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RESEARCH ARTICLE

Monitoring Türkiye's Vegetation Cover with NDVI: Terrestrial and Temporal Perspectives

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ABSTRACT

This study aims to monitor and analyze the temporal and spatial dynamics of Türkiye's vegetation cover from 2000 to 2023 using MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI (Normalized Difference Vegetation Index) data. The primary objective is to assess the changes in vegetation density across various geographical regions of Türkiye and determine how these changes are influenced by environmental factors such as land use and climate variability. NDVI data from July of each year were processed using ArcGIS to classify vegetation into six categories, ranging from water bodies to dense forests. The study reveals significant fluctuations in NDVI values, indicating both vegetation growth and degradation across different regions over time. Key findings include a positive correlation between NDVI values and forested areas, and a negative correlation in regions affected by drought or land use change. These results provide valuable insights into the long-term trends of vegetation dynamics in Türkiye and can help inform future conservation and land management strategies.

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1. Introduction

Türkiye's surrounding seas and rugged topography cause significant temporal and spatial variability in meteorological factors. The country's vegetation has undergone substantial changes over the years due to various factors such as land use practices, climate change, and anthropogenic activities. Türkiye is located at the intersection of three distinct phytogeographic regions: the Mediterranean, Euro-Siberian, and Irano-Turanian regions, hosting species from these diverse areas (Aktürk & Güney, 2021).

Traditionally, vegetation monitoring has relied on field-based observation data, which can reflect vegetation dynamics and phenological information. However, these methods often face challenges such as discontinuities in data collection and spatial gaps (Ding et al., 2012). To address these issues, remote sensing techniques have become increasingly important (Zhang et al., 2021). Among these, Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices for monitoring vegetation cover and assessing its changes over time.

NDVI is defined as a measure of surface reflectance and provides a quantitative estimate of vegetation growth and

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biomass (Y. Wu et al., 2016). This index ranges between -1 and +1, where values below zero during the growing season indicate the absence of vegetation (e.g., desert or bare soil areas), while values greater than zero represent vegetated areas (Choubin et al., 2019). The NDVI value is closely associated with the intensity of photosynthetic activity in the observed vegetation, making it an effective tool for detecting annual changes in vegetation's metabolic density and vitality (D. Wu et al., 2015). By highlighting variations in vegetation growth, NDVI can reveal the effects of temperature, precipitation, and other climatic factors, even in the absence of direct human activities or natural disasters (Ghebrezgabher et al., 2020; Jiang et al., 2021; Liu et al., 2019).

The principle behind NDVI is since green vegetation reflects more near-infrared light and less visible red light. By combining these reflections in a normalized manner, NDVI enhances the contrast between green vegetation and other land cover types (Cao et al., 2022). This capability makes NDVI particularly valuable in areas where field observations are limited or affected by discontinuities, providing crucial insights into vegetation dynamics and phenological changes (Matsushita et al., 2007).

NDVI data obtained from remote sensing methods have been crucial in eliminating errors caused by atmospheric conditions, instrument calibration, and terrain, thereby enhancing the sensitivity of vegetation monitoring efforts (Zeng et al., 2014). The broad spatial and temporal coverage of NDVI, its high sensitivity in detecting vegetation changes, low noise levels, and high comparability make it a valuable tool for assessing vegetation dynamics and phenological shifts (Alhajjar, 2024). Numerous studies have utilized NDVI to analyze trends in vegetation, detect changes in the amount of green cover, and monitor ecological changes across various ecosystems (Dai et al., 2011). Moreover, NDVI has been applied on a global scale in areas such as drought monitoring, agricultural production forecasting, land cover change detection, and ecosystem assessment (Naunyal et al., 2023).

In Kaymak (2020)'s study, the effect of morphoclimatic factors on vegetation distribution in the Sündiken Mountains was analysed. This study, which was carried out using MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI data, reveals the interaction of vegetation changes with climatic factors in detail. The study emphasises that MODIS data are widely used to study vegetation dynamics. Such analyses are critical for understanding the impacts of climate change on vegetation.

In Ateşoğlu (2021)'s study, long-term vegetation index data in the Konya Closed Basin were monitored and trend analyses were performed. This research using MODIS data reveals the trends of vegetation changes over time and emphasises how valuable these data are for environmental monitoring. Such long-term monitoring studies contribute to a better understanding of environmental changes.

While NDVI has been widely used for monitoring vegetation cover and assessing ecological changes, many studies in Türkiye have focused on localized regions or shorter timeframes. For example, previous research by Aktürk (2024) analyzed NDVI trends over a 10-year period in specific biomes of Türkiye, providing valuable insights into regional vegetation dynamics. However, there is a notable gap in studies that assess long-term vegetation trends at the national level, using a 23-year time series to examine both temporal and spatial variations across the entire country. This study aims to fill this gap by analyzing MODIS NDVI data from 2000 to 2023, providing a comprehensive view of vegetation dynamics throughout Türkiye's diverse ecosystems. By incorporating a broader geographical scope and a longer time frame, this research contributes to a more detailed understanding of how climatic and anthropogenic factors have influenced vegetation changes across the country.

