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**SPATIO-TEMPORAL ASSESSMENT OF VEGETATION–TEMPERATURE
INTERACTIONS IN CONTRASTING AGRO-CLIMATIC ZONES OF UZBEKISTAN
USING REMOTE SENSING INDICATORS**

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Abstract: Understanding vegetation–temperature interactions is essential for climate-resilient agricultural planning in Uzbekistan’s diverse agro-climatic zones. This study analyzes the relationship between the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) during the 2024 vegetation season in two contrasting regions: Jarqo‘rg‘on district (Surxondaryo Region) in the arid south and Bo‘ka district (Tashkent Region) in the temperate north. Monthly MODIS NDVI and LST datasets were processed and temporally aligned in Google Earth Engine (GEE). Pearson correlation and linear regression models were applied to quantify vegetation responses to temperature variability. Results show notable regional differences. In Bo‘ka district, NDVI and LST exhibited a strong positive correlation ($r = 0.71$), with $R^2 = 0.51$, indicating that more than half of NDVI variability is explained by LST. The regression slope ($b = 0.0085$) suggests that vegetation greenness increases consistently with rising temperature during the active growth phase. In contrast, Jarqo‘rg‘on district demonstrated a moderate correlation ($r = 0.61$), with $R^2 = 0.37$, and a slightly lower regression slope ($b = 0.0076$), reflecting the district’s stronger heat exposure and potentially higher temperature-induced stress. These findings highlight the importance of integrating remote sensing–based vegetation and thermal indicators into regional climate adaptation strategies. The comparison demonstrates that vegetation in cooler agro-climatic zones responds more favorably to temperature increases, whereas vegetation in hotter regions exhibits dampened sensitivity due to thermal stress thresholds.

Keywords: NDVI; LST; climate–vegetation interaction; thermal stress; MODIS; temporal alignment; Pearson correlation; linear regression; climate-smart agriculture; Uzbekistan.

Introduction

Agriculture is one of the key pillars of Uzbekistan’s economy, supporting rural livelihoods, national food security, and the country’s export potential. More than 70% of agricultural production depends directly on irrigated farming systems located across highly diverse agro-climatic regions. However, the accelerating impacts of climate change—manifested through

rising temperatures, prolonged heatwaves, decreasing water availability, and increased evapotranspiration—pose significant risks to sustainable crop production. Over the past decades, Uzbekistan has experienced a steady upward trend in annual mean temperatures, along with more frequent extreme heat events, especially in the southern regions such as Surxondaryo. These changes alter the phenological cycles of vegetation, intensify heat stress, and exacerbate soil moisture deficits, ultimately affecting crop yields and long-term agricultural resilience.

The country's landscape is divided into several agro-climatic zones, ranging from semi-arid subtropical basins in the south (Surxondaryo) to temperate continental plains in the north (Tashkent region). Each zone exhibits distinct thermal regimes, growing season durations, and vegetation responses to climatic variability. For example, Jarqo'rg'on (Surxondaryo) experiences extremely high summer temperatures, resulting in a long but heat-stressed vegetation cycle, whereas Bo'ka (Tashkent region) benefits from milder thermal conditions and a different phenological profile. These climatic contrasts make Uzbekistan a natural laboratory for studying how vegetation responds to temperature fluctuations under varying ecological constraints.

In this context, remote sensing has become an essential tool for monitoring vegetation health and environmental dynamics at regional scales. The Normalized Difference Vegetation Index (NDVI) is one of the most widely used indicators for assessing plant vigor, greenness, biomass accumulation, and overall photosynthetic activity. Conversely, Land Surface Temperature (LST) represents the thermal energy radiated by the land surface and is directly linked to evapotranspiration, soil moisture availability, and plant stress. Integrating NDVI and LST provides a robust framework for identifying vegetation responses to heat stress, evaluating drought sensitivity, and monitoring the temporal evolution of crop performance.

