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Assessment and Mapping of Landscapes for Agricultural Purposes in Ensuring Food Security

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ABSTRACT

Ensuring food security in arid and resource-constrained regions requires precise knowledge of landscape capabilities to optimize agricultural planning. In Uzbekistan's Central Zarafshan Basin, where climatic variability, limited water resources, and diverse geomorphic conditions pose significant challenges, identifying land suitable for sustainable cultivation is critical. However, there remains limited spatially explicit evidence on how natural landscape characteristics can be systematically linked to agricultural suitability. This study addresses this gap by integrating remote sensing, GIS-based spatial modeling and agro-climatic evaluation frameworks to classify piedmont plains and alluvial landscapes according to their agricultural potential. High-resolution Landsat-8 imagery and agro-ecological criteria developed by Kogay and Rodionov were applied to assess biophysical variables including slope, soil composition, vegetation cover, hydrology, and population density. The results delineate four suitability classes, marginally suitable, moderately suitable, suitable and highly suitable, highlighting particularly promising zones in proluvial-alluvial plains and oasis areas, while steep, saline and eroded terrains were less favorable. Microzonal analysis further identified opportunities for sustainable intensification in foothill and alluvial fan systems through improved irrigation and land management. Overall, the study demonstrates the value of geospatial technologies and agro-climatic zoning in guiding climate-resilient agriculture, offering a scientifically informed basis for enhancing productivity, resource efficiency and long-term food security in Uzbekistan and other semi-arid regions.

Keywords: Food Security, Foothill Plain, Alluvial Fan, Landscape, Assessment, Vegetation Index

INTRODUCTION

Food security challenges are especially critical in semi-arid and arid regions where climatic variability, limited water resources and land degradation directly constrain agricultural productivity. In Uzbekistan, these challenges are compounded by population growth and increasing demand for agricultural land, which intensifies pressure on foothill and alluvial landscapes. Previous research highlights that these landscapes provide both opportunities and risks: while fertile soils and irrigation potential support agriculture, steep slopes, salinity and soil erosion limit long-term sustainability (Burundukova et al. 2023). Understanding and classifying these landscapes is therefore essential for guiding land-use planning that aligns with national food security goals.

For any sovereign nation, ensuring food security and providing the population with stable access to nutritious food remains a matter of paramount importance (Wang et al. 2022; Fatemeh Kalantari et al. 2020). In Uzbekistan, food security has held a central place in the country's socio-economic policy since the early years of independence (Burundukova et al. 2023). Notably, the Resolution of the Cabinet of Ministers of the Republic of Uzbekistan titled "On Additional Measures to Accelerate the Implementation of National Goals and Objectives in the Field of Sustainable Development until 2030" designates Goal 2 as "Strengthening food security, improving dietary nutrition, and supporting the sustainable development of agriculture."

While global and regional studies on food security emphasize policy frameworks and broad agricultural strategies, fewer studies have systematically applied geospatial approaches to assess land suitability at the landscape level. Remote sensing and GIS provide powerful tools for monitoring vegetation, soil conditions, topography, and hydrological dynamics, enabling spatially explicit evaluation of agricultural potential. Studies in Central Asia (Yarashev et al. 2020; Akpoti et al. 2019) and other semi-arid regions (Săvan et al. 2024; Li et al. 2023) have demonstrated that GIS-based land suitability mapping improves accuracy and efficiency in resource-constrained environments. However, in the Central Zarafshan Basin, comprehensive geospatial assessments remain limited, leaving a knowledge gap in how landscape variability influences agricultural sustainability.

Currently, there is no universally accepted set of criteria or principles for assessing and guaranteeing food security (Jones et al. 2013). However, within the scope of ongoing research, several frameworks have been proposed. Among them are the criteria and principles for sustainable agriculture and food security indicators developed by the Food and Agriculture Organization (FAO) of the United Nations, the regional food security assessment methodology of the Russian Academy of National Economy and Public Administration, and macro-level food security forecasting models such as EPACIS, BLS, and Aglink.

Therefore, the main aim of this study is to conduct an integrated assessment and delineation of the piedmont plains and alluvial landscapes of the Central Zarafshan Basin to determine their agricultural suitability. By combining agro-ecological evaluation criteria with geospatial analysis, this study seeks not only to classify land into suitability categories but also to produce detailed spatial maps that highlight priority zones for sustainable agricultural development. This dual focus ensures that both the assessment (quantifying natural and socio-ecological conditions) and the delineation (mapping suitability classes) are achieved, providing actionable information for decision-makers.

In the context of ongoing climate change, the development and implementation of climate-resilient agriculture has become increasingly urgent (Kholbaev & Abdullaev, 2020; Jägermeyr et al. 2021). Key research directions include examining the influence of climatic factors on drought conditions and developing predictive models; generating integrated vegetation cycle maps for the Central Zarafshan Basin using satellite imagery from various space platforms (Eshquvvatov, 2020; van den Bosch et al. 2024); and constructing contour calculations and thematic maps using Geographic Information System (GIS) tools (Khaldoon et al. 2025; Abdullah et al. 2024; Săvan et al. 2024).

Contemporary global initiatives to ensure and evaluate food security are increasingly anchored in holistic assessments that integrate the constraints of natural resource availability. Scientific research has intensified across several critical domains, including the design of climate-resilient agricultural systems, the modeling and prediction of climatic impacts especially drought dynamics and the strategic advancement of resource-efficient, intensive agricultural practices. These efforts collectively aim to inform robust, adaptive food security policies capable of withstanding environmental and socio-economic uncertainties.

