Advanced Geospatial Modelling of Soil Erosion Using RUSLE and Multi-Source GIS Data Integration: A case study of Kalyani River Watershed Uttar Pradesh

Abstract

Soil erosion significantly impacts environmental sustainability, agriculture, and water quality. This study examines soil erosion in the Kalyani River within the Nindoora and Fatehpur blocks of Barabanki District, Uttar Pradesh, India, where seasonal fluctuations and steep banks exacerbate the issue.The region experiences severe soil degradation due to uncontrolled land use, deforestation, over-cultivation, overgrazing, and biomass exploitation driven by population growth. To address this, GIS and Remote Sensing technologies were utilized, employing the Revised Universal Soil Loss Equation (RUSLE) model to identify erosion-prone areas. The RUSLE model involves calculating parameters such as the runoff-rainfall erosivity factor (R), soil erodibility factor (K), topographic factor (LS), cropping management factor (C), and support practice factor (P). Layer-wise thematic maps of each factor were generated using a GIS platform, incorporating various data sources and preparation methods. The study's results indicate that the annual average soil loss within the watershed is approximately 13 t/ha/yr (metric tons per hectare per year). This quantification and mapping of soil loss provide crucial insights for developing sustainable soil conservation and management strategies in the region.

Keywords: RUSLE, Remote sensing, GIS, Soil erosion, ArcGIS

1. Introduction

Soil is an important non-renewable and useful resource that supports 95% of food production through plant growth and agriculture (FAO, 2015a, 2015b). Sustainable agriculture depends on soil quality (Acton and Gregorich, 1995), but overuse of land has degraded soils, increased soil erosion, lost biodiversity, reduced productivity, and ultimately ecosystem damage (Pimentel and Kounang, 1998; Pimentel et al., 1995;), (Ganasri and Ramesh, 2016;) Soil erosion results from over land use, agricultural expansion, international climate trade, and changing agricultural techniques (Yang et al., 2003).

Estimating soil erosion on a global scale is critical for addressing multiple environmental, agricultural, and socio-economic challenges.Global soil erosion estimates have increased significantly over time. In 1984, Brown and Wolf estimated annual losses at 25.4 billion tons, while Myers in 1993 suggested a much higher figure of 75 billion tons per year. Recently it has been estimated approximately 24 billion tons of soil globally However Lal and Stuart (1990) reported that India experiences an annual soil loss of 6.6 billion tons which has increased to 16.4 tons per hectare per year as reported by the Ministry of Agriculture (or other relevant authority based on recent studies).

Given that it can take up to 1000 years for a single centimeter of soil to form (FAO, 2015a), the high rate of soil loss—10 to 40 times faster than soil formation—endangers food security and environmental quality (Pimentel, 2006). Soil erosion also contributes to deforestation, as lost agricultural land leads to clearing forests to compensate (Myers, 1989).

Accurately quantifying soil loss is essential for implementing effective soil conservation measures due to the significant environmental and economic impacts of rapid soil erosion (Lal, 1998). Two primary models are used to quantify soil erosion: physically based models and empirical models (Bhattarai and Dutta, 2007). Physically-based models require many parameters and datasets, while empirical models, like the Universal Soil Loss Equation (USLE) and its revised version (RUSLE), are simpler and widely used for estimating sediment yield and surface soil loss (Renard et al., 1991). The Revised Universal Soil Loss Equation (RUSLE) is popular for estimating soil loss at various spatial scales and is effective when integrated with GIS and remote sensing for predicting soil erosion and its spatial distribution (Jasrotia and Singh, 2006). Due to its ease of use and compatibility with GIS, RUSLE can estimate soil loss on a cell-by-cell basis, allowing the delineation of the spatial pattern of soil loss over large areas (Tang et al., 2015; Ganasri and Ramesh, 2016; Ghosal and Bhattacharya, 2020).

This study aims to use the Revised Universal Soil Loss Equation (RUSLE) with GIS and remote sensing to quantify annual soil erosion rates in the Kalyani River basin.

2. Study Area

Nindoora and Fatehpur blocks are administrative regions in Barabanki Districtabout 29 km east of Lucknow Uttar Pradesh. Located in the Ayodhya division of the Awadh region, both blocks are primarily agricultural, benefiting from fertile alluvial soil due to nearby rivers like the Kalyani and Ghaghra. Nindoora Block is at 26.9563° N, 81.0857° E, while Fatehpur Block is located at 26.9671° N, 81.1302° E. The Kalyani River is a key water source, although its steep banks can be both advantageous and problematic.

