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How has land-use change affected vegetation productivity in Uzbekistan since 2000?

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ABSTRACT

Throughout the years, as a soviet state, Uzbekistan was highly dependent on cotton cultivation that led to land degradation and soil salinization. Since 2000, the government drastically reduced cotton growing area and increased wheat cultivation to provide diversification and food security. This poses an essential question of whether the decline in the harvested area of major crops in Uzbekistan is an indication of recovery of the ecology or is related to a decrease in vegetation productivity (NDVI) over 2000-2024. The statistical analysis of the FAOSTAT agricultural database and NDVI (Normalized Difference Vegetation Index) data for 2000-2024 shows a statistically significant negative correlation ($r=-0.75$, $t=-5.44$, $p<0.001$) between the area of cultivated cotton and mean NDVI values in the country. This suggests that as cotton fields decreased, the country consistently became greener in terms of NDVI values. Wheat acreage, however, showed no significant relationship to this greening ($r = -0.13$, $t = -0.63$, $p = 0.54$). Despite the contraction of agricultural land, both per-hectare crop yields and national NDVI increased. These findings indicate that Uzbekistan's recent "greening" is not a natural ecological recovery, but rather a reflection of intensive agricultural production on reduced land.

INTRODUCTION

Uzbekistan's agricultural transition offers an empirical case for analyzing land-use policy impacts. Soviet-era cotton monocultures fundamentally altered the region's ecology, triggering soil salinization and the desiccation of the Aral Sea basin (Glantz, 2007). Prompted by the necessity to restructure Soviet-era practices, the government has transformed the agricultural sector in terms of structural changes and reallocation of land from cotton to food crops (World Bank, 2020). Land under cotton crops has decreased by more than 50% compared to the Soviet period (USDA, 2025).

But the reduction of cotton fields is not always sufficient to overcome the adverse effects on the environment. Recent studies suggest that up to 47% to 50% of irrigated lands of Uzbekistan experience salinization (Mirzabaev & Akramkhanov, 2025; Umarov et al., 2025). The problem results in considerable costs for the state; total economic losses due to ongoing degradation of land during 2000-2021 years total \$3.7 billion (Mirzabaev & Akramkhanov, 2025). Nevertheless, restoring the damaged land is economically viable. The benefit obtained from each dollar invested in the rehabilitation of land in Central Asia over the period of 30 years amounts to $2.9-$4 (Mirzabaev & Akramkhanov, 2025). Additionally, according to the FAO report of 2022, by 2022 almost a third (37%) of the territory of the country was characterized by stressed vegetation or decline in productivity. These facts give rise to questions: Is the change in the area of the main crops a sign of ecological improvement, or a reduction in vegetation productivity between 2000 and 2024?

Scientists use the tracking of vegetation productivity, which indicates the efficiency of plant biomass production under certain conditions of water, light, and nutrient availability. This parameter is important for the assessment of food security, quality of land and terrestrial carbon cycle (Food and Agriculture Organization [FAO], n.d.). On the national scale, the best tool for monitoring such a parameter is its evaluation from satellites through NDVI.

In this paper, land-use change is defined as the year-to-year shift in the harvested hectares of Uzbekistan's two most critical crops: cotton and wheat. The focus on harvested area is intentional, as it directly reflects national land-allocation decisions and is consistently recorded in major statistical databases (FAO, n.d.).

Therefore, this study aims to determine whether year-to-year changes in the harvested area for cotton and wheat since 2000 are associated with changes in NDVI-based vegetation productivity across Uzbekistan.

LITERATURE REVIEW

The changes in the landscape of Uzbekistan from 2000 onwards signify not only an ecological change but are the cumulative result of several policies implemented, increasing climate pressure, and agricultural changes made by the country. The purpose of this review is to discuss the available information concerning agricultural changes, the use of the NDVI, and the environmental challenges faced by the Aral Sea basin. Thus, it becomes necessary to investigate how all these elements influence each other in their combination at a national scale.

2.1 Post-Soviet Agricultural Transition and "Cotton to Wheat" Change

The primary cause of land-use change in Uzbekistan has been the state's attempt to secure "food self-sufficiency." After gaining independence in 1991, the government started decreasing the huge areas allocated for cotton cultivation in Soviet times. The World Bank (2020) notes that the establishment of cotton textile clusters was a significant step towards adding value to production. Nevertheless, this change was preceded by the large-scale production of wheat. Mirzabaev (2013) states that even though the diversification of crop cultivation was aimed at securing food supply, it usually led to ineffective water management due to the different irrigation needs of wheat and cotton. This shift in what is planted is the first major variable in understanding national trends in vegetation productivity, but assessing its true physical impact requires reliable environmental monitoring.

