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AGRICULTURAL DROUGHT ANALYSIS BASED ON REMOTE SENSING: THE CASE OF AYDIN, TURKEY

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ABSTRACT: Agricultural drought is a phenomenon that arises when there is a deficiency of moisture in the soil, which has a detrimental impact on the productivity of agricultural crops. In Aydın, Turkey, particularly in the fertile Söke Plain region, agricultural drought is a major problem for farmers. The use of satellite data based on remote sensing and the indices derived from them allows for the timely and spatially detailed monitoring of vegetation health and moisture conditions over large areas. This enables the early detection and monitoring of agricultural drought. The present study evaluates the occurrence of agricultural drought in Aydın province between 1995 and 2020. For this purpose, satellite images captured by the Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) in August 1995 and 2020 and land cover maps produced by the European Space Agency (ESA) at the same dates were utilized. The Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) indices were produced using Landsat satellite images. Then, the Vegetation Temperature Condition Index (VTCI) was obtained to detect agricultural drought. Finally, the relationship between the VTCI and land cover (LC) was evaluated, as well as the changes in the VTCI index between 1995 and 2020. The study found that agricultural drought increased with rising land surface temperature and declining NDVI values in Aydın province between 1995 and 2020.

Keywords: Land cover, Landsat satellite imagery, drought, remote sensing

UZAKTAN ALGILAMAYA DAYALI TARIMSAL KURAKLIK ANALİZİ: AYDIN, TÜRKİYE ÖRNEĞİ

ÖZET: Tarımsal kuraklık, toprakta nem eksikliği olduğunda ortaya çıkan ve tarımsal ürünlerin verimliliği üzerinde zararlı etkisi olan bir olaydır. Aydın'da, Türkiye'de, özellikle de verimli

Söke Ovası bölgesinde, tarımsal kuraklık çiftçiler için önemli bir problem oluşturmaktadır. Uzaktan algılamaya dayalı uydu verilerinin ve bunlardan elde edilen indekslerin kullanımı, geniş alanlarda bitki sağlığı ve nem koşullarının zamanında ve mekansal olarak ayrıntılı bir şekilde izlenmesine olanak tanımaktadır. Bu da tarımsal kuraklığın erken tespitini ve izlenmesini mümkün kılmaktadır. Bu çalışma, 1995-2020 yılları arasında Aydın ilinde tarımsal kuraklık oluşumunu değerlendirmeyi amaçlamaktadır. Bu kapsamda, Landsat 5 Thematic Mapper (TM) ve Landsat 8 Operational Land Imager (OLI) uydularının 1995 ve 2020 Ağustos aylarında elde ettiği uydu görüntüleri ile Avrupa Uzay Ajansı (ESA) tarafından aynı tarihlerde üretilen arazi örtüsü haritaları kullanılmıştır. Landsat uydu görüntüleri kullanılarak Arazi Yüzey Sıcaklığı (LST) ve Normalize Fark Bitki İndeksi (NDVI) indeksleri üretilmiştir. Ardından, tarımsal kuraklığı tespit etmek için Bitki Örtüsü Sıcaklık Durumu İndeksi (VTCI) elde edilmiştir. Son olarak, VTCI ile arazi örtüsü (AÖ) arasındaki ilişki ve 1995-2020 yılları arasında VTCI indeksindeki değişiklikler değerlendirilmiştir. Çalışma, 1995-2020 yılları arasında Aydın ilinde artan arazi yüzey sıcaklığı ve azalan NDVI değerleri ile birlikte tarımsal kuraklığın arttığını ortaya koymuştur.

Anahtar kelimeler: Arazi örtüsü, Landsat uydu görüntüsü, kuraklık, uzaktan algılama

INTRODUCTION

Agricultural drought is a growing problem due to global climate change and human activities, resulting in an increase in the frequency and severity of drought events (Dai, 2011). Climate change affects precipitation patterns and increases the risk of drought through higher temperatures and water vapor pressure (Thenkabail et al., 2018) Agricultural drought is the result of the interaction of meteorological, hydrological, and agricultural factors, which collectively contribute to its multifaceted nature. It occurs when there is an imbalance between water demand and available water in the soil, leading to negative impacts on plant growth and productivity (Wandel et al., 2016). This situation creates a significant pressure on agricultural production by negatively affecting plant growth and productivity, and even causes damage to plant species that are not resistant to drought stress.

The wider consequences of agricultural drought are significant, including low productivity, crop loss, increased food prices, and reduced food security. This can be exemplified by the 2012-2016 drought in the United States, which resulted in the destruction of crops and an increase in global food prices (Lund et al., 2018), and the extreme weather and droughts in Australia had a significant impact on cattle farming sectors such as cattle breeding, which in turn damaged local economies (Chang-Fung-Martel et al., 2017; Yılmaz, 2023). The impacts of agricultural drought extend beyond the agricultural sector, affecting the environment and social structure. Drought can damage ecosystems, decrease water resources and biodiversity, and disrupt social life by reducing farmers' income sources and increasing unemployment (Orimoloye et al., 2022; Fleming-Muñoz et al., 2023).