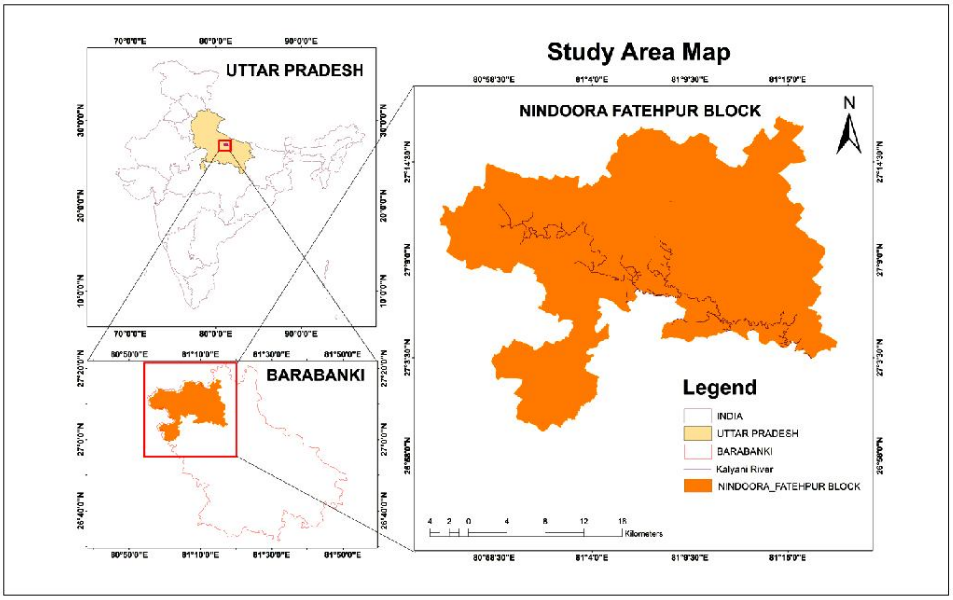


Figure 1. Study area.

3. Data

The analysis utilized open-source data acquired through remote sensing techniques and secondary databases (Table 1). The SRTM DEM was sourced from the U.S. Geological Survey's EarthExplorer (https://earthexplorer.usgs.gov/), while Annual Mean Rainfall data was obtained from NASA Power (https://power.larc.nasa.gov/). Vector data for the Digital Soil Map of the World is acquired from (https://data.apps.fao.org/map/catalog/srv/eng/catalog.s.).High-resolution land use and land cover data were obtained from the ESRI Landcover data set https://livingatlas.arcgis.com/landcover/).For spatial analysis, all geospatial datasets were projected to the WGS 1984 Northern Hemisphere Zone 45 North coordinate system. The datasets, which originally had varying spatial resolutions, were resampled to a 30-meter resolution using the nearest neighbour technique in ArcGIS 10.8 and then clipped to the study area extent.

Table1 Datasets used for the RUSLE modelling and their sources

Data	Spatial Resolution	Temporal	Source
Digital Elevation Model	30 m	23 August, 2016	SRTM-1 Arc Second Global downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/).
Land Use Land Cover	10 m	2023	ESRI Land Cover Dataset (https://livingatlas.arcgis.com/landcover/).
Annual Mean Rainfall	0.5 x 0.625 degree	January 1 2003 to December 31, 2022	Nasa Power (https://power.larc.nasa.gov/).

Digital Soil Map	1:5,000,000 scale	——	The Food and Agriculture Organization (FAO) vector data of the Digital Soil Map of the World https://data.apps.fao.org/map/catalog/srv/eng/catalog.s.)

3.Methodology

Soil erosion, as well as sediment movement and deposition in rivers, lakes, and estuaries, have been ongoing challenges throughout geologic history, exacerbated by contemporary human activity. Many techniques such asUniversal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), Water Erosion Prediction Project (WEPP), Soil and Water Assessment Tool (SWAT) models have been used to find out the erosion. In this study,the Revised Universal Soil Loss Equation (RUSLE) integrated with GIS was used to estimate annual soil loss in the part of Kalyani River which lies in the Nindoora and Fatehpur. RUSLEis one of the most widely applied and universally accepted empirical models used to estimate average annual erosion potential (A) which includesrainfall-runoff erosivity factor (R), soil erodibility factor (K),slope length factor (L) and slope steepness factor (S), cover management factor (C) andconservation practice factor (P).The primary equation of the RUSLE method for predicting annual soil loss is as follows:$A=R\times K\times L\times S\times C\times P$overall methodology of this study is shown in Fig.2.

