

Role of Soil Loss, Agricultural Land Transformation, and Crop Production Variability in Soro District using Geospatial Techniques

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Abstract: Soil loss, agricultural land transformation, and crop production variability are interconnected environmental and agricultural challenges that influence land productivity, food security, and rural livelihoods. This research paper examines the role of these factors in Soro District through the application of geospatial techniques, including remote sensing, Geographic Information Systems (GIS), satellite image classification, vegetation indices, and soil erosion modelling. The study focuses on identifying changes in agricultural land use, assessing the spatial distribution of soil erosion, and evaluating variations in crop production across different agricultural landscapes. Satellite imagery, rainfall records, soil characteristics, topographic information, and agricultural statistics provide an integrated framework for understanding the relationships between land transformation, environmental degradation, and crop productivity.

Keywords: Soil loss, agricultural land transformation, RUSLE, NDVI, land-use change, Soro District.

I. INTRODUCTION

Agriculture plays a fundamental role in supporting rural livelihoods, ensuring food availability, and maintaining regional economic stability. However, agricultural productivity is increasingly influenced by soil erosion, changing land-use patterns, climatic variability, and the degradation of natural resources. Soil loss reduces the depth and quality of fertile topsoil, affects soil moisture retention, and can diminish the availability of essential nutrients required for crop growth. At the same time, agricultural land transformation, including the conversion of cropland into built-up areas, changes in cropping patterns, and the expansion or abandonment of cultivated land, modifies the spatial organization of agricultural landscapes. These processes can influence crop production directly through changes in cultivated area and indirectly through changes in soil and water conditions.

Geospatial techniques provide an effective means of investigating these interconnected processes because they allow researchers to examine spatial patterns, monitor environmental changes, and integrate multiple datasets within a common analytical framework. Remote sensing and GIS have been widely applied to land-use and land-cover change detection, watershed management, soil erosion assessment, and agricultural resource planning (Gashaw et al., 2014; Phinzi & Ngetar, 2019). In Soro District, an integrated geospatial approach can provide a systematic framework for investigating the distribution of soil loss, the transformation of agricultural land, and spatial and temporal variability in crop production. The research is particularly relevant for understanding how environmental pressures and changing land-use conditions may affect agricultural sustainability and for developing location-specific conservation strategies.

STUDY AREA AND GEOGRAPHICAL CONTEXT

Soro is considered in this paper as the study area in Odisha, India, within the Balasore region. The agricultural landscape can be examined in relation to its terrain, drainage network, soil characteristics, rainfall distribution,

settlements, and cultivated land. However, the exact administrative boundary and the availability of district-level agricultural statistics must be established before quantitative analysis. This is important because Soro may refer to a town, a block, or a wider geographical area, and these administrative units are not interchangeable. The spatial extent selected for the study will determine the area included in satellite-image classification, erosion modelling, and crop production comparisons. A geospatial assessment should therefore begin by obtaining a verified administrative boundary and matching it with corresponding agricultural and environmental datasets. The study area can then be divided into suitable analytical units, such as watersheds, villages, land-use classes, or grid cells, to investigate the distribution of soil erosion and agricultural change. The geographical framework should also account for variations in slope, elevation, drainage density, and land cover because these characteristics influence surface runoff, soil erosion, and the suitability of land for cultivation.

RESEARCH OBJECTIVES

The primary objective of this research is to investigate the relationship between soil loss, agricultural land transformation, and crop production variability in Soro District using geospatial techniques. The specific objectives are to identify spatial and temporal changes in agricultural land use and land cover; estimate the potential and spatial distribution of soil erosion using RUSLE and GIS-based modelling; assess changes in vegetation conditions through satellite-derived indices such as NDVI; examine crop production variability using available agricultural statistics and remote-sensing indicators; and develop an integrated geospatial framework for identifying vulnerable agricultural areas and supporting sustainable land management.

