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Assessment of Soil Erosion by RUSLE Model using remote sensing and QGIS: A Case Study on Sina River Basin

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Abstract

Soil erosion is a significant environmental problem that affects river basins globally, leading to the loss of fertile topsoil, degradation of agricultural lands, and water pollution. The Revised Universal Soil Loss Equation (RUSLE) model is commonly used to assess soil erosion by considering various factors such as rainfall erosivity, soil erodibility, slope length and steepness, vegetation cover, and conservation practices. To obtain the necessary data for accurate predictions, remote sensing techniques and Quantum Geographic Information Systems (QGIS), specifically QGIS software, are utilized. The objectives of this research are to determine to estimate soil loss using the Revised Universal Soil Loss Equation (RUSLE) model for the Sina River watershed using QGIS. This research paper focuses on assessing soil erosion in the Sina River Basin located in Ahmednagar, Maharashtra, India, using the RUSLE model and QGIS, having a drainage area of 12,372 km^2. The parameters of the RUSLE model were estimated using remote sensing data and the erosion was determined using QGIS. The estimated rainfall erosivity, soil erodibility, topographic and crop management factors range from 83 to 84 MJ/mm·ha−1hr−1/year, 0 to 0.25t ha−1·MJ−1·mm−and 0 to 957.083, 0 to 0.19 respectively. The results indicate that the estimated total annual potential soil loss of about 14.37 t/yr. The predicted soil erosion rate due to the increase in a barren area is about 9.76 t/yr. The results can certainly aid in the implementation of soil management and conservation practices to reduce soil erosion in the Sina River Basin.

1. Introduction

Degradation of agricultural land by soil erosion is a worldwide phenomenon leading to the loss of nutrient-rich surface soil, increased runoff from the more impermeable subsoil, and decreased water availability to plants. Thus, the estimation of soil loss and identification of critical areas for implementation of best management practices is central to the success of a soil conservation program. The total land area subjected to human-induced soil degradation is estimated at about 2 billion hectares. By this, the land area affected by soil degradation due to erosion is estimated at 1100 Mha by water erosion and 550 Mha by wind erosion (Saha, 2003). Soil erosion is a critical environmental issue that affects river basins worldwide. It leads to the loss of fertile topsoil, degradation of agricultural lands, and pollution of water bodies. Understanding the processes and extent of soil erosion is crucial for sustainable land management and effective conservation strategies. One commonly used tool for soil erosion assessment is the Revised Universal Soil Loss Equation (RUSLE) model, which incorporates various factors that contribute to erosion and predicts soil loss rates. Soil erosion in India has a major effect on the agricultural sector, siltation of reservoirs, degradation of soils, etc. in the nation. Many actions have been taken by the government for rectification of the problem and preventing further destruction of the soil layer. In India, almost 130 million hectares of land (Kothyari, 1996), i.e., 45% of the total geographical surface area, is affected by serious soil erosion through the gorge and gully, shifting cultivation, cultivated wastelands, sandy areas, deserts and water logging. Excessive soil erosion with a resultant high rate of sedimentation in the reservoirs and decreased fertility has become solemn environmental problems for the country with disastrous economic consequences.

The RUSLE model combines multiple factors, including rainfall erosivity, soil erodibility, slope length and steepness, vegetation cover, and conservation practices, to estimate soil erosion rates. This model has been widely applied in numerous regions to evaluate soil erosion and guide land management decisions. However, for accurate predictions, the RUSLE model requires input data that are spatially explicit and representative of the study area. These data can be obtained through remote sensing techniques and geographical information systems (GIS).In recent years, GIS software, such as QGIS, has emerged as a powerful tool for spatial analysis and modeling. QGIS provides an extensive range of functionalities for data visualization, manipulation, and analysis, making it an ideal platform for implementing the RUSLE model. By integrating the RUSLE model with QGIS, researchers and land managers can assess soil erosion at a detailed spatial scale and make informed decisions to mitigate its impacts.

This research paper aims to assess soil erosion in the Sina River Basin using the RUSLE model and QGIS software. The Sina River Basin, located in Ahmednagar, is a vital watershed that supports diverse ecosystems and sustains the livelihoods of local communities through agriculture and other economic activities. However, the basin faces ongoing threats from soil erosion, driven by factors such as land use changes, rainfall patterns, and topography.The objectives of this research to determine the land use and land cover (LULC) of the Sina River watershed using Snap Tool software and to estimate soil loss using the Revised Universal Soil Loss Equation (RUSLE) model for the Sina River watershed using QGIS. By achieving these objectives, this research will contribute to the understanding of soil erosion dynamics in the Sina River Basin and provide valuable insights for land managers and policymakers to develop effective erosion control measures. The integration of the RUSLE model with QGIS will enhance the accuracy and efficiency of soil erosion assessments, enabling more informed decision-making in land management and conservation efforts.

Overall, this research paper aims to bridge the gap between soil erosion assessment models and GIS technology, highlighting the importance of using spatially explicit data and advanced analytical tools for addressing soil erosion challenges. By investigating the Sina River Basin as a case study, this research will provide valuable knowledge that can be applied to other river basins facing similar erosion issues, contributing to the broader goal of sustainable land and water resource management.

2. Description of Study Area and data

The Sina River serves as the boundary between Ahmednagar district and Ashti Tehsils of Beed district, Maharashtra, India. It is a significant left tributary of the Bhīma River. The study focuses on the outlet in the Solapur district. The coordinates of Sina dam are 18°49'39.15"N, 74°56'52.17"E, with an elevation of 579 meters above mean sea level. The river originates near Ahmednagar city, with two main sources near Jeur (about 16 km northeast) and Jamgaon (about 20 km west of Ahmednagar city). The study area covers approximately 12,372 km2, with latitudinal and longitudinal extents between 17.37°N to 19.26°N and 74.781°E to 75.924°E. The study area experiences a scarcity of rainfall, with an average annual rainfall of approximately 546 mm. The soil type is medium to fine-textured, with an available water content of 205 mm/m depth. Most soils in the area fall under the category of moderate to deep and very deep, with 85% of soils having such characteristics. The map of the study area is presented in Fig 1.

