ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

DROUGHT ASSESSMENT BY MEANS OF MODIS DATA

M.Sc. THESIS

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Department of Communication Systems

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

MODIS UYDU VERİLERİ İLE KURAKLIK DEĞERLENDİRMESİ

YÜKSEK LİSANS TEZİ

Semra KOCAASLAN
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İletişim Sistemleri Anabilim Dalı

Uydu Haberleşmesi ve Uzaktan Algılama Programı

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ARALIK 2013

Semra KOCAASLAN, a **M.Sc.** student of ITU Informatics Institute student ID **705111012**, successfully defended the **thesis** entitled "**DROUGHT ASSESSMENT BY MEANS OF MODIS DATA**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To gratitude to God Almighty,

FOREWORD

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ABBREVIATIONS

AVHRR : Advanced Very High Resolution Radiometer
EROS : Earth Resources Observation Systems
FAO : Food and Agriculture Organization of United Nations
EOS : Earth Observing System
GIS : Geographic Information Systems
HDF-EOS : Hierarchical Data Format-Earth Observing System
IWMI : International Water Management Institute
LST : Land Surface Temperature
MODIS : Moderate Resolution Imaging Spectroradiometer
NASA : National Aeronautics and Space Administration
NDVI : Normalized Difference Vegetation Index
NIR : Near Infrared
TERRA : EOS satellite-NASA flagship satellite under Earth System Enterprise
LP DAAC : Land Processes Distributed Active Archive Center
NOAA : National Oceanographic and Atmospheric Administration

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DROUGHT ASSESSMENT BY MEANS OF MODIS DATA

SUMMARY

One of the most important environmental threats facing the world is global warming. Drought takes the first place of the consequences of climate change brought about by global warming . In this study, drought issue essential for all of the world as well as in Turkey is examined.

There are numerous methods applied by many researchers from various disciplines in order to determine droughts. Since remote sensing satellites could monitor large areas fast, accurately, periodically, and economically; they have been widely used to examine drought impacts in addition to several other environmental applications. Products of one of the well known satellite system, MODIS, have been used for numerous research applications including mapping deforestation, identifying desertification, fire fuel estimation, burn scar identification, ecosystem evolution, invasive species potential, grazing impacts, and crop yield estimation, natural and non-natural disasters, such as floods and droughts in many areas setting a global and regional scale applications due to the its high temporal resolution. MODIS satellite data was used in this research as well considering the above explanation.

Terra-MODIS (Moderate Resolution Imaging Spectroradiometer) images spanning time interval between 2004 and 2013 covering Turkey region were used in this thesis. These data include 250 m spatial resolution and 16-day composite MOD13Q1 Vegetation Indices products Normalized Difference Vegetation Index (NDVI) and 1000 m spatial resolution 8-day composite MOD11A2 MODIS/Terra Surface Temperature /Emissivity Land Surface Temperature (LST).

The Digital Number (DN) of the obtained raw data converted to real NDVI values between (-1) (+1) and the LST values in the range of degrees Celsius (° C) unit. Then, LST data with spatial resolution of 1 km resampled on a resolution of 250 m in order to be compatible with 250 m NDVI values for further analysis by using the nearest neighbor method. Between the years of 2006 and 2010, time series of these data were created for NDVI and LST images. 2007 was a drought year and data obtained before and after these years were used to determine the impacts of drought over the research area. NDVI and LST images were used to observe drought impacts by using sample points covering different land cover types such as croplands, grasslands and soil areas from five different climatic regions (Konya, Antalya, Istanbul, Izmir, and Urfa). In order to observe the possible drought impacts for 10 year period (between 2004 and 2013), the most hottest month August was selected and surface temperature (LST) and vegetation (NDVI) maps were created for August month of each year. In addition, Temperature Vegatation Index (TVX) maps were created by using LST and NDVI data for august month of related 10 years as a drought-monitoring index. Temperature-Vegetation Index (TVX), combination of NDVI and LST was also used in the study considering that TVX gives more spectral information for drought detection. The relationship between NDVI and LST could

provide information for drought detection. TVX is negatively related to water condition.

Results of this research illustrated that LST values over several parts of Turkey are compratively higher for the years of 2007, 2008 and 2012; this could be interpreted as they might be likely drought years. High LST values can be seen in 2007 especially around Konya plain, Thrace region (Tekirdag, Edirne), Aegean Region. In addition, lower NDVI values over Thrace region can be easily identified in 2007.

MODIS UYDU VERİLERİYLE KURAKLIK DEĞERLENDİRMESİ

ÖZET

Yeryüzünün karşı karşıya kaldığı en önemli çevresel sorunlardan biri olan küresel ısınmanın beraberinde getirdiği iklim değişikliğinin en önemli sonuçlarından biri kuraklıktır. Bu çalışmada, tüm dünyada olduğu gibi Türkiyede de oldukça öneme sahip olan kuraklık konusu incelenmiştir.

Kuraklığın belirlenmesi noktasında çeşitli disiplinlerden çok sayıda araştırmacının sunduğu sayısız yöntem bulunmaktadır. Uzaktan algılama uydu sistemleri, erişilmesi zor ve büyük olan alanlarda hızlı, yüksek doğruluklu, periyodik ve güncel verileri ekonomik olarak sunması açısından çeşitli yeryüzü uygulamalarında kullanılmakla birlikte kuraklık etkilerinin incelenmesinde de yaygın olarak kullanılagelen yöntemlerden biridir. Bu uydu sistemlerinden biri olan MODIS uydusu; iklim modellerinde, arazi kullanımı ve arazi örtüsü haritalarının oluşturulmasında, tarımsal çalışmalarda rekolte tahmininde, yangın, sel ve kuraklık gibi doğal ve doğal olmayan afetlerin belirlenmesi gibi pek çok alanda yüksek zamansal çözünürlüğü sayesinde küresel ve bölgesel ölçekte uygulama imkanı sunmaktadır. Bu özelliklerinden dolayı bu araştırma kapsamında kuraklık etkilerinin değerlendirilmesi amacıyla MODIS uydusu seçilmiştir.

Bu tezde, 2004-2013 yılları aralığında Türkiye topraklarını içene alan bölge seçilerek Terra MODIS ürünlerinden 16 günlük 250 m mekansal çözünürlüklü bitki indekslerinden Normalize Edilmiş Fark İndeksi (NDVI- MOD13Q1) ve 8 günlük 1000 m mekansal çözünürlüklü Arazi Yüzeyi Sıcaklıkları (LST-MOD11A2) verileri kullanılmıştır.

Uygulama öncesi, elde edilen ham verilerin sayısal değerleri (DN), NDVI değerleri (-1) ile (+1) aralığında ve LST değerleri santigrat derece (^{o}C) biriminde olacak şekilde dönüşüm işlemleri uygulanmıştır. 1 km mekansal çözünürlüğe sahip LST verileri en yakın komşuluk yöntemi uygulanarak 250 m çözünürlüğe örneklenmiş ve böylece sonraki analizlerde kullanılmak üzere 250 m çözünürlüklü NDVI değerleriyle uyumlu hale getirilmiştir. Bu verilerle kurak bir yıl olarak geçtiği bilinen 2007 yılını kapsayan 2006-2010 yıllarına ait 5 yıllık zaman serileri oluşturularak bu period içerisinde çalışma bölgesindeki kuraklık etkileri incelenmiştir. Bununla birlikte, Türkiye'nin 5 farklı iklim bölgesinden 5 il (Konya, Tekirdağ, Antalya, Rize, Urfa) için tarım alanı, yeşil alan ve toprak olan alanlardan örnek noktalar seçilmiş ve periyod içerisindeki sıcaklık- bitki örtüsü ilişkisi gözlemlenmiştir.

Kuraklığın olası etkilerinin gözlemlenebilmesi amacıyla 2004 ile 2013 yılları aralığında 10 yıl için yılın en sıcak ayı olarak bilinen ağustos ayı seçilerek her yıl için sıcaklık ve bitki örtüsü haritaları oluşturulmuştur.

Kuraklık indeksi olarak, NDVI ile LST değerlerinin ilişkisinden elde edilen Sıcaklık Bitki İndeksi (TVX) seçilmiş ve 10 yıllık period için agustos ayını içeren verilerle

TVX değerleri hesaplanmış ve haritaları oluşturulmuştur.Sonuç olarak, özellikle 2007, 2008 2012 yıllarında bölgesel olarak değişmekle birlikte diğer yıllara oranla daha yüksek sıcaklığa sahip olması nedeniyle olası kurak yıllar olarak görülmüştür.

1. INTRODUCTION

Global warming is one of the most important environmental problems that the world faces. Recent studies show that global average land-surface air temperature has been increasing and many natural systems are being affected because of the temperature increases (IPCC, 2007; Sertel, 2008). One of the most important environmental problem is especially drought.

Drought is the most complex and least understood of all natural hazards, affecting more people than any other hazard (Wilhite, 2000; Mishra and Singh, 2010). In addition, drought by itself is not a disaster. Whether it becomes a disaster depends on its impact on local people and the environment. Thus, the key to understanding drought is to understand both its natural and social dimensions (Wilhite and Smith, 2005). Drought is characterized as a slow process, can happen everywhere and anytime and prolongs from months to years (Chang and Wallace, 1987). The characteristics of drought, which make it complex, include; lack of universal definition; impacts can effect outside of suffered region; and its impacts accumulate slowly over long time and might continue after drought terminates. Time and distribution of rains during the growing seasons, duration and intensity of rain, rain onset and end, temperatures, low relative humidity, and high winds play important parts on drought occurrence (Mishra and Singh, 2010). Drought has important components: onset, duration and intensity, which should be included in any study, focused on drought monitoring. Drought has many severe impacts on society and environment and they become more and more complex among other natural hazards especially with a changing climate (Wilhite et al., 2008).

In recent times, the advance in remote sensing data both spatially and temporally makes it possible to use this data for drought monitoring regionally and globally. Over the last few years, satellite data has become a main source to detect changes of the environment, which provides a comprehensive view of changes that cannot be observed from Earth’s surface. Remote sensing is essential when there is a lack of meteorological data or it is inaccurate or difficult to obtain, especially in a country like Turkey where there is no essential meteorological data; it is the only way to monitor drought and its aftermath's assessment. Remote sensing data particularly MODIS Normalized Difference Vegetation index (NDVI) data are used intensively for studying vegetation change worldwide. It is one of the most successful attempts to detect vegetation greenness globally. In addition, Land Surface Temperatare (LST) is efficiently used for investigating drought impacts. Remote sensing provides global data every one to two days continuously, which is superior all other known data.

1.1 Purpose of Thesis

The overall purpose of this research is to assess the drought conditions in Turkey during the period of 2004-2013 using remotely sensed data and indices. For this purpose, MODIS NDVI and LST products were used to analyze vegetation and land surface temperature changes and drought dynamics between these related years. MODIS derived Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and Temperature-Vegetation Index (TVX) were used to analyze vegetation and drought conditions in Turkey for the given period. NDVI, LST and TVX maps of August month of each years were created and analyzed since August is the hottest and driest month in Turkey. Specific attention was given to January 2006 and December 2010 period and time series of LST and NDVIs including all months between 2006 and 2010 were created considering that this period was including the drought year 2007.

2. DROUGHT, DROUGHT TYPES AND DROUGHT INDICES

2.1 Drought Definition

Drought is a complex disaster, which lacks a universal definition, develops over time is with unobvious impacts (Wilhite, 1992). Drought is also defined as a prolonged abnormally dry period when there is not enough water for users' normal needs, resulting in extensive damage to crops and a loss of yields (Wilhite, 2005).The World Meteorological Organization (WMO, 1986) defines drought as 'a sustained, extended deficiency in precipitation.' and the Food and Agriculture Organization (FAO, 1983) define it as 'the percentage of years when crops fail from the lack of moisture'. The National Drought Mitigation Center defined drought as a conceptional definition 'Drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield.'(NDMC). Drought is a slow-onset natural hazard, mostly related to decline in the amount of rainfall in an area for a period of time (a couple of months, season and even years) (Mishra and Singh, 2010). In addition, it is often difficult to determine the beginning and the end of a drought (UNESCO, 2005). Drought differs from other natural hazards such as floods, cyclones as its impacts accumulate slowly over a long time, and they might continue after drought termination (Wilhite, 1992). According to Sırdaş and Şen, droughts might be the major natural hazards if compared with the others in point of the damage human life and property under various meteorological and environmental conditions (2003).

