

Examining the Land Use and Land Cover Change Using Vegetation Indices in Muğla, Türkiye

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Abstract

Land use and land cover (LULC) changes are influenced by various driving factors over time, with urbanization being a significant contributor among others. Detecting these changes is crucial for effective land planning and management. Vegetation indices play a vital role in defining urban environments and can enhance traditional LULC change analyses. This study aims to determine whether spectral analysis focusing on vegetation indices provides significant insights into detecting LULC changes, thereby complementing conventional methods. Landsat imagery from the years 2013 and 2023 and remote sensing techniques were used to analyze LULC changes. Key vegetation indices used in this study include the Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), and Green Chlorophyll Index (CL Green). The results indicate that the gradual degradation of natural areas due to urbanization, along with the rapid destruction caused by wildfires, has significantly impacted the natural landscapes of Muğla. While decadal changes in LULC are commonly studied, natural disasters such as forest fires can dramatically alter extensive land cover within a single year. Therefore, there is a need to shift the research focus to monitoring annual changes. Such an approach can improve the accuracy of land planning and support the development of sustainable and green climate-resilient cities. This study advocates the incorporation of annual vegetation monitoring and LULC changes into land management practices. Future research should emphasize more short-term monitoring to effectively address the dynamic nature of LULC changes and their environmental impacts.

Keywords

Land use and land cover change (LULCC), land use planning, remote sensing, vegetation indices

1. Introduction

Detecting land use and land cover change is crucial for effective land management, as well as for the promotion of sustainability and the mitigation of climate change. Land use and land cover (LULC) serve as major catalysts for changes in global climate patterns and environmental conditions (Khalid, 2024). These shifts can result in the degradation of natural areas, biodiversity loss, and the disruption of environmental balance. Investigating the dynamic changes in vegetation and the factors that influence them is of significant practical importance for monitoring the quality of regional ecological environments and enhancing the structure and function of ecosystems (Zhang et al., 2023).

Land use and land cover (LULC) changes are growing increasingly complex, driven by multiple factors. LULC change results from the interplay of various factors, including natural elements and political influences (Wu, 2022). Also, socio-economic factors, including population and economic conditions, have played a vital role in the change of LULC (Wang and Yang, 2019). Remote sensing and geographic information systems (GIS) are essential tools for generating maps and for examining land use and land cover change in different scales (Mane et al., 2024). These scales include as the country (Ustaoglu and Aydinoglu, 2019), basin (Berihun et al., 2019; Nyatuame et al., 2020), city (Njoku and Tenenbaum, 2022), peninsula (Krivoguz et al., 2023), and district (Islam and Ul-Zannat, 2023).

Previous studies serve various purposes, including environmental assessment (Berihun et al., 2019; Nyatuame et al., 2020), quantitative assessment (Njoku and Tenenbaum, 2022), LULC modeling (Wang and Maduako, 2018; Gaur and Singh, 2023) using RS and GIS tools. Supervised classification of satellite images is a common method for mapping and evaluating land use changes (Berihun et al., 2019). Also, land change maps should include an accuracy assessment that provides a clear description of the information such as sampling design, an error matrix, and descriptive accuracy metrics such as user's, producer's, and overall accuracy (Olofsson et al., 2013).

Vegetation indices are instrumental in LULC analyses, as they allow for detailed assessments of vegetation health and density, offering deeper insights into the extent and impact of environmental changes. Vegetation indices like NDVI are primarily affected by a range of variances in natural phenomena and anthropogenic activities (Zhang et al., 2023). Normalized Difference Vegetation Index (NDVI) measures the greenness of vegetation, provides insight into vegetation density, and allows for the assessment of changes in plant health (USGS, 2024). The Green Normalized Difference Vegetation Index (GNDVI) method is a vegetation index for estimating photosynthetic activity and the Chlorophyll Index (CL Green) method is a vegetation index for estimating the chlorophyll content in leaves using the ratio of reflectivity in the NIR and green bands (ESRI, 2024). These indices were utilized to enhance the understanding of vegetation dynamics concerning LULC changes.

This study aims to determine whether spectral analysis focusing on vegetation indices provides significant insights into detecting LULC changes, thereby complementing conventional methods. In addition to examining land use and land cover changes, shifts in NDVI, GNDVI, and Chlorophyll indices were also analyzed in Muğla between 2000 and 2023. This integration greatly enhances traditional methods, contributing to more informed and sustainable land use decisions. Muğla was selected for this study as it hosts some of Turkey's most valuable ecosystems, including Mediterranean vegetation. Consequently, this study centers on two primary research questions: How has land use and land cover changed in Muğla from 2013 to 2023? and How have vegetation index values changed in Muğla over the same period?

By addressing these questions, the research aims to deepen our understanding of LULC dynamics and vegetation trends, providing valuable insights for sustainable planning in the region.