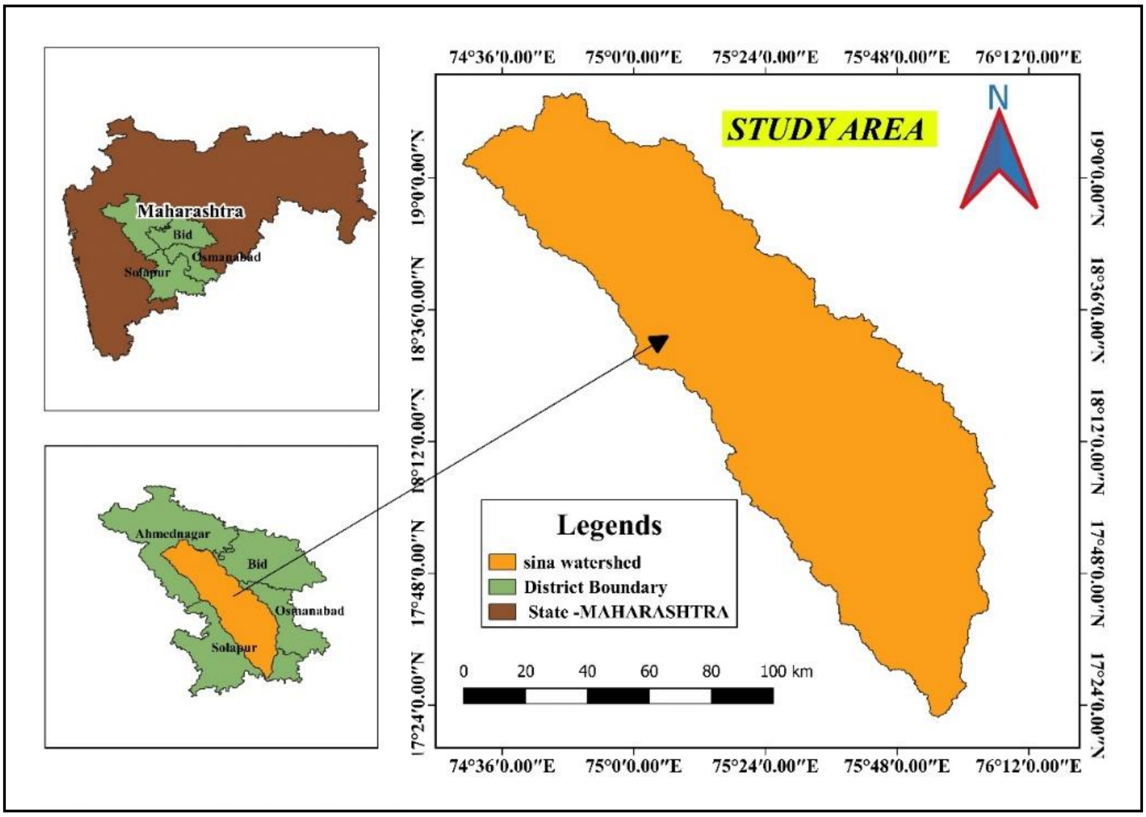


Figure 1. Study Area Map of Sina River Basin

2.1 Data Used

The DEM was downloaded from https://bhuvan.nrsc.gov.in. CARTOSAT–1. The imageswere used for Cartographic applications meeting global requirements. It has a 30 m resolution. Landsat 8 raster used for FCC of watershed DEM. Tiles downloaded for FCC from http://earthexplorer.usgs.gov .Google Maps was used for locating the River basin area. For the determination of the K-Factor digital soil map data of the world from FAO was used. LS-Factor was calculated in the QGIS environment. C-Factor was calculated in the QGIS environment by determining the NDVI. The software used in the study is QGIS 3.18, SNAP Tool.

3. Methodology and parameter estimation

For the research work, Cartosat 1 DEM of 30 m spatial resolution tiles is downloaded from the Bhuvan portal. The DEM was downloaded from https://bhuvan.nrsc.gov.in. For the delineation of the Sina River basin, 8 tiles are downloaded. Then these tiles are imported to QGIS for Further process of Watershed delineation. After the delineation of basin, the shape file of the Sina River basin is imported in QGIS later. This DEM is clipped (Clip raster by mask layer…) with a basin shape to obtain DEM the of the area of interest. Then Fill Sink (Wang & Liu) operation is carried outon clipped DEM in order to remove the small imperfections in the DEM. Then slope algorithm is used to find changes in elevation on a highly detailed level. Contours are found to represent the tridimensional shape of the terrestrial surface on a two-dimensional map. Channel network & drainage basin are found from processing algorithms in QGIS. After that bands (band 2, 3, 4, 5) downloaded from USGS Landsat 8 data for LULC operation. First do FCC on it. Then perform the task for LULCin SNAP TOOL. Draw Training Samples (polygon) in SNAP of each class for land use cover. Give it color manipulation. Plot pins in RGB layer. Transfer them the on labeled image. Calculate Accuracy for Land use classification. After that get the factors the of USLE**.** The detail methodology is depicted in fig no. 2.

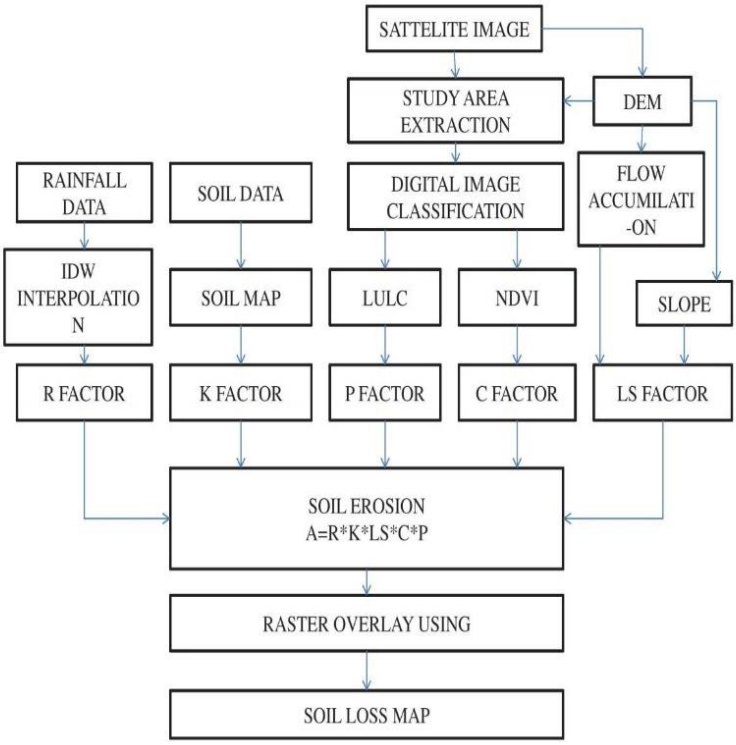


Figure 2. Flowchart of data processing for RUSLE mode

3.1 RUSLE Parameter estimation

The underlying assumption in RUSLE is that the detachment and deposition are controlled by the sediment content of the flow. The eroded material is not source limited, but the erosion is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Sedimentation must also occur during the receding portion of the hydrograph as the flow rate decreases (Kim, 2006). The basic form of the RUSLE equation has remained the same, but modifications in several of the factors have changed. In this study, RUSLE was used for the assessment of annual soil loss. RUSLE was designed to predict long-term annual averages of soil loss. A modern computer interface makes RUSLE easily used and uses physically meaningful input values that are widely available in existing databases or can be easily obtained from DEM and satellite images. RUSLE is the best available practical erosion prediction model that can be easily applied at the local or regional level. In addition to this, many parameters such as slope, aspect derived from DEM, and LULC (land use land cover) from satellite images can be easily integrated with RUSLE. The disadvantage of RUSLE is that it does not have the capability for routing sediment through channels, hence its application is limited to small areas. Therefore, the model is not applied to the very large watershed (Nearing et al., 2005). The RUSLE is applied to the Sina River Basin by representing the basin as a grid of square cells and calculating soil erosion for each cell. RUSLE (Wischmeier and Smith, 1978) computes the average annual erosion expected on field slopes using Eq. (1).

$$A = RKLSCP \quad \text{…. (1)}$$

where A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in ton per hectare per year (t ha^{-1}/yr). R = rainfall-runoff erosivity factor-the rainfall erosion index plus a factor for any significant runoff from snow melt expressed in MJ mm ha^{-1} h^{-1} per year; K = soil erodibility factor- the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope continuous clean-tilled fallow expressed in t ha $^{-1}$ MJ mm $^{-1}$: L = slope length factor- the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions; S= slope steepness factor- the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions; C = cover management factor the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow; P = support practice factor- the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope; L and S factors stand for the dimensionless impact of slope length and steepness, and C and P represent the dimensionless impacts of cropping and management systems and of erosion control practices. The stream order map and slope map of the Sina River basin were estimated in the QGIS environment which show that Sina has the highest order of 6th and 98 % of land fall under low slope, which is shown in fig.3 and 4 equation. (R factor, K Factor, LS Factor, C Factor, etc

