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Sohail Indiakar
Project Co-ordinator, Shri
Siddeshwar Government First
Grade Collage, Nargund,
Karnataka, India

Bebijan Nadaf
Assistant Teacher, Govt. High
School, Govt. High School,
Kagadal, Belgaum, Karnataka,
India

Niyaz Nadaf
M.Sc. PG-Student, Department of
Physics, Rani Channamma
University, Vidya Sangama,
Belagavi, Karnataka, India

Harish Deshpande
Assistant Professor (Agronomy),
Water and Land Management
Institute (WALMI), Chhatrapati
Sambhajanagar, Maharashtra,
India

Harshada Deshmukh
Professor and Head (Addl),
Faculty of Agriculture, Water and
Land Management Institute
(WALMI), Chhatrapati
Sambhajanagar, Maharashtra,
India

Corresponding Author:
Sohail Indiakar
Project Co-ordinator, Shri
Siddeshwar Government First
Grade Collage, Nargund,
Karnataka, India

Spatial mapping and management of soil erosion using GIS: A global perspective

**Sohail Indiakar, Bebijan Nadaf, Niyaz Nadaf, Harish Deshpande and
Harshada Deshmukh**

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Abstract

Soil erosion by water and wind continues to degrade agricultural land, reduce reservoir capacity, and impair aquatic ecosystems worldwide. Integrating Geographic Information Systems (GIS) with erosion models has transformed the ability to quantify, visualise, and manage erosion risk across scales. This review synthesises global experience on spatial soil erosion mapping using GIS, with a particular focus on water erosion and the widespread application of the Revised Universal Soil Loss Equation (RUSLE) and related models. It examines key data sources, modelling frameworks, and typical workflows, and summarises case studies from Africa, Asia, Europe, and the Americas. Special attention is given to Indian applications, including watershed-scale assessments in Nethravathi, Chilika, Sangareddy, and other basins, which illustrate how GIS-based mapping supports the prioritisation of conservation measures. The review discusses strengths and limitations of empirical and process-based models, emerging use of cloud platforms and machine learning, and the integration of GIS outputs into policy and land management. It concludes by identifying methodological gaps and proposing research and management priorities to improve erosion prediction, monitoring, and decision support under climate and land-use change.

Keywords: Soil erosion, Geographic Information System (GIS), RUSLE, spatial modelling, conservation planning

1. Introduction

Soil erosion is a primary driver of land degradation and a persistent constraint on food and water security. It strips fertile topsoil, increases sediment loads in rivers and reservoirs, and diminishes the effectiveness of investments in irrigation and infrastructure. These impacts are particularly severe in densely populated regions and fragile environments where land use pressure and intense rainfall coincide.

Conventional erosion assessment relied on plot measurements, empirical equations, and expert judgment at limited spatial scales. While valuable, these approaches could not provide detailed, spatially explicit information over large basins or national territories. The maturation of GIS and remote sensing has changed this situation. Analysts can now integrate rainfall, soil, terrain, land use, and management data into spatially distributed erosion models, and produce maps at field to continental scales ^[1, 2].

2. Soil Erosion Processes and Global Status

2.1 Drivers and forms of erosion

Soil erosion by water involves detachment, transport, and deposition of soil particles by raindrop impact and runoff. Detachment occurs when raindrop energy and shear stress exceed soil cohesion. Transport occurs as sheet flow, rills, and gullies, eventually delivering sediment to channels and reservoirs.

Key drivers include:

- **Climate:** rainfall amount, intensity, and temporal pattern determine erosivity.
- **Soil properties:** texture, structure, organic matter, and infiltration control erodibility.
- **Topography:** slope length and steepness influence runoff energy.
- **Land cover and management:** vegetation cover, litter, and conservation structures reduce

- raindrop impact and runoff.
- **Human activities:** deforestation, overgrazing, road building, and inappropriate tillage intensify erosion.

Wind erosion, mass movements, and coastal processes are also significant in many landscapes, but most GIS-based global work has focused on water erosion, especially sheet and rill erosion [2, 3].

