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INTEGRATED MULTI-CRITERIA AGRICULTURAL LAND SUITABILITY ASSESSMENT IN TASHKENT REGION USING SENTINEL-2, RUSLE, AND AHP-BASED MODELING

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Abstract:

Land suitability assessment is a critical component of sustainable agricultural planning, particularly in semi-arid regions exposed to climatic variability and soil degradation processes. This study presents an integrated multi-criteria evaluation framework for agricultural land suitability in the Tashkent region (Uzbekistan) using Sentinel-2 imagery, topographic, climatic, and erosion-related factors within a Google Earth Engine (GEE) environment. A total of 257 Sentinel-2 images (2023–2024 vegetation period) were processed to derive vegetation indices (NDVI, NDWI, EVI). Terrain characteristics were extracted from SRTM DEM, climatic variables from CHIRPS precipitation and MODIS LST datasets, and soil erosion risk was estimated using the RUSLE model. All criteria were normalized and integrated through a Weighted Linear Combination (WLC) approach based on Analytical Hierarchy Process (AHP) weights. The results indicate that 8,065.20 ha are highly suitable (S1), 595,143.66 ha moderately suitable (S2), 485,628.54 ha marginally suitable (S3), 101,540.48 ha conditionally unsuitable (N1), and no areas were classified as permanently unsuitable (N2). The proposed framework provides a reproducible and scalable spatial decision-support tool for sustainable agricultural land management.

Keywords

Land suitability, Multi-criteria analysis, Sentinel-2, RUSLE, AHP, Sustainable agriculture

Аннотация:

Оценка пригодности земель является важнейшим элементом устойчивого сельскохозяйственного планирования, особенно в засушливых регионах, подверженных климатической изменчивости и процессам деградации почв. В данном исследовании представлена интегрированная многокритериальная модель оценки сельскохозяйственной пригодности земель Ташкентской области (Узбекистан) с использованием спутниковых данных Sentinel-2, топографических, климатических и эрозионных факторов в среде Google Earth Engine (GEE). В общей сложности было обработано 257 изображений

Sentinel-2 за вегетационный период 2023–2024 гг. для расчета вегетационных индексов (NDVI, NDWI, EVI). Характеристики рельефа были получены на основе цифровой модели высот SRTM, климатические показатели — из наборов данных CHIRPS (осадки) и MODIS LST (температура поверхности земли), а риск почвенной эрозии оценивался с применением модели RUSLE. Все критерии были нормализованы и интегрированы методом взвешенной линейной комбинации (WLC) на основе весовых коэффициентов, определённых методом анализа иерархий (AHP). Полученные результаты показали, что 8 065,20 га относятся к категории высокой пригодности (S1), 595 143,66 га — средней пригодности (S2), 485 628,54 га — ограниченной пригодности (S3), 101 540,48 га — условно непригодные земли (N1), при этом территории, полностью непригодные для сельскохозяйственного использования (N2), не выявлены. Предложенная модель представляет собой воспроизводимый и масштабируемый инструмент пространственной поддержки принятия решений для устойчивого управления сельскохозяйственными землями.

Ключевые слова

оценка пригодности земель, многокритериальный анализ, Sentinel-2, RUSLE, AHP, устойчивое сельское хозяйство.

1. Introduction

Sustainable agricultural development increasingly depends on spatially explicit land suitability assessment that integrates environmental, climatic, and geomorphological factors. Soil erosion has been identified as one of the most significant drivers of land degradation worldwide (Lal, 1998; Montgomery, 2007), reducing soil fertility and long-term productivity. In semi-arid regions, irrigation expansion combined with slope-driven runoff further intensifies degradation risks (Renard et al., 1991).

Multi-criteria decision analysis (MCDA) has become a widely accepted framework for land evaluation, allowing integration of heterogeneous environmental variables into a unified suitability index. The FAO land evaluation framework emphasizes classification into suitability classes (S1–N2), based on biophysical constraints and management factors. Recent advances in cloud-based geospatial platforms enable large-scale implementation of such models using satellite time-series data.

