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Review of Soil Erosion and Land Use/Land Cover Changes using GIS and Remote Sensing in Soro District

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Abstract: *Soil erosion and land use/land cover (LULC) changes are major environmental concerns that influence agricultural productivity, soil fertility, hydrological processes, and sustainable land management. Soro, located in Balasore district of Odisha, India, experiences a combination of agricultural land use, settlement expansion, vegetation changes, and monsoon-related rainfall conditions that make the assessment of soil erosion and land transformation important. Geographic Information Systems (GIS) and remote sensing provide effective techniques for examining spatial and temporal variations in land cover, identifying erosion-prone areas, and supporting natural resource management. This review examines the applications of GIS and remote sensing for soil erosion assessment and LULC change analysis, with particular emphasis on methodologies and research published between 2010 and 2022. It discusses satellite-based land classification, the Revised Universal Soil Loss Equation (RUSLE), digital elevation models, rainfall erosivity, soil erodibility, vegetation cover, and topographic characteristics.*

Keywords: Soil erosion, land use/land cover, GIS, remote sensing, Soro, sustainable land management.

I. INTRODUCTION

Soil erosion is a natural geomorphological process that involves the detachment, transportation, and deposition of soil particles through the action of water, wind, and gravity. Although erosion occurs naturally, human activities such as deforestation, intensive cultivation, construction, vegetation removal, and unplanned urban development can accelerate soil loss and reduce the productive capacity of land. Soil erosion is particularly important in regions where seasonal rainfall, exposed soil surfaces, and changing land-use patterns interact to influence surface runoff and sediment transport. Land use/land cover (LULC) changes are closely associated with these processes because they modify vegetation density, infiltration capacity, soil exposure, and the movement of water across the landscape.

Remote sensing and GIS have become widely used tools for understanding these interactions because they allow researchers to map land-cover patterns, examine changes over time, and integrate environmental variables into spatial models. Research by Vrieling (2006), although published before the review period, established important principles for satellite-based erosion assessment, while subsequent research has expanded the application of geospatial technologies for land degradation monitoring and soil conservation.

The present review focuses on Soro, a town and surrounding region in Balasore district, Odisha, where agricultural landscapes, settlements, drainage systems, and seasonal climatic conditions provide a relevant setting for studying soil erosion and land-cover transformation. For this paper, "Soro District" is interpreted as the Soro study area, rather than an independently established administrative district. The assessment period of 2010–2022 is suitable for a retrospective analysis using satellite observations, provided that consistent imagery and reliable classification methods are available.

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The review brings together established research on GIS, remote sensing, LULC classification, and erosion modelling to develop a conceptual framework for investigating environmental changes in Soro. It does not assume that findings from other regions directly represent local conditions; instead, it identifies methods and relationships that can be tested using Soro-specific spatial data.

REVIEW OF LITERATURE

Research during 2010–2022 demonstrated the growing importance of satellite imagery and GIS in identifying land-cover changes and assessing soil erosion. The development of freely accessible Landsat imagery, improved image-processing methods, and more widely available digital elevation models enabled researchers to examine landscape transformation at different spatial and temporal scales. Roy et al. (2016) described the significance of India's Resourcesat-2 satellite and its applications in land and resource monitoring, illustrating the relevance of remote sensing for national and regional environmental assessment. Similarly, Drusch et al. (2012) discussed the Sentinel-2 mission and its potential for monitoring vegetation, land surfaces, and environmental changes through multispectral observations. These developments provided important methodological foundations for evaluating land-cover transitions and vegetation conditions.

Studies of land-cover classification also emphasized the importance of reliable training data, classification algorithms, and accuracy assessment. Congalton and Green (2019) explained the importance of confusion matrices, reference samples, and statistically sound accuracy assessment in remote-sensing classification. These principles are directly relevant to a Soro-based investigation because agricultural fields, fallow land, built-up areas, vegetation, and water bodies may have similar spectral characteristics during particular seasons. Multi-date satellite observations and field-based validation can reduce classification uncertainty and improve the reliability of LULC change estimates.

