METHODOLOGY FOR ASSESSING THE QUALITY INDICATORS OF LAND PLOTS BASED ON GEOINFORMATION MODELING (CASE STUDY OF THE SAMARKAND REGION)

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Abstract

The sustainable use of land resources in Uzbekistan requires a transition from traditional land evaluation practices toward digital and scientifically grounded approaches. This study focuses on the application of geoinformation modeling (GIS) technologies to assess the quality indicators of land resources in the Samarkand region. Using remote sensing data (Sentinel-2, Landsat-8), a Digital Elevation Model (DEM), and NDVI-based vegetation indices, the research evaluates soil fertility, salinity, meliorative status, and erosion risk. Each indicator was quantified and integrated into a composite Land Suitability Index (LSI). The findings reveal that GIS-based assessment significantly enhances the accuracy and efficiency of monitoring land degradation and supports decision-making for sustainable land management.

Keywords: land quality, GIS, modeling, NDVI, DEM, salinity, Samarkand region.

1. INTRODUCTION

Land resources constitute one of the most fundamental components of a country's natural capital and play a decisive role in ensuring food security, sustainable economic development, and ecological stability. The productivity of land directly influences agricultural output, rural livelihoods, and environmental resilience. In Uzbekistan, as in many arid and semi-arid regions, pressures from intensive agricultural activity, population growth, and climate variability have accelerated land degradation processes. Salinization, soil erosion, and declining soil fertility are among the most critical challenges that threaten the long-term sustainability of land use. The Samarkand region, known for its fertile irrigated plains and diversified cropping systems, has also experienced noticeable shifts in land quality over recent decades due to both natural and anthropogenic factors.

Accurate assessment of the quantitative and qualitative characteristics of land is therefore essential to support sustainable land-use planning, rational allocation of resources, and effective agricultural management. However, conventional land evaluation methods—based primarily on field surveys and manual data collection—often provide fragmented information that lacks spatial continuity and temporal sensitivity. These traditional approaches are time-consuming, costly, and sometimes insufficient to capture the complex interactions between soil, water, vegetation, and topography that determine overall land quality.

In contrast, the integration of **Geographic Information Systems (GIS)** and **Remote Sensing (RS)** technologies provides a powerful analytical framework for monitoring, modeling, and managing land resources. GIS enables spatial analysis and visualization of large-scale datasets, while RS offers real-time and historical observations of land surface dynamics. Together, they allow researchers and decision-makers to detect patterns of degradation, evaluate land suitability, and simulate various management scenarios with greater precision. The use of digital elevation models (DEMs), vegetation indices such as NDVI, and thematic land-cover maps derived from satellite imagery contributes to a more comprehensive understanding of land processes and spatial heterogeneity.

Moreover, these technologies facilitate the creation of continuously updated geodatabases that integrate soil, climate, and hydrological parameters. Such data-driven systems enhance the capacity to evaluate environmental risks, prioritize restoration measures, and optimize irrigation and crop management practices. In this context, GIS-based modeling has emerged as a cornerstone of modern land management science, bridging the gap between empirical field observations and predictive spatial modeling.

Consequently, the present study focuses on developing and applying a GIS-based methodological framework to assess the **qualitative condition of land resources in the Samarkand region of Uzbekistan**. By combining remote sensing indices, digital terrain analysis, and cadastral datasets, the research aims to establish a scientifically grounded, reproducible, and regionally adaptable approach to land quality assessment that can inform sustainable agricultural and environmental planning.

2. RESEARCH METHODOLOGY

This study was carried out within the diverse **agro-climatic zones of the Samarkand region**, which include irrigated plains, foothills, and semi-arid landscapes. These areas were selected to represent the full spectrum of land quality variations and environmental challenges typical of central Uzbekistan. The integration of geospatial data sources and analytical tools formed the foundation of the methodological framework.

The primary datasets utilized in this research comprised **Sentinel-2 multispectral satellite imagery**, **Digital Elevation Models (DEM)**, **Normalized Difference Vegetation Index (NDVI)** products, and official **land cadastre records** provided by the State Committee on Land Resources and Geodesy of Uzbekistan. All geospatial data processing and analyses were conducted using **ArcGIS 10.8** and **QGIS 3.28** software platforms, which together enabled precise spatial modeling, raster analysis, and cartographic visualization.

