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Assessing the Impact of Air Pollution on Plant Health in Tokat Province Using Sentinel-2 Imagery and Google Earth Engine

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Abstract

This study investigates the relationship between air quality and plant health in Tokat province from 2019 to 2022. Vegetation health was assessed using satellite-based indices, including the Enhanced Vegetation Index (EVI), Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), and Normalized Difference Water Index (NDWI), derived from Sentinel-2 imagery on the Google Earth Engine platform. Air pollution was evaluated using Sentinel-5P satellite data, focusing on NO_2 (Nitrogen Dioxide), CO (Carbon Monoxide), and O_3 (Ozone) levels.In the correlation analysis, a moderate positive correlation was observed between NO2 levels and plant health indices (EVI, NDVI, NDMI, and NDWI) (R = 0.65, R = 0.62, R = 0.66, R = 0.61). This indicates that plant health is adversely affected by increasing air pollution. A weak relationship was observed between CO and O3 parameters and plant indices. All data were obtained from satellite images. The results show that especially NO_2 has moderate negative effects on plant health in Tokat province. This research emphasises the necessity of developing environmental sustainability strategies and increasing efforts to combat air pollution in Tokat province. This study demonstrates that modern remote sensing technologies such as Google Earth Engine and Sentinel-5P can be effectively used in environmental monitoring and analyses. The findings provide important contributions to the shaping of environmental policies and management strategies at both regional and national levels. Future studies can develop a more comprehensive understanding of the relationship between air pollution and plant health to protect ecosystem health.

Keywords: *Air pollution, plant health, Sentinel-2, Google Earth Engine, NDVI.*

Tokat İlinde Hava Kirliliğinin Bitki Sağlığı Üzerindeki Etkisinin Sentinel-2 Görüntüleri ve Google Earth Engine Kullanılarak Değerlendirilmesi

Özet

Bu çalışmada, 2019-2022 yılları arasında Tokat ilindeki hava kalitesi ile bitki sağlığı arasındaki ilişki incelenmiştir. Bitki sağlığı, Google Earth Engine platformu üzerinden elde edilen Sentinel-2 uydu verileriyle hesaplanan Enhanced Vegetation Index (EVI), Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI) ve Normalized Difference Water Index (NDWI) gibi uydu tabanlı indeksler kullanılarak değerlendirilmiştir. Hava kirliliği, Sentinel-5P uydu verilerinden elde edilen NO_2 (Azot Dioksit), CO (Karbon Monoksit) ve O_3 (Ozon) parametreleri ile analiz edilmiştir. Korrelasyon analizinde, NO_2 seviyeleri ile bitki sağlığı indeksleri (EVI, NDVI, NDMI ve NDWI) arasında orta düzeyde bir pozitif ilişki gözlemlenmiştir (R = 0.65, R = 0.62, R = 0.66, R = 0.61). Bu durum, artan hava kirliliğinin bitki sağlığını olumsuz yönde etkilediğini göstermektedir. CO ve O_3 parametreleri ile bitki sağlığı indeksleri arasında zayıf bir ilişki gözlemlenmiştir. Tüm veriler, uydu görüntülerinden elde edilmiştir. Sonuçlar, Tokat ilinde özellikle NO2'nin bitki sağlığı üzerinde orta derecede olumsuz etkileri olduğunu göstermektedir. Bu araştırma Tokat ilinde çevresel sürdürülebilirlik stratejilerinin geliştirilmesi ve hava kirliliği ile mücadeleye yönelik çabaların arttırılmasının gerekliliğini vurgulamaktadır. Bu çalışma, Google Earth Engine ve Sentinel-5P gibi modern uzaktan algılama teknolojilerinin çevresel izleme ve analizlerde etkin bir şekilde kullanılabileceğini ortaya koymaktadır. Bulgular hem bölgesel hem de ulusal düzeyde çevre politikalarının ve yönetim stratejilerinin şekillenmesine önemli katkılar sağlamaktadır. Gelecekteki çalışmalar, ekosistem sağlığını korumak için hava kirliliği ile bitki sağlığı arasındaki ilişkiye dair daha kapsamlı bir anlayış geliştirebilir.

Anahtar Kelimeler : *Hava kirliliği, bitki sağlığı, Sentinel-2, Google Earth Engine, NDVI.*

1. Introduction

Air quality is critical for the protection of ecosystems and human health. Air pollution is a major environmental problem that negatively affects not only human health but also vegetation and natural ecosystems. Tokat province, with its rich vegetation and agricultural potential, is one of the most important regions of Turkey. Therefore, analyzing the relationship between air quality and plant health in the region is of great importance for environmental sustainability. Understanding how air quality impacts vegetation health can guide future agricultural strategies, land use management, and environmental protection efforts, providing vital insights for local policymakers and stakeholders.

Various factors influence agricultural productivity, including soil quality, water pH levels in both irrigation systems and growing media, climate variability, and pest infestations. The cumulative impact of these factors can negatively affect crop health, disrupt planting schedules, and alter cropping patterns [1-4]. However, air pollution, as an often-overlooked factor, can compound these challenges by imposing additional stress on vegetation, further exacerbating the difficulties faced by farmers and the natural environment in Tokat.

The spectral reflectance characteristics of plants, nutrient concentrations, and the influence of various environmental factors change throughout the development process [5]. Remote sensing techniques can determine factors such as plant stress, leaf water content, and nutrient deficiencies by examining the energy reflectance characteristics of plants. These techniques are also employed in precision agriculture applications, including fertilization and irrigation monitoring, weed control, pest control, and annual yield estimations. Vegetation indices derived from satellite imagery offer crucial information about the established vegetation. By using different vegetation indices, the distinctive characteristics of plants during their development can be monitored and analyzed. These indices are invaluable tools for assessing plant health, growth status, and adaptation to environmental conditions.

This study analyzed the relationship between air quality and vegetation cover in Tokat province between 2019 and 2022 using the Google Earth Engine platform. Vegetation health was assessed through satellite-based indices such as EVI, NDVI, NDMI, and NDWI. Air pollution data were analyzed using NO_2, CO, and O_3 parameters obtained from the Sentinel-5P satellite.

The Normalized Difference Vegetation Index (NDVI) is widely used in geospatial studies to monitor periodic changes in plant health and understand the spatial extent of vegetation [6-8]. NDVI serves as an effective observation tool for assessing vegetation density and health, which is crucial for understanding vegetation dynamics within Tokat province. This index is also commonly used to predict the onset of stress [9] and has been applied in various regional and global studies to examine vegetation distribution, photosynthetic activity, and overall plant quality [10].

NDWI, first proposed by McFeeters in 1996, is an index that detects water surfaces and measures water coverage in wetland environments [11]. Derived from the NIR (Near Infrared) and SWIR (Short Wave Infrared) channels, NDWI responds to factors such as water content in vegetation and changes in the spongy mesophyll structure [12]. NDWI is essential for monitoring wetlands, identifying water sources, and assessing water content in vegetation. Similarly, NDMI, calculated using NIR and SWIR, detects water content, water stress, and plant biomass changes, making it sensitive to canopy cover and leaf moisture [13].