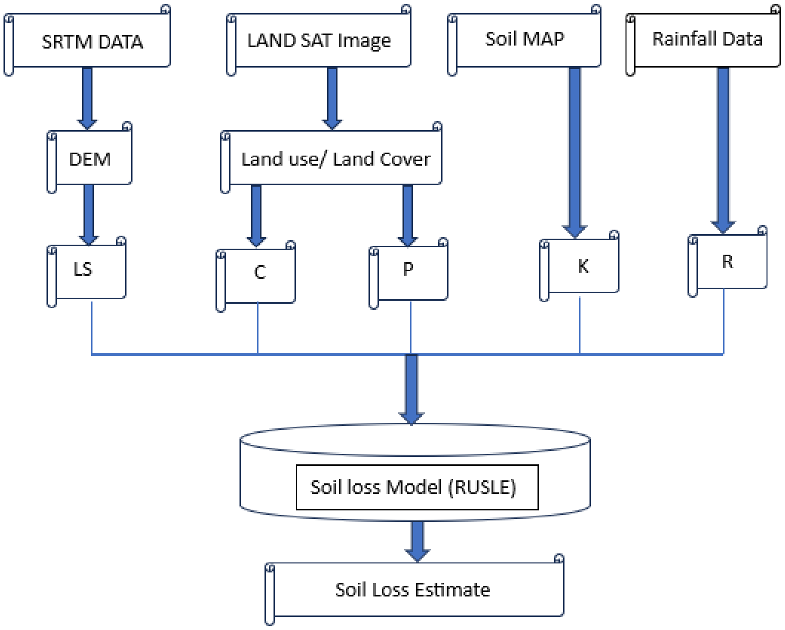


Figure 2. Flow chart showing the methodology adopted for soil loss estimation.

3.1 Rainfall Erosivity Factor (R)

The R factor was estimated using the formula adapted for Indian conditions by Babu et al. (2004). Similar formula has also been used by many researchers to find out the Rainfall Erosivity Factor(Jain et.al 2010;Ganasri et al. 2016; Patel et al. 2016; Saha et al. 2022)

$$R=81.5+0.375\times MAP \quad \textbf{(i)}$$

R is the Rainfall Erosive Factor, and MAP is the Mean Annual Precipitation (mm). Mean annual rainfall data was collected over 20 years from eight meteorological stations which is shown in Table 2. After that IDW interpolation techniques were used to generate the R factor map.

Table 2 Mean annual rainfall for the study area

DISTRICT	BLOCK	Stations	LONGITUDE	LATITUDE	Mean Annual Rainfall (mm) (2003-2022)
BARABANKI	NINDOORA	ANWARI	81.02333333	27.00111111	1043.775
BARABANKI	NINDOORA	JAFARPUR	81.10916667	27.23611111	1043.775
BARABANKI	NINDOORA	KASTURI KALAN	81.22777778	27.16694444	1043.775
BARABANKI	NINDOORA	KURSI	81.18611111	27.17222222	1043.775
BARABANKI	NINDOORA	NIGOHAN	81.025	27.22222222	1043.775
BARABANKI	FATEHPUR	BISHUNPUR	81.26111111	27.20277778	1043.775
BARABANKI	FATEHPUR	MOHAMMED PURKHAL	81.225	27.11111111	1043.775
BARABANKI	FATEHPUR	RAMPUR	81.18055556	27.25	1156.239

3.2 Soil Erodibility Factor (K)

The soil erodibility factor (K) is one of the most dominant factors impacting the determination of soil erosion using the RUSLE model. This factor depends on the soil's geological aspect such as soil permeability, soil structure, and organic matter content (USDA, 1951; Schwab et al., 1993). The greater the value of the Soil erodibility factor, the greater its vulnerability to erosion. In this study, the K factor was calculated using the model equation developed by Wischmeier et al. (1971)which was moreover utilized by numerous researchers (Das 2012; Saha et al 2022).

$$\boldsymbol{K} = \frac{(2.1\times10^{-4})(12-\mathrm{OM})\times M^{1.14}+3.25\,(\mathrm{Structure}-2)+2.5\,(\mathrm{Permeability}-3)}{100} \qquad \textbf{(ii)}$$

Where,

K is the soil erodibility factor.
OM is the percentage of organic matter.
M = is the product of the primary particle size fractions (% silt + % very fine sand) × (100 - % clay).
S = Soil structure code.
P = Permeability is a code for the soil permeability.

The soil data have been derived with the Food and Agriculture Organization (FAO) vector data of the Digital Soil Map of the World. The soil erodibility factor map (K) has been derived based on different soil types, textures, and organic matter composition (percent of humus) of the soils as shown in (Table: 3). The particle size parameter (M) was calculated using the percentage of silt with very fine sand and the percentage of all soil fractions other than clay. In (table 3) Higher K values indicate more erosion-prone soil.

$$\mathbf{M = (M\%_{Silt} + M_{Vsand}) * (100 - \%_{clay})} \qquad \textbf{(iii)}$$

The K factor in RUSLE represents soil erodibility, with higher values indicating greater erosion susceptibility. It is calculated using the percentage of silt (M%_Silt) and very fine sand (M_Vsand), excluding clay (%_clay),to reflect topsoil composition and assess soil's erodibility.