2.2 Global patterns and impacts

Recent global assessments using RUSLE-type models combined with GIS and remotely sensed datasets estimate that large parts of Africa, South and Southeast Asia, and Latin America experience soil loss rates above tolerable thresholds for sustainable agriculture. Mountainous regions, Mediterranean landscapes, and semi-arid zones often show severe localized erosion, whereas lowland plains with gentle slopes typically show lower rates [3, 4].

Impacts include

- reduced crop yields due to topsoil loss and nutrient depletion;
- increased sedimentation of reservoirs and irrigation canals;
- degradation of aquatic habitats from turbidity and nutrient enrichment; and
- elevated flood risk due to siltation and reduced channel capacity.

India typifies these pressures. High monsoon erosivity, steep slopes in the Himalaya and Western Ghats, and intensive cultivation in the Indo-Gangetic plains combine to create substantial erosion risk. GIS-based estimates indicate that in many Indian watersheds, soil loss exceeds $10 \text{ t ha}^{-1} \text{ yr}^{-1}$, which is often above locally accepted tolerable limits [4, 5].

3. GIS and Remote Sensing for Soil Erosion Mapping

3.1 Core datasets and spatial resolution

GIS-based erosion mapping relies on the integration of multiple spatial layers, typically including:

- **Digital Elevation Models (DEMs):** used to derive slope, slope length, flow accumulation, and topographic indices. Global sources include SRTM and more recent high-resolution DEMs.
- **Land use/land cover (LULC):** derived from satellite imagery (e.g., Landsat, Sentinel-2, MODIS). LULC classes feed into cover-management (C) factors or model parameters.
- **Soil maps:** provide texture, structure, organic matter, and hydrologic properties, used to derive soil erodibility (K) or parameters in physical models.
- **Rainfall and climate data:** gauge-based products, gridded climate datasets, or satellite rainfall provide inputs for rainfall erosivity (R) or hydrologic modules.
- **Management and conservation data:** locations and types of terraces, bunds, contour strips, or other practices inform support practice (P) factors or management scenarios.

Spatial resolution depends on purpose and data availability. Watershed-scale studies often use 10-30 m resolution DEMs and LULC, which balance detail and computational demands. National or continental assessments may adopt coarser grids (90-250 m or more) to match global datasets, as seen in global RUSLE applications [5, 6].

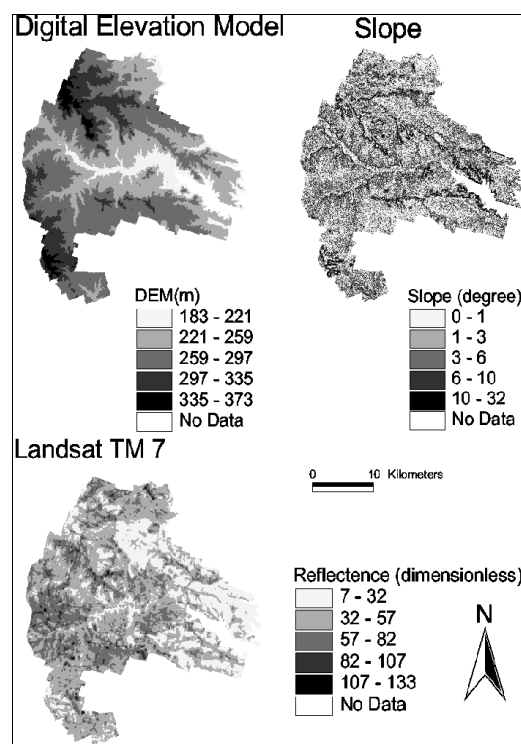


Fig 1: Shows elevation, slope steepness, and terrain influence on erosion. (Source; Wang, G., Gertner, G., Fang, S., & Anderson, A. B. (2003). Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. *Photogrammetric Engineering & Remote Sensing*, 69(8), 889-898. DOI:10.14358/PERS.69.8.889)

3.2 Standard GIS workflow for erosion mapping

A typical GIS-based workflow, especially when using RUSLE, includes:

1. **Data preprocessing:** projection, resampling, and clipping of DEM, LULC, soils, and climate data.
2. **Derivation of RUSLE factors or equivalent**
 - **R:** computed from rainfall intensity or empirical relationships with annual or monthly rainfall.
 - **K:** derived from soil texture and organic matter using standard equations.
 - **LS:** calculated from slope and flow accumulation derived from the DEM.
 - **C:** assigned based on LULC type and, where possible, vegetation indices such as NDVI.
 - **P:** assigned using information on conservation practices, often with assumptions in data-poor regions [6, 7].
3. **Raster algebra:** cell-by-cell multiplication of factor rasters to estimate annual soil loss.
4. **Classification and mapping:** grouping cell values into erosion severity classes for visualization and prioritization.
5. **Validation:** comparing model outputs with observed sediment yield, plot data, or expert knowledge where available.
6. **Scenario analysis:** evaluating alternative land management or climate scenarios by adjusting factors such as C and P [8, 9].

This workflow is now widely standardized and implemented in desktop GIS, open-source platforms, and cloud environments.

4. Modelling Frameworks Used with GIS

4.1 Empirical models: USLE and RUSLE

The Universal Soil Loss Equation (USLE) and its revised form

RUSLE remain the most widely applied models in GIS-based soil erosion mapping.

RUSLE estimates long-term average annual soil loss (A) as:

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

where R, K, LS, C, and P represent rainfall erosivity, soil erodibility, slope length-steepness, cover-management, and support practices, respectively [9, 10]. Its appeal lies in its relatively modest data requirements, modular structure, and the ease with which each factor can be represented as a raster layer in GIS. Studies across Africa, Asia, Europe, and the Americas have adapted factor estimation methods to local conditions and available data.

However, RUSLE is empirical, originally calibrated for US conditions, and primarily represents sheet and rill erosion on hillslopes. It does not explicitly simulate gully erosion, mass movements, or channel processes, and it does not directly estimate sediment yield at catchment outlets [11, 12].

4.2 Other empirical and semi-empirical models

Other empirical or semi-empirical models used with GIS include:

- **USLE variants and modified RUSLE:** adapted to specific climates or land uses, sometimes combined with sediment delivery ratio (SDR) concepts to estimate sediment export.
- **Unit stream power-based models:** linking shear stress and transport capacity to slope and discharge.
- **Multi-criteria evaluation (MCE):** combining factors such as slope, lithology, rainfall, and land cover using weighted overlays or analytical hierarchy process (AHP) to generate erosion susceptibility maps, often where calibration data are limited.

These approaches are attractive where data are sparse and where relative risk mapping is more important than precise estimation of soil loss [13, 14].

4.3 Physically based and distributed models

Physically based models represent hydrologic and erosion

processes using conservation equations and physically meaningful parameters. Common examples linked with GIS include:

- **WEPP (Water Erosion Prediction Project):** simulates infiltration, runoff, detachment, and deposition on hillslopes and in channels [15, 16].
- **SWAT (Soil and Water Assessment Tool):** models land phase and channel routing in large basins, including sediment and nutrients; widely used for scenario analysis.
- **Other distributed models:** ANSWERS, EROSION-3D, and regional models in Europe and elsewhere [16, 17].

These models offer process realism and allow event-scale simulation, but they require more detailed input data and calibration, which limits their use in data-poor regions or for very large domains.

4.4 Strengths, uncertainties, and validation

All models involve uncertainty arising from:

- input data quality and resolution;
- parameter estimation and transfer from other regions;
- structural simplifications (e.g., omission of gullies and channels in RUSLE); and
- scale mismatches between processes and grid cell size.

Comparative studies show that RUSLE in GIS often performs reasonably for relative risk mapping and for estimating mean annual soil loss where high-quality rainfall, soil, and DEM data exist. However, model predictions can differ substantially from observed sediment yields if sediment deposition, channel processes, and sediment delivery are not considered. Integration with SDR approaches and sediment monitoring networks can reduce this mismatch [17, 18].

Validation typically uses

- plot-scale erosion measurements,
- sediment yield at gauging stations,
- reservoir sedimentation surveys, or
- qualitative expert assessments.

