Estimation of Soil Erosion by RUSLE Model Using Geoinformatics Techniques: A Case Study of Mulshi Reservoir Catchment, Pune District, Western Maharashtra

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Abstract: Soil erosion is a significant and persistent environmental issue in the highlands of western ghat Maharashtra. To make matter worse, the majority of the dams in this region run the risk of reservoir sedimentation, which is a serious concern. In fact, the surface overland flow seasonal rainfall is increased in this region due to the presence of the western ghat. This research was being conducted on the Mulshi reservoir catchment area, Pune district of western Maharashtra, having an area of 250.25 km^2. This study used high-resolution satellite images to assess the average annual soil erosion. The erosion rate was calculated using the five factors of the RUSLE model: rainfall erosivity, soil erodibility, slope length and steepness, cover and management, and conservation practice factor. These five parameters were analysed using ArcGIS software version 10.8. The annual average soil loss in the study area ranges from 0 to 577.90 t/ha/yr, with an overall average of 16.3 t/ha/yr. The erosion levels were categorized into six classifications: negligible, very low, low, moderate, high, and very high, based on the severity of erosion. The high values of soil erosion (>20 t/ha/yr) are found on the highlands due to the high slope and bare lands; however, low values (<10 t/ha/yr) are found in the region of valleys and dense vegetation.

Keywords: Mulshi, Soil erosion, RUSLE, Land use & Land cover, Geoinformatics, GIS, Reservoir sedimentation, Western Maharashtra.

1. Introduction

There has been a long-standing interest in soil erosion over the decades, since it causes soil particles to separate and move from upper soil layers, lowering soil quality and decreasing the productivity of the impacted areas (Ashiagbor et al., 2013). Soil erosion is a major environmental issue worldwide, resulting from both natural and human activities (Eng, 2001). It leads to the loss of topsoil, which reduces the fertility of agricultural land (Thapa, 2020).

Soil erosion is a significant global issue that leads to nutrient depletion, deterioration of water quality, and the accumulation of sand in water bodies (Ghosh et al., 2023). Approximately one-third of the land utilised for agriculture, or roughly one-sixth of the world's geographical area, has historically experienced soil degradation. The majority of this harm was brought by wind and water erosion, but biological, chemical, and physical processes can also produce various types of soil degradation (Hurni et al., 2008). In India, approximately 29.46% of the land area is susceptible to slight erosion, whereas 3.17% faces severe erosion, potentially losing 21 tonnes of soil per hectare annually and nine out of twenty districts most vulnerable to soil loss are in the state of Assam (R. Raj et al., 2024). Due to the geographical conditions like high slope, high rainfall, and soil texture, which have a significant contribution to the potential soil loss. Likewise, high-intensity rainfall received on hilly areas of western Maharashtra produces a higher amount of soil loss as it has some similar type of the geographical conditions due to the presence of western ghat (Kurothe et al., 2001).

Due to the severe impacts of soil erosion, numerous researchers have focused on this issue, employing GIS and various models to assess soil loss. As a result, several models with different complexities have been developed, including the universal soil loss equation (USLE) (Wischmeier and Smith, 1978), the revised universal soil loss equation (RUSLE) (Renard et al., 1997), and the modified universal soil loss equation (MUSLE) (Williams, 1975). Among these, the RUSLE is the most commonly used model for estimating soil erosion, as it incorporates factors such as rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices (Ghosal & Das Bhattacharya, 2020).

The RUSLE model has been employed in this study, along with GIS environments to evaluate the soil erosion of the Mulshi reservoir catchment area, a sub-basin of the Mula river, Pune district, western Maharashtra, India. This study aims to compute the soil erosion status of the study area in tonnes/hectare/year (t/ha/yr) and to create a spatial erosion map using the RUSLE and geoinformatics techniques.

2. Materials and Methods

2.1 Description of Study Area

Current study is based on the catchment area of Mulshi reservoir, located in the Mulshi taluka of Pune district. The total geographical area is 250.25 square kilometres and has latitudinal extend from 18°25′18′′N to 18°39′59′′N and longitudinal extend from 73°20′25′′E to 73°31′18′′E. The climate of the study area is of the tropical monsoonal type, characterised by the well-defined seasons like summer, rainy, and winter. The research area’s annual average rainfall varies between 2654 mm and 3747 mm. Moreover, the researched area drainage basin (catchment) faces east and drains into the Mulshi lake, the biggest reservoir of the Mula river system. In addition, the study region has an altitude between 495 and 1088 meters above mean sea level. The catchment depicts a typical Mulshi reservoir landscape generated by SWAT (Soil & Water Assessment Tool) on the ArcGIS version 10.8 as referred to (figure 1).

2.2 Data Source

Many spatial databases obtained from diverse sources were employed in the study; Table 1 lists the database and the sources from which they sourced.

