Remote sensing for ecological status assessment of agricultural landscapes in the Surkhandarya Terrestrial Basin, Uzbekistan

Prinjon Khasanov[1,*], *Yunus* Karimov[2], *Kuvondik* Yarashev[1], *Ismoiljon* Mirzahmedov[3], and *Rasul* Mamajonov[1]

[1]Samarkand State University, University Boulevard, 140104 Samarkand, Uzbekistan
[2]Samarkand State Pedagogical Institute, 230044 Samarkand, Uzbekistan
[3]Namangan state university, 160107 Namangan, Uzbekistan

Abstract. In Central Asia, land degradation is becoming a bigger problem, particularly in agricultural areas that are susceptible to climate change and irresponsible land usage. This study evaluates the ecological state of the Surkhandarya Terrestrial Basin in Uzbekistan over the previous 20 years (2000–2020) using remote sensing and GIS-based techniques. Land use and land cover (LULC) changes, vegetation degradation, and ecological risk zones were identified by analyzing multitemporal satellite photos from Landsat 8 OLI and Sentinel-2 MSI. The findings indicate that natural grasslands and woods have been mostly replaced by agricultural land, and the number of dry and bare areas has grown, hastening land degradation. The NDVI data's spatial analysis revealed a steady deterioration in the health of the vegetation, particularly in the northern and eastern The vegetation health gradually declined, particularly in the northern and eastern regions, according to a spatial analysis of the NDVI data. High-risk areas were found in the eastern and southern regions of the basin, where deforestation and intensified agriculture have raised ecological vulnerability, according to an ecological risk assessment. The results emphasize the critical necessity for sustainable land management techniques, such as afforestation, effective irrigation, and soil conservation techniques, as well as the use of remote sensing for long-term environmental monitoring.

1 Introduction

In regions where environmental changes are happening quickly as a result of human activity and climate change, remote sensing has emerged as a crucial instrument for evaluating ecological conditions in a variety of landscapes [1]. Among the most delicate ecosystems are agricultural landscapes, which need constant observation to guarantee food security and sustainable land use. In southern Uzbekistan's Surkhandarya Terrestrial Basin (STB), agriculture is essential to the indigenous population's means of subsistence and financial security [2]. However, preserving ecological balance is severely hampered by the growth of irrigated agriculture, soil deterioration, and growing water constraint. Policymakers and land

*Corresponding author: quvondiqyarashev2019@gmail.com

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managers can gain important insights from remote sensing, which offers an economical and effective method of tracking changes in land cover, plant health, and soil conditions.

The necessity of environmental monitoring in agricultural areas is highlighted by studies conducted throughout Central Asia. Due to over-irrigation, salinization, and deforestation, the area has seen significant land degradation, which has reduced agricultural output [3]. Due to soil erosion and moisture loss, more than 90,000 km2 of land in Kazakhstan have been designated as degraded [4]. Over 50% of Turkmenistan's agriculture is severely salinized as a result of excessive irrigation [5]. About 40% of Uzbekistan's cropland is affected by desertification and soil degradation, which lowers production and increases reliance on imported food. Studies using remote sensing have shown that the expansion of cropland in Central Asia between 2000 and 2020 led to a 30% reduction in natural vegetation cover and increased the risk of soil degradation.

In Uzbekistan, remote sensing has been frequently employed to evaluate plant health, irrigation effectiveness, and changes in land use [6]. Although there are over 4.3 million hectares of irrigated land in the nation, inefficient water use results in large losses [7]. Over 50% of agricultural land in the Aral Sea region is afflicted by moderate to high levels of salinity, according to satellite-based studies that have shown concerning trends in soil salinization. In the vicinity of the STB, natural vegetation loss has also been noted; overgrazing and agricultural growth have caused pastures to shrink by roughly 15% over the previous 20 years [8]. However, despite the widespread use of remote sensing in Uzbekistan, localized ecological assessments of agricultural landscapes in the STB remain limited, leaving important knowledge gaps in understanding the dynamics of land degradation in the region [9].

