Chapter 10
Drought Conditions in Turkey Between 2004 and 2013 Via Drought Indices Derived from Remotely Sensed Data

Nazila Molavizadeh, Elif Sertel, and Hande Demirel

Introduction

Drought is one of the major hazards that has a significant adverse effect on the socio-economy, agriculture, and ecosystem. According to the United Nations Convention to Combat Desertification, drought is defined as "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems" (UN 2014). Evaporation (affected by temperature and wind), soil types and their ability to store water, the depth and presence of ground water supplies and vegetation are among the most important parameters that influences occurrence of drought. Each drought year is unique in its climatic characteristics and impacts, because drought is related to the timing and the effectiveness of the precipitation. Therefore, it is impossible to make a definition of drought that can be universally accepted (Li and Xiao 1992; Wilhite 1993). Drought can be described by three characteristics: spatial coverage, duration and

N. Molavizadeh (✉)
Satellite Communication & Remote Sensing Program, Department of Advanced Technology, Informatics Institute, Istanbul Technical University, Maslak, 34469 Istanbul, Turkey
e-mail: nazila.itu@gmail.com

E. Sertel
Geomatics Engineering Department, Istanbul Technical University, Maslak, 34469 Istanbul, Turkey

Center for Satellite Communications and Remote Sensing, Istanbul Technical University, Ground Receiving Station, Maslak, 34469 Istanbul, Turkey
e-mail: sertele@itu.edu.tr

H. Demirel
Geomatics Engineering Department, Istanbul Technical University, Maslak, 34469 Istanbul, Turkey
e-mail: demirelha@itu.edu.tr

P. Grammelis (ed.), *Energy, Transportation and Global Warming*, Green Energy and Technology, DOI 10.1007/978-3-319-30127-3_10

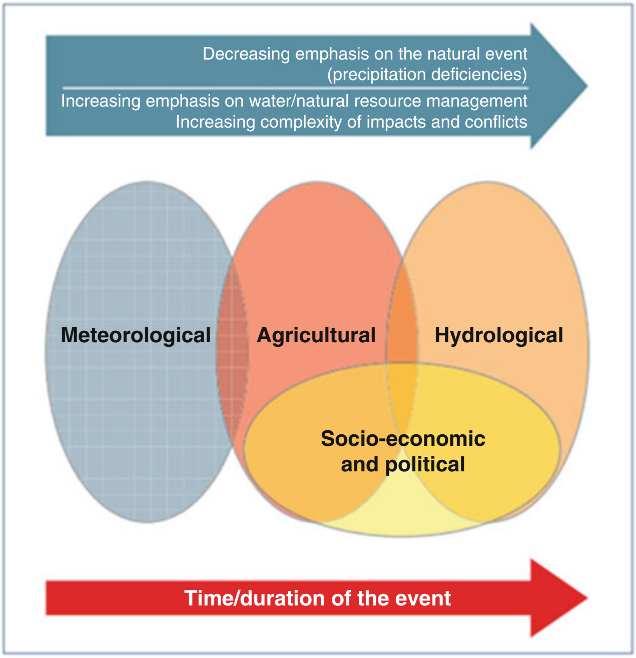

Fig. 10.1 Interrelationships between meteorological, agricultural, hydrological and socioeconomic drought (NDMC 2014)

intensity (Wilhite and Glantz 1985). Briefly, according to (Heim 2002; Keyantash and Dracup 2002), meteorological drought is a precipitation deficit, agricultural drought is a total soil moisture deficit, hydrological drought is a shortage of stream flow, and socioeconomic drought is associated with the shortage of any economic goods affected by the drought process. The relationship between meteorological, agricultural and hydrological drought is illustrated in Fig. 10.1 (NDMC 2014).

According to climate change scenarios such adverse impacts will gain speed in the near future especially for certain locations of the world, including Turkey and its neighborhood. Hence, monitoring its severity has a vital importance. This requires understanding historical droughts in the region as well as impacts of droughts during their occurrences. However, monitoring drought presents various challenges such as inadequate data collection networks with respect to density of stations, high cost of data and insufficient data sharing, difficulties in forecasting, insufficiencies of drought indices for detecting the early beginning and end of the drought, data integration problems such as soil parameters and socioeconomic indicators, mitigation and response programs needs to be regional, therefore regional assessments are required and data sharing and dissemination is limited (WMO 2006). Several of these challenges could be eased by means of spatial information technologies. Remote sensing based drought indices are becoming more popular, since it is possible to determine spatio-temporal distribution of droughts. Remote sensing satellites could monitor large areas rapidly, accurately, periodically, economically and have been widely used to examine drought impacts.