This study aims to develop a reproducible multi-criteria land suitability model for agricultural lands in the Tashkent region by integrating vegetation health, topography, climate, and soil erosion risk. The approach combines RUSLE-based erosion assessment with AHP-weighted linear combination modeling.

2. Materials and Methods

2.1 Study Area

The study area covers the Tashkent region, Uzbekistan. Agricultural lands were extracted using ESA WorldCover 2023 data. The region includes irrigated plains and foothill zones with varying slope and climatic gradients.

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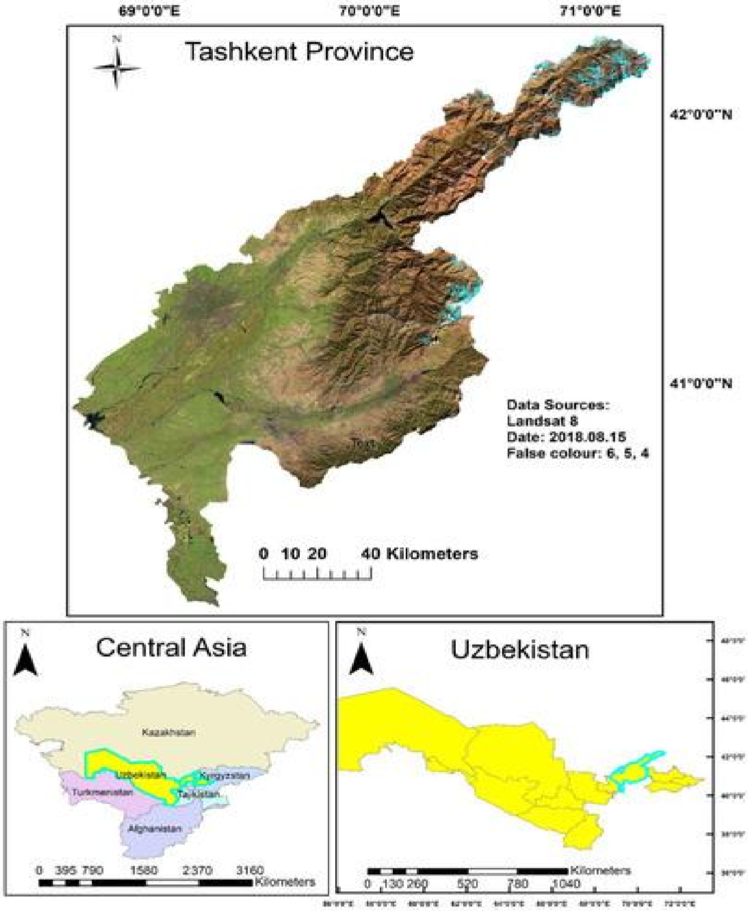

Figure 1. Study area map [6].

2.2 Data Sources

- Sentinel-2 SR Harmonized (10 m resolution, 2023–2024 vegetation period)
- SRTM DEM (30 m)
- CHIRPS precipitation dataset
- MODIS MOD11A2 Land Surface Temperature
- OpenLandMap soil texture data
- FAO GAUL administrative boundaries

2.3 Vegetation and Environmental Indicators

Vegetation condition was assessed using NDVI, NDWI, and EVI indices derived from median composite Sentinel-2 imagery. Slope was calculated from SRTM DEM. Annual precipitation and mean LST were computed from CHIRPS and MODIS datasets. Soil erosion risk was estimated using the Revised Universal Soil Loss Equation (RUSLE), integrating rainfall erosivity (R), soil erodibility (K), slope length-steepness (LS), and cover-management (C) factors.

2.4 Multi-Criteria Evaluation Model

All criteria were normalized to a 0–1 scale. The suitability index was calculated using a Weighted Linear Combination (WLC):

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$$SI = \Sigma (wi \times Xi)$$

where wi represents AHP-derived weights and Xi normalized factor values. Weights were assigned as follows: NDVI (0.25), Slope (0.20), NDWI (0.20), Erosion Risk (0.20), Climate (0.15). The resulting index was classified into five FAO-based suitability classes (S1–N2).

3. Results

Figure 1. NDVI spatial distribution during the 2023 vegetation season.