Among geographers, the origins of agricultural landscape research are attributed to scholars from Moscow State University. Under the leadership of N.A. Solnsev, a team from the university's Faculty of Geography conducted a pioneering expedition in 1951 to the Zaraysk District of Moscow Region. The primary goal of this expedition was to investigate the potential for utilizing regional landscapes for agricultural purposes (Orlova, 2014; Rodionov, 1968; Li et al. 2023; Luo et al. 2024).

Subsequent agricultural landscape studies were carried out by scholars from Moscow State University in regions such as Ryazan, Moscow, Bryansk and beyond. Similar research initiatives were also undertaken by academics from universities across Ukraine, the Baltic States, and other parts of the former Soviet Union. Notably, applied agricultural landscape research was further developed by geographers at Voronezh State University. Over time, the evaluation of landscapes for agricultural purposes expanded to Kazakhstan, Western Siberia, Central Asia, and Uzbekistan (Orlova, 2014; Li et al. 2023).

At present, new methods for modeling and forecasting the potential capabilities of landscapes are actively being developed and the methodological arsenal of landscape research continues to expand. Long-term observations under stationary conditions are being conducted, contributing significantly to scientific understanding. In particular, advancements in the field of landscape geochemistry have gained substantial importance. The adoption of modern technologies especially GIS-based approaches has opened up vast methodological opportunities for utilizing landscape complexes in agricultural planning and land use (Săvan et al. 2024).

Uzbekistan's agriculture is primarily structured around irrigated and rain-fed farming systems, horticulture, sericulture, and a diverse livestock sector. Each of these branches requires specific natural conditions more precisely, distinct agro-climatic environments for their effective development. The natural elements and landscapes of a region shape the environmental foundation necessary for the growth of these agricultural sectors.

In the context of climate change, studying the thermal regime of specific areas has become critically important for selecting appropriate crop varieties. One essential agricultural practice is the precise determination of sowing periods, particularly for cereal crops, as this directly affects crop productivity. For instance, the timing of wheat sowing in autumn must align with the region's climatic parameters; sowing during the optimal window enhances seed germination and significantly improves yield outcomes (Kholbaev & Abdullaev, 2020).

METHODOLOGY

A foundational in the development of the methodology involves the classification of landscapes according to their agricultural potential (Kogay, 1971, Mirzamakhmudov et al. 2022), agro-ecological evaluation of landscapes (Rodionov, 1968; Li et al. 2023; Luo et al. 2024), and detailed assessments of the region's natural conditions (Saidov, 1972; Burkitt & Bretherton, 2022) including geological structure, terrain characteristics, climate patterns and hydrological conditions (Hikmatov et al. 2016). Furthermore, comprehensive land suitability evaluations considering variables such as soil composition, natural vegetation coverage, and population density have enabled categorization into varying degrees of suitability: marginally suitable, moderately suitable, suitable, and highly suitable (Yarashev et al. 2020; Akpoti et al. 2019). Regional zoning and agro-ecological delineation efforts have also supported targeted agricultural planning and land use optimization (Orlova, 2014; Yansui et al. 2018; Morán-Alonso et al. 2025).

These integrated approaches offer a scientifically grounded and methodologically robust foundation for advancing sustainable agriculture in resource-constrained and climate-vulnerable landscapes, such as the Central Zarafshan piedmont plains. By aligning agroecological insights with adaptive land management strategies, they enable context-specific interventions that enhance resilience, optimize resource use, and support long-term food system sustainability (Mafuse et al. 2025).

The methodology of this study was designed to provide a systematic and transparent approach for assessing and delineating the agricultural suitability of piedmont plains and alluvial landscapes in the Central Zarafshan Basin. The process began with a clear definition of the study objective, namely to integrate geospatial techniques with established agro-ecological frameworks in order to generate suitability classifications and spatial maps. Two widely recognized evaluation systems were selected as the foundation of the analysis: the relief and population density evaluation criteria proposed by Rodionov and the agricultural landscape classification developed by Kogay. These frameworks ensured that the assessment combined both physical landscape parameters and socio-ecological pressures in determining land-use potential.

Data acquisition represented the second major stage of the methodology. Multi-temporal Landsat-8 satellite imagery, covering the vegetation season between May and July 2023, provided the primary remote sensing dataset. These images were used to compute vegetation indices and interpret land cover. Elevation data were used to derive slope characteristics, while hydrological and climatic records from the Qo'shrabot Meteorological Station supplied information on precipitation, temperature regimes, and growing season conditions. Additional contextual information, including soil types, geomorphological descriptions, and population density statistics, was compiled from regional studies and administrative sources. Together, these datasets allowed for a holistic view of the biophysical and socio-ecological conditions shaping agricultural capacity in the basin.

Pre-processing of the datasets was conducted prior to indicator construction. Landsat-8 imagery was first screened for quality, with cloud-contaminated scenes excluded, and the Normalized Difference Vegetation Index (NDVI) was calculated for each date. Seasonal composites were generated to capture land cover dynamics during the vegetation period. Elevation data were processed to derive slope maps, which formed the basis for relief evaluation. All raster datasets were harmonized to a common coordinate system, spatial resolution, and grid to ensure consistency in overlay and integration. This pre-processing phase was critical in preparing the raw data for systematic assessment.

Indicator construction formed the next step of the methodology. The slope data were reclassified according to Rodionov's five-point favorability scale, ranging from highly favorable (0–1.5°) to extremely unfavorable (12–25°). Population density was similarly reclassified into Rodionov's categories, from very sparse to extremely dense settlements. NDVI values were analyzed to distinguish between cultivated and natural vegetation, which were subsequently mapped into five primary land cover classes: water, open land, grain, cotton, and orchards or woodlands. Soil and hydrological constraints such as salinity, shallow or stony soils, and water availability were integrated as additional limiting factors. This multi-indicator construction allowed for a nuanced characterization of landscape suitability beyond a single-parameter assessment.