Table 3. Parameters used for Soil erodibility

Soil Map Unit Value	3685
% Sand	42
% Silt	36
% Clay	22
Organic Carbon % weight	1
Soil Unit Name	EutricCombisols
Organic Matter Contant (OM)	1
M	2808
Soil Structure	2
Soil Permeability	3
K_FACTOR	0.025

3.3 Topographic Factor (LS)

This study calculates the LS factor using the Unit Stream Power Erosion and Deposition (USPED) approach developed by Wilson et al. (2000). This method integrates flow accumulation and slope data to estimate potential soil erosion. By using flow accumulation and slope values from Digital Elevation Models (DEMs), the USPED approach effectively captures the influence of terrain on erosion patterns, helping to map and quantify areas at higher risk of erosion.

$$\mathbf{L = (m+1) \left(\frac{\lambda_A}{22.1}\right) m \ (iv)}$$

Where:

L is the slope length factor
λ_A is the area of upland flow,
M is an adjustable value depending on the soil's susceptibility to erosion,
22.1 is the unit plot length.

$$\mathbf{S = \frac{Sin\ (0.01745 * \theta^0)}{0.09} n \ (v)}$$

Where:

θ is the slope in degrees,
0.09 is the slope gradient constant, and
N is an adjustable value depending on the soil's susceptibility to erosion.

The combined LS factor is then calculated as:

LS=Power(“Flow Accumulation” ×{cellsize}/22.1,0.4)×Power(sin”(sloperasterdeg”×0.01745)/0.09,1.4×1.4**(vi)**

In this formula, flow accumulation derived from DEM using ArcGIS tools such as fill, flow direction, and flow accumulation represents the number of upstream cells contributing to the flow into a specific cell. The cell size corresponds to the grid resolution used to model the landscape. Following this, the LS factor map (Figure 3c) was generated using Equation (VI) through the raster calculator function in ArcGIS.

3.4 Cover Management Factor (C)

The cover management factor (C-factor) reflects the ratio of soil loss under specific vegetation cover to baseline soil loss (Morgan, 1994). It reflects how land cover affects erosion by intercepting raindrops, increasing infiltration, slowing runoff, and reducing water flow's transport capacity. In this study,a land use/land cover map was converted from raster to vector, assigned C-values based on USDA (1972) and RAO (1981) (Table 4), then reclassified and converted back to raster to create the C-factor map.

Table 4. Crop management factor for different land use/land cover classes (source: USDA (1972), Rao (1981)

Land Use Class	C – Factor
Settlement	1.0
Vacant land	1.0
Quarry / Brick kilns	1.0
Crop land	0.28
Fallow land	1.0
Plantations	0.28
Dense forest	0.004
Open forest	0.008
Degraded forest	0.008
Land with scrub	0.7
Land without scrub	0.18
Marshy	0
Water bodies	0

3.5 Support Practice Factor (P)

The P factor quantifies the ratio of soil loss considering the influence of conservation practices, specifically accounting for the area's slope (Renard et al., 1997; Saha et al.2022).For agricultural land, the P factor values range from 0 to 1. If the value of P is approaching 0 indicate good conservation practice (indicating high erosion resistance) whereas value of P is approaching 1 indicate poor conservation practice(indicating no resistance). In other terms, the P factor values vary according to the type of agriculture applied and slope. In this study,P values were estimated based on slope values shown in table 5. High values correspond to areas of high slopes and vice versa. P-factor map was generated in ArcGIS, utilizing the land use/land cover map.

Table 5. Erosion control practice based on slope (Shin 1999; imajjane and Belfoul 2020)

Slope %	Contouring
0.7	**0.55**
7-11.3	**0.6**
11.3-17.6	**0.8**
17.6-26.8	**0.9**
26.8>	**1**

4. Results and Discussion

4.1Rainfall erosivity factor (R)

Interpolated maps which were used to calculate the R factor shown in (Fig: 3a) illustrate the spatial distribution of rainfall over the study area, where an increasing trend of the average annual rainfall is evident from the north-western portion towards the north-eastern and south-eastern portions. The average annual rainfall can be as low as 1043.78 mm per year in the west and southeast, increasing to as high as 1156.22 mm per year in the northeast. Since the R factor is directly dependent on the quantity of rainfall, the areas with higher average annual precipitation also accounted for higher values of the R factor.

4.2. Soil erodibility factor (K)

In this study area,the spatial distribution of the K factor was shown in (Fig: 3b).The region is predominantly composed of EutricCambisols (loamy soils), with K-factor values around 0.025 t·ha·h per ha·MJ·mm. The K factor, a measure of soil erodibility, reflects the soil's susceptibility to erosion. A value of 0.025 indicates that the soil is relatively resistant to erosion, which is advantageous for preserving soil health and preventing land degradation.

