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# Spatiotemporal Modeling of Soil Erosion Under Agricultural Expansion in the Amravati Basin, India Using RUSLE–GIS

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**Abstract**

*Agricultural expansion and soil erosion are important environmental issues in areas where agriculture is a major source of livelihood. This study analyzes the spatial and temporal patterns of soil erosion in the Amravati Basin of Maharashtra and evaluates the impact of agricultural expansion using the Revised Universal Soil Loss Equation (RUSLE) integrated with Geographic Information System (GIS) techniques. Multi-source data, such as satellite imagery, rainfall records, soil characteristics, and topography data, were used to determine the RUSLE factors (R, K, LS, C, and P) and generate soil erosion risk maps for 2014, 2024, and the year 2034. The results of the land use/land cover (LULC) change detection indicated a significant decrease in forest cover and an increase in agricultural land cover, which was significantly correlated with high soil loss areas (> 100 t/ha/year; r = 0.94). The prediction analysis shows that there will be a sharp decline in low-erosion areas and a frightening increase in high-erosion classes by 2034, especially in upland croplands and on deforested slopes. The results indicate that concerted efforts for conservation should be conducted, such as contour farming, vegetative barriers, agroforestry, and the incorporation of soil conservation mechanisms in regional land-use plans. This study provides valuable information to policymakers and land managers to develop sustainable agricultural and environmental management practices.*

**Keywords:** Agricultural expansion, GIS, RUSLE, soil conservation, soil erosion, spatial modeling

## INTRODUCTION

Erosion and encroachment of agricultural land are key environmental issues, especially in areas such as the Amravati Basin, where agricultural activities are a primary source of livelihoods. The complex nature of these two processes requires close examination to achieve sustainable land management practices (Gupta & Uniyal, 2012) [1]. Land degradation through soil erosion, which is the removal and movement of soil particles by wind or water, decreases agricultural production and results in water body sedimentation. Soil erosion can be intensified by agricultural expansion, which is usually caused by a growing population and food demands (Rhodes, 2014) [2]. Understanding this interplay is essential for developing effective measures to counter soil loss and ensure sustainable farming practices.

The Amravati River is a major tributary of the Tapi River system and flows through the state of Maharashtra. It originates from the peripheral areas of the Sahyadri Mountains, at an altitude of 650 m above mean sea level, west of the Deccan Plateau in the Dhule district, Maharashtra. It flows 57.73 km

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eastwards and joins the Tapi River at Shendvade in the Dhule district, Maharashtra. The study basin extends between latitudes 21° 09' 44" and 21° 24' 42" N and longitudes 74° 12' 55" to 74° 44' 06" E and covers an area of 795 m square kilometres.

This study is based on critical questions regarding the interaction between land use processes and soil erosion in the Amravati Basin. Specifically, this research explains how agricultural development affects spatial and temporal changes in soil erosion between 2014 and the estimated year 2034. Moreover, it examines how land use/land cover changes, particularly forest decline and cropland increase, have altered the degree of soil loss in the basin's uneven physiographic units. The study also determines the relationship between agricultural growth and high-erosion areas, as well as the effectiveness of the integrative RUSLE-GIS modelling system in identifying existing and potential erosion hotspots. Finally, this study aims to determine priority areas for soil conservation interventions that would support sustainable land management in the Amravati Basin.

The main goal of the proposed research is to forecast soil erosion rates and evaluate the effects of agricultural expansion on soil loss in the Amravati Basin using the RUSLE model in a GIS environment. This study is important because it can provide sensitive information to policymakers and land managers to make informed decisions about land use planning, soil conservation, and sustainable agricultural development. This research will help develop the field of soil erosion modeling and encourage sustainable land management practices in the Amravati Basin and other agricultural areas by quantifying the spatial distribution of soil erosion risk and locating regions vulnerable to agricultural expansion.

## LITERATURE REVIEW

Although the problem of soil erosion is acknowledged to be important, there is a lack of research in this particular region of the Amravati Basin. Although many studies have been conducted on soil erosion using models such as the Revised Universal Soil Loss Equation (RUSLE) and geographic information systems (GIS) in other areas, studies that have predicted the overall effects of soil erosion and agricultural expansion in the Amravati Basin have been limited (Doraiswamy et al., 2007; Bahadur, 2012; Pal & Chakrabortty, 2019; Mandal et al., 2023) [3–5] The innovation of the present study is that it is localized and predictive in nature, as it uses RUSLE and GIS to measure the risk of soil erosion in different agricultural expansion scenarios in the Amravati Basin.

Soil erosion is a complex process that involves the detachment, transportation, and deposition of soil particles by various agents, including water and wind. Human activities, especially unsustainable farming practices, deforestation, and urbanization, contribute to the unhealthy development of the environment and economy because the natural processes are greatly accelerated by human activity (Sander et al., 2011) [7]. From an environmental perspective, soil erosion negatively impacts the quality of water by causing excessive sedimentation and nutrient leaching, thus adversely affecting aquatic life and even causing eutrophication. Another serious effect is habitat loss, in which the topsoil is destroyed, decreasing the land's ability to sustain a variety of plants and animals (Bhat et al., 2019) [8].