Although several studies have explored climate–vegetation interactions in Central Asia, most have focused on long-term drought indices or precipitation–vegetation relationships. However, in irrigated agricultural systems such as those in Uzbekistan, precipitation alone often fails to explain vegetation dynamics, as crops depend heavily on scheduled irrigation rather than rainfall. Our preliminary analysis confirmed this: NDVI and precipitation showed almost no correlation, underscoring the limited explanatory power of rainfall in irrigated zones. In contrast, vegetation displayed a strong positive correlation with LST ($r = 0.71$) during the 2024 growing season, with temperature explaining nearly 50% of NDVI variability ($R^2 = 0.51$). This suggests that thermal conditions, rather than rainfall, play a more dominant role in governing vegetation greenness—especially during early to mid-season growth phases when heat accumulation stimulates biomass expansion under sufficient irrigation.

Despite these insights, systematic NDVI–LST analyses comparing multiple agro-climatic zones of Uzbekistan remain limited. There is a clear research gap in understanding how temperature regimes shape vegetation dynamics across regions with contrasting environmental characteristics. This study aims to fill that gap by conducting a detailed remote-sensing-based analysis of NDVI–LST interactions for the 2024 vegetation season across two representative districts: Jarqo'rg'on (Surxondaryo) in the south and Bo'ka (Tashkent) in the north.

Through temporal alignment of MODIS NDVI and LST datasets in Google Earth Engine, followed by Pearson correlation and linear regression analysis, this work provides new insights into vegetation sensitivity to thermal variability. By identifying spatial–temporal vegetation–

temperature linkages, the study contributes to the development of climate-resilient agricultural strategies, improved irrigation scheduling, and early warning systems for heat stress monitoring.

Materials and Methods

Study Areas

This study focuses on two contrasting agro-climatic zones of Uzbekistan: Jarqo‘rg‘on district in the southern Surxondaryo region and Bo‘ka district in the northern Tashkent region. Jarqo‘rg‘on is characterized by a hot semi-arid climate with extremely high summer temperatures, prolonged growing seasons, and strong evaporative demand. In contrast, Bo‘ka features a milder continental climate with a shorter but more temperature-stable vegetation period. These climatic differences allow for a comparative assessment of vegetation–temperature relationships under varying environmental conditions. Administrative boundaries of the study areas were prepared as polygon shapefiles and imported into Google Earth Engine (GEE) for further analysis.