The research methodology was structured into **three major stages**, each aimed at ensuring data accuracy, analytical depth, and methodological consistency:

1. **Data Collection and Preprocessing**

At this stage, high-resolution Sentinel-2 imagery (10–20 m spatial resolution) was acquired from the Copernicus Open Access Hub. The raw data were subjected to radiometric and geometric corrections using the SNAP and ArcGIS environments to eliminate atmospheric distortions. Vegetation indices (NDVI) were generated to represent the photosynthetic activity and biomass density, while DEM data derived from SRTM were used to analyze the topographic and slope characteristics of the terrain. These datasets were then projected to a unified coordinate system (UTM Zone 42N) for spatial consistency.

2. **Indicator Selection and Quantification**

Key indicators affecting **land quality** were selected based on both international standards (FAO, 2021; UNEP, 2022) and regional agro-ecological conditions. The selected indicators included:

- **Soil fertility**, characterized by organic matter content and mechanical composition;
- **Soil salinity**, measured in dS/m, as a key constraint on agricultural productivity;
- **Groundwater depth**, serving as a proxy for meliorative conditions;
- **Slope gradient**, derived from DEM, to represent erosion potential;
- **Vegetation density**, assessed through NDVI values.

Each parameter was converted into a standardized numerical scale (1 to 5) to allow multi-criteria evaluation.

3. **Composite Index Modeling**

In the final analytical stage, the selected indicators were integrated into a **Land Suitability Index (LSI)** model. This integration employed a **weighted overlay technique** in the ArcGIS environment, where each indicator was assigned a weight coefficient based on its relative influence on land quality. The resulting LSI map classified the territory into five categories—ranging from highly suitable to low suitability/degraded—providing a spatially explicit representation of the region's land quality.

This systematic methodology allowed for both **quantitative** and **spatial assessment** of land quality, enabling the identification of degradation hotspots and areas with high agricultural potential. The combined use of remote sensing and GIS ensured objectivity, reproducibility, and scalability of the results, thereby establishing a scientific foundation for future land resource monitoring and management strategies in Uzbekistan.

Table 1. Land Quality Assessment Criteria

No.	Assessment Indicator	Unit	Range	Impact Direction	Data Source
1	NDVI (Vegetation Index)	—	0.1 – 0.9	High NDVI = high productivity	Sentinel-2, 2024
2	Soil Salinity	dS/m	0 – 16+	Higher = lower fertility	FAO, 2021
3	Soil Moisture	%	5 – 35	Low = high degradation risk	Landsat-8, 2023
4	Erosion Slope	°	0 – 10+	Slope >5° = high risk	DEM analysis
5	Groundwater Depth	m	0.5 – 3.0	Shallow = salinization risk	State Land Cadastre, 2024

This framework provides a structured and replicable method for spatial land quality evaluation using multi-criteria GIS modeling.

3. RESULTS AND ANALYSIS

The results of the GIS- and RS-based assessment demonstrate pronounced **spatial heterogeneity in land quality** across the Samarkand region. By integrating NDVI, DEM, and salinity data, the study provides a multidimensional understanding of the region’s agro-ecological conditions and degradation dynamics.

The **northern and central plains** of the region exhibited relatively high NDVI values (>0.6), signifying dense vegetation cover and stable soil productivity. These areas, which include the highly cultivated Bulung‘ur and Past Darg‘om districts, benefit from well-developed irrigation infrastructure and favorable agro-climatic conditions. In contrast, the **southern and foothill territories**, such as Kattaqo‘rg‘on, Urgut, and Nurobod districts, recorded NDVI values below 0.4. Such low vegetation indices indicate reduced biomass production, soil nutrient depletion, and visible signs of land degradation. These findings align with field observations showing sparse crop coverage and increasing exposure to erosive processes.

The **Digital Elevation Model (DEM) analysis** revealed that slopes exceeding 5° are predominantly found in the **Kattaqo‘rg‘on and Nurobod** districts. These zones are particularly susceptible to **surface erosion** and **runoff-induced soil loss**, exacerbated by improper tillage orientation and lack of vegetation cover. In contrast, flatter areas (slopes <2°) in the Zarafshon valley displayed minimal erosion risk and greater agricultural suitability.

The **soil salinity assessment**, derived from remote sensing–based electrical conductivity data and field validation, showed that approximately **22% of the total studied area** experiences **moderate salinity** (EC 4–8 dS/m), while about **7%** suffers from **high salinity levels** (EC > 8 dS/m). These conditions are most evident in irrigated lowlands, where inefficient drainage and high groundwater tables contribute to secondary salinization.

