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The Examination of the Relationship between Drought and Vegetation in Coastal Regions of Turkey Using the Vegetation Condition Index (VCI) and the Vegetation Health Index (VHI)

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Abstract

Enriching climate data via satellite imagery and full, up-to-date and detailed monitoring of current drought conditions is of great importance. In this study, drought analysis was performed using 16 daily and monthly temporal resolution and 250 m and 1 km spatial resolution satellite data of TERRA platform's MODIS satellite. Thus, both the information gathered about the drought has been confirmed and the question what is the best method of reflecting drought conditions has been answered. This study's findings show that satellite based plant index provides significant convenience in understanding and predicting drought. In this study, Turkey's vegetation with rich biodiversity in the coastal areas is examined for its relationship with drought conditions. In this regard, as a result of station-based drought analysis, some years have been identified as dry seasons. In some seasons coastal areas receive high rainfall. During the arid year, significant declines in the photosynthesis activity of the vegetation have been detected. These declines have been reflected both in VCI and VHI index values. In this study, more than one satellite based arid indexes have been used. Thus, the results have been confirmed. According to the results of the study, 44,6% of Turkey's coasts are not affected by the stress conditions the drought caused on plants. This rate is quite high compared to the interior regions of Turkey. In the interior regions of Turkey, the rate of vegetation affected by meteorological drought-based stress is about 80%, whereas in the coastal areas this rate is about 50%

Keywords: *Drought, Turkey, Vegetation, VCI, VHI.*

Introduction

Monitoring drought with remote sensing technique is a relatively new methodology. Enriching climate data via satellite imagery and full, up-to-date and detailed monitoring of current drought conditions is vital. Especially for countries like Turkey which meteorological station networks are undeveloped, traditional methods lack detailed results covering large areas. Monitoring drought with remote sensing provides significant convenience in predicting drought and achieving accurate results (Çelik and Karabulut, 2015).

Remote sensing based drought analyses have been used in this study. The aim of this study is to examine Turkey's vegetation's reactions to the drought conditions. The reactions are examined with the support of remote sensing data. Because, drought can harm vegetation as much as it harms human beings. In this sense, the examination of the relationship between drought and vegetation is significant both for detecting the beginning of the drought and setting forth the spatial effects of drought (Figure 1).

Name	Acronym	Category	Inputs	Sensor(s)
Enhanced Vegetation Index	EVI	Vegetation	Sat	MODIS (+/- AVHRR)
Normalized Difference Vegetation Index	NDVI	Vegetation	Sat	AVHRR
Vegetation Condition Index	VCI	Vegetation	Sat	AVHRR
Vegetation Health Index	VHI	Vegetation	Sat	AVHRR
Soil Adjusted Vegetation Index	SAVI	Vegetation	Sat	MODIS
Temperature Vegetation Dryness Index	TVDI	Vegetation	Sat	MODIS
Optimized Vegetation Drought Index	OVDI	Vegetation/ Drought		
Vegetation Drought Response Index		Vegetation/ Drought	Sat+	
Evaporative Stress Index	ESI	Vegetation/ Water	Sat+	AVHRR
Water Requirement Satisfaction Index	WRSI	Vegetation/ Water	Sat+	NOAA Rainfall Estimates (RFE)+
Normalized Difference Water Index	NDWI	Vegetation/ Water	Sat	MODIS
Land Surface Water Index	LSWI	Vegetation/ Water	Sat	MODIS
Combined Drought Indicator	CDI	Drought	Sat+	MODIS (fAPAR)+
Perpendicuar Drought Index	PDI	Drought		
Modified PDI	MPDI	Drought		
Precipitation Condition index	PCI	Water		MODIS, TRMM
Soil Moisture Condition Index	SMCI	Water		
Optimized Meteorological Drought Index	OMDI	Water		
Temperature Condition Index	TCI	Temperature	Sat	AVHRR

Figure 1. Remote Sensing for Drought Monitoring (Source: http://www.un-spider.org/).

Turkey, in particular, is a place where drought conditions often occur (Türkeş, 1996). In this respect, Turkey, which hosts rich biodiversity, has been chosen as a field of study (Figure 2). Monitoring Turkey's vegetation and achieving the answer relating how plants are affected by natural climatic conditions is of great importance for the protection of the biodiversity here.

