similar approaches, presents valuable avenues for mitigating erosion rates in cultivated lands. Simultaneously, these practices contribute to the preservation of soil organic carbon and essential nutrients.

The RUSLE model lacks the capacity to conduct event-based simulations, thus rendering it incapable of predicting occurrences that result in severe soil erosion events and also this model lacks the ability to identify significant gullies and the deposition of sediment yield. Enhancing the outcomes could involve incorporating higher-resolution satellite observations and more detailed land use/land cover data, thereby increasing the accuracy of the results.

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