In economic terms, soil erosion leads to low agricultural productivity because of the loss of topsoil, which is rich in nutrients, thereby affecting crop production and the livelihoods of farmers (Raikwar et al., 2014) [9]. Higher sedimentation in rivers and reservoirs requires high dredging expenses and decreases the amount of irrigation and drinking water storage. Moreover, soil erosion may affect infrastructure, including roads and bridges, and the government will have to invest heavily in repair and maintenance (Mahabaleshwara, 2014) [10].

One of the most significant factors contributing to rapid soil erosion is agricultural expansion driven by population growth, economic forces, and policy factors. With a growing population, the demand for food and other agricultural products increases, resulting in the conversion of forests and grasslands into agricultural land (Agone & Bhamare, 2012) [11]. The growth of agriculture can also be stimulated by economic incentives, such as subsidies or market demand for certain crops, which may not be properly balanced with the need to sustainably manage land (Agone, 2014) [12]. Government policies concerning land use, agricultural production, and environmental protection significantly influence the development of patterns of agricultural expansion and their effects on soil erosion (Branca, 2023) [13].

The Amravati Basin is an excellent case study to investigate the interaction between soil erosion and agricultural expansion, as it is a unique region in terms of environment and socioeconomic situation (Bhamare et al., 2015) [14]. This area is prone to water erosion because it has a monsoon climate characterized by heavy rainfall events. Many people in the population depend on farming as a source of income; thus, there is growing pressure on land resources (Vemu & Pinnamaneni, 2011) [15].

The dynamics of soil erosion and agricultural expansion within the Amravati Basin are important in the development of sustainable land management practices that can guarantee the environment, food security, and enhance the livelihoods of the local communities. The use of such models as the Revised Universal Soil Loss Equation and geographic information systems is a very effective methodology to forecast and map the risk of soil erosion, which allows decision-making related to land use planning and conservation.

Although the RUSLE-GIS framework has been widely used to evaluate soil erosion worldwide, there are still some significant gaps in knowledge regarding semi-arid basins in central India, especially the Amravati Basin. First, much of the past research in India has been conducted in humid or mountainous areas, such as the Western Ghats and northeastern basins, and semi-arid agricultural watersheds in Maharashtra have received relatively little research on a detailed spatial scale. Second, previous studies have focused on single-date or historical soil loss estimations; little research has been conducted on the multi-temporal analysis between land use/land cover (LULC) transitions and changing erosion risk. Third, the quantitative interdependence between rapid agricultural growth and the spatial redistribution of erosion hotspots has not been adequately studied in medium-sized Deccan basins.

Moreover, the proactive evaluation of future erosion conditions in the context of ongoing land transformation is limited in the literature for the region, which limits the ability of planners to take proactive soil conservation measures. Lastly, some studies are based on generalized national-level evaluations that do not provide basin-level decision-support mapping necessary for specific watershed management in Maharashtra.

This study fills these gaps by offering a combined, basin-wide spatiotemporal evaluation of soil erosion processes in the Amravati Basin through the RUSLE-GIS framework and multi-date land use/land cover (LULC) analysis and projection. In contrast to most previous Indian studies, which concentrated on the estimation of erosion at a single point in time, this study explicitly measures the relationship between agricultural growth and changing erosion risk areas within 2014–2034. This research also has added value by creating spatially explicit future erosion hotspots, which can be used to provide future decision support for land and water conservation planning in a semi-arid Deccan setting. This work also offers one of the limited geospatial analyses of the Amravati Basin, thus bridging the knowledge gap on the evidence for the region in Maharashtra. The combination of terrain sensitivity, land transformation dynamics, and predictive modelling into one framework allows this study to further the methodological application of RUSLE-GIS in proactive watershed management in fast-changing agricultural landscapes.

**OBJECTIVES**

1. To calculate RUSLE factors and integrate them into a GIS environment for soil erosion modeling.
2. To examine the correlation between agricultural land growth and high soil loss zones
3. To predict future trends in soil erosion and agricultural land use under current management practices

**Table 1.** Materials and data sources used in the study.

| S. No. | Data/Material | Description | Source | Spatial Resolution / Scale | Purpose in Study |
|---|---|---|---|---|---|
| 1 | Satellite Imagery (Landsat) | Multispectral satellite images for 2014 and 2024 | USGS Earth Explorer | 30 m | LULC classification and change detection |
| 2 | Digital Elevation Model (DEM) | Terrain elevation data | SRTM / USGS | 30 m | Derivation of slope and LS factor |
| 3 | Rainfall Data | Long-term average annual rainfall | IMD / CHRS / Local stations | Station-based / gridded | Computation of R-factor |
| 4 | Soil Map | Soil texture and erodibility information | NBSS&LUP / FAO Soil Map | 1:250,000 (typical) | Estimation of K-factor |
| 5 | Land Use/Land Cover Maps | Classified LULC maps (2014, 2024) | Derived from Landsat & ASTER Satellite data | 30 m | C-factor assignment and change analysis |
| 6 | Conservation Practice Data | Information on support practices | Literature / standard values | — | P-factor estimation |
| 7 | Administrative Boundary | Amravati Basin boundary | Survey of India | — | Study area delineation |
| 8 | GIS Software | Spatial analysis and RUSLE modelling | ArcGIS & TerrSet | — | Map generation and spatial analysis |
| 9 | CA–Markov / Prediction Tool | LULC future prediction (2034) | TerrSet / GIS plugin | — | Future land use & soil erosion simulation |