Research on soil erosion modelling has increasingly combined topographic, climatic, soil, and vegetation information in GIS environments. The Revised Universal Soil Loss Equation, developed from earlier empirical erosion research, is widely used to estimate long-term average sheet and rill erosion. Renard et al. (1997) provided the foundational RUSLE framework, while later GIS-based applications demonstrated how spatial datasets can be integrated to map relative erosion susceptibility. Panagos et al. (2015) presented a European-scale assessment of soil erosion by water, illustrating the value of spatially integrated erosion modelling and the importance of considering rainfall, soil properties, topography, land cover, and conservation practices. Although this study does not directly describe Soro, its modelling framework is relevant to designing a regional erosion assessment.

Research on land degradation has also highlighted the importance of vegetation cover and land management. García-Ruiz et al. (2015) reviewed the influence of land-use changes on soil erosion in Mediterranean environments, emphasizing that the effects of land transformation depend on vegetation, climate, and land-management practices. Their findings support the general proposition that changes in land cover can modify erosion processes, but the magnitude and direction of those effects must be evaluated within the local environmental context. For Soro, this means that conversion of vegetated or agricultural land to built-up surfaces, changes in cropping patterns, or the removal of protective vegetation should be examined using local satellite data rather than presumed to have a uniform effect.

The literature further indicates that GIS and remote sensing are most useful when integrated with field observations and supporting environmental datasets. Satellite-derived land-cover maps can reveal spatial patterns, while digital elevation models can characterize slope and drainage, rainfall data can represent climatic forcing, and soil maps can describe erodibility. However, the accuracy of erosion estimates depends on the resolution, temporal consistency, and quality of these inputs. Consequently, a comprehensive assessment of Soro for 2010–2022 should combine multi-temporal satellite imagery with validated LULC classification, spatial erosion modelling, and ground-based observations.

STUDY AREA: SORO, ODISHA

Soro is situated in Balasore district in the coastal region of Odisha. Its surrounding landscape can be investigated through a combination of agricultural land, settlements, vegetation, drainage networks, and terrain characteristics. The interaction of seasonal rainfall, soil properties, land management, and surface topography provides the basis for examining potential soil erosion patterns. However, the distribution and extent of these characteristics within the precise Soro study boundary must be established from official administrative maps, satellite imagery, and field observations.

The wider Odisha region provides relevant comparative research. Srinivasan et al. (2019) applied the Universal Soil Loss Equation framework with remote sensing and GIS in a coastal Odisha study area. Their analysis identified spatial differences in soil erosion susceptibility and associated higher-risk locations with foothills and steeper slopes. This provides a regional methodological reference, but its numerical results should not be transferred directly to Soro.

APPLICATION OF REMOTE SENSING IN LULC CHANGE DETECTION

Remote sensing enables the systematic observation of land-surface characteristics over repeated periods. Landsat imagery is particularly useful for historical analysis because its long observation record supports comparisons across years, while Sentinel-2 imagery provides finer spatial detail for more recent land-cover mapping. A Soro-focused study could use satellite images from representative years such as 2010, 2015, 2020, and 2022, selecting comparable seasonal windows to reduce the effects of seasonal vegetation changes. Image preprocessing should include cloud and shadow screening, geometric consistency, and appropriate atmospheric correction.

Land-cover classification could distinguish agricultural land, forest or dense vegetation, other vegetation, built-up land, water bodies, and barren or exposed soil. Supervised classification methods, including Random Forest and Support Vector Machines, can be used to assign pixels to these categories. Classification accuracy should be assessed using independent reference samples and a confusion matrix, reporting overall accuracy, class-specific accuracy, and the number of validation samples. Congalton and Green (2019) provide methodological guidance for designing and interpreting such assessments.

Changes between years can be quantified using a transition matrix, which identifies the conversion of one land-cover class into another. For example, the analysis could identify whether agricultural land was converted to built-up land, whether exposed soil became vegetated, or whether vegetation changed to another class. Such transitions are potential indicators of environmental change, but their actual direction and magnitude in Soro must be derived from classified imagery rather than assumed.