2. Materials and Methods

2.1. Material

2.1.1. Study area

The study area of Türkiye is in the Northern Hemisphere, between 36°-42° north latitudes and 26°-45° east longitudes, covering an area of approximately 780,000 km² (Figure 1). Being situated in the temperate climate zone promotes rich ecological diversity. Türkiye hosts approximately 11,000 plant species, 35% of which are endemic, offering remarkable biodiversity. This ecological foundation provides an ideal environment for analyzing NDVI trends across different biomes (Aktürk, 2024).

Figure 1. Study area.

2.1.2. Satellite data

The study relies on NDVI data derived from the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Indices, specifically MOD13A3 Version 6.1 (LP DAAC, https://lpdaac.usgs.gov/), with a spatial resolution of 1 km and a temporal resolution of one month. These data are suitable for large-scale vegetation monitoring due to their consistent global coverage and long time series, making them valuable for observing broad trends over time. However, the relatively low spatial resolution of 1 km poses limitations, particularly when applied to regional or local-scale studies. At this resolution, fine-scale heterogeneity in vegetation cover - such as small patches of forest, agricultural land, or urban areas- may not be adequately captured. This can lead to a smoothing effect, where detailed variations within the landscape are averaged out, potentially obscuring localized changes in vegetation. Therefore, the results of this study should be interpreted with caution, particularly when drawing conclusions about smaller or more fragmented landscapes.

To address this limitation, the analysis focuses on broad-scale trends across Türkiye rather than small-scale, highly localized changes. While the MODIS data provide valuable insights into long-term and large-area vegetation dynamics, future studies aiming for higher spatial accuracy could benefit from incorporating higher-resolution satellite data (e.g., Landsat, Sentinel) or complementing NDVI with other vegetation indices, such as the Enhanced Vegetation Index (EVI), to reduce atmospheric and soil brightness effects.

By acknowledging the limitations of MODIS data and its implications for spatial analysis, this study aims to provide a comprehensive understanding of vegetation dynamics at the national scale, while recognizing the need for more localized studies to capture finer details of vegetation change.

2.1.3. Normalized Difference Vegetation Index (NDVI)

NDVI is calculated using the formula (NIR - Red) / (NIR + Red), where NIR represents the near-infrared band and Red represents the red band of the electromagnetic spectrum. NDVI values range from -1 to +1, with higher values generally indicating denser and healthier vegetation. A value of -1 typically corresponds to water bodies or man-made surfaces, 0 represents bare soil, and values close to +1 suggest dense green vegetation. Based on previous studies, several NDVI classes were established for the study area (Table 1). Values between -1 and 0 are generally associated with water surfaces, and values between 0 and 0.2 represent bare soil (Essaadia et al., 2022). The ranges 0.2-0.23, 0.23-0.36, 0.36-0.45, and 0.45-1 correspond to areas with varying degrees of vegetation density (Turgut & Turgut, 2022). However, it is important to note that NDVI values can vary based on local environmental conditions, atmospheric influences, and satellite sensor characteristics, and should not be interpreted as definitive vegetation types without ground-based validation data.

Table 1. NDVI class values and surface characteristics.

NDVI	Surface Characteristics	Class Values
-1-0	Water surfaces	1
0-0.2	Bare soil	2
0.2-0.23	Shrub, Sparse vegetation	3
0.23-0.36	Open grassland, Annual plants	4
0.36-0.45	Sparse vegetation, Forest	5
0.45-1	Dense vegetation, Forest	6

These classifications allow for a detailed analysis of vegetation cover across different regions of Türkiye, providing insights into the varying degrees of vegetation density.

2.1.4. Land use

MODIS, carried by the Terra and Aqua satellites and used to study Earth's surface, is a fundamental tool for environmental monitoring and remote sensing. MCD12Q1 is one of the MODIS data products, and MCD12Q1 V6 refers to Land Cover Type version 6 provided by the Moderate Resolution Imaging Spectroradiometer. This product includes various classification schemes to identify the surface cover of the Earth. These classifications are typically used to distinguish different land cover types such as vegetation, agricultural areas, water bodies, and urban regions. Satellite images partially downloaded from MCD12Q1 version 6 were combined using ArcGIS software to create a land use map of Türkiye, resulting in a map that depicts land use within the borders of Türkiye.

2.1.5. Software used

ArcGIS, a Geographic Information Systems (GIS) software developed by Esri, was used for processing all NDVI images from 2000 to 2023. ArcGIS allows for the importation of various data types, the establishment of relationships between data, geographic queries, map creation, geostatistical analysis, and database management. Additionally, XLSTAT software was used for correlation analysis to evaluate the relationships between variables within each NDVI class.

2.2. Method

In this study, NDVI data within the borders of Türkiye were obtained by downloading images for each July from the MOD13A3 Version 6.1 dataset for the years 2000-2023. Each downloaded NDVI image was imported into ArcGIS software. Using the Reclassify tool available in the ArcGIS toolbox, the NDVI values were categorized into six classes (-1 to 0, 0 to 0.2, 0.2 to 0.23, 0.23 to 0.36, 0.36 to 0.45, and 0.45 to 1). This classification represents different land cover types, including water surfaces, bare soil, and varying densities of vegetation.