## METHODOLOGY AND DATABASE

This section explains the methodology used to forecast soil erosion and examine the consequences of agricultural expansion in the Amravati basin. This study is based on the Revised Universal Soil Loss Equation (RUSLE) model, which has been incorporated with geographic information system (GIS) methods. RUSLE was chosen because it has been shown to be effective, has data availability requirements, and is applicable for estimating soil erosion under different land uses and management practices. GIS is an effective tool that supports spatial data management, analysis, and visualization, which helps to integrate RUSLE factors and evaluate the risk of erosion throughout the basin. The methodology included study area characterization, data acquisition and processing, RUSLE factor calculation, GIS implementation, and a study of the impacts of agricultural expansion. Such a method enables a comprehensive understanding of soil erosion processes and the effects of farming on land degradation. Table 1 presents the data sources, spatial resolution, and their respective purposes in the study.

### Data Acquisition and Processing

This study employed different sets of data to estimate the RUSLE factors and to examine agricultural expansion. Land use/land cover (LULC) classification was performed using satellite imagery, namely Landsat 8 and ASTER. Supervised and unsupervised classification methods were applied to define various LULC classes. Soil properties, including soil texture, amount of organic matter, and permeability, were found on soil maps received from the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) or state government agencies. Daily and monthly rainfall data were obtained from meteorological stations at the Indian Meteorological Department (IMD) inside and outside the Amravati Basin. Topographic parameters, such as slope length and steepness, were calculated using a digital elevation model (DEM) generated using data sources such as the Shuttle Radar Topography Mission. Agricultural statistics, such as crop type, planting dates, and yields, were obtained from the Department of Agriculture and farmer interviews. Pre-processing involved cleaning up data by correcting geometrical distortions in satellite images, enhancing images to a level where they could be interpreted visually, cleaning up rainfall and soil data, and converting formats so that the various datasets could be compatible. ArcGIS 10.8 was used to perform spatial analysis and RUSLE modelling, and supervised classification of satellite imagery was used to perform land use/land cover classification. The CA-Markov model used in the TerrSet software was used to conduct LULC predictions in 2034.

**RUSLE Factor Calculation**

The research methodology of the present research is founded on field data, R.S. and GIS data. The estimate of soil loss is based on the Revised Universal Soil Loss Equation (RUSLE), developed by the U.S. Soil Conservation Department. Soil Conservation Department. Soil Conservation Department. Soil Conservation Department. Soil Conservation Department. The possible natural unit area soil loss in plateaus or river basin is dependent on the surface configuration, soil characteristics, local climatic situation and the applied management practices in the unit. These conditions determine the development of streams, gullies, and gullies formed by direct rain and surface runoff. These conditions determine the development of streams, gullies and gullies formed by direct rain and surface runoff. The revised universal soil loss equation can be expressed as:

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

Where, A= The computed spatiotemporal soil loss per unit area (tons /ha/year)
R= Rainfall erodivity factor (MJ mm/ha/hr/year) MJ means Mega Joule
K= soil erodibility factor (Tones/ha)
LS= slope length and steepness factor.
C = cover management factor and
P = the conservation practice factor

**Rainfall Erosivity Factor (R)**

The rainfall erosivity factor is often determined based on precipitation intensity when such data are available. In the present study, 32 years of monthly precipitation data (1990 to 2022) were used to calculate the R factor using Equation 2 developed by Wischmeier and Smith (1978):

$$\mathrm{R} = \sum_{1}^{12} 1.735 \times 10^{(1.5\log_{10}(P_i/P)-0.08188)} \quad (2)$$

where $R$ is a rainfall erositivity factor (MJ mm $ha^{-1}$ $h^{-1}$ per year); $P_i$ is monthly rainfall (mm); $P$ is annual rainfall (mm).

***Soil Erodibility Factor (K)***

The soil erodibility factor K was approximated according to soil texts, which is the rate of loss of soil in relation to the erosivity index of rainfall and runoff (R). Wischmeier and Smith suggested that the best sources of soil erodibility factors (K) are direct measurements on natural runoff plots or a nomograph to determine the K factor of soil depending on texture, % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability (Wischmeier and Smith, 1978). With the integration of GIS, remote sensing, and soil erosion models, researchers have been able to examine the patterns of soil erosion and determine the contributing factors in greater spatial detail to make more precise predictions and specific mitigation strategies.

$$\mathrm{K} = 27.66 \times m^{1-14} \times 10^{-8} \times (12 - a) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3) \quad (3)$$

where, $m$ = silt (in %) + very fine sand (in %) × (100—clay (in %))
$a$ = organic matter (%)
$b$ = structure code in which (1) is very structured or particulate, (2) is fairly structured, (3) is slightly structured, and (4) is solid
$c$ = profile permeability code in which (1) is rapid, (2) is moderate to rapid, (3) is moderate, (4) is moderate to slow, (5) is slow, and (6) very slow