REVIEW OF LITERATURE

1. Soil Erosion and Agricultural Productivity

Soil erosion is a major form of land degradation that affects agricultural sustainability through the removal of nutrient-rich topsoil, reduction in soil depth, and changes in soil-water relationships. The magnitude of erosion depends on rainfall intensity, soil properties, topography, vegetation cover, and land management practices. In agricultural landscapes, the removal of topsoil can reduce the capacity of land to support productive cropping systems, particularly where soil conservation measures are insufficient. Phinzi and Ngetar (2019) reviewed the application of GIS and remote sensing in catchment-level erosion assessment and explained how RUSLE-based methods integrate rainfall erosivity, soil erodibility, topography, cover management, and conservation practices. Their review also emphasized the importance of evaluating uncertainties in remotely sensed model parameters. These findings provide a methodological basis for examining soil erosion in Soro District, where local soil and rainfall conditions would need to be incorporated into the analysis.

2. Geospatial Assessment of Soil Loss

The integration of remote sensing and GIS has expanded the capacity to estimate soil erosion over large geographical areas. Digital elevation models can be used to derive slope and flow-related topographic characteristics, while satellite imagery supports the identification of land-cover classes and vegetation conditions. These datasets can be integrated into spatial models to identify erosion-prone locations and examine the relationship between soil loss and land management. Ghosh et al. (2023), although published just outside the specified 2010–2022 literature period, reported an application of GIS, remote sensing, and RUSLE in the Mayurakshi River Basin in eastern India. The study illustrates how spatially distributed erosion estimates can be categorized into different severity classes to support conservation planning. Because it was published in 2023, it is not included in the core reference period of this paper; it is mentioned only as subsequent methodological context.

3. Agricultural Land Transformation

Agricultural land transformation refers to changes in the spatial extent, distribution, and use of cultivated land over time. Such changes may result from settlement expansion, infrastructure development, changes in agricultural practices, shifts in cropping intensity, and environmental pressures. Remote sensing allows researchers to classify land into

categories such as cropland, built-up land, vegetation, water bodies, and fallow or barren land. Comparing classified satellite images from different years can reveal the direction and magnitude of land-use transitions. Gashaw et al. (2014) examined land-use and land-cover changes and their environmental implications in the Andassa watershed of Ethiopia, demonstrating the relevance of multitemporal spatial analysis for understanding landscape transformation. Although the geographical setting differs from Soro, the methodological approach provides a foundation for studying agricultural land conversion in the proposed study area.

RESEARCH METHODOLOGY

1. Research Design

The study adopts a quantitative, spatially oriented research design based on the integration of remote sensing, GIS, terrain analysis, soil erosion modelling, and agricultural data analysis. A multitemporal approach is proposed to investigate changes in land use and crop conditions over a selected period. The research should distinguish between observed data, modelled estimates, and interpretations derived from spatial associations. The period 2010–2022 can be used as the main analytical window, subject to the availability and comparability of satellite imagery and agricultural records. Landsat imagery may be used for historical land-cover classification, while Sentinel-2 imagery can provide additional detail for the later years of the study. Consistent image processing, cloud masking, geometric alignment, and classification procedures are necessary to ensure that apparent land-use changes reflect actual landscape transformation rather than differences in image quality or processing.

2. Data Collection and Sources

The proposed analysis requires satellite images, a digital elevation model, soil information, rainfall records, administrative boundaries, and agricultural production statistics. Landsat imagery can provide a consistent historical record for land-cover classification, while Sentinel-2 imagery can support detailed vegetation analysis during its operational period. Elevation data can be used to derive slope and terrain variables, and rainfall records can support the calculation of rainfall erosivity. Soil maps or field-derived soil properties are required to estimate soil erodibility. Agricultural statistics should include crop-wise cultivated area, production, and yield for the selected years. These datasets should be harmonized to a common coordinate system and spatial resolution. The study should also document data gaps, differences in reporting units, and uncertainties associated with satellite classification and agricultural records.

3. Land-Use and Land-Cover Classification

Land-use and land-cover classification is an important component of the proposed research because agricultural transformation cannot be assessed without identifying the spatial distribution of cultivated and non-cultivated land. Satellite images can be classified into major categories such as agricultural land, built-up land, forest or other vegetation, water bodies, and fallow or barren land. A supervised classification approach, such as Random Forest, may be applied using representative training samples and suitable spectral features. Classification accuracy should be evaluated using independent reference samples and a confusion matrix, including overall accuracy and class-specific measures. Multitemporal comparison can then be used to construct a land-use transition matrix, identifying changes such as cropland-to-built-up conversion, fallow-to-cropland transition, and changes in vegetated land. The resulting maps can help quantify the extent and spatial distribution of agricultural land transformation in Soro District.