Suitability analysis and delineation were carried out through a rule-based integration of the constructed indicators. Each mapping unit was evaluated against the combined thresholds of relief, population density, vegetation cover, soil quality and hydrological availability. Based on these factors, four land suitability categories were established: marginally suitable, moderately suitable, suitable and highly suitable. Marginally suitable areas were characterized by steeper slopes and limited soil fertility, suitable only for low-intensity agriculture or grazing. Moderately suitable zones displayed gentler slopes and moderate fertility, supporting rain-fed cereals or orchards with careful management. Suitable areas offered more favorable conditions, with moderate slopes, accessible groundwater, and high fertility, allowing for diversified cropping systems. The most productive, highly suitable zones featured flat or gently sloping terrain, fertile soils, and established irrigation, supporting intensive and commercial-scale agriculture. The final suitability map, produced using ArcGIS, spatially delineated these four classes across the Central Zarafshan Basin.

In addition to broad suitability mapping, a micro-zonal analysis was performed to identify finer spatial variations within the piedmont plains and alluvial fans. This analysis was based on NDVI gradients, vegetation cover, transpiration indices, and geomorphic characteristics, and it resulted in the identification of five microzones: the Oqtog‘ foothill and hill zone, the Qoratog‘ foothill and hill zone, the Oltinsoy–Maydonsoy alluvial fan, the Ko‘ksaroysoy alluvial fan, and the Oqtepasoy alluvial fan. Each microzone was analyzed for its unique soil-water interactions, slope dynamics, and vegetation potential and the results were cross-validated with field knowledge and existing land-use practices. This micro-level analysis enriched the broader suitability classification by highlighting specific opportunities and challenges at the landscape unit scale.

The overall methodology is summarized in a workflow diagram (Figure 1), which illustrates the sequential stages from the selection of evaluation criteria and data acquisition, through pre-processing and indicator construction, to suitability classification and micro-zonal delineation. This structured, step-by-step approach ensured that the analysis was both methodologically rigorous and practically applicable. By integrating classical agro-ecological frameworks with modern geospatial techniques, the study provides a comprehensive methodological foundation for guiding sustainable land-use planning and agricultural intensification in arid and semi-arid regions.

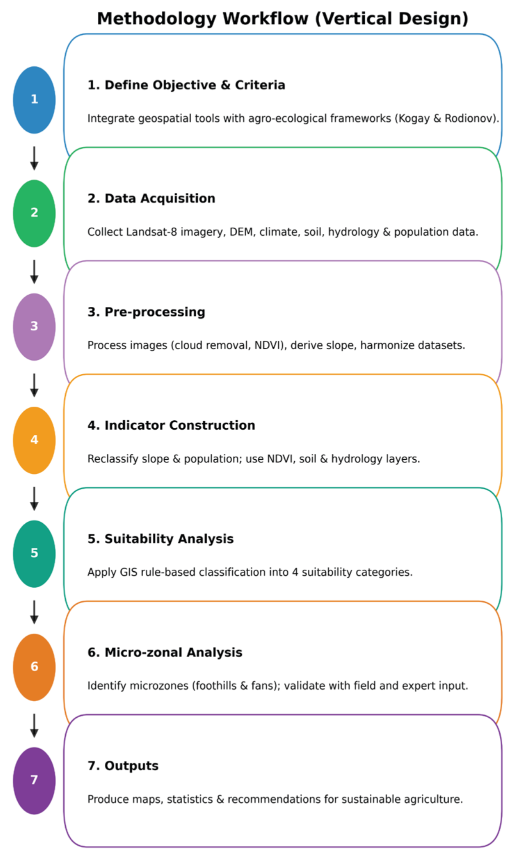

FIGURE 1. The flow chart of the methodology

RESULTS AND DISCUSSION

When assessing a region’s agricultural potential, one of the primary methodologies involves the integrated analysis of natural factors such as geological formations, terrain, climate, water availability, and landscape resources to determine the degree of suitability or constraints imposed by environmental conditions. In recent years, landscape-based analysis has gained widespread application in evaluating areas for agricultural development, playing a critical role in efforts to ensure food security. In this regard, aligning specific crop types and agricultural sectors with landscape characteristics has proven to be an effective strategy. Natural geographic and agro-climatic zoning maps have been recognized by numerous scholars as essential sources of information for agricultural planning and production (Eshquvvatov, 2020).

In determining the suitability of a given natural environment for agricultural use, the key criterion is not merely the presence of individual environmental components, but rather the typological landscape complexes that represent zones with relatively homogeneous natural-geographic conditions. These are areas defined by similar combinations of geology, relief, soil composition, vegetation cover, water resources, and climate components that directly or indirectly influence agricultural productivity (Saidov, 1972; Burkitt & Bretherton, 2022).

Furthermore, when evaluating landscapes for agricultural development, it is important to acknowledge the limiting characteristics of the land that may hinder its use. Such constraints include the degree of soil development, salinity levels, natural moisture availability, surface stoniness, clay or sandy-gravel composition, uneven terrain, slope steepness, and fragmentation. Recognizing and accounting for these factors is crucial in forming a realistic and sustainable approach to land-use planning.

Based on the aforementioned factors, N.A. Kogay (Kogay 1971; Mirzamakhmudov et al. 2022) proposed a classification system for agricultural landscapes, categorizing them into six typological classes: very low quality, low quality, below average, average, above average, and high-quality natural complexes. Applying Kogay's classification criteria, the landscape complexes of the Central Zarafshan Basin were evaluated for their agricultural suitability (Table 1). The analysis revealed that the natural complexes of alluvial, alluvial-deltaic, and proluvial-alluvial plains fall within the "above average" quality category, indicating that these areas are well-suited for agricultural development.

