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Agricultural Drought Monitoring Using Surface Temperature and Vegetation Indices from Satellite Images

Uydu Görüntülerinden Elde Edilen Yüzey Sıcaklığı ve Vejetasyon İndeksleri ile Tarımsal Kuraklığın İzlenmesi

M. Yousif KHOZIMA[1]

Serafettin AŞIK[2*]

Tuğba Yıldırım[3]

Abdelmalik M. ABDELMALIK[4]

Abdulmajeed Jamal KHASHOGGI[5]

[1]Land and Water Research Center, Agricultural Research Corporation, ARC, Wad Medani, Sudan

[2]Faculty of Agriculture, Department of Farm Structures and Irrigation, Ege University, Turkey

[3]Oklahoma State University, USA

[4]Dryland Research Center, Agricultural Research Corporation, ARC, Khartoum, Soba, Sudan

[5]King Abdulaziz City for Science and Technology, Saudi Arabia

[1]**ORCID:** 0000-0001-6753-2413

[2]**ORCID:** 0000-0002-5888-8829

[3]**ORCID:** 0000-0001-9302-0876

[4]**ORCID:** 0000-0001-5795-0830

[5]**ORCID:** 0000-0003-1568-1403

***sorumlu yazar:** serafettin.asik@ege.edu.tr

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ABSTRACT

Objective: This study aimed to examine and investigate the agricultural drought in the Menemen Right Bank Irrigation Area with the help of Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index indices (SAVI).

Material and Method: LANDSAT-8 OLI satellite images were used in the study. Transferring of satellite images to computer and processing of it was carried out with ArcGIS 10.3 and ENVI 10.4 software. NDVI, SAVI and LST indices were used in the assessment of drought.

Results: The results of the study revealed that R^2 values between LST and NDVI were 0.82 and 0.95 for the years 2015 and 2016 respectively, while the corresponding values for the LST-SAVI correlation were 0.87 and 0.87. The R^2 values between NDVI and SAVI were 0.77 and 0.76 for 2015 and 2016 respectively. This study shows that satellite data and the vegetation indices derived from it can be used in monitoring agricultural drought.

Keywords:

Remote sensing, GIS, agricultural drought, NDVI, SAVI, LST.

ÖZ

Amaç: Bu çalışmanın amacı, LST, NDVI ve SAVI indeksleri yardımıyla LANDSAT 8 uydu görüntüleri kullanılarak Menemen Sağ Sahil sulama alanındaki tarımsal kuraklığı irdelemek ve incelemektir.

Materyal ve Metot: Araştırmada LANDSAT-8 OLI uydu görüntülerinin bilgisayar ortamına aktarılması ve işlenmesi, ArcGIS 10.3 ve ENVI 10.4 yazılımlarıyla gerçekleştirilmiştir. Kuraklığın değerlendirilmesinde, NDVI, SAVI ve LST indeksleri kullanılmıştır.

Sonuçlar: Araştırma sonucunda, LST-NDVI arasındaki ilişkinin R^2 değerleri 2015 ve 2016 yıllarında sırasıyla 0,8203 ve 0,9496 olurken LST-SAVI arasındaki ilişkinin R^2 değerleri ise yıllara göre sırasıyla 0,8725 ve 0,8682 olmuştur. NDVI ve SAVI arasındaki ilişkinin R^2 değerleri 2015 ve 2016 yıllarında sırasıyla 0,7702 ve 0,7574 olmuştur. Bu çalışmayla, uydu verilerinin ve bunlara bağlı olarak elde edilen vejetasyon indekslerinin tarımsal kuraklığın izlenmesinde kullanılabileceği ortaya konulmuştur.

Anahtar Sözcükler:

Uzaktan algılama, CBS, tarımsal kuraklık, NDVI, SAVI, LST.

INTRODUCTION

Drought is one of the most dangerous natural disasters in the world that adversely affects people, the environment and the economy. Because where there is drought, problems such as water scarcity, food security, migration, deaths, degradation of agricultural lands and decrease in productivity are inevitable (FAO, 2018). Although there are types of drought such as meteorological, hydrological, socio-economic and agricultural droughts, those types of droughts are also related to each other. Agricultural drought is a climatic event that causes severe damages in agricultural areas and has a long-lasting effect. The most prominent feature is the decrease in moisture in the soil due to the low rainfall, which negatively affects plant growth and causes a decrease in yield (Perez et al., 2016). Turkey is a country based on agriculture, about 30% of the total surface area is farmland (Bayar, 2018). For this reason, monitoring of drought is very important for early warning of those who manage water such as producers and irrigation associations.