Classified NDVI maps for each year were created to analyze and compare annual vegetation changes. The temporal and spatial monitoring of vegetation changes across Türkiye was facilitated through NDVI maps. To determine the distribution of the six NDVI classes over the total area from 2000 to 2023, ArcGIS software was used to extract the proportional distribution of each class. Subsequently, distribution graphs were generated in Excel to examine changes within each class for each year. Following this, correlation analysis was conducted using XLSTAT software to evaluate the relationships between variables within each NDVI class and to statistically determine the strength and significance of these relationships.

Correlation analysis is a widely used statistical method to understand the strength and direction of the relationship between two variables. Typically, the analysis is conducted using the Pearson correlation coefficient, with results ranging from -1 to +1. A positive correlation indicates a linear relationship between variables, while a negative correlation signifies an inverse relationship.

This comprehensive approach integrates geographic analysis, statistical analysis, and data visualization techniques to explore the temporal and spatial dynamics of vegetation in Türkiye using NDVI data. The use of ArcGIS for spatial analysis, Excel for data management, and XLSTAT for correlation analysis establishes a robust methodology for rigorously examining vegetation changes over time.

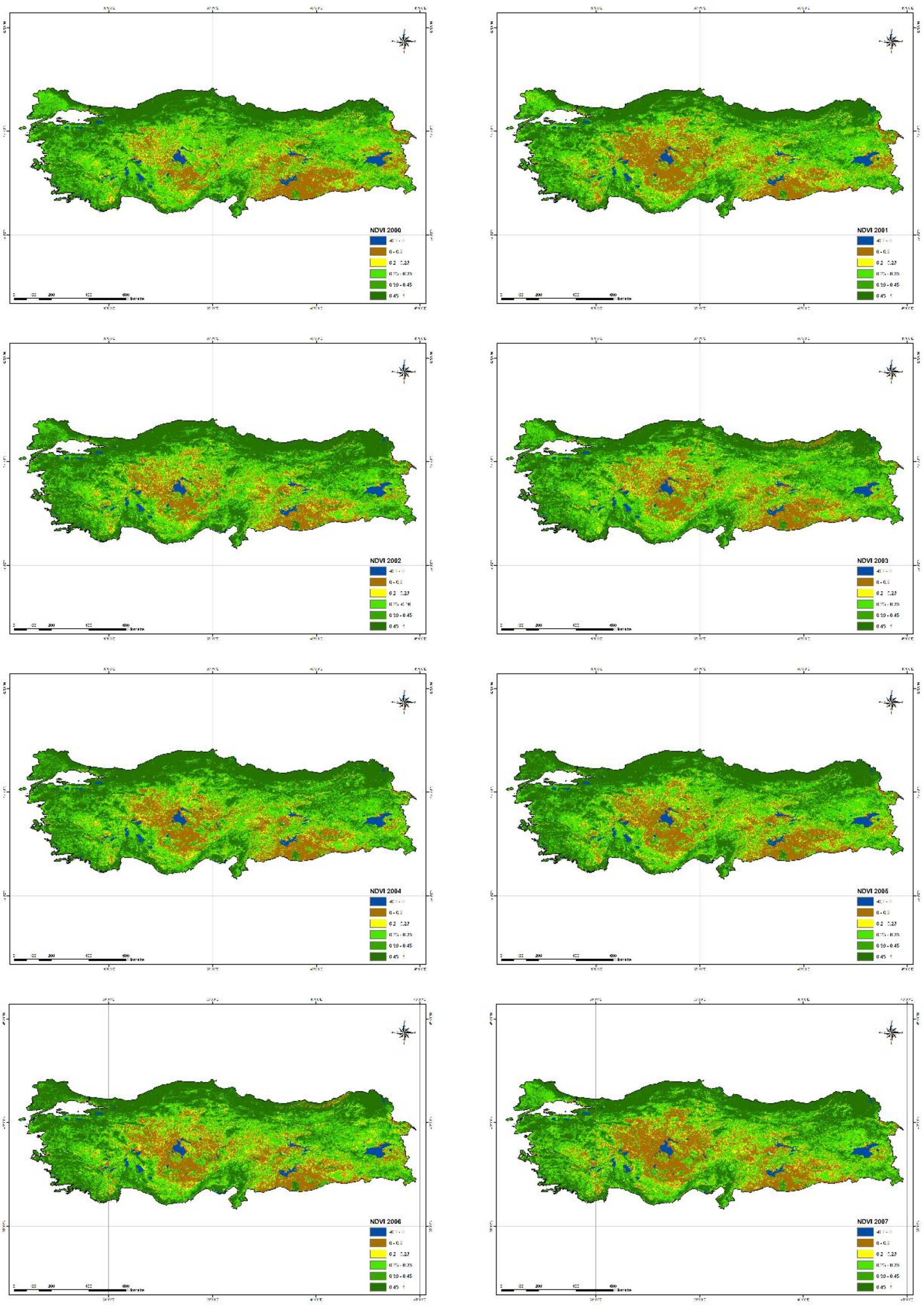
3. Results

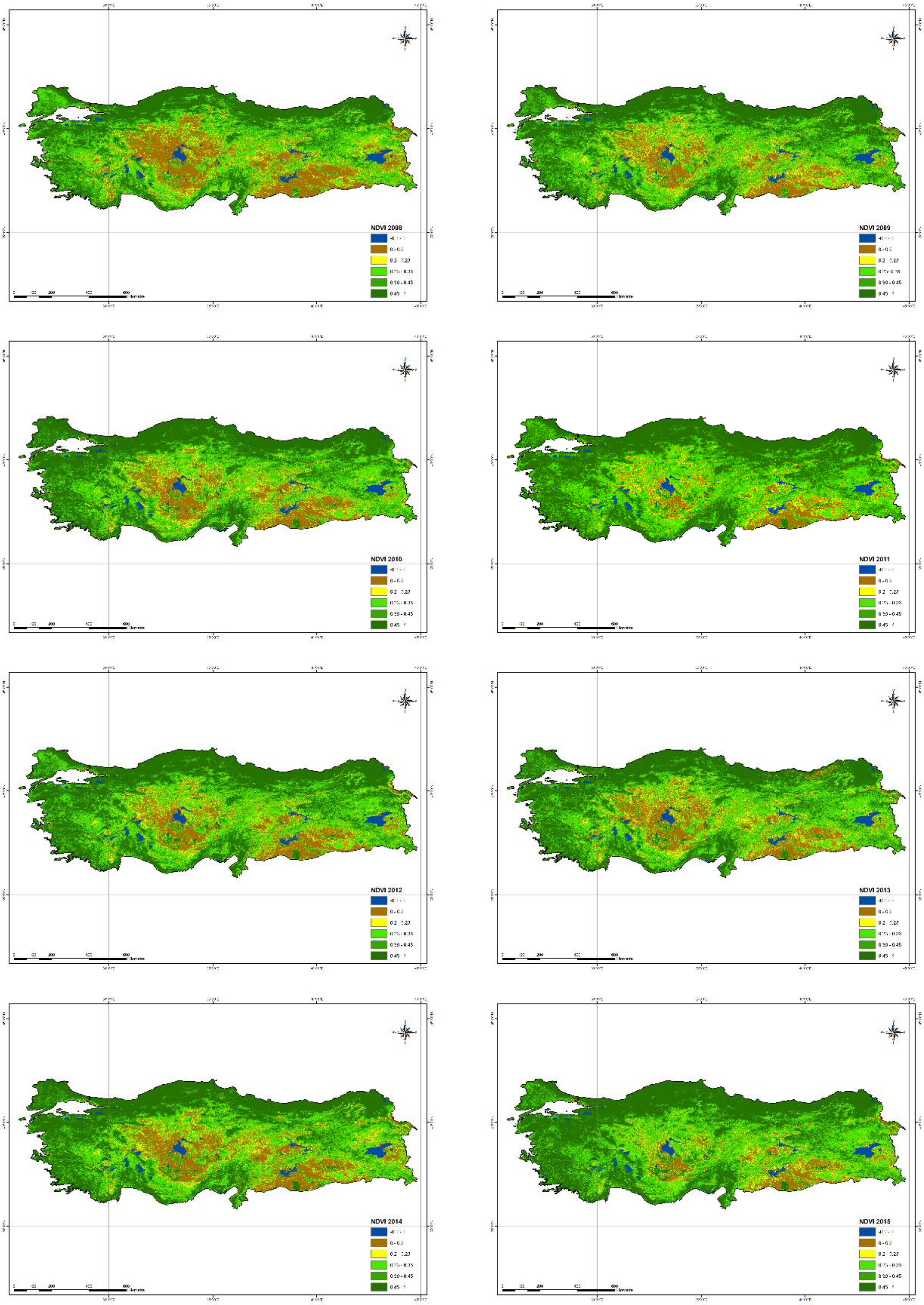
3.1. Temporal Variability of the NDVI in Türkiye

The analysis of NDVI data over the 23-year period from 2000 to 2023 reveals significant variability in vegetation density across Türkiye. NDVI serves as a crucial indicator for monitoring vegetation dynamics and environmental changes.

High NDVI values, typically associated with dense and healthy vegetation, are observed in areas such as forested regions, agricultural lands, and wetlands. These areas are represented in dark green on the NDVI distribution maps. Conversely, low NDVI values, indicative of declining or stressed vegetation, are observed in regions affected by desertification, drought, fire, agricultural land degradation, or loss of vegetation. These areas are depicted in brown or blue on the NDVI maps, representing barren lands or water surfaces, respectively (Figure 2).

The spatial and temporal dynamics of NDVI changes across Türkiye since 2000 have been thoroughly analyzed. The arithmetic mean of NDVI values over the 23-year period reveals preliminary evidence of changes in vegetation density.