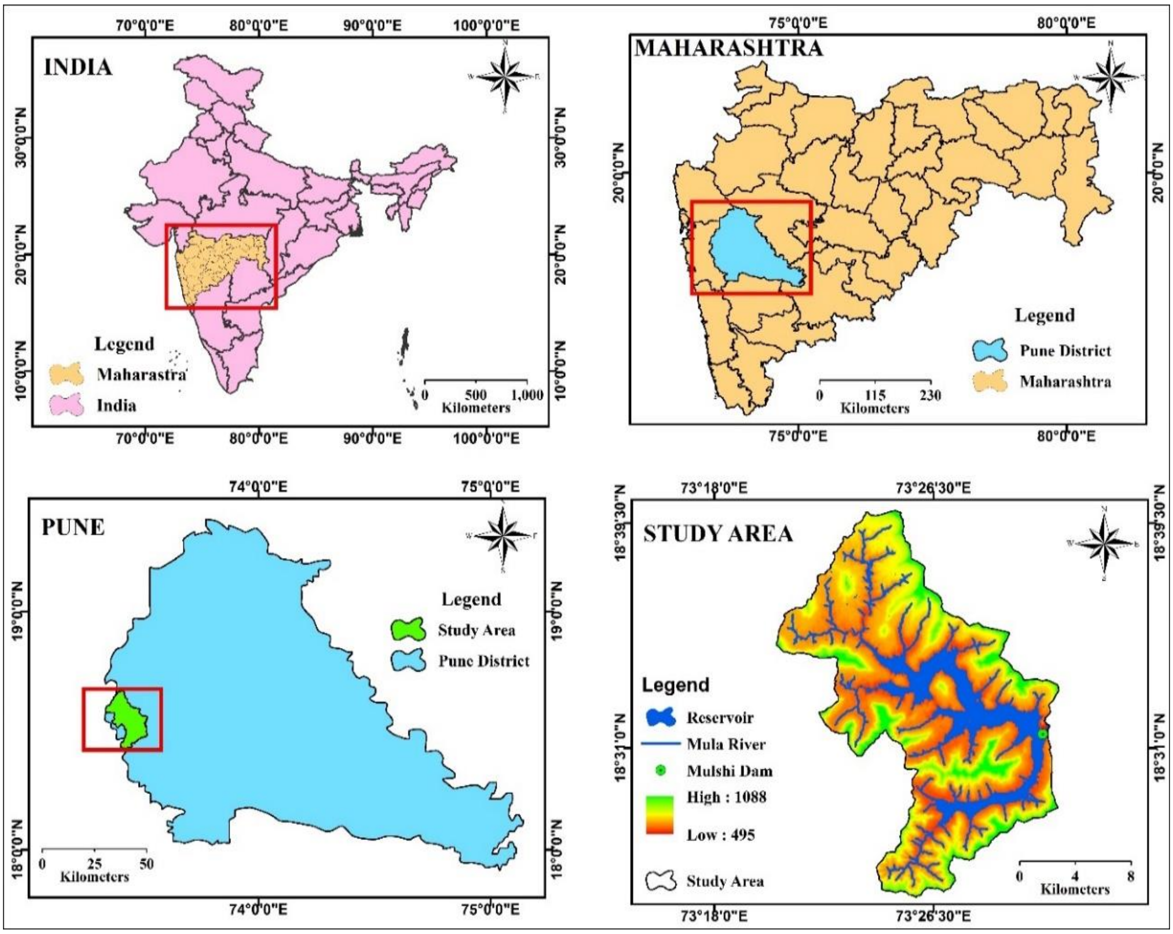

Figure 1. Location map

Parameter	Material	Resolution/ data type	Year	Data source
Rainfall data	Annual rainfall data	0.25×0.25 grided data	2011-2022	IMD (India meteorological department) data https://www.imdpune.gov.in/cmpg/griddata/rainfall_25_netcdf.html
Soil data	Field work data	Primary data	2024	Soil sampling
Topographical data	Dem (digital elevation model) data	12.5 meters	2023	Alos palsar data https://vertex.daac.asf.alaska.edu/
Land use land cover data	Sentinel-2	10-60 meters	2022	Copernicus open access hub https://scihub.copernicus.eu/maintenance.html#/home

Table 1. Data base

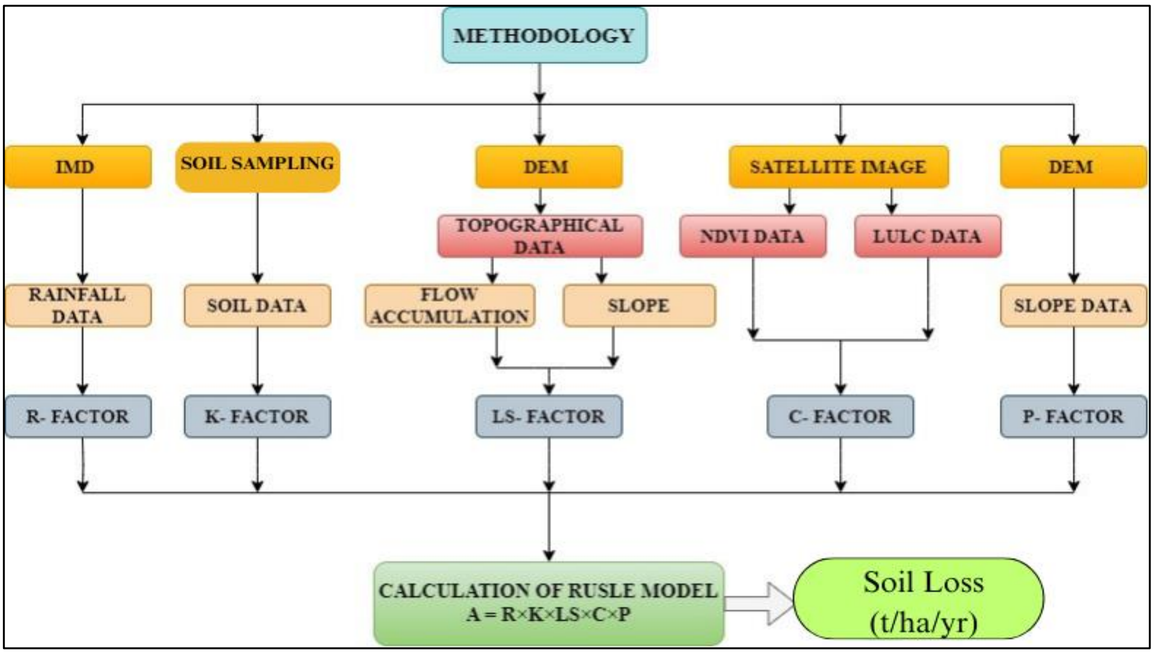

Figure 2. Methodology

*NDVI- Normalized Difference Vegetation Index; LULC- Land Use Land Cover; DEM- Digital Elevation Model