The total annual water potential of Turkey, which has 112 billion m^3, the agricultural sector employs about 74% of freshwater resources (Orman ve Su İşleri Bakanlığı, 2014). If the necessary measures are not taken in the coming years Turkey will be among the countries that will experience water shortage. Therefore, by predicting possible droughts, it will be possible to reduce the severity of the drought-related hazards that may occur. In recent years, droughts in the Aegean Region, where the study area is located, an agricultural drought is a climatic event that causes various problems in agricultural areas and thus negatively affects food security and therefore the socio-economic structure (Perez et al., 2016). The insufficiency in water resources restricts agricultural production, thus making the effective use of water resources mandatory. Menemen Plain is a region with high agricultural potential. Cotton, cereals, grapes, vegetables and fruits, olives, tobacco, and garden are grown widely in the basin (Kukul et al., 2008). Cotton is the first place in the plant pattern with a planting rate of 66% (Yıldırım, 2012).

The simulation results of the water budget model show that the surface water in Gediz and Big Menderes Basins will decrease by approximately 20% by 2030; It showed that by 2050 and 2100, this ratio could be 35% and more than 50%, respectively. The decreasing surface water potential of the basins will cause serious problems among water users, especially agricultural, domestic, and industrial water users (Ozkul et al., 2009). Among these vegetation indices; Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) are among the commonly used group. The main purpose of the study was to monitoring agricultural drought with the help of vegetation indexes such as (land surface temperature (LST), normalized difference vegetation index (NDVI), and soil adjusted vegetation index (SAVI)) obtained from satellite images.

In the study carried out by Alemu (2019) in Ethiopia's Blue Nile River Basin, a relationship was revealed between the spatial and temporal distributions of NDVI and LST values between 1986-2016. In the study, LST values have increased over the years and this increase is 0.081°C per year and vegetation varies constantly. The relationship between LST and NDVI values was found to be negative. As a result, it has been reported that there is deterioration in vegetation and an increase in land surface temperatures over the years in question. Gündoğdu and Benjamin (2018), determined the parcel-based distribution of NDVI values by using 29 Landsat satellite images covering the farmland of Uludağ University Faculty of Agriculture between 2013-2017 and created NDVI maps. They also revealed the relationship between the yields of wheat, corn, sunflower and clover products and NDVI values in the plots. They found the highest relationship (R^2) as 0.945 between the images obtained during the flowering period and yield.

Nancy et al. (2015), investigated the use of remote sensing data in Sudan to distinguish between different grassland areas using the NDVI and SAVI indexes. They selected three pasture areas according to soil types and vegetation diversity and stated that NDVI and SAVI indices can be used to distinguish between the grassland areas with different characteristics depending on the soil types.

The aim of this study is to determine the drought impact in the Menemen Right Bank Irrigation District, located in the lower Gediz Basin with the help of individual values or combinations of them with LST, NDVI and SAVI values using high-resolution LANDSAT-8 satellite images of 2015 and 2016.

MATERIAL AND METHOD

Study area

The study was conducted at Menemen Right Bank Irrigation District, Lower Gediz Basin (Figure 1) that located within the Aegean Region of Western Turkey, at latitude 38° 04′–39° 13′ N, and longitude 26° 42′–29°

45′ E (Unal et al., 2004). The climate prevails in the area in summers are generally dry and hot, winters are relatively rainy and mild. Most of the precipitation occurs in winter (Toprak Su, 1971). The average temperature is 16.9 ° C, and the annual average precipitation is 535.3 mm, the average flow is 108.3 mm year^{-1} and the total evaporation amount is 1516.3 mm, and the elevation is 20 m (70 ft.).

Satellite imagery

Remote sensing data, which considered the main data source of the study, was obtained from LANDSAT-8 OLI-TIRS satellite images. The spectral resolution of the LANDSAT-8 OLI-TIRS satellite is 0.43-12.51µm, the radiometric resolution is 16 bits, temporal resolution is 16 days, scan width is 183x170 km. LANDSAT-8 OLI-TIRS satellite has a total of 11 bands, 2 of which are thermal. Satellite images used in the study were taken during the periods 2015-2016 because water scarcity was an important problem in the Gediz Basin and covering the Menemen Right Bank Irrigation District.

NDVI indices

NDVI provides information on the density of the green vegetation based on the reflection differences of the electromagnetic spectrum in the red and near-infrared regions. NDVI values were calculated using the following equation (Rouse et al. 1974; Waters et al., 2002). When the temperature is higher, the NDVI value is lower which show decrease in the vegetation density. The basic principle of this index is that the inner mesophilic structure in healthy green leaves strongly reflects the radiation in the near-infrared (NIR) region; It is based on chlorophyll and other pigments absorbing most of the radiation in the visible red area (Rouse et al., 1973).

$$NDVI = (NIR - RED)/(NIR + RED)$$

Where: NIR, near-infrared band; RED is the red band. The 4th band of the LANDSAT-8 OLI satellite gives red (RED) and the 5th band gives near-infrared (NIR) reflections.