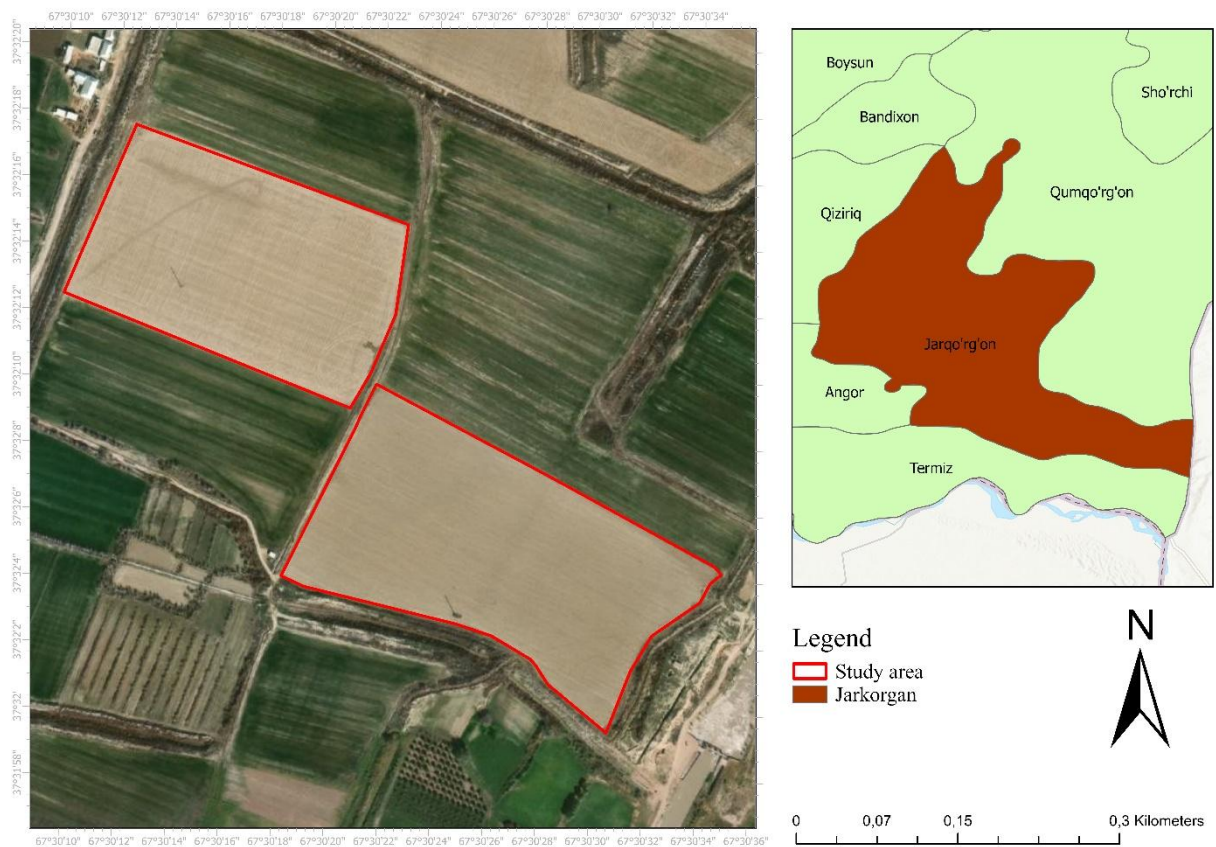


Figure 1. Geographic location of study area plot, Jarkurgan district, Surkhandarya region, Uzbekistan.

In contrast, Bo‘ka experiences relatively cooler temperatures, higher rainfall, and a longer moisture-sufficient growing season.