In general, traditional ground-based drought monitoring methods are time consuming and expensive. Hence, the use of Remote Sensing (RS) and Geographic Information Systems (GIS) is crucial in identifying and monitoring agricultural drought for the sustainability of agricultural lands and food security. RS, which involves analyzing earth's surface using electromagnetic radiation data collected from space or from distant platforms such as space or aircraft, enables the measurement of important parameters such as vegetation indices, soil moisture content, and water resource status (Navalgund et al, 2007). Remote sensing technologies are of great importance for monitoring and assessing agricultural drought over large areas, especially in large agricultural areas or in hard-to-reach areas, because they provide continuous and objective data and allow monitoring of changes in agricultural drought conditions over time. They also reduce costs by shortening data collection and analysis processes and providing faster results (Mishra and Singh, 2010; Karnieli et al., 2010; AghaKouchak et al., 2015).

GIS, on the other hand, is a technology that stores, analyses, and visualizes geo-referenced data, making it ideal for analyzing agricultural land use, water resources management, and drought risk mapping (Reddy, 2018; Tomaszewski, 2020). By integrating agricultural land characteristics, water resources, and climate data, drought risk maps can be created to identify areas at risk and facilitate emergency responses. The combination of RS and GIS has been successfully utilized all over the world, allowing for the identification of areas at risk and effective coordination of emergency responses (Wang and Qu, 2009; Belal et al., 2014).

Agricultural drought can have significant economic and social consequences in regions where agriculture is a significant economic activity, such as Aydın province. Hence, the use of RS and GIS is crucial in Aydın province to enable data-driven decision-making for the optimization of agricultural areas, the reduction of drought risk and the management of water resources. In this sense, this study aims to map and evaluate the occurrence of agricultural drought in Aydın province between 1995 and 2020 based on remote sensing spectral indices using Landsat 5 TM and 8 OLI satellite images (namely, NDVI, LST and VTCI index derived from them).

MATERIAL AND METHODS

The main material of this study consists of Aydın province, the Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) satellite images in August 1995 and 2020, ArcMap 10.5 and DRYAD v1.2.2 software (Desktop EA, 2011; Jo and Lee, 2023). The Landsat satellite data were selected from cloudless images on dates when the vegetation in Aydın was particularly vigorous and dense, and the air temperatures were high. The dates of the 1995 Landsat 5 TM satellite data are 29 July, 14 August, and 15 September. For the year 2020, the dates are 17 July, 2 August, and 3 September. Whilst ArcMap 10.5 software was used to calculate Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST), DRYAD v1.2.2 software was used to obtain the Vegetation Temperature Condition Index (VTCI) for both years.

The study area, Aydın is a province located in the Aegean Region of Turkey. It is notable for its rich agricultural areas and historical background. The province plays a significant role in terms of agriculture and tourism (Tonyaloğlu and Atak, 2022). Aydın is bordered by Denizli to the east, Izmir to the north, the Aegean Sea to the west and Muğla to the south (Figure 1). Aydın is one of the most productive regions of Turkey in terms of agricultural production. The region's climate, soil structure and water resources provide optimal conditions for the cultivation of a diverse range of crops. The region's principal agricultural products include figs, olives, chestnuts, cotton, corn, and a variety of fruit and vegetable products. Aydın is particularly famous for its figs, which are exported worldwide. In addition to figs, olives and olive oil, vine, chestnuts, cotton, citrus and various vegetables also play an important role in the regional economy (Yüksel and Sürmen, 2019).

