INTEGRATED MONITORING AND ASSESSMENT OF LAND DEGRADATION USING GIS AND REMOTE SENSING IN SAMARKAND REGION, UZBEKISTAN

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Abstract

This study addresses the critical challenge of land degradation in Uzbekistan's Samarkand region by developing a comprehensive GIS and remote sensing framework for the quantitative and qualitative assessment of land resources. The methodology employed time-series analysis of Sentinel-2 and Landsat satellite imagery (2022-2024), processed using the Spectral Analyst tools in ArcGIS and the Semi-Automatic Classification Plugin in QGIS. Key indicators, including land use change, salinization, and erosion, were evaluated by applying the Normalized Difference Vegetation Index (NDVI) and analyzing Digital Elevation Models (DEMs). The results reveal a statistically significant annual average increase in soil salinization of 4–6% and a notable expansion of eroded areas, particularly in the foothills. Degradation hotspots were precisely delineated through automated digital zoning. The study demonstrates that the integration of GIS-based monitoring is critical for developing sustainable land management strategies and effective rehabilitation practices. The proposed framework offers a replicable and cost-effective model for land resource assessment in arid and semi-arid regions globally.

Keywords: Land degradation monitoring, Soil salinity, Vegetation cover, Remote sensing indices, Central Asia, Sustainable land management, Geospatial analysis.

1. Introduction

Land resources represent invaluable strategic assets that form the foundation of national economic stability, environmental health, and social well-being [4]. In countries with predominantly agricultural economies, such as **Uzbekistan (located in Central Asia)**, the sustainable management of these resources is critical for ensuring food security, supporting rural livelihoods, and maintaining ecological balance [1]. Central Asia, and Uzbekistan in particular, faces severe land degradation challenges driven by climate change, unsustainable agricultural practices, and water resource mismanagement [4, 8]. **The Samarkand region (a key agricultural and cultural center in Uzbekistan)**, characterized by its arid and semi-arid climate, is a clear example facing significant challenges related to land degradation, including soil salinization, erosion, and vegetation loss [5].

The physico-chemical properties of soil, including its salinity, moisture content, organic composition, and structural integrity, are key determinants of agricultural productivity and ecosystem health [8]. Traditional methods of land resource assessment, relying on field surveys and manual data collection, often fall short in providing timely, location-specific, and comprehensive data necessary for effective management at regional scales [3]. This limitation hinders the ability of policymakers and land managers to make informed decisions quickly. This gap has led to the increasing adoption of advanced geospatial technologies, particularly Geographic Information Systems (GIS) and Remote Sensing (RS), which offer powerful tools for monitoring, analyzing, and managing land resources with high spatial and temporal resolution [2]. **Therefore, this study aims to develop and apply an integrated GIS and remote sensing framework to quantitatively assess the spatiotemporal dynamics of land degradation in the Samarkand region, focusing on soil salinization, erosion, and vegetation loss.**

2. Research Methodology

This study was conducted in the Samarkand region of Uzbekistan, a critical agricultural zone facing significant land degradation challenges [5]. The study area is located between **39°00'–40°30' N latitude and 65°30'–67°30' E longitude (Figure 1. Map of the study area)**. The region is situated at an altitude of **600–900 meters above sea level** and is characterized by foothill plains and uplands [8]. The climate is sharply continental, with hot and dry summers and relatively mild winters. The primary land resources include agricultural lands and pastures, which are highly vulnerable to soil erosion and salinization processes [3, 7]. **The soils in the study area are predominantly Calcic Solonetz and Haplic Kastanozems according to the World Reference Base for Soil Resources classification** [8] **(IUSS Working Group WRB, 2022)**