2. Data and Methodology

2.1. Case study

Muğla is located in the southwestern part of Türkiye. Muğla is bordered on the western side by the Egean Sea, on the northern by the Aydın province, on the southeast by Antalya, and on the east by Burdur and Denizli. Muğla's population was 1,161,702 in 2023 (TURKSTAT, 2024).

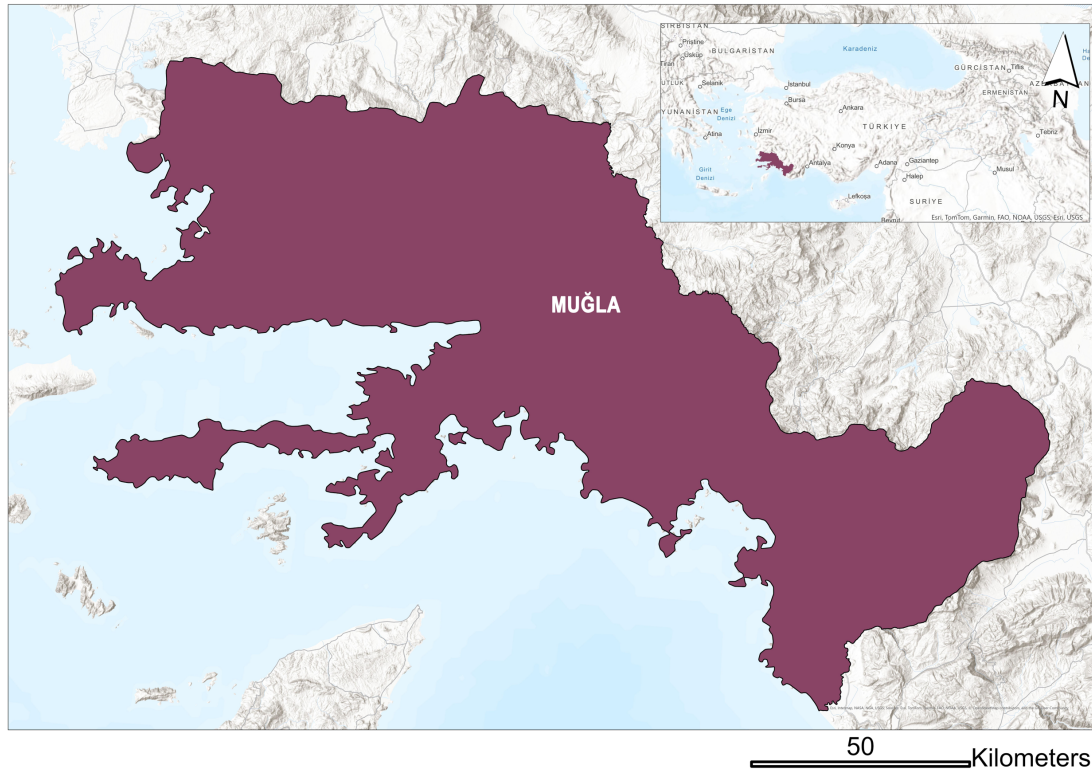


Figure 1. Location of Case Study

2.2. Methodology

In this study, Geographic Information System (GIS) and remote sensing techniques were employed to analyze land use and land cover (LULC) changes in Muğla. Landsat satellite images for the years 2013 and 2023 were obtained from the US Geological Survey (USGS, 2024), with all images captured in July to enhance classification accuracy (Cloete et al. 2024). To ensure a comprehensive representation of the study area, a cloud cover filter was applied, and multiple images from the same year were mosaicked together. This approach facilitated a more accurate and detailed assessment of the LULC dynamics in the Muğla region over the selected periods. The images were then clipped to the province borders, and an infrared composite image was generated for each year.

Following the pre-processing stage, the images were classified into six distinct land use and land cover (LULC) categories: forest, shrubland, agriculture, artificial areas, bare land, and water bodies. An accuracy assessment was conducted for each relevant land cover class, aiming to achieve an acceptable accuracy threshold of 80% or higher (Deng et al., 2009). In the accuracy assessment process, the study adhered to

the “rule of thumb” to commonly accepted guidelines for generating accuracy points (Atay Kaya and Kut Görgün, 2020).

Silva et al. (2020) emphasized that different vegetation indices exhibit varying levels of performance in identifying land cover classes, highlighting the importance of using multiple indices in a comparative approach to improve classification accuracy. Therefore, the use of three different vegetation indices was proposed in this study to enhance the reliability of land cover classification. In addition to the LULC analysis, a comprehensive examination of vegetation cover changes was conducted using the NDVI, GNDVI, and Green Chlorophyll indices in ArcGIS Pro Imagery Indices tools. After completing these steps, a ten-year change detection analysis between 2013 and 2023 was conducted in Muğla.