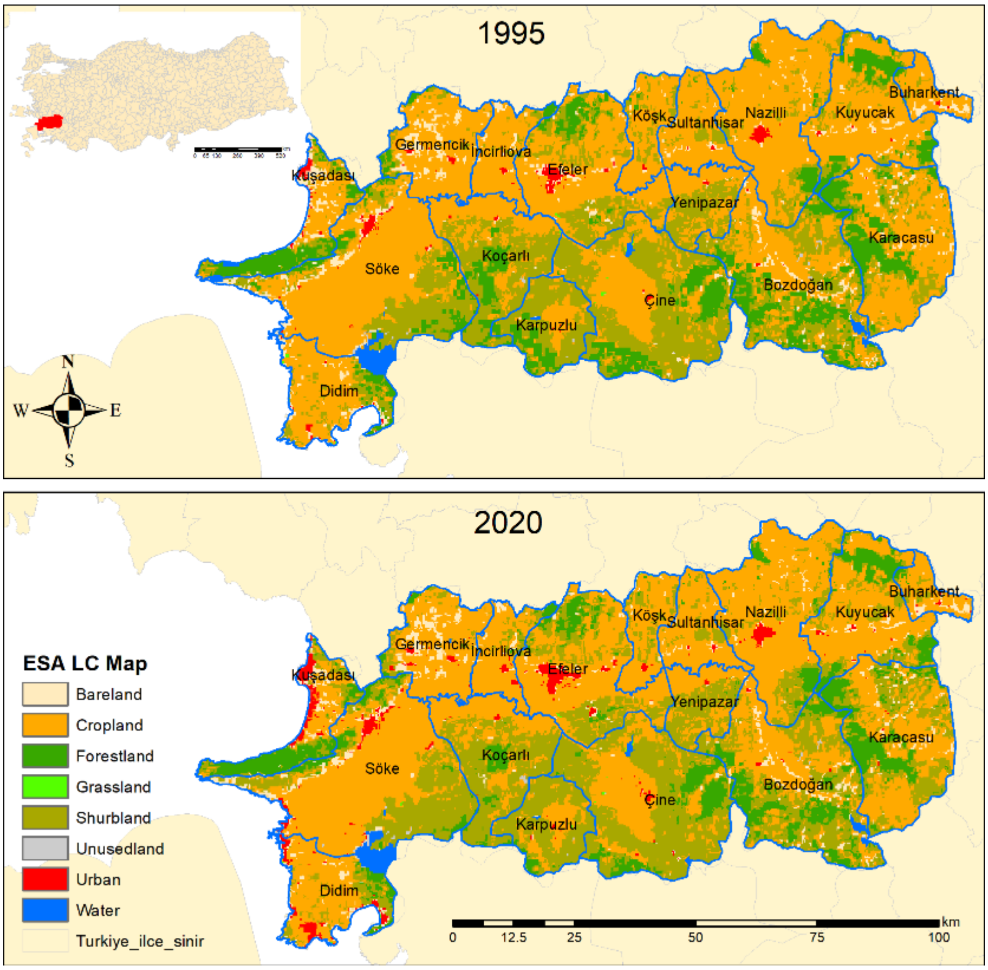

Figure 1. Location of The Study Area and ESA LC Maps.

The cloud free 6 Landsat satellite images of August 1995 and August 2022 were obtained free of charge from the United States Geological Survey (USGS) EarthExplorer website for the drought analysis. In this study, the Vegetation Temperature Condition Index (VTCI) was employed for the purpose of detecting agricultural drought. The VTCI is a remote sensing index employed to assess the water stress and health of vegetation. VTCI employs a combination of the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) data to analyze the thermal and spectral characteristics of vegetation. This index is of particular significance in the monitoring of agricultural droughts and the assessment of plant health (Buma and lee, 2019). The VTCI index ranges from 0 to 1. A lower VTCI value indicates a higher occurrence of drought (Wan et al., 2004; Buma and Lee, 2019).

The steps and formulas for the calculation of NDVI and LST are presented below. NDVI is used to determine the density and health of vegetation. NDVI is calculated using the red (R) and near infrared (NIR) bands (Eq. 1). For Landsat 8 OLI, the NIR and Red Bands consist of Band 5 and Band 4, and for Landsat 5 Thematic Mapper (TM), Band 4 and Band 3, respectively.

$$NDVI = (NIR+R)/(NIR-R) \quad (1)$$

For Landsat 8 OLI, the thermal Bands consist of Band 10 and Band 11, and for Landsat 5 Thematic Mapper (TM), Band 6, respectively. For the second step Landsat data must first be converted from digital numbers (DN) to TOA (Top-of-Atmosphere) radiance (Eq. 2).

$$L\lambda = ML \times Qcal + AL \tag{2}$$

Lλ: TOA Spectral radians ($W/m^2 sr\mu m$), ML: Band-specific radiance multiplier, $Qcal$: Calibrated digital number (DN), AL: Band-specific radiance addend.

The next step is the conversion to Brightness Temperature (BT). In this step, the TOA radiance is converted to the brightness temperature (Planck's inverse function) (Eq. 3).

$$BT = K2 / \ln(K1 / L\lambda + 1) \tag{3}$$

BT: Brightness temperature (Kelvin), K1ve K2: Band-specific thermal conversion constants.

At this stage, the value 273.15 is subtracted from BT to convert from Kelvin to Celsius. The next step is the estimation of Land Surface Emissivity (LSE- ε). LSE determines the thermal radiation emitted by the earth's surface and can be calculated using NDVI (Eq. 4).

$$\varepsilon = 0.004 \times NDVI + 0.986 \tag{4}$$

In the last step, the surface temperature is calculated using the land surface temperature and emissivity (Eq. 5).

$$LST = BT / 1 + (\lambda \text{ x } BT / \rho) \text{ x } \ln(\varepsilon) \tag{5}$$

λ: Central wavelength of the thermal band, usually in the range 10.9-12 μm, ρ: Constant based on Planck's constant.

The VTCI is calculated using LST and NDVI indices utilizing the DRYAD v1.2.2 program. Whilst NDVI and LST maps are evaluated in ArcMap 10.5 using Zonal Statistics tool, the VTCI maps are evaluated in ArcMap 10.5 by reclassifying them into 5 classes according to (Buma and Lee, 2019).

RESULTS AND DISCUSSION

The area of Aydın province is 8.116 km^2. In 1995 and 2020, the dominant land cover type in Aydın was cropland (56.81% and 53.67% of the total area, respectively) (Figure 2). This is followed by Shrubland, Forestland, and Bareland in both years respectively.