In order to analyze the possibilities of remote sensing based drought indices, three different indices namely Temperature Condition Index (TCI), Vegetation Condition Index (VCI) and Vegetation Health Index (VHI) were generated to determine drought conditions in Turkey for the last decade. MODIS-derived Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) values were used to derive these indexes. NDVI values could be used to identify healthy and unhealthy vegetation, where LST values derived from thermal bands indicates the variations in temperature. Since, LST and NDVI are negatively correlated; drought areas and periods could be investigated for the research area. The paper is set out as follows: Section “Introduction”, introduces the problem and the aim of the study. Section “Data and Methodology” covers case study area, the data and methodology used. In Section “Results and Conclusion”, the achieved results, problems encountered, major findings and conclusions from the study is presented.

Data and Methodology

The development of remote sensing, spatial drought monitoring and assessment has become possible in the last decades (Kanellou et al. 2008). Remote Sensing data presents significant advantages and is the integral part of monitoring drought, especially for the spatial and temporal evolution. A number of satellite drought-monitoring indices are developed based on the Advanced Very High Resolution Radiometer (AVHRR) of National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellite series, MODIS (Moderate Resolution Imaging Spectroradiometer) and others. Historically, the most commonly used remote sensing tool for large-area drought monitoring has been the daily orbiting National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), partially because there is now a sufficiently long time series to let for the identification of anomalies to compare to “normal” conditions. MODIS is superior to AVHRR because it provides higher spatial and spectral resolutions, improved atmospheric corrections and more precise geolocation. When compare the MODIS and AVHRR data sets such as NDVIAVHRR with NDVIMODIS atmospherically corrected MODIS NDVI generally displays a higher dynamic range than atmospherically corrected AVHRR NDVI. This is attributed to the small bandwidth of MODIS (Huete et al. 2002; IWMI 2014). Within this study, The Moderate-resolution Imaging Spectroradiometer (MODIS) data is used. MODIS sensor was launched into Earth orbit by NASA in 1999 on board the Terra (EOS AM) Satellite, and in 2002 on board the Aqua (EOS PM) satellite. The MODIS has 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm and at varying spatial resolutions (two bands at 250 m, five bands at 500 m and 29 bands at 1 km). Together the instruments image the entire Earth every 1–2 days.

They are designed to supply measurements in large-scale global dynamics, including changes in Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere. More information on MODIS data could be obtained from NASA web-page (NASA 2014). Products of one of the well known satellite system, MODIS, have been used for numerous research applications including mapping deforestation, identifying desertification and crop yield estimation, natural and non-natural disasters—such as floods and droughts—in many areas due to the its high temporal resolution and coverage. Terra MODIS monthly composite NDVI images of 1 km resolution and Terra MODIS 8-day composite LST of 1 km resolution were used in this research for the period 2004–2013.

The three remote sensing based drought indices, Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI) were generated and analyzed to determine drought conditions in Turkey for the last decade.

Vegetation Condition Index (VCI): Kogan (1987) proposed a vegetation condition index based on the relative NDVI change with respect to minimum historical NDVI value. VCI is pixel based normalization of NDVI values. The basic assumption is that drought conditions will weaken the growth of vegetation resulting in lower NDVI values in multiyear NDVI values (Du et al. 2013; Kogan 1995). VCI is a good indicator of drought stress and its values scaled between 0 and 1. In case of very dry month, vegetation conditions will be weakened and the value will close to zero whereas a VCI value of 0.5 reflects fair vegetation conditions (Du et al. 2013). It is defined as following:

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{10.1}$$

where NDVI, $NDVI_{max}$, and $NDVI_{min}$ the smoothed monthly NDVI, multi-year maximum NDVI and multi-year minimum NDVI, respectively, for each grid cell.