SAVI indices

The main difference between SAVI and NDVI is that SAVI is considering the soil properties values. The soil correction factor (L; 0.5) was used to minimize the effect of soil (Huete, 1988). SAVI values were calculated using the equation below (Huete, 1988).

$$SAVI = \frac{NIR - RED}{NIR + RED + L}(1 + L)$$

Figure 1. General view of Menemen Right Bank Irrigation District(area with red color)
Şekil 1. *Menemen Sağ Sahil Sulama Alanının Genel Görünümü(kırmızı renkli alan)*

Where: NIR means the near-infrared band; RED is the red band; L indicates to the soil brightness correction factor (L). L values vary depending on the green density of the vegetation. When the vegetation is completely green, this value is = 0 or 0.25, whereas it is 1 when it is not green. When the L value is zero, NDVI and SAVI values become equal (NDVI = SAVI). However, the L value is generally taken as 0.5.

LST data

Land surface temperatures Land surface temperatures (LST) were calculated using the data obtained from the thermal bands of the LANDSAT-8 satellite image. The 10th and 11th bands of the TIRS sensors (Thermal Infrared Sensor) available in the satellite. Reflection values were used and transformed to estimate the brightness temperature as digital numbers (DN). These values are then converted to spectral reflectance values from DN to Equal to ground surface temperature with the equation below (Waters et al., 2002). It was converted digital numbers values to °C by subtracting 273.15 value from Ts values in Kelvin.

$$T_s = \frac{K_2}{\ln\left(\frac{\varepsilon_{NB} K_1}{R_C} + 1\right)}$$

Where: Ts, the land surface temperature (Kelvin); εNB, narrowband emission; Rc, corrected thermal radiation, and constant coefficients for K1, K2, LANDSAT-8 satellite images. These coefficients for the 10th band are 774.89 and 1321.08 respectively, while for the 11th band it is 480.89 and 1201.14.

RESULTS AND DISCUSSION

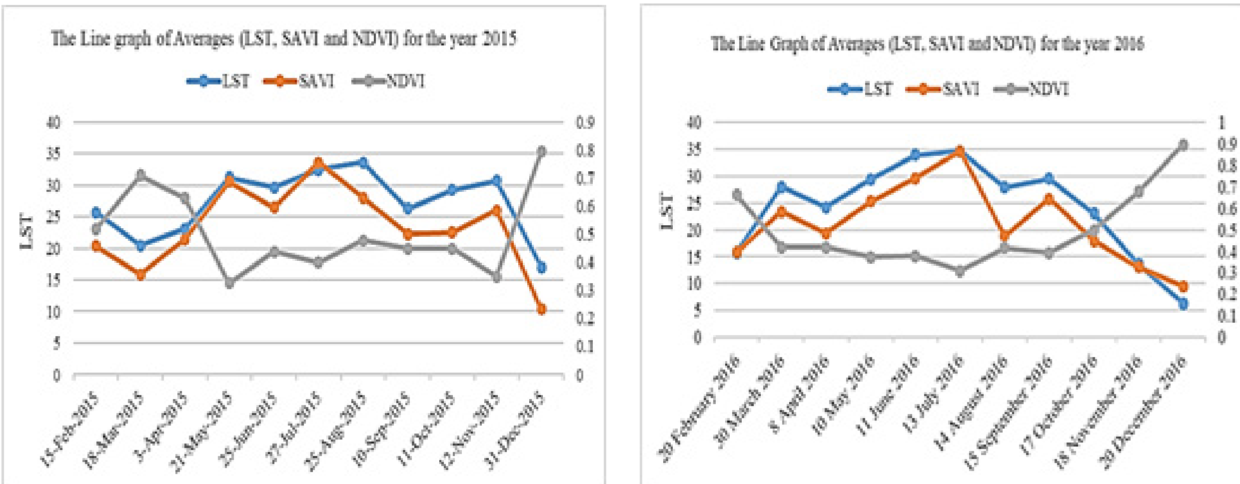
Satellite images comparison

The averages of the LST, SAVI and NDVI values of each month for both 2015 and 2016 are stated in Figure 2 The results show the average values of the monthly LST values for the study area in both years. On average, the highest LST values (28.3-44.7 °C) on July 13, 2016, during the warming season, the lowest LST values (1.2-10.9 °C) on December 31, 2015, were observed during the cold season. A reverse proportional relationship was observed between the LST and NDVI values, while a directly proportional relationship was found between the LST and SAVI values. When the LST values increased, NDVI values are decreased and SAVI values are increased. The study conducted by Joshi and Bhatt (2012), stated that the areas with vegetation and water body have lower temperatures in comparison to the built-up areas. Yue et al. (2007), found that the average of LST and NDVI values related to varied land use kinds are different significantly.