In briefly, there is no any universal definition for drought. Therefore, the definition of drought actually depends on the selection of indicators so types of drought.

2.2 Types of Drought

In literature, scientists often classify drought into four classes depending on the parameters used to describe it. According to Wilhite (2008); Mishra and Singh

(2010); Turkish State Meteorological Service, these drought classes are shown in Figure 2.1;

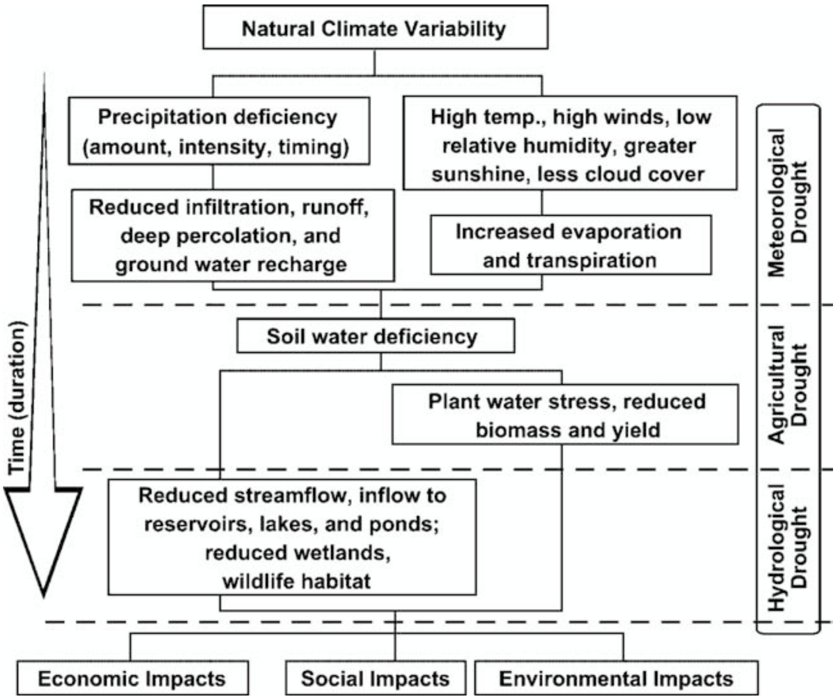


Figure 2.1 : Relationship between various types of drought and duration of drought events (Wilhite, 2008).

2.2.1 Meteorological drought

Meteorological drought is defined usually based on the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Meteorological drought definition must be considered as region specific because the atmospheric conditions that result in lacks of precipitation are extremely variable from region to region (NDMC). It might be given an example of different drought definitions range from the United States' less than 2.5 rnrn of precipitation in forty-eight hours to Libya's annual precipitation of less than 180 mm (Wilhite et al., 1985).

2.2.2 Hydrological drought

Hydrological drought is related to a period with inadequate surface and subsurface (i.e., streamflow, reservoir and lake levels, groundwater) water resources for established water uses of a given water resources management system.Streamflow data have been widely applied for hydrologic drought analysis. While all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system (Şen, 1980; Mishra and Singh, 2010; NDMC).

2.2.3 Agricultural drought

Agricultural drought, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. A decline of soil moisture depends on several factors, which affect meteorological and hydrological droughts along with differences between actual evapotranspiration and potential evapotranspiration. Various drought indices, based on a combination of precipitation, temperature and soil moisture, have been derived to study agricultural droughts (Mishra and Singh, 2010). A convenient definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity (NDMC).

2.2.4 Socio-economic drought

Socio-economic drought is related with failure of water resources systems to meet water demands and hence associating droughts with supply of and demand for an economic good such aswater, forage, food grains, fish, and hydroelectric power (AMS, 2004; NDMC; Mishra and Singh, 2010). Actually, socio-economic drought is generally depends on the other drought types and their negative effects on human life.

2.3 Drought Impact

Drought is the most important weather-related natural disaster often getting worse by human actions, since it cause varios negative impacts for very large areas throughout months and years. Direct impacts are usually of biophysical nature such as reduced crop yield, pastures and water levels and increased livestock mortality rates and fire risk. Indirect impacts are results of direct impacts associated with socioeconomic and long-term change such as decreased income for farmers and agro-pastoralists, increase in food prices and unemployment (Wilhite at el., 2007).

2.4 Drought Monitoring

While impacts of drought increase, there is a growing need for monitoring and predicting drought. To handle with the problem of drought assessment and monitoring requires typically the dealing with a spring of meteorological, agricultural, hydrological and even socioeconomic data (Wilhite and Glantz 1985; McKee et al. 1993; Mishra and Singh 2010). For this purpose, many indices were proposed for assessing drought and monitoring its onset, duration and severity, which will provide information for decision makers to decrease and mitigate its impacts. Drought indices divided into two main categories, depending on the data and parameters used. These are meteorological drought indices and remote sensing drought indices. In addition, these various types of each indices include each its own strengths and weaknesses. According to a study of European Commission Joint Research Center (JRC) in 2008, there are more than 50 types of drought indices (shown as Figure 2.2).

NMDC – Normalized Multi-Band Drought Index
VCADI – Vegetation Condition Albedo Drought Index
PDI – Perpendicular Drought Index
MPDI – Modified Perpendicular Drought Index
RDRI – Remote Sensing Drought Risk Index
VegDRI – Vegetation Drought Response Index
ADI – Aggregate Drought Index
SMDI – Soil Moisture Deficit Index
ETDI – Evapotranspiration Deficit Index
RDI – Reconnaissance Drought Index
RSDI – Regional Streamflow Deficiency Index
SDI – Sperling Drought Index
NDVI – Normalized Difference Vegetation Index
VCI – Vegetation Condition Index
NDVIA – Anomaly of Normalized Difference Vegetation Index
SVI – Standardized Vegetation Index
NDWI – Normalized Difference Water Index
NDII – Normalized Difference Infrared Index
LWCI – Leaf Water Content Index
DTx – agricultural drought index
DFI – Drought Frequency Index
TCI – Temperature Condition Index
VHI – Vegetation Health Index
SRWI – Simple Ratio Water Index
GVWI – Global Vegetation Water moisture Index

WI – Water Index
%N – percentage of normal
DECILES – deciles
RAI – Rainfall Anomaly Index
BMDI – Bhalme and Mooly Drought Index
SAI – Standardized Anomaly Index
DSI – Drought Severity Index
PAI – Palfai Aridity Index
EDI – Effective Drought Index
Q90 – low flow index
BFI – Base Flow Index
SWSI – Surface Water Supply Index
PHDI – Palmer Hydrological Drought Index
RDI – Reclamation Drought Index
CMI – Crop Moisture Index
SMDI – Soil Moisture Drought Index
CSDI – Crop Specific Drought Index
CDI – Corn Drought Index
SCI – Soybean Drought Index
KBDI – Keetch-Byram Drought Index
NBR – Normalized Burn Ratio
PDSI – Palmer Drought Severity Index
PMDI – Palmer Modified Drought Index
Z-Index – Palmer Z-Index

Figure 2.2: Existing drought indices (JRC, 2008).

2.4.1 Meteorological drought indices

Meteorological drought indicators are related to climatological variables such as precipitation, temperature, and evapotranspiration. Meteorological indices include the Palmer Drought Severity Index (PDSI) (Palmer, 1965); the Decile Index (Gibbs and Maher, 1967) which is used in Australia and quite easy to calculate; the Crop Moisture index (CMI; Palmer, 1968); the Surface Water Supply Index (SWSI; Shafer and Dezman, 1982); the China-Z index (CZI) which is used by the National Metrological Center of China (Wu et al., 2001), and the Standardized Precipitation Index (SPI) (McKee et al., 1993) which is worldwide used for drought monitoring (Steinemann at al., 2005) such as the the United States Drought Monitor (USDM) and the National Drought Mitigation Center (NDMC; http://www.drought.unl.edu), the Turkish State Meteorological Service (http://www.mgm.gov.tr/veridegerlendirme/kuraklik-analizi.aspx).

2.4.2 Remote sensing-based drought indices

The development of Earth observation satellites from the 1980s onwards equipped with sensors mainly in the optical domain opened a new road for drought monitoring and detection. The new technologies allowed for the derivation of truly spatial information at global or regional coverage with a consistent method and a high repetition rate. Numerous indices were developed to describe the state of the land surface, mainly of vegetation, with the potential to detect and monitor anomalies especially droughts. A good overview on the first generation of remote sensing based drought monitoring is given in Gutman (1990), while Kogan (1997) provides an update almost one decade later. (Bayarjargal et al., 2006; Niemeyer, 2008).

The Normalized Difference Vegetation Index (NDVI) is the most commonly used vegetation index (Jensen, 1996) which was first developed by Rouse et al. (1974); and Tucker (1979). This study triggered several derivates for drought monitoring such as the Vegetation Condition Index (VCI; Kogan, 1990, 1995) which shows close the NDVI of the current month is to the minimum NDVI calculated from the long-term record., the anomaly of the NDVI called NDVIA (Anyamba et al., 2001), or the Standardized Vegetation Index SVI (Peters et al., 2002).

Besides the information derived from the optical domain, also the thermal channels of Landsat Thematic Mapper (TM), the Advanced Very High Resolution Radiometer

(AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors were exploited, resulting in the retrieval of land surface temperature estimates (LST). Applying the thermal channels to drought monitoring, Kogan (1995) proposed the Temperature Condition Index (TCI). Most promising was the final combination of optical and thermal information into the Vegetation Temperature Index (VTI) or Vegetation Health Index VHI by Kogan (1997).

Ghulam et al. (2007) proposed the Perpendicular Drought Index (PDI) which derived directly from the atmospherically corrected reflectances in the near infrared and red band and a perpendicular geometrical construction on the two bands' reflectance space. Then, he improved The Modified Perpendicular Drought Index (MPDI) which includes the fraction of vegetation of a pixel that accounted for soil moisture and vegetation growth. Niemeyer (2008) gives a recent review.

In recent years, many indices produced and much more them might be kept going on producing by taking into account each of main strengths and weaknesses by means of availability of remote data, covering wide regions over relatively long periods of time.

3. METHODOLOGY

3.1 MODIS (Moderate Resolution Imaging Spectroradiometer)

NASA launched the Terra and Aqua platforms in1999 and 2002, respectively, as part of its Earth Observing System (EOS). Both carry MODIS instruments distinguished by morning (Terra) and afternoon (Aqua) overpasses, providing complementary sources of daily global optical data that can be used in operational drought monitoring. MODIS is a 36-band sensor from which 10 by 10 degree products cast in the Sinusoidal projection can be derived at 250-m, 500-m, and 1-km spatial resolution. (URL 1; Brown et al., 2008). The specifications of MODIS 36-band and their primary use are illustrated in Figure 3.2.

MODIS is more frequent than Landsat 7 and higher spatial resolution than AVHRR and comparable bandwidths as shown below;

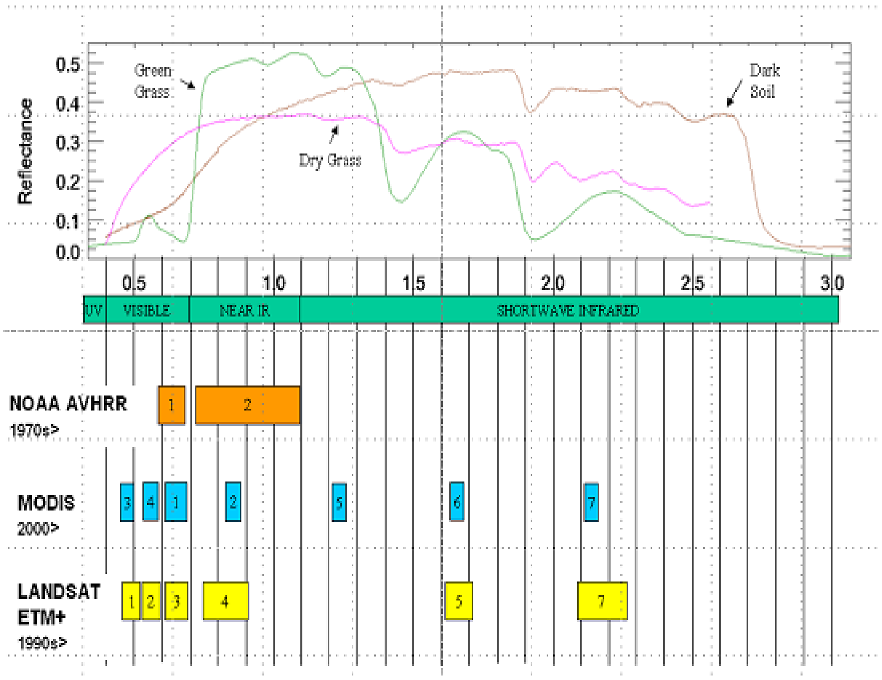


Figure 3.1 : The optical (land) channel band widths for NOAA AVHRR, MODIS and Landsat ETM+ instruments.