Both NDVI and EVI are strongly linked to healthy vegetation, as they are closely associated with photosynthesis and plant transpiration processes [14]. NDVI generally responds to changes in the red band, while EVI is more sensitive to changes in the NIR, and it helps to mitigate saturation problems in dense vegetation areas [15]. These indices provide valuable insights into plant health, photosynthetic activity, and broader environmental changes, making them crucial for monitoring vegetation health in the context of air pollution and other stress factors.

Sentinel satellites have been instrumental in providing essential information for global monitoring programs, such as climate change, water resource management, hydrology, agriculture, forests, and the monitoring of vegetation health and productivity. Sentinel-5, as part of the Copernicus Air Quality program, is the first mission dedicated to air pollution monitoring. Sentinel-5 can detect pollutants such as ozone, methane, formaldehyde, aerosols, carbon monoxide, NO_2, and SO_2 gases. Satellite imagery from Sentinel-5, especially through the TROPOMI (TROPOspheric Monitoring Instrument) sensor, provides daily global data on air pollution, which is crucial for assessing the spatial distribution of pollutants and their impact on vegetation health [16-20].

The aim of this study is to determine the effects of air pollution on plant health and to reveal the interaction between these two variables. The findings aim to contribute to the development of environmental sustainability strategies and strengthen policies to combat air pollution in Tokat province. By understanding the relationship between air quality and vegetation, this study will provide valuable guidance for regional environmental management. It also demonstrates how effective Google Earth Engine and Sentinel-5P’s modern remote sensing technologies can be for environmental monitoring and analysis.

This paper provides essential information on the relationships between air pollution and plant health in Tokat province, emphasizing that these findings can be applied to shaping both regional and national environmental policies. With the growing challenges of environmental degradation, the findings from this study are expected to play a pivotal role in supporting the implementation of evidence-based strategies for mitigating air pollution's impact on vegetation and improving agricultural practices.

Remote sensing has emerged as an essential and effective tool for monitoring and analyzing changes in the Earth's natural systems [21]. It is a cost-effective method for analyzing large-scale spatial data, particularly in land cover and vegetation monitoring [22]. Remote sensing techniques are increasingly used for long-term vegetation change detection and environmental and climatic analysis [21]. The integration of cloud-based platforms, such as Google Earth Engine, has gained significant importance due to its ability to process vast amounts of satellite data efficiently, providing fast and accurate analyses for environmental studies [23].

2. Material and Methods

In this study, vegetation health indices and air pollution data were used as data sources. Vegetation health assessments were conducted using the EVI, NDVI, NDMI, and NDWI indices derived from Sentinel-2 satellite imagery, calculated using the Google Earth Engine (GEE) platform. These indices provide information on vegetation density, health, moisture status, and water content. Air pollution data were obtained from the Sentinel-5P satellite. Within Google Earth Engine, the concentrations of NO_2, CO, and O_3 were analyzed.

Sentinel-2 and Sentinel-5P Satellite Data

Sentinel-2 satellites are high-resolution optical satellites provided by the European Space Agency (ESA) and used to monitor the Earth's land surface. Sentinel-2 utilizes 13 spectral bands to monitor a wide range of environmental parameters, particularly focusing on changes in vegetation, water, soil, and urban areas. Sentinel-2's various spectral bands, with a resolution of 10-60 m, are particularly effective in calculating vegetation health indices [24-26].

Sentinel-5P is part of ESA’s atmospheric monitoring mission and is used primarily to monitor air quality. The satellite, equipped with the TROPOMI (TROPOspheric Monitoring Instrument) sensor, can detect air pollutants such as CO, NO_2, O_3, and SO_2. Sentinel-5P's high spatial resolution allows for detailed analysis of air quality in smaller areas, such as cities and industrial zones [27-28].

Advantages of the Google Earth Engine (GEE) Platform

Google Earth Engine is a powerful cloud-based platform for processing and analyzing large-scale remote sensing data. GEE enables users to access and process vast datasets quickly, offering significant advantages in applications such as vegetation health analysis and environmental change monitoring [29]. With the capability to analyze satellite data from around the world, Google Earth Engine is a critical tool for tracking environmental changes. The platform accelerates data processing workflows and simplifies the management of large datasets.

Study Area

Tokat Province is an important region located in the Black Sea Region of Turkey, known for its agricultural activities. The province plays a significant role in agricultural production due to its climate and fertile soil. Agriculture in Tokat is characterized by a combination of modern techniques and traditional farming methods. The location of Tokat Province is shown on the map in Google Earth in figure 1.

Figure 1. Location of Tokat province on Google Earth platform.

The scientific rationale for selecting Tokat as the study area is based on the region's ecosystem diversity, agricultural potential, and sensitivity to air pollution. Furthermore, the area serves as an important example for studying the interaction between agriculture and environmental factors. Studying the interactions between vegetation health and air quality in Tokat is crucial for understanding environmental issues in the region and for developing sustainable agricultural practices.
In this study, vegetation cover changes and air pollution dynamics between 2019-2022 were analyzed using remote sensing data. Vegetation health indices (EVI, NDVI, NDMI, NDWI) derived from Sentinel-2 imagery were used to monitor vegetation health, while air pollution dynamics (NO_2, CO, O_3) were analyzed using air pollution data from the Sentinel-5P satellite. These analyses contribute to a better understanding of environmental changes and the sustainability of agriculture in Tokat Province. This process has provided a scientific foundation for monitoring the environmental condition of Tokat and evaluating the impact of air quality on vegetation health.

Data Processing Steps

In this study, vegetation health and air pollution data for Tokat Province from 2019-2022 were analyzed. The first step involved calculating vegetation health indices (EVI, NDVI, NDMI, NDWI) from Sentinel-2 imagery using the Google Earth Engine platform, and analyzing the changes over time. In the second step, air pollution parameters (NO_2, CO, and O_3 concentrations) were obtained from Sentinel-5P satellite data and monthly averages were calculated. These parameters were analyzed based on daily measurement data, with monthly averages calculated for analysis.
NDVI is an index used to evaluate vegetation health by calculating the difference between the red (Red) and near-infrared (NIR) bands. EVI is another index used to measure vegetation health, using a combination of the red and blue bands to reduce atmospheric effects. NDWI is used to assess water content in plants by calculating the difference between the SWIR and NIR bands. NDMI measures moisture levels in vegetation and is similarly calculated using the SWIR and NIR bands.

Statistical Analysis and Correlation

Pearson correlation analysis was conducted to determine the relationships between vegetation health indices and air pollution parameters. This analysis was used to evaluate the linear relationship between the two variables. The correlation coefficients obtained helped us understand the impact of air pollution parameters on vegetation health.

Geographical Distribution and Visualization

The Google Earth Engine platform enables the geographic distribution of vegetation health and air pollution data within Tokat Province to be visualized on a map. This visualization allows for a detailed examination of the spatial distribution of both vegetation health and air pollution parameters.