2.2 Monitoring Land Productivity via Remote Sensing

However, to evaluate the physical reality of these policy changes, the utilization of the Normalized Difference Vegetation Index (NDVI) became the gold standard in Central Asia. As is evident from the work of Yilmaz (2025), there was a statistically proven "greening" trend in Uzbekistan between 1995 and 2024. Nonetheless, other researchers advise against interpreting this trend too simplistically. In particular, Dubovyk et al. (2016) performed a long-term analysis of land degradation in Uzbekistan with the help of satellite imagery. As a result, they found out that "greening" in certain areas covers the problem of soil salinity. Specifically, the authors argue that an increase in the NDVI value does not necessarily indicate "healthier" land; sometimes, it just means the spread of salt-tolerant weeds and irrigation in new areas. Therefore, there is a major interpretational problem in the literature: a high NDVI value does not automatically imply sustainable agricultural productivity; it requires evaluation of soil health.

2.3 Land Degradation Neutrality (LDN) and Soil Health

Finally, LDN research helps to understand why certain territories fail to demonstrate productivity gains despite the aforementioned policy changes. The analysis of irrigated areas in Uzbekistan reveals the fact that almost half of irrigated lands experience different levels of soil salinization (Mirzaqobulov et al., 2023). First of all, the legal framework of the Republic of Uzbekistan (2019), formulated in terms of presidential decrees (for instance, UP-5853), stresses "modernization of agriculture." However, as noted by academic critics of these regulations, the legal requirement does not necessarily lead to soil recovery. According to Kust et al. (2023), due to its proximity to the Aral Sea, Karakalpakstan experiences a "dust-salt" phenomenon that actively decreases vegetation productivity irrespective of the type of plant (cotton or wheat). Regional climate shifts do not merely parallel these soil issues; they accelerate the physical processes of degradation across Uzbekistan’s territory.

2.4 Climate Variable: Warming and Drying

Lastly, the literature discusses all agricultural and soil changes in relation to the "warming and drying" nature of Central Asia. Agricultural land-use change is one human variable, whereas the climate acts as a natural limitation. Yilmaz (2025) cites an increase in Land Surface Temperature (LST) and a decrease in soil moisture in the past two decades. Importantly, natural precipitation has stagnated at a critically low level of about 206 mm/year – significantly lower than the 300 mm/year necessary for agricultural sustainability (World Bank, 2014; Yilmaz, 2025). As per regional hydrological analysis (Ametov, 2022; FAO, 2022), high-yield greening has been solely dependent on the limited and highly managed river water available from the Amu Darya and Syr Darya basins rather than rain-fed crop cultivation. For a country that is doubly landlocked, like Uzbekistan, this creates an unsustainable balance where short term optical greening conceals the long term depletion of water resources.

2.5 Research Gap

Whereas the literature has established the warming and greening trend of Uzbekistan, there exists no study that integrates all these variables into a study of how the change in the use of land is directly related to vegetation trends. There have been studies of the effects of changing land uses on vegetation productivity in localized regions. However, most of these studies focus on either climatic factors, localized soil health, or agricultural policies.

This study is meant to fill that void. Using the analysis of mean NDVI of each nation in combination with the agricultural land allocation data from FAOSTAT from 2000 to 2024, this research will analyze the relationship between vegetation productivity (NDVI) and land-use change in response to harvested land areas for cotton and wheat (the most significant crops in Uzbekistan). The connection between national agriculture data and the satellite environmental indicators discovered in the longitudinal study of Yilmaz (2025) will help find out what effect has been made by the "cotton-to-wheat" switch has had on the landscape of the country.

3. METHODS

In this section, the method used to assess the effects of agricultural land-use changes on vegetation productivity in Uzbekistan from 2000 to 2024 is described. The method is based on a longitudinal design.