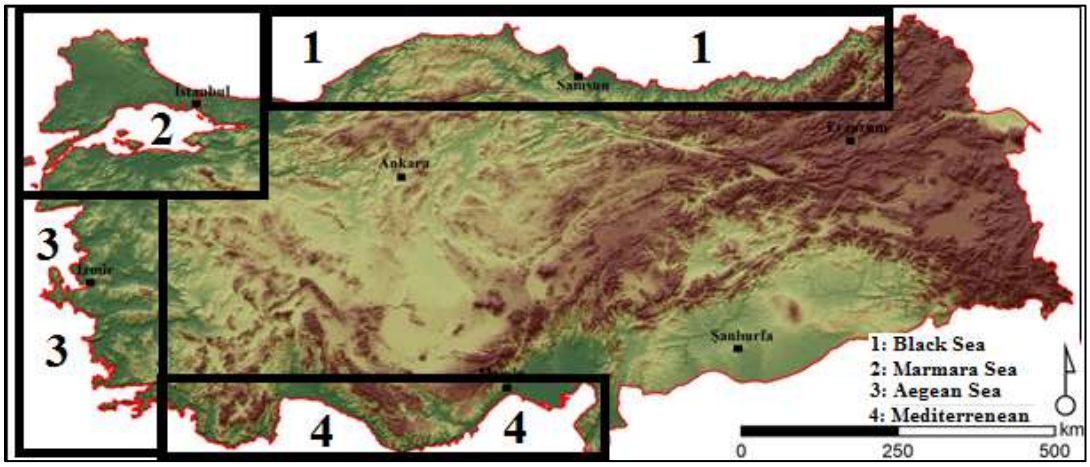

Figure 2. Field of study.

DATA AND METHOD

this study, the relationship between vegetation stress conditions and drought in Turkey's coastal areas which host significant biodiversity and forest wealth was examined.

In this study, data from the TERRA platform's MODIS satellite was used. With this aim, MOD13Q1 data was derived from USGS Earth Explorer (http://earthexplorer.usgs.gov/). This data has 16-day temporal, 250 m spatial resolution.

VCI, which means normalization of NDVI in pixels over a period of time, was developed by Kogan (1990;1995). VCI's aim is to filter geographical resources' contribution to NDVI's spatial variability and by doing so relatively evaluating changes in NDVI's signs. Studies show that, VCI has a high level of accuracy predicting drought and exhibiting drought's effects on vegetation (Ganesh, 2007; Quiring and Ganesh, 2010; Shahabfar et al., 2012). VCI is calculated as follows:

According to the formula, NDVI represents the mean NDVI value, NDVImin represents the minimum NDVI value in the year, NDVImax represents the maximum NDVI value in the year. The formula gives results in a range of 0-100 values. This range refers to the percentage. For example, the value 25 represents 25% (Karabulut, 2006). According to the formula, NDVI represents the mean NDVI value, NDVImin represents the minimum NDVI value in the year, NDVImax represents the maximum NDVI value in the year.
Finally, vegetation's healthy conditions in wet and dry seasons were monitored. A formulation developed by Kogan in 2001 was used for this purpose (Kogan, 2001; Kogan, 2002; Kogan et.al., 2004; Karnieli et.al., 2006). VHI is calculated as follows:

This equation is as follows: The equation results in an image consisting of values from 0 to 100. While 100 shows that the vegetation is 100% healthy, 0 shows that vegetation is fully dried and 0% healthy.

The resulting percentage of the observed value is situated between the extreme values (minimum and maximum) in the previous years. Lower and higher values therefore indicate bad and good vegetation state conditions, respectively (Figure 3).

Value	Category
90 - 100 %	No Drought
80 – 90 %	No Drought
70 – 80 %	No Drought
60 – 70 %	No Drought
50 – 60 %	No Drought
40 – 50 %	No Drought
30 – 40 %	Light Drought
20 – 30 %	Moderate Drought
10 – 20 %	Severe Drought
0 – 10 %	Extreme Drought

Figure 3. Categorization of VHI results
Source: http://www.unspider.org/book/export/html/9206)

Results

The structure and functions of forest ecosystems largely depend on the climate. Depending on the changes in climatic conditions, the forest' structure and function undergo changes. Turkey is one of the places where climatic conditions change largely over the years (Ölgen, 2010). Climatic variability is one of the most important factors affecting the vegetation presence along with the human factor. Studying the relationship between drought and Turkey's coastal regions, which contain a large part of Turkey's forest wealth, is significant in the context of protecting vegetation by understanding the reactions of vegetation to the drought conditions.