Results and Evaluation

In this study, the relationship between air quality and vegetation health in Tokat Province was examined through a four-stage process. In the first stage, vegetation health indices from Sentinel-2 and air pollution data from Sentinel-5P were collected. In the second stage, the collected data were analyzed separately. In the third stage, the relationship between vegetation health and air pollution was evaluated using statistical methods, and it was found that NO_2 had a moderate negative impact on vegetation health. Finally, the findings emphasized the need for further efforts in environmental sustainability strategies and air pollution control, highlighting the importance of these findings in shaping environmental policies and management strategies.

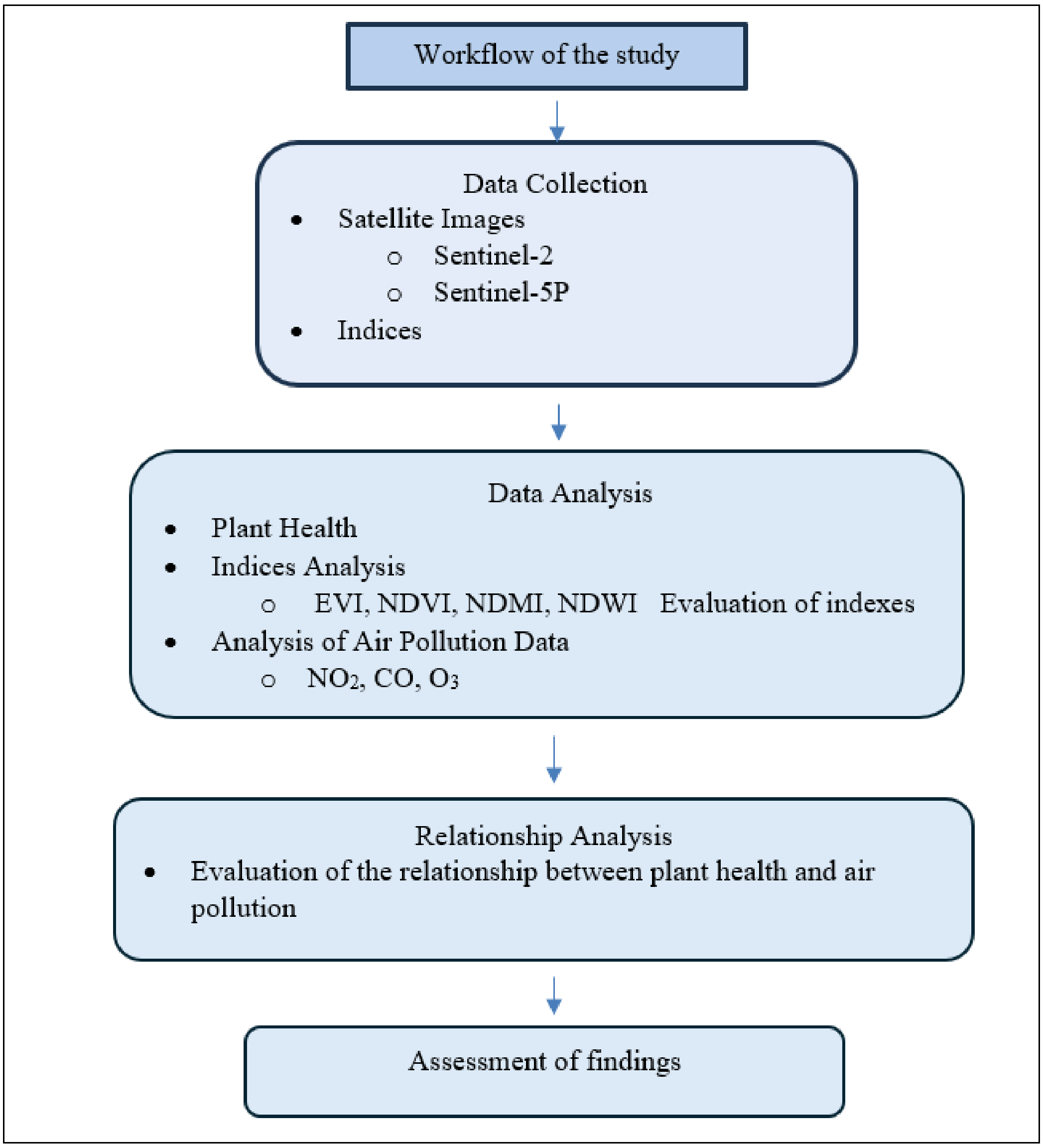


Figure 2. Workflow of the study

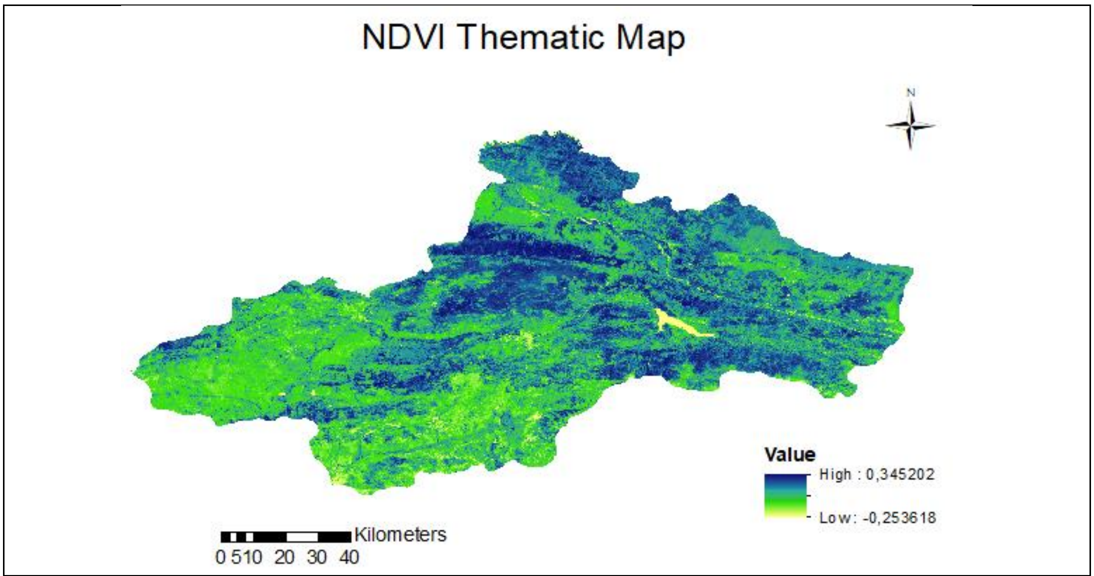
Figure 2 presents the workflow diagram, explicitly detailing the inputs utilized within the Google Earth Engine (GEE) platform. Specifically, Sentinel-2 imagery was employed to calculate vegetation health indices, including EVI, NDVI, NDMI, and NDWI, while Sentinel-5P data was utilized to derive air quality parameters such as NO_2, CO, and O_3. All maps presented in this study were generated using the ArcGIS software. The exclusive use of GEE facilitated a seamless workflow for integrating and analysing satellite imagery alongside environmental datasets, enabling a comprehensive evaluation of the relationships between vegetation health and air quality. Methodological details, including the tools and datasets employed, are thoroughly described in the "Materials and Methods" section to ensure transparency and reproducibility.

