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UNSUPERVISED MAPPING OF SEASONAL VEGETATION AROUND THE CHARVAK RESERVOIR

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ABSTRACT---

Seasonal vegetation in the Charvak Reservoir basin (northeastern Uzbekistan) was evaluated using Landsat 9 Collection 2 Level-2 surface reflectance imagery for March, July, and October 2024. Cloud and cloud-shadow pixels were removed with the QA_PIXEL band. NDVI was calculated from SR_B4 (red) and SR_B5 (near-infrared) and summarized as monthly median composites. The three seasonal NDVI layers were stacked and classified in Google Earth Engine using unsupervised K-means clustering (k = 5; 5000 samples). Five spatially coherent classes with distinct seasonal NDVI signatures were obtained, separating persistently dense vegetation along valleys and moist slopes from seasonally variable hillslope vegetation, and from sparsely vegetated, bare-soil, and rocky surfaces on exposed ridges. The NDVI-cluster map provides a compact baseline for vegetation monitoring and spatial planning in the Charvak tourist–recreational zone and highlights areas potentially sensitive to degradation under climate variability. Limitations include the single-year, three-snapshot design and the interpretive nature of unsupervised labels.

KEYWORDS: *NDVI, Charvak Reservoir basin, seasonal variation of vegetation cover, Landsat 9, cluster analysis, K-means*---

1.INTRODUCTION

Changes in vegetation cover are among the key indicators of ecosystem transformation, reflecting the combined influence of both natural and anthropogenic factors. Vegetation plays a fundamental role in the climate system, participating in the regulation of heat and moisture exchange between the land surface and the atmosphere, in carbon and biogeochemical cycles, as well as in preventing erosion processes [1–3]. Monitoring the state of vegetation cover is essential for regional and global climate modelling, forecasting land degradation and desertification risks, assessing biodiversity and ecosystem resilience, and supporting decision-making in the field of environmental management [4]. In recent decades, the primary drivers of changes in vegetation cover have been climate shifts and human activities. Climate-related factors include increases in mean annual temperature, changes in precipitation regimes, and the growing frequency of extreme weather events such as droughts and heavy rainfall, all of which intensify plant stress and may shorten the growing season [5,6]. Anthropogenic impacts are associated with changes in land use, the expansion of agricultural lands, urbanization, infrastructure development, recreational pressure, and alterations to the hydrological regime due to the construction and operation of reservoirs [7].

Remote sensing methods provide unique opportunities to assess vegetation dynamics over large areas and with high temporal resolution [8]. Among these, the Normalized Difference Vegetation Index (NDVI) occupies a prominent position and is widely used to assess the condition and seasonal dynamics of vegetation in various climatic zones [9-11]. NDVI correlates with key vegetation parameters such as leaf area index (LAI), biomass, and percent cover, making it a versatile tool for monitoring [12]. Moreover, the use of multi-season NDVI data makes it possible to identify spatiotemporal patterns of change and to classify territories accordingly.

One of the effective tools for analyzing multidimensional NDVI data is the K-means clustering algorithm, which groups pixels with similar spectral characteristics. This approach is particularly useful in mountainous and semi-arid regions, where the spatial heterogeneity of vegetation and complex topography complicate traditional

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classification. Applying cluster analysis to multi-season NDVI data makes it possible to identify areas with different vegetation dynamics, detect zones of degradation or recovery, and assess the influence of climatic and anthropogenic factors on ecosystems [13].

The Charvak Reservoir area in the mountainous part of the Tashkent region represents a unique natural–anthropogenic complex combining intensive recreational use, changes in the hydrological regime, and climatic variability. Monitoring seasonal changes in vegetation cover in this region is important for developing measures to conserve natural resources, prevent ecosystem degradation, and plan sustainable land use. The objective of this study is to perform a cluster analysis of seasonal NDVI changes in the Charvak Reservoir area, identify spatial patterns of vegetation distribution, and assess its current state in the context of modern natural and anthropogenic impacts.

2.DATA AND METHODS

The study area is the Charvak Reservoir and its surrounding basin, located in the western Tian Shan Mountains of northeastern Uzbekistan. This region lies within a geodynamically active zone affected by ongoing intracontinental deformation of the Eurasian lithospheric plate. The reservoir, constructed at the confluence of the Chatkal, Pskem, and Koksu rivers, spans approximately 37.3 km² and reaches depths of up to 150 m. The mountainous surroundings are intersected by several major fault systems, including the Pskem, Kumbel-Kokand, Ugam, and Chatkal faults, which contribute to elevated seismic hazard and increase the risk of processes such as reservoir-induced seismicity and shoreline instability. The combination of active tectonics, pronounced altitudinal gradients, and climatic variability makes the Charvak basin a valuable site for studying vegetation responses to environmental change (Figure 1).