2.3 Methodology

In this study, soil loss in the Mulshi reservoir catchment area was estimated using the RUSLE method inside a GIS framework. The effects of topography, soil, precipitation, land cover & land use, and support methods on soil erosion are represented by the RUSLE variables (figure 2). After multiplying all the variables of the RUSLE model, we will get the soil erosion in t/ha/yr expressed by an equation (1).

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

Where, A denotes soil loss measured in tonnes/hectare/year, R signifies the rainfall erosivity expressed in megajoules/millimetre/hectare/hour/year, K represents the soil erodibility factor in tons/hour/ megajoule/millimetre, LS indicates the slope-length and slope steepness factor (which is dimensionless), C refers to the cover management factor (also dimensionless), and P stands for the conservation practices factor (dimensionless as well).

2.3.1 Calculations of RUSLE factors

(a) Rainfall Erosivity (R)

The rainfall erosivity factor refers to the capacity of rainfall to influence or displace soil particles depending on the amount of precipitation. However, rainfall that is heavy and falls quickly can destroy soil particles more quickly than typical rainfall. The formula utilised in this work to calculate the rainfall erosivity for each zone in India is given by Singh et al. (1981), which is expressed by equation (2).

$$R = 79 + 0.363 \times AAR \quad (2)$$

Where, AAR is the annual average rainfall in mm. Numerous studies have been conducted using this method in various locations of India (Karthick & Periyasamy, 2017; Parveen & Kumar, 2012). The R-factor is evaluated based on the precipitation data taken from IMD over a period of 12 years. In this study, IDW interpolation technique was used to compute spatial variability in the rainfall erosivity of Mulshi reservoir catchment area, which is referred to in (figure 3).

The rainfall erosivity map indicates that the rainfall erosivity has a value between low and high, 1042 and 1439, respectively. In the western portion of the reservoir, greater rainfall values indicate higher rainfall erosivity, and the eastern part of the reservoir is less vulnerable to rainfall erosivity because of low rainfall values, as referred to in (figure 4)