3.1 Data Sources

Agricultural Land-Use Data: Annual harvested-area (hectares) and yield (kilograms per hectare) data for Uzbekistan's two primary crops, seed cotton (unginned) and wheat, were downloaded directly from the FAOSTAT Crops and livestock products domain. Data cover the full period 2000–2024 and were filtered for the "Seed cotton, unginned" (item code 01921.01) and "Wheat" item code 0111) under the "Area harvested" and "Yield" elements.

Vegetation productivity in this study is represented using published NDVI summaries rather than newly processed satellite imagery. National mean NDVI values were extracted from Yilmaz (2025, Figure 5) using WebPlotDigitizer 4.7. The extraction process involved a four-point coordinate system calibration to map pixel positions to the figure's numerical axes with a digital resolution of 0.001 units to ensure data fidelity. NDVI values in Yilmaz's study were determined using the standard spectral reflectance ratio, where *NIR* represents the near-infrared reflectance, and *RED* refers to the red-light reflectance.

Volkan Yilmaz's analysis of Uzbekistan (1995–2024) reports historically low national mean NDVI values (approximately 0.04–0.085), a modest upward long-term trend, and substantial spatial heterogeneity across provinces, making these results appropriate for examining land-use drivers of vegetation change (Yilmaz, 2025).

3.2 Synthesis and Argumentation

The core of this research involves putting these two distinct datasets into conversation. By looking at the yearly dynamics of harvested area of wheat and cotton along with the annual mean NDVI value, the study uncovers long-term ecological patterns. In particular, by contrasting the sharp reduction in the area of cotton cultivation after 2008 with NDVI trends across the country, one can establish whether changes in vegetation productivity are caused either by the diversification of crops or by the abandonment of the degraded lands.

3.3 Specific Design and Procedures

The longitudinal research design will be employed, setting up 2000 as the base year to match satellite-based NDVI monitoring (such as MODIS).

Variables: The independent variable is the land use change, which will be operationalized as the annual change in the number of harvested hectares of 2 crops: wheat and cotton. The dependent variable is vegetation productivity, operationalized through the mean annual NDVI.

3.4 Statistical Analysis

To establish whether the relationship between crop allocation and vegetation productivity is statistically significant, the following procedures will be applied:

Trend Analysis: Trend lines in the harvested area of cotton, wheat, NDVI, and agricultural land were visualized with the exact values for each year from 2000 to 2024.

Pearson Correlation Coefficient: The Pearson correlation coefficient (r) was used to determine the relationship between the harvested area of both crops (seed cotton and wheat) per year and the national average value of NDVI during the period of 2000–2024.

Significance Testing: To determine if the results were statistically significant, a two-tailed t-test was performed with 23 degrees of freedom (df = n - 2). The t-statistic was calculated using the formula $t = r\sqrt{(n-2)/(1-r^2)}$ when n=25, representing 25 years from 2000 to 2024.