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE[delta]T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
[2] Spectral Radiance values are (W/m^2 -µm-sr)
[3] SNR = Signal-to-noise ratio
[4] NE(delta)T = Noise-equivalent temperature difference

Note: Performance goal is 30-40% better than required

Figure 3.2: Specifications of MODIS channels (NASA-MODIS Website).

3.1.1 Comparing MODIS and AVHRR data for drought assessment

Until two decades ago, the most commonly used remote sensing instrument 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 allow for the identification of anomalies to compare to "normal" conditions. The historical record for AVHRR data extends back over two decades globally at 4- to 8-kilometer (km) resolution (Tucker et al., 2005). However, MODIS data has higher spatial resolution as it demonstrate above Figure 3.1. Moreover, the AVHRR data are monthly, while MODIS data have the temporal resolution of 8 days and a single pixel level 10 by 10 km with AVHRR data and 0.5 by 0.5 km with MODIS (Brown et al., 2008; IWMI, 2004). Although MODIS is a successor to AVHRR, both sensors and their related data types have distinctly different features, as was described in previous section above (Figure 3.1). Apart from this, the two data sets have other differences including, but not limited to, preprocessing methods (e.g., atmospheric correction) and spatial resolution. To ensure continuous flow of data for drought assessment, inter-sensor relationships are needed. The two data sets overlap for the 2-year period from 2000 to 2001. This offers the opportunity to explore the relationships between the two data sets such as linking $NDVI_{AVHRR}$ with $NDVI_{MODIS}$. When compare these data, atmospherically corrected MODIS NDVI generally exhibits a higher dynamic range than atmospherically corrected AVHRR NDVI. This is attributed to the narrow band width of MODIS (Huete et al., 2002; IWMI, 2004).In addition, both of them available globally at no cost to the public, the products generated from MODIS are also superior to AVHRR because they provide higher spatial and spectral resolutions, more precise geolocation, and improved atmospheric corrections (Brown et al., 2008).

All things considered, MODIS data was chosen for this research because of all above the superiorities.

3.2 NDVI (Normalized Difference Vegetation Index)

NDVI is a proportion that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

Tucker (1979) first suggested NDVI as an index of vegetation health and density.It is the most commonly used vegetation index (Jensen 1996).

The NDVI is calculated by using the following algorithm:

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \quad \textbf{(3.1)}$$

Many satellites have sensors that measure the red and near-infrared spectral bands, and many variations on the NDVI exist. One of important satellites is MODIS which has a 36 channel radiometer with channels in the red (channel 1) and near infrared (channel 2) potion of the spectrum.

R_{NIR} and R_{RED} are the reflectance in the near infrared and red bands refer to the reflectance of MODIS band1 (620–670 nm) and band2 (841–876 nm), respectively.

NDVI values range from -1 to +1. Because of high reflectance in the NIR portion of the EMS (Electro Magnetic Spectrum), healthy vegetation is represented by high NDVI values between 0.1 and 1. Conversely, non-vegetated surfaces such as water bodies yield negative values of NDVI because of the electromagnetic absorption quality of water. Bare soil areas represent NDVI values, which are closest to 0 due to high reflectance in both the visible and NIR portions of the EMS (Lillesand and Kiefer, 1994; Karabulut, 2002).

Chloroplasts reflect the green light while absorb red and blue light for photocynthesis. Near infrared light is highly scattered by water in the spongy mesophyll cells (McVicar and Jupp, 1998). Figure 3.3 example of green leaf can be given in order to explain the principles of the remote sensors details.

Two characteristics of the NDVI that make it good for vegetation monitoring are that no other surface exhibits higher NDVI values than vegetated surfaces and that, when vegetation vigour changes due to the nature of vegetation growth and development or environmental induced stress such as drought, the NDVI also changes (Tucker, 1987). Hence, NDVI play a significant role in drought assessment and monitoring.

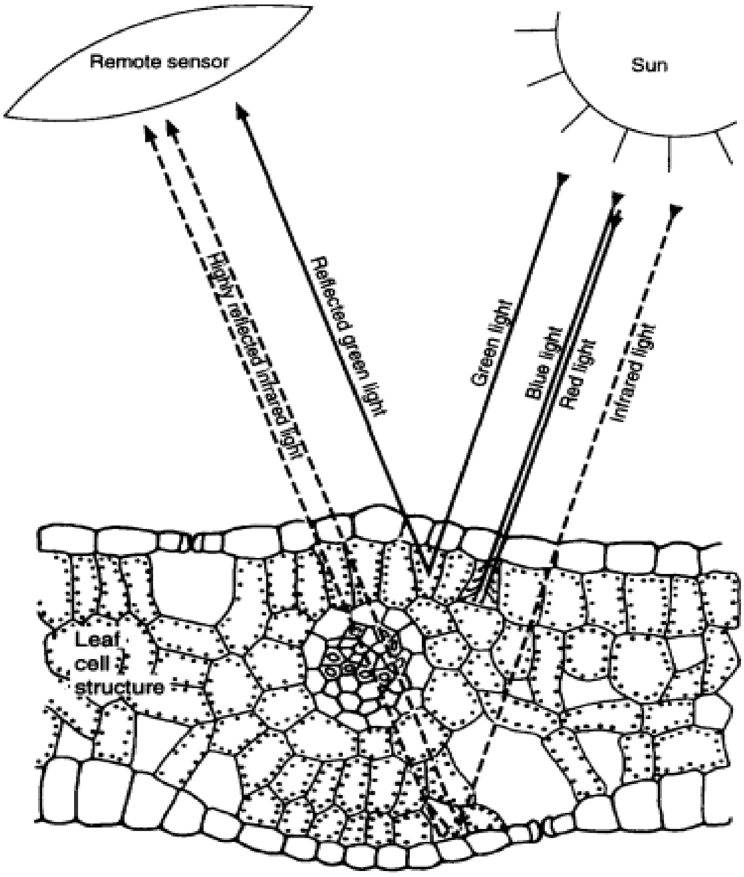


Figure 3.3 : Schematic reflectance of a typical green leaf in cross section (McVicar and Jupp, 1998).

3.3 LST (Land Surface Temperature)

LST is a good indicator of the energy balance at the earth's surface processes on regional and global scales (Wan et al., 2004). The main drawback using LST to detect drought is that it is quite difficult to normalize the variation of daily meteorological conditions such as net radiation, air temperature, wind speed, humidity, which affect daytime thermal measurements (McVicar and Jupp, 1998). Therefore, the vegetation index (NDVI) and LST are combined to evaluate drought status in most cases.LST is derived using the local split-window algorithm, which is a common and popular way to calculate the LST. Based on the local split-window method, for three thermal bands of MODIS data is shown in equtions **(3.3)** and **(3.4)**;

$$T_{s,1} = A_0 + P_1 \frac{T_1 + T_2}{2} + M_1 \frac{T_1 - T_2}{2} \quad \textbf{(3.3)}$$

$$T_{s,2} = A_0 + P_2 \frac{T_1 + T_3}{2} + M_2 \frac{T_1 - T_3}{2} \quad \textbf{(3.4)}$$

Where T_1, T_2 and T_3 are the brightness temperature for 1^{st}, 2^{nd}, and 3rd thermal infra-red band respectively. A_0 is a constant, P_1, P_2, M_1 and M_2 can be expressed as functions of emissivities (ε_1, ε_2, ε_3) in these four thermal infrared bands. Theoretically, $Ts_{,1}$ is equal to $Ts_{,2}$. Because of the effects of emissivity and atmosphere, the temperatures derived from equations 4 and 5 are different in practice. MODIS has 5 thermal bands, 29, 30, 31, 32, and 33. Because band 30 has too much ozone absorption to use, band 33 located in the edge of thermal bands, so bands 29, 31, 32 are used to constitute two groups to determine the LST (Xue et al., 2005).

There are numerous drought indices by using the ratio of NDVI and LST data retrieved by MODIS. The combination of NDVI and LST has proved better understanding of drought events with their close inter-relations with surface drought status. The ratio of NDVI and LST, also called the temperature-vegetation index TVX proposed by Nemani and Running (1989) and Goward et al. (1994) which is based on negative correlation between Ts and NDVI. Besides the LST/NDVI approach, based on the "Triangle" space, the vegetation temperature condition index (VTCI) (Wang et al., 2001) and the temperature-vegetation dryness index (TVDI) (Sandholt et al., 2002) (Figure 3.4), moisture index (Dupigny-Giroux and Lewis, 1999), and the VI/Trad relation (Kustas et al., 2003).

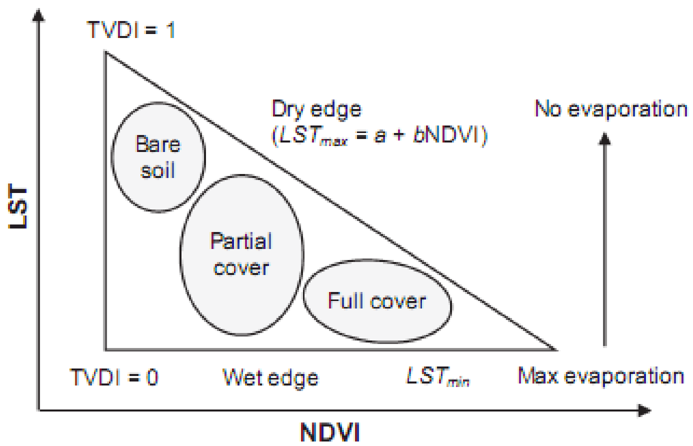


Figure 3.4: A conceptual LST-NDVI triangle (Sandholt et al., 2002).

3.4 TVX (Temperature Vegetation Index)

The temperature-vegetation index (TVX) method, developed by Nemani and Running (1989) and Goward et al. (1994), has been applied successfully to estimate near surface air temperature from several satellites. This method is based on the assumption that there is strong and negative correlation existing between land surface temperature and a vegetation index. Numerous studies have documented and interpreted this negative correlation relationship (Nemani et al., 1993; Qin et al., 2008; Zhu et al., 2013).

In theory, it originates mainly from the combined impact of vegetation cover on the average surface thermal characteristics and on the evaporative control of energy portioning. The heat capacity of dense vegetation is similar to that of the surrounding air. Thus, Ts tends to approach air temperature with increasing of vegetation cover, and the radiometric temperature of a fully vegetated canopy (NDVImax) is in equilibrium with the temperature of the air within the canopy, even without evapotranspiration taking place (Zhu et al., 2013; Nieto et al., 2011). TVX defined as;

$$TVX = \frac{LST}{NDVI} \tag{3.5}$$

The principle of the TVX method is to identify a strong negative correlation between Ts and NDVI.

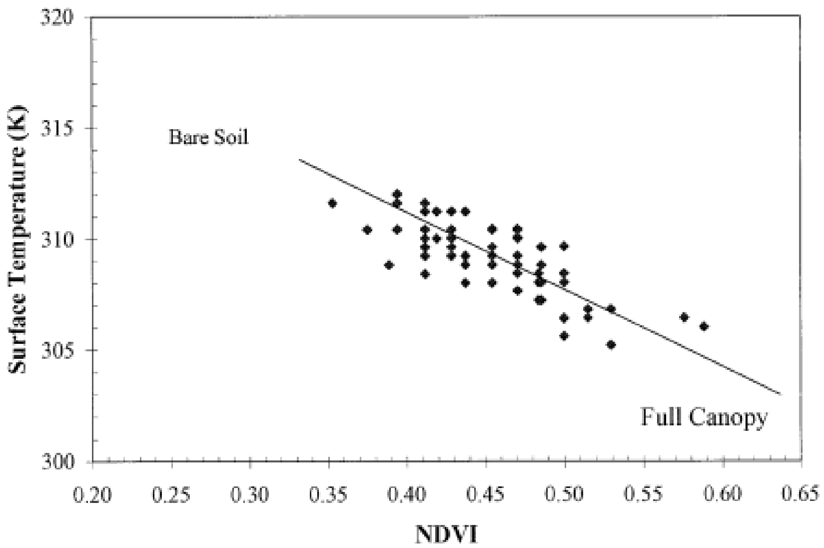


Figure 3.5 : Example of TVX plot (Goward et al., 2002).