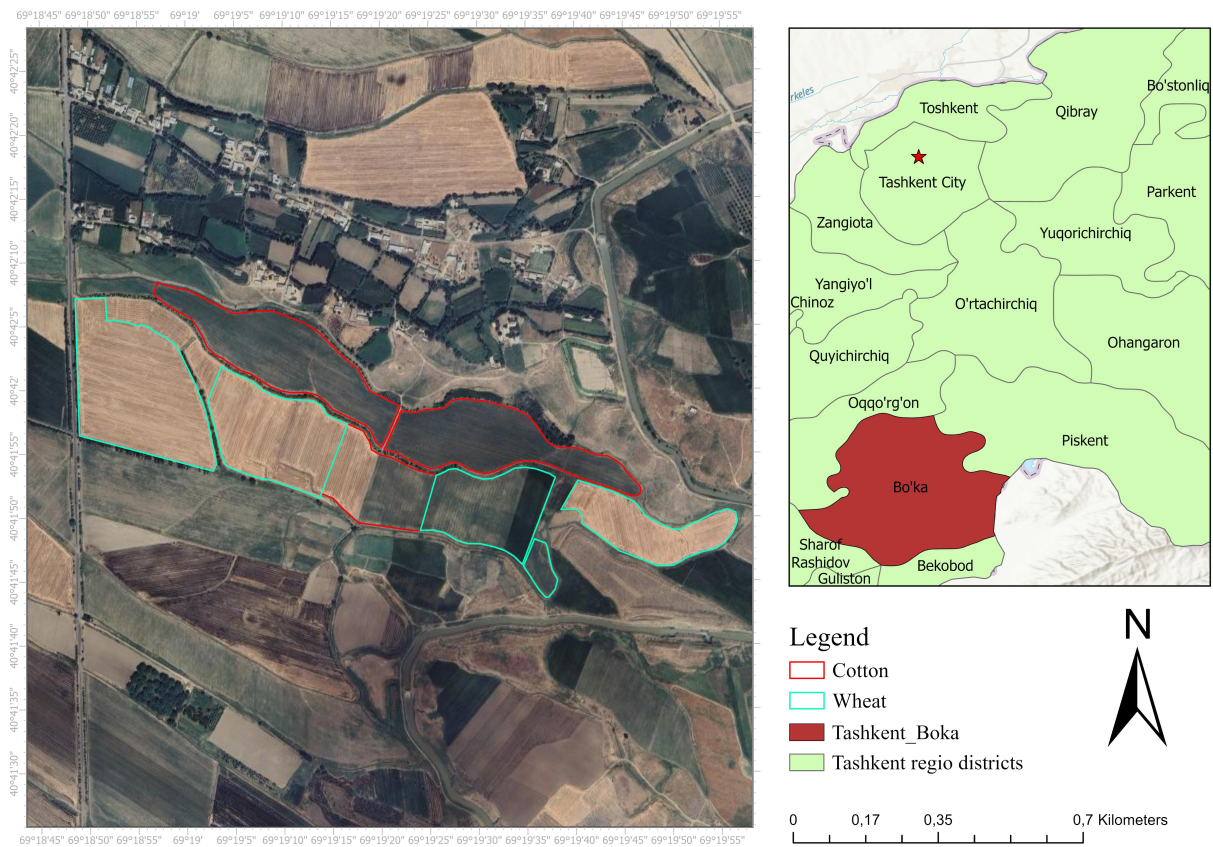


Figure 2. Geographic location of study area plot, Boka district, Tashkent region, Uzbekistan.

These climatic differences create distinct vegetation development patterns, making the regions ideal for comparative climate–vegetation analysis. Administrative boundaries for both districts were sourced from GADM and preprocessed in GIS for spatial clipping of remote sensing datasets.

Data Sources

Satellite-Derived Vegetation Data (NDVI)

Vegetation greenness was assessed using the MOD13Q1 product (MODIS/006/MOD13Q1), providing: 250 m spatial resolution, 16-day temporal frequency, NDVI values pre-corrected for atmospheric and bidirectional reflectance effects. The dataset is widely used for vegetation monitoring in semi-arid agricultural systems and provides consistent long-term observations.

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$$

The product includes cloud-screened, atmospherically corrected surface reflectance, making it highly suitable for long-term vegetation monitoring.

Land Surface Temperature was obtained from the MOD11A2 dataset (MODIS/061/MOD11A2), which includes:

- 1 km spatial resolution

- 8-day composites
- Daytime and nighttime LST bands
- Temperature in Kelvin units, later converted to °C

Daytime LST was used for correlation with NDVI, as it better reflects thermal stress affecting vegetation function. The analysis covers the 2024 vegetation season (January–December 2024). Monthly composites were generated for both NDVI and LST to ensure temporal harmonization.

Google Earth Engine Workflow

All data processing and statistical computations were conducted using Google Earth Engine. The workflow included:

- Importing study area shapefiles
- Loading MODIS NDVI (MOD13Q1) and LST (MOD11A2) datasets
- Monthly compositing and temporal alignment
- Zonal time-series extraction
- Correlation and regression analysis in GEE JavaScript editor

This cloud-based workflow eliminated the need for local storage and ensured access to large satellite time series in real time.

Results and Discussion

NDVI and LST seasonal dynamics (2024)

Both districts showed typical seasonal patterns: NDVI increased from early spring to early summer, stabilizing during peak growth periods, while LST steadily rose toward the mid-summer maximum. However, Jarqo‘rg‘on experienced substantially higher temperatures due to its subtropical semi-arid climate, whereas Bo‘ka maintained cooler thermal conditions throughout the season. These climatic contrasts form the basis for differences observed in vegetation–temperature relationships (Fig.4 and Fig.5).