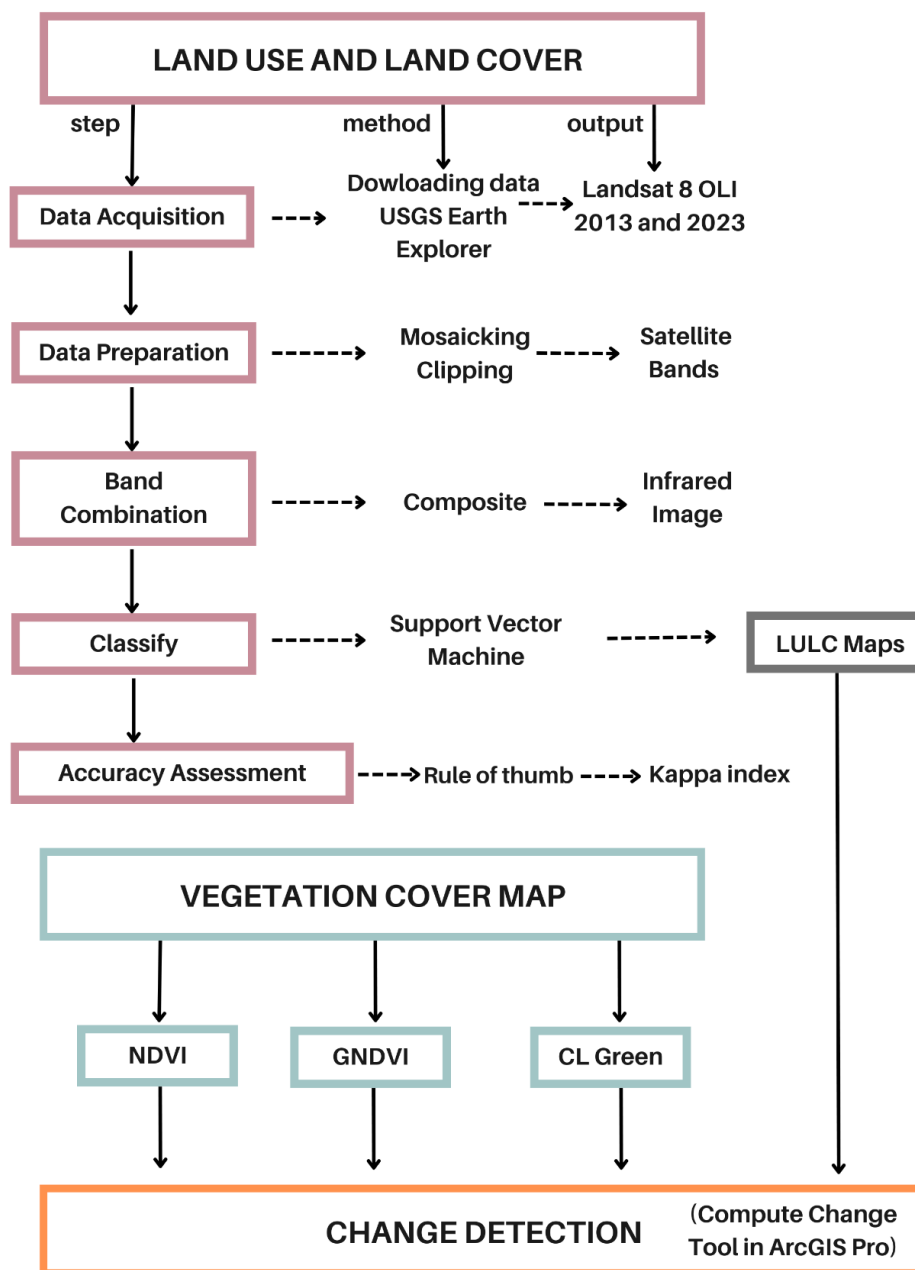


Figure 2. Flowchart

3. Results

3.1. Land use and land cover change

LULC maps were prepared for Muğla in 2013 and 2023 (Figure 3). The results revealed a decrease of 18% in agricultural land, 49% in artificial areas, and 16% in water bodies, while barren land and forest areas increased by 7% and 4%, respectively. It is important to note that "artificial areas" include not only settlements but also other human activities such as mining. Therefore, the decrease in artificial areas does not necessarily indicate a decrease in urbanization activities.