Temperature Condition Index (TCI): is a remote sensing based thermal stress indicator that is used to quantify temperature component of droughts. There is a higher LST in the drought year than the same month of normal years and this index assumes that drought event will decrease soil moisture and cause land surface thermal stress (Du et al. 2013; Kogan 1995). TCI is used to find out thermal stressed regions by using the maximum/minimum temperature in a given time series. Since drought is expected to decrease soil moisture and increase LST values, higher LST values are signal for drought conditions and lower LST values indicates favorable conditions, opposite to the NDVI (Du et al. 2013). Thus, the TCI formula was modified as the following expression 10.2.

$$TCI = \frac{LST_{max} - LST}{LST_{max} - LST_{min}} \tag{10.2}$$

where LST, LST_{max} and LST_{min} are the values of LST, maximum LST and minimum LST of each pixel respectively in the same month during the study period of January 2004–December 2013. The is a good indicator to determine drought and to find out its beginning time, intensity, duration and dynamics. The VCI could be successfully used to define both prolonged and short-term droughts either global or localized (Kogan 1995).

Vegetation Health Index (VHI): is calculated from an empirical formula by giving equal weights to Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI) to reflect the impacts of both temperature and vegetation components. The equation of VHI is below:

$$VHI = 0.5\,(VCI + TCI) \tag{10.3}$$

The TCI indicates areas that are hotter than usual and the VCI's normalized NDVI anomalies identify areas where vegetation is more or less dense than usual. VHI reflects both vegetation cover and temperature anomalies and also it has been widely applied for the early drought warning, monitoring of crop yield and production, and assessment of irrigated areas and extreme wetness (Karnieli et al. 2006) The classification of indices for drought conditions are presented in Table 10.1 (Kogan 2001).

Results and Conclusion

Turkey is located in Anatolia and the Balkans, bordering the Black Sea, between Bulgaria and Georgia, and bordering the Aegean Sea and the Mediterranean Sea, between Greece and Syria. The total land area is about 783,562 km^2, of which 756,816 km^2 are in West Asia (Anatolia) and 23,764 km^2 are in Southeastern Europe (Thrace). Climatic conditions of Turkey vary significantly from one region to another, due to topography and the geo-location of the country. While the coastal regions have milder climates, extreme hot summers with limited rain fall and cold winters are generally experienced at the inner Anatolian plateau (Sensoy et al. 2008). The Aegean and Mediterranean coasts have cool, rainy winters and hot, moderately dry summers. Annual precipitation in those areas varies from 580 to 1300 mm, depending on location. The Black Sea coast receives the greatest amount of rainfall. The eastern part of that receives 2200 mm annually and is the only region of Turkey that receives rainfall throughout the year. Climate types of Turkey are presented in Fig. 10.2 (Atalay and Efe 2012).

In order to automate the process of generating indices and data handling, codes were written in Interactive Data Language programming language and all indices

Table 10.1 Classification of VCI, TCI and VHI drought conditions (Kogan 2001)

VCI, TCI, VHI values * 100	<10	10–20	20–30	30–40	40–60	>60
Drought conditions	Extreme	Severe	Moderate	Mild	Normal	Wet

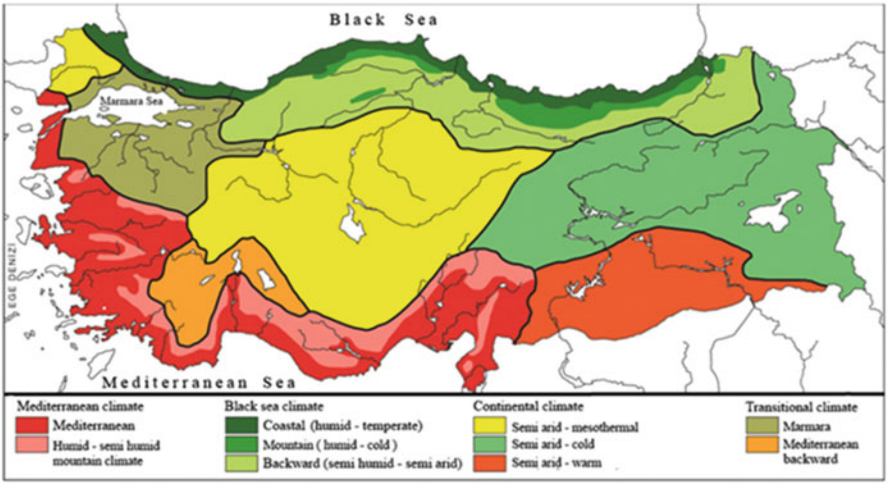

Fig. 10.2 Climate types of Turkey (Atalay and Efe 2012)

were generated automatically. In the last 10 years, Turkey observes two drought periods, the first one start from 2006. This drought period, is observed from November and December of 2006 until December of 2008. This long period between 2007 and 2008 clearly can be observed by analyzing the VCI and VHI maps.