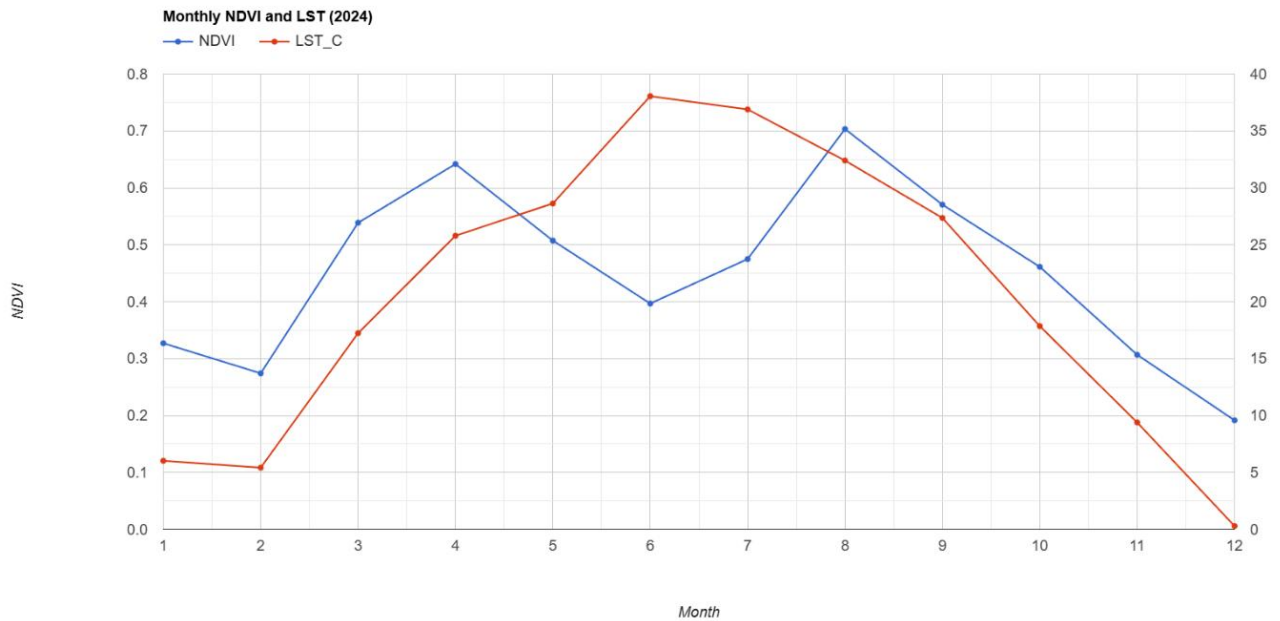


Figure 3. Monthly NDVI and LST dynamics in Boka district.