This study, conducted in Tokat province from 2019 to 2022, explored the relationship between air quality and vegetation in a systematic four-step process. First, vegetation health indices were calculated using Sentinel-2 data within the GEE platform, while air pollution parameters were retrieved from Sentinel-5P observations. In the second step, vegetation health indices and air pollution data were analyzed independently to understand their spatial and temporal variations. The third step involved assessing the relationship between vegetation health and air pollution using statistical methods. The analysis revealed a moderate negative effect of NO_2 on vegetation health, highlighting the impact of air pollution on ecosystems. Lastly, the findings underscored the need for environmental sustainability strategies and intensified efforts to mitigate air pollution, offering conclusions and recommendations crucial for shaping environmental policies and management practices.

The period from 2019 to 2022 was selected for analysis due to its representativeness of recent environmental and climatic trends. These years encompass significant variations in meteorological conditions and air quality, providing a comprehensive dataset for understanding the dynamics of vegetation health and air pollution. Additionally, this timeframe includes advancements in satellite observation technology, ensuring high-quality data availability for accurate analysis.

3. Results and Discussion

Between 2019 and 2022, seasonal fluctuations were observed in NDVI, NDMI and NDWI EVI indices. Increases in these index values in spring and summer months and decreases in autumn and winter months were determined. These changes reflect the seasonal growth and resting periods of vegetation. The data obtained reveal the health and density of vegetation throughout the year. These indices are directly related to the water and moisture status of the plants.



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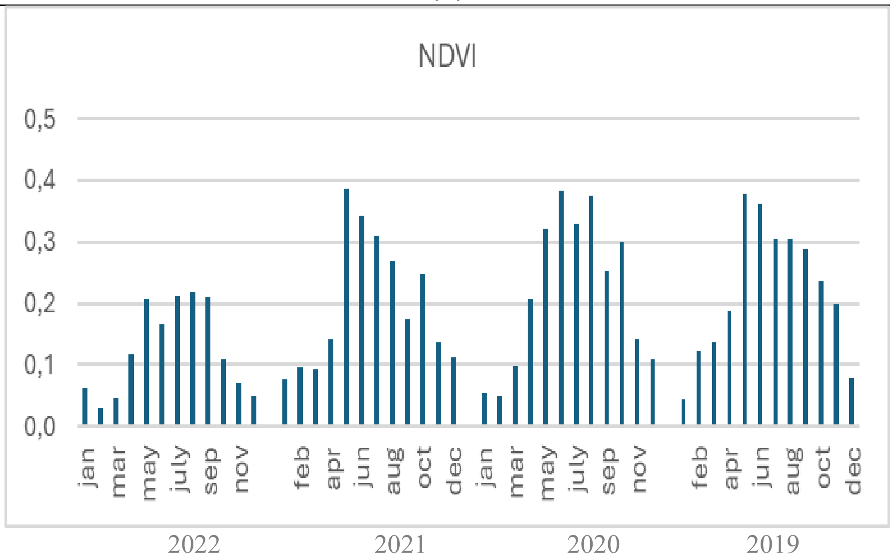


(b)

Figure 3. (a) NDVI thematic map (b) Graph of NDVI values

Figure 3a shows the thematic map of NDVI values in 2016-2022. It is observed that NDVI values are lower in Sulusaray and Yeşilyurt districts compared to other districts. Niksar, Pazar and Almus districts have higher NDVI values than other districts. Figure 3b shows the graph of NDVI values in 2019-2022. In 2022; it was observed that the NDVI value reached the highest values in August and the lowest values in February. In 2021; it was observed that the NDVI value reached the highest values in May and the lowest values in January. In 2020; it was observed that the NDVI value reached the highest values in June and the lowest values in February. In 2019; it was observed that the NDVI value reached the highest values in May and the lowest values in January.