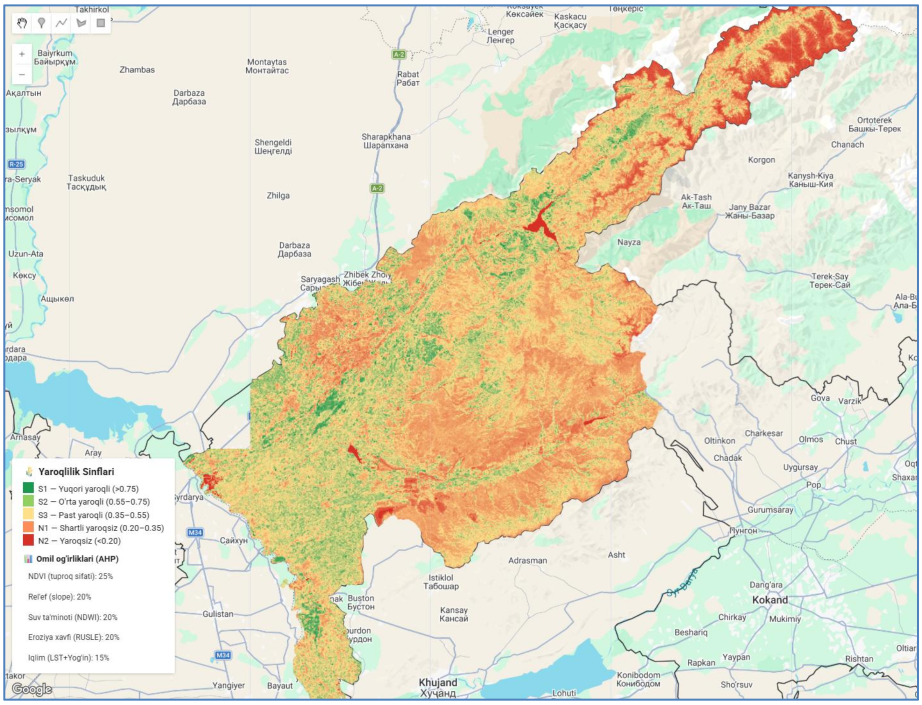

Figure 2. RUSLE-based soil erosion risk map for Tashkent region.