The Central Zarafshan Basin presents a highly diverse landscape mosaic, classified into twelve distinct categories based on agro-ecological potential and natural constraints. At the lower end of suitability, high mountain landscapes (Classes I–III), particularly in the Chaqilkalon Range and surrounding elevations above 2000 meters, exhibit steep slopes (>30°), rocky substrates and minimal soil cover rendering them largely unsuitable for conventional agriculture. Nevertheless, these areas support limited traditional activities such as grazing, beekeeping and the seasonal harvesting of medicinal plants. Moving into low-quality zones (Classes IV–VII), landscapes such as foothills, saline former seabeds, and aeolian sandy plains offer marginal potential due to poor soil quality, steep inclines, and salinity. However, innovative approaches such as phytomelioration, hydroponic greenhouses and reclaimed irrigation systems enable some degree of productive use, particularly for orchards and spring cereals.

Below-average and average quality landscapes (Classes VIII–IX), such as arid denudation plains and piedmont valleys, exhibit moderate constraints including gypsum-rich or stony soils, yet offer opportunities for meliorated irrigated farming, viticulture, and vegetable production. In contrast, above-average quality areas (Class X), such as river meanders and terrace plains, possess fertile soils and gentle slopes, enabling productive use through minor land leveling and supporting a mix of rice cultivation, orchards, and market gardening.

At the highest end of agricultural potential, piedmont proluvial-alluvial plains (Class XI) and oasis landscapes (Class XII) such as those around Samarkand and Kattaqo'rg'on demonstrate optimal conditions for intensive agriculture. These zones benefit from anthropogenic modifications and well-developed irrigation infrastructure, supporting double cropping systems, fruit orchards, sericulture, and melon cultivation. The classification underscores the need for regionally tailored agricultural strategies that align land use practices with inherent landscape capacities to ensure sustainable and resilient food production systems.

While Kogay's classification system is highly effective for evaluating large-scale regional complexes from an agricultural perspective, it proves less efficient when applied to smaller-scale typological and morphological units such as the piedmont and alluvial landscapes of the Central Zarafshan Basin. This limitation has been observed in subsequent studies evaluating landscapes for various purposes, including agricultural land use planning.

The analysis of the Central Zarafshan piedmont plains and alluvial landscapes produced the following key results: (i) vegetation and land cover patterns, (ii) slope and terrain classification, (iii) suitability assessment, and (iv) microzonal differentiation

TABLE 1. Classification of Central Zarafshan Basin Landscapes Based on Agricultural Suitability

Evaluation Class	Landscapes	Regions	Landscape Quality	Agricultural Use Potential
Very Low Quality	I. High mountain landscapes	Watershed areas of the Chaqilkalon Range	Unsuitable for agriculture due to lack of soil cover, steep slopes (>30°), and highly uneven relief	Grazing, large livestock, beekeeping, seasonal medicinal plant use
	II. High mountain meadow-steppe landscapes	Above 2000 m in Chaqilkalon and Chumqortog'	Rocky and steep slopes (>30°), unsuitable for agriculture	Grazing, rain-fed cereals, beekeeping, medicinal plants
	III. Mid-altitude forest-meadow landscapes	1000–2000 m in Chaqilkalon, Qoratepa, etc.	Eroded soils and dissected terrain with slopes >20°	Grazing, rain-fed farming, viticulture, sericulture, orchards

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Low Quality	IV. Low mountains and foothills	Below 1000 m in Qoratog‘, Ziyovuddin, etc.	Rocky, steep (8°–40°) terrain, minimal farming use	Spring cereals, drip irrigation orchards, grazing, greenhouses
	V. Saline and former seabed plains	Western Central Zarafshan terraces	High soil salinity, almost unsuitable	Reclaimed farming, orchards, hydroponic greenhouses
	VI. Aeolian sandy plains	Lower western foothills and ridges	Sandy terrain with deflation/ accumulation, not farmable	Grazing, orchards, beekeeping, spring cereals via phytomelioration
	VII. Wind-altered delta plains	Dry stream fans in western region	Selective farming possible with phytomelioration	Small-scale farming, groundwater-based orchard development
Below Average Quality	VIII. Arid denudation plains	Foothills of Qaroqchitog‘, Ziyovuddin, etc.	Shallow gypsum-rich soils, limited use	Meliorated irrigated farming, grazing, orchards, beekeeping
Average Quality	IX. Valley bottoms and fragmented piedmont plains	Stream valleys in Oqtog‘, Chaqilkalon	Stony soils and uneven terrain limit use	Irrigated farming, orchards, vineyards, vegetable crops
Above Average Quality	X. River meanders, lakes, and terrace plains	Western Zarafshan terraces	Fertile soils, suitable with minor leveling	Irrigated farming, rice, orchards, vegetable and fruit farming
High Quality	XI. Piedmont proluvial and alluvial plains	Piedmont zones of Chaqilkalon, Qoratepa, etc.	Optimal conditions for all agriculture	Irrigated crops, orchards, sericulture, melon cultivation
Very High Quality	XII. Oasis landscapes	Samarkand and Kattaqo‘rg‘on oases, major fans	Anthropogenically modified, very favorable	Irrigated farming, double cropping, orchards, viticulture

*Compiled by the author based on N.A. Kogay’s evaluation criteria.

In assessing food security challenges, one of the key international frameworks comes from the Food and Agriculture Organization (FAO), whose methodology facilitates the evaluation of landscapes for agricultural purposes. The FAO outlines fundamental principles for ensuring agricultural sustainability, including: increasing the efficiency of resource use, conserving and protecting natural resources, enhancing the resilience of agroecosystems to external shocks, and promoting responsible and effective governance mechanisms in agricultural management.