***Topographic Factor (Ls)***

The topographic factor, which is the ratio of soil loss under given conditions to the soil loss that would occur at a site with a standard slope steepness of 9% and slope length of 22.6 m, is composed of two significant factors: slope length (L) and slope steepness (S). The length of the slope, the distance between the beginning of the overland flow and the commencement of deposition or entry of the runoff water into a well-organized channel, also influences erosion. The longer the slope, the greater the soil loss per unit area. Conversely, the steepness of a slope is the influence of the steepness of the inclination on the erosion and is more significant than the length of a slope. The steeper the slope, particularly between 10% and 25%, the greater the erosion. Therefore, the topographic factor is calculated using Eq. 4. The combination of GIS, remote sensing, and soil erosion models can be used to conduct a thorough examination of soil erosion patterns, with the main factors that contribute to soil erosion being soil erosion factors, topographic factors, and land management practices.

$$LS = \left[\frac{Q_a M}{22.13}\right]^y \times \left(0.065 + 0.045 \times S_g + 0.0065 \times S_g^2\right) \quad (4)$$

where LS = Topographical factor.
where Qa is the flow accumulation grid.
where Sg is the grid slope in percentage.
M = Grid size (x × y),
y is the dimensionless exponent, which assumes a value of 0.2–0.5.

***Crop Management Factor (C)***

A map of crop management factors was developed based on a land use and land cover map of the study area. The land use and land cover of the Amravati Basin was categorized into six broad categories based on ground information: water body, forest area, built-up land, wasteland, agricultural land, and other areas. The Indian remote sensing satellite 1D-LISS-3 image was processed with supervised classification with an overall accuracy of approximately 82%, and it identified these features. The algorithm was trained using ground truth data obtained using a GPS to achieve accurate extraction. Specific C values were then assigned to each category to generate the C factor map for the study.

***Conservation Support Practice Factor (P)***

The P factor value ranges between 0 and 1, with a value close to 0 signifying good conservation practice and a value close to 1 signifying poor conservation practice. No field data on conservation practices in the Amravati Basin were available; therefore, the P factor was set at 1 as most parts of the study area are under forest cover. The P factor of the Amravati Basin suggests poor conservation practices.

***GIS Implementation***

RUSLE factors were incorporated in a GIS environment (ArcGIS) to model soil erosion rates. All RUSLE factors were in the form of a raster layer with a spatial resolution of 30 m. The raster calculator tool in ArcGIS was used to execute the RUSLE equation by overlaying and multiplying the RUSLE factor layers to produce a soil erosion map. The map obtained provided the spatial pattern of soil erosion rates within the Amravati Basin.

***Analysis of Agricultural Expansion Impact***

Change detection methods were used to measure agricultural development, for example, by comparing LULC maps from two time points (i.e., 2014 and 2024). Different images were compared after differencing and comparison after classification was performed to determine the extent to which agricultural land encroached into other land cover categories, such as forests. The effects of agricultural expansion on soil erosion were determined by the rate of erosion that existed prior to and after expansion. This entailed superimposing the soil erosion maps of the two time points and computing the change in erosion rates in places that had experienced agricultural expansion. The significance of the observed changes in erosion rates was determined using statistical analysis.

## RESULTS AND DISCUSSION

### Results

This section presents the results of soil erosion modeling based on the RUSLE model and discusses the effects of agricultural expansion on soil erosion rates in the Amravati Basin. The geographical locations of soil erosion risk are charted, and statistical associations between agricultural growth and erosion are measured. The findings are discussed with reference to local conditions, past studies, and study limitations.