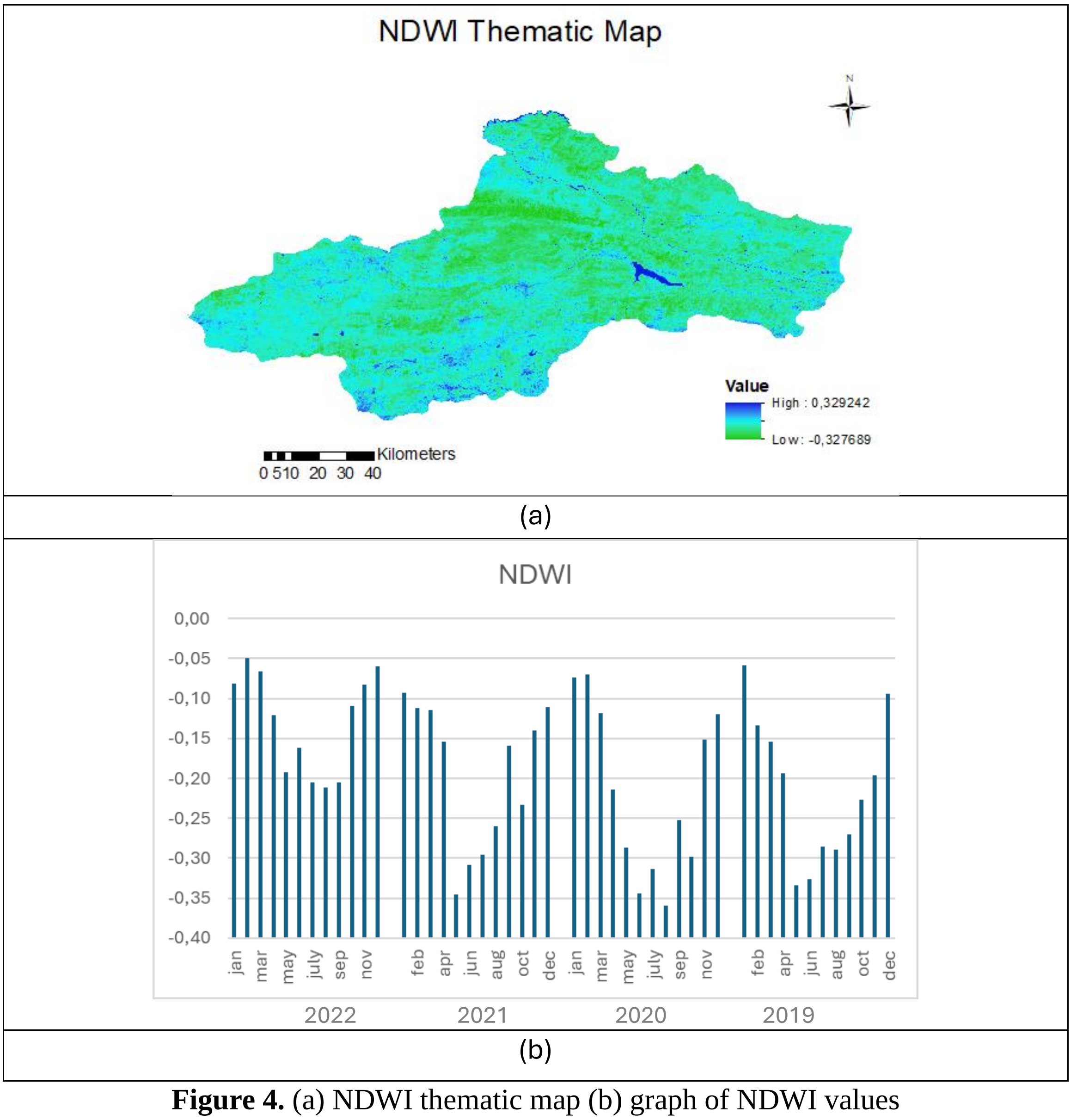


Figure 4. (a) NDWI thematic map (b) graph of NDWI values

Figure 4a shows the thematic map of NDWI values in 2019-2022. It is observed that the lowest values are reached in Pazar and Başçiftlik districts. Figure 4b shows the graph of NDWI values in 2019-2022. In 2019-2022, it was observed that NDWI generally remained between -0.3 and 0.0 values. This indicates that moderately arid, thirsty surfaces are intense. In general, it was observed that it was between -0.3 and -1 values in May, June and July. In these months, it was observed that arid, thirsty surfaces increased.

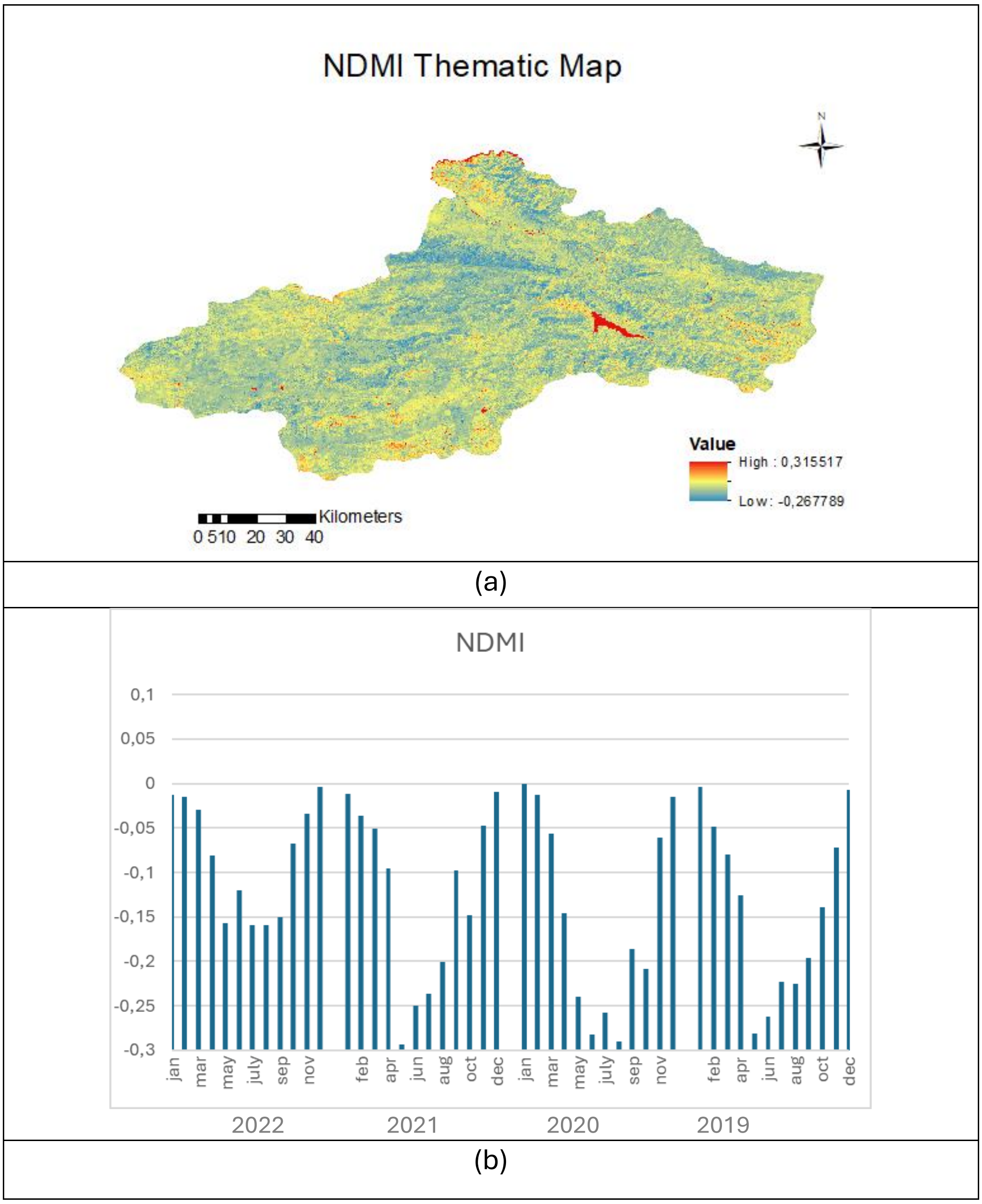


Figure 5. (a) NDMI thematic map (b) graph of NDMI values

Figure 5a shows the thematic map of NDMI values in 2019-2022. It is observed that the lowest values are reached in Pazar and Başçiftlik districts. NDMI makes it possible to immediately identify green areas or agricultural areas with water stress problems. NDMI also takes a value between -1 and 1, and when it approaches 1, it means that there is enough water and there is no water stress [18]. Figure 5b shows the graph of NDMI values in 2019-2022. It was observed that it remained between higher values in November, December, January and February. It was observed that there was sufficient water in these months. Especially in June and July, lower values indicate that there is not enough water.

