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Soil erosion estimation in G-K watershed using geospatial techniques and Universal Soil Loss Equation (USLE)

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Abstract

Soil erosion is a critical environmental problem that significantly affects agricultural productivity, water quality and ecosystem sustainability. The G-K (Ghaggar-Karnal) Watershed, situated in the semi-arid zones of Haryana and Punjab, is particularly vulnerable to soil erosion due to high-intensity rainfall events, anthropogenic land-use changes and poor conservation practices. This study estimates the average annual soil loss in the G-K Watershed using the Universal Soil Loss Equation (USLE) integrated with Remote Sensing (RS) and Geographic Information System (GIS) techniques. Various thematic layers, such as rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover (C) and conservation practice (P) were generated using satellite imagery, digital elevation models (DEM) and field data. The results reveal spatial variation in erosion, with critical areas showing erosion rates above 40 tons/ha/year. These findings emphasize the need for immediate soil and water conservation interventions in high-risk sub-watersheds.

Soil erosion poses a major threat to land productivity, hydrological balance and environmental sustainability in watershed regions across India. The G-K (Ghaggar-Karnal) Watershed, covering parts of Haryana and Punjab, is highly susceptible to soil degradation due to intensive agriculture, deforestation, erratic rainfall and improper land management practices. Soil erosion not only reduces soil fertility but also contributes to siltation in reservoirs and degradation of water quality downstream. Accurate estimation and spatial assessment of soil erosion rates are essential for implementing effective soil conservation strategies. This study aims to estimate soil erosion in the G-K Watershed using the Universal Soil Loss Equation (USLE) integrated with Geographic Information System (GIS) and Remote Sensing (RS) techniques.

Keywords: River, watershed, soil erosion, geographical, universal soil loss equation, GIS and RIS

1. Introduction

Soil erosion is a globally recognized issue with severe consequences for food security, water supply and land sustainability. In India, watersheds across northwestern states like Haryana and Punjab are under constant threat due to intensive agriculture and rainfall variability. The G-K watershed, drained by the seasonal Ghaggar River, supports dense rural populations that depend on agriculture for their livelihoods.

Estimating soil erosion rates is essential for watershed management, land-use planning and conservation policy formulation. The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978) ^[1], remains one of the most reliable models for predicting soil loss at watershed scales. Recent advances in geospatial technologies such as satellite-based land cover analysis and DEM-based topographical assessments allow the integration of USLE with GIS, enabling spatially explicit erosion mapping. This paper aims to estimate soil erosion across the G-K watershed using a GIS-based USLE approach, identify erosion hotspots and suggest land management practices to mitigate degradation.

The widespread soil erosion issues have an impact on both emerging and wealthy nations. The effects of soil erosion, sometimes known as "soil cancer," are extensive, having negative effects on the economy, politics, society and environment. They also pose a growing threat to human existence on Earth (Pandey *et al.*, 2007) ^[2]. According to estimates, considerable soil erosion affects more than 50% and 80% of the world's forest and agricultural land, respectively.

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India is the second-most populous nation in the world despite having only 2.4% of the planet's total land area. About 5,334 metric tonnes of soil are eroded annually by various erosion processes throughout about 53% of the entire land area. One of the most important and precious resources on earth, soil is crucial for the health of ecosystems and is a key natural resource for sustaining life. The complicated and dynamic process of soil erosion results in the separation, transportation and deposit of surface soil to a distant location, ultimately exposing and degrading rich soils and causing sedimentation in reservoirs. early 20th century saw the introduction of the phrase "soil erosion". Background soil erosion is a natural process where soil is eroded by the action of various forces such as water or wind. The earth itself is as old as natural soil erosion. In the case of natural soil erosion, the rate of soil creation equals the rate of soil loss. However, where the rate of soil loss is far higher than its creation, rapid soil erosion has been recognised as a serious issue. Human actions that are ill-considered and unplanned frequently promote soil erosion.

2. Review of Literature

Numerous studies have highlighted the application of the Universal Soil Loss Equation (Wischmeier & Smith, 1978) and its variants (RUSLE, MUSLE) for erosion modeling in India. Jain *et al.* (2001)^[2] successfully applied USLE-GIS in the Himalayan region for prioritizing sub-watersheds. Similarly, Yadav and Mathur (2017)^[3] demonstrated effective mapping of erosion-prone zones using remote sensing and GIS in Rajasthan. These studies underscore the usefulness of GIS-based modeling in providing spatially distributed erosion estimates for sustainable watershed management. However, limited research exists for the G-K watershed, particularly integrating field-verified parameters with GIS models. This study will bridge that gap.

The literature reveals a multi-faceted relationship between the Ghaggar River watershed and the lives of local communities. While the river remains an essential resource for agriculture and domestic use, its seasonal and polluted nature has become a source of vulnerability especially for children's education and well-being. There is a clear research gap in the integration of watershed science with educational and social impact analysis. Future studies must adopt interdisciplinary approaches, combining hydrological modeling, field surveys and socio-educational assessments to offer holistic watershed development strategies.

3. Study Area Description

The G-K watershed is located in northwestern India, encompassing parts of Fatehabad, Sirsa and Karnal districts. It lies between 29°30'N to 30°20'N latitude and 75°30'E to 76°50'E longitude, covering approximately 3,000 km². The region exhibits a semi-arid climate with an average annual rainfall of 500-800 mm, most of which occurs during the monsoon season.