Table 1: GIS-Based Soil Erosion Models and Their Key Parameters

Model Name	Type	Key Parameters	Strengths	Limitations
RUSLE	Empirical	R (Rainfall erosivity), K (Soil erodibility), LS (Slope length-steepness), C (Cover-management), P (Support practices)	Widely used, relatively simple to implement, modifiable to local conditions	Does not simulate gully or channel erosion, primarily for sheet and rill erosion
WEPP	Physically-based	Precipitation, soil texture, vegetation cover, slope, land use	More process-based, simulates hydrology and erosion processes, including channel erosion	Data-heavy, requires detailed inputs, higher computational demands
SWAT	Physically-based	Land use, soil properties, weather data, hydrology, topography	Simulates both water quality and quantity, large-scale applicability	Requires large datasets, complex calibration and validation
USLE	Empirical	R (Rainfall erosivity), K (Soil erodibility), LS (Slope length-steepness), C (Cover-management), P (Support practices)	Simpler alternative to RUSLE, widely applied, especially for smaller-scale studies	Less accurate compared to RUSLE, less suitable for large or complex landscapes
MCE (AHP)	Multi-criteria	Slope, land cover, lithology, rainfall	Integrates multiple factors for risk mapping, flexible in data-sparse regions	Does not provide quantitative estimates of soil loss, subjective weighting of parameters

5. Global Applications and Case Studies

5.1 Africa

African landscapes show strong spatial variability in erosion due to contrasting climates, soils, and land use. GIS-based RUSLE applications across Ethiopia, North Africa, and other countries illustrate the power of spatial mapping for prioritization.

In Horo district, western Ethiopia, Olika and co-authors applied RUSLE in a GIS environment using 12.5 m DEM, LULC, soil,

and rainfall data. They reported mean annual soil loss of about 23 t ha⁻¹ yr⁻¹, with some hotspots exceeding 80 t ha⁻¹ yr⁻¹. High erosion occurred on steep cultivated slopes with sparse cover, whereas forested and gently sloping land experienced low losses. The resulting maps guided recommendations for terracing, contour ploughing, and afforestation [19, 20].

In North Africa, several studies in Algerian and Tunisian watersheds combined USLE/RUSLE with GIS to map erosion

severity. In the Mellegue watershed at the Algeria-Tunisia border, annual soil loss showed strong spatial heterogeneity, with vulnerable areas concentrated on steep slopes with degraded vegetation. These maps supported prioritization of check dams and reforestation [21, 22].

At continental scale, reviews of soil loss estimation in Ethiopia and neighbouring countries highlight the dominance of GIS-RUSLE approaches, often combined with SDR and watershed prioritization frameworks [22, 23].

5.2 Asia (excluding India)

Across Asia, monsoon climates, steep terrain, and rapid land-use change create intense erosion pressures. GIS-based mapping has been widely adopted.

In Dolakha district, Nepal, Thapa used RUSLE with GIS to map soil erosion under different land use categories. The study reported that about one-third of the district experienced moderate to very severe erosion, driven mainly by steep slopes and deforested or intensively cultivated land. Forest and grassland showed much lower erosion rates, reinforcing the role of vegetation cover [24, 26].

In Bangladesh, Al Shoumik and colleagues applied RUSLE and GIS to tertiary hill tracts from 2017 to 2021, finding average soil loss around 30 t ha⁻¹ yr⁻¹ in highly erodible hilly areas. The study emphasized how deforestation and expanding settlements increased erosion risk [28, 29].

In Pakistan's Jhelum River watershed (Azad Jammu and Kashmir), Waseem *et al.* combined RUSLE with high-resolution GIS layers to map erosion risk classes. Annual soil loss ranged from near zero to thousands of tons per hectare per year in localized steep zones, with severe classes concentrated on steep, sparsely vegetated slopes. The maps helped identify priority sub-watersheds for interventions [30, 31].

5.3 Europe

European studies often integrate long-term monitoring, detailed soil databases, and high-resolution DEMs.

Several Mediterranean catchments have been analysed using RUSLE and GIS, highlighting strong seasonality and high erosion from intense storms on degraded shrublands and cultivated slopes. In many cases, studies combine RUSLE with AHP or other multi-criteria methods to derive composite erosion-susceptibility indices [32, 33].

