# Contemporary landscape changes in Syrdarya region: a remote sensing and gis analysis

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## Abstract

This article analyzes the landscape transformation processes of Syrdarya region over the past three decades (1990–2024) using remote sensing and geographic information systems (GIS). The study draws on Landsat and Sentinel-2 satellite imagery, ERA5 reanalysis and meteorological station records, and soil monitoring data. The results show that, alongside the steady expansion of irrigated cropland, secondary salinization and land degradation have intensified: the share of strongly salinized land increased from 8% to 16%, while natural pasture and desert landscapes shrank by almost a half. Mean annual temperature rose by approximately 1.8 °C between 1980 and 2024, and a declining tendency was detected in atmospheric precipitation. The combined effect of anthropogenic factors and climate change is expressed through disturbance of the groundwater regime and the progressive desertification of steppe landscapes. The findings can support more sustainable use of land and water resources and the improvement of landscape monitoring systems in the region.

**Keywords:** *landscape change, land cover, secondary salinization, land degradation, remote sensing, climate change, Syrdarya region.*

## 1. Introduction

Landscape change is the transformation of the composition, structure and functions of geosystems over time as a result of the interaction between natural and anthropogenic factors. In the arid regions of Central Asia, these processes are particularly intense due to the expansion of irrigated agriculture, the redistribution of water resources and global climate change [1]. As demonstrated by the case of the Aral Sea crisis, human activity is capable of fundamentally transforming desert-zone landscapes within a short historical period [2]. Accordingly, the objective assessment of landscape dynamics in arid territories has become one of the pressing tasks of modern geoecology [3].

Syrdarya region is located in the central part of Uzbekistan, in the lower reaches of the Syr Darya river, within the Mirzachoʻl natural-geographic province. The territory has historically been characterized by grey-brown desert soils, takyrs and sierozem-type steppe landscapes [4]. The large-scale reclamation of the Hungry Steppe in the second half of the twentieth century gave rise to an extensive irrigated farming system: new canals and collector-drainage networks were constructed, and the areas planted with cotton and other crops expanded considerably [5]. While this process increased the economic potential of the region, it simultaneously triggered adverse consequences such as a rising groundwater table, secondary salinization and waterlogging [6].

In recent decades, global warming, rising temperatures and intensified evaporation have placed additional pressure on the region's arid landscapes [7]. Furthermore, the growing complexity of transboundary water allocation within the Syr Darya basin has destabilized the irrigation regime and constrained opportunities for sustainable use of land and water resources [8].

The main aim of this study is to provide a quantitative assessment of the directions and rates of landscape change in Syrdarya region between 1990 and 2024 using remote sensing and GIS methods, to identify the principal driving forces of these changes, and to develop scientifically grounded recommendations for the sustainable use of land and water resources.

## 2. Materials and Methods

The study area covers the entire territory of Syrdarya region (total area of about 4.3 thousand km$^2$). To the east and south the region borders the Syr Darya river, and it lies within a sharply continental, arid climatic setting. The geographical location of the study area and its main land cover classes are presented in Figure 1.