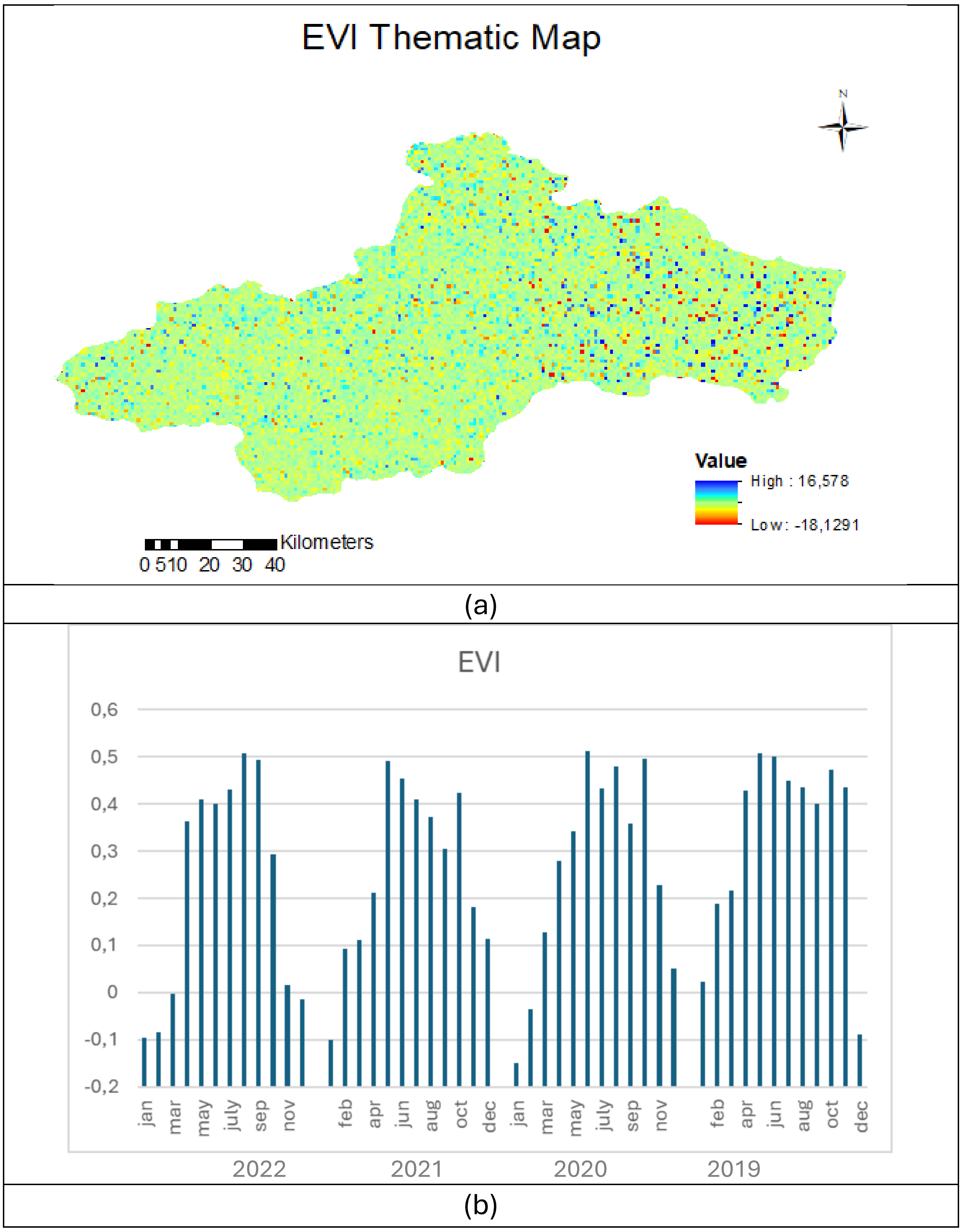
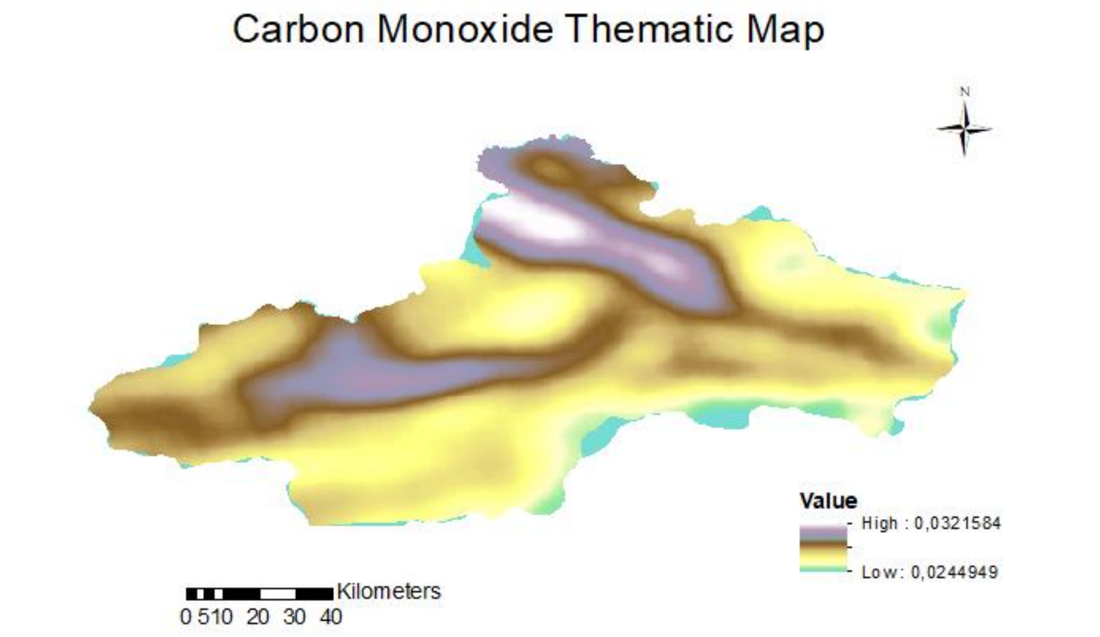


Figure 6. (a) EVI thematic map (b) graph of EVI values

Figure 6a shows the thematic map of EVI values in 2022-2019. It is observed that Pazar and Sulusaray districts have reached the lowest values. Figure 6b shows the graph of EVI values in 2022-2019. It is observed that EVI values reach high values in April and October. It is observed that EVI values reach the lowest values in December, January, and February.

NO_2, CO and O_3 levels in Tokat between 2019-2022 were analyzed. Seasonal changes were observed in NO_2 and CO levels, and there were increases in the levels of these pollutants in winter months. O_3 levels increased in summer months. This situation reveals that air pollution varies seasonally.



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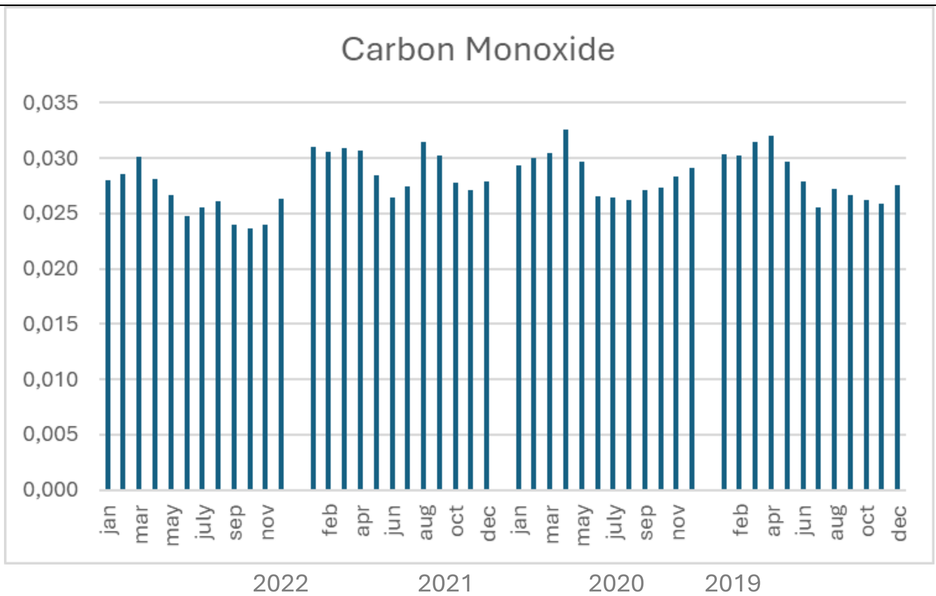