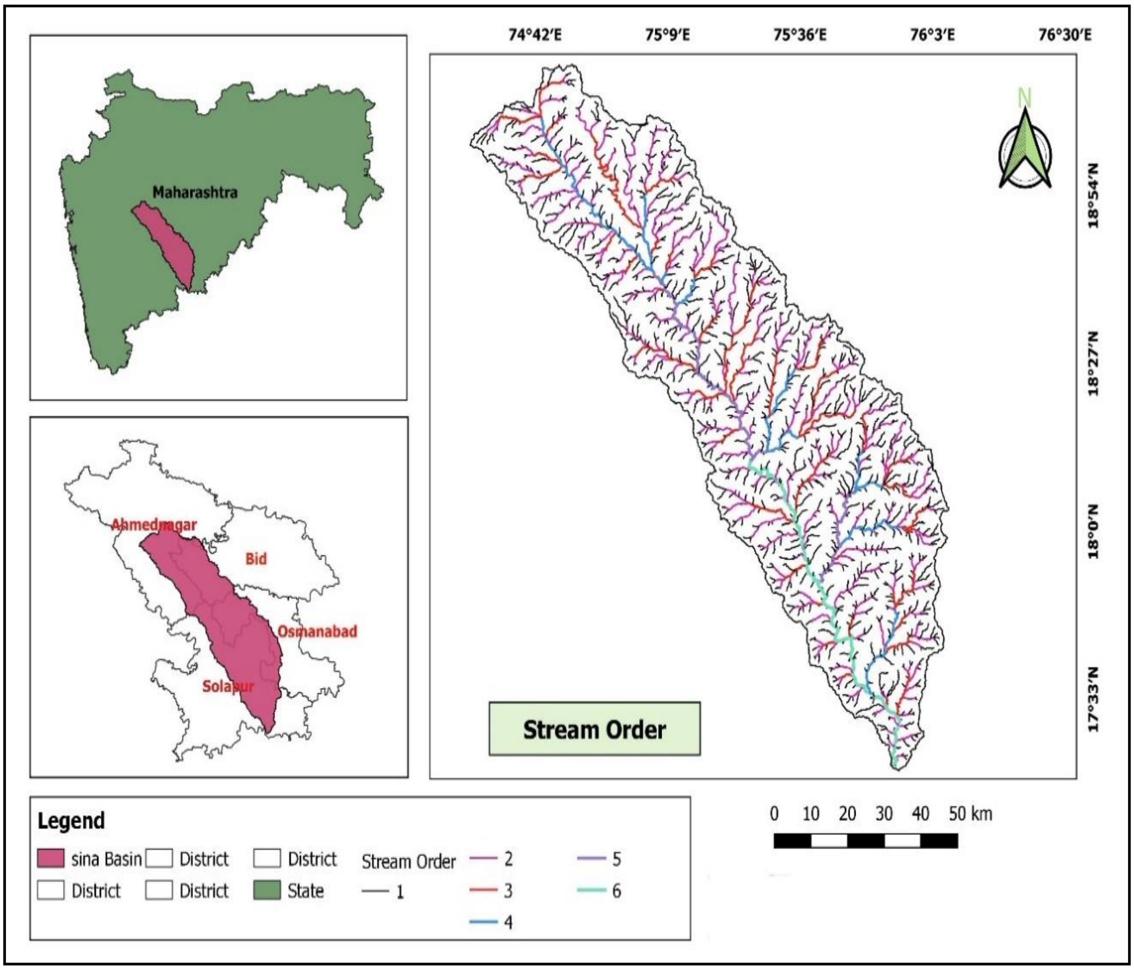
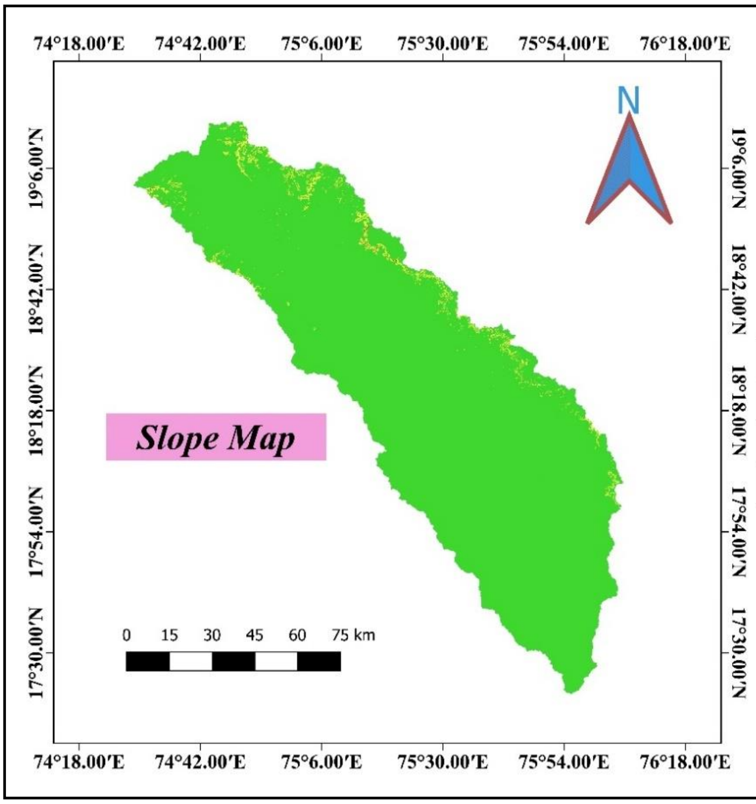


Figure 3. Spatial Distribution Stream order Map of study area



Area in KM^2	Area in %	Value
12041.088	98.07123368002671	Low
232.362	1.8925223368817141	Moderate
4.494	0.036602350564836	High

Figure 4. Spatial Distribution Slope map of study area

The Hill shade map and contours map of the Sina River basin were estimated in the QGIS environment which is shown in fig. 4 and 6.