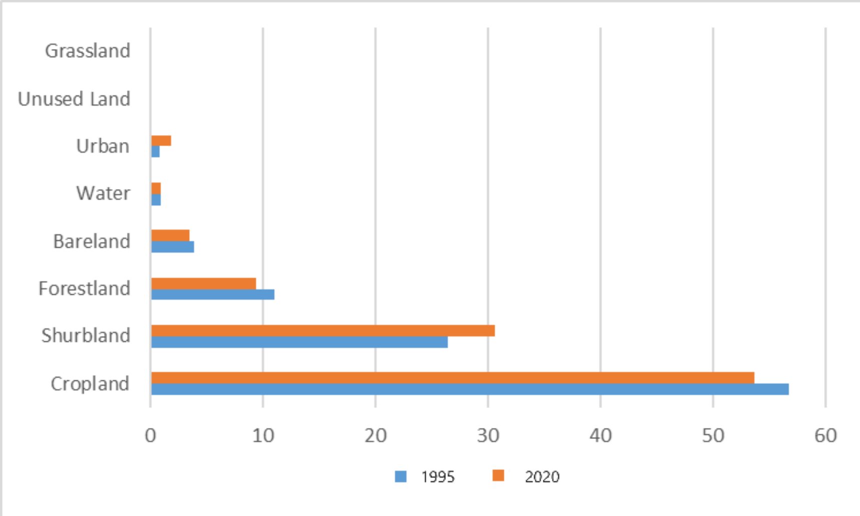

Figure 2. Areal Distribution of Land Cover Types.

Urban areas have doubled in the last 25 years and reached 1.85 %. Whilst there was no spatial change in water surfaces, Grassland was determined as the land cover type with the least area on both dates.

The distribution of NDVI values in the study area is shown in Figure 3. The mean NDVI value in Aydın province showed an increase of 0.01 in 2020 compared to 1995 (Table 1). However, the maximum and minimum NDVI values were 0.714 and -0.32 in 1995 and 0.64 and -0.24 in 2020. This indicates that there is a decrease in healthy vegetation with the decline in both forests and agricultural areas. When evaluated by districts in terms of NDVI, it was observed that the mean NDVI values generally decreased despite the slight increase in 6 districts among 17 districts.

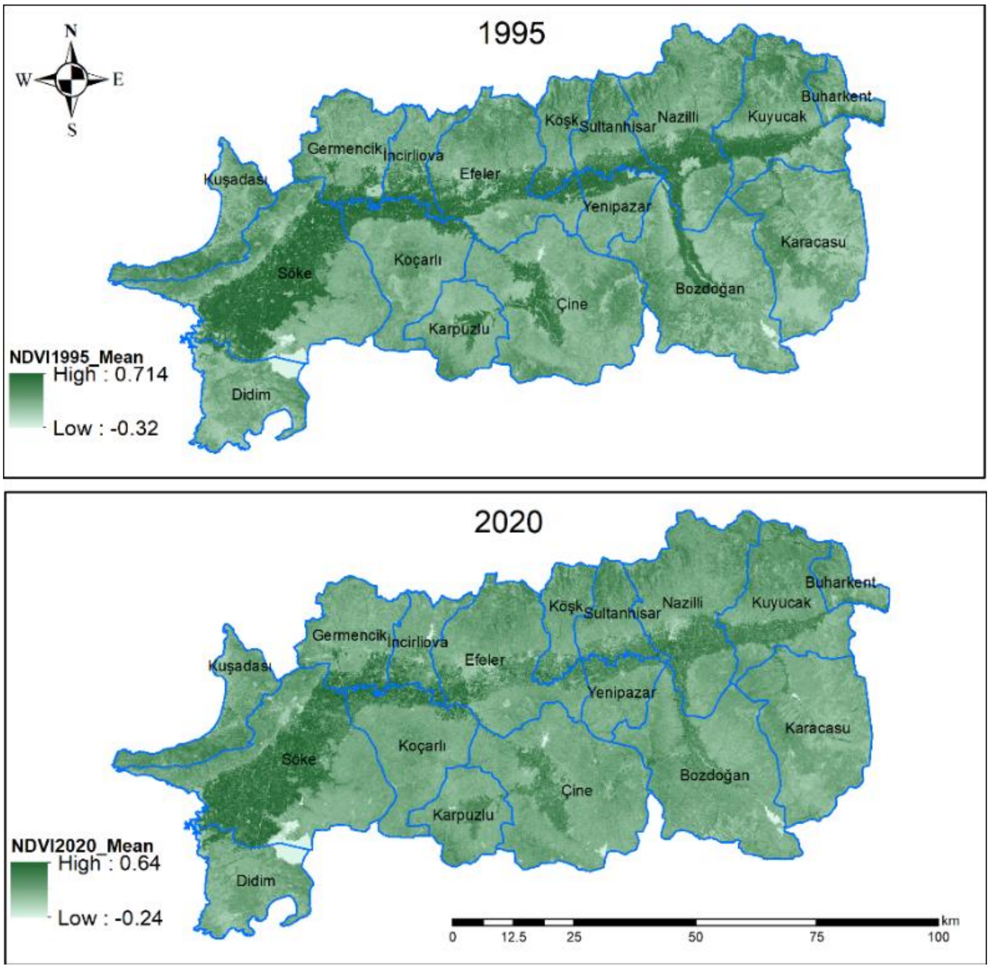

Figure 3. Mean NDVI Maps for 1995 and 2020.