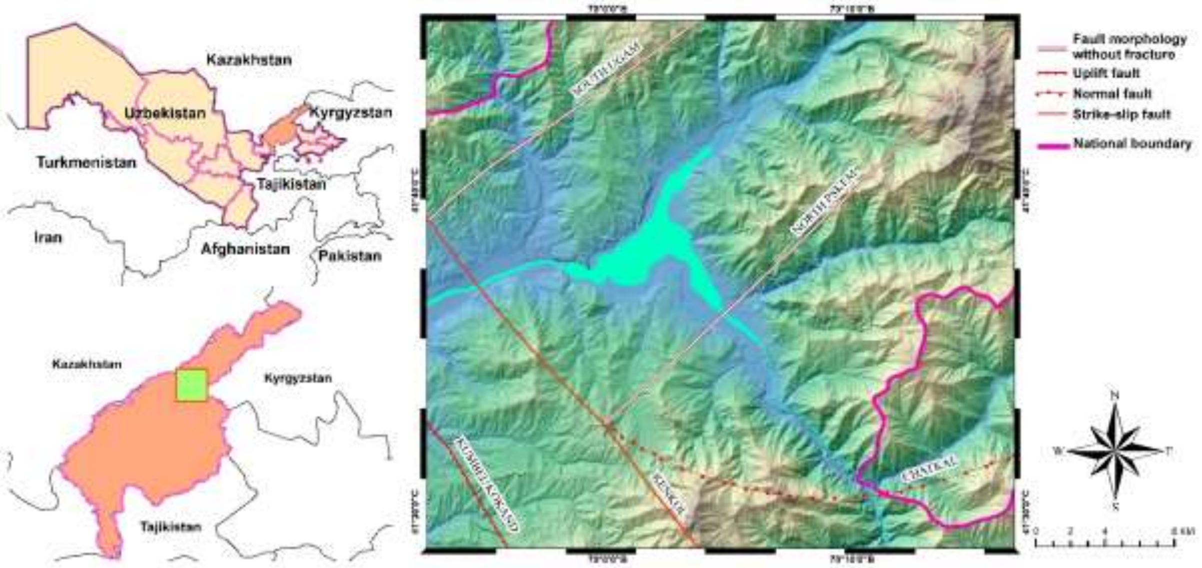

Figure 1. Study area map showing the boundaries of the Charvak Reservoir region in northeastern Uzbekistan.

To capture seasonal vegetation dynamics, we used Level-2 surface reflectance products from Landsat 9 Collection 2 Tier 1 (USGS). These products include atmospherically corrected surface reflectance bands and quality assessment (QA) layers for cloud and shadow masking. Three representative months were selected to characterize vegetation states across different seasons [14]:

March 2024 – early growing season (spring onset),
July 2024 – peak summer season with potential water stress,
October 2024 – post-growing season (autumn senescence).

The imagery has a spatial resolution of 30 m and a revisit period of 16 days. All data were accessed and processed in Google Earth Engine (GEE), enabling efficient handling and analysis without the need for local storage of raw imagery.

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The workflow consisted of the following main stages [15] (Figure 2):

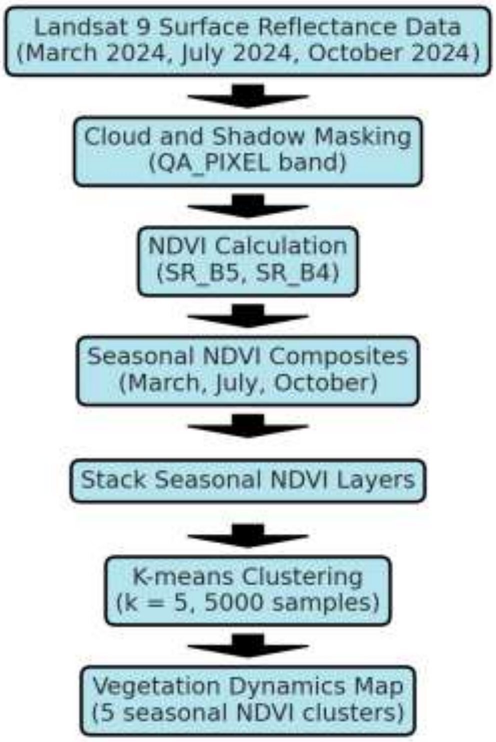

Figure 2. Workflow for multi-season NDVI analysis and K-means clustering

Pre-processing and Cloud/Shadow Masking. The `QA_PIXEL` band from the Landsat 9 Level-2 product was used to identify and mask clouds and cloud shadows. Bits 3 (cloud) and 4 (shadow) were tested and masked, ensuring that only clear-sky pixels were retained for NDVI calculation.