Above Fıgure 3.5 demonstrate that the inverse relation between surface temperature and the NDVI.

The major advantage of TVX is that it integrates both the reflective bands and thermal bands of remote sensing data, which offers more spectral information for drought detection. The main drawback is that there are several other factors influencing TVX values such as land cover change, sensor drift, atmospheric effect, cloud etc. Furhermore, if the NDVI value is very small, the TVX value tends to infinite values. So, at places where NDVI is very small, one can use the arctangent of LST/NDVI which is expressed in degrees (Qin et al., 2008).

4. APPLICATION

4.1 Data

The Land Processes Distributed Active Archive Center (LP DAAC) stores a variety of MODIS land products. There are several composite MODIS vegetation products. Sixteen-day composites are available at 250 m; 500 m, 1 km and 0.05-degree resolutions.There are also monthly composites with 1 km, and 0.05-degree resolutions. Each file contains bands of data for both the traditional NDVI (Normalized Difference Vegetation Index). Besides, LST (Land Surface Temperature) products are avalible various daily, eight-day and monthly composites with 1 km and 0.05-degree resolutions (Yale ,2010).

In this study, the time interval between 2004 and 2013 Terra-MODIS data sets for covering whole Turkey region were used. These data include 250 m spatial resolution and 16-day composite MOD13Q1 Vegetation Indices products Normalized Difference Vegetation Index (NDVI) and 1000 m spatial resolution 8-day composite MOD11A2 MODIS/Terra Surface Temperature /Emissivity Land Surface Temperature (LST). For 2004, 2005, 2011, 2012, 2013 years have only august month data and the other years data spanning from January 2006 to December 2010 time interval (Table 4.1).

Tablo 4.1: The acquired MODIS data for 10 years.

Dates	Data	Pieces
2004 August	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	2 + 4
2005 August	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	2 + 4
2006 Jan to Dec	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	23 +46
2007 Jan to Dec	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	23 +46
2008 Jan to Dec	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	23 +46
2009 Jan to Dec	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	23 +46
2010 Jan to Dec	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	23 +46
2011 August	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	2 + 4
2012 August	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	2 + 4
2013 August	16-day MODI13Q1 NDVI & 8-day MOD11A2 LST	2 + 4
Total		375

MODIS images are typically distributed as HDF (Hierarchical Data Format) 10 by 10 arcdegree-tiles, projected in the sinusoidal projection. Geographers have promoted the sinusoidal projection as the most suited projection for global image databases (Chang Seong et al., 2002). Unfortunately, both HDF format and sinusoidal projection are yet not supported in many GIS. Therefore, before MODIS images are used, need to run some pre-processing to mosaic and convert the data into a more usable format.

For this purpose, all NDVI and LST time series data in sinusoidal projection were reprojected into the Universal Transverse Mercator (UTM) projection by using MODIS Reprojection Tool Web Interface (MRT) (*https://mrtweb.cr.usgs.gov/*). Also, all of the images were converted to tagged image file format (TIFF), which is applicable for remote sensing and GIS software by using same tool (Figure 4.1).

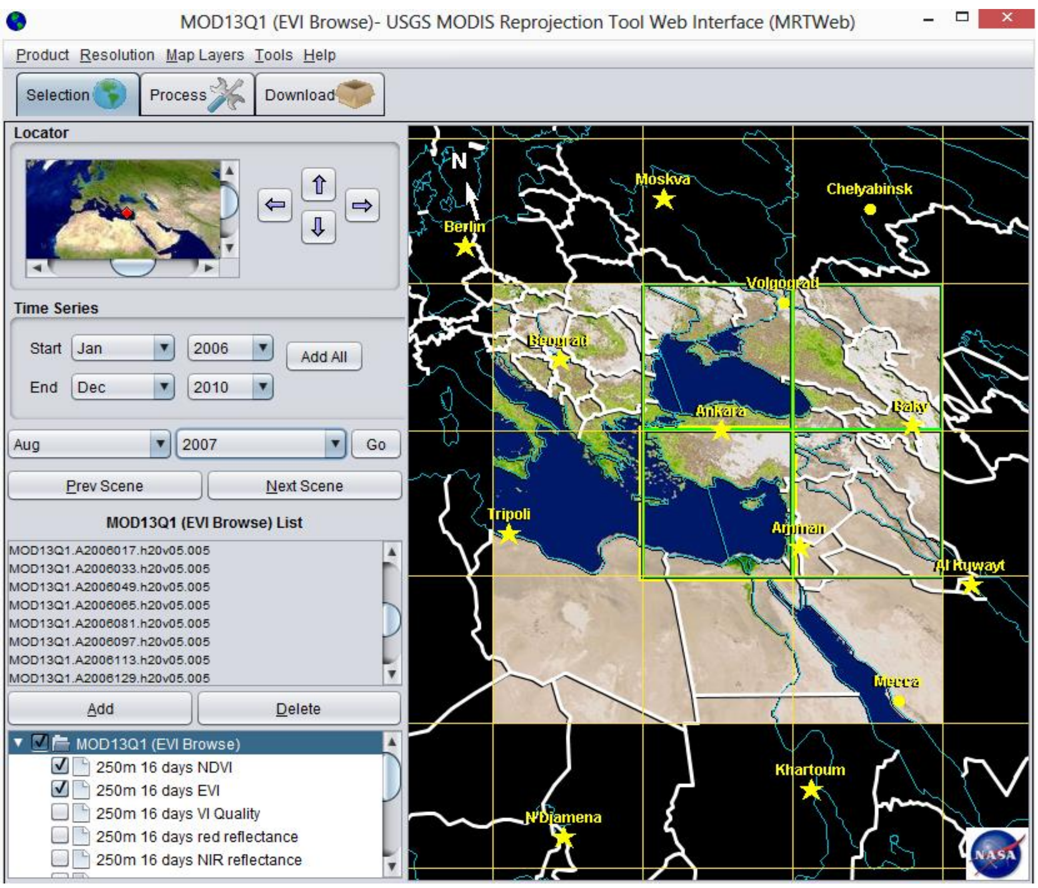


Figure 4.1: MODIS Reprojection Tool Web Interface (MRTWeb).

4.2 Study Area

The territory of Turkey is more than 1,600 kilometres (1,000 mi) long and 800 km (500 mi) wide, with a roughly rectangular shape. It lies between latitudes 36° and 42° N, and longitudes 26° and 45° E (Figure 4.2). Althought Turkey is situated in large Mediterranean geographical location where climatic conditions are quite temperate, diverse nature of the landscape, and the existence in particular of the mountains that run parallel to the coasts, result in significant differences in climatic conditions from one region to the other. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall (Sensoy, S. et al, 2008). The climate diagram of Turkey is shown as Figure 4.3.

Figure 4.2: Geographic location of Turkey.

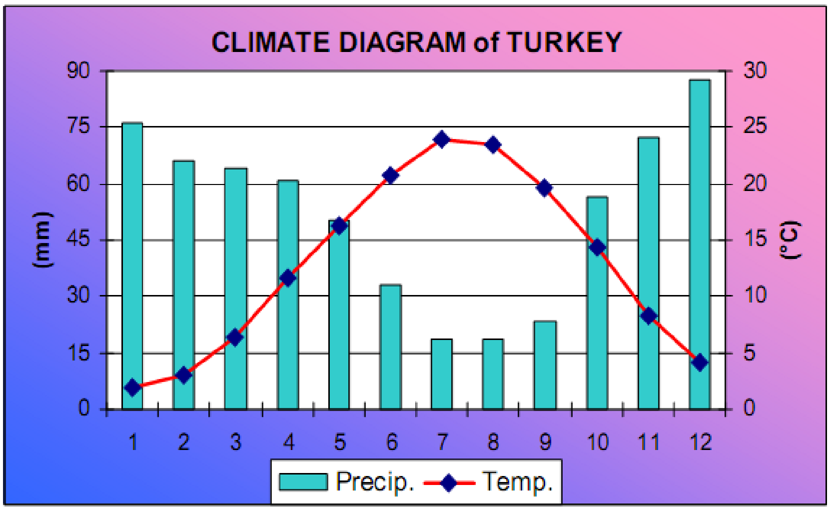


Figure 4.3: Climate diagram of Turkey (Sensoy, S. et al, 2008).

4.3 Data Processing

Vegetation products MOD13Q1 data type is 16 bit signed integer, which has a theoretical range of values from -32,768 to +32,768. The documented data range is from -2000 to +10000 with a fill value of -3000 therefore, cell values divided by 10,000 (Yale Uni, 2010). Likewise, MOD11A2 Land Surface Temperature & Emissivity 8-Day L3 Global 1km products values converted to degree Celcius by using below equation;

$$LST = LST_{MODIS} * 0.02 - 273.15 \quad \textbf{(4.1)}$$

In order to transform these values by using Model Maker (Erdas Field Guide, 2010), which enables you to create graphical models using a palette of easy-to-use, is used Figure 4.4 illustrate the model of conversion from MODIS LST to LST in Celcius degree.

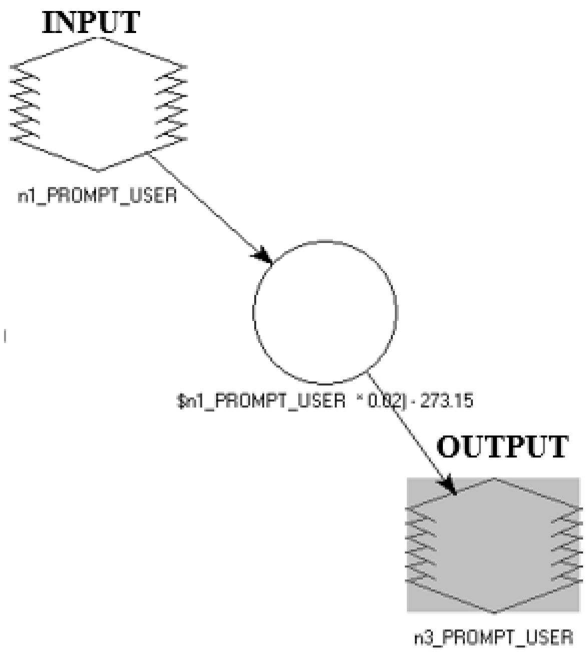


Figure 4.4: Model of LST transformation to Celcius (Erdas, 2010).

Another step of data processing is transforming all downloaded data from integer to float data type in order to obtain continuous values for the whole area of interest by using Erdas Imagine 2010 software subsetting tool.

Then, 5-year time series are generated from 16-day composite NDVI (each one in a year 23 pieces) images spanning from January 2006 to December 2010 (23*5) and 8-day composite LST images (46*5).

1000 m spatial resolution MODIS LST 5-year monthly time series image was resampled to 250 m MODIS LST data in order to be compatible with the 250 m 16 day MODIS NDVI data by using nearest neighbor resampling method that uses the value of the closest pixel to assign to the output pixel value (Figure 4.5).

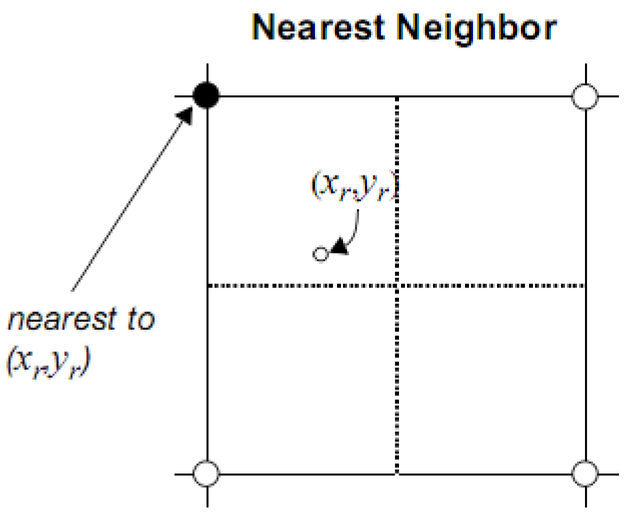


Figure 4.5: Resampling (Erdas Field Guide, 2010).