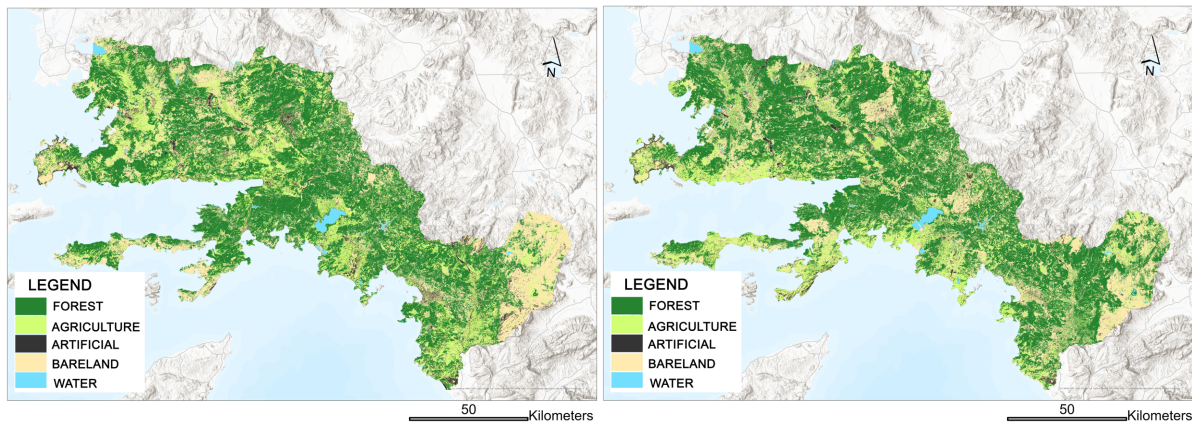


Figure 3. Land use and land cover map in 2013 and 2023

3.2. Accuracy assessment of LULC

The accuracy score and kappa statistic were used to evaluate the performance and reliability of the model. A total of 50 points per class, for a total of 250 points per year, were scored on the card (Figure 4). According to the evaluation results, the model showed that the model achieved an accuracy of 0.85 and a kappa index of 0.82 in 2013, and the accuracy of the model was 0.84 with a kappa index of 0.80 in 2023. Therefore, the results indicate that these values are acceptable, as they exceed the threshold of 0.8.

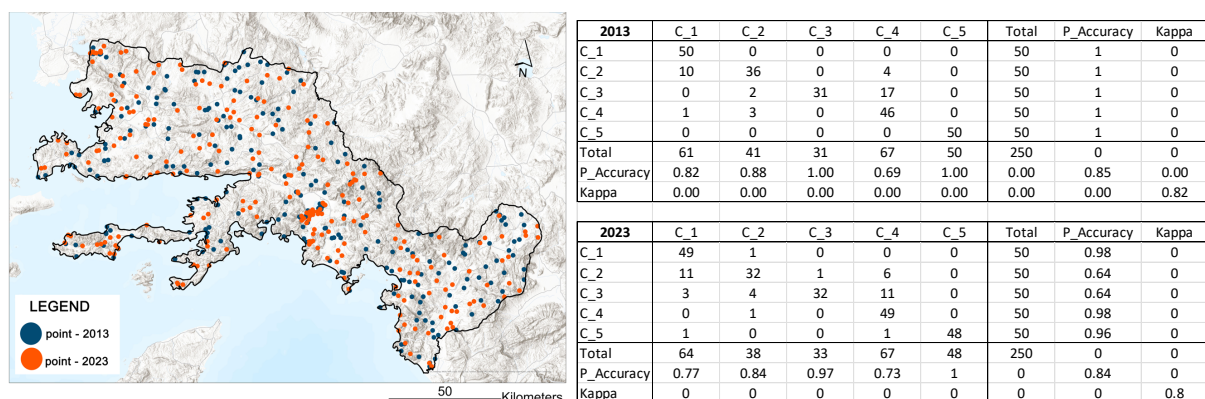


Figure 4. Accuracy assessment points and accuracy matrix

These four major transitions illustrate a dynamic landscape characterized by significant shifts among forest, barren, and agricultural areas. The conversion from forest to barren land (830 km²) is particularly notable, indicating substantial deforestation. Interestingly, an almost equal area of barren land is transitioning back to forest, suggesting efforts toward reforestation or natural regeneration. The transitions from agriculture to barren land (751 km²) and from agriculture to forest (664 km²) also represent substantial land use changes, reflecting possible land abandonment or shifting priorities toward habitat restoration. However, a more detailed analysis of vegetation change using vegetation indices provides additional insights, as shown in the results below (Figure 5).

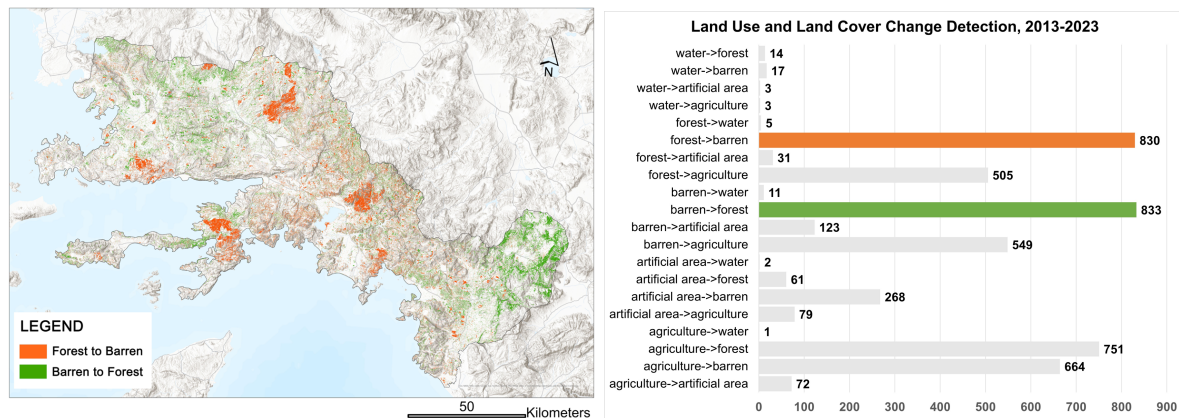


Figure 5. Land use and land cover change from 2013 to 2023 (km²)