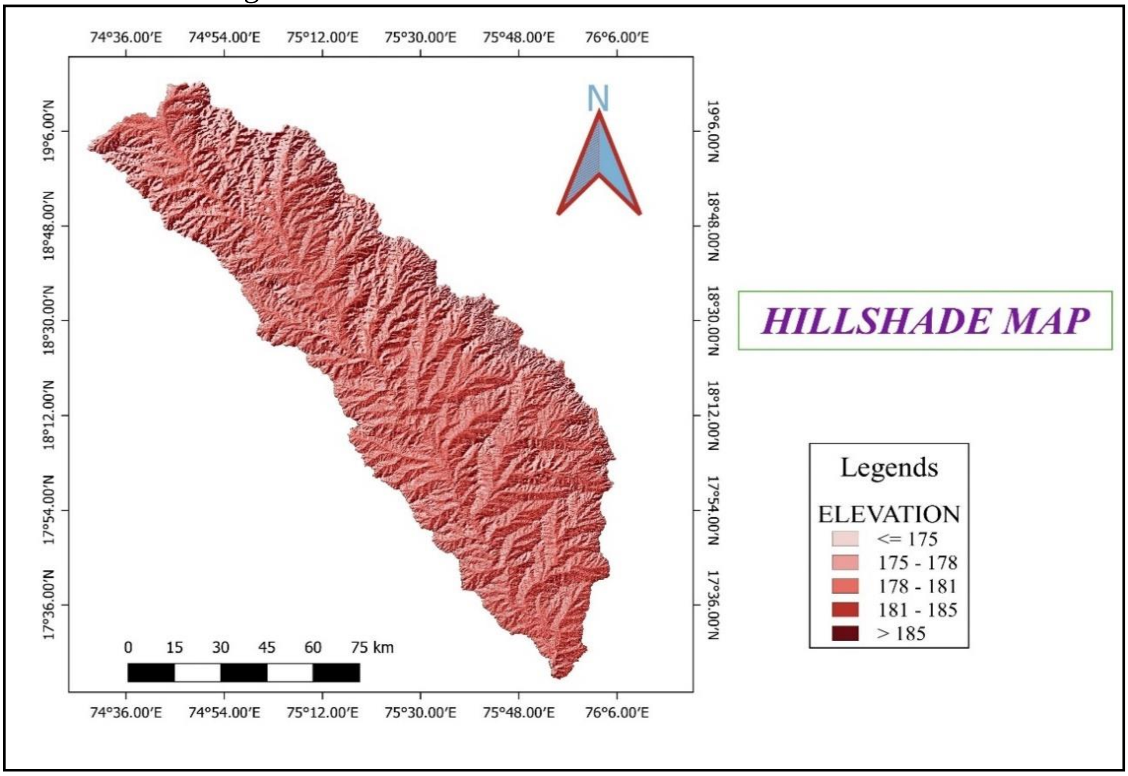


Figure 5. Spatial distribution of Hill shade Map in the study area

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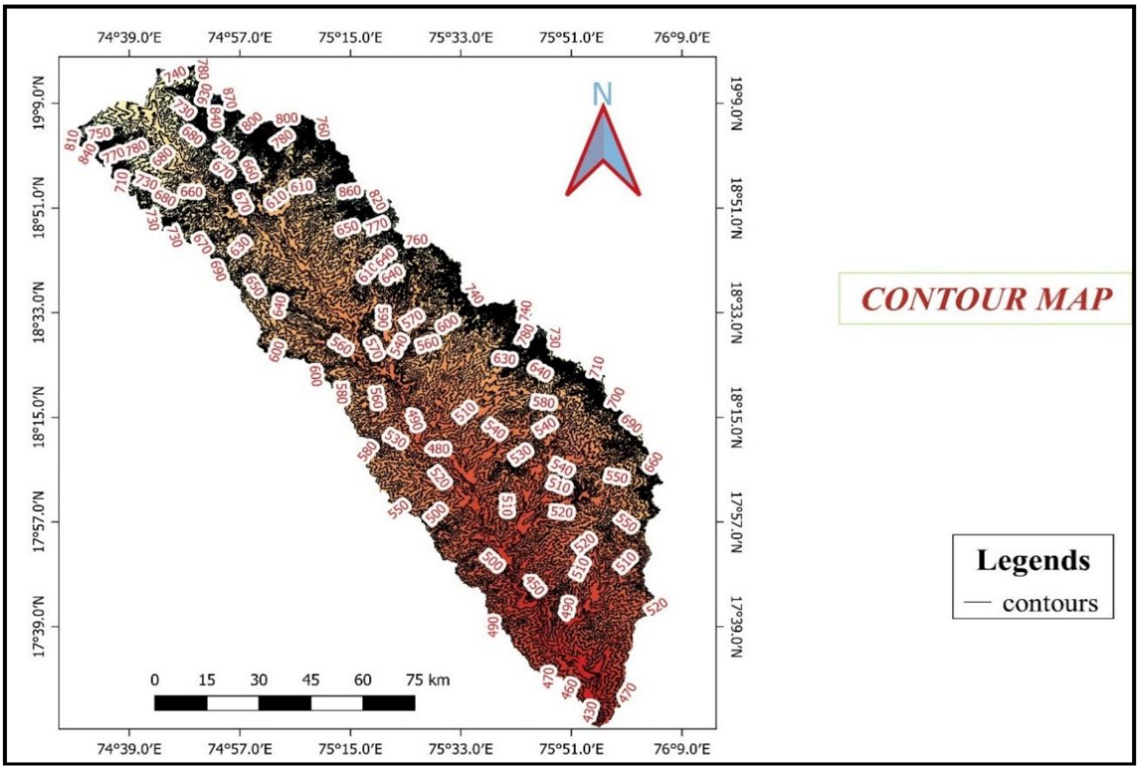

Figure 6. Spatial Distribution Contour Map of the study area

3.2 LULC of Sina River Basin

LULC map of an area provides information to help user to understand the current landscape in the current study 5 classes i.e., Water, Agriculture, Barren, Settlement, and Forest were supervised with the help of supervised classification. For estimation of land used land cover a false-color composite was prepared using 3 bands 4,3,2 and it was interpreted, which is shown in Fig. 7. The total percentage are was also calculated which is depicted in table no. 2, were as the accuracy was determined using Kappa coefficient which is depicted in table no.1.