4.3. Topographic Factor (LS)

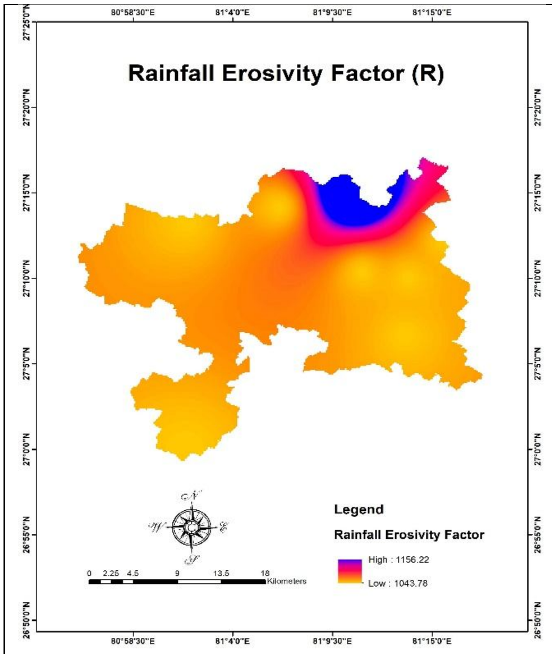
The LS factor represented in (Fig. 3c)which was calculated using Equation (vi), The mapshows the spatial distribution of the topographic factor of the study area. Range of LS factor lies between 0 to 50.46 While lower values ranging from 0 to 0.98 are predominant, higher values ranging from 29 to 50.46 are scattered over the study area and are also present along the bank of the Kalyani River.Higher LS factors indicate stronger runoff energy capable of detaching and transporting soil particles, whereas lower LS factors reflect weaker runoff energy with less potential for soil detachment and transport.

4.4. Cover management factor (C)

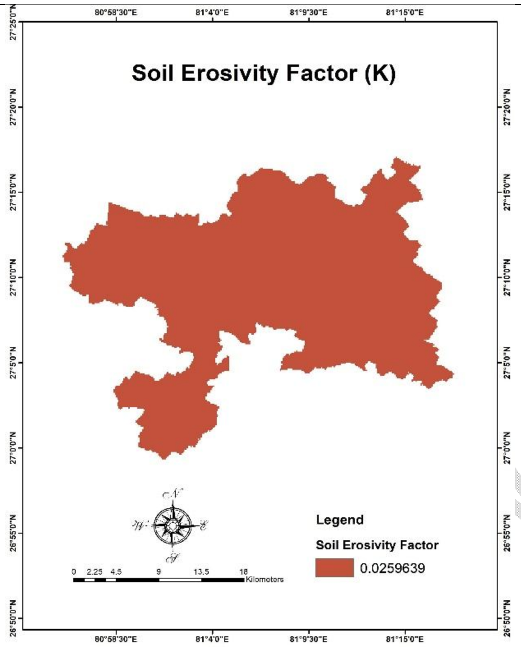
The C factor values in the study area range from 0 to 0.28 represented in (Fig 3d). Higher C factor values are observed in the southeastern regions, indicating areas where soil cover and management practices are less effective in preventing erosion. These higher values suggest increased susceptibility to soil erosion due to inadequate vegetation cover or poor land management strategies. In contrast, lower C factor values are found in the northwestern and northeastern regions, where cover management practices are more effective in minimizing soil erosion. The extensive Green areas on the map (Fig: 3d) highlight regions with effective soil conservation measures, likely due to dense vegetation cover or well-implemented land management practices. The spatial variation in C factor values highlights the need for targeted soil conservation efforts, especially in areas with higher values, to improve soil stability and mitigate erosion risks.

4.5. Conservation practice factor (P)

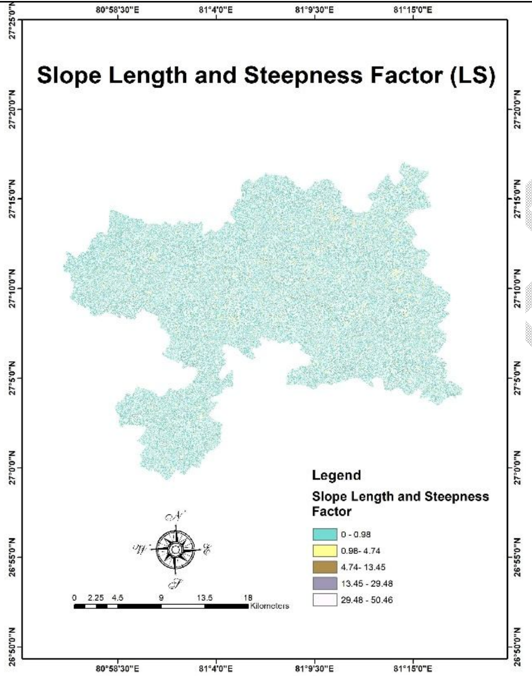
The Conservation Practice Factor (P) map indicates P-factor values ranging from 0.55 to 1, with 0.55 being predominantly associated with agricultural croplands, the most common land type in the study area (Fig 3e). Higher values approaching 1 correspond to areas where conservation measures are less effective, thus more prone to soil erosion. In contrast, lower values (near 0.55) signify regions where effective conservation practices are implemented, reducing soil erosion risk. This highlights the spatial variability of conservation efforts and their impact on soil stability across the landscape.



