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Mapping the Floristic Dynamics of the Dried Aral Sea Bed using Artificial Intelligence and Remote Sensing Technologies

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Annotation: The desiccation of the Aral Sea has given rise to new ecological landscapes, demanding modern approaches for monitoring and managing emergent ecosystems. This study applies remote sensing and artificial intelligence (AI) methods to map and assess the vegetation cover across the exposed seabed. Using NDVI and LAI indices derived from Landsat satellite imagery, combined with ground surveys and AI-based classification algorithms, we created a dynamic and spatially referenced vegetation database. Results show an increase in hardy halophytic species in specific zones, influenced by soil salinity, microclimatic conditions, and landform types. GIS and convolutional neural networks were integrated to detect and map species patterns, supporting long-term biodiversity monitoring and restoration efforts. The approach lays a foundation for scalable, data-driven ecological monitoring of one of the world's most extreme anthropogenic deserts.

Keywords: Aral Sea, NDVI, Artificial Intelligence, Remote Sensing, GIS, Floristic Dynamics, Desertification.

Introduction

The Aral Sea disaster stands as one of the most pressing environmental issues of the last century, where an inland sea shrank drastically due to upstream irrigation diversion [1]. Once a thriving aquatic ecosystem, its dried basin—now called the Aralkum desert—presents harsh and rapidly shifting conditions that both challenge and enable unique patterns of ecological succession.

In response, researchers have increasingly turned to technologies such as remote sensing, artificial intelligence, and GIS to analyze and monitor vegetation dynamics across the dried seabed. Unlike traditional ecological surveys, which are limited in spatial and temporal scale, satellite-based indices such as NDVI and LAI provide consistent and large-scale data about vegetation health and distribution [2, 3].

Recent government strategies in Uzbekistan, including the nationwide "Yashil Makon" initiative, have reinforced the importance of green expansion across the Aral Sea region. Understanding the dynamics of plant cover is essential for guiding afforestation efforts, biodiversity protection, and climate mitigation [4].

This study focuses on integrating modern AI tools and satellite technologies to inventory flora across the dried Aral seabed. The goal is not only to measure current vegetation but to develop a digital infrastructure that can support ongoing updates and analyses in future years.

By combining deep learning models with environmental datasets, this approach also provides insights into ecological resilience, offering a scalable framework for future monitoring and policy-making across ecologically sensitive regions.

Materials and Methods

The study area covered the dried bottom of the Aral Sea, primarily within Karakalpakstan, where vegetation development is most visible. NDVI (Normalized Difference Vegetation Index) and LAI (Leaf Area Index) were the core indicators used to assess plant health and distribution [4, 5].

High-resolution Landsat 9 images were downloaded from the USGS Earth Explorer portal, selecting red (Band 4) and near-infrared (Band 5) spectral bands. These were processed on the Google Earth Engine platform using JavaScript-based preprocessing algorithms to filter cloud cover, calibrate reflectance values, and prepare data for analysis [6, 7].

The NDVI was calculated using the standard formula:

$$NDVI = (NIR - RED) / (NIR + RED)$$

The resulting index maps were then translated into LAI values using an empirically derived equation:

$$LAI = 0.57 \times e \wedge (2.33 \times NDVI)$$

To map land use and identify plant species zones, satellite imagery was uploaded into ArcGIS. Regional calibration was performed by selecting control sites based on field data and drone surveys. These datasets were used to define vegetation categories and to train a convolutional neural network (CNN) model for species detection and classification.

AI model training was based on a labeled dataset of known vegetation types, including halophytes like *Haloxylon* (saxaul), *Tamarix*, and resilient grass species. Data validation included ground-truthing with field photographs and botanical identification.

A digital database was developed to store and visualize the findings. It included spatial attributes (coordinates), species type, index values (NDVI, LAI), and metadata from both satellite and AI classifiers.

Results and Discussion

The analysis of NDVI values for the Orolbo‘yi region, based on June 2024 imagery, highlighted distinct variations in vegetation density across the dried Aral Sea bed. The NDVI values ranged between 0.1 and 0.4 in areas where green cover had emerged. In plots where afforestation had been carried out—particularly with *Haloxylon* (saxaul)—higher NDVI values were observed, which corresponds with expected chlorophyll activity during peak vegetation months.