4. RESULTS

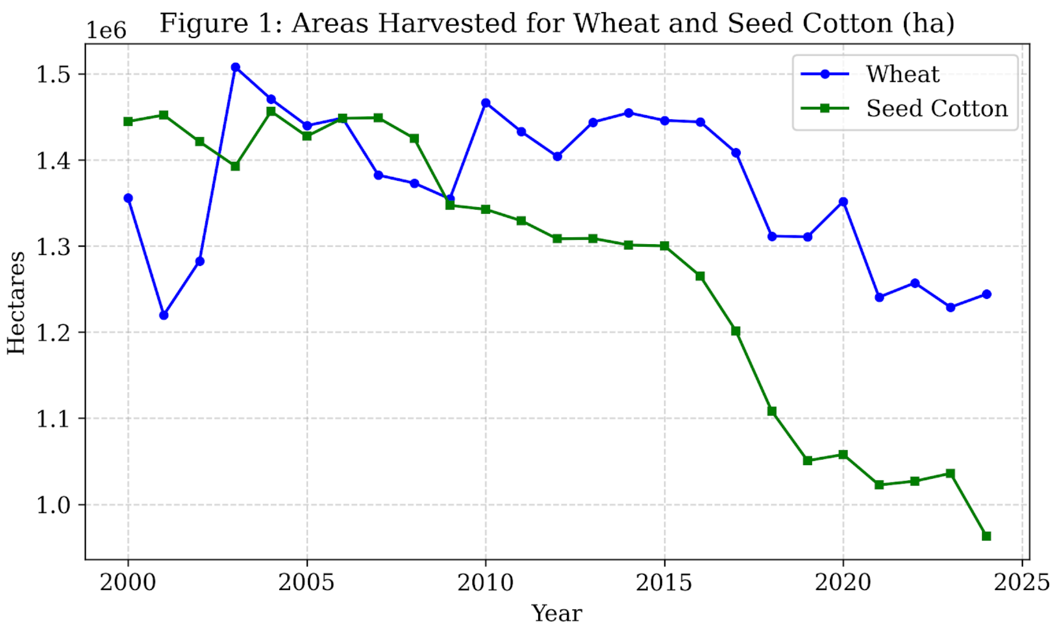

Figure 1 illustrates the decline in harvested area for wheat and cotton from 2000 to 2024. Between 2000 and 2008, the harvested area of seed cotton (unginned) fluctuated between 1.35 million and 1.45 million hectares. After 2008, however, it declined sharply, falling from 1,425,000 hectares to 963,072 hectares by 2024. Wheat followed a different pattern: its harvested area increased between 2001 and 2003, rising from 1,219,800 hectares to 1,507,600 hectares. From 2003 to 2024, it showed an overall downward trend, reaching 1,243,993 hectare

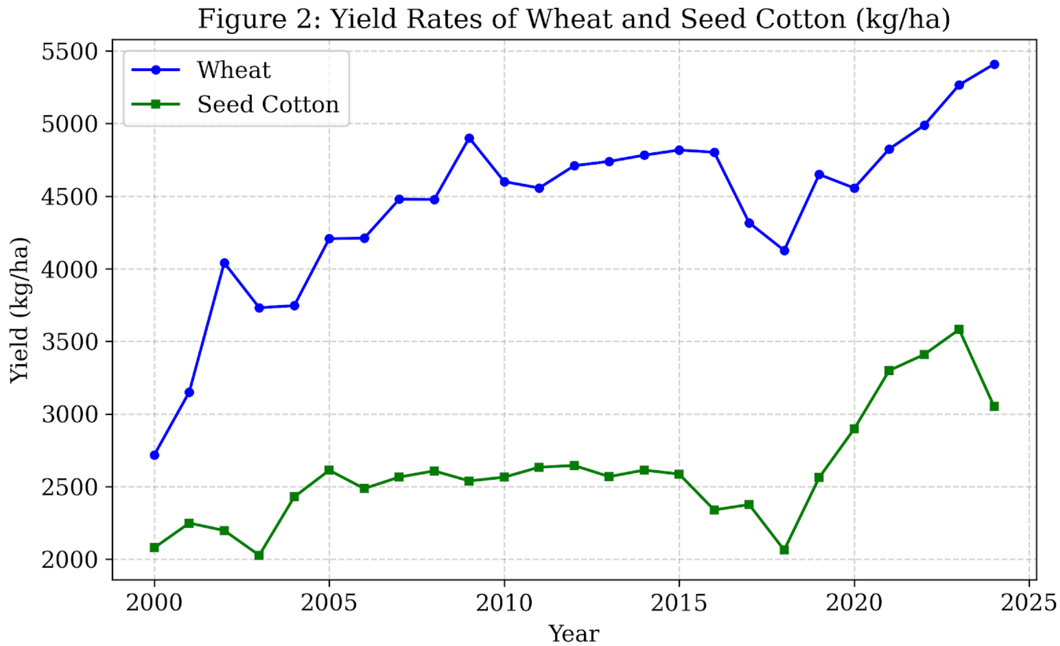

Figure 2 represents the yield rates in kg/ha for wheat and seed cotton from 2000 to 2024. Crop yields for both wheat and seed cotton increased substantially in the study period (Figure 2). The yield rate of wheat fluctuated between 2717 kg/ha and 5409kg/ha, with the highest value of 5409 kg/ha in 2024. Values for seed cotton remained relatively stable, with a sharp increase between 2018 and 2023.