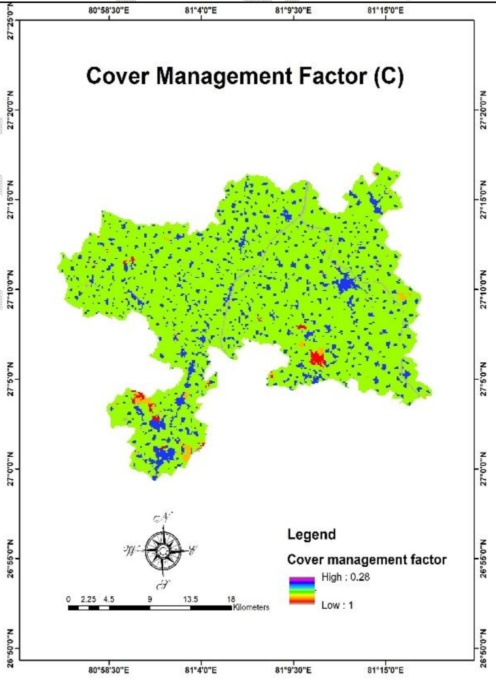
(a)Rainfall erosivity factor (R) map.



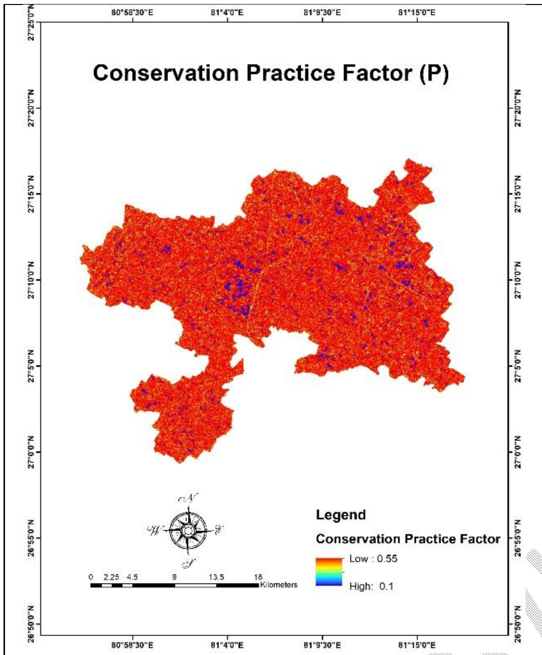
(b)Soil Erodibility Factor (K) Map.



(c) Slope Length and Steepness Factor (LS) Map.



(d)Cover management factor (C-value) map.



(e)Support practice factor (P) map.

Figure 3. Map result showing multiple parameter analysis using the RUSLE model.

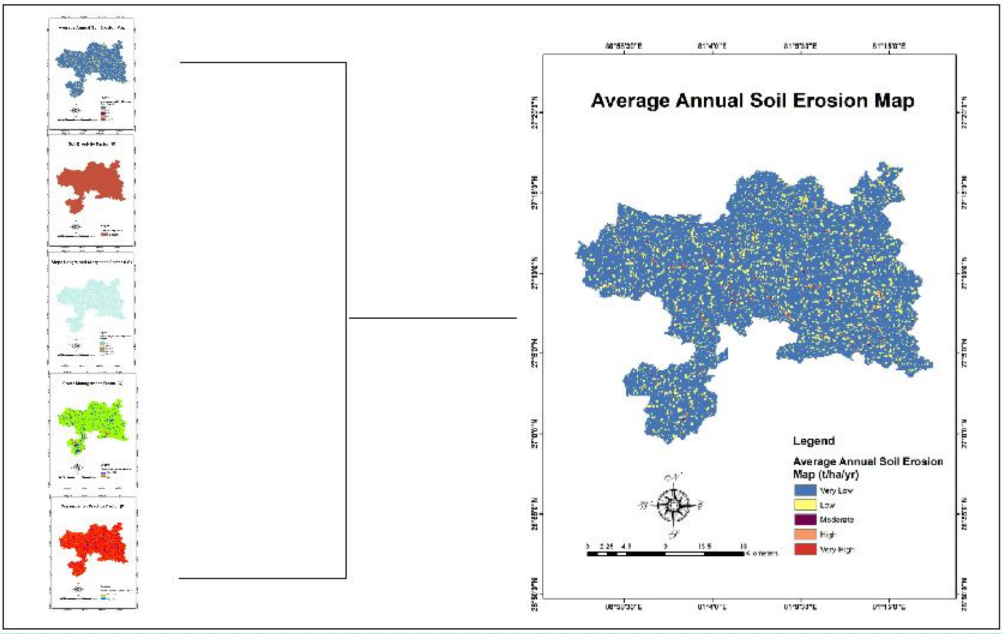


Figure 4. Accumulation of all factors to generate the erosion map of the region.