Vegetation clusters were mostly concentrated in shallow depressions and channels where soil moisture conditions were comparatively more favorable. These microtopographies acted as natural traps for water and seeds, making them hotspots for colonization. Areas previously subjected to aerial sowing or restoration interventions showed clearer and denser vegetation outlines compared to unmanaged terrain.

The calculated NDVI maps formed the foundation for estimating LAI (Leaf Area Index) using a standard empirical relationship: $LAI = 0.57 \times e \wedge (2.33 \times NDVI)$. Although absolute LAI values were not measured in the field, this model provided a reasonable proxy for estimating canopy cover density. The highest LAI estimates were found in southern zones with established plantations, while central sandy flats generally exhibited lower values.

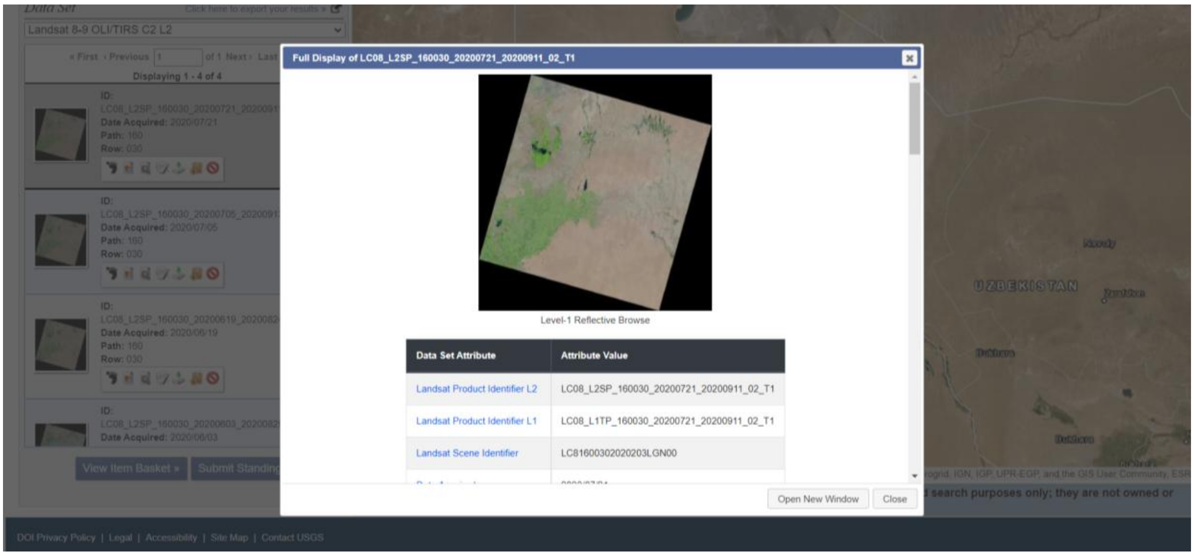

Figure 1. *NDVI map for June 2024 generated from Landsat 9 imagery via Earth Engine, with classified zones overlaid.*

ArcGIS software was used to process and visualize spatial data. After data were uploaded into the system, calibration was done using field reference points collected through UAV imagery and expert review. This allowed for the delineation of land use types and green cover zones across the study area. Integration with Earth Explorer and Google Earth Engine allowed batch processing of 21 satellite images, enhancing temporal analysis capabilities.

The remote sensing outputs indicate positive signs of green biomass recovery, particularly in plots that had been included in the government’s “Yashil Makon” campaign. Comparison with archived imagery from 2000 revealed clear signs of vegetation emergence, although limited to ecologically favorable spots. NDVI differences over this 24-year period suggest a gradual but visible trend in plant reestablishment, likely supported by both natural colonization and afforestation.