The relationship between LST-NDVI for the year 2015 in Figure 2 shows that the LST values in May, June, July, August, September, October, and November were higher than other months (February, March, April, and December). In March the LST values were (≈20 °C) and December (≈17 °C), where LST values were the lowest, the NDVI values reached the highest values with 0.71 and 0.79 values, respectively. Whereas the relationship between LST-NDVI for the year 2016 in Figure 2 (b), shows that the LST values in March, April, May, June, July, August, and September were higher than other months (February, October, November, and December). In February and December where LST values were the lowest (≈16 °C) and (≈6 °C) respectively, the NDVI values reached the highest values with 0.66 and 0.89 values, respectively. Xingbang et al. (2019), found that there was a negative correlation between LST values and NDVI values, especially in the warm period when solar radiation is sufficient for plant growth, in other words when the stress factor is only rainfall or soil moisture. Nivedha Deve et al. (2017) in a study conducted in the Thuraiyur Taluk region of India between 2013 and 2016, the relationships between LST and NDVI values were determined and they reported that these relations were negative and their coefficients were -0.763 for 2013 and -0.685 for 2016.

Land surface temperature (LST)

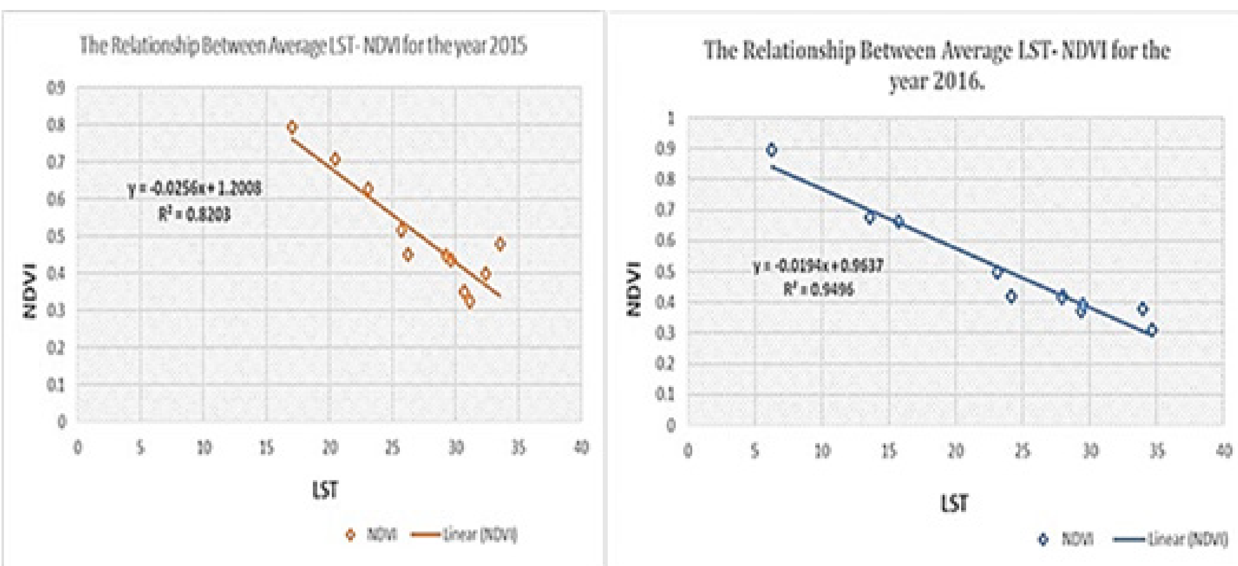
The last LST map of the Landsat 8-TIRS scene was calculated automatically by using the thermal bands (Band10 and Band11), after inputting required bands into the LST tool. Results in Figure 4 below indicate that the highest LST values was observed on July 13, 2016 (28.3-44.7 °C), and the lowest temperatures on December 31, 2015 (1.2-10.9 °C) respectively. The northern part of the study area was found to be the hottest part due to the bare land or low vegetation cover, while the southern part was found to be the coolest due to the cultivated areas. Results in Figures 3 below show that there was a negative proportional relationship and correlation (-0.91 for the year 2015; and -0.97 for the year 2016) between LST and NDVI values. According to study results, Lower NDVI values (≈0.23) were attained on July 13, 2016, due to low cropping intensities that leading to high LST (28.3-44.7 °C) values, because the soil moisture was not sufficient for the healthy growth of the crops. These results agreed with Gaikwad and Kale (2015), where they reported that the NDVI value was -0.143 and the SAVI value was less than 0.5 and according to these results, they stated that the soil moisture was not sufficient for the healthy growth of the plants. The regression between LST and NDVI clearly shows a negative proportion and strong relationship. Regression analysis between the average LST and NDVI shows that R^2 values were 0.82 for the year 2015 and 0.95 for the year 2016 (Figure 3). This result agreed with Gorgani et al. (2013), where they found that R^2 between LST and NDVI = 0.64. They also stated that LST values are the lowest and NDVI values are the highest and therefore the land surface temperatures are high in places where vegetation is low or bare soil. Deng et al. (2018), in a study conducted in China, Deng et al. (2018), investigated the relationships between LST and NDVI values depending on the land use pattern, and the R^2 values of the relationship were 0.382 for forest areas; 0.2058 for construction sites; 0.2688 for cultivated land and 0.135 for grazing land.