The primary challenge in the Surkhandarya basin is the increasing pressure on land and water resources resulting from the rapid expansion of agriculture. Although more than 80% of total water consumption in the region is directed to irrigation, water use efficiency remains low, with losses exceeding 40% due to aging irrigation infrastructure. Soil fertility is declining at an alarming rate, with organic matter content in many croplands falling below 1.5%, increasing reliance on chemical fertilizers. Rising temperatures and erratic rainfall patterns are further threatening agricultural productivity, with projections indicating a 10-15 percent reduction in crop yields by 2050 under current climate scenarios [10].

Considering all of the aforementioned, the purpose of this study is to use remote sensing techniques to evaluate the ecological state of agricultural landscapes in the STB. In order to detect patterns of deterioration and important risk locations, the study will examine changes in land use, soil conditions, and plant health across time. The project aims to create an evidence-based framework for sustainable land management using satellite images and GIS analysis, which will support regional initiatives to prevent environmental degradation and guarantee agricultural sustainability.

2 Materials and methods

One of Uzbekistan's most significant agricultural areas is the Surkhandarya land basin, which spans an area of around 20,100 km2 (Figure 1). Over 60% of its 2.8 million inhabitants work in agriculture and associated fields. However, preserving ecological balance is severely hampered by the growth of irrigated agriculture, rising soil degradation, and dwindling water supplies. With summer temperatures above 40°C and an average annual rainfall of 250–300 mm, the area is particularly vulnerable to drought and desertification.

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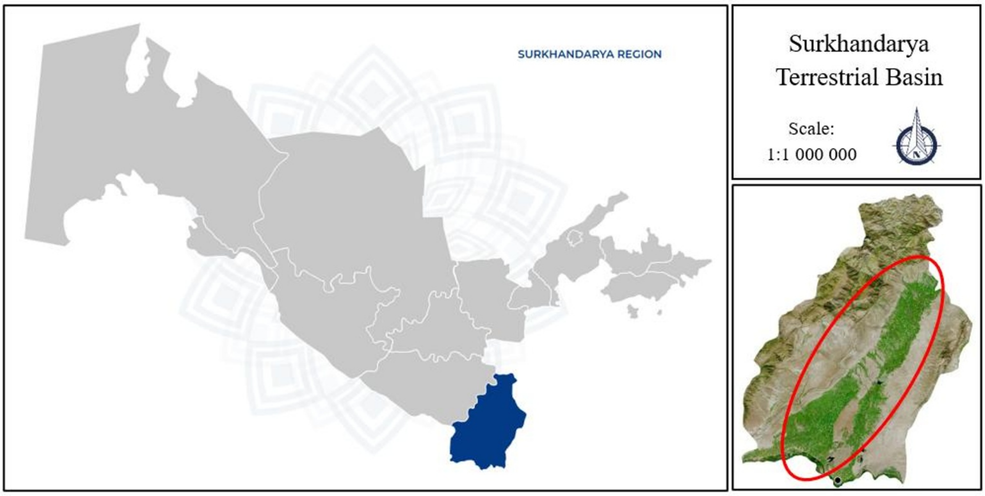

Fig. 1. Map of the study area.

Satellite imagery was acquired from multiple sources, including the Landsat 8 Operational Land Imager (OLI) and the Sentinel-2 MultiSpectral Instrument (MSI), covering the period from 2000 to 2020. Landsat 8 provides imagery in the visible and fine infrared bands with a spatial resolution of 30 meters. 10-meter resolution in the spectral bands important for vegetation analysis. To ensure high temporal consistency, cloud-free composite imagery with a temporal frequency of at least one image per season was selected for analysis to account for seasonal changes in vegetation growth and land cover. Vegetation health and land degradation were assessed using spectral indices derived from satellite data.