NDVI Calculation. NDVI was computed for each image as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

where NIR corresponds to band SR_B5 (near-infrared) and RED corresponds to band SR_B4 (red).

Separate NDVI composites were created for each month using the median of all available images after masking.

Image Stacking. The three seasonal NDVI layers were combined into a single multi-band stack (NDVI_March, NDVI_July, NDVI_October), enabling the simultaneous use of seasonal information in the clustering stage.

Unsupervised Classification (K-means Clustering). A sample of 5000 pixels from the NDVI stack was used to train the **Weka K-means** algorithm in GEE. The number of clusters (k=5) was selected based on preliminary testing, balancing spatial detail with interpretability. The trained model was applied to the entire NDVI stack to generate a classification map, where each cluster represents areas with similar seasonal NDVI profiles.

Post-processing and Export. The classification result was visualized using a random color palette for interpretation. The final map was exported in GeoTIFF format at 30 m resolution in UTM Zone 42N (EPSG:32642) for further GIS analysis.

This methodology allowed us to identify spatial patterns of vegetation dynamics based on multi-season NDVI variations, facilitating the detection of stable vegetation zones, areas of high seasonal variability, and potential degradation hotspots.

3.RESULTS AND DISCUSSION

Seasonal NDVI composites derived from Landsat 9 surface reflectance imagery (March, July, and October 2024) and classified using K-means clustering (k = 5) reveal a pronounced spatial heterogeneity of vegetation conditions within the Charvak Reservoir basin (Figure 3). The mapped clusters represent distinct seasonal NDVI profiles rather than strictly defined land-cover types; nevertheless, their spatial arrangement provides meaningful insight into the dominant ecological gradients shaping vegetation distribution in the mountainous reservoir environment. The Dense Persistent Vegetation cluster forms coherent patches primarily along valley bottoms, well-watered slopes, and riparian corridors connected to the main inflow/outflow system of the reservoir. This pattern suggests the presence of vegetation communities capable of maintaining relatively high photosynthetic activity across the three seasonal snapshots, which is typical for forested areas and stable riparian vegetation in mountain landscapes. In contrast, the Seasonal Vegetation cluster occupies the largest share of the study area and is especially widespread across transitional slopes and foothill zones. Its dominance indicates vegetation with strong phenological variability—characterized by a peak in mid-summer NDVI and reduced greenness in early spring and autumn—which is consistent with herbaceous cover, open woodland, and areas influenced by seasonal moisture availability.

Non-vegetated surfaces are captured by the Bare Soil and Rocky Terrain clusters, which occur extensively on exposed ridges, steep slopes, and morphologically complex areas where thin soils, limited moisture retention, and high surface roughness restrict vegetation development. The Sparse Vegetation cluster commonly surrounds or intermixes with these non-vegetated classes and likely represents degraded or semi-arid surfaces with low but detectable vegetation activity, as well as mixed pixels where vegetation and soil occur within the 30 m Landsat footprint. Together, these three clusters outline areas that are potentially more sensitive to erosion and land degradation, particularly where sparse or bare surfaces coincide with steep terrain.