Table 1. Remote-sensing datasets and their proposed applications

Dataset	Approximate spatial resolution	Proposed application
Landsat 5 TM	30 m	Historical land-cover mapping where suitable imagery is available
Landsat 7 ETM+	30 m	LULC comparison, with attention to scan-line gaps
Landsat 8 OLI	30 m	Land-cover classification and vegetation analysis
Sentinel-2 MSI	10–20 m for relevant bands	Detailed recent LULC classification
SRTM DEM	Approximately 30 m	Elevation, slope, and drainage analysis
Rainfall observations or gridded rainfall	Dataset-dependent	Rainfall erosivity estimation
Soil resource maps	Dataset-dependent	Soil erodibility estimation and soil characterization

Table 2. RUSLE factors, data requirements, and relevance to Soro

Factor	Required data	Relevance to the study
R – Rainfall erosivity	Rainfall records and intensity information	Represents the erosive potential of rainfall
K – Soil erodibility	Soil texture, organic matter, structure, permeability	Represents the susceptibility of soil to detachment

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LS – Topography	DEM, slope, flow accumulation	Identifies terrain conditions associated with runoff and erosion
C – Cover management	LULC maps, vegetation indices, crop information	Represents the protection provided by vegetation and management
P – Conservation practices	Field surveys and land-management information	Represents the influence of erosion-control practices

RELATIONSHIP BETWEEN LULC CHANGES AND SOIL EROSION

Land-cover change can alter erosion processes by changing the amount of soil exposed to rainfall and the capacity of the surface to absorb and retain water. Vegetated areas generally provide protection through canopy interception, litter cover, root systems, and improved soil structure. When vegetation is removed, soil may become more vulnerable to raindrop impact and surface runoff, particularly where the ground is bare during intense rainfall. However, the relationship depends on vegetation type, slope, soil conditions, and management practices; therefore, forest, agricultural, and grassland categories should not be assigned identical erosion characteristics.

Agricultural land can experience different levels of erosion depending on crop type, planting calendar, tillage, residue retention, and the duration of exposed soil. In a Soro assessment, seasonal satellite imagery would be important because the same agricultural field may appear green during one season and bare during another. A single image could therefore misrepresent the protective cover available during the most erosive rainfall period.

Urban expansion can also change the hydrological response of a landscape through the construction of roads, buildings, and other impervious surfaces. These surfaces may increase runoff concentration and redirect water toward exposed soil or drainage channels. Nevertheless, impervious surfaces themselves should not automatically be treated as sources of sheet and rill soil loss in a RUSLE model. Their effects may instead require additional analysis of drainage, construction sites, channel erosion, and sediment transport.

Regional research in Odisha illustrates the importance of assessing LULC changes independently rather than assuming uniform trends. Kaur et al. (2019) examined land-use and forest-cover dynamics in Odisha from 1996 to 2016 and reported changes in forest and built-up categories at the state scale. Their results establish a regional context for studying land transformation, but they do not provide direct measurements for Soro.

MAJOR RESEARCH FINDINGS AND COMPARATIVE EVIDENCE

The available literature indicates that GIS-based erosion modelling and satellite-based land-cover mapping can be combined to investigate soil degradation and environmental change. However, studies conducted in different geographical settings produce different erosion estimates because rainfall, topography, soil characteristics, and land management vary considerably.

Srinivasan et al. (2019) applied USLE-based modelling and geospatial techniques in a coastal Odisha study area. Their results indicated that 90.91% of the mapped area fell within the very-low soil erosion category, while smaller proportions were assigned to higher erosion classes. The study also identified elevated erosion susceptibility in foothill and upper-slope locations. These findings illustrate how topographic variation and vegetation cover can contribute to spatial differences in erosion risk. They are useful for developing a methodological framework for Soro, but the reported percentages are specific to the original study area.