The density and strength of vegetation were evaluated using the Normalized Difference Vegetation Index (NDVI), and agricultural regions were categorized as healthy, moderately stressed, and degraded using the NDVI thresholds. Using training samples from high-resolution satellite data and field observations, a supervised classification approach was used to classify land use and land cover (LULC). Agriculture, water, open land, grassland, woodland, wetland, and dry land were among the classified categories. Overall, the aforementioned methodology also produced an ecological status risk map.

3 Results and discussion

A two-year (2000–2020) land use and land cover (LULC) analysis of the STB revealed significant trends in agricultural expansion, vegetation change, and land degradation (Figure 2).

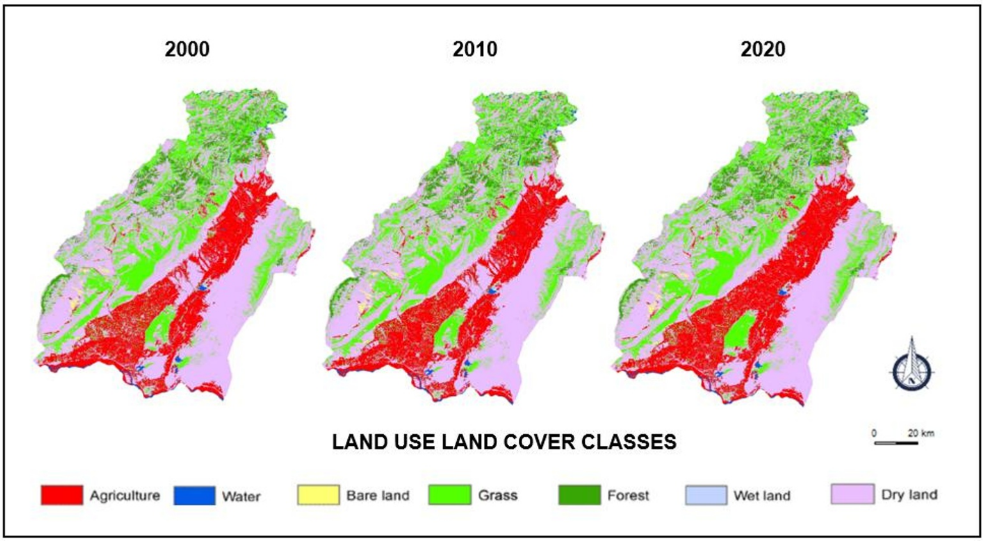

Fig. 2. Land use and land cover (LULC) changes in the Surkhandarya Terrestrial Basin from 2000 to 2020.

Agricultural land was already widely distributed in 2000, particularly in the study area's southern and central regions. Grasslands and other natural vegetation were gradually replaced by farmed land. The agricultural footprint had grown somewhat by 2010 and continued to grow in 2020, mostly occupying formerly wooded and grassland regions. This pattern points to continued agricultural intensification, which is probably caused by rising food production demands and increased irrigation. Although they have been declining over time, forested areas have a comparatively consistent tendency. Certain forested areas in the northern region seem to have been cleared for farming and deforestation between 2000 and 2020. Pastures show a similar trend, with significant declines over time reflecting a gradual transition to cropland.

In the southeast and southwest regions, drylands remain dominant, with little change over the years. However, the presence of bare land and degraded areas appears to have increased slightly, indicating soil erosion or desertification processes. Wetlands, although limited in area, show a decline from 2000 to 2020, which may indicate a decreasing water supply or increased land conversion. Water bodies appear relatively stable, with minor fluctuations that may be related to seasonal changes or hydrological changes.

An analysis of land degradation in the STB from 2000 to 2020 revealed that degraded areas are increasing, particularly in the northern and central regions of the study area (Figure 3).