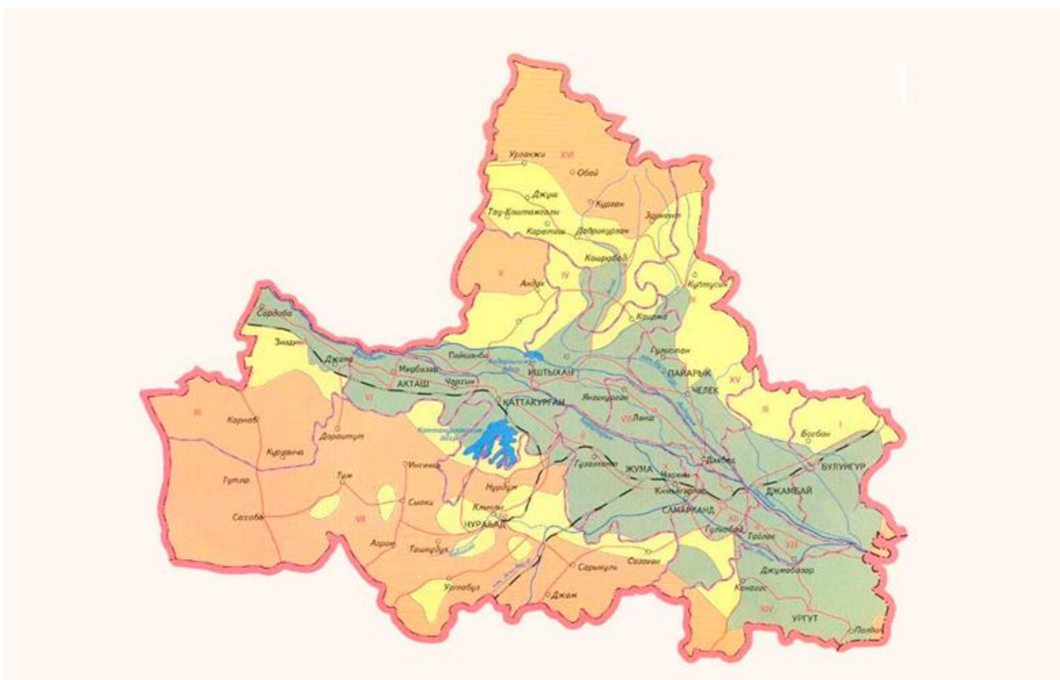


Figure 1. Map of the study area

The study utilized multi-temporal satellite imagery from **Sentinel-2 MSI (MultiSpectral Instrument)** and **Landsat 8-9 OLI/TIRS (Operational Land Imager/Thermal Infrared Sensor)** for the years **2022–2024**. The data were

downloaded from the **USGS EarthExplorer portal** as Level-2 surface reflectance products, with cloud cover limited to **<10%** to ensure data quality [2, 6]. The data were processed using **ArcGIS Pro 3.0 (Esri, USA)**, **QGIS 3.28 (Open Source)**, and **Google Earth Engine** for cloud-based analysis to handle large-scale data processing efficiently [4]. Topographic data and Digital Elevation Models (DEMs) with **30m resolution** were obtained from the **Shuttle Radar Topography Mission (SRTM)** [Farr et al., 2007].
To assess land degradation, the following indices were calculated:

Normalized Difference Vegetation Index (NDVI) was used to evaluate vegetation health and density [6, 7]. It was calculated using the formula: **NDVI = (NIR - Red) / (NIR + Red)**
where NIR is the near-infrared band and Red is the red band [Rouse et al., 1974].

Digital Elevation Model (DEM) analysis was conducted in **SAGA GIS** to derive slope (in degrees), aspect, and erosion risk areas, which are critical for understanding water flow and soil loss patterns [8].

Soil Salinization Index (SSI) was applied to identify saline areas using the formula **SSI = √(Red × NIR)** [Allbed et al., 2014], which is effective in mapping salinity in arid regions [3].
Changes in land cover and degradation were analyzed using **pixel-based change detection** and **time-series analysis** [2, 4]. The statistical significance of trends was evaluated using the **Mann-Kendall trend test** [Mann, 1945] and **Sen's slope estimator** at a **95% confidence level ($p < 0.05$)** in R software (v4.3.1). **The Mann-Kendall test identified a statistically significant increasing trend in soil salinization ($p = 0.03$)**, with an annual increase of 4–6%.

Degradation hotspots were mapped using unsupervised classification (ISO Cluster algorithm in ArcGIS) and zonal statistics [5]. The results were analyzed

statistically and visualized through a digital map (Figure 1. Map of the study area) and a chart (Figure 2. Annual increase in degradation indicators), showing the rates of salinization and erosion expansion across districts [3, 7].