In the European Union, large-scale modelling efforts integrate RUSLE-type approaches with harmonized soil and climate datasets to generate continental erosion risk maps. These products inform agricultural and environmental policy, including cross-compliance measures and soil conservation guidelines [34, 35].

5.4 The Americas

In North and South America, GIS-based erosion mapping includes both RUSLE applications and physically based models. In Brazil, Barbosa and co-authors reviewed RUSLE-based modelling for diverse Brazilian landscapes, emphasising how differences in rainfall regime, soils, and land use require careful regional calibration of factors, especially R and C. Similar work in the United States and Mexico has integrated RUSLE with high-resolution DEMs and detailed land cover datasets to support conservation planning [36, 37].

Process-based models such as WEPP and SWAT are also widely applied in the Americas. For example, SWAT-based studies in West Bengal (India) and other regions demonstrate how hydrologic-sediment models can complement RUSLE by simulating sediment routing and evaluating reservoir sedimentation [38, 39].

Table 2: Case Studies of GIS-Based Soil Erosion Mapping in Different Regions

Region	Model Used	Soil Loss Estimates	Key Findings	Conservation Measures Recommended
Africa (Ethiopia)	RUSLE	23 t ha ⁻¹ yr ⁻¹ (mean), 80 t ha ⁻¹ yr ⁻¹ (hotspots)	High erosion on steep slopes with sparse vegetation, forested areas had lower erosion rates	Terracing, contour ploughing, afforestation
Asia (Nepal)	RUSLE	Moderate to very severe erosion in one-third of the district	Steep slopes and deforested land led to increased erosion	Vegetative barriers, reforestation, contour farming
Europe (Mediterranean)	RUSLE with MCE (AHP)	High seasonal variation in erosion rates	Degraded shrublands and cultivated slopes experienced higher erosion during storms.	Check dams, slope stabilisation, and vegetation cover enhancement.
India (Chilika)	RUSLE with GIS and Remote Sensing	Low to very high, with hotspots contributing to lake sedimentation	High erosion risk in upper catchments, especially in deforested areas	Soil and water conservation measures, watershed management, and afforestation

6. Indian Experience with GIS-Based Soil Erosion Mapping

6.1 National and regional perspectives

India has been a major adopter of GIS-based erosion mapping due to its diverse agro-ecological zones and large investments in watershed development and soil conservation. National-scale assessments by research institutes and government agencies have used RUSLE-type models to classify erosion risk across states and prioritize interventions. These assessments typically integrate:

- gridded rainfall products for erosivity;
- national soil databases for erodibility;
- SRTM or similar DEMs for LS factors; and
- national LULC maps for C factors.

At regional and watershed scales, Indian studies provide detailed examples of how GIS-based mapping supports land and water management [40, 41].

6.2 Nethravathi Basin, Karnataka

Ganasri and Ramesh applied the RUSLE model within a GIS environment to the Nethravathi Basin in Karnataka, using rainfall, soil, LULC, and topographic data. They derived factor maps and computed cell-wise soil loss, classifying erosion into five severity classes [41, 42].

Key findings included

- a large proportion of the basin under low to moderate erosion;
- severe erosion concentrated in steep, deforested or cultivated uplands; and
- strong sensitivity of estimates to the LS factor derived from the DEM.

The study demonstrated that RUSLE-GIS can identify erosion hotspots in a humid tropical basin and support planning of check

dams, contour bunds, and reforestation. Its methodology has been widely cited and adapted in other Indian watersheds [43, 44].

6.3 Chilika Lake watershed, Odisha

Chilika Lake, a brackish coastal lagoon in Odisha, faces sedimentation and ecological stress from upstream erosion. Behera and co-authors used RUSLE combined with remote sensing and GIS to quantify soil loss in the Chilika watershed. The study computed R, K, LS, C, and P factors from rainfall, soil maps, DEM, and multi-temporal LULC, and produced erosion maps showing that:

- roughly three-quarters of the watershed area fell under low erosion risk;
- a smaller but critical fraction experienced high to very high erosion, especially in deforested upper catchments; and
- these hotspots contributed disproportionately to sediment inflow to the lake.

These outputs are directly relevant for targeting soil and water conservation measures in sub-watersheds feeding Chilika, and for protecting the lake's fisheries and biodiversity [45, 46].

