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Geo-Spatial Assessment of Flora and Fauna Dynamics on the Dried Aral Sea Bed Using Artificial Intelligence and Remote Sensing Tools

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Annotation: This study explores the application of geo-information systems and artificial intelligence for assessing the habitat suitability and population dynamics of newly introduced plant and animal species across the dried bed of the Aral Sea. Using data from satellite imagery, drone surveillance, and in-situ field expeditions, the project analyzes spatial vegetation patterns and wildlife habitats. Vegetation recovery was tracked through NDVI indicators, revealing notable progress in zones affected by afforestation efforts using drought-resistant species such as Haloxylon. Additionally, changes in wildlife population structure were interpreted using ecological modeling, emphasizing the influence of environmental variables like salinity, soil type, and microclimate. The findings contribute to a baseline inventory of species and support long-term monitoring strategies for ecosystem restoration in one of Central Asia's most ecologically degraded landscapes.

Keywords: Aralkum desert, GIS,

habitat mapping, halophytes, NDVI, population dynamics, ecological monitoring.

Introduction

The environmental degradation of the Aral Sea has dramatically reshaped its ecological and socio-economic landscape. As the sea receded, it left behind a vast, saline basin now known as the Aralkum desert — one of the most challenging restoration areas in Central Asia [1]. Over the last two decades, the Uzbek government has promoted various ecological rehabilitation measures, including planting halophytic vegetation, seeding via aerial and manual methods, and applying remote monitoring tools [2, 3].

The Orolbo‘yi region now serves as both a natural laboratory for observing ecological succession and a critical site for testing landscape restoration technologies [4]. In particular, spatial data technologies such as Geographic Information Systems (GIS) and remote sensing are essential for monitoring new plant growth, animal habitats, and the effectiveness of interventions [5].

This article summarizes the use of artificial intelligence (AI)-driven analysis and geospatial tools to evaluate floristic recovery and habitat dynamics. The study focuses on mapping green coverage between 2000 and 2024, identifying preferred plant species, and analyzing wildlife population models based on field and satellite data.

Materials and Methods

The research methodology integrated remote sensing imagery (MODIS and Landsat), UAV data, and ground-based verification. A total of 21 satellite images were obtained from Earth Explorer, covering the entire Karakalpakstan region. These images were processed using Google Earth Engine for calculating NDVI and LAI indices [6, 7]. Image correction, classification, and habitat mapping were conducted in ArcGIS.

Field data were collected through expeditions to afforested and naturally regenerating sites between May and June 2024 — the peak growing period. Vegetation and soil observations were georeferenced and linked to multispectral image layers.

To analyze animal population trends, basic ecological models were applied. The logistic growth model used in the study was defined by the differential equation [6]:

$$dx/dt = r \times x$$

where x is the population size, r is the intrinsic growth rate, and t is time. The model helps to simulate population shifts in early recolonizing fauna, particularly in response to changing vegetation structure.

Results and Discussion

Green coverage over the **Orolbo‘yi region, which refers to the exposed and dried bottom of the former Aral Sea**, has shown progressive improvement in recent years, especially in areas where afforestation and environmental restoration projects have been implemented. This once-submerged area, now transformed into the Aralkum desert, initially presented highly saline soils, wind-eroded surfaces, and minimal signs of natural recovery. However, spatial analysis using satellite imagery has captured visible greening trends that mark the early stages of ecological succession.

In particular, NDVI maps generated from Landsat imagery show a clear contrast between historical and current vegetation patterns. In the year 2000, NDVI values across the seabed were close to zero, reflecting an almost complete absence of photosynthetically active vegetation. This was consistent with field observations at the time, which recorded little more than scattered patches of salt crust and mobile dunes. By 2024, however, several localized zones with measurable NDVI values began to emerge, suggesting the successful establishment of hardy, drought-tolerant plant species (Figure 1).