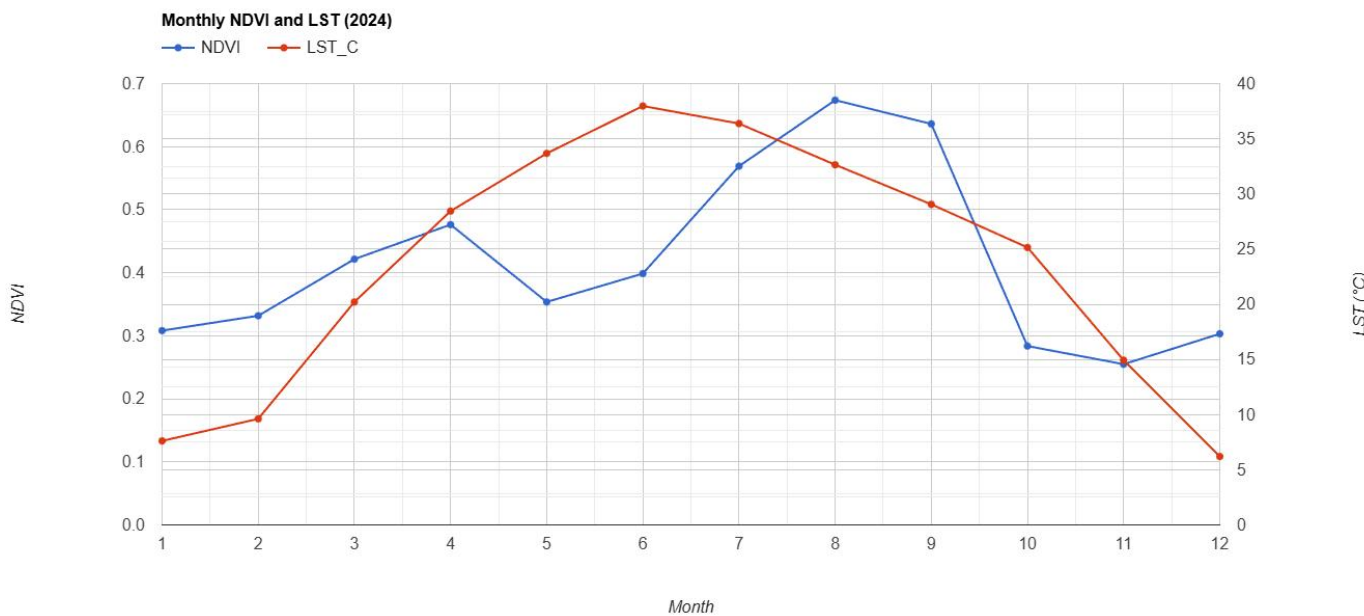


Figure 4. Monthly NDVI and LST dynamics in Jarkurgan district.

Both study areas demonstrated similar temporal trajectories, though Jarqo‘rg‘on showed higher peak temperatures due to its semi-arid subtropical climate, whereas Bo‘ka maintained comparatively moderate thermal conditions. Despite these differences, the general vegetation response pattern remained consistent.

Correlation between NDVI and LST

Bo‘ka District (Fig.5)

- Pearson correlation: $r = 0.7128$
- $R^2: 0.5080$
- Slope (b): 0.00852
- Intercept (a): 0.27536

The strong positive correlation indicates that vegetation in Bo'ka responds robustly to rising temperatures. This behavior is typical in moderately warm regions where higher temperatures stimulate photosynthesis and canopy development without exceeding heat-stress thresholds. The high R^2 value shows that temperature explains over 50% of vegetation variability, suggesting that LST can serve as a reliable proxy for phenological development in this region.

Jarqo'rg'on District (Fig.6)

- Pearson correlation: $r = 0.6114$
- $R^2: 0.3738$
- Slope (b): 0.00755
- Intercept (a): 0.24018