6.4 Semi-arid and plateau regions: Telangana, Madhya Pradesh, West Bengal

In semi-arid and plateau regions, GIS-based erosion mapping has focused on rainfed agriculture and drought-prone districts.

Sangareddy district, Telangana

A study in Sangareddy district used RUSLE within GIS to estimate spatial patterns of soil loss. Using rainfall, soil, DEM, and LULC data, the authors found that:

- most of the district experienced soil loss below $5 \text{ t ha}^{-1} \text{ yr}^{-1}$;
- limited areas showed losses above $20 \text{ t ha}^{-1} \text{ yr}^{-1}$, especially on steep cultivated land; and
- validation against observed sediment data ($R^2 \approx 0.82$) indicated satisfactory model performance.

The study recommended prioritizing contour farming, vegetative barriers, and check dams in high-loss zones.

Anuppur district, Madhya Pradesh

In Anuppur district, a recent study employed RUSLE with GIS tools to estimate both soil erosion and fertility risk. The authors computed R, K, LS, C, and P using rainfall time series, soil texture, DEM-derived slopes, and LULC, and highlighted that steep, deforested slopes and mining-affected areas showed very high erosion. The findings support targeted watershed treatment in central Indian highlands [47, 48].

Dwarakeswar-Rupnarayan basin and neighbouring basins, West Bengal

In West Bengal, RUSLE and SWAT have been used to analyse soil erosion and its future trends in the Dwarakeswar and neighbouring basins. These studies showed:

- substantial erosion on cultivated uplands with lateritic soils;
- sensitivity of soil loss to projected land-use change and rainfall variability; and
- opportunities to test management scenarios such as increased vegetative cover or conservation tillage [48, 49].

The integration of RUSLE with Google Earth Engine for the Dwarakeswar-Rupnarayan basin and similar basins illustrates how cloud platforms can speed analysis and facilitate multi-temporal mapping.

6.5 Lessons for Indian land and water management

From these and many other case studies across India, several lessons emerge:

1. **High spatial variability:** even within a single district, soil loss can vary from less than $1 \text{ t ha}^{-1} \text{ yr}^{-1}$ in plains or forest to more than $50 \text{ t ha}^{-1} \text{ yr}^{-1}$ on steep, cultivated slopes. GIS-based maps capture this variability and prevent uniform, inefficient interventions.
2. **Importance of LULC:** conversion of forest or scrub to cropland or built-up area often leads to rapid increases in erosion, especially where slopes are moderate to steep.
3. **Sensitivity to DEM and rainfall data:** LS and R factor estimation strongly influence results; higher-resolution DEMs and improved rainfall products significantly enhance reliability.
4. **Policy relevance:** outputs can feed directly into programmes such as watershed development, MGNREGA-supported soil conservation, and reservoir sedimentation management [44, 49].

7. From Maps to Management: Policy and Decision Support

7.1 Prioritizing interventions and ecosystem services

Erosion maps generated in GIS are not ends in themselves; they are decision-support tools. They enable:

- **Prioritization of critical areas:** sub-watersheds or micro-watersheds with the highest erosion risk receive early attention and more intensive treatment.
- **Targeting of measures:** slope, land use, and erosion severity guide selection of interventions such as terracing, vegetative strips, gully control structures, or reforestation.
- **Ecosystem service assessment:** erosion reduction benefits soil fertility, carbon storage, and downstream water quality; GIS outputs can be linked with valuation frameworks.

For example, in the Horo district of Ethiopia and in Indian watersheds such as Nethravathi and Chilika, erosion maps have informed location-specific combinations of agronomic, vegetative, and structural measures that maximize conservation impact per unit investment.

7.2 Mainstreaming GIS into agricultural and watershed programmes

The effectiveness of GIS-based mapping depends on its integration into institutional processes. Important aspects include:

- **Standardized methods:** adoption of common RUSLE factor estimation protocols and data sources within national agencies supports consistent planning.
- **Capacity building:** training extension staff and watershed planners in basic GIS and interpretation of erosion maps increases utilisation of the outputs.
- **Monitoring and feedback:** periodically updating LULC and erosion maps allows evaluation of conservation investments and refinement of models.