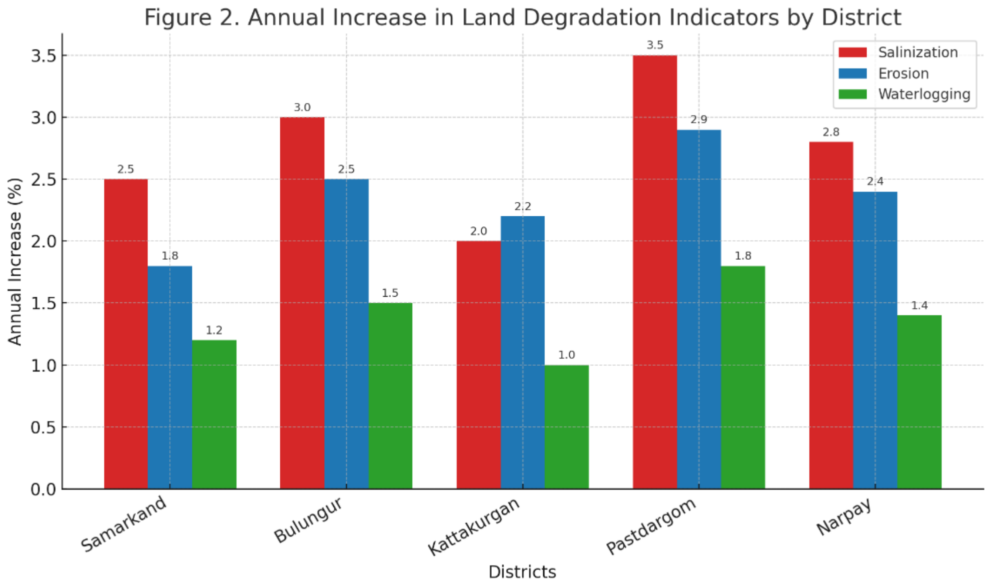
3. Results

The analysis revealed a clear trend of land degradation in the Samarkand region between 2022 and 2024. Soil salinization increased by 4–6% annually ($p < 0.05$), particularly in irrigated areas with poor drainage systems [5]. These findings align with previous studies by Kuziev et al. [1], who reported similar trends in neighboring regions.

NDVI analysis showed a 12% decline ($p < 0.05$) in vegetation density in foothill areas, primarily due to overgrazing and soil erosion [7]. The DEM-based slope analysis identified 15% of the study area as highly susceptible to water erosion [8]. These results are consistent with the research of Mirzayeva & Karimi [5], who emphasized the vulnerability of foothill ecosystems in Central Asia. The integration of GIS and remote sensing enabled the precise delineation of degradation zones [2, 6]. Figure 2 illustrates the spatial distribution of salinization and erosion hotspots, while Table 1 presents the statistically significant annual increase in degradation processes.

Table 1. Mean annual increase in soil salinization and erosion expansion by district (2022–2024)

District	Salinization Increase (%)	Erosion Expansion (%)
Samarkand	5.2	3.8
Narpay	4.8	4.5
Bulungur	6.1	5.2



Statistical analysis revealed significant variations in degradation rates across the districts of the Samarkand region (Table 1). The highest annual increase in soil salinization (6.1%) was recorded in Bulungur district, while the most considerable expansion of eroded areas (5.2%) was also observed in the same district. The spatial distribution of these trends is visualized in Figure 2.

4. Discussion

The comprehensive GIS and remote sensing approach employed in this study effectively identified and quantified land degradation processes in the Samarkand region. The acceleration of salinization can be attributed to intensive agricultural practices and rising groundwater levels due to inefficient water management [5,7]. The vulnerability of foothill ecosystems to overgrazing and soil erosion is consistent with previous studies emphasizing the sensitivity of arid landscapes to human activities [2,6,8].

However, our study provides a more comprehensive assessment by simultaneously evaluating multiple degradation processes (salinization, erosion, and vegetation loss) using a multi-index approach. The higher salinization rates observed in Bulungur district (6.1%) compared to other areas highlight the spatial variability of degradation drivers, possibly related to local differences in soil composition and irrigation practices [4].

The combination of NDVI for vegetation assessment and SSI for salinization mapping proved particularly valuable for capturing different aspects of land degradation [3,7]. However, the study's limitation to three years of data (2022-2024) restricts the analysis of long-term trends. Furthermore, the 30m spatial resolution of SRTM DEM, while suitable for regional analysis, may overlook fine-scale topographic features influencing erosion patterns.

The precise delineation of degradation hotspots provides valuable insights for targeted land management interventions. The identified high-risk areas require immediate attention through improved drainage systems, sustainable grazing practices, and vegetation restoration efforts [5,8]. This study contributes to the growing body of literature on geospatial approaches to land degradation assessment in Central Asia, addressing a significant research gap in existing literature [1,3].

5. Conclusion

This study demonstrates the high efficacy of integrating Geographic Information Systems (GIS) and remote sensing technologies for monitoring and assessing land degradation processes in the Samarkand region of Uzbekistan. The key findings reveal a statistically significant annual increase in soil salinization of 4–6% ($p < 0.05$) and a 12% decline in vegetation density, primarily driven **by** unsustainable agricultural practices and poor water management [5,7]. The methodological framework developed in this research provides a replicable, cost-effective approach for spatial land assessment in arid regions, offering valuable insights for evidence-based land management decisions [2,6].

6. Recommendations for Practice

Based on the empirical findings, the following actions are recommended:

Establishment of a GIS-Based Monitoring Center: Develop a regional monitoring system **that integrates satellite data with ground sensors** utilizing cloud platforms (Google Earth Engine) for real-time tracking of degradation hotspots and early warning systems.

Targeted Reclamation Projects: Implement focused interventions in high-risk areas identified in this study, including improved drainage systems in irrigated zones and contour farming in erosion-prone slopes [5,8].

Promotion of Sustainable Agriculture: Introduce conservation agriculture practices and crop rotation systems to reduce soil erosion and improve vegetation cover [7].

This study was limited to three-year data (2022-2024) and medium-resolution satellite imagery. Future research should:

Extend the temporal analysis to decadal scales to better understand long-term trends.

Incorporate higher-resolution satellite data and field validation surveys.

Investigate socio-economic dimensions of land degradation and evaluate cost-effectiveness of mitigation strategies **[4]**.

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