(a) (b)

Figure 2. Average values of LST, SAVI, and NDVI for 2015 (a) and 2016 (b)

Şekil 2. *2015 (a) ve 2016 (b) yıllarına ait aylara göre ortalama LST, NDVI ve SAVI değerleri*



(a) (b)

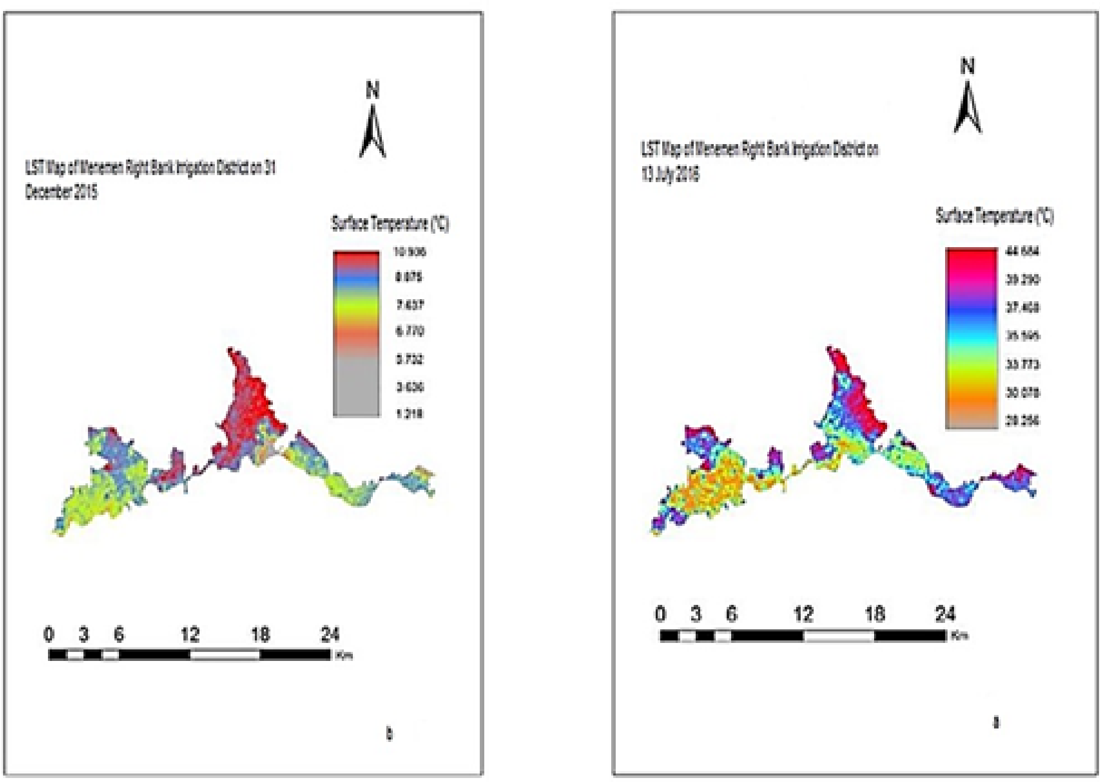
Figure 3. Relationship between average values of LST and NDVI for 2015 (a) and 2016 (b)

Şekil 3. *2015 (a) ve 2016 (b) yıllarında LST ve NDVI ortalamaları arasındaki ilişki*

For LST index maps (Figure 4), the blue color indicates low surface temperatures, while the red color indicates areas with high surface temperatures. In Figures 4 (a, b), are presented the LST maps of the Menemen Right Bank Irrigation District for the years, 2015 and 2016 are presented. The surface temperature for the year 2016 has high values in the northern parts of the area, while, for 2015 the surface temperature was observed in the northern and eastern parts of the area. The highest LST values range between 28.3 - 44.7 °C on July 13, 2016 Figure 4 (a), while, the lowest LST values ranged between 1.2-10.9 °C on 31 December 2015 in Figure 4 (b). Kayet et al. (2016), studied the relationship between LST and vegetation indicators (NDVI, RVI, SAVI), where he stated that there was negative correlation between them. They also reported that the negative correlations were as follows: poor negative correlation value for RVI (R^2 = 0.12), good negative correlation in SAVI (R^2 = 0.47), and moderate negative correlation in NDVI (R^2 = 0.34). Kumar and Shekhar (2015), reported that the NDVI and the LST have a contrasting tendency can be seen as entire in spatial variation, NDVI values in the urban fringe areas were significantly greater than those in urban centers when the LST values of the urban areas were significantly greater in comparison to fringe areas.