NDVI 2008
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NDVI 2013
NDVI 2014
NDVI 2015

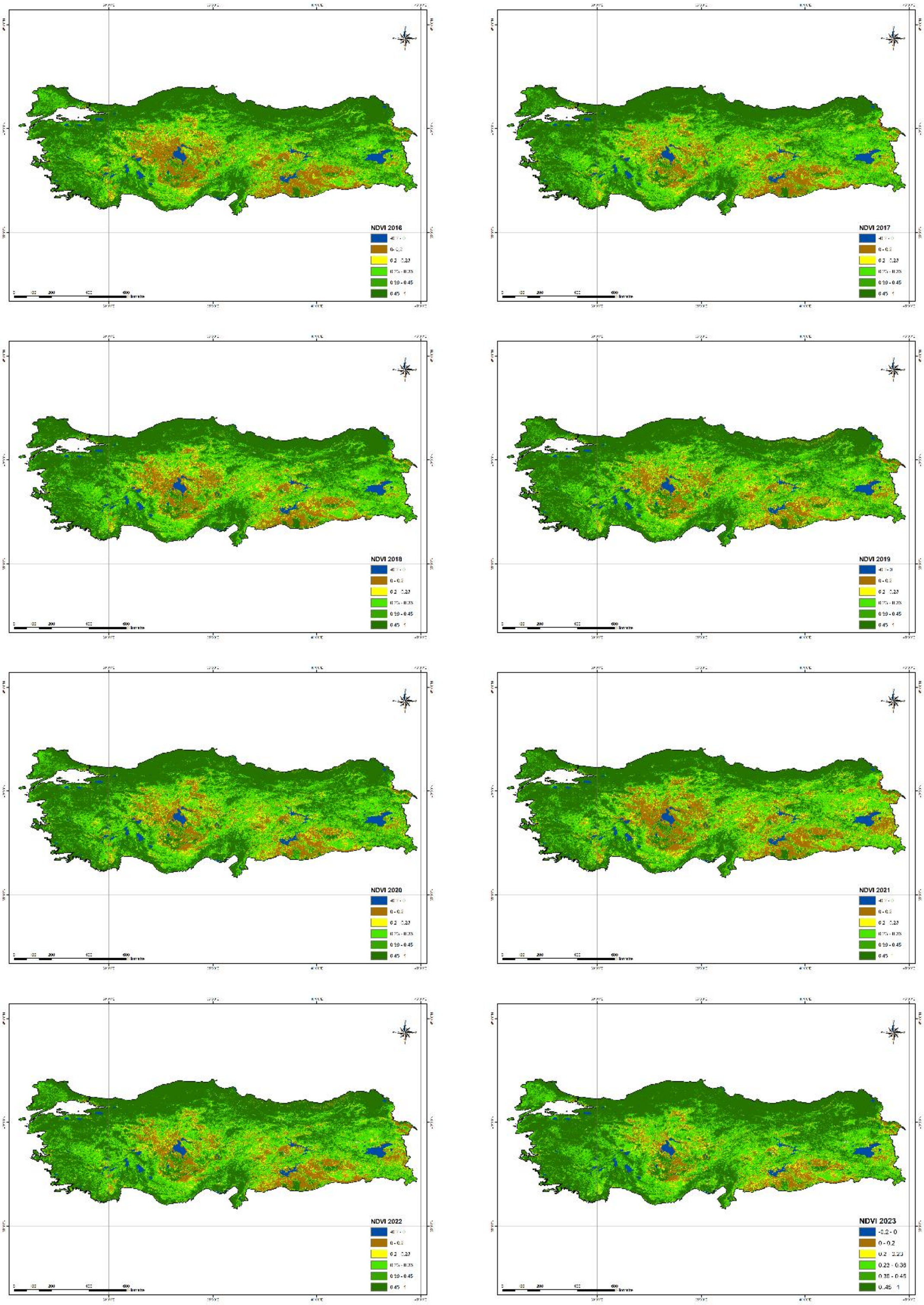

Figure 2. NDVI maps from 2000 to 2023.

When evaluating NDVI maps from 2000 to 2023 alongside land use maps, it was observed that areas with high vegetation density generally have NDVI values between 0.45 and 1. These regions are depicted in dark green on the NDVI maps. Similarly, these areas overlap with forested regions shown in various shades of green on the land use maps. Conversely, regions with low NDVI values, ranging from -1 to 0, are typically identified as water surfaces on the NDVI maps and are represented in blue on the land use maps (Figure 3).