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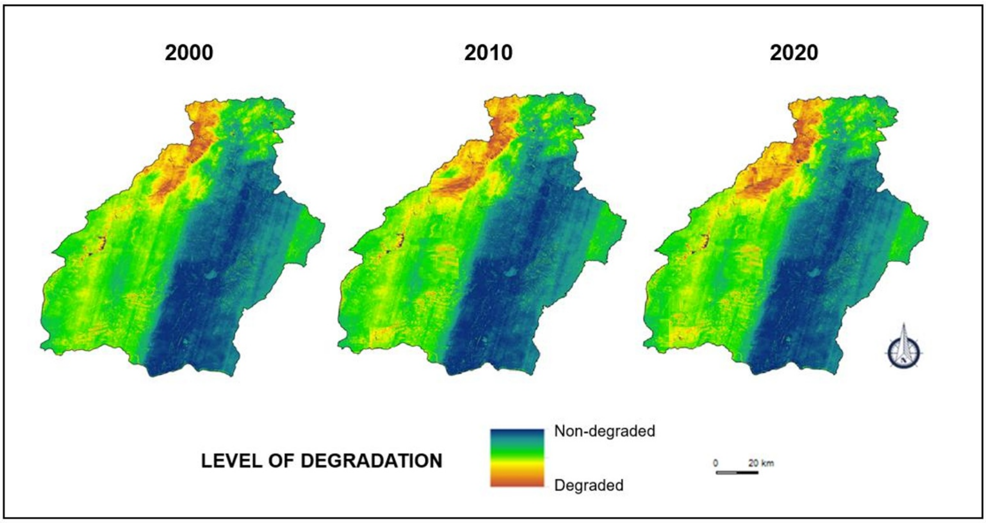

Fig. 3. Land degradation trends in the Surkhandarya Terrestrial Basin from 2000 to 2020.

Large green and blue regions indicated rather stable ecological conditions in 2000, and the majority of the basin shown minimal levels of deterioration. The lower zones and agricultural fields, where soil conditions and vegetation cover were maintained, were the main locations of the non-degraded areas. Nonetheless, there were some minor indications of deterioration in the northern region, where early soil damage was indicated by yellow and orange areas. The degree of degradation had increased by 2010, with yellow and orange zones growing considerably, particularly in the northern mountainous regions and transitional agricultural lands. This pattern suggests that poor water management and unsustainable land use practices are causing more soil erosion, vegetation loss, and possible salinization. While most of the basin has remained relatively stable, moderate degradation has become more evident, indicating the need for intervention measures to prevent further deterioration.

By 2020, the level of degradation had worsened significantly, as evidenced by the widespread occurrence of yellow, orange and red zones, especially in the northern and northeastern regions. The shift from green to yellow and orange indicates the loss of vegetation cover, the decline in soil fertility and the increase in fertile land. These changes are caused by prolonged agricultural activities, overgrazing, deforestation and waterlogging. The progression of degradation over a 20-year period highlights the increasing ecological pressures on the basin and the urgent need for sustainable land management and conservation strategies to mitigate ecological damage.

Ecological risk assessment and vegetation degradation analysis provide a spatial understanding of ecological threats affecting the STB (Figure 4).

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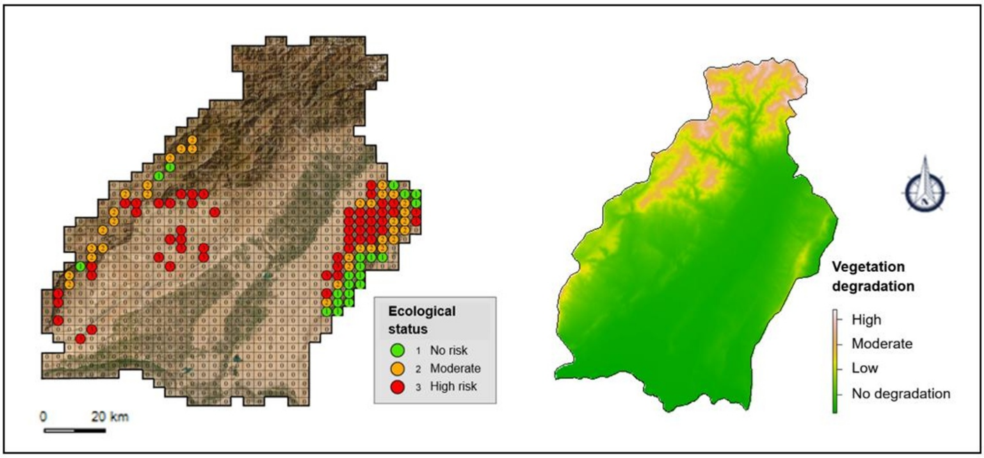

Fig. 4. Ecological risk assessment and vegetation degradation in the Surkhandarya Terrestrial Basin.

