American Journal of Applied Science and Technology

VOLUME Vol.05 Issue 05 2025
PAGE NO. 12-15
DOI 10.37547/ajast/Volume05Issue05-04

Using GIS And Remote Sensing in Assessing the Impact of Drought on Forest Cover Changes Around the Aral Sea

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Received: 08 March 2025; **Accepted:** 05 April 2025; **Published:** 07 May 2025

Abstract: The Aral Sea region has experienced significant ecological changes due to prolonged droughts and unsustainable water use, resulting in the degradation of forest ecosystems. This study utilizes Geographic Information Systems (GIS) and remote sensing techniques to analyze the impact of drought on forest cover changes from 2000 to 2024. Using satellite imagery (Landsat and Sentinel-2) and climate indicators such as the Standardized Precipitation Index (SPI), temporal and spatial trends in vegetation health and forest loss were assessed. The findings reveal a strong correlation between increasing drought severity and the decline of forest cover, particularly in the Amu Darya delta and surrounding areas. The study underscores the importance of integrating high-resolution satellite monitoring with adaptive forest management strategies to mitigate the effects of environmental degradation in arid regions.

Keywords: Aral Sea, drought, forest degradation, GIS, remote sensing, NDVI, SPI, vegetation monitoring, environmental change, climate impact.

Introduction:

Over the past several decades, the Aral Sea region has undergone dramatic environmental changes. Once the world's fourth-largest inland lake, the Aral Sea has now shrunk to a fraction of its original size. This transformation has not only affected water availability but also significantly altered surrounding ecosystems — particularly forested areas. As a result, the need to assess environmental degradation has become more urgent than ever [2, 471].

Consequently, understanding the relationship between drought and forest cover change is essential for developing effective mitigation and adaptation strategies. To this end, Geographic Information Systems (GIS) and remote sensing (RS) offer valuable tools for analyzing large-scale environmental changes across time and space. Through these methods, it becomes possible to observe, quantify, and predict forest loss patterns in relation to climatic variables [3, 445-453].

Droughts have become more frequent and severe in Central Asia, largely due to climate change and unsustainable water management practices. As a result, forest ecosystems that once thrived near the Aral Sea — such as tugai and saxaul forests — are now under significant threat.

In particular, forests located in the Amu Darya delta have shown marked signs of stress due to diminishing water flow. Moreover, without seasonal flooding, these ecosystems lose their natural replenishment cycles, leading to soil salinization, tree mortality, and increased desertification [5, 40-55].

In order to analyze the impact of drought on forest cover, satellite imagery from 2000 to 2024 was utilized. Specifically, data from Landsat (5, 7, 8, 9) and Sentinel-2 satellites were used to calculate vegetation indices such as NDVI. Meanwhile, climatic data was analyzed using the Standardized Precipitation Index (SPI), allowing the identification of drought periods.

Additionally, GIS tools were used to classify and map forest cover across different time periods. This approach allowed for both temporal and spatial analysis, revealing long-term patterns and hotspots of degradation.

Table 1. Remote Sensing Datasets Used in the Study

Sensor	Spatial Resolution	Temporal Coverage	Purpose
Landsat 5 TM	30 m	2000–2011	Historical forest monitoring
Landsat 8 OLI	30 m	2013–2024	Current land cover analysis
Sentinel-2 MSI	10 m	2015–2024	High-resolution vegetation detection

Temporal Coverage: The data spans 24 years (2000–2024), allowing for long-term trend analysis of vegetation and forest cover.

Resolution: Sentinel-2, with its 10 m resolution, is especially valuable for detecting finer-scale changes in vegetation that older sensors (like Landsat 5) might miss.