Table 1 Mean NDVI, LST and VTCI Values for Aydın Province and Districts

	1995			**2020**		
	NDVImean	**LSTmean**	**VTCImean**	**NDVImean**	**LSTmean**	**VTCImean**
Aydın	0.27	29.39	0.65	0.28	34.19	0.45
Kuyucak	0.29	28.08	0.70	0.29	32.73	0.51
Buharkent	0.25	29.52	0.63	0.28	34.17	0.44
Söke	0.37	27.63	0.75	0.34	31.99	0.54
Karpuzlu	0.22	32.55	0.50	0.25	37.34	0.30
Karacasu	0.20	30.50	0.59	0.23	35.13	0.42
Germencik	0.26	30.30	0.61	0.27	35.82	0.37
Koçarlı	0.28	30.24	0.61	0.28	35.08	0.40
Çine	0.24	30.62	0.59	0.25	35.32	0.40
Köşk	0.31	28.57	0.67	0.29	34.02	0.44
Bozdoğan	0.22	30.04	0.61	0.25	34.81	0.42
Nazilli	0.30	28.81	0.67	0.29	34.14	0.44
Sultanhisar	0.33	28.57	0.67	0.30	34.27	0.43
Yenipazar	0.27	29.61	0.64	0.27	35.08	0.40
Efeler	0.30	29.00	0.66	0.28	33.89	0.46
Didim	0.18	30.18	0.60	0.22	34.52	0.44
Kuşadası	0.29	26.78	0.75	0.29	30.58	0.63

İncirliova	0.31	28.73	0.68	0.28	34.02	0.45

The map of the distribution of mean LST values in Aydın province is given in Figure 4. The mean LST values throughout the province were 29.39 °C and 34.19 °C in 1995 and 2020, respectively. This indicates an increase of 4.8 °C in the mean of July, August, and September in the province. A comparison of the maximum and minimum LST values observed in 1995 and 2020 reveals a relatively modest increase of 0.52 °C in the maximum value, while the minimum value has risen by a more substantial 7.89 °C. In particular, the Söke plain, which is characterized by high levels of agricultural production and Germencik, Çine, Nazilli, Sultanhisar, and Yenipazar districts, exhibited an increase of greater than 5 °C in the mean LST values over the 3-month period.