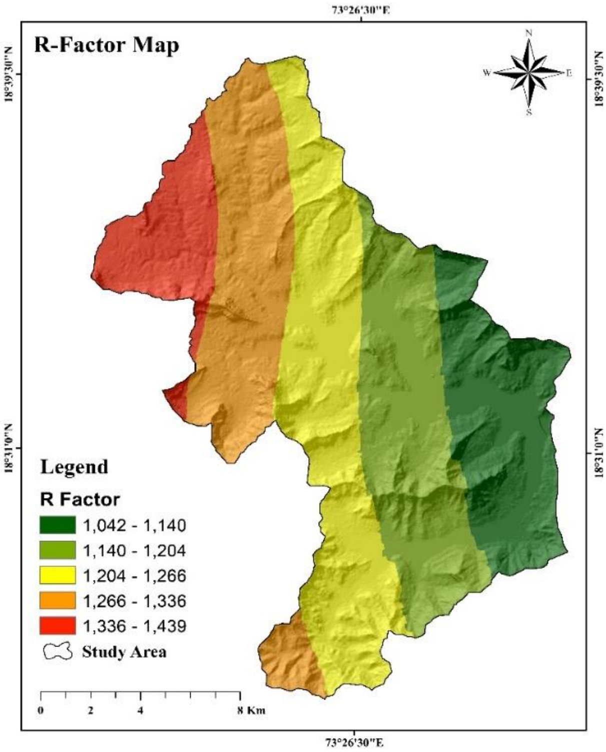

Figure 3. Rainfall erosivity map

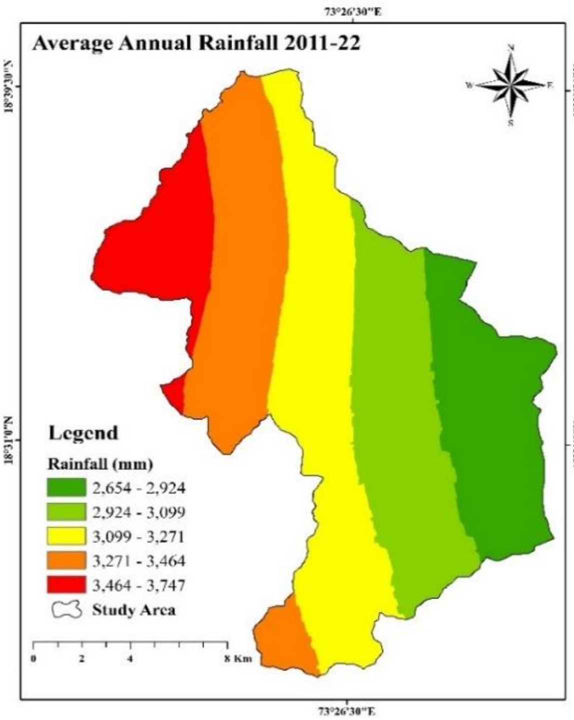

Figure 4. Rainfall map

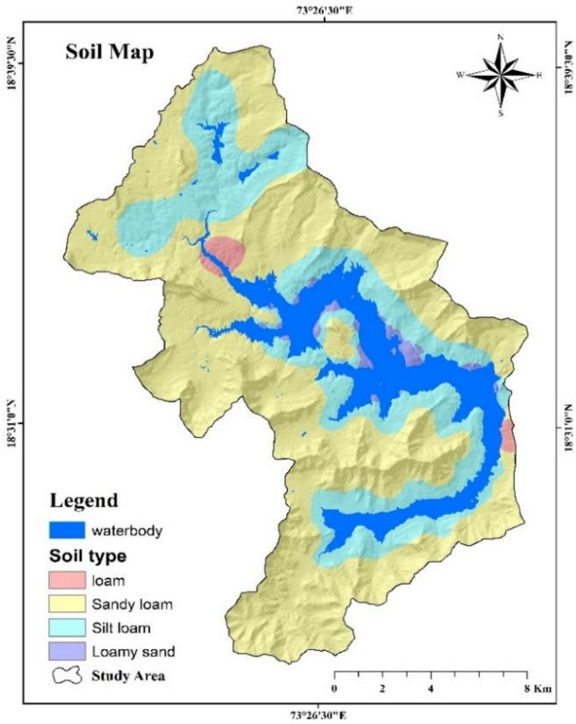

Figure 5. Soil type map

(b) Soil Erodibility (K)

Soil erodibility refers to the ability of soil to resist the impact of raindrops or surface runoff. This factor is assessed based on four key parameters: the percentage of organic matter, as well as the proportion of sand, silt, and clay percent in the soil (Djoukbala et al., 2019).

Soil samples were collected from 52 different locations with the help of a core tube and hammer within the study area and measured in a soil lab for the following properties, including percentage of silt, sand, clay, and organic matter, and it was found that there are majorly four soil types: sandy loamy soil, silt loam soil, loam soil, and the last one is loamy sand soil (figure 5). In this study, we have used this soil data to calculate the required parameter over the whole Mulshi reservoir catchment area.

Soil erodibility was determined using the following formulas given by Williams et al. (1995) as represented in equation (3).

Where, SIL, SAN, and CLA indicate the proportions of silt, sand, and clay, respectively, whereas OC refers to the organic carbon content. In this research, the field data base (table 2) was used to determine Fcsand using equation (4), Fcl-si using equation (5), Forgc using equation (6), and Fhisand using equation (7) in order of calculation. The obtained values from all of these computations were multiplied to determine the k-factor values. The k-factor is associated with four different values based on the types of soil. Sandy loam soil has a lower value of 0.15, indicating lower susceptibility to soil loss compared to silt loam soil, which has a value of 0.19, as shown in (figure 6).

$$K = Fcsand \times Fcl-si \times Forgc \times Fhisand \quad (3)$$

Where,

$$F\,csand = \left[0.2 + 0.3 \times exp\left(-0.256 \times SAN\left(1 - \frac{SIL}{100}\right)\right)\right] \quad (4)$$

$$Fcl-si = \left[\frac{SIL}{CLA + SIL}\right]^{0.3} \quad (5)$$

$$Forgc = \left[1 - \frac{0.25\,OC}{OC + exp(3.72 - 2.95\,OC)}\right] \quad (6)$$

$$Fhisand = \left[1 - \frac{0.7\left(1 - \frac{SAN}{100}\right)}{\left(1 - \frac{SAN}{100}\right) + exp\left[-5.51 + 22.9\left(1 - \frac{SAN}{100}\right)\right]}\right] \quad (7)$$

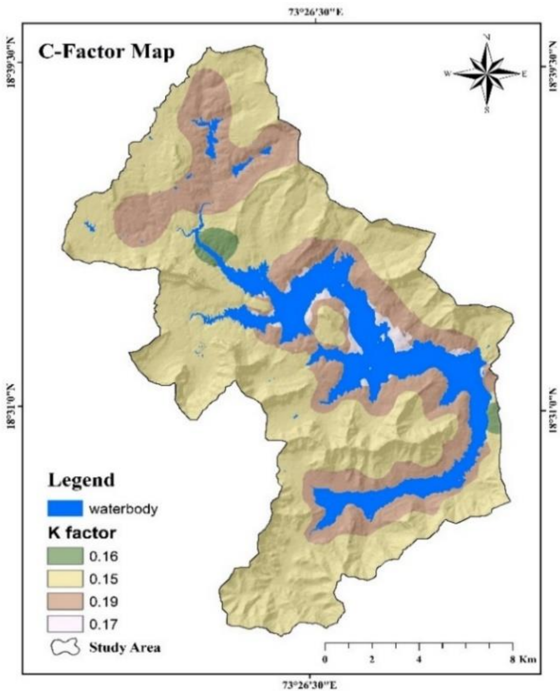

Figure 6. Soil erodibility map

Table 2. K- factor calculation

Soil type	Sand %	Silt %	Clay %	OC %	Fcsand	Fcl-si	Forg	Fhisand	K factor
Loam	46.86	47.61	3.08	1.41	0.2	0.98	0.83	0.99	0.16
Sandy loam	57.05	38.33	2.24	1.5	0.2	0.98	0.81	0.99	0.15
Silt loam	44.77	51.3	3.02	0.6	0.2	0.98	0.98	0.99	0.19
Loamy sand	73.65	25.12	0.76	0.18	0.2	0.99	0.99	0.90	0.17

(c) Slope Length and Slope Steepness (LS)

The characteristics of slope length and steepness are influenced by the combined effects of the slope gradient factor (S) and the slope-length factor (L). The factor of slope length is essential in modelling soil erosion and determining the transport potential of surface runoff. When the length of a slope increases, it indicates a steeper incline and results in higher soil loss per unit area.