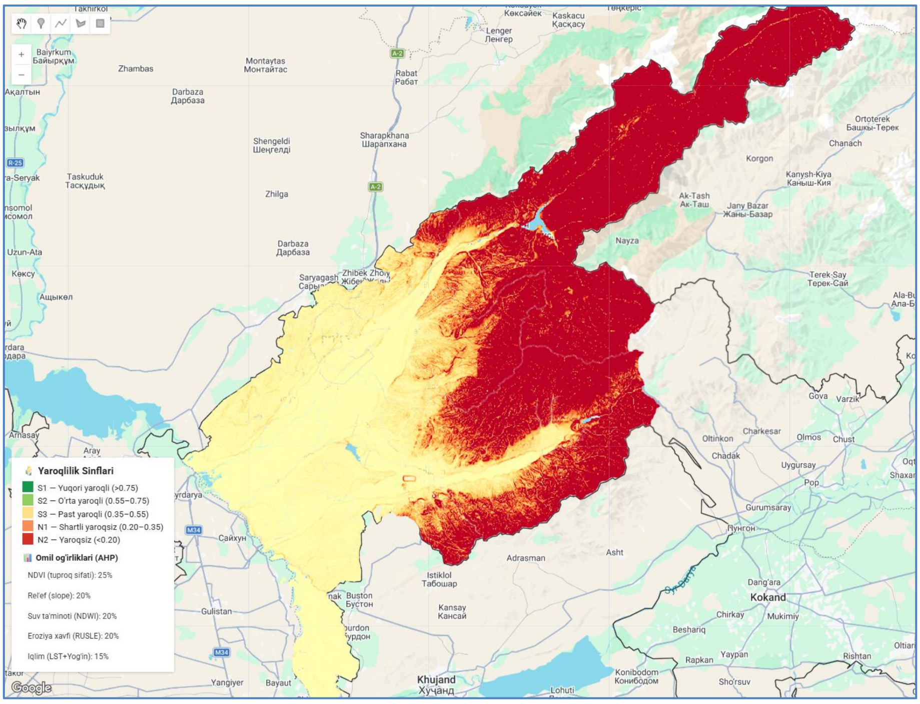

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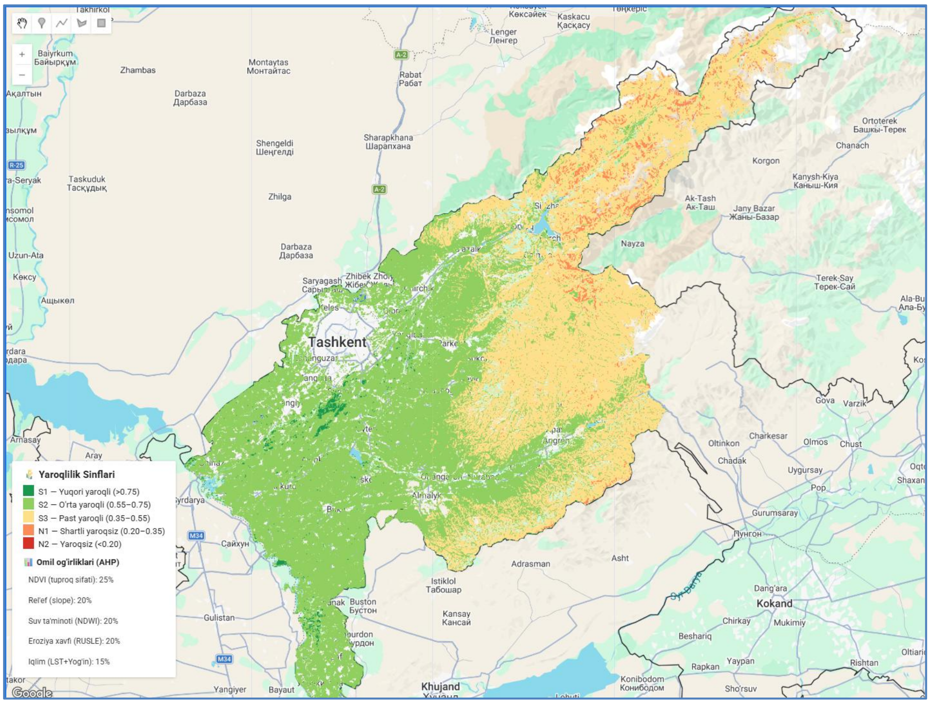
Figure 3. Final agricultural land suitability classification map (S1–N2).



A total of 257 Sentinel-2 images were processed. The distribution of suitability classes is as follows:

- S1 (Highly suitable): 8,065.20 ha
- S2 (Moderately suitable): 595,143.66 ha
- S3 (Marginally suitable): 485,628.54 ha
- N1 (Conditionally unsuitable): 101,540.48 ha
- N2 (Unsuitable): 0 ha

Moderately suitable lands (S2) dominate the agricultural landscape. Highly suitable zones are primarily located in low-slope areas characterized by strong vegetation cover and moderate erosion risk.

4. Discussion

The dominance of S2-class lands indicates that most agricultural territories exhibit moderate agro-environmental suitability under current climatic and topographic conditions. The limited spatial extent of S1 areas reflects slope and erosion constraints, which align with global findings highlighting terrain-driven productivity limitations (Montgomery, 2007).

The integration of RUSLE within the suitability framework ensures that erosion risk is explicitly incorporated into decision-making. Given the importance of soil conservation for long-term sustainability (Lal, 1998), the inclusion of erosion as a weighted criterion strengthens the robustness of the model.

The absence of permanently unsuitable lands (N2) suggests that agricultural potential remains high across the region, although management interventions are required in N1-class areas to mitigate erosion and optimize irrigation practices.

5. Conclusion

This study demonstrates that integrating Sentinel-2 vegetation indices, topographic variables, climatic factors, and RUSLE-based erosion modeling within an AHP-WLC framework provides a reliable spatial decision-support tool. The methodology is scalable and transferable to other semi-arid agricultural regions. The generated suitability map supports evidence-based land use planning, erosion mitigation strategies, and sustainable agricultural development.

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