4. Assessment of Crop Production Variability

Crop production variability can be investigated through the analysis of crop-wise production, cultivated area, and yield records across the selected years. Production should be distinguished from productivity: total production refers to the quantity harvested, whereas yield represents output per unit of cultivated area. This distinction is necessary because production may decrease when cultivated area contracts even if yield remains stable. Similarly, production may increase because of area expansion rather than improvements in agricultural productivity. Satellite-derived NDVI can provide additional information about vegetation conditions during crop-growing seasons, but the relationship between NDVI and yield should be tested using available crop statistics and appropriate crop calendars. Statistical analysis can

include year-to-year percentage changes, descriptive statistics, correlation analysis, and trend analysis. Where sufficiently detailed spatial data are available, the results can be compared with erosion-risk zones and land-use transition areas to investigate whether crop production variability is spatially associated with environmental and land-use changes.

RESULTS AND DISCUSSION: PROPOSED ANALYTICAL FRAMEWORK

Important research note: The following section presents the expected analytical structure and interpretation framework. Actual soil-loss values, agricultural land-change percentages, crop yields, and statistical results for Soro District have not been calculated from local datasets. Therefore, no numerical findings are presented as observed results.

1. Spatial Distribution of Soil Loss

The spatial distribution of soil loss is expected to vary according to the combined influence of rainfall erosivity, soil erodibility, terrain characteristics, vegetation cover, and conservation practices. Areas with greater slope steepness, exposed soil, or intensive cultivation may require particular attention during erosion assessment. However, the presence of steep terrain alone does not establish that a location experiences high soil loss, because vegetation cover, soil properties, rainfall intensity, and land management also influence erosion. RUSLE-based mapping can provide a spatial estimate of potential sheet and rill erosion and identify locations for field verification. Previous research has demonstrated the use of integrated remote sensing and GIS methods to estimate soil loss and identify erosion hotspots, although estimates remain dependent on model assumptions and input data quality (Phinzi & Ngetar, 2019).

2. Agricultural Land Transformation and Environmental Pressure

Changes in agricultural land use can affect the spatial distribution of exposed soil, vegetation cover, and surface runoff. Conversion of cultivated land to built-up areas may reduce the area available for farming, while changes in cropping practices or the abandonment of fields may alter seasonal vegetation cover. These transformations can also modify the spatial distribution of erosion susceptibility. Multitemporal satellite classification can identify where agricultural land has changed and whether those transitions coincide with areas of elevated modelled soil loss. Nevertheless, spatial coincidence does not establish causation. For example, a reduction in agricultural area and an increase in soil erosion may occur in the same region without one being the sole cause of the other. The interpretation should therefore consider rainfall, topography, land management, and other relevant factors.

3. Crop Production Variability

Crop production variability should be examined through changes in cultivated area, harvested output, and yield. A decline in production may reflect a reduction in agricultural land, unfavorable seasonal conditions, changes in irrigation, or changes in crop management. Soil degradation is one potential contributing factor, but its independent influence cannot be established from production statistics alone. Integrating agricultural records with satellite-derived vegetation indices and soil-loss estimates can help identify spatial associations that warrant further investigation. Crop-specific analysis is particularly important because different crops have different growing seasons, water requirements, and responses to environmental conditions. The research should therefore avoid combining all crop types into a single indicator without considering their individual characteristics.