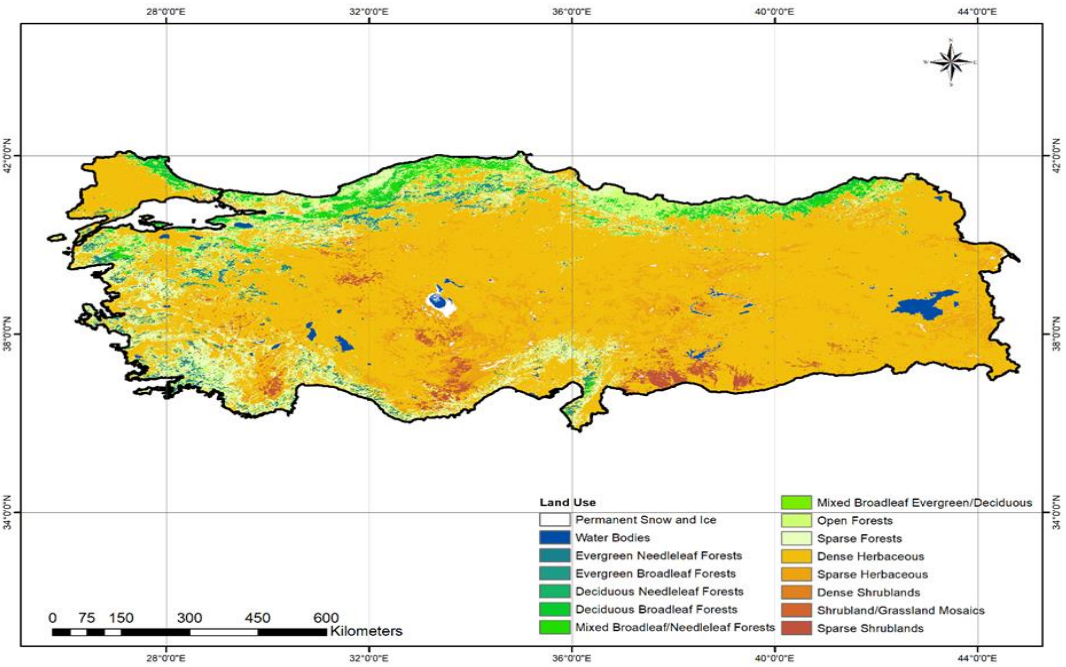

Figure 3. Land use map of Türkiye.

3.2. NDVI Distribution Graphs of Türkiye by Year

To track NDVI changes between 2000 and 2023, the maps presented in Figure 1 were utilized. Graphs depicting the average NDVI values for each class over the 23-year period were employed to analyze the annual NDVI variations. These graphs visualize periodic NDVI fluctuations to provide a clearer understanding of long-term vegetation changes (Figure 4).

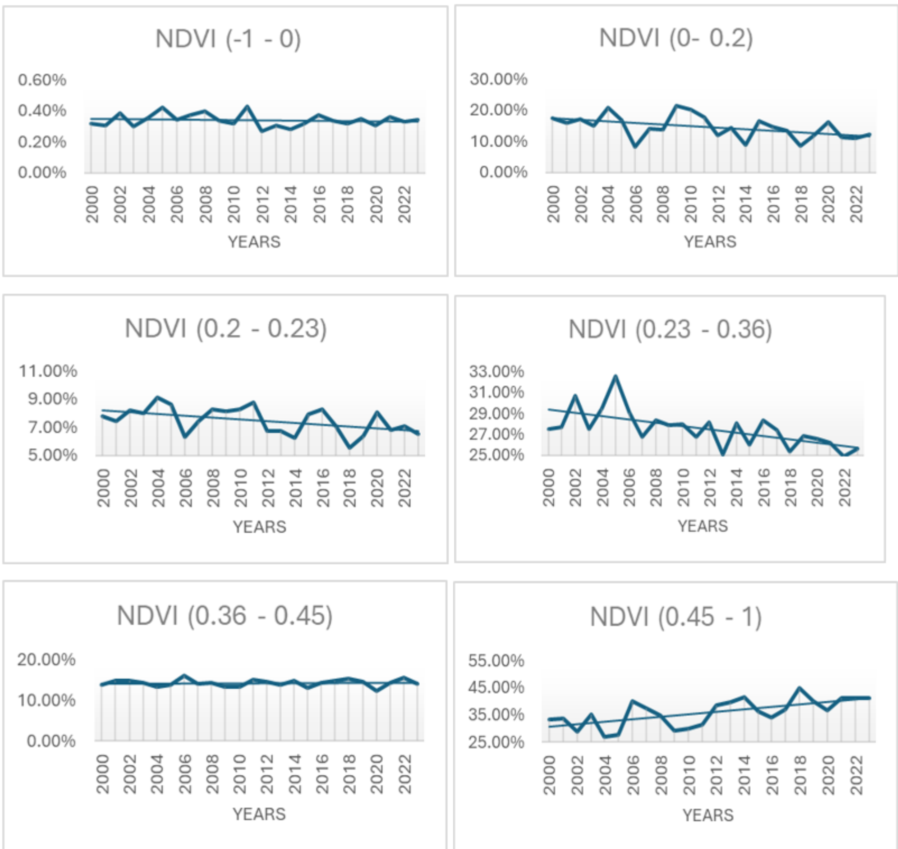

Figure 4. Annual average graphs of NDVI classes.

The presented analysis illustrates the variation in the class ranges of the Normalized Difference Vegetation Index (NDVI) over the years (-1 to 0, 0 to 0.2, 0.2 to 0.23, 0.23 to 0.36, 0.36 to 0.45, 0.45 to 1) in understanding vegetation dynamics.