Table 1. Distribution of Turkey's forest wealth by region (Source: https://www.ogm.gov.tr/SitePages/OGM/OGMDefault.aspx).

Regions	%		%
Black Sea	24.48	The coast	78.53
Aegean	16.85		
Mediterranean	24.3		
Marmara	12.9		
Eastern Anatolia	10.83	Interior Parts	21.47
Central Anatolia	7.54		
Southeast	3.1		

VHI is vegetation's health index, in other words, it reflects plants' high or low photosynthesis activity. The average VHI of the last 19 years (2000-2018) for the Black Sea is 59% (Figure 4). 2010 was a very wet period in the Black Sea Region. The average VHI value during this period was around 64%. In the entire Black Sea Region, 2014 was a very dry period. During this period, 46% of the vegetation was under drought-related stress conditions (Table 1).

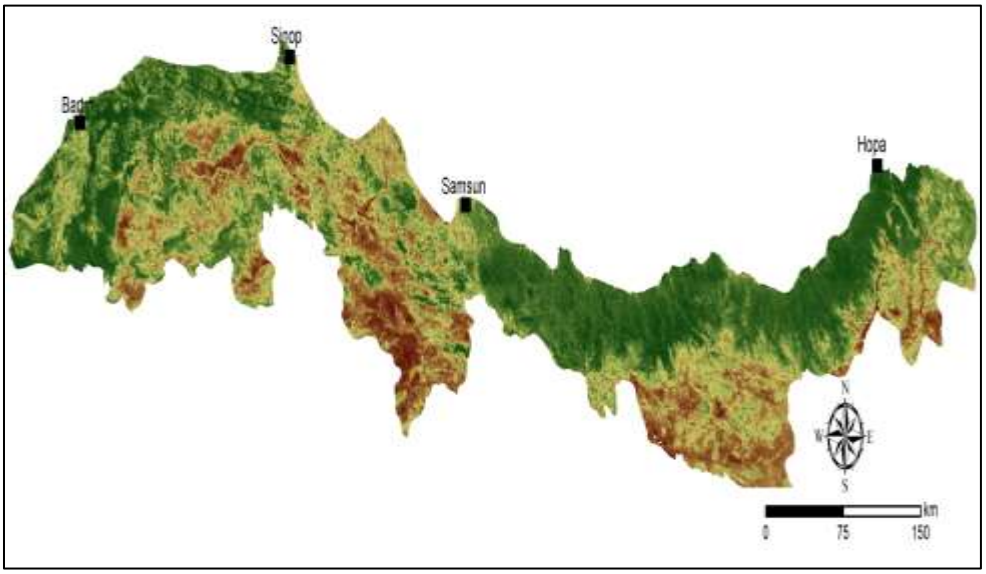

Figure 4. A VHI map obtained from the last 19 years' (2000-2018) composite images of the Black Sea region.

The average value covering 2000-2018 is 43% for Marmara Region (Figure 5). In other words, according to the VHI average of Marmara Region, 57% of the region is affected by the stress conditions drought causes. 2010 was an extremely wet period in the Marmara region. The average VHI value in the region during this period was 46%. In other words, in 2010, which was wet, areas that were not affected by stress conditions increased by 3%. During this period, the soil and plant were saturated with water. In the entire Marmara Region, 2005 was a very dry period. During this period, 60% of the vegetation was under drought-related stress conditions. The rate for the vegetation that were not affected by the drought based stress conditions was 40%. While the rate for the plants that are under vegetative stress increases 3% during extremely dry periods, the rate decreases 3% during wet periods (Table 2).