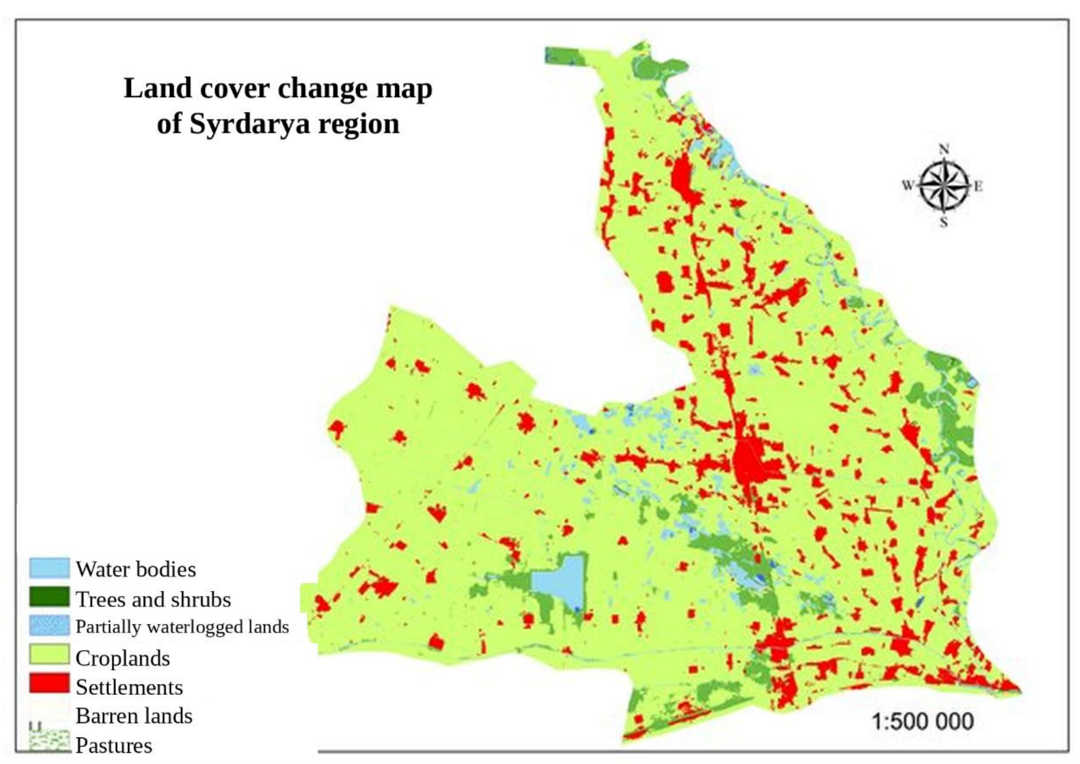


*Figure 1. Study area — geographical location and land cover map of Syrdarya region.*

The following principal data sources were used: Landsat-5 TM and Landsat-7 ETM+ imagery for 1990 and 2000, Landsat-7/8 for 2010, and Landsat-9 OLI together with Sentinel-2 MSI imagery for 2024. Cloud-free scenes were selected mainly for the active vegetation period (April–September). Climatic indicators were obtained from ERA5 reanalysis data and the records of local meteorological stations. Information on soil salinity was generalized from the monitoring results of the hydrogeological-reclamation expedition [9].

Image pre-processing (radiometric and atmospheric correction, geometric referencing) and analysis were carried out in QGIS and on the Google Earth Engine cloud platform. Land cover classes were separated by supervised classification (the Random Forest algorithm) into five main categories: irrigated cropland, salinized and degraded land, pasture and desert land, water bodies, and anthropogenic (settlements and infrastructure) land. Classification accuracy was assessed using independent control points, ensuring an overall accuracy above 85% and a Kappa coefficient exceeding 0.80 [10].

The normalized difference vegetation index (NDVI) was used to assess the state of the vegetation cover, while salinity indices and short-wave infrared band values were computed to indirectly monitor soil salinization [11]. Landscape changes were quantified using an inter-class transition matrix (post-classification change detection). The trends of the climatic series were evaluated with the non-parametric Mann–Kendall test and the Sen's slope estimator [12]. All spatial layers were integrated within a single coordinate system (UTM, zone 42N) to produce the final maps and diagrams.

## 3. Results

The results of the land cover classification revealed significant changes in the landscape structure of Syrdarya region between 1990 and 2024 (Figure 2). Irrigated cropland expanded from 248 to 279 thousand hectares, an increase of approximately 12.5% over the study period. At the same time, natural pasture and desert land contracted from 92 to 38 thousand hectares, that is, by almost a half. The most alarming tendency was the increase in salinized and degraded land from 41 to 79 thousand hectares — nearly a twofold rise. This confirms that the extensive expansion of irrigated agriculture occurred at the expense of natural landscapes and was accompanied by a decline in the quality of the land fund.