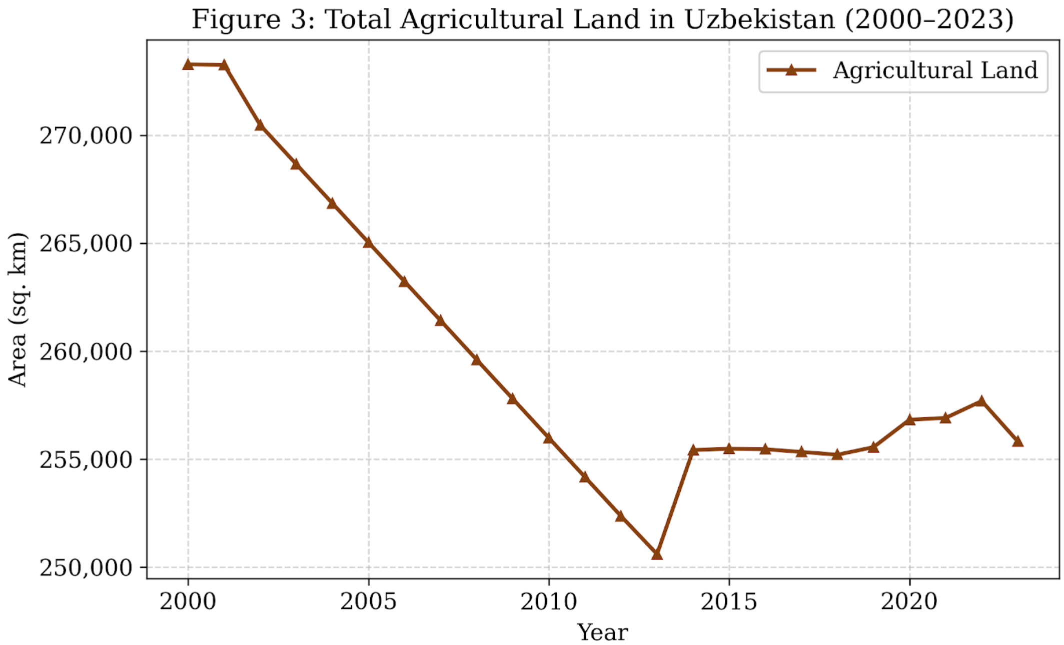

Figure 3 shows the agricultural land area in Uzbekistan, measured in square kilometres, from 2000 to 2023. Overall, the area of agricultural land declined over this period, which may be associated with the conversion of cropland into built-up land. From 2002 to 2013, the data showed a steady downward trend, reaching its lowest value since 2000 of 250,600 sq. km in 2013. From 2013 to 2023, agricultural land values fluctuated but increased overall across the decade. The values remained almost constant between 2014 and 2018.