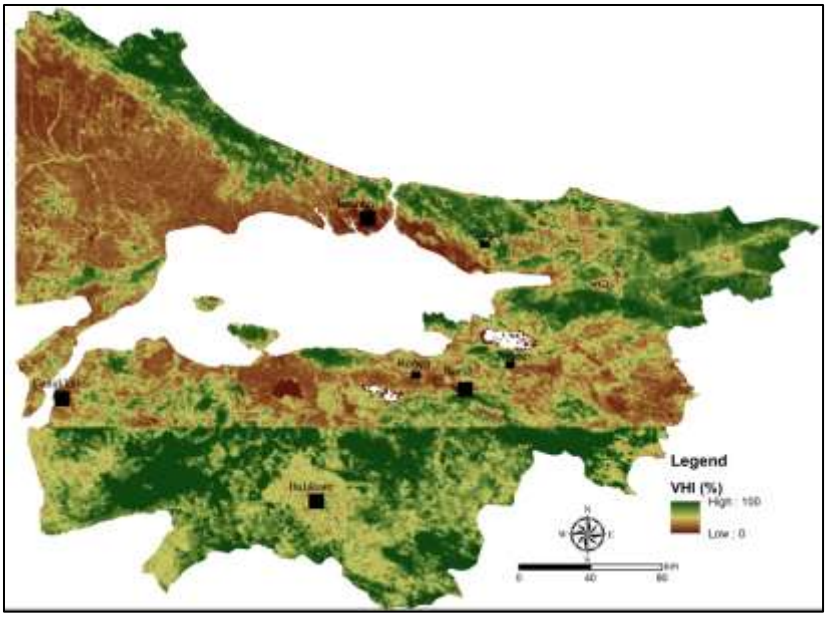

Figure 5. VHI map obtained from the last 19 years' (2000-2018) composite images of the Marmara region.

The average of VHI covering the years 2000-2018 is 40% in the Mediterranean Region (Figure 6). 2005 was a very dry period in the Mediterranean region. On the other hand, 2010 was a year dominated by exceptionally wet climate features. Drought-based stress conditions increase during the arid period. During wet period, stress conditions decrease. In 2005, the vegetation stress rate was 62%. In the wet period of 2010, the vegetative stress rate was 55% (Table 2).

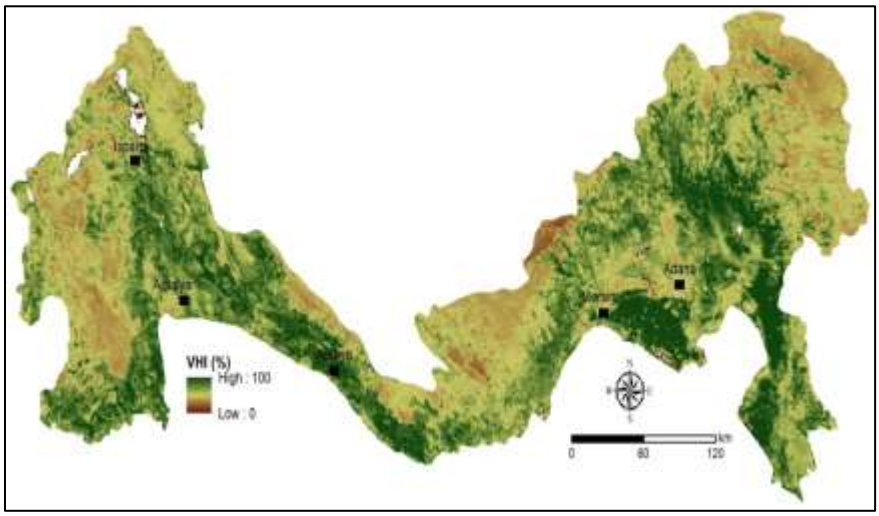

Figure 6. VHI map of the Mediterranean region obtained from the last 19 years' (2000-2018) composite images.

The average of VHI covering the years 2000-2018 is 42% in the Aegean region (Figure 7). In other words, according to the last 19 years' data average, the vegetative stress rate is 58% for Aegean Region. This rate varies depending on the climate being wet or dry. For example, in 2010 climate was humid and during this period the stress rate decreased from 58% to 55%. In 2005, however, the climate was quite dry. And during this period, the drought-based stress rate increased up to 63% (Table 2).