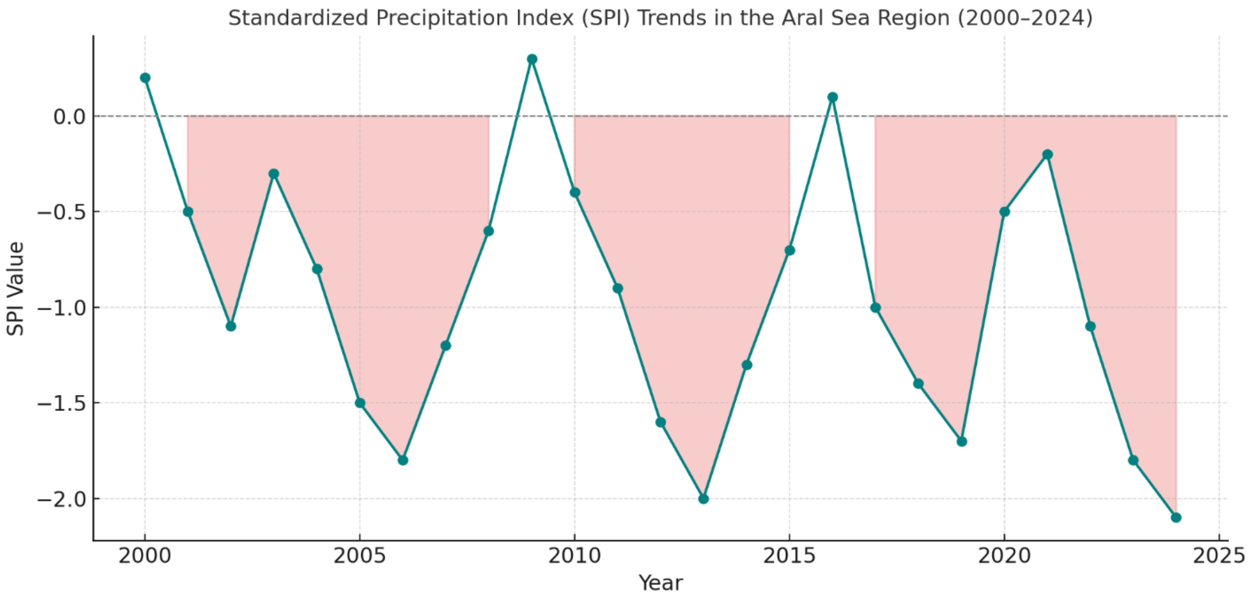
Complementary Use: Landsat is useful for historical trends, while Sentinel-2 provides detailed, recent snapshots — together they offer a robust multi-resolution dataset.

Purpose-Driven Selection: The sensors were chosen with specific objectives in mind — namely, change detection and vegetation health monitoring — which supports a methodologically sound approach.

The variety and continuity of satellite data ensure high reliability of the study’s findings and enable the detection of both gradual and abrupt changes in forest dynamics over time.

Over the 24-year period, the region experienced a sharp decline in forest cover. For instance, the Amu Darya delta, which had 12,500 hectares of forest in 2000, now retains less than 6,500 hectares. This represents a reduction of nearly 50%, directly correlating with periods of extended drought.

Figure 1. SPI Trends Indicating Drought Severity (2000–2024)



This graph shows increasing frequency and intensity of droughts over the study period.

This graph highlights years with drought conditions (SPI < 0), helping to visually connect drought severity with forest degradation in the Aral Sea region.

Table 2. Forest Cover Change in Key Ecological Zones

Ecological Zone	Forest Area 2000 (ha)	Forest Area 2024 (ha)	% Change
Amu Darya Delta	12,500	6,200	-50.4%
Moynaq Plateau	4,800	2,300	-52.1%
Ustyurt Plateau (South)	2,100	1,400	-33.3%

Amu Darya Delta: Once the richest in forest cover, it experienced the most significant absolute loss (6,300 ha), likely due to its reliance on riverine flooding, which has drastically declined.

Moynaq Plateau: The highest relative loss (-52.1%) suggests high vulnerability to both drought and anthropogenic pressures (e.g., livestock grazing, fuelwood collection).