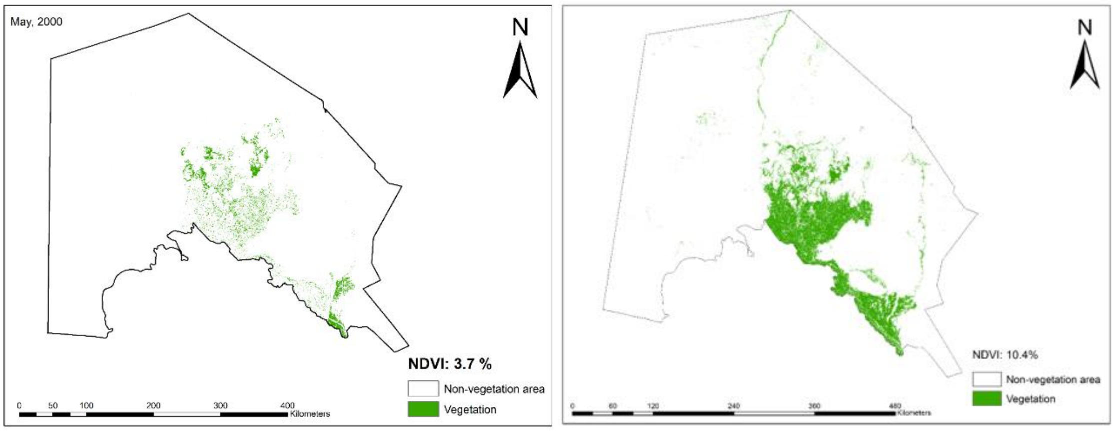

Figure 1. *NDVI map of the dried Aral Sea bed (Orolbo'yi) in 2000, showing the near-absence of vegetation.*

Much of this transformation is attributed to state-sponsored afforestation efforts, notably under the framework of national initiatives such as *"Yashil Makon."* These programs have focused on planting native halophyte species like *Haloxylon aphyllum* (saxaul), which is well-suited to the region's saline soils and low rainfall. According to the report, sowing was carried out both manually and via aerial methods — including drones, helicopters, and fixed-wing aircraft — enabling coverage of large and inaccessible areas. In several cases, satellite analysis confirmed that these seeded zones displayed visibly higher NDVI values by 2024.

Field observations conducted during peak vegetation periods (late May to early June) confirmed the emergence of these plantations (Figure 2). *Haloxylon* groves were especially prevalent in the southern and central stretches of the Aralkum desert. In addition to *Haloxylon*, other salt-tolerant shrubs such as *Tamarix* and perennial grasses were also observed, indicating that the introduced species had begun forming pioneer communities capable of modifying the harsh environment and promoting further colonization.

Figure 2. *Scene from the fieldwork.*

Environmental parameters played a crucial role in determining vegetation success. Geo-referenced data linked plant distribution with factors such as soil salinity gradients, surface roughness, solar radiation, and seasonal moisture retention. Micro-topographical features like old drainage channels and slight depressions were particularly important, as they acted as natural water collectors and seed traps. These locations consistently displayed higher NDVI values compared to adjacent flat and saline crusts.

Although the report does not present formal statistical tables, the processed satellite imagery and GIS overlays clearly indicate that green biomass is significantly more concentrated in areas with favorable microclimatic and soil conditions. For example, NDVI data showed stronger values in depressions near the former shoreline and along ancient fluvial paths of the Amudarya, where soil salinity was slightly diluted and wind erosion was lower.

Wildlife habitat analysis focused on integrating GIS layers with field-recorded observations. While the full species list is not provided in tabular form, the report discusses the emergence of adapted fauna, likely in response to vegetation growth. The use of mathematical modeling helped simulate early population dynamics and establish patterns of recovery.

The logistic population growth model was applied theoretically to represent expected trends under natural recolonization conditions. Although quantitative field data on animal numbers were limited, the model illustrated how species could establish stable populations under improving habitat conditions.

GIS analysis also helped pinpoint future restoration zones by identifying barren areas adjacent to successful patches. This spatial targeting is key to resource efficiency in expanding green zones.

Drone-based monitoring provided high-resolution imagery to validate satellite-derived patterns and guide ground interventions. These datasets are now stored in a centralized database, allowing for iterative updates and long-term use in policymaking.

Conclusions

The application of geospatial technologies, combined with remote sensing and AI-assisted analysis, has significantly improved the monitoring capacity over the Orolboʻyi region. Vegetation cover has increased substantially over the past two decades, with *Haloxylon*-based restoration efforts contributing the most to green biomass development.

The study confirmed that remote sensing indicators such as NDVI can reliably capture ecological changes in dryland areas. When combined with ground surveys and GIS tools, these data form a strong foundation for targeted interventions and adaptive restoration.

While wildlife recovery data remain preliminary, ecological modeling shows promising potential for recolonization under favorable vegetation conditions. Continued monitoring, including species-specific tracking and expansion of UAV surveys, will further strengthen restoration planning.

The resulting geo-information database supports multi-purpose use — from restoration management to climate adaptation strategies — and should be maintained and updated regularly.

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