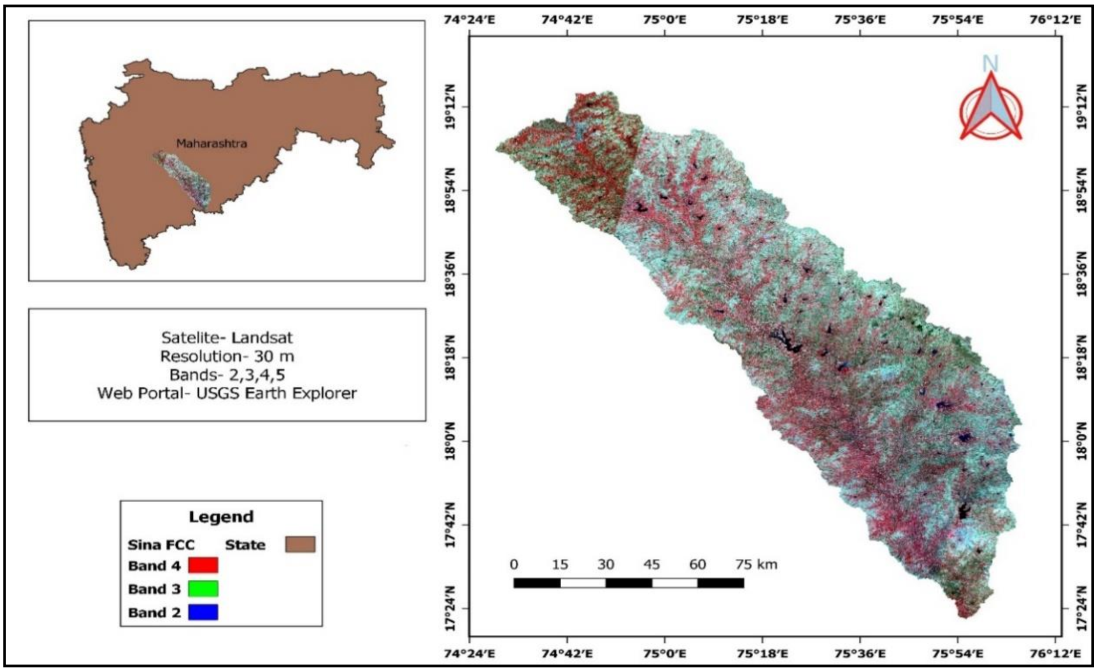

Figure 7. Spatial Distribution FCC of study area

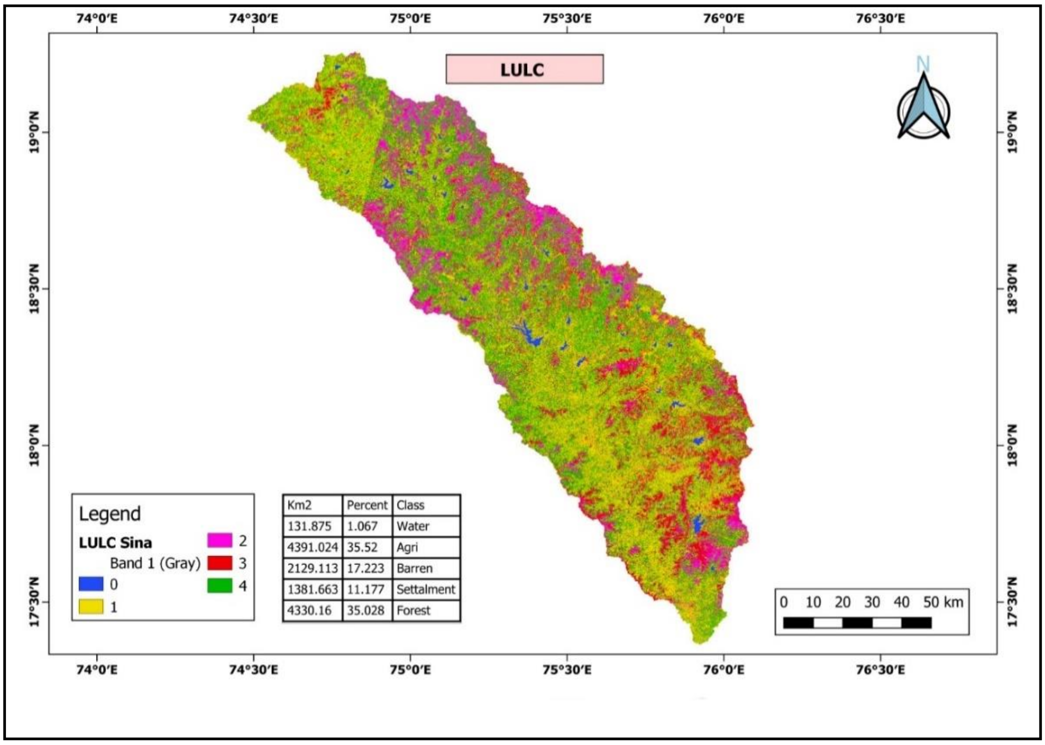

Figure 8. Spatial Distribution LULC MAP of study area

Table 1: Accuracy Assessment table

Accuracy Assessment Table						
	Water body	**Barren Land**	**Forest**	**Agricultural**	**Settlement**	**Total User**
Waterbody	**41**	0	0	0	0	41
Agriculture	0	**30**	4	0	0	40
Barren Land	0	0	**40**	0	0	40
Settlements	0	0	1	**39**	0	40
Forest	0	9	0	0	**28**	37
Total Producer	41	39	45	39	34	198

Formula:

Overall Accuracy (O.A) = (Total reference pixel* Total corrected Pixel) *100
(178 /198) *100
O.A. = 89.89899%

Kappa coefficient = (T.R.P*TCP) - (sum of column Total*Row total)/ (T.R.P) 2) -(sum of column Total*Row total)
K.C. = 87.36%

Table 2: LULC Area of Each class

Classes	**Area (in km^2)**	**Percentage**
Water	131.875	1.067 %
Agriculture	4391.024	35.515%
Barren	2129.113	17.22%
Settlements	1381.663	11.175%
Forest	4330.16	35.023%

The table no. 2 shows the Area (in Km^2 and %) of each class of the basin i.e., Water, Agriculture, Barren Land, settlement, and Forest. Water has occupied 131.875 km^2 Area and it is less Area 1.067% of the basin Land use. Agriculture has Occupied 4391.024km^2 Area and it is a high area of 35.515% of the basin land use. Barren has occupied 2129.113 km^2 Area and it is 17.22% area of the basin land use. Settlement has occupied 1381.663 km^2 Area and it is 11.175 % of the basin land use. Forest has occupied 4330.16 km^2 Area and it is 35.023 % of the basin land use. The Accuracy of the Land use of the basin is about

87.36%.

3.3 R factor

The rainfall-runoff erosivity factor (R-Factor) quantifies the effects of raindrop impacts and reflects the amount and rate of runoff associated with the rain. The R-factoris one of the parameters used by the Revised Unified Soil Loss Equation (RUSLE) to estimate annual rates of erosion. The rainfall-runoff erosivity factor (R-Factor) quantifies the effects of raindrop impacts and reflects the amount and rate of runoff associated with the rain. The R-factoris one of the parameters used by the Revised Unified Soil Loss Equation (RUSLE) to estimate annual rates of erosion. The spatial distribution of average annual precipitation (P) in the study area is estimated using the IDW method of interpolation. In the process of interpolation, 10 years of rainfall data from 2012 to 2022 years of the study area were considered. The map of R factor is shown in fig. 9.

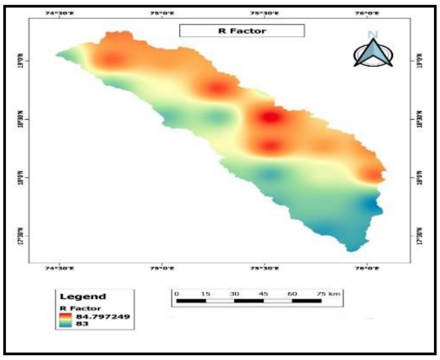

Figure 9. Spatial distribution of R factor Map of Study area

3.4 Soil erodibility Factor (K)

In the universal soil loss equation (USLE), the soil erodibility factor (K) corresponds to the collective effects of the detachment susceptibility of soil and the sediment transportability well as the amount and rate of runoff under the given erosivity. The basin consists of 2 soil types as present in Fig. 10 with varying soil characteristics. Clay soils have a low K value because these soils are resistant to detachment. Silt loam soils have moderate to high K values as the soil particles are moderately to easily detachable, infiltration is moderate to low producing moderate to high runoff, and the sediment is moderately to easily transported. The K factor is a numerical value that varies from 0 to 1 in which soil erodibility values closer to 0 are less prone to soil erosion.