3.3. Vegetation cover change

In 2013, the maximum value of the NDVI was 0.534, the mean value was 0.189, and the minimum value was -0.164. The NDVI values for the year 2023 are as follows: a maximum of 0.525, a mean of 0.189, and a minimum of -0.442. The stability of the mean NDVI value indicates a balance in land cover changes, whereby increases in vegetation in some areas may offset declines in others. Nevertheless, the 63% reduction in the minimum NDVI value suggests a notable decline in vegetation health or cover at the local level. In 2013, the GNDVI exhibited a maximum value of 0.488, a mean value of 0.209, and a minimum value of -0.227. By 2023, the maximum GNDVI exhibited a slight decline, reaching 0.476, while the mean value demonstrated a marginal decrease, falling to 0.203. Notably, the minimum value experienced a notable reduction, reaching -0.520. The most notable change is the 56.35% decrease in the minimum GNDVI value. In 2013, the Green CI exhibited a maximum value of 1.905, a mean value of 0.537, and a minimum value of -0.370. By 2023, the maximum Green CI value had decreased slightly to 1.813, the mean value had declined marginally to 0.520, and the minimum value had decreased significantly to -0.685. The most notable change is the 45.99% decrease in the minimum Green CI value, which declined from -0.370 to -0.685.

As a result, the minimum values of the NDVI, GNDVI, and Green CI indices demonstrated a significant decline, indicating a severe deterioration in vegetation health in specific locations. These findings underscore the necessity for a targeted spatial analysis to identify the areas experiencing the most pronounced decline.