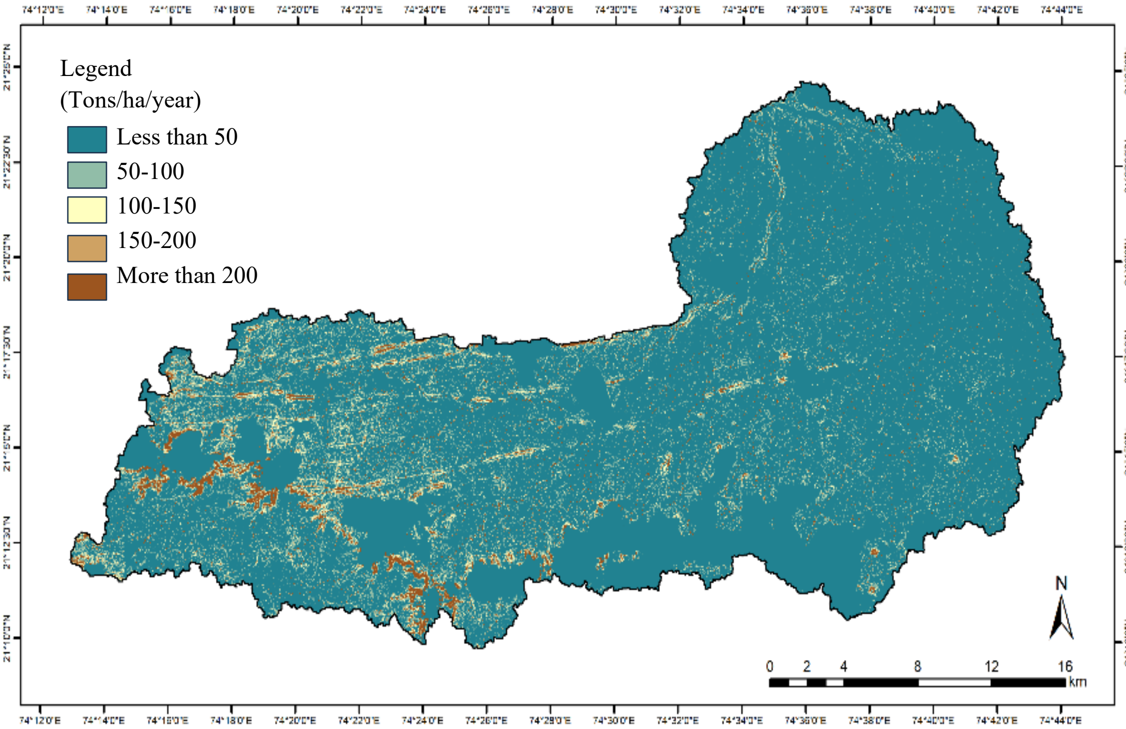
***Soil Erosion Mapping***

A map of the spatial distribution of soil erosion rates in the Amravati Basin was produced using the RUSLE model in a GIS environment. Erosion rates were divided into various risk areas: low, moderate, high, and very high. The most eroded areas were mostly found in regions with steep slopes and under intensive agriculture. In contrast, erosion rates were minimal in regions with high vegetation cover and relatively flat topography. The quantitative distribution of soil loss categories for 2014 and 2024 is presented in Table 2.

The spatial distribution of soil erosion risk is also well described on the map and shows the areas where urgent measures should be taken to conserve the soil. These results support the realization that soil erosion is mainly caused by topography and land use.

RUSLE and GIS-based assessments have shown that the intensity of soil erosion in the Amravati basin has undergone significant spatiotemporal changes between 2014 and 2024 as shown in table 2. Areas with low soil losses (<50 t/ha/yr) decreased by 21.87 km$^2$ (2.60%) to 644.90 km$^2$ (81.12%), whereas zones with higher erosion classes increased. The share of moderate erosion zones (50 100 t/ha/yr) increased to 81.41 km$^2$ (9.63%), which is an increase in area compared with 71.91 km$^2$ (8.71%) in 2014, and the share of severe erosion zones (> 100 t/ha/yr) increased to 68.68 km$^2$ (8.64%) (5.83%) in 2024. Spatially, such increases are probably focused on upland croplands and deforested slopes, where vegetation clearing to make way for crops has led to increased runoff and rill development as shown in figure 1.

The identified trend is closely linked to agricultural growth and forest clearing, resulting in a loss of protective cover and increased erosion forces during monsoonal rains. This change highlights the urgency of establishing specific soil conservation practices, including contour farming, vegetative barriers, and agroforestry, to reduce erosion in areas that are prone to erosion in the sub-watershed.




*Source: calculated by researcher*

**Figure 1.** Potential annual soil erosion estimation (2024).

**Table 2.** Soil loss in the Amravati basin.

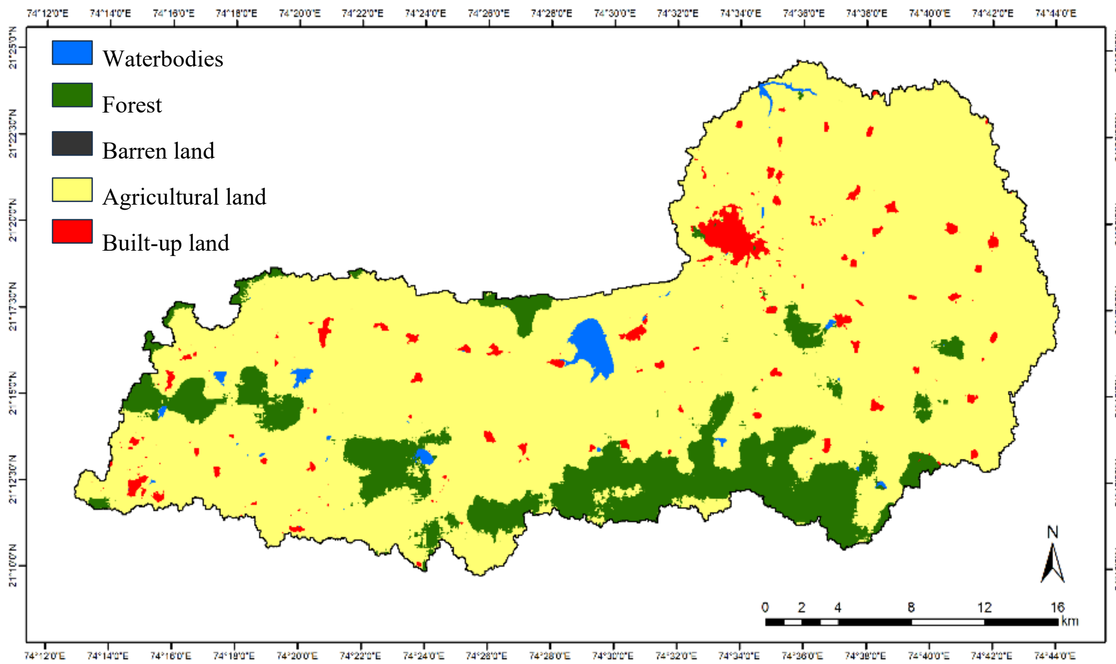
| **Year** | **2014** | | **2024** | |
|---|---|---|---|---|
| ***Soil Loss (tones / hectare / year)*** | ***Area (sq.km)*** | ***Area (%)*** | ***Area (sq.km)*** | ***Area (%)*** |
| Less than 50 | 676.77 | 85.13 | 644.90 | 81.12 |
| 50 - 100 | 71.91 | 9.05 | 81.41 | 10.24 |
| 100 - 150 | 20.34 | 2.56 | 23.69 | 2.98 |
| 150 - 200 | 9.03 | 1.14 | 15.34 | 1.93 |
| More than 200 | 16.94 | 2.13 | 29.65 | 3.73 |