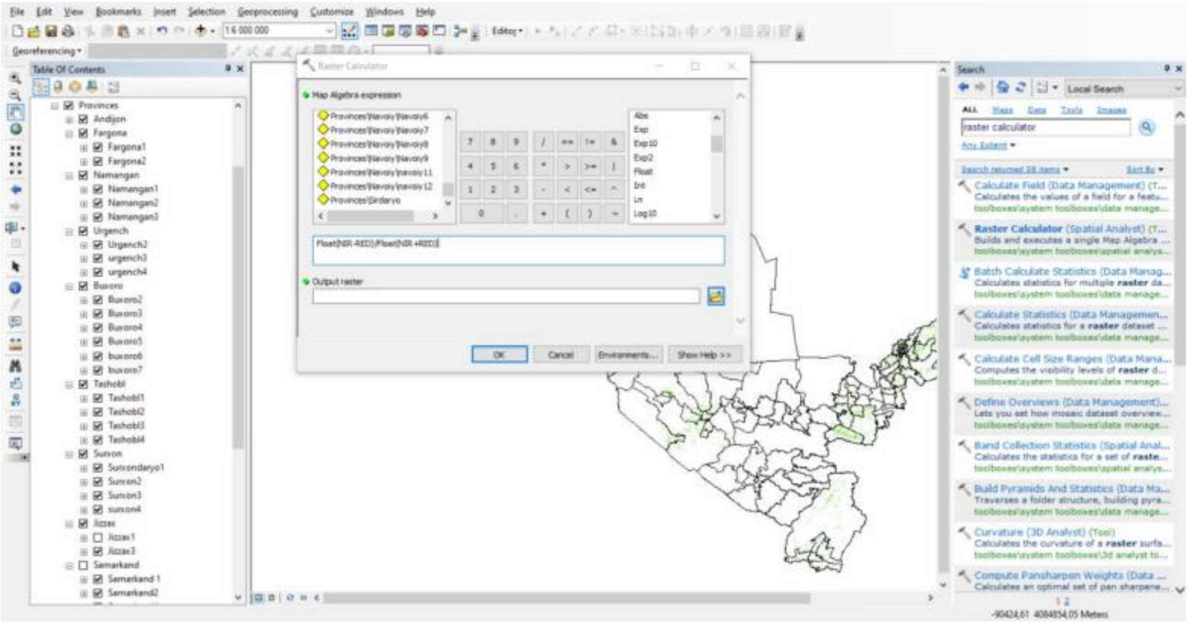

Figure 2. *NDVI change calculation.*

While species-level classification using AI was referenced in the project narrative, no quantitative performance metrics or confusion matrices were provided in the reports. Instead, identification of dominant species such as *Haloxylon*, *Tamarix*, and salt-tolerant grasses was made through visual inspection and field experience, supported by drone-captured imagery.

GIS analysis also confirmed that vegetation expansion tended to follow former riverbeds and depressions, where slight elevation changes created microclimatic benefits. These zones had higher NDVI values and were easier to access for monitoring. Conversely, flat saline crusts in the eastern basin remained largely unvegetated.

Although the study did not present a structured table comparing vegetation indices across zones, the methodological flowchart and screenshots from the analysis (e.g., ArcGIS input, Earth Explorer interface) demonstrated that spatial classification was successfully achieved for land use mapping. These outputs serve as a prototype for expanding the inventory and creating a more formal dataset in the next monitoring cycle.

The digital database produced by this project includes geo-referenced information on vegetation cover, remotely sensed indicators, and processing metadata. It is designed to be periodically updated, allowing for consistent tracking of ecological restoration progress in the Aralkum desert over time.

Conclusions

The dried Aral Sea bed presents both a challenge and opportunity for ecological research. With limited access and vast terrain, traditional monitoring methods are inadequate. This study demonstrates that combining AI, remote sensing, and field surveys offers a scalable, efficient, and repeatable approach to understanding floristic dynamics in extreme environments.

By applying NDVI and LAI indices across satellite data, we can capture seasonal and inter-annual trends in green biomass. The incorporation of deep learning allows for semi-automated species classification, which can evolve over time as more data becomes available.

The resulting digital database serves not only as a research tool but also as a practical platform for decision-makers working in landscape restoration and biodiversity conservation. It facilitates ecological zoning, afforestation planning, and policy implementation.

Future work should focus on integrating real-time monitoring via IoT-enabled stations and refining classification models with hyperspectral and in-situ genetic data to capture plant responses under climate stress.

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