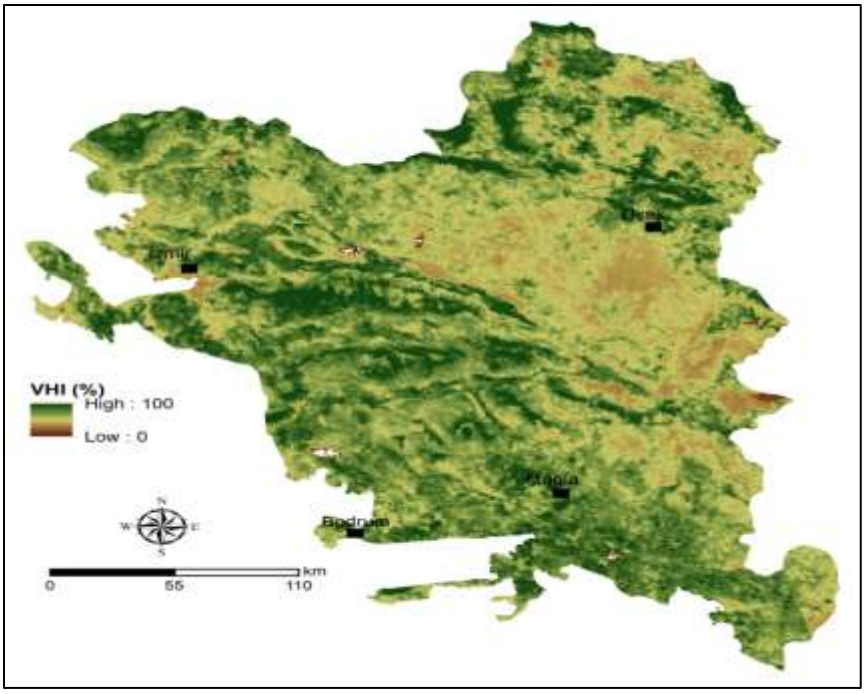

Figure 7. VHI map obtained from the last 19 years' (2000-2018) compound images of the Aegean region.

Table 2. Table demonstrating the relationship between drought and VHI values.

Years/Regions	Black Sea	VHI (%)	Aegean	VHI	Marmara Sea	VHI	Mediterranean	VHI
2000	Moderately Moist	58	Normal	42	Normal	42	Moderately Dry	40
2001	Severely Dry	56	Moderately Dry	40	Moderately Dry	41	Moderately Dry	40
2002	Moderately Moist	57	Moderately Moist	43	Abnormally Moist	44	Exceptionally Moist	44
2003	Normal	58	Abnormally Moist	42	Normal	43	Normal	41
2004	Normal	57	Very Moist	45	Normal	43	Extremely Moist	43
2005	Normal	58	Exceptionally Dry	37	Moderately Dry	40	Severely Dry	38
2006	Moderately Moist	59	Abnormally Moist	41	Abnormally Moist	42	Moderately Dry	38
2007	Moderately Dry	55	Abnormally Dry	40	Abnormally Dry	41	Normal	39
2008	Normal	56	Moderately Dry	40	Moderately Dry	39	Abnormally Dry	38
2009	Abnormally Dry	57	Abnormally Dry	41	Moderately Dry	39	Abnormally Dry	38
2010	Exceptionally Moist	64	Extremely Moist	45	Extremely Moist	46	Exceptionally Moist	45
2011	Abnormally Moist	59	Moderately Moist	44	Exceptionally Moist	47	Normal	40

2012	Moderately Moist	60	Normal	42	Abnormally Dry	42	Very Moist	42
2013	Normal	57	Moderately Moist	43	Moderately Moist	44	Normal	40
2014	Exceptionally Dry	54	Normal	42	Moderately Dry	42	Moderately Dry	39
2015	Normal	57	Very Moist	44	Extremely Moist	45	Normal	39
2016	Moderately Moist	59	Moderately Moist	43	Normal	43	Normal	40
2017	Extremely Moist	61	Abnormally Dry	41	Normal	42	Moderately Dry	38
2018	Moderately Dry	56	Moderately Dry	40	Normal	42	Normal	40

On the coasts of Turkey, 2005 was quite dry and 2010 was exceptionally moist. While VHI values decreased in all regions during dry season, values were above average during moist 2010 period.