The integrated LS factor was calculated utilizing DEM data for the Mulshi reservoir catchment, using the ArcGIS, as formula proposed by Simms et al. (2003) which is expressed by equation (8).

$$LS = \left(Flow\ Accumulation \times \frac{Cell\ Size}{22.13}\right)^{0.4} \times \left(\frac{Sin\ Slope}{0.0896}\right)^{1.3} \quad (8)$$

where, cell size is the spatial resolution of input data (DEM), which is 12.5 meters in this case and flow accumulation represents the cumulative upslope area that contributes to a particular cell. The Mulshi reservoir catchment area, LS-factor, shows higher values as it is surrounded by the mountains from all sides, which is a major factor in soil loss. Apart from the reservoir, the majority of the region exhibits high LS-factor values, which vary from 0 to 114.67 and indicate a high soil loss risk (figure 7)

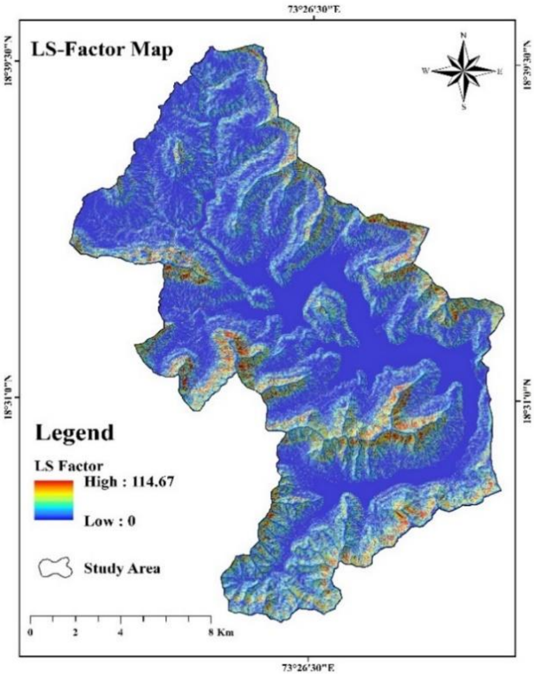

Figure 7. Slope length and Steepness Map

d) Cover & Management Factor (C)

The process of water erosion is significantly slowed down by vegetation, so it is regarded as a significant factor influencing the risk of soil erosion (Kalman, 1967).

In this study, NDVI data (2022) was obtained from a satellite image (sentinel-2) which having a 10 meters spatial resolution. Its values span from -1 to +1, with values below 0.1 signifying barren areas such as sand, snow, or rock, values between 0.2 and 0.5 indicating sparse vegetation like shrubs and grassland, and values between 0.6 and 0.8 indicating temperate and tropical rainforest. In order to calculate C-factor, firstly, NDVI was calculated using the equation (9) to get detailed information about the vegetation. After the NDVI calculation using Durigon et al. (2014) equation (10) got the required values for C-factor.

$$NDVI = \frac{(NIB - RSB)}{(NIB + RSB)} \quad (9)$$

$$C = \frac{(-NDVI + 1)}{2} \quad (10)$$

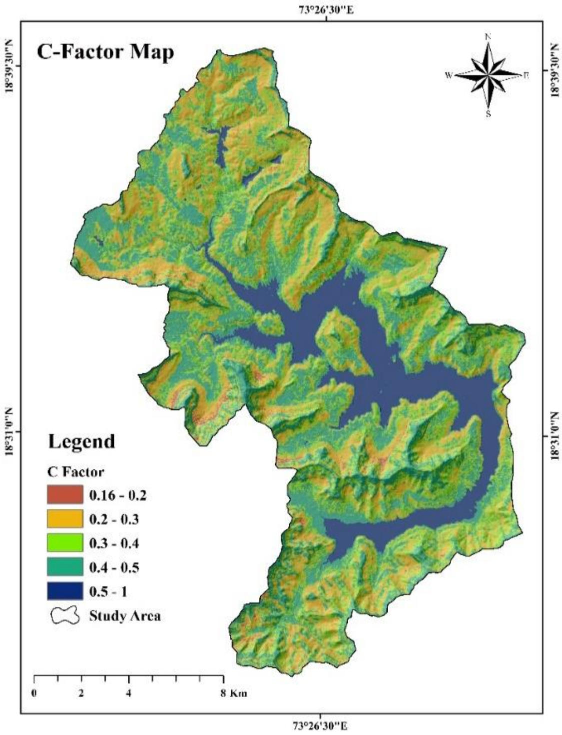

Figure 8. Cover and management map

Where, NIB- near infrared band (Band 8); RSB- red spectral band (Band 4). Numerous research studies have suggested various methods for calculating the cover management factor by utilising the NDVI to evaluate soil loss (Saha, 2018). High C-factor values indicate increased susceptibility to erosion. The presence of additional plants serves as a barrier against eroded soil, typically reducing the pace of soil erosion. High C-factor values shows that the region is more prone to soil loss (figure 8), representing values ranging from 0.16 to 1

(e) Conservation practice factor (P):

The conservation practice factor aimed at minimising soil erosion is reflected in the support practice factors. These practices encompass terracing, strip cropping, and contour ploughing (Marondedze & Schütt, 2020).