Drought is a slow occurring process starts with precipitation deficits, then causing soil moisture deficits resulted in higher Land Surface Temperature (LST) values. Finally, vegetation growth is affected because of water deficits and temperature increases (Du et al. 2013). In this research LST and NDVI data were used to monitor LST and NDVI anomalies during 10 year period using TCI and VCI indexes. In order to represent both soil moisture deficit and vegetation growth, VHI was calculated using TCI and VCI. VHI values between 40–60 % represent normal conditions whereas VHI values lower than 0.4 represents drought higher than 0.6 represents wet climatic conditions.

TCI is based on LST values and could be used to identify regions that are hotter or colder than usual values. For drought affected regions, higher temperature values resulted in lower TCI values than normal conditions. TCI values lower than 30 % might give the signal of extreme, severe and/or moderate drought conditions. In drought conditions, land surface will have thermal stress and TCI could be used to determine temperature-related drought conditions (Du et al. 2013; Kogan 1995).

VCI is based on NDVI anomaly values and could be used to identify areas where vegetation is more or less than usual values. In normal/usual conditions VCI presents same seasonal pattern and presents higher values in May-September period and lower values in October-April period. Figure 10.3 shows an example of VCI for 2004 a normal year in terms of climatic conditions. As can be seen from the figure VCI values are comparatively higher between May and September. Vegetation response in the May–September period is related to the very wet period from November–April (months where most of the geographic regions receive most of