Agricultural landscape evaluations have also been conducted by D.A. Rodionov, who developed a classification system tailored for conditions in Russia (Rodionov, 1968; Li et al. 2023; Luo et al. 2024). His assessment method involves two major components:

1. Relief Evaluation – Based on a 100-point scale across five categories:

   a. Slope 12–25°: Extremely unfavorable (80–100 points)
   b. Slope 6.2–11.9°: Unfavorable (62–79 points)
   c. Slope 3.8–6.1°: Moderately favorable (44–61 points)
   d. Slope 1.6–3.7°: Favorable (17–43 points)
   e. Slope 0–1.5°: Highly favorable (0–16 points)

2. iPopulation Density Evaluation – Also on a 100-point scale with five categories:

   a. 300–1000 people/km²: Extremely dense (80–100 points)
   b. 200–299 people/km²: Dense (62–79 points)
   c. 50–199 people/km²: Moderately dense (44–61 points)
   d. 15–49 people/km²: Sparse (17–43 points)
   e. 0–14 people/km²: Very sparse (0–16 points)

This study employed the comprehensive evaluation framework developed by D.A. Rodionov (Li et al. 2023; Luo et al. 2024) to systematically assess the agricultural suitability of piedmont plains and alluvial landscapes. The methodology integrates key biophysical parameters such as soil characteristics, topographic features and climatic constraints, providing a scientifically robust basis for land classification and agroecological zoning.

Leveraging Rodionov’s methodological foundation, we establish the following classification system to support targeted agricultural land use planning:

1. Marginally Suitable – These areas feature slopes ranging from 2° to 3°, corresponding to 10–25 points in the relief evaluation category (Figure 3). Population density is low, with 10–12 people per km², rated at 14 points. The landscape retains natural vegetation cover, used primarily for livestock grazing and rain-fed farming, and is rated at 10 points. The soil is dark sierozem, located in the upper part of the plain, with moderate fertility rated at 16 points.
2. Moderately Suitable – These areas have slopes between 1° and 2°, aligning with 15–30 points in relief categories. Population density remains low, at 15–20 people per km², rated at 22 points. The landscape supports natural vegetation and is primarily used for rain-fed cereal cultivation. Given the high potential for drip irrigation, it is rated at 20 points. The soil is typical sierozem, found in the middle part of the plain, with good fertility rated at 24 points.
3. Suitable – These zones exhibit minimal slope (1°–1.5°), with a relief score of 55 points. Population density is moderate, with 50–60 people per km², rated at 45 points. The land supports cotton and vegetable cultivation, as well as orchard development, rated at 50 points. The soil is intensively cultivated typical sierozem, located in the central zone of the plain, with high fertility rated at 46 points.
4. Highly Suitable – These areas have slopes ranging from 0.1° to 1°, receiving 65–70 points. Population density is high, with 200–220 people per km², rated at 65 points. Due to the absence of natural vegetation, these lands are fully cultivated with cotton, cereals, and other crops, including orchards, receiving an evaluation of 80 points. The soil is typical sierozem, situated near the elevated river terraces and lower sections of the plain.

Prior to implementing the proposed evaluation framework, a comprehensive landscape analysis of the Central Zarafshan Basin was undertaken through the interpretation of multi-temporal Landsat-8 satellite imagery acquired between May 10 and July 27, 2023. This remote sensing approach enabled the extraction of vegetation indices and the generation of corresponding contour profiles, which collectively served as critical inputs for assessing the agro-ecological characteristics and suitability of the region's landscape complexes (Figure 1 and Figure 2).

The total area of the Central Zarafshan Basin is 13,570.52 km², comprising:

1. Water bodies: 127.36 km²
2. Open land: 5,881.84 km²
3. Grain cultivation areas: 3,008.86 km²
4. Cotton fields: 2,537.85 km²
5. v.Orchards, woodlands, shrublands, and sparse forests: 2,014.59 km²

These land use classifications were generated using automated NDVI (Normalized Difference Vegetation Index) calculations, with a spatial accuracy reaching 105 hectares. Based on the satellite imagery during the 2023 vegetation season (Figure 2), we developed an integrated vegetation map of the Central Zarafshan region. A total of six satellite images taken between May 10 and July 27, 2023, were processed for this purpose (Eshquvvatov 2020).

Figure 2 illustrates the land use distribution of the Central Zarafshan Basin. The map, developed using satellite imagery and GIS techniques, categorizes the landscape into five primary land use classes: water bodies, open land, grain cultivation areas, cotton fields and orchards or woodlands. The spatial configuration of these classes provides critical insights into the region's agricultural capacity, land productivity and resource availability.

Water bodies, are scarce and appear as isolated patches, indicating limited surface water sources. This scarcity underscores the need for efficient water management strategies, especially in light of climate variability and increasing irrigation demands. The open land predominantly occupying the western and northern parts of the basin. These lands are likely underutilized or degraded and may consist of desert plains, rangelands, or fallow fields, revealing significant potential for future land reclamation, soil restoration, or afforestation initiatives.

Grain cultivation zones, span much of the central and southern areas. These areas serve as core zones for cereal production and are essential for food security and rural economic stability. Cotton fields, which cluster along rivers and canal-irrigated zones, reflecting their dependence on controlled water supply systems. Given cotton's high water requirements, these areas will benefit significantly from the adoption of water-saving irrigation technologies and sustainable cropping practices.

Orchards and woodlands primarily located near oasis areas and productive piedmont zones. These areas highlight the role of horticulture and agroforestry in enhancing local biodiversity, supporting nutrition and providing economic opportunities. However, the relatively limited extent of orchards suggests an opportunity to expand perennial cropping systems, especially in marginal or degraded lands, to improve land resilience and ecological stability.