MODIS LST Resolution

Before resampling : { x : 926.63m y : 926.63m}

After resampling : { x': 231.66m y': 231.66m}

Following this preprocessing, 15 sample sites from different climatic region and vegetation cover were selected in the time series images to collect LST and NDVI samples in order to observe changing of surface temperature and vegetation density due to possible drought impacts.

The selected sample test points locations from croplands, grasslands and soil areas are demonstrated in Figure 4.6.

Figure 4.6 : The locations of selected 15 points from different climatic features.

Below figure shows the geographic coordinates of the selected points from the Konya, Tekirdağ, Antalya, Rize and Urfa regions for the cropland, grassland and soil sites samples.

Tablo 4.2: The geographic coordinates of selected points.

Points	Cropland (º ‘ ‘’)	Grassland (º ‘ ‘’)	Soil (º ‘ ‘’)
Konya	Lat 38 28 56.03 N	Lat 38 22 06.08 N	Lat 38 34 26.03 N
	Lon 33 49 44.31 E	Lon 33 55 07.40 E	Lon 33 48 44.59 E
Tekirdag	Lat 40 59 06.75 N	Lat 40 59 44.24 N	Lat 40 59 30.50 N
	Lon 27 53 34.17 E	Lon 27 54 23.02 E	Lon 27 54 35.69 N
Antalya	Lat 36 55 40.14 N	Lat 36 55 33.36 N	Lat 36 53 23.80 N
	Lon 30 53 16.32 E	Lon 30 52 54.48 E	Lon 30 50 05.78 N
Rize	Lat 41 04 39.45 N	Lat 41 05 31.38 N	Lat 41 03 37.92 N
	Lon 40 43 20.24 E	Lon 40 43 59.28 E	Lon 40 44 16.75 N
Urfa	Lat 37 15 28.74 N	Lat 37 20 34.24 N	Lat 37 15 23.61 N
	Lon 39 12 42.12 E	Lon 38 58 06.62 E	Lon 39 14 36.45 N

5 RESULTS AND DISCUSSION

5.1 NDVI and LST Relationship

Considerable attention has been given to the inverse relation between LST and NDVI with respect to drought monitoring. During drought periods, NDVI at a given pixel will typically be relatively low, whereas LST is expected to be relatively high because of both vegetation deterioration and higher contribution of a soil signal (Kogan 2000).

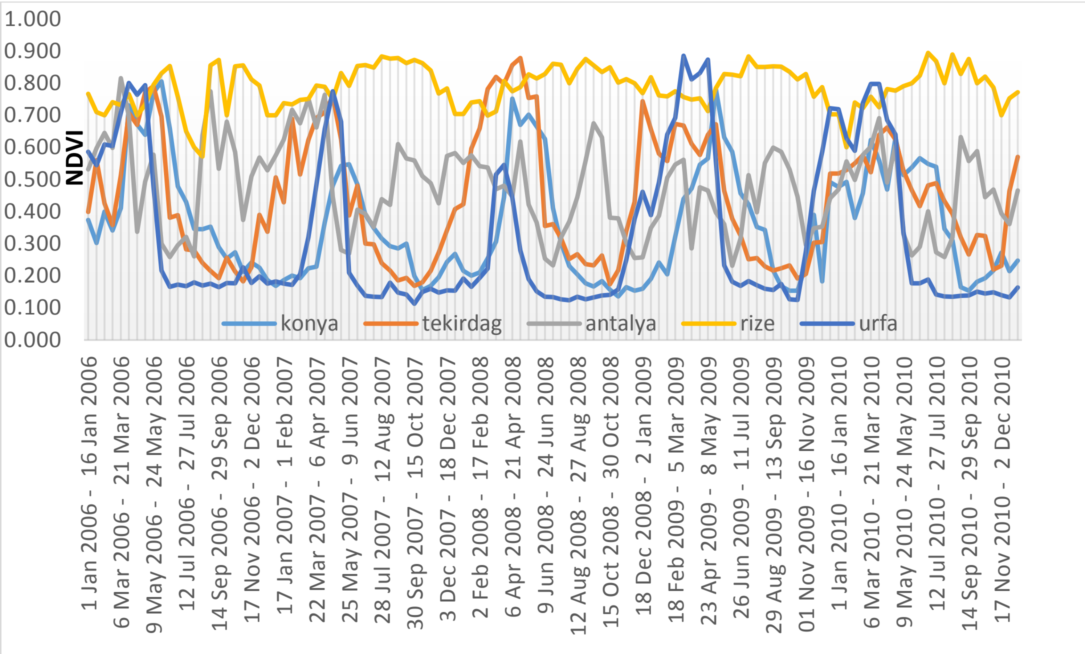


Figure 5.1 : MODIS NDVI (16-day composite) between 2006 - 2010 time series.

Rize is the most humid city having the highest amount of rainfall with extensive vegetated areas. This can be seen in Figure 5.1 as well with higher NDVI values compared to other cities.

Konya is a drought cirt and Urfa is located on the most southern part of Turkey facing with continental climate with hot and dry summers. Both of these cities have lower NDVI values compared to other cities.

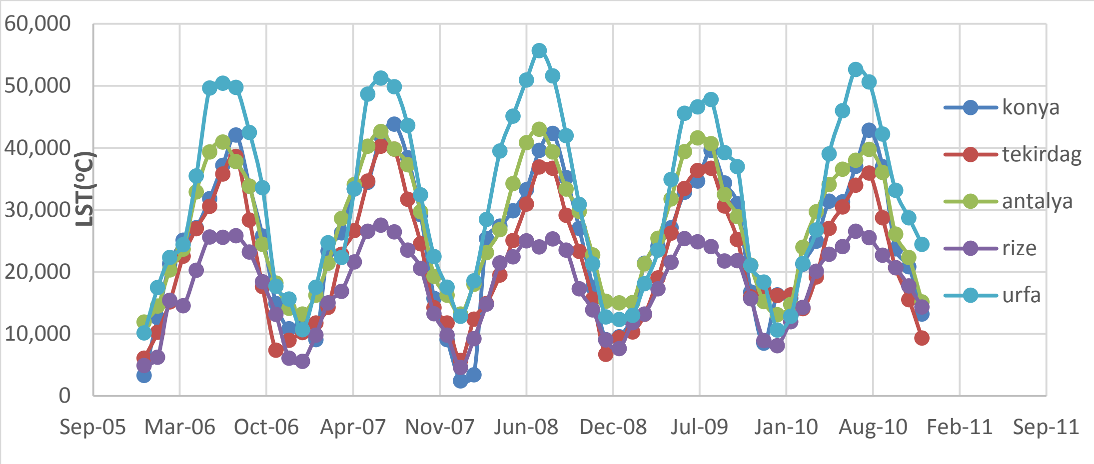


Figure 5.2 : MODIS LST (monthly composite) between 2006 – 2010 time series.

According to the time series of LST;

- Unlike NDVI time series, Rize has lower LST values whereas Konya, Urfa and Antalya have higher temperatures.
- Konya has the highest LST values.
- Mall of the citites have their highest temperature values in August.
- 2007 and 2008 temperatures are higher than other years (2007 was a drought year).

5.1.1 Comparison of sample points selected from croplands

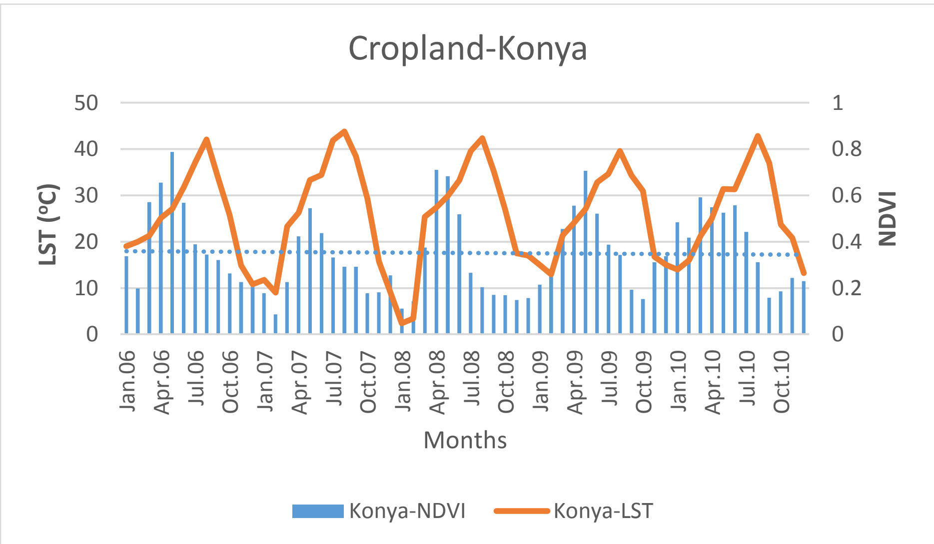


Figure 5.3: NDVI & LST relationship in cropland-Konya.

As shown in above Figure 5.3, while temperature values increase from january to august peak points, NDVI values increase only up to april, from april to august in appearently negative correlation can be seen between NDVI and LST. Then, both of them decrease in time.

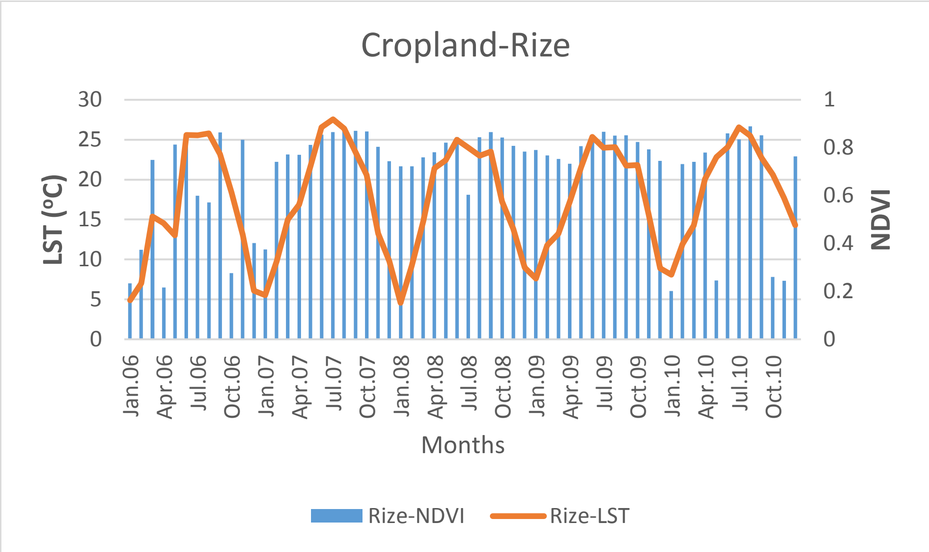


Figure 5.4: NDVI & LST relationship in cropland-Rize.

Because of the climate of rize as it mentioned before, there is no significant correlation between NDVI and LST values enough to observe drought impacts in cropland (Figure 5.4).

5.1.2 Comparison of sample points selected from grasslands

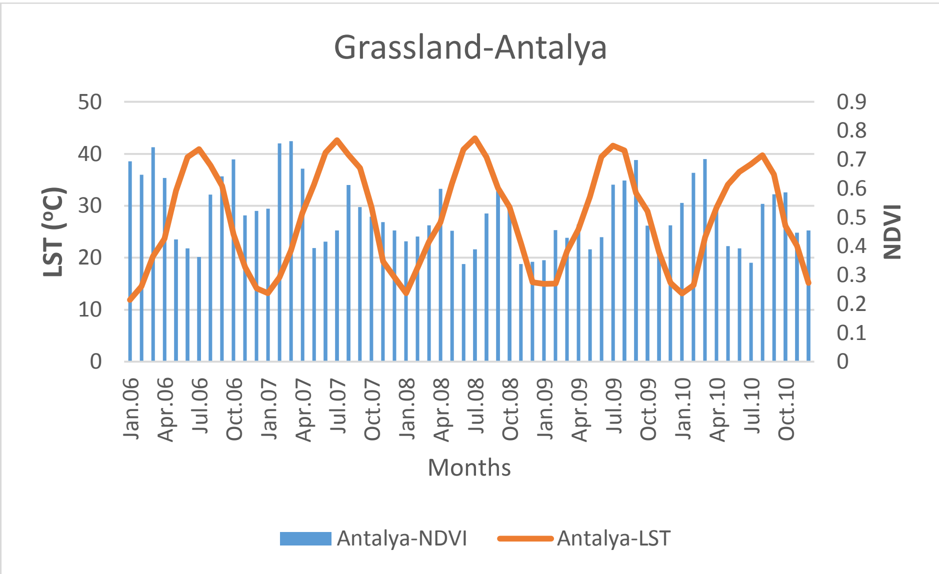


Figure 5.5: NDVI & LST relationship in grassland-Antalya.