The value of the P factor falls within the range of 0 and 1, where 0 denotes the conservation practices have maximum effectiveness and 1 denotes the absence of any support practices, as shown in (figure 9). As Mulshi reservoir catchment is a part of western ghat, building terraces that closely resemble farmland is a method of conservation farming that is used in farming operations on slopy agriculture land.

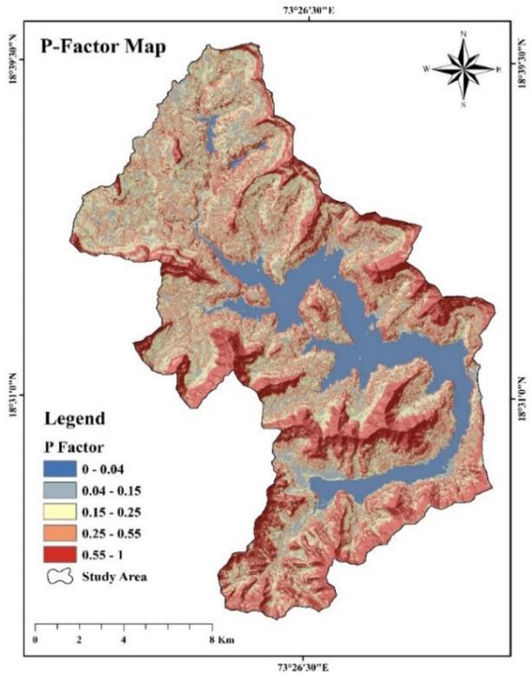

Figure 9. Conservation practice factor map

For the calculation of the P-factor the DEM data was used to prepare slope% map, and it was merged with LULC data using overlay analysis in ArcGIS. The LULC data generated by supervised classification in the ArcGIS 10.8 using sentinel 2 (2022) satellite image (figure 10). The P-factor values were then allocated to the merged classes of the different slope ranges percent with respect to the LULC types (Table 3).

3. Assessment of soil loss

The soil loss map (figure 11.) was generated using ArcGIS, by multiplying each RUSLE factors using geoinformatics techniques. The research area's annual soil loss ranges from 0 to 577.90 t/ha/yr, with an average annual soil loss of 16.3 t/ha/yr. Based on the degree of erosion, the research region is further divided into six classes: negligible, low, very low, high, and very high, and moderate. Table 4 illustrates the percentages of the research area that are subject to soil loss based on severity: 37.88% as negligible, 18.6% as very low, 10.76% as low, 10.57% as moderate, 11.48% as high, and 10.71% as very high (Table 4). The soil loss map further reveals that areas characterized by barren land and steep highlands are particularly vulnerable to soil erosion, as depicted in (figure 12).

Table 3. Data of LULC and Slope%

LULC Type	Slope%	P- Factor values
Vegetation	0 - 5	0.1
	5 – 10	0.13
	10 – 20	0.15
	20 – 30	0.2
	30 – 50	0.4
	> 50	0.75
Barren land	0 – 5	0.25
	5 – 10	0.35
	10 – 20	0.45
	20 – 30	0.55
	30 – 50	0.75
	> 50	1
Agriculture	0 – 5	0.1
	5 – 10	0.13
	10 – 20	0.15
	20 – 30	0.2
	30 – 50	0.4
	> 50	0.75
Build Up Area	0 – 100	0.05
Waterbody	0 – 100	0

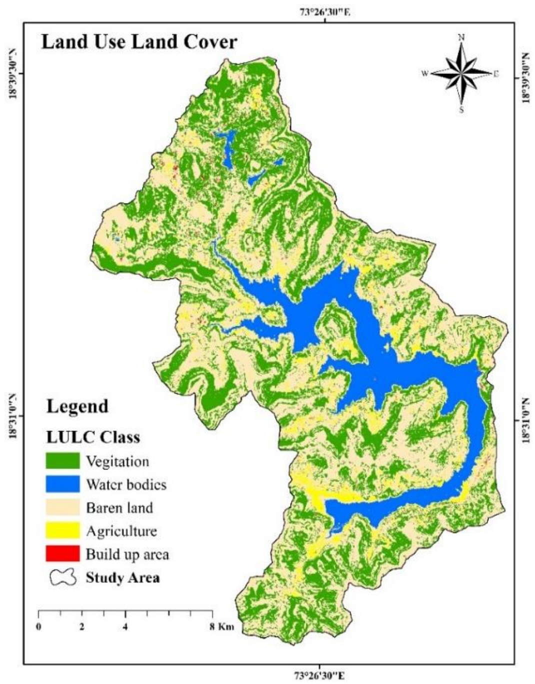

Figure 10. Land use & Land cover map

Table 4. Soil loss classes

Class	Values (t/ha/yr.)	Area%
Negligible	<1	37.88
Very Low	1-5	18.6
Low	5-10	10.76
Moderate	10-20	10.57
High	20-50	11.48
Very High	>50	10.71