(b)

Figure 7. (a) Thematic map of CO (b) Graph of CO values

Figure 7a shows the thematic map of CO values in 2016-2022. It is observed that the CO value is lower in Artova districts compared to other districts. It is observed that CO values are higher in Niksar and Erbaa districts compared to other districts. Figure 7b shows the graph of CO values in 2022-2019. It is observed that CO values reach high values in January, February and March. It is observed that CO values reach the lowest values in July and June.

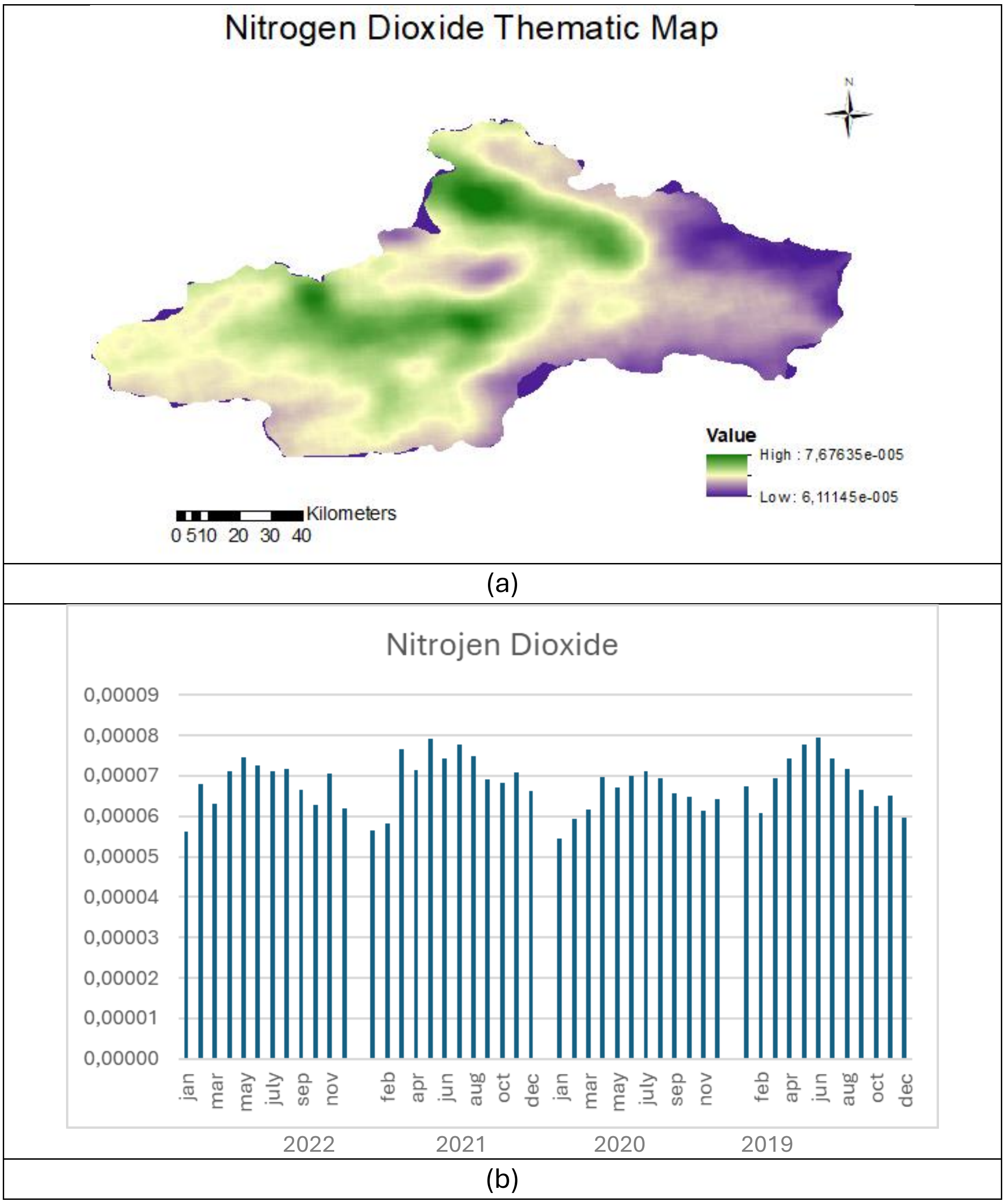

Figure 8. (a) NO_2 thematic map (b) graph of NO_2 values

Figure 8a shows the thematic map of NO_2 values in 2016-2022. It is observed that NO_2 values in Reşadiye districts are lower than other districts. It is observed that NO_2 values are higher in Turhal and Pazar districts compared to other districts. Figure 8b shows the graph of NO_2 values in 2022-2019. It is observed that NO_2 values reach high values in May and June. It was observed that NO_2 values reached the lowest values in January and December.