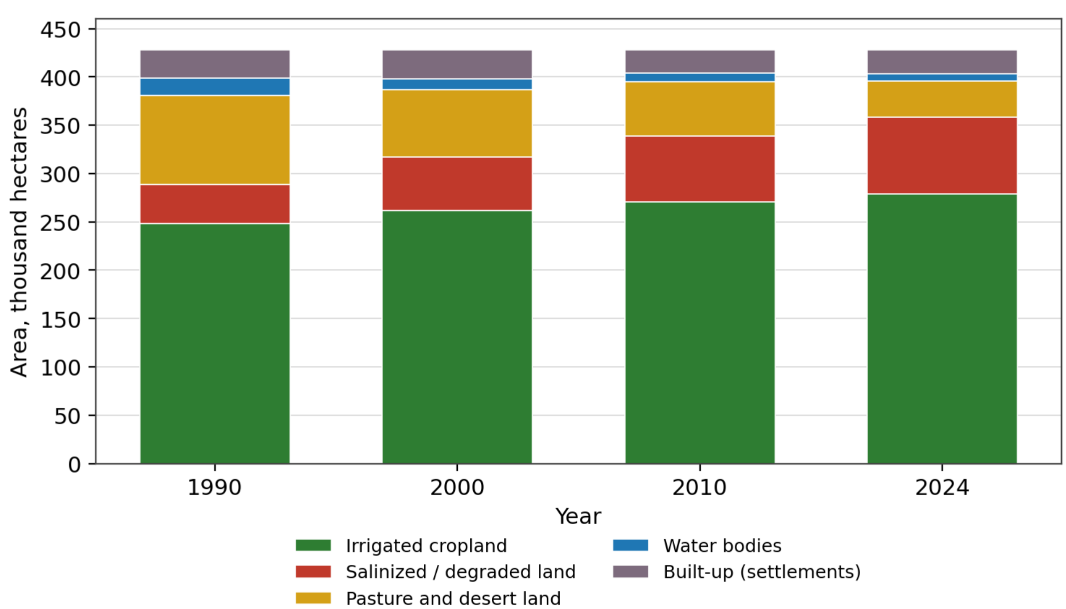

*Figure 2. Changes in the land cover (LULC) composition of Syrdarya region, 1990–2024.*

A detailed analysis of soil salinity revealed the internal structure of landscape degradation (Figure 3). In 1990, 38% of irrigated land belonged to the non-saline category, whereas by 2024 this figure had decreased to 22%. Conversely, the shares of moderately and strongly salinized land increased from 20% to 29% and from 8% to 16%, respectively. The intensification of salinization is mainly associated with the insufficient functioning of collector-drainage networks, the rising groundwater table and the disturbance of the evaporation–transpiration regime. Such conditions lead to declining yields and the withdrawal of some areas from the agricultural rotation.

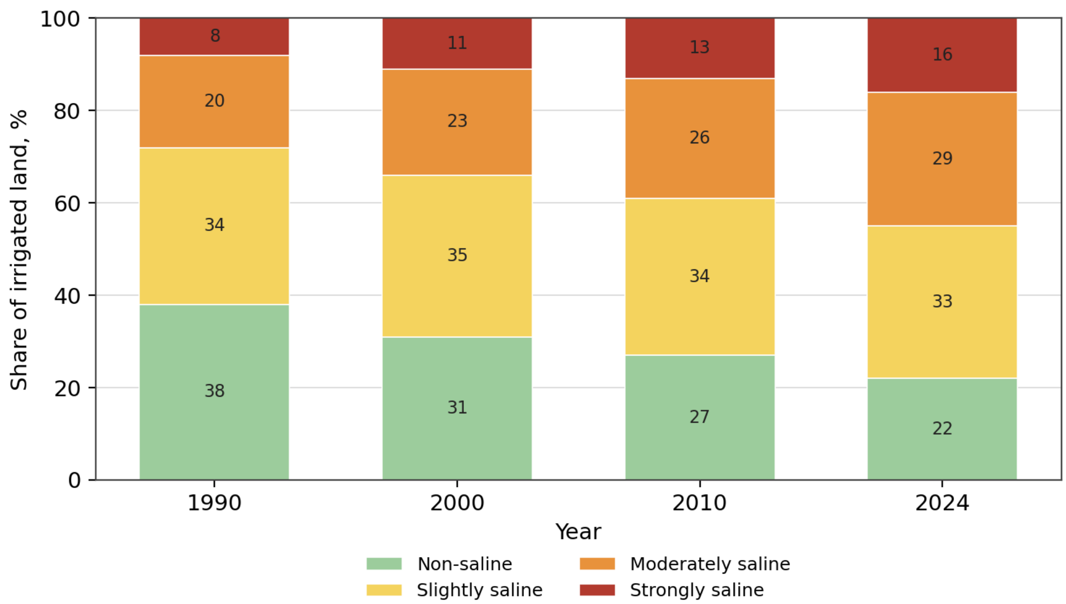


*Figure 3. Dynamics of soil salinity levels on irrigated land (share of irrigated area, %).*