A broader example is provided by Kaur et al. (2019), who examined Odisha's land-use and forest-cover dynamics over 1996–2016. Their research reported a decrease in the proportion of forest cover and an increase in built-up land at the state level. These results demonstrate the usefulness of multi-temporal satellite imagery for identifying long-term landscape transformations. However, they cannot establish the exact land-cover changes occurring in Soro between 2010 and 2022.

RESEARCH GAPS AND LIMITATIONS

Despite advances in GIS and remote sensing, several limitations remain relevant to a detailed assessment of soil erosion and LULC change in Soro. First, the absence of a verified local time-series classification means that the exact amount of agricultural land, vegetation, built-up area, and exposed soil cannot be established in this review. Second, the spatial resolution of satellite imagery may not adequately capture narrow drainage channels, small erosion gullies, field boundaries, and localized construction activities. Third, cloud cover and seasonal differences can affect image quality and classification accuracy. These limitations can be reduced through careful image selection, consistent preprocessing, multi-season observations, and field-based validation.

Another important limitation concerns the empirical nature of RUSLE. The model estimates long-term average sheet and rill erosion under specified conditions, rather than directly measuring actual sediment movement during individual storms. The accuracy of its outputs depends on the quality of rainfall, soil, topographic, vegetation, and conservation-practice data. In addition, soil erosion estimates may be affected by the use of generalized factor values instead of locally measured parameters. Consequently, a Soro-specific investigation should validate model outputs through field observations, erosion plots where feasible, sediment measurements, or comparison with documented erosion features.

A further research gap is the limited integration of LULC transition analysis with erosion modelling at the local scale. Mapping land-cover change and preparing an erosion-risk map independently may not fully explain how environmental transformation influences soil loss. A more comprehensive approach would calculate erosion estimates for multiple years and compare them with corresponding LULC maps. This would allow researchers to investigate whether changes in vegetation, cultivation, or settlement patterns coincide with changes in modelled erosion susceptibility.

RECOMMENDATIONS FOR SUSTAINABLE LAND MANAGEMENT

GIS and remote sensing can support sustainable land management by identifying locations where erosion-control measures may be required. In agricultural areas, potential interventions include maintaining crop residue, using cover crops, practicing contour cultivation on suitable slopes, and establishing vegetated buffer strips along drainage lines. Such measures can help reduce exposed soil and interrupt surface runoff, although their suitability must be assessed against local farming practices and terrain.

In locations where settlement expansion or construction exposes soil, erosion-control planning may include temporary ground cover, stabilization of disturbed surfaces, appropriate drainage design, and sediment-retention measures. Vegetation restoration and protection of existing ground cover may also contribute to soil conservation where these interventions are environmentally appropriate.

For Soro, conservation planning should be based on spatially explicit evidence rather than generalized assumptions. A GIS-based erosion-risk map could be combined with agricultural land-use information, drainage networks, settlements, and field observations to identify priority areas for further investigation. The resulting information could support local planning, watershed management, agricultural extension, and environmental monitoring.

II. CONCLUSION

The review demonstrates that GIS and remote sensing provide a systematic framework for assessing soil erosion and land use/land cover changes. Multi-temporal satellite imagery can be used to identify landscape transformations, while digital elevation models, rainfall information, and soil datasets can be integrated to estimate spatial patterns of erosion susceptibility. The RUSLE model provides a practical method for combining rainfall erosivity, soil erodibility, topography, vegetation cover, and conservation practices within a GIS environment.

Research from Odisha, including the studies of Kaur et al. (2019) and Srinivasan et al. (2019), provides relevant regional evidence and methodological guidance. Nevertheless, their findings should not be interpreted as direct measurements of Soro's land-cover changes or annual soil loss. Establishing those conditions requires a dedicated local analysis using consistent satellite imagery, reliable soil and rainfall datasets, accurate administrative boundaries, and field-based validation.

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A comprehensive assessment covering 2010–2022 could contribute to understanding the spatial relationship between land-cover transitions and erosion susceptibility in Soro. By integrating remote sensing, GIS, RUSLE modelling, and field observations, future research could produce validated land-cover maps, identify areas requiring conservation attention, and provide an evidence base for sustainable agricultural and land-use planning.

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