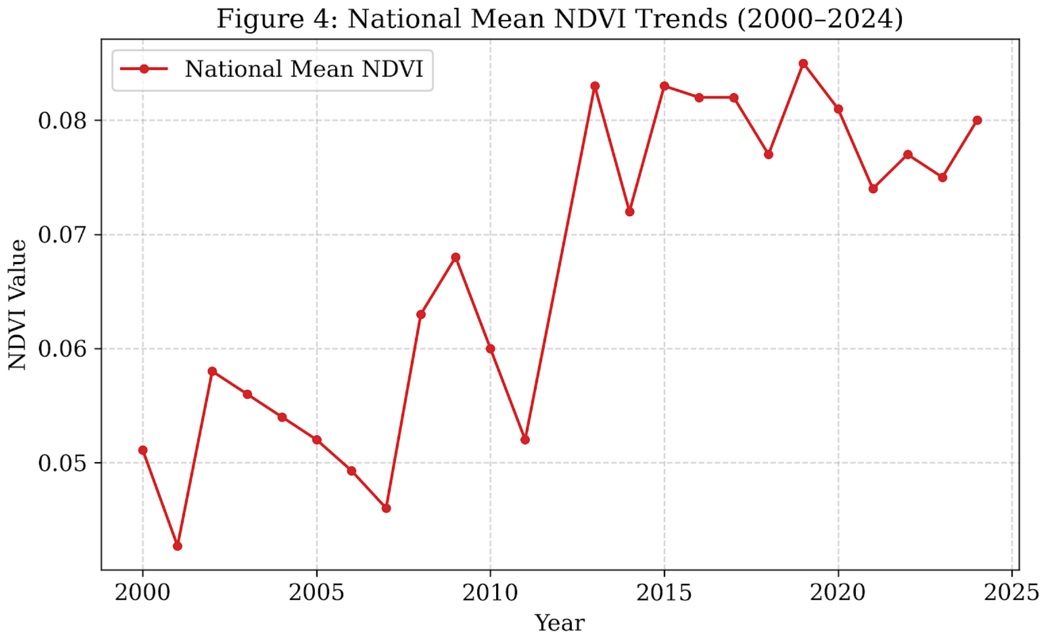

Figure 4 illustrates the mean NDVI values for Uzbekistan from 2000 to 2024. The national mean NDVI showed a consistent upward trend from 2000 to 2024 (Figure 3). Between 2000 and 2011, values fluctuated between 0.04 and 0.07. Mean NDVI values increased by 0.031 units between 2011 and 2013, from 0.052 to 0.083. However, this national mean masks significant spatial heterogeneity. The most notable NDVI increases are concentrated in the eastern regions of Uzbekistan, while western areas like Karakalpakstan remain suppressed by the 'dust-salt' effect of the desiccating Aral Sea (Yilmaz, 2025; Umarov et al., 2025).

To statistically quantify the relationship between crop allocation and vegetation productivity, Pearson correlation coefficients (r), t-statistics (t), and significance levels (p) were calculated for the 25 years. The analysis revealed a strong negative correlation between the harvested area of seed cotton and national mean NDVI ($r = -0.75$, $t = -5.44$, $p<0.001$). This indicates that as the land dedicated to cotton cultivation significantly decreased, vegetation productivity consistently increased; this relationship is highly significant, meaning there is less than a 0.1% probability that this trend occurred by chance. In contrast, the correlation between the harvested area of wheat and mean NDVI was negligible and not statistically significant ($r=-0.13$, $t=-0.63$, $p=0.54$), indicating that fluctuations in wheat acreage had no meaningful linear relationship with the national greening trend. These statistical results are summarized in Table 1.

Table 1. Statistical Summary of Pearson Correlations

Variable Pair	Correlation(r)	Significance(p)	Interpretation
Cotton area vs. NDVI	-0.75	<0.001	Strong Negative, Highly Significant
Wheat Area vs. NDVI	-0.13	0.54	Negligible, Not Significant

5. DISCUSSION

In summary, the results show that land use changes for agriculture in Uzbekistan after 2000 are linked to an increase in the national NDVI. Nevertheless, the increasing greenery cannot be taken as a straightforward ecological restoration process. The findings instead suggest a complex transition in which planned agricultural changes, rapid efficiency gains, and persistent environmental constraints are occurring simultaneously. While total agricultural land contracted (Figure 4) – potentially reflecting cropland-to-urban conversion – the persistent greening trend aligns closely with a model of agricultural intensification, suggesting it is a more significant correlate than land abandonment.

The most significant finding of this study is that the dramatic decline in cotton-harvested areas does not imply an ecological decline or the abandonment of vegetated land. This is well evidenced through the statistical study, which shows a strong negative correlation ($r= -0.75$, $p< 0.001$) between the harvested area of seed cotton and the national mean NDVI. Since there is an inverse correlation between the two variables, this clearly means that reduction in the traditionally dominant and land-degrading cotton monoculture has a significant impact on the greening of the nation. These reductions in cotton acreage likely reflect a calculated policy shift toward higher-value, more concentrated agricultural clusters rather than passive land abandonment.

Conversely, the correlation between the harvested area of wheat and mean NDVI was found to be exceptionally weak ($r = -0.13$, $p = 0.54$). From 2001 to 2003, there was a sharp increase in harvested wheat area intended to boost national food self-sufficiency, coinciding with the initial decrease in cotton area. However, it should be noted that the absence of any long-term correlation demonstrates that changes in wheat acreage cannot be considered a crucial factor behind the general vegetation changes in the country during those 24 years.

The data provided shows an important paradox: despite the reduction of the total area for cultivation of cotton and wheat and the shrinkage of total agricultural land (which was equal to 273,280 sq. km in 2000 and was 255,820 sq. km in 2023), the values of national NDVI have been increasing throughout the analyzed period. This means that there has been agricultural intensification, that could be seen from significant increases in crop yield. During 2000-2024, the yield rate of wheat has increased by 99% (from 2,717.4 kg/ha to 5,409.5 kg/ha), the yield rate of cotton – by almost 47% (from 2,078.1 kg/ha to 3,050.7 kg/ha), and mean NDVI – by 57% (from 0.051 to 0.080). It means that a decrease in the total area harvested, along with increases in yield rates, can be explained by intensification, better land management practices, and concentration of resources.