Normalized difference vegetation index (NDVI)

NDVI, which is the most widely used in the monitoring and interpretation of vegetation changes, was proposed as an index of vegetation health and density. NDVI is a good indicator of green biomass, leaf area index and production pattern.



(b) **(a)**

Figure 4. The LST maps of the Menemen Right Bank Irrigation District for the years 2015 (b) and 2016 (a)

Şekil 4. *Menemen Sağ Sol Sahil Sulama Bölgesinin 2015 (b) ve 2016 (a) yıllarına ait LST haritaları*

The highest NDVI values for the years 2015 and 2016 were recorded during the irrigation season, with an obvious increase during May- September for the year 2015, and during June only for the year 2016 (Figures 2 a, b). In the year 2016 the highest NDVI values showed in western and eastern parts of the area, while the lowest NDVI recorded in the central part of the area for the year 2015 (Figure 6). The results show a negative relationship and correlation between NDVI and SAVI in the years 2015 and 2016 with values -0.88 (R^2 = 0.77), and -0.87 (R^2 = 0.76), respectively Figures 5 (a, b). Gündoğdu and Benjamin (2018), determined the parcel-based distribution of NDVI values by using 29 Landsat satellite images covering the farmland of Uludağ University, Faculty of Agriculture between 2013-2017 and created NDVI maps. They also revealed the relationship between the yields of wheat, corn, sunflower and clover products and NDVI values in the plots. They found the highest relationship (R^2) as 0.945 between the images obtained during the flowering period and yield. Vani (2017), investigated the relationship between NDVI and SAVI for different land-use situations in India. He stated that R^2 value between NDVI and SAVI was 0.999 depending on the land use method. In China, Lu et al. (2015) determine the relationship between NDVI and SAVI values depending on the land use method, they reported that the correlation coefficients were as follows: 0.9422 (for forest areas), 0,9849 (for large plains), 0.9773 (for mixed forest), 0,9998 (for cultivated land) and 0,9999 (for pastureland).