Overall, Figure 2 presents a clear visual narrative of land use patterns within the Central Zarafshan Basin. It highlights the concentration of agriculture along fertile river corridors and the dominance of open or underutilized land in peripheral areas. This spatial structure provides a valuable basis for regional planning, especially in guiding land reclamation, crop diversification, irrigation development, and sustainable land use interventions aimed at strengthening long-term food security and ecological sustainability.

Building upon the preceding analyses, this study advances a detailed investigation of the piedmont plains and alluvial fan systems situated along the southern slopes of the Oqtog‘ and Qoratog‘ natural-geographic regions, with a focus on their geomorphological structure and agricultural suitability. These zones are situated in the northern and northeastern sectors of the Central Zarafshan administrative region, encompassing foothill plains and dissected hill slopes along the southern margins of the Oqtog‘ and Qoratog‘ mountain ranges. They also include alluvial fan systems formed by episodic hydrological activity from seasonal streams originating in these highland catchments.

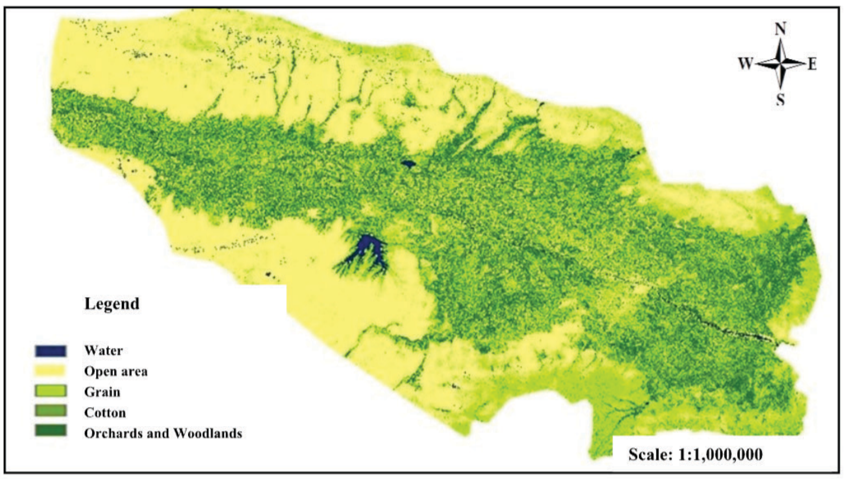

FIGURE 2. Integrated Vegetation Index Map of the Central Zarafshan Landscapes

The terrain of this region is undulating and heavily dissected by arid and ephemeral stream basins. The slope of the land ranges from 2° to 56° (Figure 3). The elevation of the region varies between approximately 670 and 1,000 meters above sea level. The soil types primarily consist of light and typical sierozem, with darker sierozem soils found on the alluvial fans. The natural vegetation includes a mix of desert plant species and ephemeral flora such as white saxaul (Haloxylon persicum), saltwort, wormwood, mallow, irises, wild thyme, Eremurus, and ferula.

Figure 3 provides a false-color elevation index map of the Central Zarafshan Basin, highlighting spatial variation in surface characteristics across the region. The map employs a color gradient from green to red to represent varying values of elevation. These zones support robust agricultural activity due to favorable topography, soil moisture retention and water availability.

Of particular note is the red rectangular overlay, which delineates a focused study area along the northern and northeastern sector of the basin. This region, encompassing the southern slopes of the Oqtog‘ and Qoratog‘ ranges, is characterized by a mosaic of elevation zones and landscape complexity, as evidenced by the variation in color tones. The selected area represents a transition zone between highland and piedmont systems, where slope dynamics, soil redistribution and water flow patterns shape land suitability.

From a strategic standpoint, Figure 3 serves as a critical tool for terrain analysis, agro-ecological zoning and land capability classification. By visually differentiating elevation conditions, the map supports decision-making in precision agriculture, watershed planning and climate-resilient land use strategies. Moreover, this spatial visualization reinforces the importance of topographic and ecological heterogeneity in guiding sustainable agricultural intensification and landscape management across the Central Zarafshan Basin.

High-resolution satellite imagery integrated within the ArcGIS environment enabled precise delineation of the Nurota foothill proluvial, deluvial and alluvial plains, covering an estimated area of 2,748 km². The region exhibits pronounced spatial variability in annual precipitation, with values reaching up to 372 mm in Oqtog‘ and decreasing to 200–250 mm in Qoratog‘. The majority of rainfall is concentrated between February and April, highlighting the seasonal dependency of water availability critical to agricultural planning and landscape resilience (Hikmatov et al. 2016).

According to hydrometeorological data obtained from the Qo‘shrabot Meteorological Station, the period with temperatures exceeding +5°C begins on April 6 in Oqtog‘ and continues until November 20, while in Qoratog‘ it starts earlier, on March 13, and ends on November 12, resulting in 258 days and 243 days, respectively. During this period, the accumulated positive temperatures range from 4,380°C to 4,750°C. Days with temperatures above +10°C typically span from early April to the end of October, amounting to approximately 200–210 days, with accumulated temperatures between 4,080°C and 4,390°C.

The frost-free growing season in the study area typically begins between April 6 and 14 and extends until October 12 to 14, offering a cultivation window of approximately 180 to 190 days. Climatic conditions are characterized by mild winters and hot summers, with average January temperatures ranging from –2.4°C to –0.7°C, and July averages stabilizing around 27.0°C. Spring precipitation, occurring within the +5°C to +15°C temperature range, varies between 131 mm and 54 mm, while summer precipitation declines to 61–47 mm. The onset of the dry season occurs as early as May 16 in Qoratog‘ and by June 3 in Oqtog‘, marking a critical transition period for agricultural water management (Jiang & Zhou, 2023; Aitekeyeva et. Al, 2020). During the observation period, the maximum Normalized Difference Vegetation Index (NDVI) values ranged from 0.15 to 0.17, indicating low to moderate vegetation density across the study area.