*(Source: calculated by researcher using ArcGIS and RUSLE model)*

**Table 3.** LULC of the Amravati basin.

| **Year** | **2014** | | **2024** | |
|---|---|---|---|---|
| **LULC** | **Area (Sq.km)** | **Area (%)** | **Area (Sq.km)** | **Area (%)** |
| Forest | 165.5 | 20.82 | 127.2 | 16.00 |
| Agricultural land | 554.02 | 69.69 | 572.4 | 72.00 |
| Built-Up Land | 42.78 | 5.38 | 55.65 | 7.00 |
| Barren land | 8.6 | 1.08 | 7.95 | 1.00 |
| Water bodies | 24.1 | 3.03 | 31.8 | 4.00 |

*(Source: Landsat 8 & ASTER satellite data)*




*Source: ASTER Satellite & Landsat 8, 2020*

**Figure 2**. Land use of the Amravati basin (2024).

***Impact of Agricultural Expansion on Soil Erosion***

The expansion of agriculture in the Amravati Basin has been shown to increase soil erosion. Correlation and regression statistical analyses indicated a very high positive association between the size of agricultural land and the predicted soil loss. In particular, the clearing of forests or grasslands to cultivate land has caused a significant increase in erosion. Tables and graphs are used to show how the erosion rate varies with the type of land use/land cover, with agricultural land always recording higher erosion rates than other types of land cover. This emphasizes the sensitivity of newly cultivated farmlands to soil erosion, particularly at the early stages of cultivation. The analysis of change detection can be applied to demonstrate changes in farm ponds. The changes in land use/land cover between 2014 and 2024 are detailed in Table 3 and the spatial distribution of land use/land cover classes in 2024 is illustrated in Figure 2.

***Correlation Analysis***

In the Amravati basin, there was a definite correlation between soil erosion intensity and agricultural land expansion from 2014 to 2024. The agricultural land area increased between 2014 and 2024 by 18.38 $km^2$ to 572.4 $km^2$ (72.00%), with a net increase of 18.38 $km^2$. During the same interval, the area of soil loss > 100 t/ha/yr increased: the "100-150" category grew to 23.69 $km^2$, 150-200 to 15.34 $km^2$, and >200 to 29.65 $km^2$. The spatial pattern shows that there was a change in land use, especially the expansion of agricultural land into forested land (forest cover decreased by 38.3 $km^2$ to 127.2 $km^2$), which could be causing the rise in erosion levels.

The Pearson correlation coefficient testing of the percentage of agricultural land and the percentage of high soil loss area (category >100 t/ha/yr) yields $r \approx 0.94$, implying a very strong positive correlation. This implies that the percentage of high soil loss areas increases with an increase in agricultural area, possibly as a result of less vegetation cover and more intensive farming on slopes that are vulnerable to soil erosion.