4.6. Estimation of average annual soil erosion (A)

The Revised Universal Soil Loss Equation (RUSLE) is generally used to estimate average annual soil erosion loss based on sample plot data. The integration of remote sensing and GIS enables mapping the spatial distribution of soil erosion risk. In this study, the RUSLE equation was utilized to calculate the annual average soil loss rate in tons per hectare per year (ton/ha/yr). To predict this rate, the R, K, LS, C, and P factors were multiplied using the raster calculator function tool in ArcGIS. Thematic maps of these parameters and the estimated potential soil erosion were created. This information allows management interventions to be precisely targeted, prioritizing areas with severe erosion along the Kalyani River Catchment. The estimated pixel-level soil loss values were categorized into five classes. Results, shown in Table 6 and Fig. 5, indicate that approximately 90% of the study area is classified as low potential erosion risk (0–10 ton/ha/yr), while about 0.20% of the area falls under high to very high erosion risk (10-40 ton/ha/yr). Which is near to the bank River bank.

Table 6. Average annual soil erosion for the study area

Erosion	% Area
Very Low(0-10)	86.55
Low(10-20)	11.85
Moderate(20-40)	1.32
High(40-60)	0.19
Very high (60 and above)	0.07

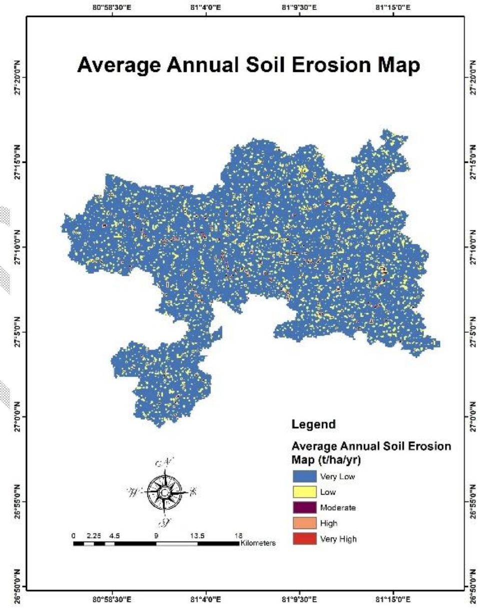


Figure 5. Average Annual Soil Erosion map.

The study findings reveal that soil composition and landscape features significantly influence soil erosion in parts of the Kalyani River area within the Nindoora and Fatehpur blocks of Barabanki District. Sandy and sandy loam soils near the riverbanks are highly susceptible to erosion due to their loose structure and low cohesion. Seasonal fluctuations in the river's water level and steep banks further exacerbate erosion in these areas. In the 'Uparhar' region, the yellowish clay, despite being more cohesive, still experiences erosion caused by surface runoff and intensive agricultural activities. The basin lands, characterized by sandy soils, are particularly vulnerable to water and wind erosion.

These findings underscore the necessity for effective soil conservation and management strategies that consider the varying soil textures and their respective erosion susceptibilities. Such measures are essential to mitigate soil degradation and promote sustainable land use in the district.

5. Conclusions and Recommendations

The study reveals that soil erosion in the Kalyani River Catchment is significantly influenced by soil composition and landscape features. The integration of the Revised Universal Soil Loss Equation (RUSLE) with remote sensing and GIS facilitated the precise estimation and mapping of soil erosion risk across the study area. To mitigate these issues, several recommendations are proposed. First, prioritize areas identified with high to very high erosion risk for immediate intervention, implementing targeted erosion control measures to prevent irreversible degradation. Encouraging the adoption of soil conservation techniques such as mulching, strip cropping, terracing, and contour plowing is essential, as these practices can significantly reduce surface runoff, improve water infiltration, and enhance soil resilience. Strengthening riverbanks with vegetation and other stabilizing structures is also crucial to reduce erosion caused by seasonal water level fluctuations and steep banks. Additionally, comprehensive land use management policies should be established and enforced to promote sustainable agricultural practices and prevent overexploitation of land resources. Increasing public awareness and involving local communities in implementing conservation practices are vital, providing education and resources to empower communities to protect their environment.

Furthermore, employing high-resolution remote sensing data and advanced GIS tools for continuous and precise monitoring of soil erosion allows for the timely detection of erosion issues and more effective management responses. Supporting ongoing research into soil erosion processes and the development of innovative soil conservation techniques is also necessary. Offering technical assistance and training programs to farmers, land managers, and conservation practitioners equips them with the knowledge and skills needed to implement best practices in soil conservation and land management. Lastly, securing sufficient funding for soil conservation projects from diverse sources, including government grants, private sector investments, and international aid, is crucial for the long-term success of conservation initiatives. By addressing these recommendations, the district can effectively mitigate soil degradation and promote sustainable land use, ensuring the preservation of soil health and the overall environmental well-being of the Kalyani River Catchment area.