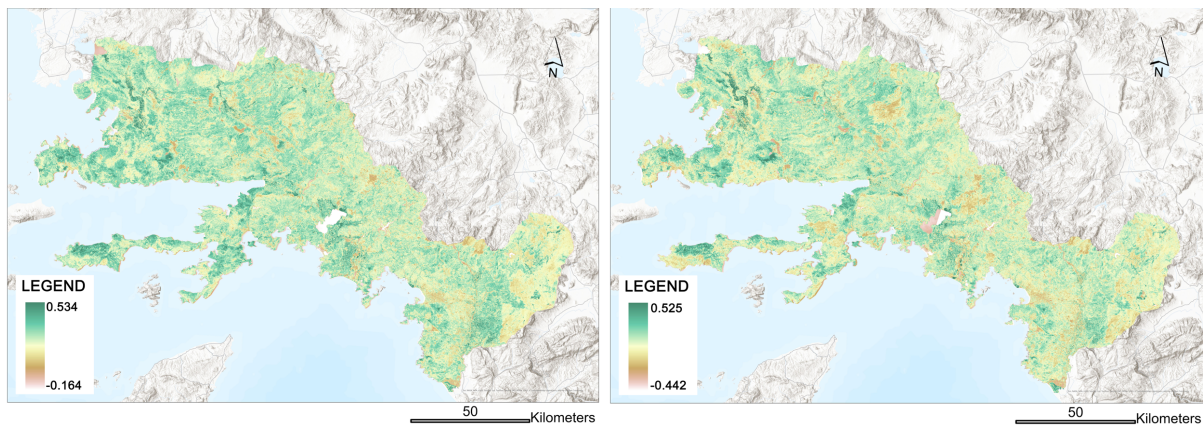


Figure 6. NDVI analysis in 2013 and 2023

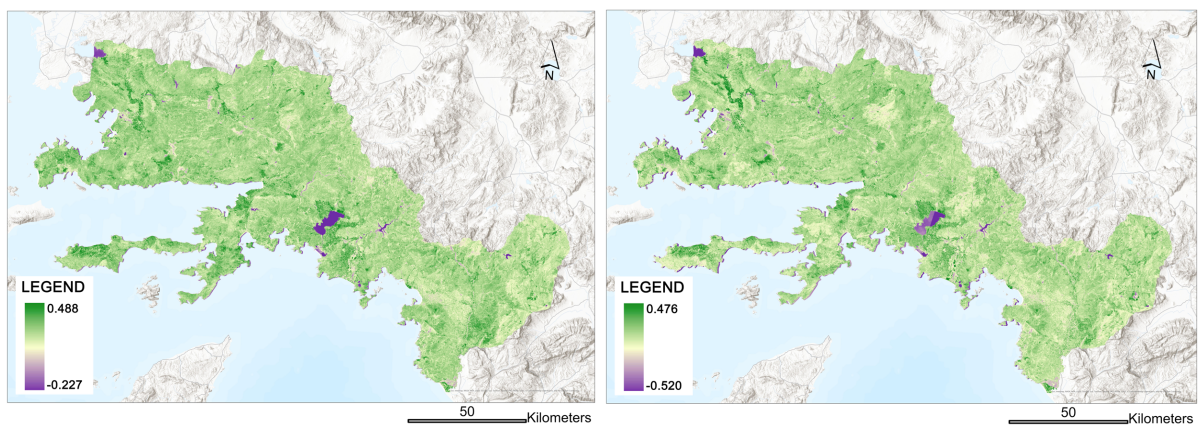


Figure 7. Green NDVI analysis in 2013 and 2023

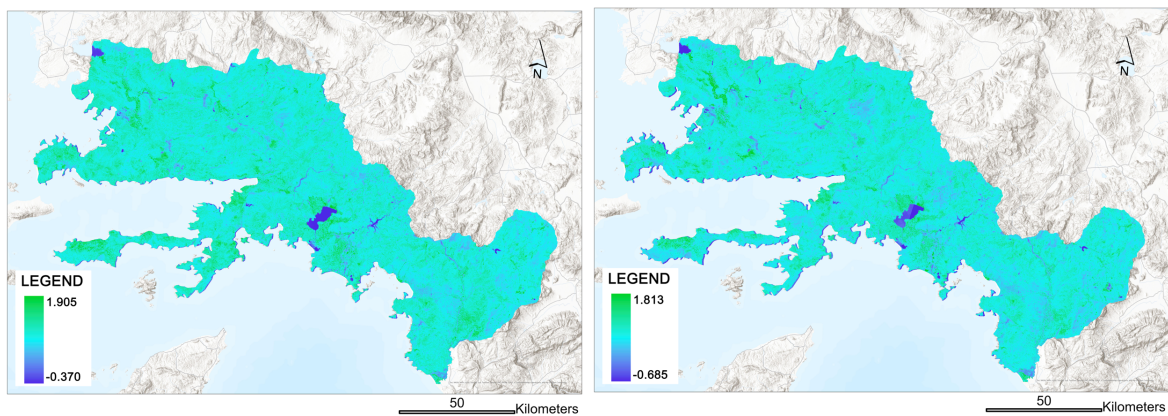


Figure 8. Green Chlorophyll analysis in 2013 and 2023

A comprehensive spatial analysis was conducted to evaluate the interannual variations in index values across all indices (Figure 9-11). Within these change detection analyses, negative values denote a decline in the measured indices from 2013 to 2023. Notably, significant declines were identified in four distinct zones, highlighting that the reductions are not uniformly distributed throughout the entire study area.

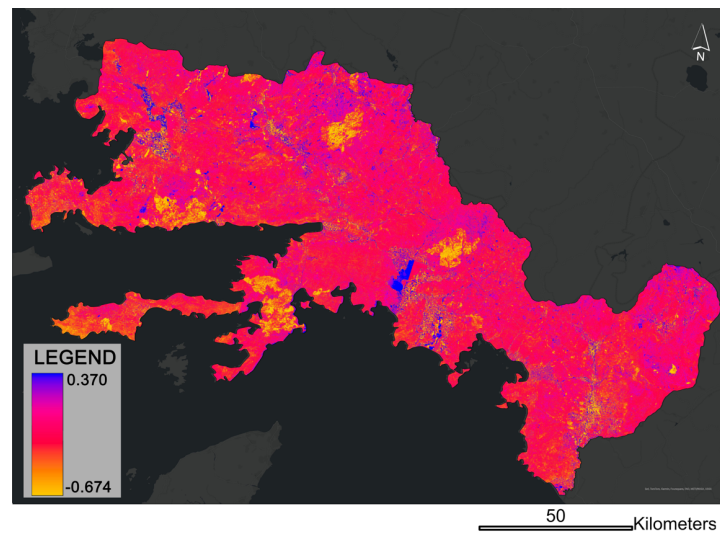


Figure 9. Spatiotemporal Change in Vegetation Cover Based on NDVI (2013–2023)

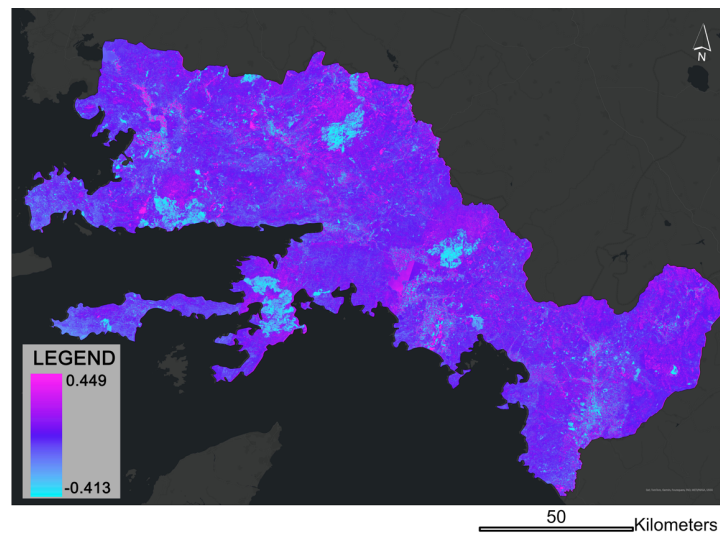


Figure 10. Spatiotemporal Change in Vegetation Cover Based on GNDVI (2013–2023)