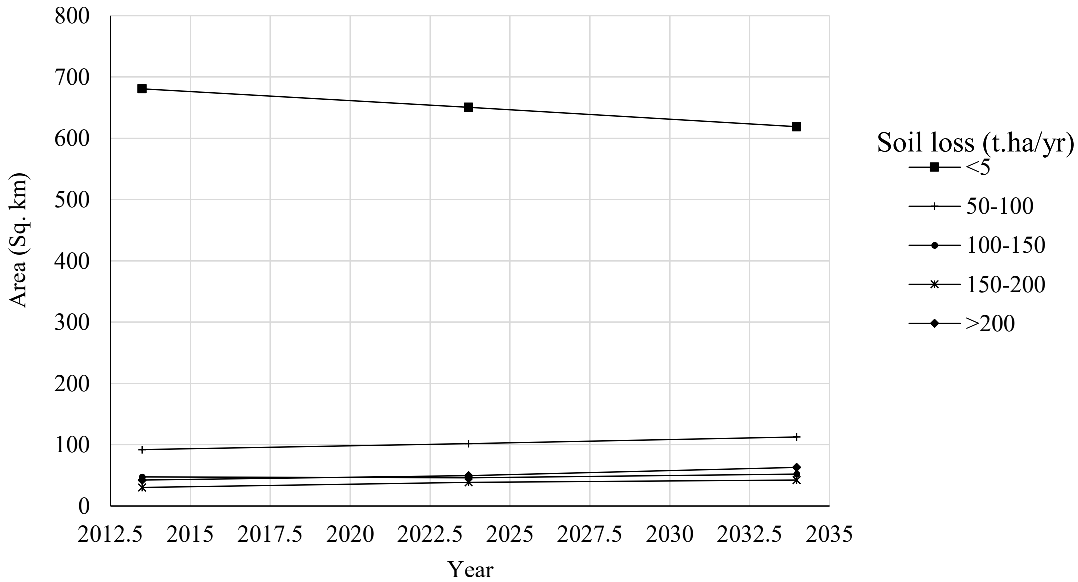



**Figure 3.** Soil loss prediction in Amravati basin.

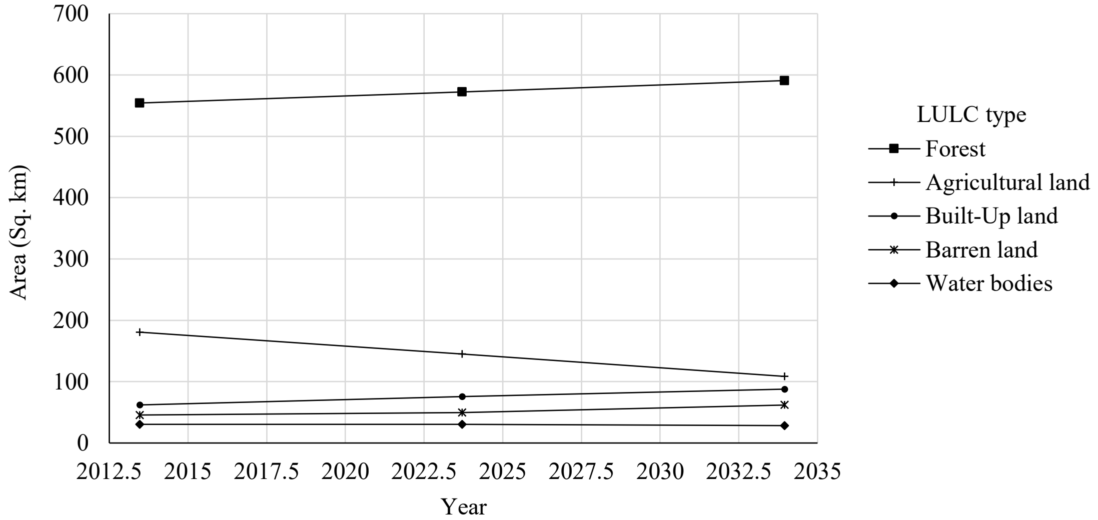



**Figure 4.** LULC prediction in Amravati basin.

***Prediction Analysis***

In Figure 3, The environmental trends depicted by the prediction analysis of soil erosion and land use/land cover (LULC) changes in the Amravati basin between 2014 and 2034 are significant. According to the soil erosion categories, the regions with < 50 t/ha/year soil reduction are expected to reduce by 676.77 sq. km to 613.03 sq. km between 2014 and 2034, implying an increasing intensity of erosion. In contrast, the erosion levels of 150–200 t/ha/year and >200 t/ha/year are likely to increase drastically, by 9.03 sq. km and 16.94 sq. km in 2014 to 21.65 sq. km and 42.36 sq. km in 2034, respectively. This implies that there is an increasing threat of land degradation unless mitigation strategies are applied.

In Figure 4, The LULC prediction shows significant changes in land cover. It is projected that forest cover will decrease significantly (165.50 sq. km in 2014 to 88.90 sq. km in 2034), and agricultural land will expand (554.02 sq. km in 2014 to 590.78 sq. km in 2034); however, built-up areas are likely to increase (42.78 sq. km in 2014 to 68.52 sq. km in 2034), which implies pressure on urban areas. It is estimated that water bodies will increase to 39.50 sq. km and decrease to 24.10 sq. km, possibly because of the development of reservoirs or a shift in hydrological patterns, and barren land will decrease to 7.30 sq. km and increase to 8.60 sq. km.

A high directional change in the severity of erosion and land cover type was observed based on the linear trend analysis. The reduction in the low-erosion categories is associated with deforestation and the growth of agricultural land, whereas the increase in high-erosion types is related to the growth of cities and the expansion of bare land. These trends are clearly visible in the prediction scatter plots, which provide a metric-based visual interpretation of spatial dynamics between 2014 and 2034.