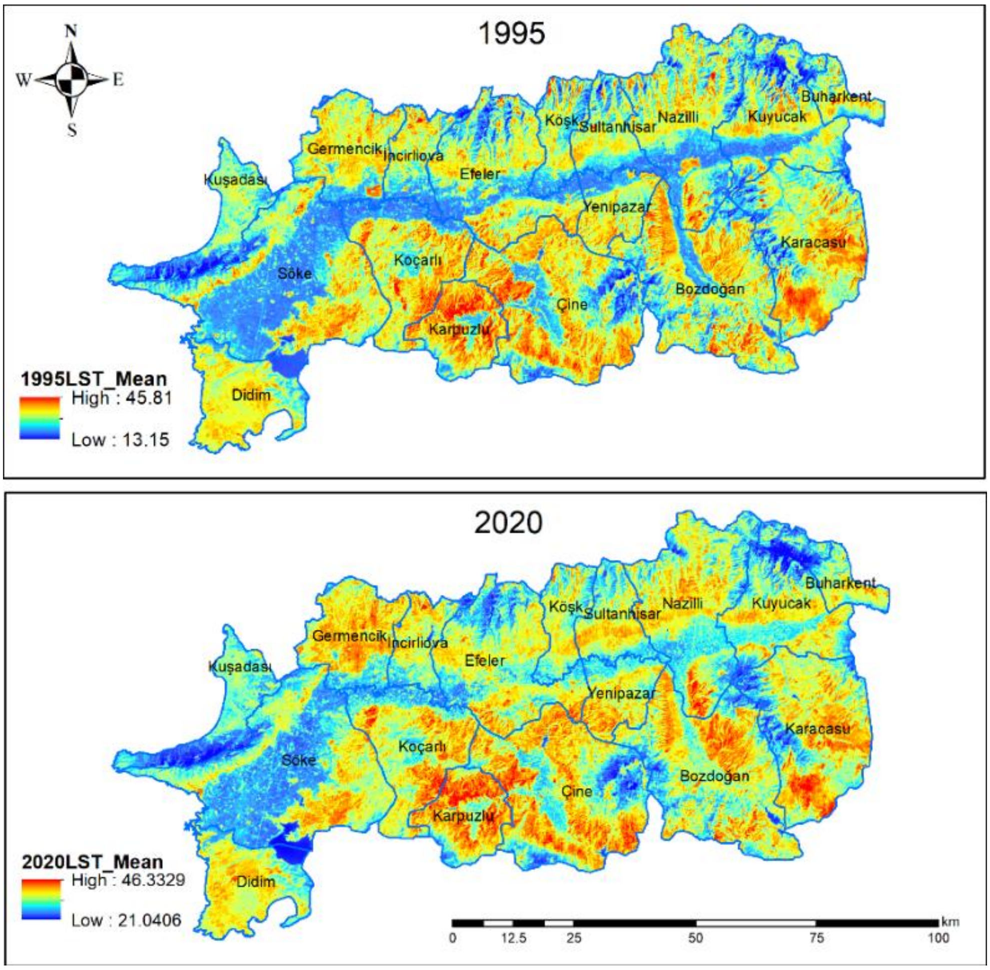

Figure 4. Mean LST Maps for 1995 and 2020.

Figure 5 represents the distribution of mean VTCI values across Aydın province. The mean VTCI value, which decreased by 30.78% in Aydın Province, indicates the occurrence of agricultural drought in 2020. Furthermore, in all districts except Kuşadası district (16.87%), there was a decrease of more than 25% in the value of VTCI index, while in eight districts there was a decrease of more than 35%. A comparison of the mean VTCI value in different land cover types revealed a decrease of 0.23 (34.09%) in cropland and a decrease of 0.20 (37.30%) in grassland. This finding indicates that the drought was particularly severe in agricultural areas (Table 2).

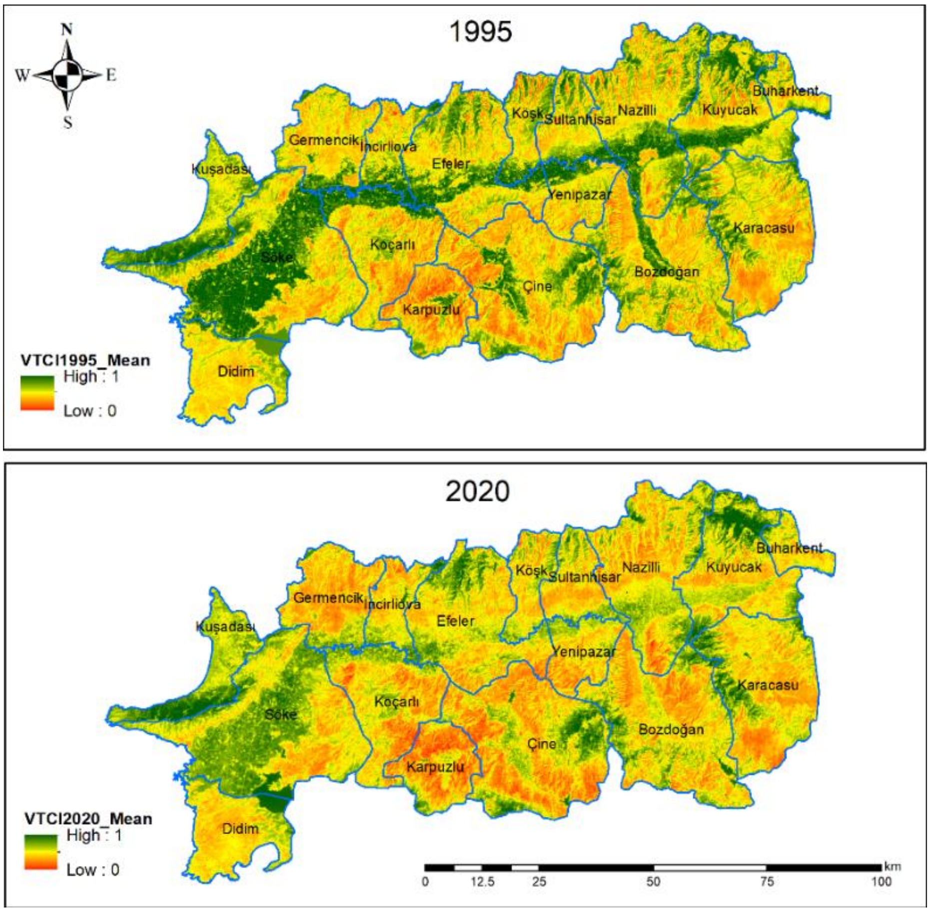

Figure 5. Mean VTCI Maps for 1995 and 2020.

Table 2 Mean VTCI Values in Different Land Cover Types

	1995 (%)	2020 (%)	Difference	% Difference
Cropland	0.66	0.44	**-0.23**	**34.09**
Forestland	0.74	0.65	-0.09	12.14
Shurbland	0.57	0.40	-0.18	30.65
Grassland	0.53	0.33	**-0.20**	**37.30**
Unusedland	0.56	0.46	-0.10	17.55
Urban	0.63	0.45	-0.18	28.56
Bareland	0.58	0.40	-0.19	32.09
Water	0.79	0.74	-0.05	6.41

Whilst Table 3 shows the areal distribution of agricultural drought categories, Figure 6 represents the agricultural drought maps for 1995 and 2020.