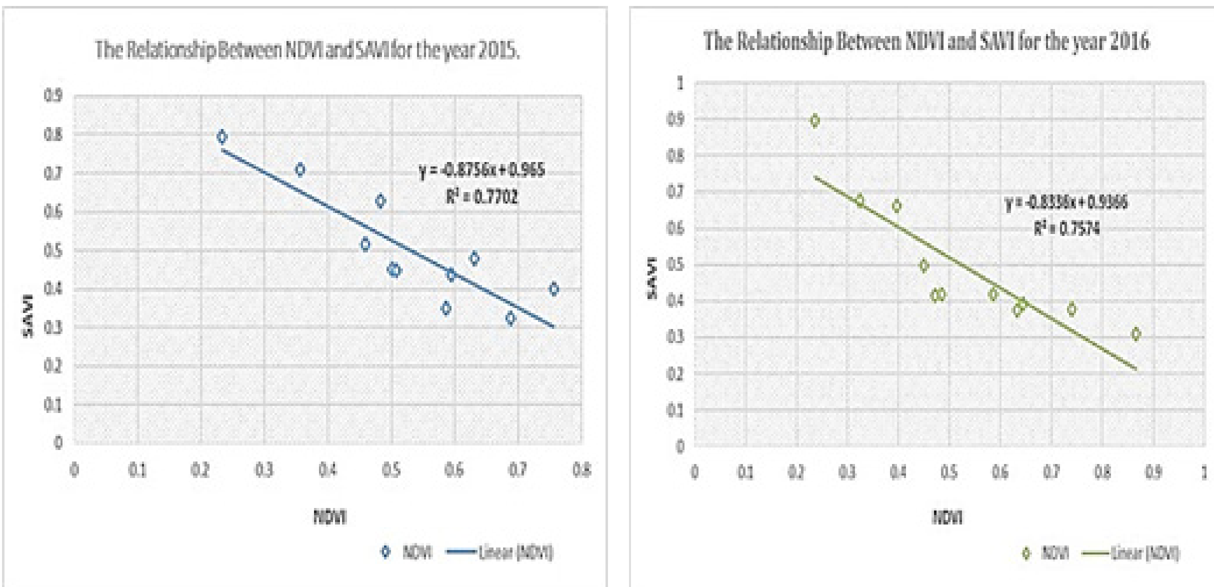


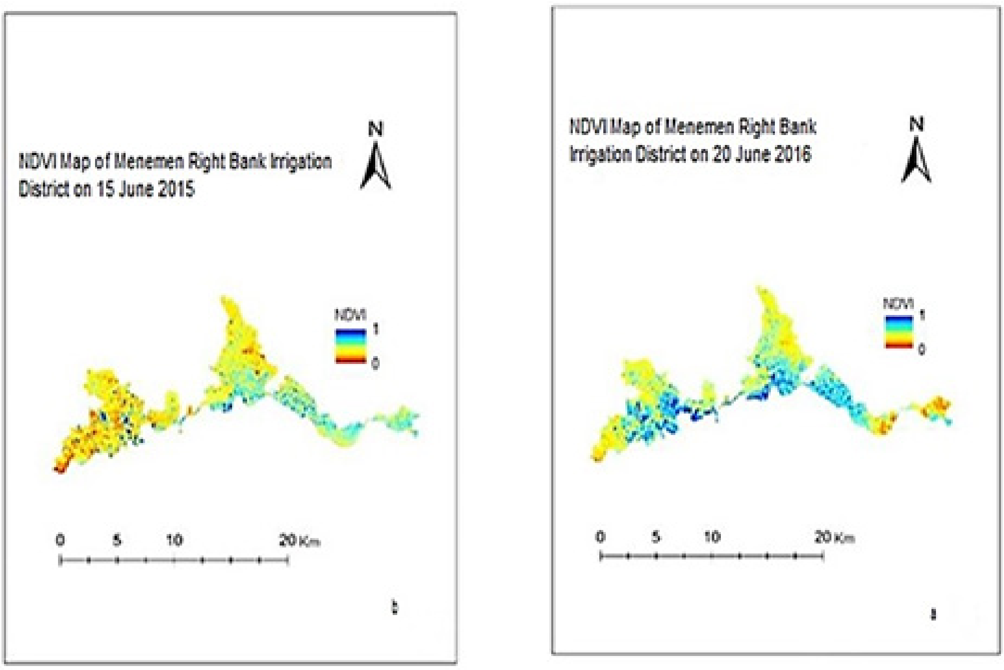
Figure 5. Relationship between average values of NDVI and SAVI for 2015 (a) and 2016 (b)
Şekil 5. *2015 (a) ve 2016 (b) yıllarında NDVI ve SAVI ortalamaları arasındaki ilişki*

Soil adjusted vegetation index (SAVI)

Results of SAVI for both years (2015 and 2016) are stated in Figure 2 (a, b) above. For the year 2015, SAVI in February, March, April, and December showed the lowest values compared to the remaining month of the year. The lowest LST values were observed in March (≈20 °C) and December (≈17 °C). The SAVI values reached the lowest values with 0.36 and 0.23. For the year 2016, the lowest value of SAVI was observed in February, April, August, October, November and December compared to another month of the year. LST values in February were 16 °C with 0.39 SAVI, while in December was 6 °C with 0.24 SAVI. The regression results between LST and SAVI values are shown in Figure 7 (a, b) below. The strong and direct relationship between LST and SAVI was found with 0.87 R^2 for both studied years. Many studies stated that there was a negative correlation between SAVI and LST, and LST values for all study periods tend to be negatively correlated with SAVI values (Hishe et al. 2017; Vani and Mandla, 2017; Wiesam et al., 2012).

SAVI index maps

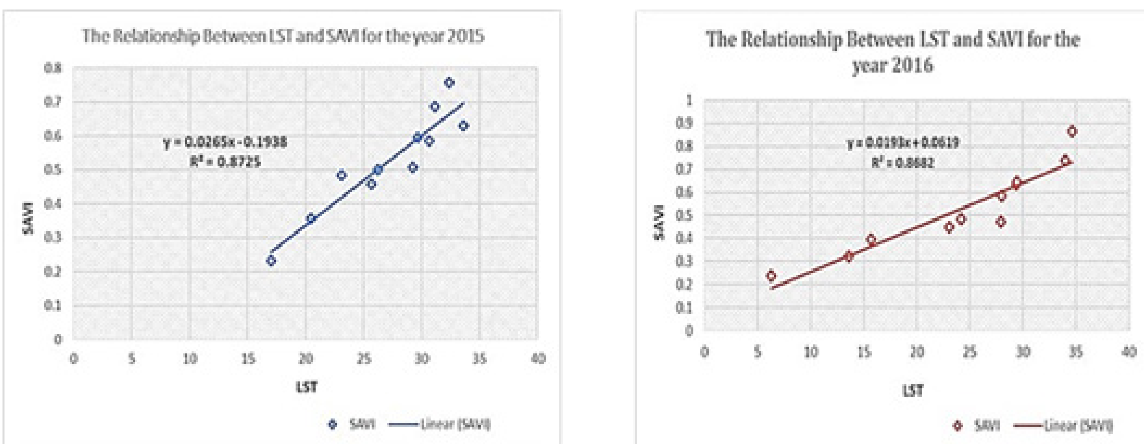
SAVI depicted maps in Figure 8 (a, b) below, show that the highest SAVI during the irrigation season was observed on 15 June 2015, in the western and eastern parts of the area, however the lowest SAVI values were mostly remarked on 20 June 2016 and it was concentrated in the central and western parts of the area.