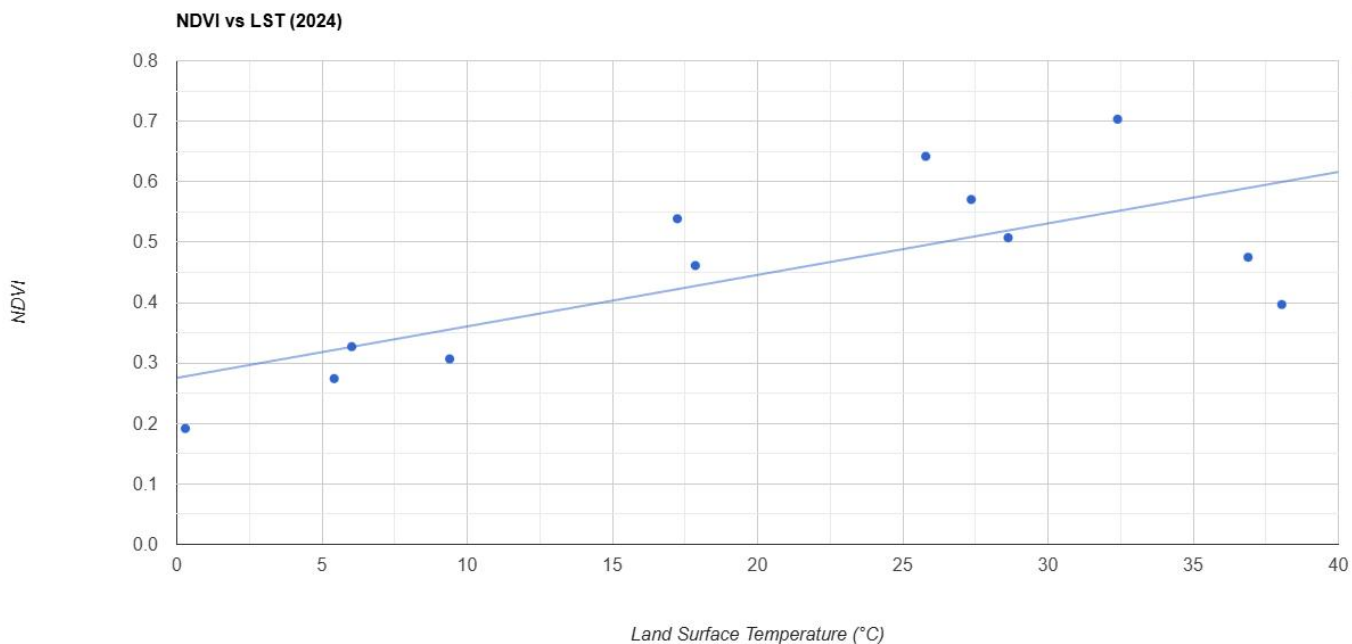


Figure 5. NDVI and LST relations in Boka district

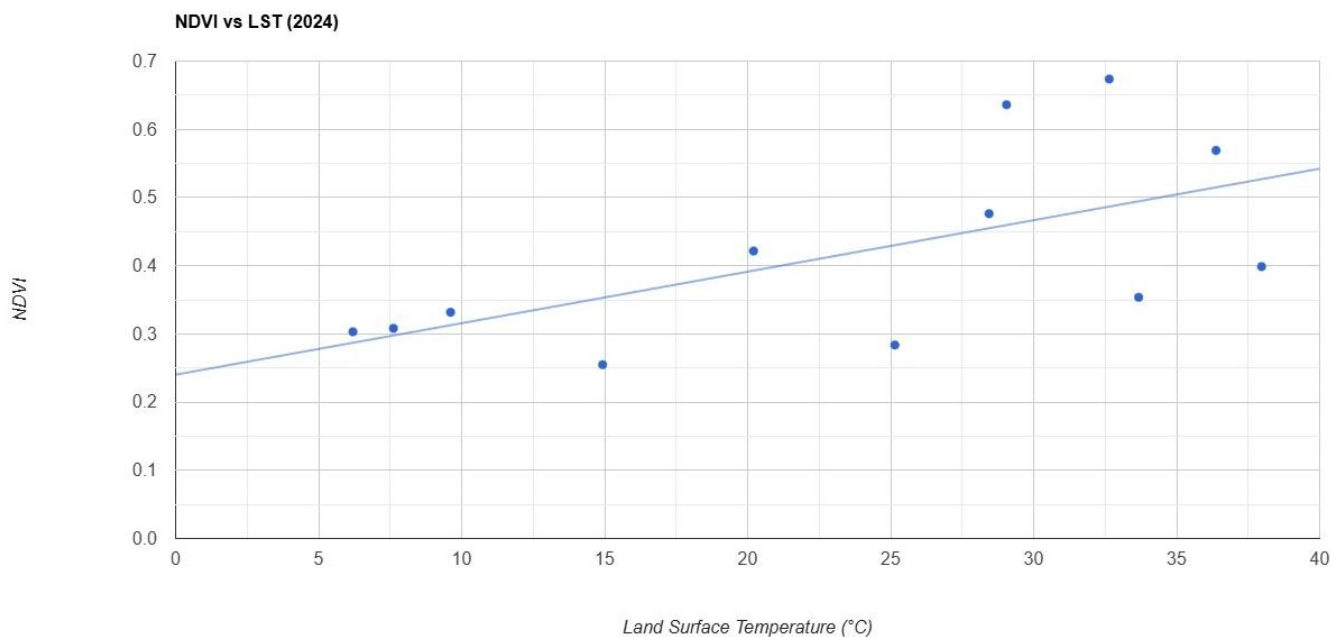


Figure 6. NDVI and LST relations in Jarkurgan district

The correlation is weaker but still statistically meaningful. Compared to Bo'ka, Jarqo'rg'on experiences significantly higher temperatures, which may surpass optimal thermal ranges for vegetation, reducing NDVI sensitivity to temperature. The lower R^2 indicates that only $\sim 37\%$ of vegetation greenness is explained by temperature alone—suggesting additional effects of heat stress, water limitation, or irrigation timing.