Figure 4 illustrates the agricultural suitability map-scheme of the piedmont plain landscapes along the southern slopes of the Oqtog‘ mountain range. The map categorizes the landscape into four suitability classes, marginally suitable, moderately suitable, suitable and highly suitable based on a composite assessment of slope, soil characteristics, land cover and hydrological conditions. The spatial differentiation presented in the map provides a clear understanding of the distribution of land capability for agricultural development within this transitional zone between highlands and lowlands.

The marginally suitable areas, are predominantly located along the upper and steeper foothill margins. These areas are typically constrained by shallow, eroded soils, steep slopes and limited moisture retention capacity. Agricultural use in these zones is restricted, and such lands are better suited for extensive grazing, silvopastoral systems or limited dryland farming with soil conservation interventions.

In contrast, the moderately suitable areas, occupy a broad transitional belt. These zones may have moderate slope gradients and improved soil profiles, allowing for rain-fed cereal crops or low-intensity horticulture. However, these areas still require agronomic and water management enhancements to increase productivity.

The suitable areas, mark regions where the physical and ecological conditions are generally favorable for agriculture. With moderate slope, accessible groundwater and workable soils, these landscapes support diversified farming systems, including seasonal cropping, orchards and irrigation-based agriculture. These areas offer significant potential for sustainable intensification, especially with the implementation of water-efficient technologies such as drip irrigation.

The most promising zones are the highly suitable areas. These landscapes are generally flat or gently sloping, well-drained and enriched with fertile soils. They form the core of high-productivity agricultural zones, ideal for intensive cropping, horticulture and high-value commercial farming. These areas are strategic for investment in agribusiness, value chain development and regional food security initiatives.

Overall, Figure 4 provides a scientifically grounded and spatially explicit framework for land use planning in the Oqtog‘ piedmont region. It highlights both the opportunities for agricultural expansion and the constraints that must be managed through appropriate policy, infrastructure development and sustainable land management practices. This suitability map serves as a vital tool for guiding evidence-based agricultural decision-making, climate adaptation strategies and long-term land productivity enhancement in the Central Zarafshan Basin.

Based on agro-climatic indicators, microzonal differences in vegetation index (NDVI), degree of vegetation cover, and transpiration index, the following microzones were identified within the study area:

1. Oqtog‘ Foothill and Hill Zone Microzone
2. Qoratog‘ Foothill and Hill Zone Microzone
3. Oltinsoy–Maydonsoy Alluvial Fan Microzone
4. Ko‘ksaroysoy Alluvial Fan Microzone
5. v.Oqtepasoy Alluvial Fan Microzone.