Table 3 Mean NDVI, LST and VTCI Values for Aydın Province

	1995 (%)	2020 (%)	% Difference
No	22.25	2.62	-19.63
Mild	30.63	16.09	-14.54
Moderate	41.62	37.69	-3.93
Severe	5.48	39.51	34.03
Extreme	0.01	4.09	4.08

According to the mean VTCI index, the proportion of drought-free agricultural areas in 1995 was 22.25% of the total area, while in 2020 this had decreased to 2.62%. In the regions classified as mild, there was a further decrease, from 36.63% to 16.09%. In regions where the severity of the drought was classified as moderate, a reduction of 3.93% was observed.

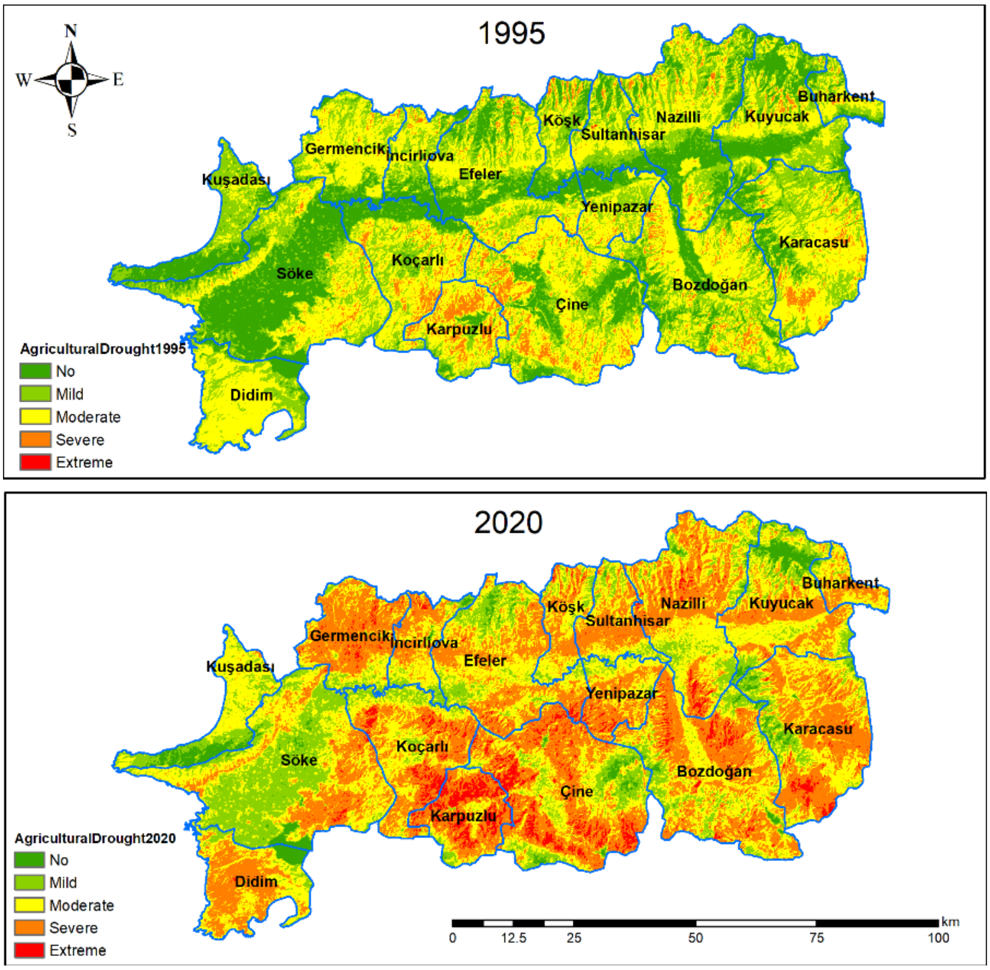

Figure 6. Agricultural Drought Maps for 1995 and 2020.

On the other hand, an increase of 34.03% and 4.08% was observed in areas where agricultural drought was classified as severe and extreme. This demonstrates that the severe and extreme drought risk, which was observed in only 5.49% of the total area of Aydın province in 1995, has extended to 38.11% of the total area in 2020.

In 1995 and 2020, the Söke Plain, a key agricultural area in Aydın, demonstrated higher VTCI values, reflecting unfavorable vegetation conditions during these periods. Similarly, the mountainous area of Kuşadası Dilek Peninsula Natural Park also showed elevated VTCI values, suggesting that these regions had unfavorable climatic and environmental conditions conducive to vegetation health. Conversely, the mountainous regions of Aydın, specifically Kapuzlu and Çine, recorded the lowest VTCI values. This indicates that these areas experienced more favorable conditions for vegetation, possibly due to factors such as higher precipitation, lower temperatures, or richer soil quality. A noteworthy observation is the significant decrease in VTCI values in 2020 in regions with high urban density agricultural fields, such as Efeler, Nazilli, and Kuyucak. This decline can be attributed to the effects of urbanization and its associated impacts, such as increased surface temperatures (the urban heat island effect), reduced green spaces, and increased water demand. These factors have likely strained the local vegetation and reduced overall vegetation health. In conclusion, while some regions, such as the Söke Plain and the Dilek Peninsula, exhibited low resilience or deterioration in vegetation conditions, the adverse impacts of urbanization and challenging environmental conditions in other areas led to a decline in VTCI values, emphasizing the significance of sustainable urban and environmental management practices.