The left panel of the figure shows the state of ecological risk across the region, with a network-based classification identifying areas with varying degrees of environmental vulnerability. The presence of red markers representing high-risk zones is concentrated in the southwestern and eastern parts of the basin, indicating areas experiencing significant ecological stress. These areas may be affected by intensive agriculture, deforestation, overgrazing, and soil degradation. Moderate-risk zones are scattered throughout the basin, primarily along the transition zones where human activities are intervening in natural landscapes. In contrast, low-risk zones are primarily observed in the northwest and along the central axis of the basin, where vegetation cover and ecological stability appear relatively intact.

The right panel highlights the degree of vegetation degradation, providing information on how ecological stressors have affected vegetation cover. Much of the basin remains intact, indicating that significant parts of the region still retain healthy vegetation cover. However, low to moderate levels of degradation are evident in various parts of the basin, particularly in transitional landscapes where land use change has occurred. The northern highlands show high levels of vegetation degradation, indicating severe ecological stress due to deforestation, soil erosion, and climate change.

The study's findings show that over the past 20 years, the STB has experienced substantial changes in land use and land cover (LULC), with a distinct pattern of agricultural expansion at the expense of grasslands and natural vegetation. The observed decrease in vegetation cover and the growing number of degraded lands, as shown by the geographical analysis of ecological hazards, highlight the growing ecological stresses on the area. These alterations are in line with more general patterns seen in Central Asia, where extensive land degradation and decreased ecological stability have resulted from agricultural expansion, deforestation, and unsustainable land management.

Particularly in the southern and central regions of the basin, agricultural land significantly increased between 2000 and 2020, frequently displacing grasslands and wooded areas, according to the LULC research. This pattern is similar to that seen in other parts of Uzbekistan, where government policies encouraging agricultural development and growing food demand have led to an expansion of irrigated cropland. But this growth has also increased ecological fragility, decreased plant cover, and raised soil salinity. Research conducted in the Aral Sea area has demonstrated that excessive irrigation and poor water management have resulted in degraded soil and decreased land productivity. Concerns over long-term sustainability and food security are raised by the rise in bare and dry land over time, which suggests that certain places have become desertified [7]. The degradation analysis further confirms that land degradation has increased over the period under review, particularly in the northern and northeastern regions. The shift from low to high levels of degradation is consistent with known environmental stressors in the region, including overgrazing, unsustainable farming practices, and reduced water availability. Similar degradation patterns have been observed in Kazakhstan and Turkmenistan, where the decline in vegetation is associated with soil erosion and declining groundwater levels [8]. Previous remote sensing studies in Uzbekistan have shown that more than 50% of agricultural land in arid regions is moderately to highly saline, leading to loss of productivity. The expansion of degraded land in the STB indicates that these processes are accelerating, requiring urgent intervention.

The ecological risk assessment has identified hotspots for environmental degradation, with high-risk zones concentrated in the southwestern and eastern parts of the basin. These areas coincide with areas of increased agricultural expansion, overgrazing, and deforestation. Moderate-risk zones, scattered across transitional landscapes, indicate that environmental pressures are gradually increasing in previously stable buffer zones [9]. Comparison with vegetation degradation maps shows that ecological risk is strongly associated with vegetation loss, reinforcing the need for proactive land conservation efforts. Similar studies in semi-arid regions of Uzbekistan have shown that afforestation, sustainable irrigation practices, and soil restoration techniques can effectively mitigate degradation trends.