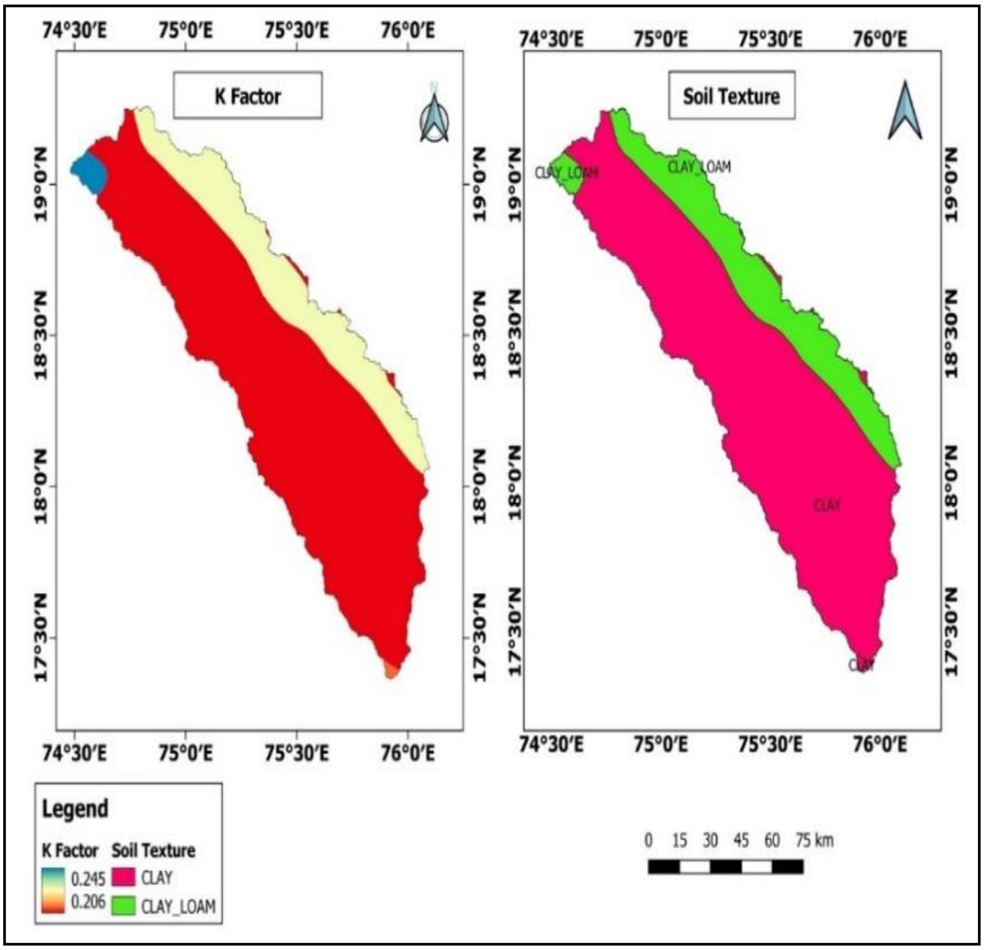

Figure 10. Spatial Distribution K Factor & Soil Texture Map of study area

3.5 Topographic factor Factor (LS)

LS factors = the slope length factor L computes the effect of slope length on erosion and the slope steepness factor S computes the effect of slope steepness on erosion.Values of both L and S equal 1 for the unit plot conditions of 72.6 ft. length and 9 percent steepness. The LS factor represents a ratio of soil loss under a given condition to that at a site with standard slope steepness of 9% and slope length of 22.13m. Wischmeier and Smith came out with varying values of exponent m for different slopes depending on slope steepness, being 0.5 for slopes exceeding 4.5%, 0.4 for 3–4.5% slopes, 0.3 for 1–3%, and 0.2 for slopes less than 1%. The slope map in percentage is prepared from the DEM for the Sina river Basin as shown in Fig. 11.

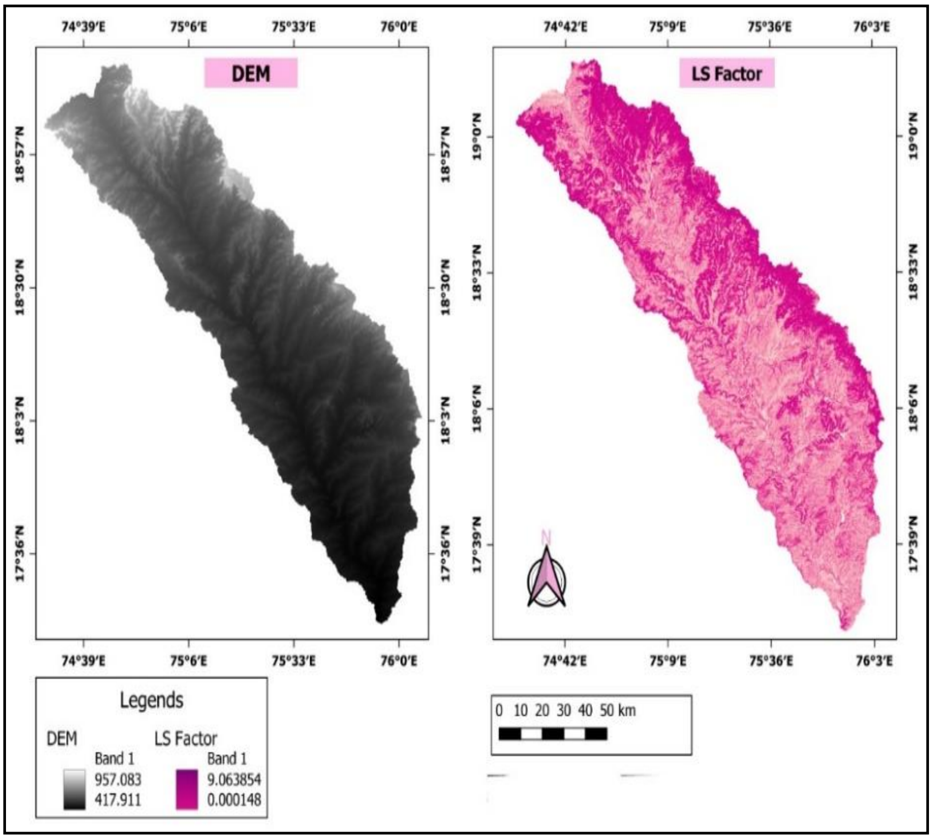

Figure 11. LS Factor Map Sina River watershed

3.6 C Factor

The C factor is the cover-management factor. The C-factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. A "C" Factor value is an average soil loss ratio weighted according to the distribution ofrainfall during the year. The crop management factor map Fig. 12 was prepared on the basis of a land use land cover map of the study area. The land use-land cover of the Sina River Basin was classified into five land use-land cover classes, namely, Water, Agriculture, Barren, Settlement, and Forest shown in Fig. 9. The overall accuracy of the supervised classification method was about 89.99%. The area associated with each land use-land cover class has been calculated and C-factors were assigned Table no. 3. The Kappa coefficient was determined as 86.36 %.

Table 3: C factor Range and respective class

Class	Area in (km^2)	Area in percent	C factor range
Water	131.875	1.067	0.99
Agriculture	4391.024	35.515	0.71
Barren	2129.113	17.22	0.76
Settlement	1381.663	11.175	0.81
Forest	4330.16	35.023	0.71