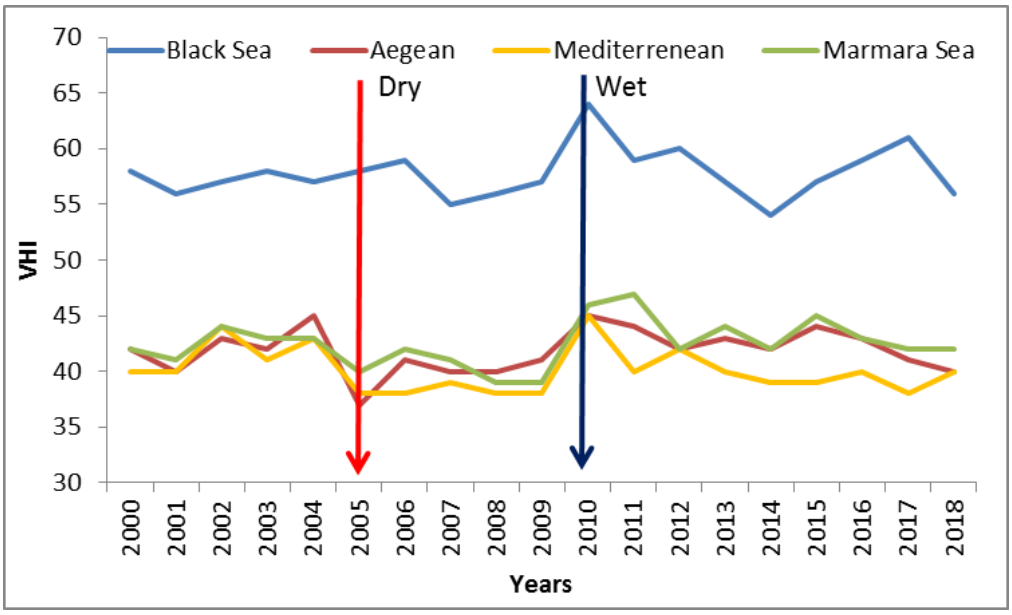

Figure 8. VHI values in dry 2005 and moist 2010, Turkey's coasts.

Conclusions

In this study, an area in the coasts of Turkey was studied. Studying Turkey's coastal areas has two significant reasons. Firstly, these areas experience extreme climatic conditions in recent periods. In other words, for the last periods, extremely wet and extremely dry years in Turkey's coasts have been increasing. Another major importance of the study of Turkey's coasts is that they contain significant forest wealth and are rich in biodiversity which means that Turkey's coasts are the most unique parts of Turkey in terms of biological wealth and forest reserves.

According to the latest data published by Turkey's General Directorate of Forestry in 2018, 29% of Turkey's surface area is covered with forests. Turkey's forest presence rate is closer to the world's statistics. Accordingly, 30% of the world's surface is covered with forests. Turkey's 29% forest wealth is mainly

located in coastal area. In this context, it is important to study forest presence's relationship with drought. So that, the forest's presence can be maintained.

In this study, Turkey's coasts' biodiversity rich vegetation's relationship with draught conditions is examined. In this regard, as a result of station-based drought analysis, some years have been identified as dry seasons. In some seasons coastal areas receive high rainfall. During the arid year, significant declines in the photosynthesis activity of the vegetation have been detected. These declines have been reflected both in VCI and VHI index values. In this study, more than one satellite based arid indexes have been used. Thus, the results have been confirmed. According to the results of the study, 44.6% of Turkey's coasts are not affected by the stress conditions drought causes on plants. This rate is quite high compared to the interior areas of Turkey. In the interior regions of Turkey, the rate of vegetation affected by meteorological drought based stress is about 80%, whereas in the coastal areas this rate is about 50%.

In addition, wet and dry climatic conditions' effects on vegetation are seen especially during and after September, in which plants starts to grow up. In other words, vegetation strongly reacts to the dry and wet climatic conditions between September and December.

According to VHI analysis covering 2000-2018, the healthiest period for the vegetation is the first and the last days of the year. According to the VHI analysis results, the vegetation is at its greenest in this period. Because in this period, due to the increased rainfall, water is sufficient in the soil. Vegetation is at its lowest photosynthesis activity during summer, in which soil lacks water the most.

In the following years, the phenomenon of drought will become a more serious issue and there should be more studies covering drought. The methods used in this study and the findings are of the kind that will serve as a base and source for the related institutions. Therefore, related institutions working on the forest, biodiversity, drought and climate change may further extend their knowledge and skills in understanding draught, using the methods used in this study. Consequently, the damage caused by the drought can be reduced significantly.

Both satellite based and station based drought models have advantages and limitations. In this study, the limitations were eliminated by integrating both methodologies. Thus, more reliable, accurate and detailed results were obtained.

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