Table:1 Geospatial Techniques and Their Research Applications

Table 1. Proposed geospatial framework for assessing soil loss, agricultural land transformation, and crop production variability in Soro District

Research component	Data and technique	Main analytical output
Agricultural land transformation	Multitemporal Landsat and Sentinel-2 imagery; supervised classification	Land-use maps and transition matrix
Soil erosion assessment	RUSLE integrated with GIS	Estimated annual soil loss and erosion-risk maps
Terrain analysis	Digital elevation model; slope and flow analysis	Terrain-related erosion susceptibility

Vegetation monitoring	NDVI and seasonal satellite composites	Vegetation condition and seasonal change
Crop production analysis	Crop-wise area, production, and yield statistics	Annual variability and trends
Integrated assessment	GIS overlay and statistical analysis	Spatial associations among erosion, land transformation, and crop variability
Conservation planning	Erosion-risk mapping and agricultural land assessment	Identification of priority areas for field verification and management

Table:2 Proposed Soil Erosion Classification

Category	Annual soil loss (t/ha/year)	Interpretation
Very low	0–5	Relatively low modelled erosion
Low	5–10	Low estimated soil loss
Moderate	10–20	Moderate estimated soil loss
High	20–40	Elevated estimated soil loss
Very high	Above 40	High-priority area for assessment

LIMITATIONS OF THE STUDY

The proposed research faces several methodological and data-related limitations. First, the precise administrative boundary of Soro District must be verified to ensure that satellite imagery and agricultural statistics represent the same geographical unit. Second, the accuracy of land-use classification depends on image quality, cloud cover, training data, and the ability to distinguish spectrally similar land-cover classes. Third, RUSLE estimates sheet and rill erosion and does not directly represent all forms of soil degradation, gully erosion, or sediment transport. Its outputs are also sensitive to the accuracy of rainfall, soil, topographic, and land-management parameters. Phinzi and Ngetar (2019) specifically highlighted the importance of evaluating uncertainty in remotely sensed RUSLE inputs.

Fourth, agricultural statistics may be available only at block or district level rather than at village or field level, limiting the spatial detail of crop production analysis. Finally, satellite-derived vegetation indices provide indirect information about crop conditions and cannot independently establish actual harvested yields. These limitations should be addressed through field observations, accuracy assessment, consistent data processing, and transparent reporting of uncertainty.

II. CONCLUSION

The proposed research provides an integrated geospatial framework for investigating the role of soil loss, agricultural land transformation, and crop production variability in Soro District. By combining satellite imagery, GIS-based land-use classification, RUSLE soil erosion modelling, vegetation indices, and agricultural statistics, the study can examine how environmental conditions and changing land-use patterns are associated with agricultural production. Soil loss is relevant to agricultural sustainability because erosion can remove fertile topsoil and alter soil-water conditions, while agricultural land transformation may change the spatial extent and distribution of cultivated land. Crop production variability, in turn, reflects multiple interacting influences, including cultivated area, climate, irrigation, soil conditions, and agricultural management.

The integration of these variables can support the identification of vulnerable agricultural locations and the development of spatially informed conservation strategies. However, the proposed methodology does not establish actual erosion rates or crop production trends in Soro District without verified local data. Future empirical research should therefore prioritize accurate administrative boundaries, multitemporal satellite imagery, reliable agricultural statistics, and field validation. Such evidence would provide a stronger foundation for sustainable agricultural planning, soil conservation, and environmental resource management in the study area.

REFERENCES

1. Gashaw, T., Tulu, T., & Argaw, M. (2014). Erosion risk assessment for prioritization of conservation measures in the Andassa watershed, Blue Nile basin, Ethiopia. *Environmental Systems Research*.
2. Phinzi, K., & Ngetar, N. S. (2019). The assessment of water-borne erosion at catchment level using GIS-based RUSLE and remote sensing: A review. *International Soil and Water Conservation Research*, 7(1), 27–46.
3. Gashaw, T., Tulu, T., & Argaw, M. (2018). Erosion risk assessment for prioritization of conservation measures in the Andassa watershed, Blue Nile basin, Ethiopia. *Environmental Systems Research*.
4. Ghosh, A., Rakshit, S., Tikle, S., Das, S., Chatterjee, U., Pande, C. B., Alataway, A., Al-Othman, A. A., Dewidar, A. Z., & Mattar, M. A. (2023). Integration of GIS and remote sensing with RUSLE model for estimation of soil erosion. *Land*, 12(1), 116.
5. Phinzi, K., & Ngetar, N. S. (2019). The assessment of water-borne erosion at catchment level using GIS-based RUSLE and remote sensing: A review. *International Soil and Water Conservation Research*, 7(1), 27–46. Article page.