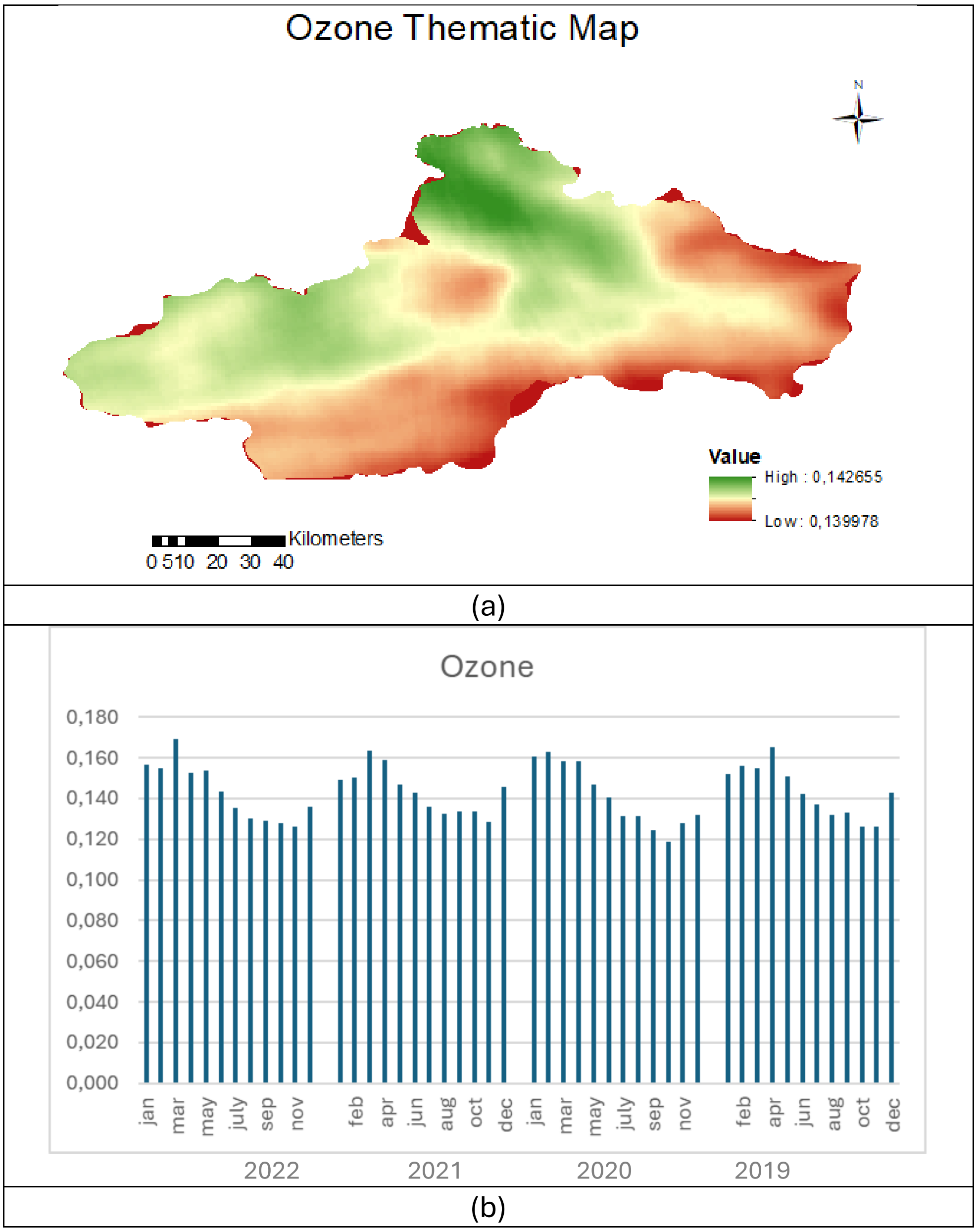

Figure 9. (a) O_3 thematic map (b) Graph of O_3 values

Figure 9a shows the thematic map of O_3 values in 2016-2022. It is observed that O_3 values are lower in Reşadiye and Başçiftlik districts compared to other districts. It is observed that the O_3 value in Erbaa districts is higher than other districts. Figure 9b shows the graph of O_3 values in 2022-2019. It was observed that O_3 values reached high values in February and March. It was observed that O_3 values reached the lowest values in October and November.

In the correlation analysis, a moderate correlation was observed between NO_2 levels and plant health indices (EVI, NDVI, NDMI, and NDWI), with correlation coefficients of R=0.65, R=0.62, R=0.66, and R=0.61, respectively. This indicates that increasing air pollution adversely affects plant health. A weak relationship was observed between CO and O_3 parameters and the plant health indices. All data were derived from satellite imagery.

These findings highlight that air pollution in Tokat province negatively impacts plant health. High levels of NO_2 were found to reduce the photosynthesis capacity of plants and adversely affect overall plant health. For instance, a 10-15% reduction in NDVI values was recorded in areas with high NO_2 concentrations. This situation is likely to have detrimental consequences for agricultural productivity in the region.

The adverse effects of air pollution on vegetation threaten not only agricultural areas but also natural ecosystems. Therefore, it is essential to develop effective policies to improve air quality.

The research findings emphasize the need to formulate environmental sustainability strategies in Tokat province. Strengthening local administrations and environmental policies is crucial in combating air pollution. This can be achieved by controlling industrial activities, increasing green spaces, and promoting the use of renewable energy sources. Improvements in air quality are expected to yield positive outcomes for both human health and vegetation. For example, a potential 8% increase in average NDVI values in analyzed regions could be observed with reduced air pollution levels.

In this context, comprehensive and integrated environmental management strategies should be developed. This study demonstrates that modern remote sensing tools, such as Google Earth Engine and Sentinel-5P, can be effectively utilized for environmental monitoring and analysis. Satellite data offers robust tools for monitoring and analyzing changes over time across large geographical areas. For example, the data from 2019-2022 revealed the quantitative impacts of NO_2 levels on plant health, providing concrete evidence of the need to combat air pollution.

4. Conclusion

This study aimed to analyze the relationship between air quality and vegetation cover in Tokat province between 2019–2022 using the Google Earth Engine platform. The data obtained within the scope of the research comprehensively evaluated the relationship between plant health indices (EVI, NDVI, NDMI, NDWI) and air pollution parameters (NO_2, CO, O_3).

The results revealed that increasing air pollution levels in Tokat province had significant negative effects on plant health, with particularly noticeable declines in plant health indices during periods of high NO_2 levels. These findings align with similar studies conducted in other regions, highlighting the detrimental impacts of air pollution on vegetation. Elevated levels of NO_2 have been shown to reduce photosynthetic activity and overall plant health, leading to decreased vegetation vitality and productivity. This study builds upon existing research by confirming these relationships in the context of Tokat province and emphasizing the need for region-specific environmental management strategies.

The findings of this study underscore the necessity of developing robust environmental sustainability strategies for Tokat province. The results suggest that strengthening local administrations and environmental policies, controlling industrial activities, increasing green spaces, and encouraging the use of renewable energy sources are essential measures in mitigating air pollution. These strategies will not only improve air quality but also contribute positively to both vegetation health and human well-being. The study's findings highlight the critical role that effective policy interventions can play in mitigating the negative consequences of air pollution on ecosystems and public health.

Additionally, this research demonstrates the potential of modern remote sensing technologies, such as Google Earth Engine and Sentinel-5P, in environmental monitoring and analysis. These technologies provide powerful tools for tracking changes over time in large geographical areas, offering detailed insights that are essential for informed decision-making in environmental management.

Satellite imagery, with its high spatial resolution, proves to be a valuable data source for local-scale predictions. These images are particularly useful in capturing spatial variability in vegetation health and air quality. However, while these data are effective for local analysis, they may have limitations in generalizing findings to other areas with different environmental conditions [30-31].

Future studies should aim to explore the relationship between air pollution and plant health in even greater detail, considering a wider range of environmental factors. Expanding the scope of research to include other factors such as water quality and soil fertility would further enhance the effectiveness of regional environmental policies and management strategies. The findings of this study provide crucial insights for the conservation and sustainable development of ecosystems in Tokat province, contributing to the broader goal of achieving environmental sustainability.

Declarations
Competing interests
Author of the present study do not have any conflicts of interest.

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Author contributions
Nehir Uyar: Investigation, Analysis, Writing - Review&Editing.

Availability Statement
Not applicable

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