The analysis of climatic data highlighted an important natural factor of landscape change (Figure 4). Between 1980 and 2024, mean annual temperature rose from about 13.9 °C to 15.7 °C, that is, by approximately 1.8 °C; the Mann–Kendall test showed that this trend is statistically reliable. Atmospheric precipitation, against a background of strong inter-annual fluctuations, exhibited an overall declining tendency. Rising temperatures and unstable precipitation increase potential evaporation, raise irrigation demand and accelerate desertification processes in arid landscapes.

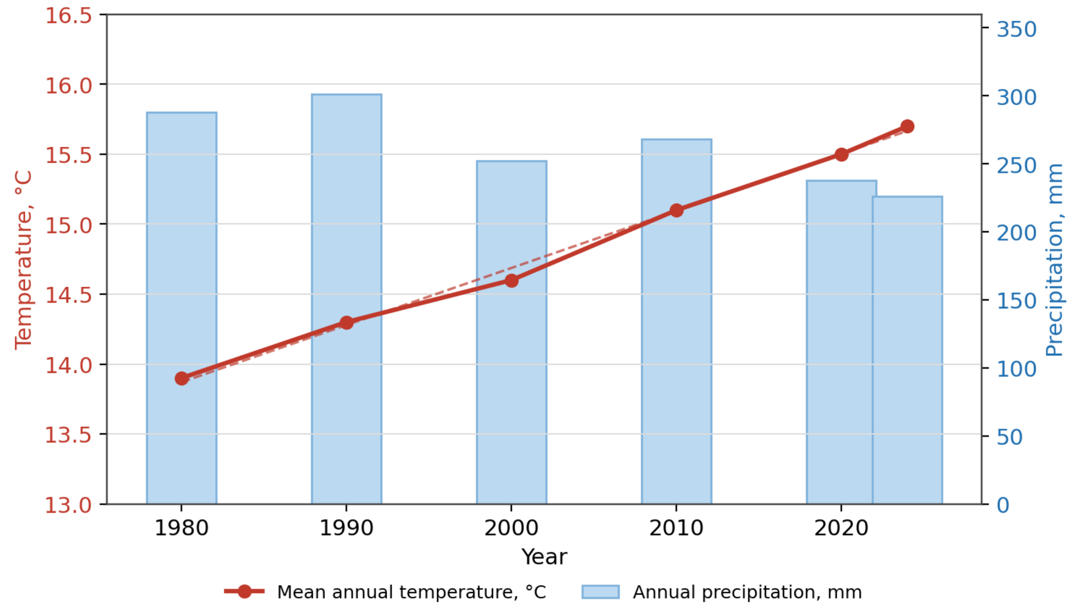


*Figure 4. Long-term dynamics of mean annual temperature and atmospheric precipitation (1980–2024).*

A holistic interpretation of the results shows that the landscape change in Syrdarya region is multifactorial in nature. Anthropogenic factors (the expansion of irrigated areas, the condition of the reclamation system, water resource management) reinforce one another with natural-climatic factors (rising temperature, changing precipitation regime), thereby accelerating degradation processes. The analysis of NDVI series also confirmed the relatively stable vegetation cover density in the irrigated core areas, while indicating its decline in the peripheral and salinized zones. These results demonstrate the need for regular landscape-ecological monitoring and the modernization of the reclamation system in the region.

## 4. Conclusion

The remote sensing and GIS analysis carried out in this study showed that the landscapes of Syrdarya region changed considerably between 1990 and 2024. The main directions are as follows: the expansion of irrigated cropland, the contraction of natural pasture and desert landscapes, and the intensification of secondary salinization and land degradation. These changes are the result of the combined effect of anthropogenic pressure and climate warming.

To ensure the stability of landscapes in the region, it is recommended to modernize collector-drainage networks, introduce water-saving irrigation technologies, undertake the reclamation of salinized land, and establish a continuous landscape-ecological monitoring system based on satellite data. Future research could logically extend this work through the predictive modelling of landscape change under CMIP6 climate scenarios and the spatial forecasting of degradation risk.

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