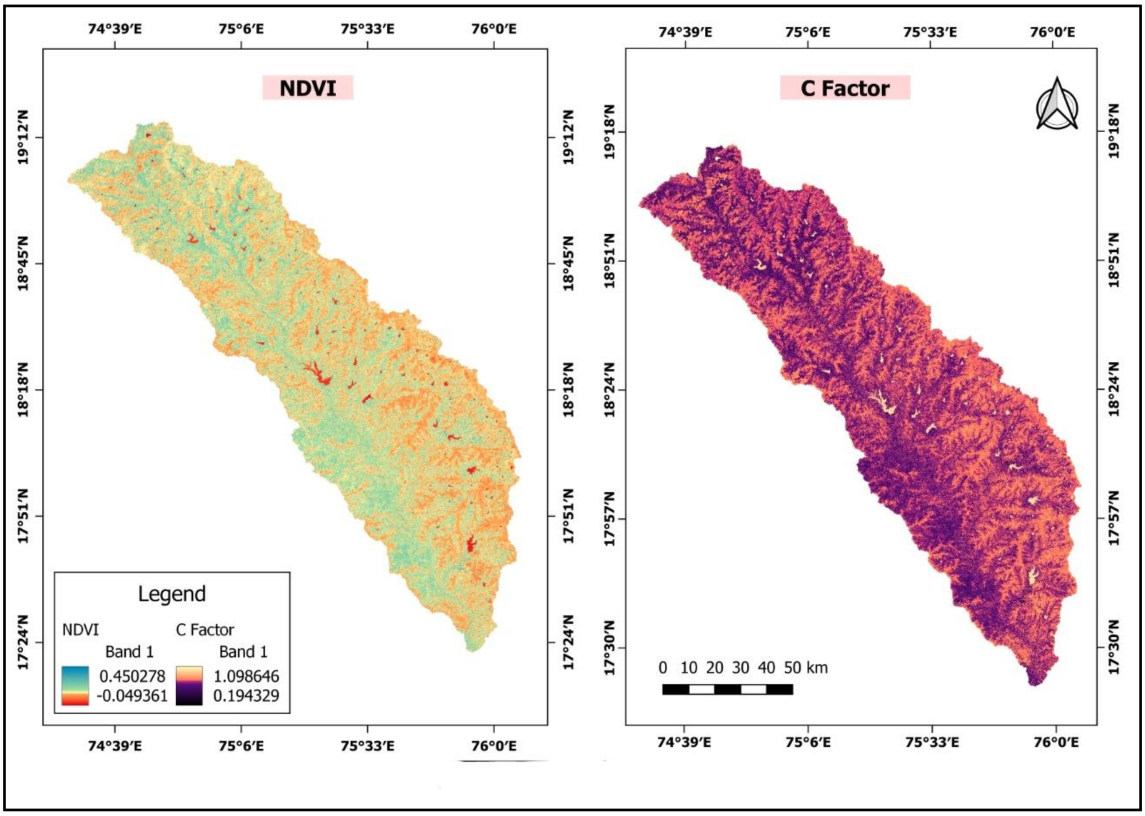

Figure 12. Spatial distribution of C factor and NDVI in the study area

4. Results and discussions

4.1 Rainfall-Runoff Erosivity Factor (R):

Many studies (Jain et al., 2001, Dabral et al., 2008) revealed that the soil erosion rate in the catchment is more sensitive to rainfall. Daily rainfall is a better indicator of variation in the rate of soil erosion to characterize the seasonal distribution of sediment yield. While the advantages of using annual rainfall include its ready availability, ease of computation, and greater regional consistency of the exponent (Shinde et al., 2010). The rainfall-runoff erosivity factor quantifies the effect of rainfall impact and alsoreflects the amount and rate of runoff likely to be associated with precipitation events. R-Factor range is **83.**

4.2 K- Factor (soil erodibility)

K-factor values are assigned based on respective soil types in the region to preparea soil erodibility map. K-Factor ranges from **0.206 to 0.245 i.e**., the Sina River watershed hasclay and clay loam-type of soil textures. The lower value of the K Factor is associated with the soils having low permeability low antecedent moisture content, etc.

4.3 LS Factor (Topographic factor)

The topographic factor signifies the effect of slope length and slope steepness on the soilloss process LS factor tor was designed by considering the flow accumulation and slope in percentage. LS-factor increases as it varies from **0.0001** to **0.818 as** the flow accumulationand slope increase.

4.4 Crop Management (C)

The plant cover factor C expresses the relation between erosion on bare soil anderosion under cultivation and is based on plant cover, production level, and cropping techniques. The crop management factor ranges from **0.19** in water bodies to **1.09** in agriculture **75** to **84.7.**

4.5 Conservation Practice Factor (P)

The erosion control practice factor (P-factor) is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope cultivation. TheP factor value assumes a **1.**

4.6 Soil loss

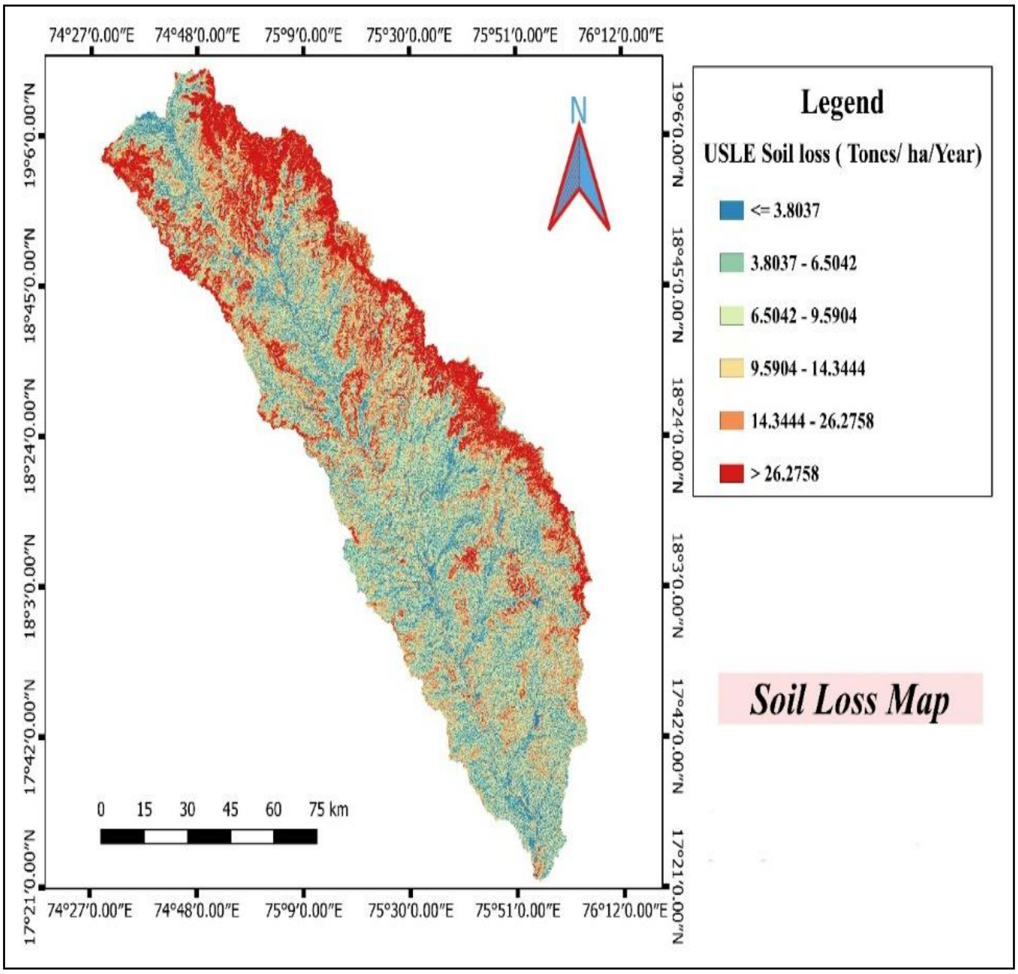

Figure 13. Spatial distribution Soil Loss Estimation Map of the Study area

Table no. 4 shows the soil loss with respect to the slope of each class. The given tableshows Barren land has the highest soil erosion occurs. Which is **9.79 tons/ha/yr.** and **58.29%.** Wate**r** bodies have the lowest soil erosion occurs. Which is **0.00 tons/ha/yr.** and **0.00 %.** The total soil was estimated as 14.37 tonnes/yr.