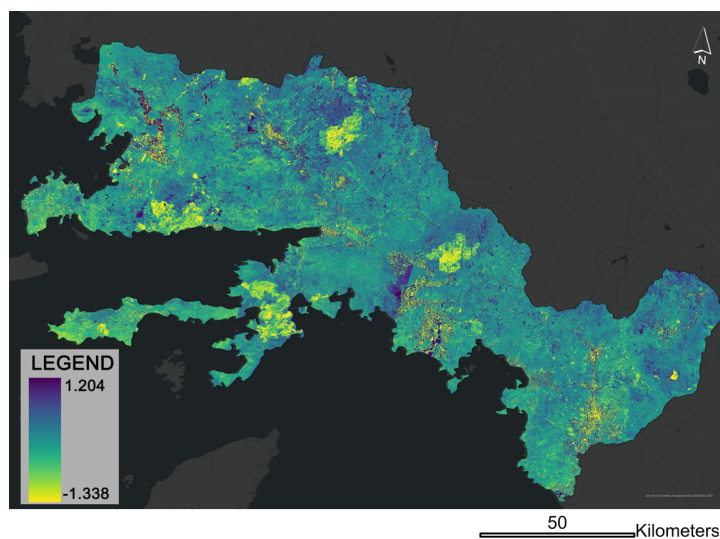


Figure 11. Spatiotemporal Change in Vegetation Cover Based on CL Green (2013–2023)

As demonstrated by the forest cover change analysis presented by Global Land Analysis, these four zones were identified as significant areas of deforestation by 2022 (Figure 12). The marked decline in vegetation cover across these region, evident in areas undergoing a transition from forested ecosystems to barren landscapes, has necessitated an assessment of the potential for wildfires. An examination of data provided by NASA confirmed that wildfire events occurred in this region on August 3, 2021 (Figure 13).

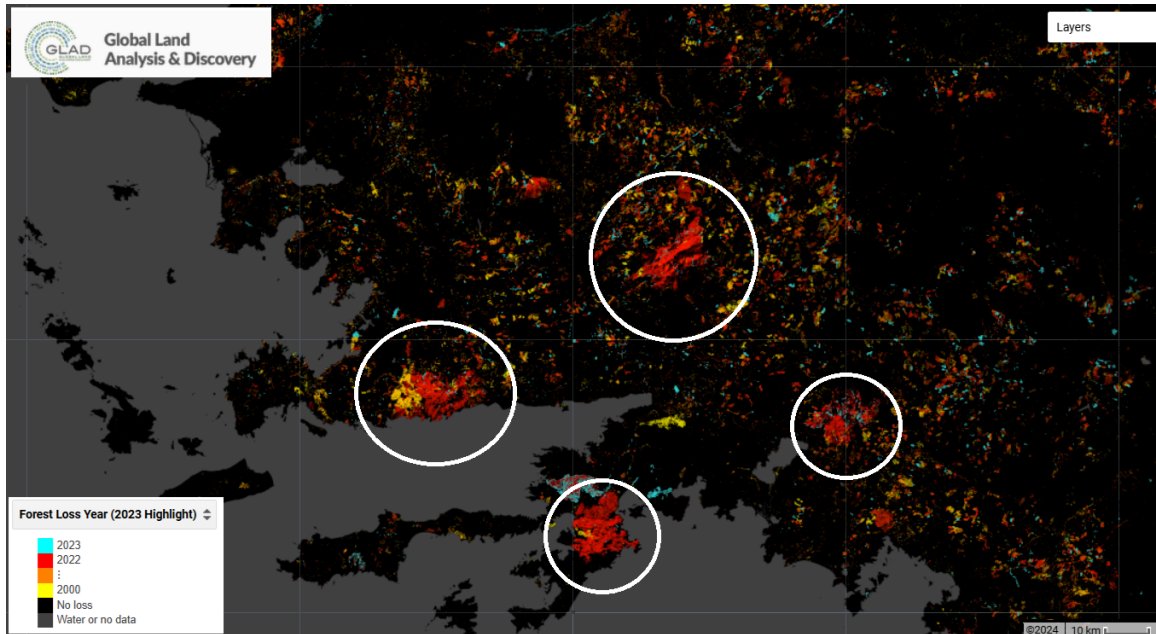


Figure 12. Density of Forest Loss in 2023 in Muğla Province (Global Land Analysis & Discovery, 2024)