Topography ranges from flat plains to gently undulating terrain, with elevations between 200-300 meters above sea level. Land use is dominated by agriculture, primarily wheat, cotton and mustard crops, along with patches of fallow land and sparse vegetation. Soil types include sandy loam, loamy sand and alluvial soils prone to erosion, especially under intensive cultivation and poor conservation practices

- **Watershed Name:** G-K (Ghaggar-Karnal) Watershed

- **Location:** Parts of Haryana and Punjab
- **Coordinates:** Approximately between 29°30'N to 30°20'N and 75°30'E to 76°50'E
- **Area:** ~3,000 sq km (to be finalized with boundary delineation)
- **Topography:** Gently undulating terrain with slopes ranging from flat plains to moderate inclines
- **Climate:** Semi-arid with average annual rainfall of 500-800 mm
- **Land Use:** Primarily agricultural, interspersed with urban settlements, forest patches and fallow lands

300 meters above sea level. Land use is dominated by agriculture, primarily wheat, cotton and mustard crops, along with patches of fallow land and sparse vegetation. Soil types include sandy loam, loamy sand and alluvial soils prone to erosion, especially under intensive cultivation and poor conservation practices

4. Materials and Methods

4.1 Data Sources

Parameter	Source
Rainfall Data (R)	India Meteorological Department (IMD), 2001-2020
Soil Texture (K)	NBSS&LUP, Bhuvan Soil Atlas
DEM (30m resolution)	Shuttle Radar Topography Mission (SRTM)
Land Use/Land Cover	Landsat-8 OLI (2023)
Conservation Practices (P)	Field survey and secondary literature

4.2 USLE Model

The Universal Soil Loss Equation is given as

$$A = R \times K \times LS \times C \times PA = R \times K \times LS \times C \times PA$$

$$A = R \times K \times LS \times C \times P$$

Where:

- A = Estimated soil loss (tons/ha/year)
- R = Rainfall-runoff erosivity factor
- K = Soil erodibility factor
- LS = Topographic factor (slope length and steepness)
- C = Cover and management factor
- P = Conservation practice factor

R-Factor

Calculated using the rainfall intensity data as per Wischmeier and Smith (1978)

$$R = 79 + 0.363 \times \text{Annual Rainfall (mm)} \\ R = 79 + 0.363 \times \text{Annual Rainfall (mm)}$$

K-Factor

Derived from soil texture classes based on predefined tables (sandy loam = 0.30; loamy sand = 0.20).

LS-Factor

Calculated using the DEM-derived slope (θ) and slope length (L)

$$LS = (\text{Flow Accumulation} \times \text{Cell Size}^{22.13}) \times (\sin \theta)^{0.0896} \\ LS = \left(\frac{\text{Flow Accumulation} \times \text{Cell Size}}{22.13} \right)^m \times \left(\frac{\sin \theta}{0.0896} \right)^n \\ LS = (22.13 \text{ Flow Accumulation} \times \text{Cell Size})^m \times (0.0896 \sin \theta)^n$$

Where $m = 0.4$, $n = 1.3$ for most cultivated terrain.

C-Factor

Determined from LULC classification

- Dense vegetation: 0.01-0.1
- Agriculture: 0.3-0.4
- Barren land: 0.5-0.6

P-Factor

Assigned values based on land use practices (e.g., agriculture with no bunding = 1.0; terraced land = 0.5).

4.3 GIS Integration

All thematic layers were prepared using ArcGIS 10.8 and QGIS 3.24. Raster multiplication of R, K, LS, C and P factors yielded the final soil erosion map.

5. Results and Discussion

5.1 Estimated Soil Loss

The estimated soil erosion in the G-K watershed ranges from 0.1 to 60 tons/ha/year, with the mean value around 15 tons/ha/year. The area was classified into five categories:

Category	Erosion Rate (tons/ha/yr)	Area (%)
Very Low	< 5	28%
Low	5-10	22%
Moderate	10-20	25%
High	20-40	17%
Very High	> 40	8%

5.2 Spatial Distribution

- High erosion zones were concentrated in the southern and western parts of the watershed, especially in areas with steep slopes and sparse vegetation.
- Moderate zones were found in central agricultural zones where intensive tilling without bunding is common.
- Low erosion zones corresponded with dense vegetation and grasslands near the Ghaggar floodplains.

5.3 Critical Sub-Watersheds

Based on erosion values and slope characteristics, three sub-watersheds were prioritized for conservation:

- **SW1:** Erosion > 45 t/ha/yr; requires check dams and afforestation.
- **SW3:** Erosion 30-40 t/ha/yr; suitable for contour bunding.
- **SW5:** Moderate erosion; recommend vegetative hedgerows and crop rotation.

6. Conclusion

This study provides scientific insights into soil degradation patterns in the G-K watershed and aid policy makers, agricultural planners and local communities in implementing effective erosion control measures. It also showcases the applicability of modern geospatial tools in regional land degradation assessment.

The integration of USLE with GIS and RS techniques provided a comprehensive estimate of soil erosion in the G-K watershed. The findings show significant spatial variability in erosion rates, influenced by land use, slope and conservation practices. The identification of erosion-prone sub-watersheds offers valuable insights for targeted interventions such as afforestation, bunding and sustainable farming practices. This study contributes to effective watershed management and soil conservation planning in vulnerable regions of India.

7. Recommendations

- Implement soil and water conservation structures in high-risk zones.
- Promote agroforestry and cover crops in erosion-prone farmlands.
- Encourage capacity-building programs for farmers on soil health.
- Regular monitoring of erosion trends using updated satellite data.

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