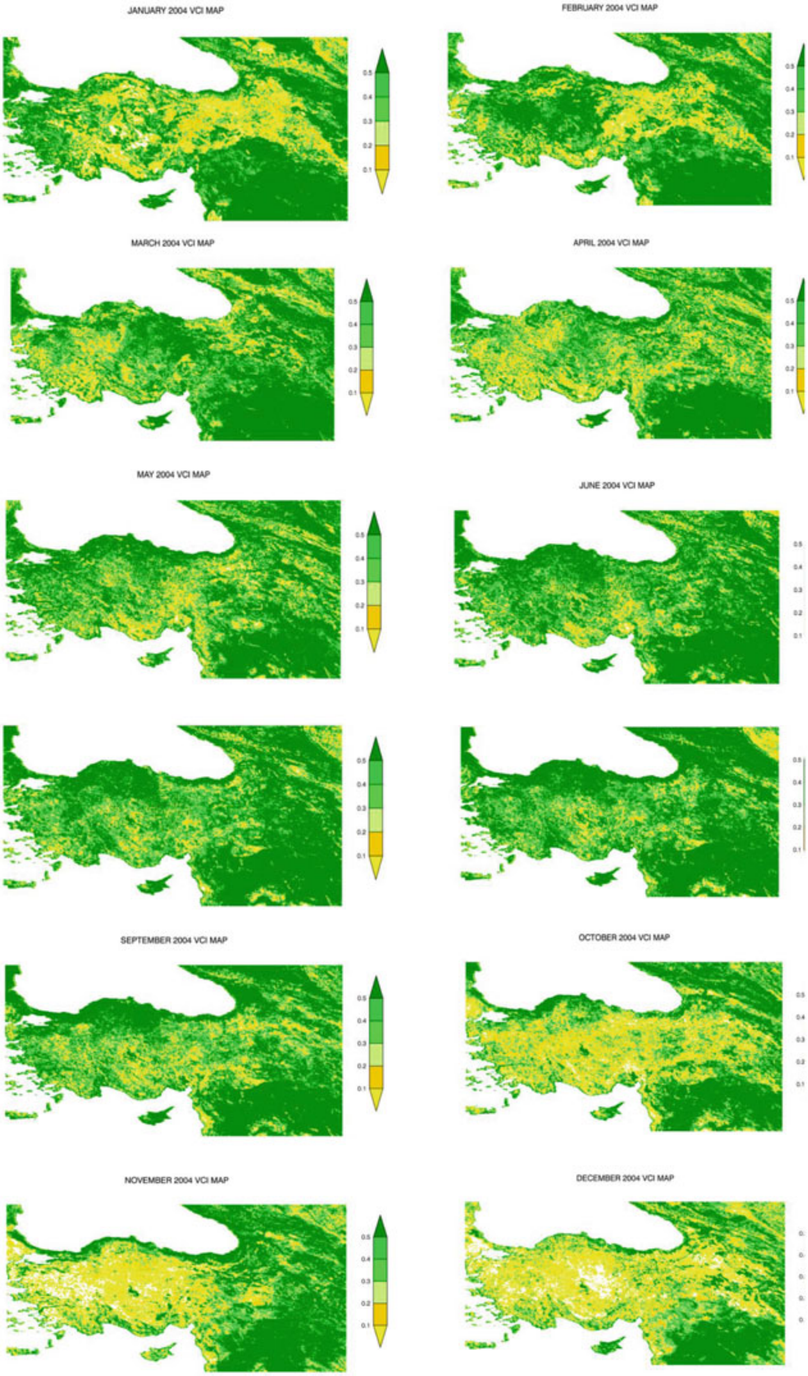

Fig. 10.3 VCI maps for the year 2004

the precipitation). For drought occurring years such as 2007, VCI presents lower values in May–September period as well unlike the normal conditions mentioned.

Turkey has different climatic regions as shown in Fig. 10.2. Black Sea Region having coastal (humid-temperate) climate has vegetation throughout the year resulting in higher VCI values as can be seen in Fig. 10.3. This region is highly vegetated with mostly evergreen forests causing higher NDVI values. Considering Turkey boundaries, during the winter months, most of the country has lower NDVI values due to the fact that there are not planted agricultural areas and deciduous plants.

Analysis of TCI, VCI and VHI maps illustrated that 2007, 2008 and 2013 were drought impacted years in Turkey. In order to consider for temperature and vegetation growth, VHI maps were extensively analyzed. Figure 10.4 illustrates the comparison of a normal (2004) and drought (2007) years. After comparing 12 months of each year, it was found that impact of drought is more detectable between July and September. As can be seen from Fig. 10.4, during the drought year 2007 most of the country has VHI values lower than 0.2 indicating the excess or very excess drought conditions.

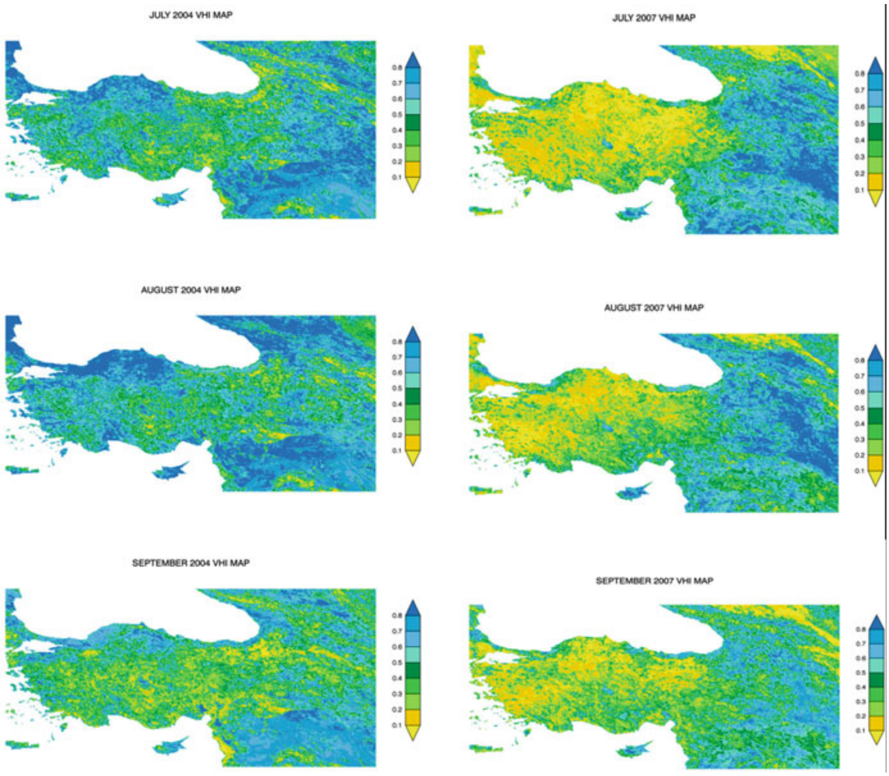

Fig. 10.4 Comparison of VHI maps between 2004–2007 for July, August and September

Droughts can lead significant environmental, social, and economic consequences by impacting agriculture, ecology and socio-economy. Therefore, it is important to monitor droughts and their impacts in local, regional and global scales. Meteorological data and drought indices derived from these data could be used to monitor drought conditions however their spatial and temporal availability are limited. To this end, remotely sensed data derived indices could be an important asset to monitor drought conditions globally and timely.

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