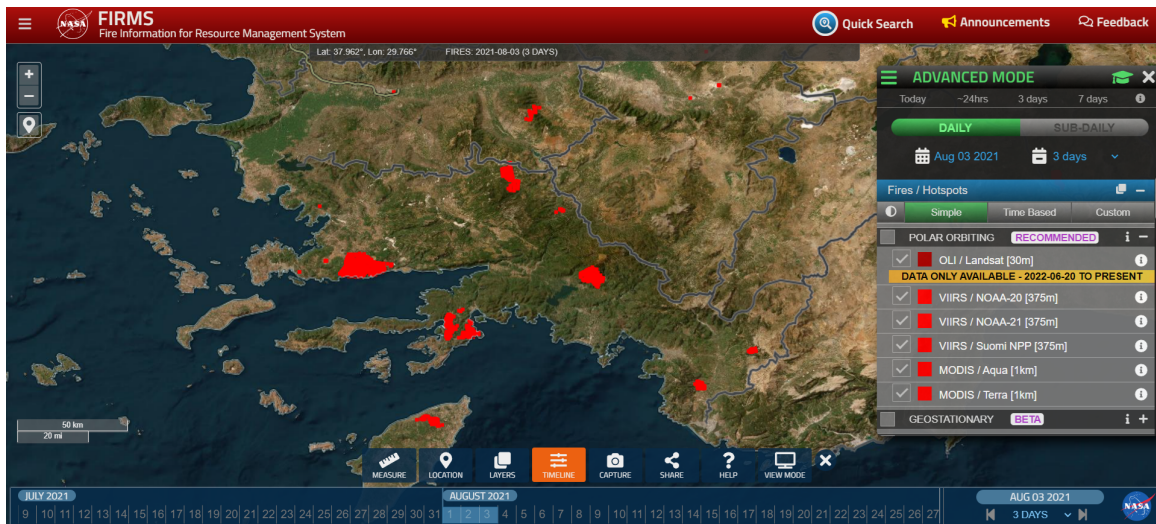


Figure 13. Fire Hotspots Detected in Muğla on 3 August 2021 According to NASA FIRMS Data (2024)

4. Conclusion

In the study, changes in land cover were examined using both LULC dynamics and vegetation indices. Although the areas transitioning from forest to bare land and from bare land to forest are similar in extent, vegetation index analyses reveal significant changes at minimum values. Specifically, four zones represent spatial variability underscoring the necessity for targeted interventions in the most affected regions to address vegetation degradation effectively. When examining the causes of change in these four regions, wildfires were identified as the primary factor. This finding emphasizes that wildfires are significant drivers of land use and land cover (LULC) changes in Muğla. This conclusion aligns with findings by Parente et al. (2023), who also identified wildfires as a key factor in LULC dynamics. However, it is different from earlier studies, such as Sejati et al. (2018), which primarily attributed deforestation to urbanization pressures rather than wildfire activity.

The stability in the mean NDVI, GNDVI, and Green CI indices values hints at a general equilibrium in vegetation cover changes across the studied region. However, the sharp decline in the minimum values underscores the presence of critical areas undergoing substantial vegetation degradation. To address these localized issues effectively, it is essential to conduct detailed spatial analyses to identify and target the most affected regions. The LULC findings supported by vegetation indices have shown considerable significance in this regard. This approach improves the clarity and reliability of LULC assessments and provides a more detailed understanding, thereby enhancing interpretability and insight. Consequently, using vegetation indices reveals critical spatial details about vegetation quality changes that may not be evident in standard LULC analyses.

Wildfires have multifaceted effects on forests, leading to changes in vegetation structure, risks to biodiversity, and the release of greenhouse gases, such as carbon dioxide, which intensify climate change (Gajendiran et al., 2024). Understanding land use and land cover (LULC) changes is essential for guiding sustainable development goals and implementing effective climate change adaptation strategies. Comprehensive knowledge of LULC dynamics promotes sustainable agricultural practices, improved land management, and biodiversity conservation. Additionally, consistent monitoring of land use is crucial for disaster management, enabling the identification of at-risk areas, enhancing disaster preparedness, and mitigating socio-economic impacts. LULC research also addresses environmental justice issues by revealing disparities in resource distribution and exposure to risks. Globally, forests hold the highest carbon stocks, followed by croplands and wetlands, highlighting the importance of conserving these critical ecosystems.

Current regional vegetation degradation assessment methods based on long-term data have key limitations, including low resolution and dependence on complex vegetation indicators (Sun et al., 2019). Looking forward, future research on land change monitoring will increasingly rely on advanced technologies such as remote sensing, machine learning, and big data analytics to achieve high accuracy. While urban expansion remains a significant driver of land change, other factors like wildfires also play a crucial role and must be integrated into monitoring frameworks. Relying solely on decades of land use change data may not provide a comprehensive picture, as it can overlook anomalies and non-linear trends. Future studies should consider different temporal scales, including vegetation cover alongside land use and land cover. By adopting these approaches, stakeholders can better manage land resources, support sustainable development, and enhance resilience against environmental challenges.

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