The first graph represents NDVI values ranging from -1 to 0, which correspond to water surfaces. The analysis reveals a generally linear trend; however, some years exhibit increases and decreases in water surfaces, which can be associated with climatic factors such as drought or excessive rainfall.

In the analysis of NDVI data for July from 2000 to 2023, NDVI values in the 0 to 0.2 range were found to represent bare soil areas. The second graph shows a slightly decreasing trend, though not pronounced. It was observed that NDVI values exhibited irregular fluctuations, with decreases in some years and increases in others. Years with higher NDVI values may suggest the presence of annual vegetation in the environment.

The third graph indicates that the NDVI class range of 0.2 to 0.23 represents shrubs and sparse vegetation. The analysis reveals a linear decreasing trend in this graph. Similarly, the NDVI class range of 0.23 to 0.36 reflects open grasslands and annual plants, showing a similar decreasing trend as observed in the 0.2 to 0.23 range. The NDVI class range of 0.36 to 0.45 represents sparse vegetation and forest areas, showing notable changes.

When evaluating the two graphs derived from the 23-year average NDVI values for July together, it is evident that the NDVI class range of 0.2 to 0.23 corresponds to areas with shrubs and sparse vegetation, while the 0.45 to 1 range represents forested areas with dense vegetation. A distinct contrast is observed between these two graphs: a linear decreasing trend in the 0.2 to 0.23 range versus a linear increasing trend in the 0.45 to 1 range.

In the graph representing shrubs and sparse vegetation (0.2-0.23), years with increasing NDVI values correspond to years with decreasing NDVI values in the graph depicting dense vegetation (0.45-1). For example, between 2004 and 2006, there was an increase in NDVI values for shrubs and sparse vegetation, peaking in 2005 and then decreasing in 2006. During the same period, the graph for dense vegetation initially showed a decrease, followed by an increase. This pattern can be explained by increased production activities in forested areas from 2004 to 2006, leading to higher NDVI values for sparse vegetation while causing a decline in NDVI values for dense vegetation due to reduced coverage. A similar trend is observed in 2018.

This contrasting pattern indicates spatial heterogeneity in vegetation dynamics during the studied years. These observed trends reflect the dynamic nature of vegetation and underscore the importance of NDVI in monitoring and analyzing vegetation changes over time.

Table 2. Correlation analysis of NDVI classes.

Variables	-1-0	0-0.2	0.2-0.23	0.23-0.36	0.36-0.45	0.45-1
-1-0	**1**	0.225	0.472	0.395	0.101	-0.421
0-0.2	0.225	**1**	0.857	0.323	-0.694	-0.896
0.2-0.23	0.472	0.857	**1**	0.490	-0.531	**-0.907**
0.23-0.36	0.395	0.323	0.490	**1**	-0.031	-0.683
0.36-0.45	0.101	-0.694	-0.531	-0.031	**1**	0.450
0.45-1	-0.421	-0.896	-0.907	-0.683	0.450	**1**

The correlation analysis presented in table 2 highlights the relationships between different NDVI class ranges. The 0.2-0.23 range exhibits a strong positive correlation with both the 0-0.2 and 0.23-0.36 ranges, indicating that areas with moderate vegetation are consistent with other moderate vegetation ranges. Conversely, the highest negative correlation (-0.907) is observed between the NDVI class ranges of 0.2-0.23 (shrubs and sparse vegetation) and 0.45-1 (dense vegetation forest). The 0.45-1 range, representing the highest vegetation values, shows a negative correlation with most of the other ranges, suggesting that this range specifically represents dense and distinct types of vegetation. These correlations help in understanding how different NDVI classes reflect changes in vegetation density and how they relate to each other.

4. Discussion

The findings of this study demonstrate significant temporal and spatial variations in NDVI values across Türkiye from 2000 to 2023, reflecting both vegetation growth and degradation. These results are consistent with previous studies, such as Aktürk (2024), who examined NDVI trends over a 10-year period in specific biomes of Türkiye. However, the current study extends this analysis by covering a 23-year period and encompassing a broader geographical scope, thereby providing a more comprehensive assessment of long-term vegetation changes at the national scale.

In contrast to the study by Tian et al. (2024), which analyzed NDVI trends across continental Europe over a similar timeframe, the present findings emphasize unique regional factors influencing vegetation dynamics in Türkiye, including land use changes and climate variability in the Mediterranean and Anatolian regions. These results highlight the importance of accounting for local environmental conditions when interpreting NDVI trends, as broad-scale assessments may overlook critical regional differences.

Furthermore, the current study complements the work of Aktürk and Güney (2021), who analyzed vegetation cover changes in Türkiye's phytogeographic regions using CORINE datasets from 1990 to 2018. While their research focused on land cover changes, the NDVI trends observed in this study offer additional insights into the health and density of vegetation over time. The extended temporal range of this study provides a more nuanced understanding of long-term vegetation dynamics, particularly in response to increasing climate pressures and land use changes.