Temporal NDVI trend analysis between **2022 and 2024** revealed a **4.3% decline in vegetation productivity** across the region. This reduction correlates strongly with **irrigation inefficiencies**, **increasing groundwater salinity**, and the **expansion of non-cultivated areas**. The decrease was most noticeable during the summer growing season, coinciding with peak water demand and limited supply.

Spatial modeling of the **Land Suitability Index (LSI)** classified the territory into five categories—ranging from highly suitable to degraded. Approximately **38%** of the region was identified as highly suitable for agriculture, **41%** as moderately suitable, and the remaining **21%** as marginal or degraded lands. These results underscore the urgent need for targeted land reclamation and precision agriculture practices.

Overall, the integration of **GIS and RS tools** proved instrumental in identifying and visualizing spatial patterns of land degradation. The resulting thematic maps and datasets not only illustrate the current status of land quality but also serve as **decision-support instruments** for regional authorities. These products can be used to prioritize **land rehabilitation**, **optimize irrigation scheduling**, and guide **long-term spatial planning** in the Samarkand region.

4. Discussion

The findings of this study clearly demonstrate that **GIS-based spatial modeling** offers significantly greater precision and analytical capacity than traditional, survey-based land evaluation methods. By integrating multi-source geospatial datasets—such as NDVI (Normalized Difference Vegetation Index), DEM (Digital Elevation Model), and salinity maps—the analysis achieved a multidimensional understanding of the spatial and temporal dynamics of land quality in the Samarkand region.

This integration of multi-layered data enables **early detection of degradation processes**, including soil salinization, erosion risk, and vegetation stress, which often remain undetected using conventional field methods. Moreover, the GIS-based approach allows for the generation of **high-resolution thematic maps** that highlight problem areas, serving as an essential input for spatial decision support systems (SDSS). These tools not only improve environmental monitoring but also facilitate **precision agriculture**, where site-specific management strategies can be applied based on spatial heterogeneity in soil and vegetation conditions.

The proposed **Land Suitability Index (LSI)** represents a key contribution of this study, offering a **quantitative and reproducible framework** for evaluating land quality. By weighting and integrating multiple environmental indicators—such as soil fertility, salinity, slope, groundwater depth, and vegetation vigor—the LSI enables policymakers to **prioritize land reclamation, irrigation optimization, and conservation programs**. This systematic approach supports resource-efficient agricultural planning and provides a scientific foundation for mitigating risks associated with salinization and erosion.

Importantly, the outcomes of this research are consistent with international best practices promoted by organizations such as the **FAO (Food and Agriculture Organization)** and the **United Nations Convention to Combat Desertification (UNCCD)**, which advocate for the adoption of geospatial technologies in sustainable land governance. The results confirm that implementing GIS- and RS-based monitoring systems can substantially enhance **data transparency, spatial accuracy, and temporal responsiveness** in land resource management—key prerequisites for achieving environmental sustainability and food security in Uzbekistan's arid and semi-arid zones.

5. Conclusion

The integration of **Geographic Information Systems (GIS)** and **Remote Sensing (RS)** technologies into land quality assessment provides an **innovative, scientifically grounded, and operationally efficient** methodology for monitoring and managing land resources. When applied to the Samarkand region, this geospatial approach enabled the precise identification of areas experiencing land degradation, salinity buildup, and erosion hazards. It also facilitated the creation of spatially explicit models that can inform **data-driven policy formulation and land-use planning**.

The developed methodological framework proved to be both **scalable and cost-effective**, making it suitable for replication in other regions of Uzbekistan and Central Asia. By combining satellite-derived datasets with in-situ observations and digital elevation models, the approach supports **evidence-based agricultural decision-making**, enhances environmental sustainability, and contributes to the modernization of the **national land cadastre system**.

For future research, the methodology can be expanded through the integration of **machine learning algorithms**, **time-series vegetation modeling**, and **climate projection data** to improve the **predictive capacity** of land suitability and degradation models. Such enhancements would allow for the anticipation of long-term land-use trends under varying climatic and anthropogenic scenarios.

Ultimately, this study lays the groundwork for establishing a **digitally enabled, geospatially integrated land management system** in Uzbekistan—one that aligns with global trends in smart agriculture, spatial data infrastructure, and sustainable resource governance.

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