(a) **(b)**

Figure 6. NDVI maps for 2015 (b) and 2016 (a)

Şekil 6. *2015 (b) ve 2016 (a) yıllarına ait NDVI haritaları*

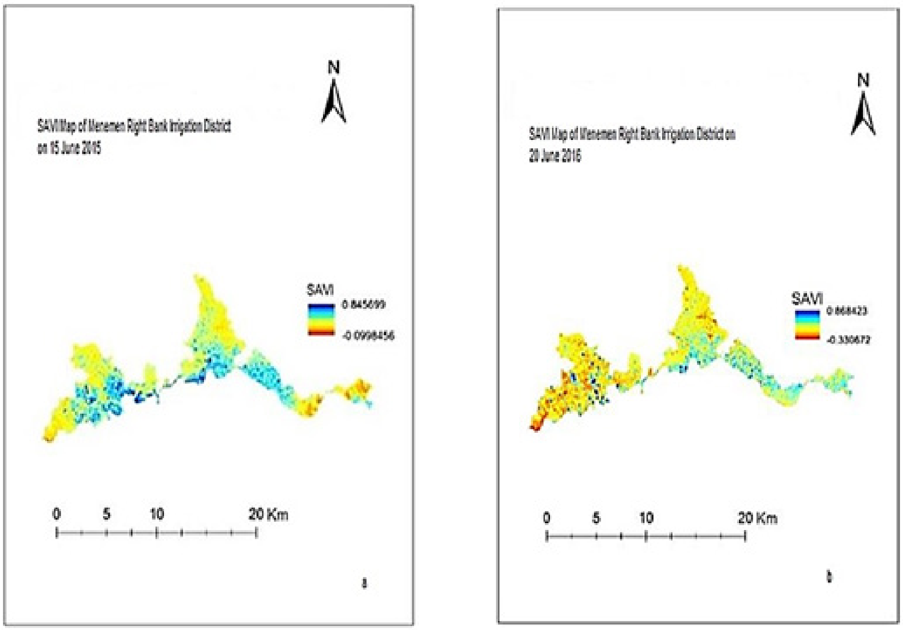


(a) **(b)**

Figure 7. Relationship between average values of LST and SAVI for 2015 (a) and 2016 (b)

Şekil 7. *2015 (a) ve 2016 (b) yıllarında LST ve SAVI ortalamaları arasındaki ilişki*

Saini et al. (2016), reported that there was a negative correlation between LST and SAVI, where the LST values were high, while SAVI values were low. Moreover, they stated that both LST and SAVI values were low in areas covered with water. They stated that the reason for the LST increase was due to low vegetation in that areas. Regarding this, Gaikwad and Kale (2015) found the NDVI value below -0.143 and the SAVI value below 0.5 and they stated that soil moisture content was insufficient for the healthy growth of the plants. Lu et al. (2015), investigated the relationships between NDVI and SAVI values depending on the land use method and found that the correlation coefficients of the relationship were 0.9422 for forest areas; 0,9849 for large plains; 0.9773 for the mixed forest; 0,9998 for cultivated land and 0,9999 for pastureland.



(a) **(b)**

Figure 8. SAVI maps for 2015 (a) and 2016 (b)

Şekil 8. *2015 (a) ve 2016 (b) yıllarına ait SAVI haritaları*

CONCLUSION

During the irrigation season of both study years (May, June, July, August, and September), NDVI values were generally lower than other months, while SAVI values were higher. When the NDVI values were the highest (0.71; 0.79) in March and December of the year 2015, the LST values were the lowest; and SAVI values were the lowest (0.36; 0.23). Moreover, in February and December of 2016, when the LST values were the lowest, the NDVI values were the highest (0.66; 0.89); SAVI values were the lowest (0.39; 0.24). NDVI values, which are one of the important indicators of drought, were generally lower in the irrigation season. For this reason, producers and water users may be advised to use water resources more carefully and manage irrigation more effectively in order to minimize the possible drought damage. The complexity of the drought phenomenon discourages our full understanding of their impact. This paper has shown that the effects of drought on vegetation can be highly diverse, varying with different factors including, land-use, and vegetation characteristics. Furthermore, there may be other significant factors not included in this study that also can impression the spatial differences in the influence of drought on vegetation.

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