## Discussion

Soil erosion in the Amravati Basin is caused by several factors, one of which is the expansion of agriculture. The deforestation of the natural vegetation cover and intensive tillage leave the soil susceptible to greater impact from rainfall and surface runoff, which accelerates erosion. These results support studies that have reported the negative impacts of agricultural expansion on soil degradation in other areas. The type of soil, climate, and topography in an area also affect the vulnerability of land to erosion.

The study is limited in its scope. Erosion rate estimates may be inaccurate because of uncertainties in the input data used by the RUSLE model, especially the rainfall erosivity and soil erodibility factors. Potential sources of error are also posed by assumptions in the RUSLE model and limitations of GIS analysis. For example, the RUSLE model ignores gully erosion and other complicated erosion mechanisms. In addition, better results may be obtained through bio-inspired optimization. Even with these limitations, the study helps gain invaluable information about the spatial distribution of soil erosion risk and the effects of agricultural expansion in the Amravati Basin. A comparison of these findings with those in the same agro-climatic zone can be used to develop a better approach to soil conservation and encourage good land management practices. In future, the study should focus on the use of more detailed data and sophisticated modeling methods to enhance the accuracy of soil erosion forecasting and the effectiveness of various soil conservation practices.

The results of the current study agree with many watershed-scale studies that have shown that land use change has a significant impact on soil erosion processes. For example, Tang et al. (2014) [16] demonstrated that the combination of RUSLE and GIS is a useful tool to quantify spatial patterns of soil loss and aid watershed management planning in the Loess Plateau in China. They also focused on the significance of vegetation cover and slope features in the severity of erosion. Similarly, Melese et al. (2021) [17] found that soil erosion in the Tagaw watershed was increasing along with changes in land cover, which validates the high applicability of the RUSLE-GIS framework in identifying spatiotemporal erosion patterns in large basins.

The positive correlation between agricultural expansion and high soil loss areas, as seen in this study, is similar to the findings of Moisa et al. (2020) [18], who observed that the transformation of forest and grassland to cultivated land had a significant effect on mean soil loss in the Temeji watershed. The fact that cultivated land is the most erosion-susceptible category, as pointed out in their study, corroborates the current observation that upland croplands and deforested slopes in the Amravati Basin are becoming significant erosion hotspots. Tsegaye and Bharti (2021) [19] showed that steeper and topographically dissected areas of watersheds always have a higher rate of soil loss, which supports the influence of the LS factor that was found in the present analysis.

The findings of the current study are generally in line with previous watershed-level studies conducted in India and other countries, which highlight the prevailing role of land use change in accelerating soil erosion. For example, Ganasri and Ramesh (2016) [20] in the Nethravathi Basin of the Western Ghats found that agricultural and human activities had a significant effect on soil erosion, especially on steep slopes, similar to the findings regarding the development of high-erosion regions in the upland croplands of the Amravati Basin. Likewise, in the Kangsabati basin, West Bengal, Bhattacharya et al. (2020) [21] established that the change in erosion susceptibility patterns in response to the change from forest to agricultural land was significant, supporting the current finding that forest-to-agricultural conversion is a major cause of erosion intensification.

The high topographic control found in this study is also supported by recent Indian studies. In the Subansiri River basin (Assam), Dutta et al. (2024) [22] demonstrated that the most intense soil erosion occurred in steep slope areas and under active human disturbance, which is consistent with the high LS factor impact and hotspot concentration in the Amravati basin. Furthermore, the multi-factor patterns of erosion identified in the present study are further supported by regional work in the Konkan region of Maharashtra, which identified rainfall erosivity and land cover as the main determinants of basin-scale soil loss using RUSLE-GIS methods.

The current study is more valuable than most Indian studies, which only provide estimates of erosion in the past or present, as it involves a future projection (2034). This prospective element enhances the practicality of the research for watershed planning in semi-arid areas of central India. In all, the consistency of the current results with earlier Indian case studies proves the strength of the combined RUSLE-GIS system and highlights the urgency of specific soil conservation actions in rapidly changing agricultural basins.

## CONCLUSION

This study was able to forecast the risk of soil erosion and the consequences of agricultural expansion in the Amravati Basin using the RUSLE model in a GIS environment. The results identified the locations that are susceptible to soil erosion, which is vital information for implementing interventions. This research is important because it can guide sustainable land management activities, which are vital in sustaining agricultural productivity and environmental health under pressure from rising land demands. Soil erosion is a crucial issue to address for long-term food security and maintaining ecosystems.

To reduce soil erosion, we suggest popularizing conservation agricultural practices, such as no-till farming, contour plowing, and cover crops. In addition, soil loss may be minimized by adopting agroforestry systems and vegetation buffer strips along watercourses. These measures must be incorporated into regional land-use plans and farm extension services to achieve widespread adoption.

Future studies should include climate change scenarios in erosion prediction models to consider altered rainfall patterns and temperature regimes. By employing more sophisticated erosion models, such as process-based models, a more detailed account of erosion processes may be gained. The predictions of the models should be validated by conducting field validation studies to calibrate and validate the predictions. Exploring the socioeconomic causes of agricultural expansion and their effects on land degradation is an important step in designing effective and sustainable land management measures. Additional research on the effectiveness of bio-inspired optimization algorithms for land management would also be possible.

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