The results of this study highlight the importance of remote sensing and GIS-based approaches for land degradation monitoring, offering a scalable and cost-effective way to track ecological changes over time. By combining multi-temporal satellite data, spectral indices, and field surveys, this study provides a comprehensive assessment of degradation patterns and ecological risks [10]. However, despite the advantages of remote sensing, there are some limitations, including the difficulty in isolating specific drivers of degradation, the need for high-resolution imagery for detailed analysis, and the reliance on field data for accuracy verification. Future research should focus on machine learning techniques, soil moisture analysis, and climate modeling to improve degradation assessment and prediction capabilities.

4 Conclusions

According to the study's findings, the STB has experienced substantial changes in land cover and usage during the previous 20 years, with increased soil degradation and a decrease in native vegetation as a result of agricultural growth. The patterns show that farmland is gradually replacing grasslands and woodlands, and the expansion of dry and barren areas is a sign of growing ecological stress. These results align with more general regional trends in Central Asia, where ecological degradation has been accelerated by climate variability and unsustainable land use.

Land degradation is growing in impacted areas, particularly in the northern and eastern regions where soil erosion and vegetation loss are rising, according to spatial analysis. The ecological risk assessment also found high-risk areas in the basin's eastern and southwestern regions, where deforestation, overgrazing, and agricultural intensification have put more strain on the environment. These patterns demonstrate the necessity of enhancing land management techniques in order to prevent additional environmental deterioration.

References

1. F. Löw, A.V. Prishchepov, F. Waldner, O. Dubovyk, A. Akramkhanov, C. Biradar, J. P. A. Lamers, Mapping cropland abandonment in the Aral Sea Basin with MODIS time series, Remote Sensing **10(2)**, 159 (2018).
2. S. Song, X. Chen, Z. Hu, C. Zan, T. Liu, P. De Maeyer, Y. Sun, Deciphering the impact of wind erosion on ecosystem services: An integrated framework for assessment and spatiotemporal analysis in arid regions, Ecological Indicators **154**, 110693 (2023).
3. S. Khasanov, R. Kulmatov, F. Li, A. van Amstel, H. Bartholomeus, I. Aslanov, G. Chen, Impact assessment of soil salinity on crop production in Uzbekistan and its global significance, Agriculture, Ecosystems & Environment **342**, 108262 (2023).
4. A. Hamidov, K. Helming, D. Balla, Impact of agricultural land use in Central Asia: A review, Agronomy for Sustainable Development **36**, 1–23 (2016).
5. K. M. De Beurs, G. M. Henebry, B. C. Owsley, I. Sokolik, Using multiple remote sensing perspectives to identify and attribute land surface dynamics in Central Asia 2001–2013, Remote Sensing of Environment **170**, 48–61 (2015).
6. C. Conrad, M. Usman, L. Morper-Busch, S. Schönbrodt-Stitt, Remote sensing-based assessments of land use, soil and vegetation status, crop production and water use in irrigation systems of the Aral Sea Basin: A review, Water Security **11**, 100078 (2020).
7. Y. Qin, J. He, M. Wei, X. Du, Challenges threatening agricultural sustainability in Central Asia: Status and prospect, International Journal of Environmental Research and Public Health **19(10)**, 6200 (2022).
8. A. Omonov, T. Kato, S. Khasanov, A. Fitriyah, F. Li, S. Musayev, Z. Ismoilov, Integrated approach to soil salinity assessment using SEM in Sirdarya province, Uzbekistan, Remote Sensing Applications: Society and Environment **35**, 101214 (2024).
9. L. Dugerdil, O. Peyron, G. Ménot, D. Egamberdieva, J. Alimov, S.A. Leroy, S. Joannin, First paleoenvironmental calibrations for modern pollen rain of Tajikistan and Uzbekistan: A case study of pollen-vegetation functional biogeography of Arid Central Asia, Global and Planetary Change, 104857 (2025).
10. S. Song, X. Chen, T. Liu, C. Zan, Z. Hu, S. Huang, Y. Sun, Indicator-based assessments of the coupling coordination degree and correlations of water-energy-food-ecology nexus in Uzbekistan, Journal of Environmental Management **345**, 118674 (2023).