In the Aydın province, where agricultural production plays a significant role in the regional economy, agricultural irrigation is typically conducted during the summer and early September, when rainfall is relatively scarce (Akçay et al., 2007). Yetmen (2013) asserts that, despite the limited number of dry periods, the longest dry periods in terms of duration occur in Aydın province, as evidenced by his drought analysis and models conducted using 1975-2008 precipitation data. Additionally, in 2023 the Aydın Provincial Directorate of Agriculture and Forestry reports that the average annual rainfall in the Aegean region, including Aydın province, was above the normal rainfall of 600 mm in 1995, while it was around 470 mm in 2020. Although these values exhibited a slight increase in 2021, they subsequently declined again in 2022. It has been also reported that there was no or very little precipitation in July, August, and September in the province of Aydın in 2020. Furthermore, this report highlights the observed decline in precipitation, rivers, dams, and ponds, as well as the reduction in underground and surface water levels, and the discrepancy between water supply and demand.

The findings of this study corroborate the prevailing literature on the intensification of agricultural droughts, characterized by declining precipitation and rising temperatures. The expansion of the area affected by severe and extreme droughts in 2022 indicates that droughts may be experienced in the future in Aydın province. In this context, it is evident that the utilization of remote sensing-based indices, such the Vegetation Temperature Condition Index (VTCI), which is also the subject of this study, where NDVI and LST data are also employed, will considerably facilitate the long-term agricultural drought evaluation and monitoring of extensive areas in a relatively short period of time (Buma and Lee, 2019).

On the other hand, it is also important to consider that the VTCI index presents time-dependent and region-specific results (Wan et al., 2004). Although this study demonstrates the utility of remote sensing-based indices in informing agricultural drought assessment, the evaluation of each date between 1995 and 2020 in the study will facilitate the acquisition of a more comprehensive picture that can assist in the evaluation of the agricultural drought trend and pattern between the relevant years. This will enable the formulation of more informed management decisions, which would serve as the foundation for agricultural production and drought management in Aydın province (Buma and Lee, 2019).

CONCLUSION

This study aimed to map and evaluate the occurrence of agricultural drought in Aydın province between the years 1995 and 2020 based on remote sensing spectral indices, utilizing Landsat 5 TM and 8 OLI satellite images (namely, NDVI, LST and VTCI derived from them). The study revealed a notable increase in the regions where severe and extreme agricultural drought was experienced, accompanied by a decline in NDVI and an increase in LST values in 2020 compared to 1995. A comprehensive analysis of land cover dynamics, vegetation health indicators and climatic trends in Aydın province between 1995 and 2020 revealed significant changes and their consequences. Despite the agricultural lands that have not changed significantly in area, urban expansion has doubled, affecting natural landscapes and vegetation health. Decreases in healthy vegetation, especially in forests and agricultural areas, indicate deforestation, land degradation and climate variability. The increasing temperatures of the land surface, particularly in agricultural areas, have the effect of increasing water stress and the risk of agricultural drought. The increasing severity of agricultural drought patterns across the province serves to emphasize the vulnerability of agricultural systems to changing climatic conditions. It is therefore imperative that urgent action be taken to reduce drought risks and to manage water resources effectively. In addition, integrated water resources management strategies and adaptive agricultural practices are of vital importance to increase resilience to climate variability and drought. In order to address these challenges, it is necessary to adopt a holistic approach that takes into account both socioeconomic and environmental factors and involves local stakeholders.

By prioritizing sustainable land management and the protection of water resources, the Aydın province can protect agricultural livelihoods and increase resilience for future generations. In this sense, the findings of this study demonstrate that remote sensing technologies offer a significant advantage in monitoring and assessing agricultural drought in regions such as Aydın, where there are extensive and inaccessible agricultural areas. RS technologies provide continuous and objective data, enabling the monitoring of changes in drought conditions over time. They also offer cost savings by reducing the time and expense of data collection and analysis, yielding faster results. However, remote sensing data quality can be affected by atmospheric conditions and cloud cover, leading to potential data loss, especially for optical satellites unable to operate in cloudy weather. Additionally, the spatial resolution of remote sensing data may not always be sufficient for agricultural applications, particularly in small-scale agricultural areas where low resolution data may not allow for detailed analysis. Overall, despite limitations, as used in this study remote sensing technologies have significant advantages in monitoring agricultural drought as well as other natural hazards.

AUTHOR CONTRIBUTIONS

Ebru ERSOY TONYALIOĞLU: Conceptualization, Visualization, Investigation, Writing-original draft. **Birsen KESGİN ATAK:** Data curation, Methodology, Software, Validation, Writing-review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

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