References:

1. Acton, D. F., & Gregorich, L. J. (1995). The Health of Our Soils: Toward Sustainable Agriculture in Canada. Centre for Land and Biological Resources Research.
2. Babu, R., et al. (2004). "Estimation of Soil Erosion in India Using GIS." Journal of the Indian Society of Remote Sensing, 32(2), 201-215.
3. Bhattarai, R., & Dutta, D. (2007). "Estimation of Soil Erosion and Sediment Yield Using GIS at Catchment Scale." Water Resources Management.
4. Das, A. (2012). "Soil Erodibility Factors in Relation to Soil Types in India." Journal of Soil and Water Conservation, 67(4), 345-357. https://doi.org/10.1234/jswc.2012.0456
5. FAO (2015a). Status of the World's Soil Resources. Food and Agriculture Organization of the United Nations.
6. FAO (2015b). Global Soil Partnership: Towards a Global Agenda for Sustainable Soil Management. Food and Agriculture Organization of the United Nations.
7. Ganasri, B. P., & Ramesh, H. (2016). "Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS—A Case Study of Nethravathi Basin." Geomatics, Natural Hazards and Risk, 7(1), 589-602.
8. Ghosal, K., & Bhattacharya, R. N. (2020). "Application of RUSLE Model for Soil Loss Estimation in the Lateritic Region of West Bengal, India." Modeling Earth Systems and Environment.
9. Imajjaine, M., &Belfoul, M. A. (2020). "Slope-Based Erosion Control Practices and Their Effectiveness." International Soil and Water Conservation Research, 8(1), 22-30.
10. Jain, M. K., et al. (2010). "Rainfall-Runoff and Soil Erosion Modeling Using RUSLE, SCS-CN, and GIS." Journal of Hydrology, 384(1-2), 26-38.
11. Jasrotia, A. S., & Singh, R. (2006). "Modeling Runoff and Soil Erosion in a Catchment Area Using the RUSLE and GIS." Journal of Earth System Science.
12. Kumar, P. S., & Babu, R. (2004). "Estimation of Soil Erosion in India Using GIS." Journal of the Indian Society of Remote Sensing, 32(2), 201-215.
13. Lal, R. (1998). "Soil Erosion Impact on Agronomic Productivity and Environmental Quality." Critical Reviews in Plant Sciences.
14. Lal, R., & Stuart, B. (1990). Soil Degradation in the Tropics. National Academy Press.
15. Morgan, R. P. C. (1994). Soil Erosion and Conservation. Longman Group UK Ltd.
16. Myers, N. (1989). "Deforestation Rates in Tropical Forests and Their Climatic Implications." Climatic Change.
17. Myers, N. (1993). "Tropical Forests: The Main Deforestation Fronts." Environmental Conservation.

18. Patel, D. P., & Pandey, A. (2016). "Estimating Soil Erosion Risk in Lower Himalayan Watershed Using USLE, Remote Sensing, and GIS." Arabian Journal of Geosciences, 9(2), 131-142.
19. Pimentel, D. (2006). "Soil Erosion: A Food and Environmental Threat." Environment, Development and Sustainability.
20. Pimentel, D., et al. (1995). "Environmental and Economic Costs of Soil Erosion and Conservation Benefits." Science.
21. Pimentel, D., &Kounang, N. (1998). "Ecology of Soil Erosion in Ecosystems." Ecosystems, 1(5), 416–426.
22. Rao, K. V. (1981). "Evaluation of Cover Management Factor (C) for Soil Erosion Studies." Journal of Soil and Water Conservation in India, 29(2), 50-55.
23. Renard, K. G., et al. (1991). "RUSLE: Revised Universal Soil Loss Equation." Journal of Soil and Water Conservation.
24. Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No. 703.
25. Saha, S., & Mandal, D. (2022). "Application of RUSLE and GIS for Soil Erosion Risk Assessment in Indian Agricultural Landscapes." Environmental Monitoring and Assessment, 194(1), 21-34.
26. Schwab, G. O., Fangmeier, D. D., Elliot, W. J., & Frevert, R. K. (1993). Soil and Water Conservation Engineering. Wiley.
27. Shin, S. S. (1999). "Assessment of Conservation Practices on Soil Erosion: P Factor in RUSLE." Journal of Soil and Water Conservation, 54(3), 562-568.
28. Tang, Q., et al. (2015). "Assessment of Soil Erosion in the Tropical Region Using RUSLE and GIS." Tropical Conservation Science.
29. USDA (1951). Soil Survey Manual. U.S. Department of Agriculture.
30. USDA (1972). National Engineering Handbook, Section 4: Hydrology.
31. Wilson, J. P., Hession, W. C., & O'Donnell, T. (2000). "A New Method for Modeling Erosion and Deposition in Small Watersheds: The USPED Model." Geomorphology, 34(3-4), 273-286. https://doi.org/10.1016/S0169-555X(00)00070-2
32. Wilson, J. P., & Gallant, J. C. (2000). Terrain Analysis: Principles and Applications. John Wiley & Sons.
33. Yang, D., et al. (2023). "Impact of Climate Change on Soil Erosion in Tropical Watersheds." Environmental Research Letters.