In Figures 5.5 and 5.6, while LST takes max values mostly summer seasons, NDVI values takes min values. This shows the negative corelations which is a trace of drought periods especially in Tekirdağ 2007 and 2008 years.

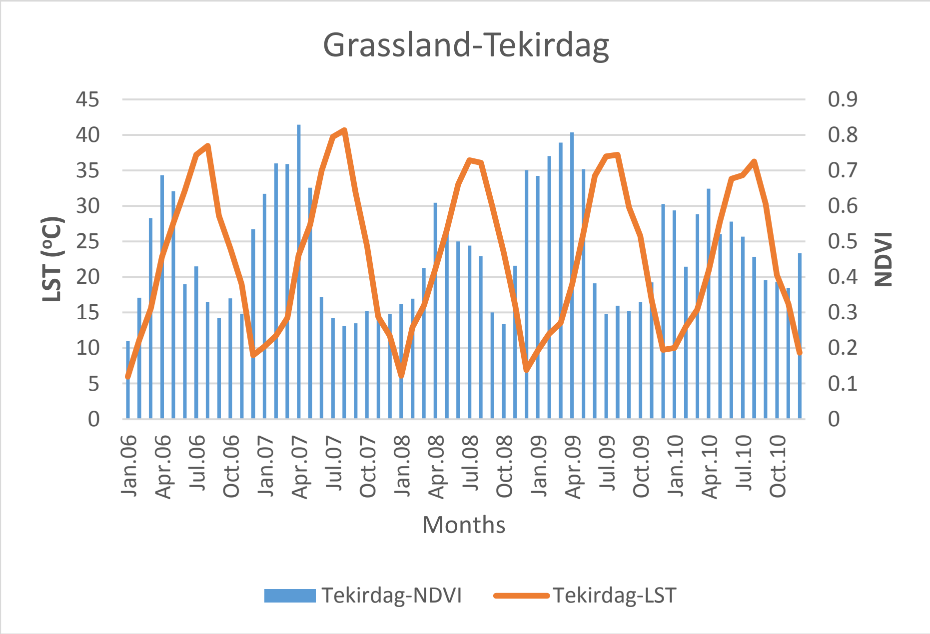


Figure 5.6: NDVI & LST relationship in grassland-Tekirdag.

5.1.3 Comparison of sample points selected from soil

Our country, after 2006, 2007 and 2008 dry years, since 2009 has undergone a period of rainier (DMI, 2012). This effect can be seen in soil area-Urfa (Figure 5.7).

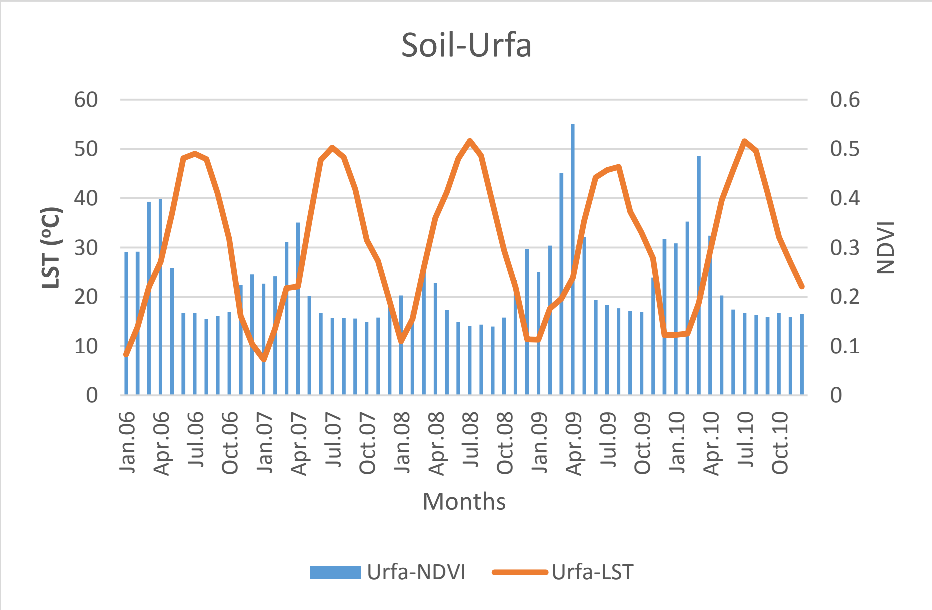


Figure 5.7: NDVI & LST relationship in soil area-Urfa.

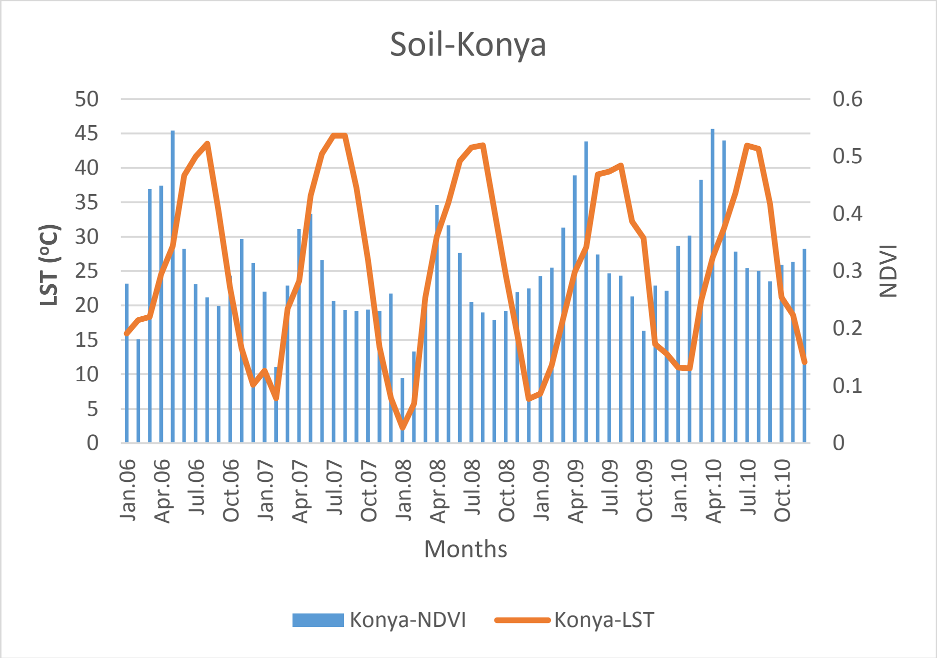
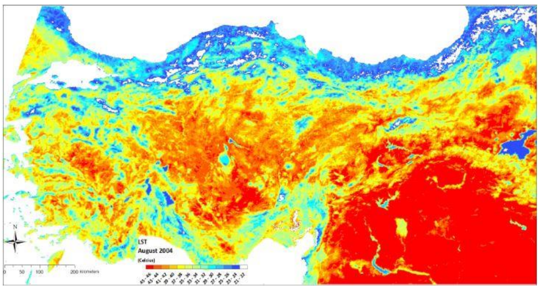


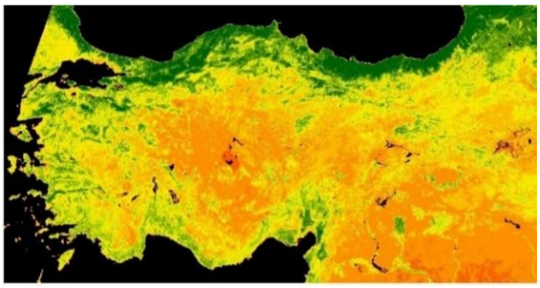
Figure 5.8: NDVI & LST relationship in soil area-Konya.

As it can be seen that figure 5.7 and 5.8 look like each other with their sharply increased NDVI values in spring terms of 2006, 2009, 2010 years because of the possible rainfall as explained before according to DMI reports (2012) after 2009 rainfall has increased.

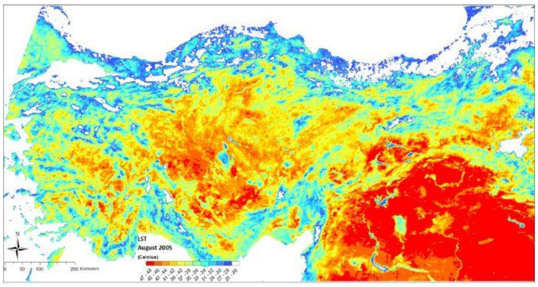
5.2 Comparison of 2004-2013 August MODIS LST and NDVI

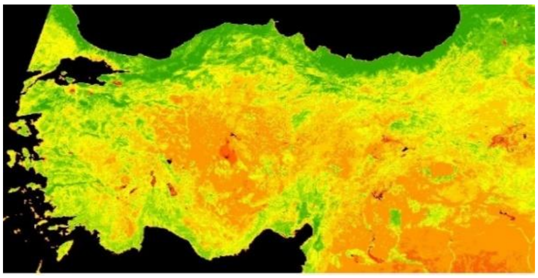
The relationship between NDVI and LST could provide information for drought detection. LST values derived from thermal bands are important since temperature is sensitive to the drought phenomenon and it is negatively correlated with NDVI values (McVicar, 2001). By using this correlation, drought areas and periods for the research area were investigated. For this purpose, NDVI and LST maps were created for each year from 2004 to 2013 for August month (Figure 5.9). Besides, using NDVI and LST data TVX ,which is negatively related to water condition, created as a drought index and TVX maps plotted (Figure 5.10). Although, LST and NDVI has negative correlation, this relationship in fact varies with location, season, and vegetation type (Karnielli et al., 2010).



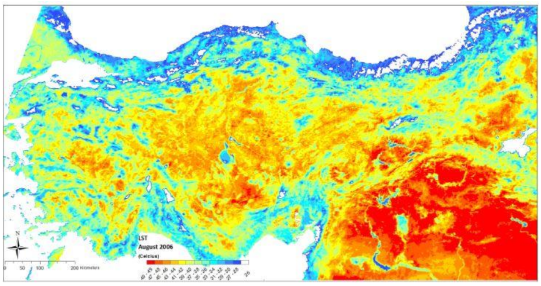


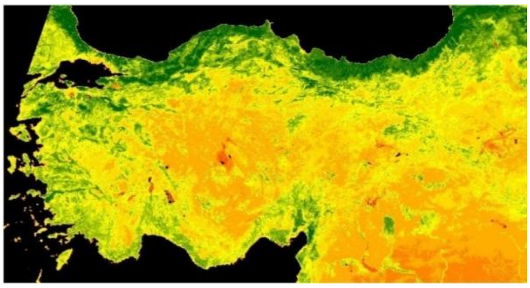
(a) 2004 August LST Map 2004 August NDVI Map



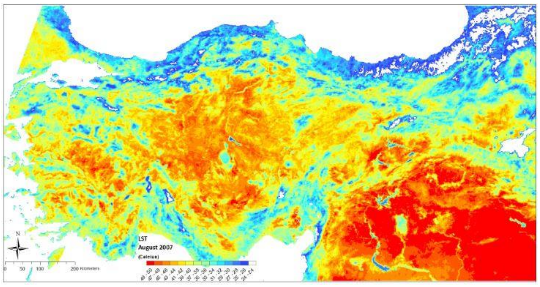


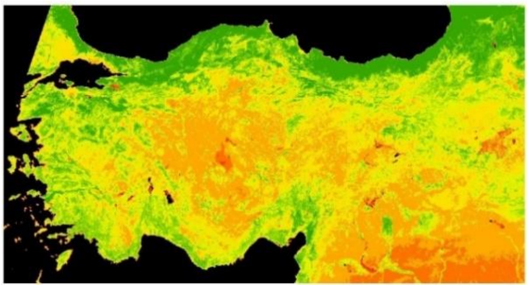
(b) 2005 August LST Map 2005 August NDVI Map