In India, the integration of remote sensing and GIS into watershed development programmes under various ministries has already begun. Extending these approaches to all major river basins and aligning them with state-level soil conservation services would further enhance impact [49, 50].

7.3 Cloud platforms, open data, and participatory tools

New technologies are lowering barriers to sophisticated erosion assessments:

- **Cloud platforms (e.g., Google Earth Engine):** enable

rapid processing of large satellite and climate datasets for RUSLE and other models, as illustrated by recent work in Mediterranean and Indian basins.

- **Open-source tools:** QGIS, GRASS GIS, and open libraries support reproducible modelling without expensive licences.
- **Web-based viewers:** interactive maps allow local stakeholders and decision-makers to explore erosion patterns and proposed interventions.
- **Citizen science and local data:** integrating local observations, photos, and simple field measurements can improve model calibration and foster ownership.

These tools, when properly used, can make erosion information accessible beyond specialized technical teams.

8. Knowledge Gaps and Future Directions

Despite substantial progress, important gaps remain in GIS-based soil erosion mapping:

1. **Representation of gully and channel erosion:** RUSLE-based approaches primarily capture sheet and rill erosion. Incorporating gully and channel contributions, especially in semi-arid and hilly regions, remains difficult but essential for accurate sediment yield estimates.
2. **Improved sediment delivery modelling:** Coupling RUSLE with SDR, routing models, or process-based frameworks can better link hillslope loss with downstream sedimentation, reservoir life, and flood risk.
3. **Data quality and resolution:** Many regions still lack high-resolution, up-to-date soil maps, rainfall intensity data, and accurate DEMs. Investment in base datasets and sharing protocols will directly enhance erosion modelling [47, 50].
4. **Uncertainty quantification:** Few applied studies provide systematic uncertainty analysis. Adopting ensemble approaches, sensitivity analysis, and probabilistic mapping would allow decision-makers to understand confidence levels.
5. **Climate and land-use change integration:** While some case studies in India and elsewhere model future scenarios, most assessments remain static. Expanding scenario analysis with regional climate projections and land-use models would support long-term soil and water conservation planning.
6. **Machine learning and hybrid methods:** There is growing interest in combining RUSLE or physically based models with machine learning techniques that exploit large archives of satellite and environmental data. These hybrid approaches may improve prediction where process understanding is incomplete but data are abundant.
7. **Socio-economic integration:** Erosion maps are rarely combined with socio-economic layers such as poverty, land tenure, or livelihood dependence. Integrating these dimensions would help target interventions where both biophysical risk and social vulnerability are high [50, 51].

For India, in particular, expanding multi-scale erosion monitoring networks and integrating them with GIS models would underpin robust calibration and support adaptive management under changing monsoon behaviour.

9. Conclusion

GIS-based spatial mapping of soil erosion has become a central tool for diagnosing land degradation and supporting conservation planning worldwide. The integration of RUSLE and related models with DEMs, satellite-derived land cover, soil maps, and climate datasets allows detailed, spatially explicit estimation of erosion risk from field to global scales. Case

studies from Africa, Asia, Europe, and the Americas demonstrate that these approaches consistently reveal strong spatial heterogeneity in erosion, concentrate risk in steep and poorly covered slopes, and identify priority areas for intervention [52, 53].

The Indian experience illustrates both the utility and challenges of these methods. Studies in Nethravathi, Chilika, Sangareddy, Anuppur, and other basins show how erosion maps have informed watershed treatment, soil conservation, and reservoir protection. They also highlight persistent issues: dependence on empirical models, sensitivity to input data, and limitations in representing gully and channel erosion.

Overall, the evidence indicates that GIS-based erosion mapping, when carefully implemented and validated, provides a powerful basis for targeting conservation investments, safeguarding ecosystem services, and supporting climate-resilient agriculture. Future progress will depend on improving data quality, expanding process-based and hybrid modelling, better accounting for uncertainty, and integrating socio-economic and climate change dimensions. For India and other countries experiencing rapid environmental and socio-economic change, strengthening these approaches and embedding them in policy and planning frameworks is essential to protect soil resources and the livelihoods that depend on them [54].

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