Table 4: Soil loss percentage in each class.

Class	**Soil loss tonnes/yr.**	**Soil loss percentage of class**
Water	0.00	0.00 %
Agriculture	3.45	34.69 %
Barren	9.79	58.29 %
Settlement	0.69	1.53 %
Forest	0.49	5.48 %
Total	14.37	100

Table 5: Soil loss with respective texture.

ID	Soil texture	Area (%)	Soil loss (tons/ha/yr.)	Soil Loss%
0.245	Clay loam	1.312	0.06	4.22 %
0.206	Clay	77.898	1.09	45.47%
0.227	Clay loam	20.573	4.58	50,13%
0.212	Clay	0.216	1.44	0.16%

The table no. 5 shows the Sina River watershed contains two types of soils i.e., Clay and clay loam as shownin the table. Clay soil acquired **78.114 %** of the total area and **2.53 tons/ha/yr.** Accordingto the soil texture properties size of the clay particle is < 0.002 mm therefore, soils with smaller particles have a larger surface area than those have larger particles, and a large surface area allows the soil to hold more water (1.75 - 2.50 inches. of water per foot of soil).The infiltration rate of clay soil is **1- 5 mm/hr.** On the other hand, clay loam soil acquired area of the watershed i.e., **20.789%,** and soil loss is **10.64 tons/ha/yr**. The size of the clay loam particle is slightly greater than 0.002 mm and the water holding capacity as the same as the clay particle i.e., 1.75- 2.50 inch of water per foot of soil and the infiltration rate is **5- 10 mm/hr.** Clay soil forms very tight layers that won't allow for drainage. Thus, after precipitation drainage issues most likely present themselves. This soil loss result with soil texture shows that the clay type soil has a very low percentage of soil loss as compared to clay loam.

4.6.1 Soil loss with Reclassify Soil loss

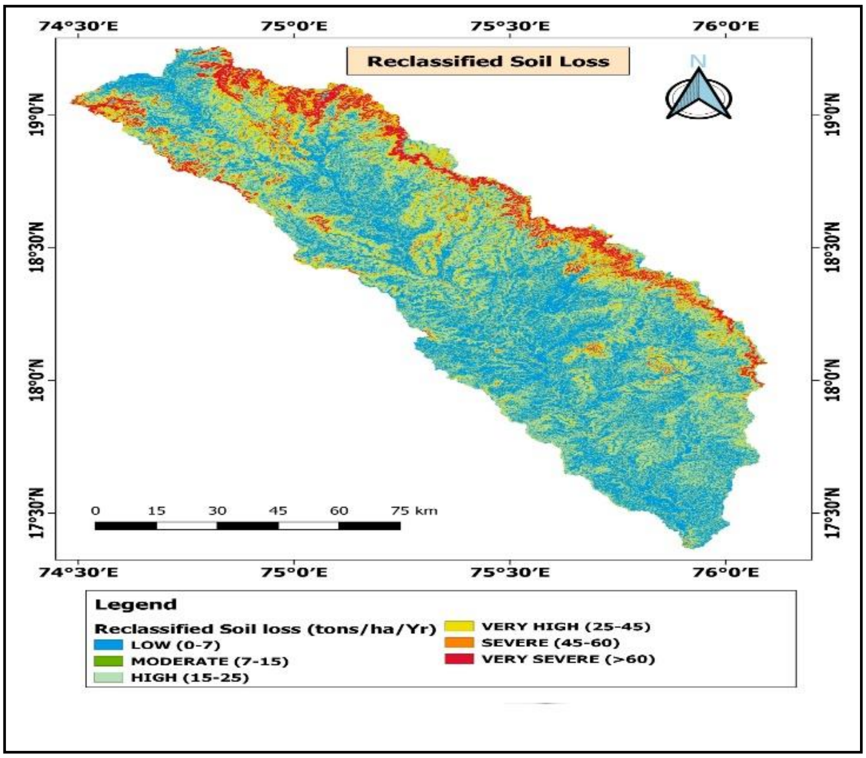

Figure 15. Reclassify Soil Loss Map of the Sina River watershed

Table 6: Soil Loss with Reclassify Soil Loss

Class	Area in Percent	Soil loss tons/ha/yr.	Soil loss percent
Low (0-7)	94.31%	1.02	57.46%
Moderate (7-15)	3.53%	10.06	21.18%
High (15-25)	1.25%	19.12	14.30%
Very high (25-45)	0.71%	32.37	13.80%
Severe (45-60)	0.12%	51.14	3.75%
Very severe (60 - >60)	0.05%	69.97	2.35%

The table shows the soil erosion risk class and proportion of soil loss in different regions of the watershed. **94.3 %** area has low soil erosion risk with **57.46 %** soilloss. The moderate erosion class has **21.18%** soil erosion in **3.53 %** area. There are three classes where soil erosion occurs very much i.e. very high erosion risk class soil lossis **32.37 tons/ha/yr**. and **13.80 %**. Severe erosion risk class soil loss is **51.14 tons/ha/yr.** and **3.75 %.** Very severe erosion risk class soil loss is **69.97 tons/ha/yr.** and **2.35%.** The very severe erosion risk class is the first highest soil erosion class shown in the table. Severe is the second-highest soil erosion class are shown in the table. The low erosion risk class is the lowest soil erosion class inthat soil loss is **1.02 tons/ha/yr.**

5. Summary & conclusions

This project focuses on the Sina River Basin in the Ahmednagar District of Maharashtra State, with a total area of 12372 km2. The basin's outlet is located in Solapur district. The Sina basin's geographical coordinates are approximately 17° 22’43’’N, 19°09’09’’E, with an elevation of 649 m above mean sea level. The latitudinal and longitudinal extent of the study area ranges from 74°43’11’’ N to 75°53’48’’ E. To conduct supervised image classification, the SNAP Tool was employed, utilizing a CARTOSAT-1 file downloaded from Bhuvan.nrsc with a resolution of 2.5m. For land use/land cover (LULC) analysis, a Landsat 8 image with a resolution of 30 m was used, and all LULC operations were performed using the Snap desktop tool.

In terms of conclusions, the estimation of soil loss plays a pivotal role in determining sediment yield in watershed and catchment-level studies. Within the 12372 km2 total area, the low erosion class covers 94.31% of the area, with a soil loss of 1.02 tons/ha/yr, contributing to 57.46% of the total soil loss. The moderate erosion class covers 3.53% of the total area, with a soil loss of 10.06 tons/ha/yr, representing 21.18% of the total soil loss. Furthermore, the high erosion class encompasses 1.25% of the total area, experiencing a soil loss of 19.12 tons/ha/yr, accounting for 14.30% of the total soil loss. The very high erosion class occupies 0.71% of the total area, with a soil loss of 32.37 tons/ha/yr, contributing to 13.80% of the total soil loss. The severe erosion class encompasses 0.12% of the total area, with a soil loss of 51.14 tons/ha/yr, representing 3.75% of the total soil loss. Finally, the very severe erosion class covers 0.05% of the total area, experiencing a soil loss of 69.97 tons/ha/yr, accounting for 2.35% of the total soil loss. Effective Soil and Water Conservation practices are necessary for the severe and very severe erosion classes to prevent future calamities.

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