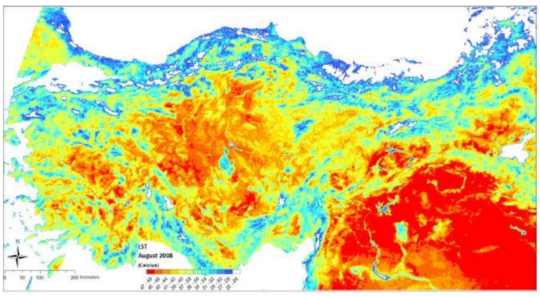


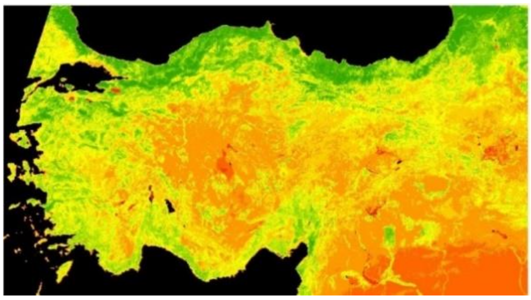
(c) 2006 August LST Map 2006 August NDVI Map





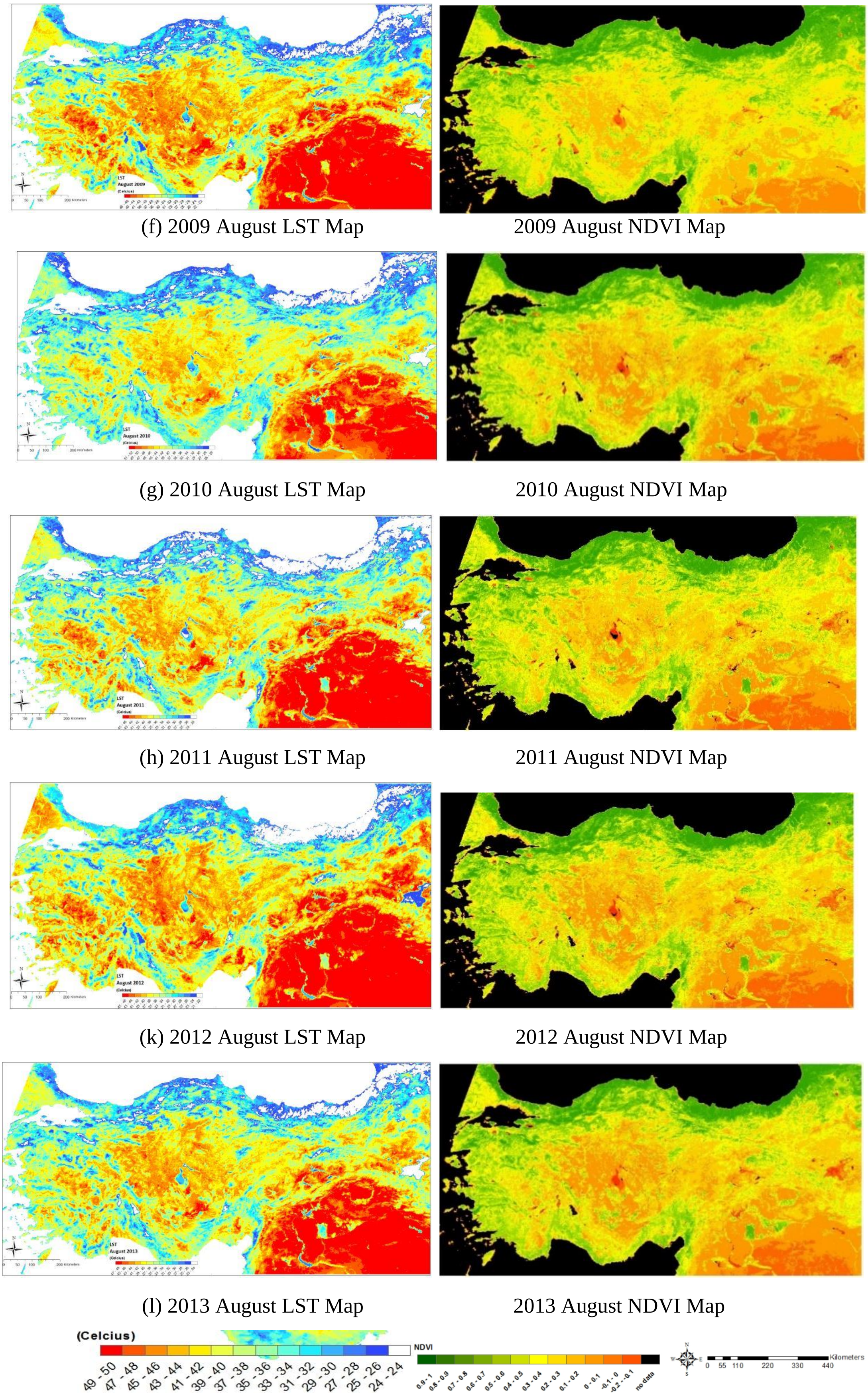
(d) 2007 August LST Map 2007 August NDVI Map





(e) 2008 August LST Map 2008 August NDVI Map

Figure 5.9 : 2004-2013 August MODIS LST and NDVI maps.



(f) 2009 August LST Map — 2009 August NDVI Map

(g) 2010 August LST Map — 2010 August NDVI Map

(h) 2011 August LST Map — 2011 August NDVI Map

(k) 2012 August LST Map — 2012 August NDVI Map

(l) 2013 August LST Map — 2013 August NDVI Map

Figure 5.9 : Cont. 2004-2013 August MODIS LST and NDVI maps.

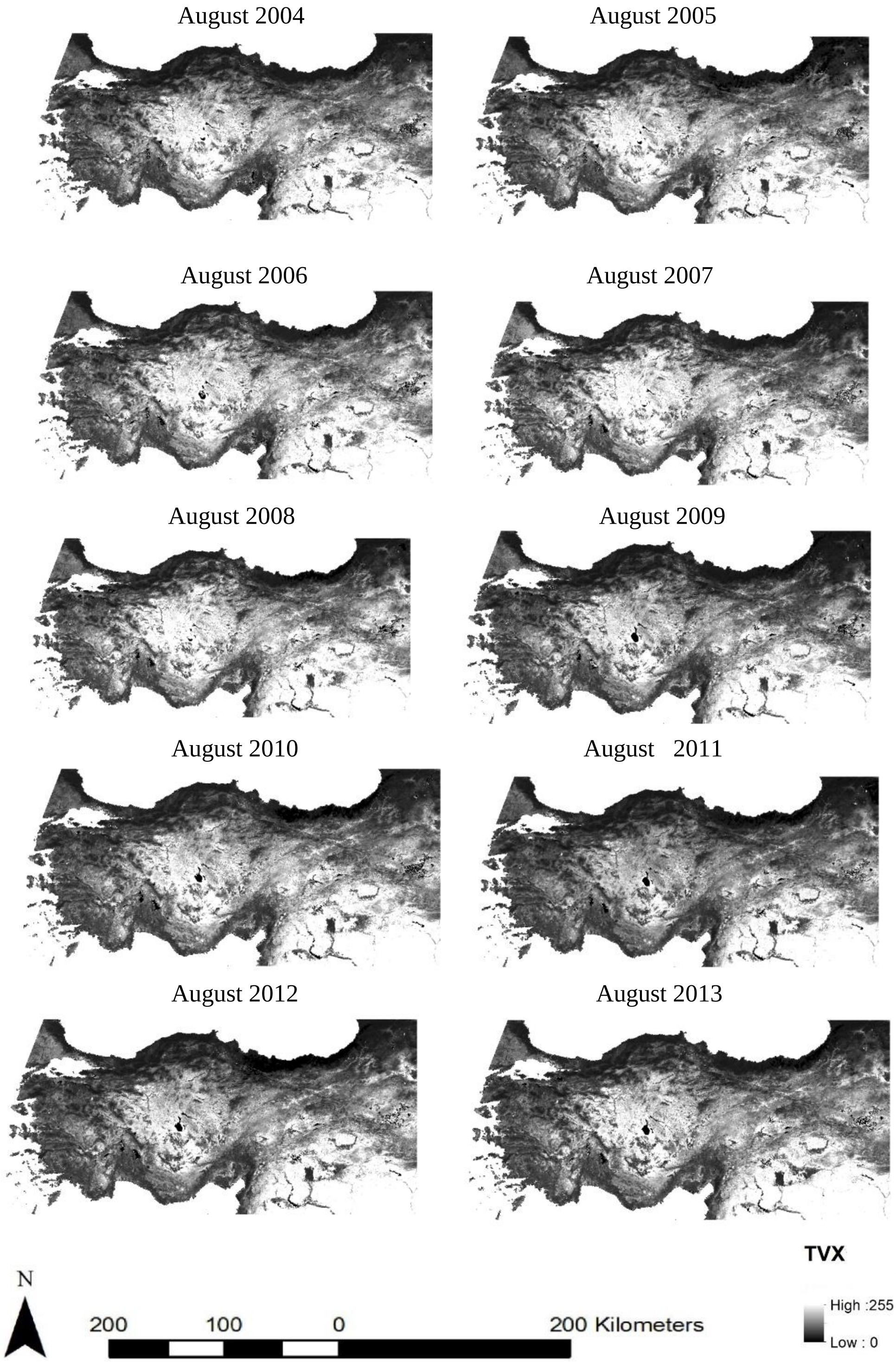


Figure 5.10 : 2004-2013 August TVX maps calculated from MODIS LST and NDVI data.

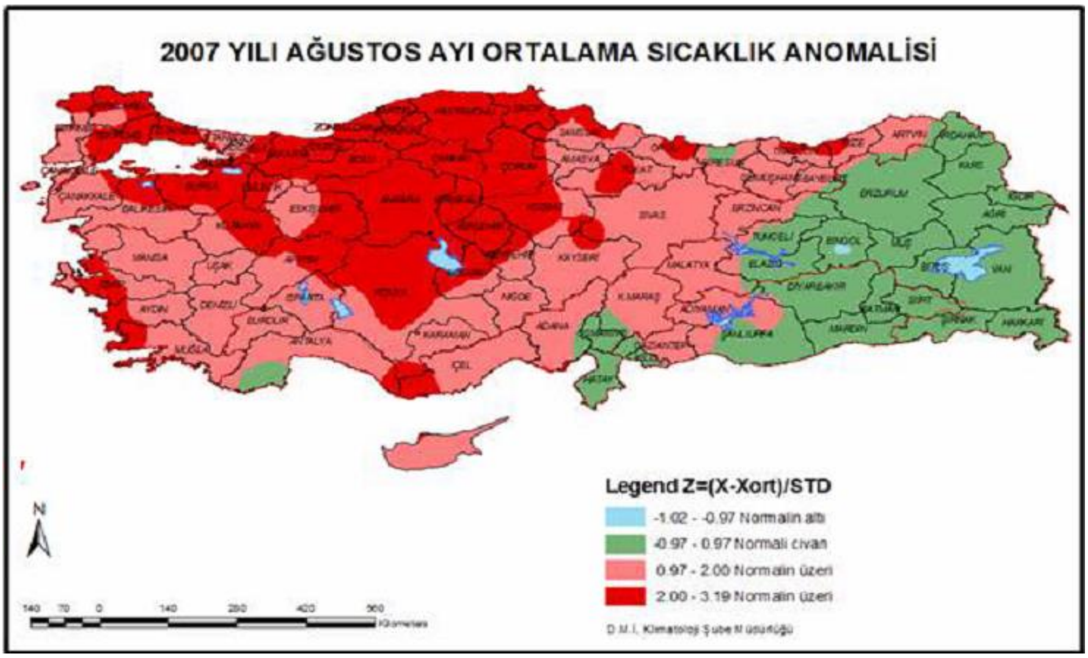


Figure 5.11: The average temperature anomaly map of august 2007 (Sensoy et al, DMI, 2007).

According to Turkish State Meteorological Service, the summer of 2007 season, the average air temperature was 24.9 ° C. With this result, the summer of 2007, 1.9 ° C anomaly in the hot summer and has been held since 1940. In general, a large part of our country's average temperatures in Summer 2007 watching above seasonal norms, to the east of Eastern and Southeastern Anatolia average temperatures were recorded around seasonal normals (Sensoy et al, 2007).