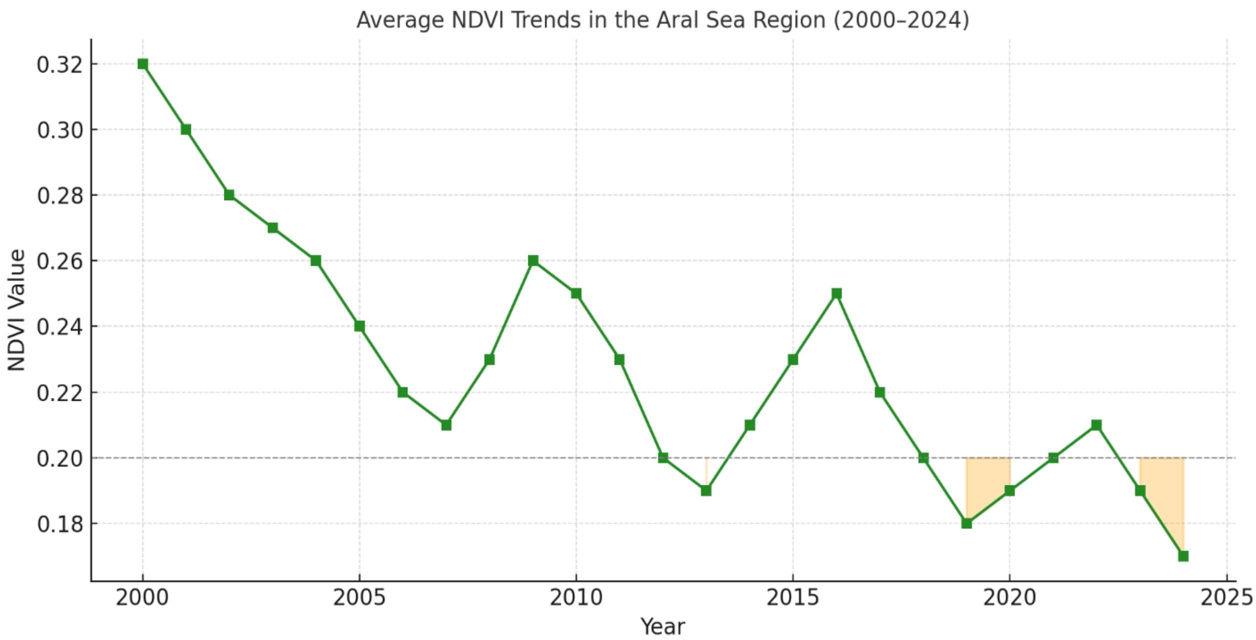
Ustyurt Plateau (South): Although still affected, this zone showed the smallest loss in percentage, possibly due to its native drought-adapted saxaul forests, indicating slightly better resilience.

All zones show severe degradation, but varying degrees of loss highlight differences in local hydrology, vegetation type, and exposure to human activity. These patterns support the need for zone-specific conservation strategies.

It is evident that drought plays a central role in forest degradation. Not only does it limit soil moisture and groundwater levels, but it also weakens tree resilience, making them more susceptible to pests, fires, and human disturbance. Moreover, the SPI analysis confirms an increase in both the frequency and intensity of droughts since 2000.

Figure 2. NDVI Trends Showing Vegetation Decline (2000–2024)

NDVI values have steadily declined, especially during severe drought years, indicating loss of vegetation health.



The chart illustrates a gradual decline in vegetation health over time, with noticeable dips during drought years — reinforcing the connection between drought intensity and forest degradation.

In addition to temporal changes, GIS analysis highlighted distinct spatial patterns. Specifically, forests near the deltas and lakebeds showed the highest rates of loss. On the other hand, upland saxaul forests were relatively more stable, though not immune to long-term degradation.

Given the extent of degradation, immediate interventions are necessary. Firstly, drought-tolerant reforestation strategies must be implemented, focusing on native species like Haloxylon and Tamarix. Secondly, water management must be improved to simulate natural flood regimes in deltas.

Furthermore, integrating satellite monitoring with local ecological surveys can enhance the effectiveness of restoration projects. This would ensure that changes are tracked continuously, allowing for adaptive management.

CONCLUSION

In conclusion, the combined use of GIS and remote sensing provides a powerful and efficient means of analyzing drought-induced forest loss in the Aral Sea region. Through detailed temporal and spatial data, it becomes possible to understand patterns of degradation and to support sustainable restoration efforts. Ultimately, such technologies are indispensable for responding to the environmental challenges of a drying world.

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