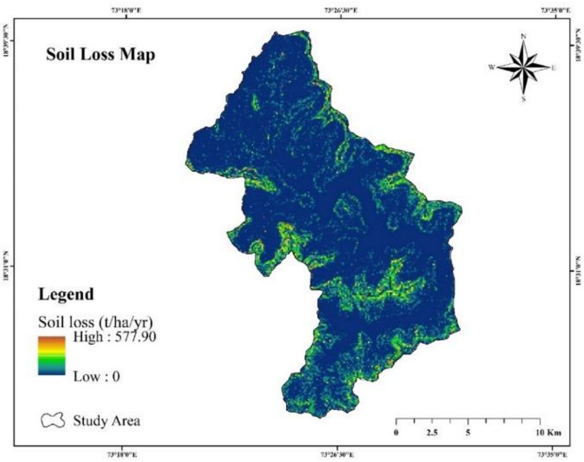

Figure 11. Average annual Soil loss map

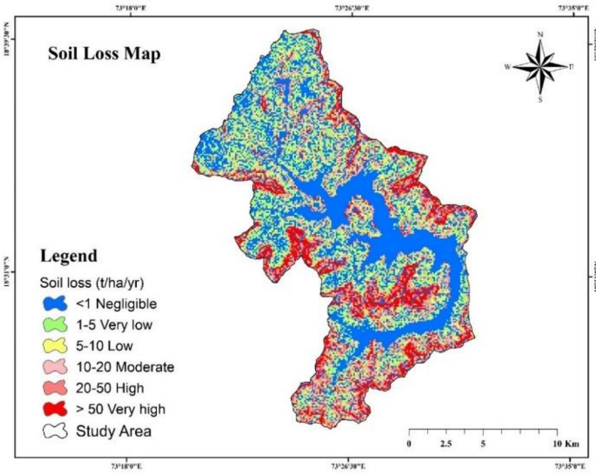

Figure 12. Soil loss classification map

4. Discussion

In the present study, we utilize ArcGIS (version 10.8) to evaluate soil erosion within the catchment area of the Mulshi reservoir, employing the RUSLE model. Our findings indicate a significant range of soil loss, varying from 0 to 577.90 t/ha/yr. Most of the soil loss is due to the bare land and slopy highlands, which may result in many hazardous problems such as loss of productive soil and sedimentation in the Mulshi reservoir. As there is a dam on the reservoir, it will collect all the eroded soil, and as a result, the overall water capacity of the reservoir will reduce.

The goal of our research was, evaluation of the soil erosion status of the study region in t/ha/yr and to create a spatial erosion map using RUSLE model and geoinformatics techniques. From (Table 4) we can see that 22.19% of the region is classified in the high and very high erosion risk categories: if the precautionary steps are not followed, it will lead to hazardous issues in the upcoming future. Numerous studies have been carried out on this issue; for example, Mahabaleshwara & Nagabhushan (2014) found that the accumulation of eroded soil (sediment) at the catchment outlet over time leads to an expansion of floodplain areas along the river, resulting in obstruction under bridges and culverts.

Based on our findings, it is evident that the majority of erosion originates from steep highlands and barren areas. Therefore, we should focus our efforts on implementing protective measures in these specific locations. This could involve actions such as maintaining a robust, perennial plant cover, using mulch, and planting cover crops like winter rye in vegetable gardens. Also, in order to provide a temporary vegetative cover, we can think about using grasses, grains, legumes, and various other plant species should be considered. Utilising broken stones, wooden pieces, and similar materials in high-traffic areas where flora is difficult to manage and develop is an additional option.

Furthermore, two issues may compromise the results of this study. First, it is not able to consider soil loss from mass wasting events and gully erosion, and second, to predict the potential soil loss (Benavidez et al., 2018); however, in this study, we are not predicting the potential soil loss. High-quality satellite image data has been used in this study, so the values and spatial maps of the erosion that we have obtained are compelling enough to use it for soil erosion conservation purposes.

5. Conclusions

RUSLE serves as an effective methodology for quantifying the annual average soil loss. Using a variety of geoinformatics tools, several thematic layers were created for the study area in order to determine the outcome. The RUSLE factors, which include rainfall erosivity, soil erodibility, slope length and steepness, cover and management practices, and conservation practice factors, were systematically mapped. This research aims to provide a thorough understanding of soil loss within the Mulshi reservoir catchment area, and the key findings are as follows:

- The study area exhibits an annual average soil loss that varies between 0 and 577.90, with an average annual soil loss calculated at16.3 t/ha/yr.
- 37.88% out of the total area comes under negligible (<1 t/ha/yr) amount soil erosion was found on the valley of the catchment, mostly in the Mulshi Reservoir and the river streams that feed the reservoir.
- Areas covered with vegetation have a very low and low danger of soil erosion (1 to 10 t/ha/yr), which represents for 29.36% of the overall area since the soil particles there are still attached to the surrounding vegetation.
- On the contrary, barren ground and the Slopy Highlands have a very high amount of soil erosion (20 to >50 t/ha/yr), which is about 22.19% of the total area and it is responsible for the majority of soil loss.
- Moderate amount of soil erosion (10 to 20 t/ha/yr) were seen in between the valley and hilltop of the mountain ranges, which accounts for 10.57% of the total area.