As well as as shown above temperature maps 2007 August surface temperature map is the hottest year if it compare the other years. This trace can be reflect an impact of possible drought year.

5.3 Soil Moisture Maps retrieved by European Space Agency (ESA)

The important role of soil moisture for the environment and climate system is well known. Soil moisture influences hydrological and agricultural processes, runoff generation, drought development and many other processes. Soil moisture was recognised as an Essential Climate Variable (ECV) in 2010.

This global ECV soil moisture data set has been generated using active and passive microwave spaceborne instruments and covers the 32 year period from 1978 to 2010. The active data set was generated by the Vienna University of Vienna (TU Wien) based on observations from the C-band scatterometers on board of ERS-1, ERS-2 and METOP-A. The passive data set was generated by the VU University Amsterdam in collaboration with NASA based on passive microwave observations from Nimbus 7 SMMR, DMSP SSM/I, TRMM TMI and Aqua AMSR-E (Url-2).

This thesis does not iclude analysis with using soil moisture data. Because, according to my research there is no avaible suppliers these convenient data for the study area. Consequenly, the comparison with 2007-2010 years for August month ESA soil moisture data viewer are used to reflect moisture situation of Turkey as shown in Figure 5.12.

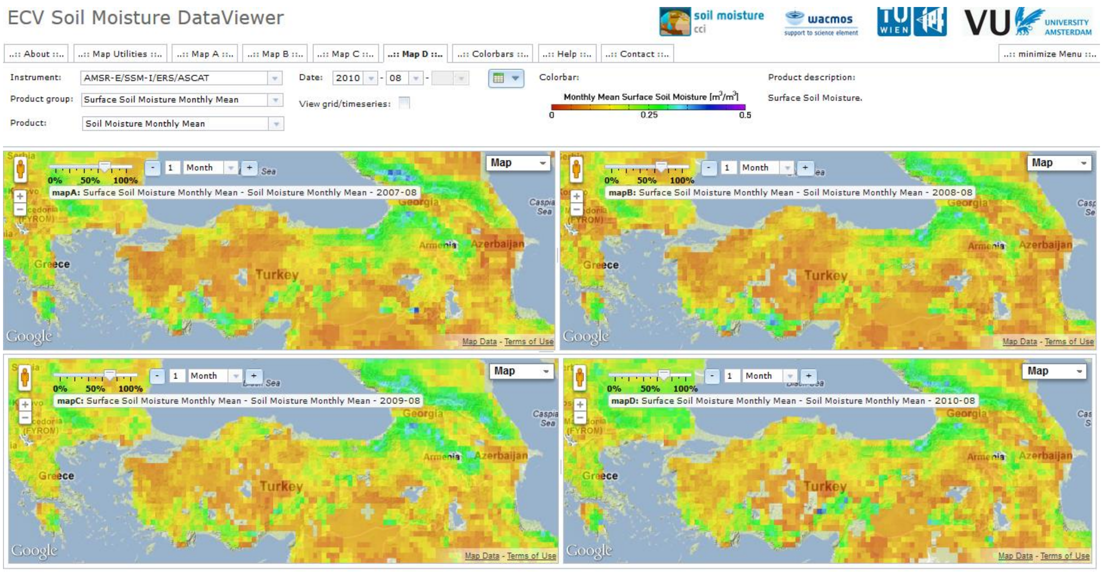


Figure 5.12 : ESA soil moisture view for Turkey 2007-2010 August.

6. CONCLUSION

According to results of this study, analysis of remotely sensed data provided valuable information for assessing and monitoring of the possible drought effects comparing within long period and large areas as Turkey.

Traditional methods of drought assessment and monitoring requires rainfall data and it is hard to find extensive, accurate and near-real time rainfall data for several parts of Turkey. While meteorological data are noncontinuous or nonexistence, remote sensing data can provide continuous data in order to investigate drought dynamics and monitoring.

Another significant feature of remotely sensed data is that there are many satellites such as MODIS, NOAA AVHRR, Landsat TM/ETM, MERIS etc. no- cost avaible data for global or regional scales. And MODIS is designed for the land imaging component combines characteristics of the Advanced Very High Resolution Radiometer (AVHRR) and the Landsat Thematic Mapper, adding spectral bands in the middle and long-wave infrared (IR) and providing up to 250 m spatial resolution data. It is more frequent than Landsat 7 and higher spatial resolution than AVHRR.

This study utilized the spatial and temporal relationship between MODIS NDVI and LST in forest, croplands, grassland, soil areas for early warning and mitigation measures especially during the summer season, which can be applied for forecasting the changing of temperature and vegatation stress case of a drought situation. The relationships are vital for successful near real time drought assessment.

August is the hottest and driest month in Turkey, therefore NDVI and LST maps of this month was plotted for each year between 2004 and 2013. The results show that particularly, 2007, 2008 and 2012 years temperatures are higher than other years (2007 was a drought year). This effect can be observed especially around Konya plain, Thrace region (Tekirdag, Edirne) Also, lower NDVI values over Thrace region can be easily identified in 2007 and higher NDVI values can be seen in 2009.

Bu using NDVI and LST negative correlation TVX was calculated as a drought index and TVX maps of August were created for related 10 years. Unlike, the common perception that LST and NDVI are typically negatively correlated, research demonstrated that this relationship in fact varies with different locations and years.

There are various remote sensing derived indices for drought monitoring but each should be tested for the related area and available sensor.

Operational drought monitoring programs could be also developed using satellite images obtained from different sensors in order to provide near-real time information about drought conditions such as changes in temaperatures and its impact on vegetation.

For future studies, much more remote sensing satellite based drought indixes can be investigated and compared meteorological based drought indexes.

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APPENDICES

APPENDIX A.1 : 2007 year 16-day composite NDVI values table.

APPENDIX A.2 : 2007 year 8-day LST values table.

APPENDIX A.1

No	Images (Julien day)	Dates	konya	tekirdag	antalya	rize	urfa
1	NDVI07_001	1 Jan 2007 - 16 Jan 2007	0,168	0,506	0,575	0,011	0,182
2	NDVI07_017	17 Jan 2007 - 1 Feb 2007	0,186	0,429	0,624	0,738	0,175
3	NDVI07_033	2 Feb 2007 - 17 Feb 2007	0,200	0,689	0,717	0,734	0,171
4	NDVI07_049	18 Feb 2007 - 5 Mar 2007	0,192	0,515	0,675	0,748	0,204
5	NDVI07_065	**6** Mar 2007- 21 Mar 2007	0,223	0,623	0,752	0,751	0,320
6	NDVI07_081	22 Mar 2007 - 6 Apr 2007	0,228	0,692	0,662	0,793	0,483
7	NDVI07_097	**7** Apr 2007 - 22 Apr 2007	0,366	0,709	0,764	0,789	0,657
8	NDVI07_113	23 Apr 2007 - 8 May 2007	0,48	0,759	0,447	0,75	0,775
9	NDVI07_129	9 May 2007 - 24 May 2007	0,542	0,625	0,28	0,831	0,68
10	NDVI07_145	25 May 2007 - 9 Jun 2007	0,547	0,388	0,269	0,792	0,209
11	NDVI07_161	10 Jun 2007 - 25 Jun 2007	0,484	0,48	0,406	0,853	0,169
12	NDVI07_177	26 Jun 2007 - 11 Jul 2007	0,39	0,3	0,393	0,856	0,137
13	NDVI07_193	12 Jul 2007 - 27 Jul 2007	0,349	0,298	0,352	0,848	0,134
14	NDVI07_209	28 Jul 2007 - 12 Aug 2007	0,316	0,239	0,439	0,883	0,133
15	NDVI07_225	13 Aug 2007 - 28 Aug 2007	0,292	0,216	0,421	0,876	0,178
16	NDVI07_241	29 Aug 2007 - 13 Sep 2007	0,285	0,185	0,61	0,878	0,147
17	NDVI07_257	14 Sep 2007 - 29 Sep 2007	0,300	0,193	0,565	0,862	0,141
18	NDVI07_273	30 Sep 2007 - 15 Oct 2007	0,199	0,168	0,559	0,872	0,112
19	NDVI07_289	16 Oct 2007 - 31 Oct 2007	0,155	0,179	0,51	0,862	0,149
20	NDVI07_305	1 Nov 2007 - 16 Nov 2007	0,168	0,215	0,488	0,839	0,159
21	NDVI07_321	17 Nov 2007 - 2 Dec 2007	0,195	0,272	0,426	0,768	0,147
22	NDVI07_337	3 Dec 2007 - 18 Dec 2007	0,243	0,342	0,573	0,784	0,154
23	NDVI07_353	19 Dec 2007 - 3 Jan 2008	0,268	0,408	0,582	0,704	0,153

APPENDIX A.2

No	Images (Julien day)	Months	konya	tekirdag	antalya	rize	urfa
1	LST07_001	Jan	8,81	9,21	10,79	4,83	-0,13
2	LST07_009	Jan	10,07	11,35	12,65	7,85	9,69
3	LST07_017	Jan	11,79	12,25	15,13	9,35	17,09
4	LST07_025	Jan	16,35	7,95	14,15	0,07	15,99
5	LST07_033	Feb	-6,83	6,27	12,19	10,59	12,11
6	LST07_041	Feb	-1,53	11,51	16,37	11,99	18,93
7	LST07_049	Feb	19,29	16,13	18,99	8,01	19,97
8	LST07_057	Feb	25,21	13,11	17,33	8,57	19,03
9	LST07_065	Mar	26,53	11,61	20,45	13,37	24,47
10	LST07_073	Mar	26,69	16,51	19,49	16,65	22,57
11	LST07_081	Mar	23,63	12,31	24,21	14,33	26,75
12	LST07_089	Mar	16,43	16,55	21,35	15,69	24,89
13	LST07_097	Apr	28,55	20,03	27,39	13,75	20,35
14	LST07_105	Apr	21,73	25,19	27,21	20,17	20,03
15	LST07_113	Apr	28,53	23,21	31,27	16,67	26,57
16	LST07_121	May	32,81	21,21	32,93	16,83	30,71
17	LST07_129	May	31,11	28,31	35,79	20,87	27,51
18	LST07_137	May	34,47	28,97	33,13	25,09	35,45
19	LST07_145	May	34,89	27,99	34,39	23,49	39,91
20	LST07_153	Jun	32,25	33,05	34,47	25,53	44,89
21	LST07_161	Jun	33,75	31,11	37,27	25,53	52,27
22	LST07_169	Jun	34,83	37,39	44,05	26,61	47,39
23	LST07_177	Jun	36,79	36,99	45,17	28,47	50,09
24	LST07_185	July	40,29	39,69	43,91	27,11	50,87
25	LST07_193	July	39,21	41,77	43,59	28,13	51,07
26	LST07_201	July	44,61	41,83	43,05	27,59	49,47
27	LST07_209	July	43,37	37,65	39,89	27,33	53,57
28	LST07_217	Aug	45,67	41,19	38,23	27,09	51,15
29	LST07_225	Aug	43,77	37,77	37,15	26,51	49,65
30	LST07_233	Aug	42,23	41,21	42,63	25,71	47,79
31	LST07_241	Aug	43,65	38,99	41,15	26,33	50,79
32	LST07_249	Sep	40,07	29,75	37,79	25,71	45,87
33	LST07_257	Sep	39,49	34,01	38,23	23,07	45,95
34	LST07_265	Sep	37,99	32,79	37,39	23,31	44,31
35	LST07_273	Sep	36,13	30,23	35,57	21,83	38,23
36	LST07_281	Oct	33,69	25,73	33,75	23,01	35,77
37	LST07_289	Oct	27,75	26,05	29,11	21,01	30,65
38	LST07_297	Oct	26,19	21,87	26,23	17,71	30,89
39	LST07_305	Nov	21,67	16,83	23,25	15,65	28,27
40	LST07_313	Nov	14,49	15,95	18,59	12,51	18,87
41	LST07_321	Nov	15,45	13,25	18,65	14,15	24,05
42	LST07_329	Nov	11,21	10,73	16,61	10,65	18,63
43	LST07_337	Dec	11,13	12,17	16,09	10,75	16,37
44	LST07_345	Dec	8,65	13,51	15,23	10,03	14,23
45	LST07_353	Dec	7,27	5,91	12,53	6,77	11,95
46	LST07_361	Dec	8,05	6,97	13,21	5,25	14,13

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