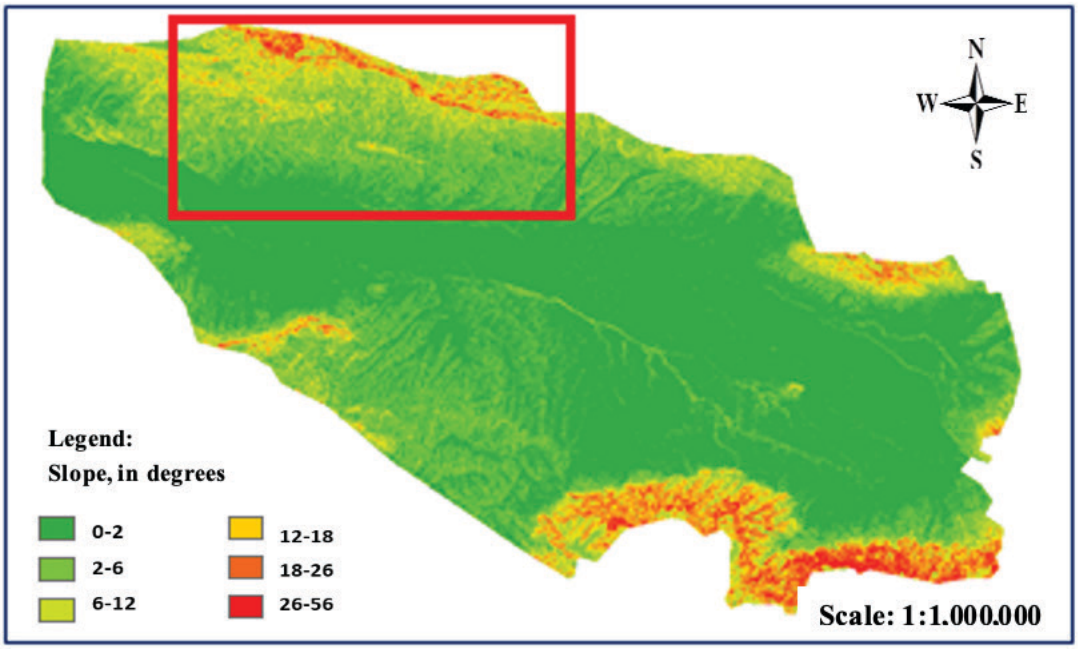

FIGURE 3. Slope Map of the Central Zarafshan Basin

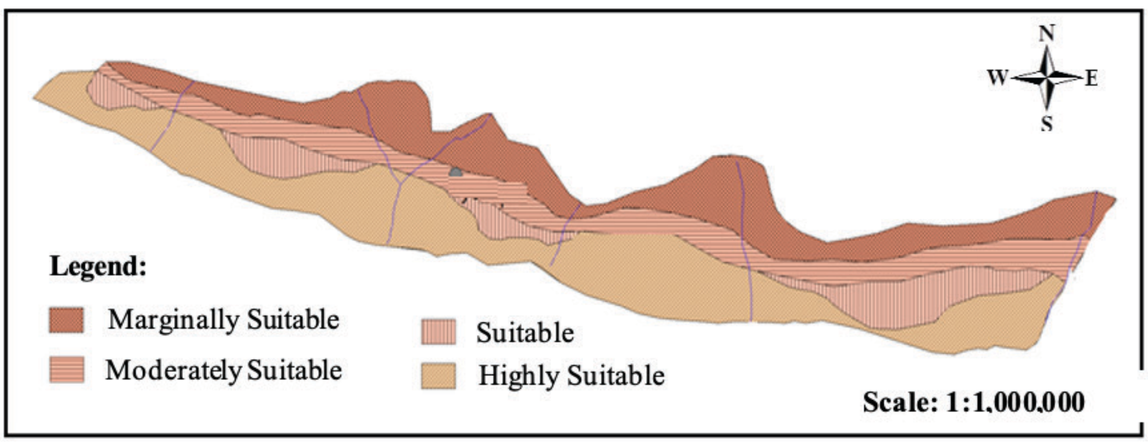

FIGURE 4. Agricultural Suitability Map-Scheme of the Piedmont Plain Landscapes along the Southern Slopes of Oqtog‘

For instance, the Oqtepasoy alluvial fan is covered with loess-like sediments reaching depths of up to 15–20 meters, which also partially overlie the third terrace. The hydrological conditions of this fan are directly associated with the Oqtepasoy stream, which originates from the southern slopes of the Nurota mountain range. The stream has a total length of 60 km and drains a basin covering 715 km². After flowing past the village of Ocha, the stream forms an alluvial fan spanning an area of 16.45 km². The fan width ranges from 1–2 km at its upper reaches to 3–3.5 km near the village of Baxrin in its lower section.

The fan region is densely populated, with many large villages. In the upper valley of the stream, seasonal tributaries and small gullies, which often dry up in summer, are widespread. Paleogene and Neogene formations lie at depths of 20–30 meters in the subsurface (Yarashevet al. 2020). Currently, 40–50% of the area is actively used for irrigated agriculture, including extensive vineyards. The remaining areas are primarily utilized for rain-fed agriculture and pastoral livestock. Approximately 80% of the fan is covered with deep, typical sierozem soils with a soft mechanical composition, while the remaining 20% consists of thin, stony sierozem soils typical of alluvial fans.

Oqtepasoy is formed by the confluence of Qo‘shrabotsoy and G‘ujumsoy, and it has numerous tributaries, the most significant of which include Pangatsoy, Shovvasoy, and Qizilolmasoy. The stream's average long-term discharge is 0.312 m³/sec. During the spring season, Oqtepasoy occasionally experiences intense flash floods, typically lasting 1.5 to 2 days.

Groundwater depth varies across the fan:

1. In the upper zone near Ocha village, the water table lies at 7–8 meters
2. In the middle section near Shavona, at 25–30 meters
3. In the lower area near Bahrin, at 8–10 meters

In recent years, a decline in surface water flow, lowering of groundwater levels, and reduction in the number of springs have been observed. Experts attribute this to climate change, human activities, and vegetation degradation. To optimize water resource use, construction of the Oqtepasoy Reservoir is planned in the upper part of the fan and the narrow section of the valley. With a useful capacity of 25 million m³, the reservoir is expected to enable an additional 3,500 hectares of irrigated agriculture upon completion.

Recently, agricultural land in the fan has been expanding due to better utilization of surface and groundwater. Notably, in 2022, 700 hectares were developed using drip irrigation, leading to the establishment of intensive walnut and vineyard plantations.

The soils of the fan are primarily typical and light-colored sierozem, with humus content ranging from 1.2% to 1.5–2.0%. These soils are partially used for irrigated farming, though rain-fed agriculture remains dominant. Commonly cultivated crops include wheat, barley, and safflower. The region's vegetation comprises wormwood (Artemisia), saltwort, white saxaul, couch grass, mallow, and various dye plants, which are widely used as livestock fodder.

The fan landscape features numerous geomorphic units, such as seasonal stony dry streambeds, ravine-like small gullies, narrow terraces, hillocks surrounding the stream, and undulating plains.

CONCLUSION

The Central Zarafshan Basin is characterized by a complex terrain that fundamentally shapes its landscape diversity and agricultural potential. This complexity underscores the importance of terrain analysis as a key criterion in evaluating land suitability for agricultural use. By integrating the genesis and characteristics of the basin's landscapes into the evaluation process, it becomes possible to identify their capacity to support different forms of economic activity, particularly agriculture.

The use of remote sensing and GIS-based approaches, including the interpretation of Landsat-8 imagery and the calculation of vegetation indices (NDVI), has proven highly effective in examining the internal structure of landscape complexes. These tools not only facilitated the assessment of agricultural potential but also provided insights into ecological processes such as vegetation dynamics, soil-water interactions, and land degradation. The generation of slope classification maps further added value by offering practical guidance for agricultural zoning, reclamation initiatives, and irrigation improvement strategies.

The findings highlight that while a significant proportion of the piedmont plains and alluvial fan landscapes are suitable or highly suitable for cultivation, their potential remains underutilized. Strategic application of modern irrigation technologies, soil restoration practices, and targeted land management in these zones could substantially expand intensive and diversified farming systems. In doing so, the Central Zarafshan Basin could strengthen its role as a key contributor to regional food security.

Overall, this study demonstrates that the integration of agro-ecological evaluation frameworks with geospatial technologies provides a robust scientific foundation for sustainable land-use planning. The approach offers decision-makers spatially explicit evidence for prioritizing investment in agriculture, optimizing natural resource use, and building resilience against climate variability. By leveraging these findings, Uzbekistan can advance climate-resilient agriculture and enhance its long-term food security goals.

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DECLARATION OF COMPETING INTEREST

None.

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