If the current pace of soil loss from the highlands persists, it could result in soil degradation and sedimentation in the reservoir, making it unusable for various purposes such as agriculture, electricity generation, and drinking water supply. Different kinds of water and soil conservation measures are required as soon as feasible to address these issues. To improve the quality of result we have used high-resolution satellite images, which has 12.5-meter-high resolution data. Future research may be enhanced by incorporating local field-based observations data at ultra-high spatial resolutions than those utilized in the current study

Conflict of interest

Author confirms that there is no conflict of interest

References

Ashiagbor G., E. K. Forkuo and R. Aabeyir (2013). Modeling soil erosion using RUSLE and GIS tools. *International Journal of Remote Sensing & Geoscience (IJRSG)*, *2*(4). www.ijrsg.com

Benavidez R., B. Jackson, D. Maxwell K. Norton (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): With a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences*, *22*(11), 6059–6086. https://doi.org/10.5194/hess-22-6059-2018

Djoukbala O., M. Hasbaia, O. Benselama and M. Mazour (2019). Comparison of the erosion prediction models from USLE, MUSLE and RUSLE in a Mediterranean watershed, case of Wadi Gazouana (N-W of Algeria). *Modeling Earth Systems and Environment*,*5*(2),725–743. https://doi.org/10.1007/s40808-018-0562-6

Durigon V. L., D. F. Carvalho, M. A. H. Antunes, P. T. S. Oliveira and M. M. Fernandes (2014). NDVI time series for monitoring RUSLE cover management factor in a tropical watershed. *International Journal of RemoteSensing*,*35*(2),441–453. https://doi.org/10.1080/01431161.2013.871081

Eng M. (2001). Application of RUSLE model on global soil erosion estimate Thai Nam PHAM1, Dawen YANG2, Shinjiro KANAE3, Taikan OKI4, and Katumi musiake5 1 Student Member. In *Annual Journal of Hydraulic Engineering* (Vol. 45).

Ghosal K. and S. D. Bhattacharya (2020). A Review of RUSLE Model. In *Journal of the Indian Society of Remote Sensing* (Vol. 48, Issue 4, pp.689–707). Springer.https://doi.org/10.1007/s12524-019-01097-0

Ghosh A., S. Rakshit, S. Tikle., S. Das., U. Chatterjee, C. B. Pande, A. Alataway, A. A. Al-Othman, A. Z. Dewidar and M. A. Mattar (2023). Integration of GIS and Remote Sensing with RUSLE Model for Estimation of SoilErosion.*Land*,*12*(1). https://doi.org/10.3390/land12010116

Hurni H., K. Herweg, B. Portner and H. Liniger (2008.). *Chapter 4 Soil Erosion and Conservation in Global Agriculture*.

Kalman R (1967) Essai d'évaluation pour le pré-Rif du facteur couver- ture végétale de la formule de Wischmeier de calcul de l'érosion. Rapport Rabat 1–12.

Karthick P. and R. Periyasamy (2017). Estimation of soil erosion vulnerability in Perambalur Taluk, Tamilnadu using revised universal soil loss equation model (RUSLE) and geo information technology. www.isca.in

Kurothe R. S., O. Challa, J. S. Sharma and M. Velayatham (2001) Assessment of soil erosion in Maharashtra. *Indian J. Soil Cons.* 29(2): 133-137.

Mahabaleshwara H. and H. M. Nagabhushan (2014). A study on soil erosion and its impacts on floods and sedimentation.*IJRET: International Journal of Research in Engineering and Technology*. http://www.ijret.org

Marondedze A. and S. Brigitta (2020). Assessment of Soil Erosion Using the RUSLE Model for the Epworth District of the Harare Metropolitan Province, Zimbabwe. Sustainability. 12. 8531. 10.3390/su12208531.

Parveen R and U. Kumar (2012). Integrated Approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for soil loss risk assessment in Upper South Koel Basin Jharkhand. Journal of Geographic Information System 4: 588–96.

Raj R., M. Saharia and S. Chakma (2024). Geospatial modeling and mapping of soil erosion in India. *CATENA,107996.https://doi.org/10.1016/j.catena.2024.107996*

Renard K., G. Foster, G. Weesies, D. McCool and D. Yoder (1997). Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). US Government Printing Office, Washington, DC.

Saha A. (2018). GIS Based Soil Erosion Estimation Using Rusle Model: A Case Study of Upper Kangsabati Watershed, West Bengal, India. *International Journal of Environmental Sciences & Natural Resources*, *13*(5). https://doi.org/10.19080/ijesnr.2018.13.555871.

Simms A. D., C. D. Woodroffe and B. G. Jones (2003) Application of RUSLE for erosion management in a costal catchment, Southern NSW. In: Proceedings of the international congress on modeling and simulation: integrative modeling of biophysical, social and eco-nomic systems for resource management solutions, Australia, pp 678–683.

Singh G, S. Chandra and R. Babu (1981). Soil Loss and Pre-diction Research in India. Bulletin No T-12/D9 Central Soil and Water Conservation Research Training Institute Dehradun.

Thapa P. (2020). Spatial estimation of soil erosion using RUSLE modeling: a case study of Dolakha district, Nepal.*EnvironmentalSystemsResearch*,*9*(1).https://doi.org/10.1186/s40068-020-00177-2.

Williams J. R. (1975). Sediment-yield prediction with Universal Equation using runoff energy factor, present and prospective technology for predicting sediment yield and sources. ARS-S-40. Brooksville, FL: US Department of Agriculture, Agricultural Research Service, 244–252.

Williams J. R. (1995). The EPIC model. In V. P. Singh (Ed.), Computer models of watershed hydrology (pp. 909-1000). Water Resouces publication, Highlands Ranck, CO.

Wischmeier W. H. and D. D. Smith (1978). Predicting Rainfall Erosion Losses: a Guide to Conservation Planning. Agriculture Handbook 282. USDA-ARS, USA