The detailed analysis of NDVI data from 2000 to 2023 offers valuable insights into the temporal and spatial dynamics of vegetation across Türkiye. Through the examination of NDVI trends and correlations, several key patterns and implications emerge. The NDVI maps and graphs indicate notable variability in vegetation density over the years. High NDVI values, representing dense and healthy vegetation, are predominantly associated with forested areas, agricultural lands, and wetlands, whereas low NDVI values correspond to water bodies and barren lands (Yasin et al., 2022). These fluctuations in NDVI values suggest that changes in vegetation density are driven by factors such as climatic conditions, land use practices, and environmental policies.

Correlation analyses reveal that the 0.2-0.23 NDVI class, which represents shrubs and sparse vegetation, shows a strong positive correlation with the 0-0.2 and 0.23-0.36 NDVI ranges, suggesting that areas with moderate vegetation are consistent across these categories. Conversely, the 0.45-1 NDVI class, representing dense vegetation, displays a significant negative correlation with the 0.2-0.23 range, indicating that dense vegetation areas are distinct from those with sparse vegetation. These correlations underscore how different NDVI classes reflect changes in vegetation density and highlight their interrelationships (Omar & Kawamukai, 2022).

Further analysis of annual NDVI graphs reveals that periods of increased NDVI in sparse vegetation categories often correspond to decreases in dense vegetation categories. For example, during 2004-2006, increased NDVI in shrubs and sparse vegetation aligned with decreased NDVI in dense vegetation. This trend may be linked to increased production activities or land use changes affecting vegetation density during that time.

The study also emphasizes the spatial heterogeneity of vegetation dynamics across Türkiye. The observed variations in NDVI trends across different regions are primarily driven by diverse environmental conditions, land use practices, and climate variability. These findings stress the importance of localized analyses to fully capture the complexity of vegetation changes, as broader, national-level assessments may obscure critical regional dynamics.

By situating these findings within the context of previous studies, this research significantly contributes to the broader understanding of NDVI trends in Türkiye. It offers a more detailed and comprehensive analysis of how vegetation has evolved over time, shaped by both natural factors such as climate and topography, and anthropogenic influences such as land use changes. The inclusion of long-term data spanning 23 years enables the identification of key patterns and trends that may be overlooked in shorter-term studies, offering valuable insights for future research and environmental management strategies.

This study employs NDVI data from the Terra MODIS sensor to assess vegetation cover dynamics across Türkiye. While NDVI is a widely used tool for remote sensing of vegetation, its accuracy in identifying specific vegetation types can be enhanced through the integration of ground truth (in-situ) data. Ground truth data provide direct field observations that validate remote sensing classifications, thereby improving the precision of NDVI-based analyses.

However, due to the large spatial and temporal scope of this study, no ground-based validation data were available to directly confirm the association between NDVI values and specific vegetation types in the study area. The absence of in-situ data represents a methodological limitation, as NDVI values alone may not fully capture fine-scale vegetation variability or differentiate between similar land cover types.

Future studies would benefit from the integration of ground truth data to validate NDVI classifications, particularly when investigating specific vegetation types or localized ecosystems. Such data would enhance the reliability of the results and allow for more precise conclusions about the relationship between NDVI values and vegetation characteristics. Furthermore, combining NDVI with additional remote sensing indices and incorporating local environmental conditions would further strengthen the robustness of the analysis.

By acknowledging this limitation, the study highlights the importance of ground-based validation in remote sensing research and emphasizes the need for more localized and field-validated analyses in future studies.

5. Conclusion

This study provides a comprehensive analysis of Türkiye's vegetation cover dynamics from 2000 to 2023, utilizing MODIS NDVI data to assess temporal and spatial trends across diverse geographical regions. The findings reveal significant variations in NDVI values, highlighting both vegetation growth in forested areas and degradation in regions impacted by factors such as land use changes and climate variability. The spatial heterogeneity observed in vegetation dynamics underscores the importance of localized analysis to understand the complex interactions between environmental conditions and anthropogenic activities.

In comparison to previous studies, this research offers a broader scope by covering a 23-year period and analyzing NDVI trends at the national scale, filling a notable gap in the literature on Türkiye's vegetation dynamics. The results align with other studies that examined shorter timeframes or specific regions, while also providing new insights into long-term trends and the drivers behind vegetation changes.

The study emphasizes the value of NDVI as a tool for monitoring vegetation health and density, while also acknowledging the limitations of using a single index. Future research should aim to incorporate additional remote sensing indices and ground-based validation data to enhance the accuracy and reliability of vegetation assessments. Furthermore, the findings from this study can contribute to the development of more effective land management and conservation strategies, particularly in regions vulnerable to climate change and unsustainable land use practices.

In conclusion, the long-term monitoring of vegetation dynamics across Türkiye provides a critical foundation for understanding how natural and human-induced factors are shaping the country's ecosystems. The insights gained from this research can inform future studies and policy decisions aimed at preserving and managing Türkiye's diverse vegetation cover in the face of environmental challenges.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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