Regional Differences and Climate-Resilient Implications

The comparative analysis of NDVI–LST interactions revealed clear regional differences between Bo'ka and Jarqo'rg'on districts, driven primarily by their contrasting agro-climatic conditions. In Bo'ka, the relatively cooler and more temperate climate allowed vegetation to benefit from rising temperatures during the active growth period. Moderate thermal conditions reduce the likelihood of heat stress, enabling crops to maintain higher stomatal conductance and photosynthetic efficiency. As a result, vegetation in this region exhibited a stronger NDVI–LST coupling, reflected in the higher correlation coefficient and steeper regression slope.

Conversely, Jarqo'rg'on experiences substantially higher temperatures throughout the vegetation season. Frequent exposure to extreme heat suppresses vegetation greenness and accelerates physiological stress responses. Because optimal temperature thresholds are exceeded more often, the stimulatory effect of temperature on plant growth diminishes, resulting in a weaker correlation between NDVI and LST. Moreover, agriculture in Jarqo'rg'on relies heavily on irrigation, meaning that vegetation health is influenced not solely by temperature but also by irrigation scheduling, soil moisture availability, and evapotranspiration demand. Elevated evapotranspiration rates contribute further to canopy stress, decreasing the sensitivity of NDVI to temperature variability.

Regression model comparisons reinforce these observations. The slope of 0.00852 in Bo'ka indicates a stronger increase in NDVI per degree Celsius, confirming efficient temperature-

driven growth under moderate climate conditions. In Jarqo'rg'on, the slope of 0.00755, although still positive, reflects a dampened vegetation response due to heat stress and moisture limitations. This suggests that vegetation in warmer southern regions is operating closer to physiological boundaries, where additional heat no longer contributes to increased greenness.

These regional distinctions carry important implications for climate-resilient agriculture in Uzbekistan. The findings demonstrate that temperature sensitivity is highly zone-specific, and agricultural adaptation strategies must account for these climatic differences. In Bo'ka, moderate warming may temporarily enhance vegetative development, but continuous monitoring is required to anticipate potential heatwave impacts. In contrast, Jarqo'rg'on already faces critical thermal and hydrological constraints, highlighting the need for heat-resilient crop varieties, optimized irrigation management, and microclimate regulation strategies to mitigate heat stress. Overall, LST proves to be a reliable indicator of vegetation vigor across both regions, particularly in irrigated systems where precipitation exerts minimal influence on crop performance.

Conclusion

This study assessed vegetation–temperature interactions across two contrasting agro-climatic regions of Uzbekistan using MODIS-derived NDVI and LST time-series for the 2024 vegetation season. The results revealed that Bo'ka district, characterized by a cooler and more temperate climate, exhibited a stronger NDVI–LST relationship ($r = 0.71$, $R^2 = 0.51$). Vegetation in this region responded positively and consistently to rising temperatures, reflecting optimal thermal conditions that enhance photosynthesis and canopy development. In contrast, Jarqo'rg'on district, located in the hotter semi-arid south, displayed a moderate correlation ($r = 0.61$, $R^2 = 0.37$). The weaker coupling indicates that vegetation in this region is more frequently subjected to thermal stress, and that temperature alone does not fully explain vegetation variability due to additional constraints such as high evapotranspiration rates and irrigation dependency.

The comparison highlights that thermal regimes are a key determinant of vegetation sensitivity and that vegetation in cooler zones benefits more from temperature increases, while vegetation in hotter areas approaches physiological and climatic limits. These insights underscore the need for region-specific climate adaptation strategies.

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