Nonetheless, it is important to understand that this "greening" should be considered in the context of established ecological norms to interpret the findings correctly. The increase in NDVI by 57% looks impressive; however, the absolute NDVI growth (about 0.029 units) is quite modest. According to Central Asian ecological standards, NDVI below 0.05 is considered "highly degraded" or bare soil, and NDVI from 0.05 to 0.145 is considered "moderately degraded". Therefore, the improvement of Uzbekistan should be understood as an improvement from "highly degraded" to "moderately degraded. The data provides context for the findings of Yilmaz (2025) about the long-term greening of Uzbekistan. However, aligning with the cautions of Dubovyk et al. (2016), this intensified greening may mask underlying vulnerabilities like soil salinization. High yields require intensive irrigation. As Ametov (2022) notes, gains in vegetation productivity in a "warming and drying" climate are heavily dependent on shrinking river water supplies.

5.1 Limitations

A primary limitation is the use of NDVI in a territory where annual mean values range from 0.04 to 0.085. In such sparsely vegetated regions, the spectral signal is highly sensitive to soil background reflectance. While NDVI effectively captures the "greening" trend, it does not distinguish between the expansion of salt-tolerant, invasive shrubs and genuine soil remediation.

Additionally, this analysis relies on MODIS MOD13Q1 summaries at a 250m resolution. While appropriate for national trends, this pixel size is often too coarse to capture the "fragmentation" of land cover or the specific outcomes of the new farm-level "Cotton-Textile Cluster" models. Furthermore, the use of annual mean summaries may mask "subseasonal flash droughts" that have become more frequent in Central Asia as of 2025. Moreover, as a secondary analysis of longitudinal data, this study identifies a strong linear association($r = -0.75$, $p<0.001$) but cannot definitively isolate policy-driven land use from confounding climate variables like shifting groundwater tables or Land Surface Temperature (LST) fluctuations.

5.2 Future Research

Multi-Index Cross-Validation: Future studies should integrate the Soil-Adjusted Vegetation Index (SAVI) and the Enhanced Vegetation Index (EVI) to minimize atmospheric distortions and soil brightness effects. This would provide a more robust verification of whether the "greening" identified in this study represents sustainable biomass growth.

High-Resolution Precision Monitoring: With Uzbekistan's 2026 plan to launch two ultra-high-resolution Earth observation satellites, researchers can soon move beyond 250m pixels to sub-meter imagery. The Agency for Space Research and Technology (Uzbekcosmos) plans to launch two Earth observation satellites in 2026 with an ultra-high resolution of 0.3 meters per pixel. This sub-meter precision will allow future researchers to evaluate individual irrigation plots and finally distinguish between genuine crop vigor and the expansion of salt-tolerant, invasive shrubs. This will allow for the evaluation of individual irrigation plots to determine which specific "cluster" management practices are most water-efficient.

Groundwater and TWS Modeling: To solve the "greening paradox," future research must incorporate Terrestrial Water Storage (TWS) data from the GRACE satellite mission. This is essential to determine if the high yields identified in this study are being sustained by the dangerous depletion of non-renewable aquifers.

6. CONCLUSION

This study shows that Uzbekistan's shift away from Soviet-era cotton farming has fundamentally changed the country's vegetation footprint. The rise in national NDVI values during the reduction in areas of degraded lands cultivated with cotton indicates a positive trend, but does not imply that the environment has healed. Given that the area of land used for agriculture declined while the level of agricultural output increased dramatically, rising NDVI values indicate the development of intensive agriculture, as opposed to environmental recovery.

Through the effective use of smaller land areas in cultivation of higher-yielding plants, Uzbekistan has achieved agricultural modernization. However, this "greening" effect visible from above covers up a much more fragile situation below. High-yield farming requires massive, consistent amounts of irrigation. As Central Asia faces a warming climate and shrinking river supplies, the current agricultural strategy may be pushing the region's already stressed water resources to their limit. Given that NDVI rose 57% without a corresponding increase in precipitation (approximately 206 mm/year), the observed greening is unlikely to be rainfall-driven. This pattern is consistent with an irrigation-dependent explanation, though direct data on irrigation withdrawal or river discharge would be needed to confirm this mechanism. Moving forward, researchers need to look beyond satellite images of greenness and focus on localized soil moisture and groundwater data to determine if this intensive farming model is truly sustainable for the future.

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