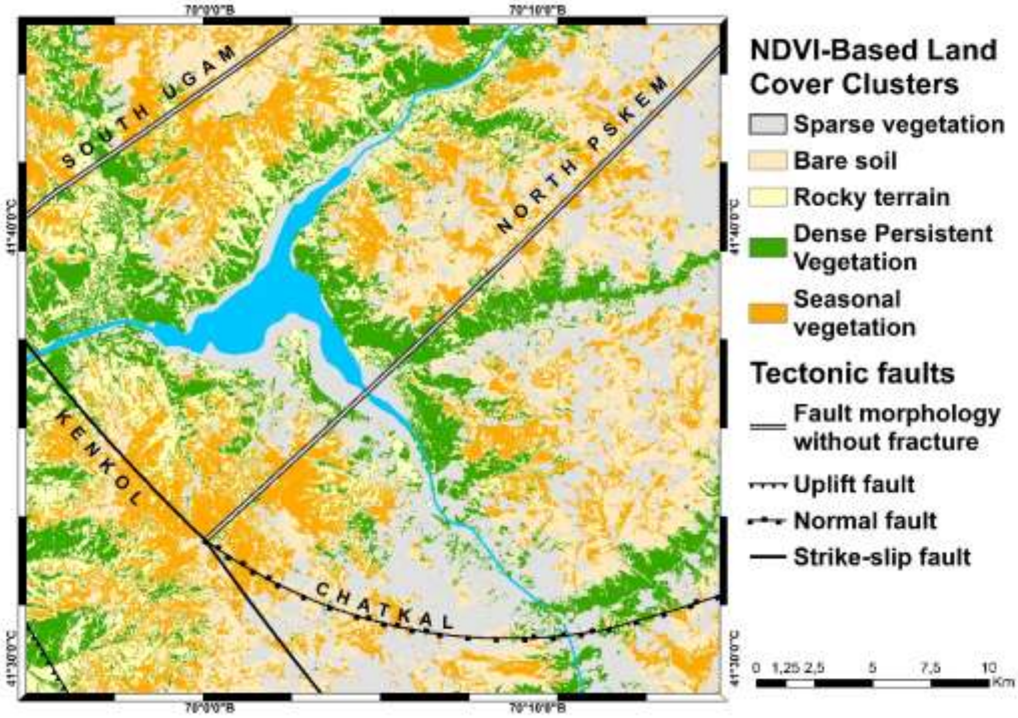

Figure 3. Seasonal vegetation pattern map based on K-means clustering of Landsat 9 NDVI composites (2024)

A visual comparison with the mapped tectonic faults indicates that fault traces intersect multiple vegetation clusters, suggesting that structural features do not control vegetation distribution directly, but may influence it indirectly through relief formation, drainage organization, and lithological contrasts. In several segments, elongated patches of higher NDVI appear to follow valley-aligned structures and fault-parallel zones, which could reflect localized moisture concentration (e.g., enhanced infiltration and groundwater movement along fractured rocks) and topographic effects. However, such relationships remain interpretative and require targeted validation using hydrogeological observations, lithological mapping, and topography-derived parameters.

From an applied perspective, the derived cluster map provides an efficient representation of vegetation condition and seasonal variability relevant to spatial planning in the Charvak tourist–recreational zone. Areas classified as

Seasonal Vegetation may be more vulnerable to short-term climatic anomalies and anthropogenic pressure (grazing, recreation-related land disturbance), whereas Dense Persistent Vegetation belts can function as ecological corridors and zones of higher ecosystem stability. Bare Soil, Rocky Terrain, and Sparse Vegetation areas delineate surfaces where ecological restoration is constrained and where geomorphic sensitivity may be higher, making these zones important targets for integration with slope- and hazard-related assessments.

Several limitations should be noted. The classification is based on three seasonal snapshots within a single year and therefore does not capture interannual variability. NDVI is also influenced by soil background, terrain shadowing in mountainous terrain, and mixed pixels at 30 m resolution. Additionally, unsupervised K-means clustering groups pixels by similarity in NDVI seasonal behavior, so the assigned class names should be treated as interpretive descriptors rather than definitive land-cover categories. Future work should extend the analysis to multi-year time series, incorporate complementary indices (e.g., NDWI/EVI), and include an accuracy assessment using higher-resolution imagery and, where possible, field validation.

4.CONCLUSIONS

A reproducible Google Earth Engine workflow was developed to assess seasonal vegetation conditions in the Charvak Reservoir basin using Landsat 9 imagery (March, July, and October 2024) by generating NDVI composites and applying unsupervised K-means clustering (k = 5). The resulting map delineates five spatially consistent classes with distinct seasonal NDVI profiles, distinguishing persistently dense and seasonally variable vegetation from areas dominated by sparse vegetation, bare soil, and rocky surfaces that prevail under limited moisture and relief-constrained conditions. The produced NDVI-cluster layer can serve as a baseline for environmental monitoring and spatial planning in the Charvak tourist–recreational zone, including the identification of potentially degradation-prone areas. Interpretation should account for methodological constraints, as the classification relies on three seasonal snapshots within a single year and reflects groups of similar NDVI behavior; further refinement requires multi-year time series, complementary indices, and validation using higher-resolution data and/or field observations.

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