DROUGHT DETERMINATION BY USING LAND SURFACE TEMPERATURE AND NORMALIZED DIFFERENCE VEGETATION INDEX

E. Ozelkan[a]*, I. Papila[a], D.Z. Uca Avci[a], M. KARAMAN[a]

Istanbul Technical University, Center for Satellite Communications and Remote Sensing, Ayazaga Campus, Maslak, Istanbul.
(emre, papila, damla, muhittin)@cscrs.itu.edu.tr

Abstract - Today, many places of different locations on Earth especially semi-arid areas face the risk of desertification due to severe drought. However, the very basic data required for the analysis is unavailable for the regions without a meteorological station. In this case, land surface temperature (LST) is derived from a thermal band as an alternative meteorological station's data. In this research, Muğla, located in the eastern Mediterranean part of Turkey, was selected as the study area. By using Landsat TM data, LST&NDVI images were produced. A negative correlation, which indicated a trend for drought, was observed between LST&NDVI during a twenty six-year period. Standard precipitation index (SPI), which is a measure of drought and assessed from meteorological data, was used to verify remote sensing results. Consequently, it can be said that the negative correlation between LST&NDVI can be used as an indicator for drought as an alternative to meteorological data.

Keywords: Drought, Remote Sensing, LST, NDVI, Meteorological Station Data, SPI.

1. INTRODUCTION

Due to semi-arid climate and drought, desertification among the geography of Turkey moves on very fast. In drought studies, data sets of meteorological variables and land-cover measurements are required. However obtaining these measurements for each region of the Earth, and accordingly to get the analysis results for all regions with high accuracy is not always available since placing the weather stations everywhere is not possible both in economic and in positional reasons. By the advantage of using remote sensing methods, it may be possible to make predictions and comments about the current state of the natural phenomena, its development, future and history.

The normalized difference vegetation index (NDVI), extracted from the infrared visible regional band arithmetic can state the health and moisture contents of the vegetation and used in the drought analysis. The LST derived from the thermal bands of satellite images, gives us information about the region's surface temperature. In 2009, Karnieli and his friends studied on relationship of NDVI&LST for drought analysis. They have done a 21-years of study for North America and found out that the emergence of the negative correlation values between NDVI&LST is determinant for the drought analysis. (Karnieli, 2009) In 2009, Thai Van and his friends made a study on Ho Ci Minh City's surface temperature distribution defined by thermal remote sensing. During their studies Landsat and Aster satellite images were used. In the study they emphasized that it is not possible to engage meteorological stations everywhere. In this case derived temperature values by the thermal remote sensing methods can be used as an alternative, in which the values may have 2 or less degrees deviation. (Van, 2009) In addition, due to the economic senses, it would be beneficial using thermal remote sensing data, when compared with the cost of meteorological stations. Standardized Precipitation Index (SPI) is used to determine and predict the drought status, frequency and the severity. In Gülmez and Durdu's study, in 2010, the meteorological drought was explored for Büyük Menderes basin, which has important agricultural lands. Büyük Menderes basin's SPI data were derived from the precipitation data acquired from 10 meteorological stations, for the period 1976-2005. The relationship between the SPI values in the region and the yield of products produced were put forward. At the same time, solutions for the drought risk of Büyük Menderes basin were produced by using SPI data. In this study, it was seen that SPI data can be effectively used to detect the drought. (Gülmez, 2010) In 2003, the study performed by Sırdaş and Şen, the drought modeling of Turkey was done. Between the years 1930-1990, in accordance with the data obtained from the 60 largest climate stations, drought indices were obtained. After land observations, it was seen that the results derived from the SPI are highly accurate. It was stated that, Turkey has a wide arid and semi-arid areas; and the steps required to block the drought that has emerged were also mentioned.

In this study, drought and precipitation analysis of Muğla region were examined by studying the NDVI&LST values derived from images obtained in five different dates between the years 1985-2010 and SPI data obtained in dates between 1965-2010, from three meteorological stations.

Figure 1. The location of Muğla

*corresponding author

Authors would like to thank to USGS.

2. STUDY AREA

Muğla, which is between 36° 17' and 37° 33' northern parallels, 27° 13' and 29° 46' eastern meridians, is a city in the south-western Turkey. Muğla Down Town, Dalaman and Fethiye provinces have been identified as prior work areas and districts in Muğla City. (Figure 1) (URL-1)

In Muğla, Mediterranean climate is seen. Summers are hot and dry; the winters are mild and rainy. As moved to the inner land the continental climate is seen and heat decreases. Temperature stands between +43.7°C-12.6°C Precipitation can vary between 1180-775 mm according to the districts. Nearly 75% of the city land of Muğla is covered with forests and moor. Most of the mountains are covered with forests and the coastal slopes are covered with shrubs. In the forests, mostly, red pine, larch, pine, cedar, juniper can be found; and scented sweet gum. In the valleys and on the water banks, sycamore, willow and cypress trees mostly take place. The 4.5% of the city land is covered with meadow and pasture, and 16% is covered with the cultivated area. (URL-2)

3. MATERIALS AND METHOD

3.1 Materials

In this study, multispectral Landsat 5-TM data acquired on 08.06.1985, 14.06.1987, 07.06.2002, 26.06.2003, 13.06.2010 were used. In this study, thermal infrared band was used to obtain LST values. Also near infrared and visible red band were used to obtain NDVI values. The spectral intervals, spatial and radiometric resolution of Landsat 5-TM bands are shown in Table A. (URL-3) Also, the daily average precipitation data from Muğla and Fethiye meteorological stations between the years 1965-2006 and data from Dalaman meteorological station between the years 1965-2010 were used to generate SPI values.

3.2 Method

In this study, U.S. Geological Survey's five different dated Landsat 5-TM archive data were used to obtain LST&NDVI values. Converting Landsat 5-TM thermal bands to Kelvin degrees was the first step of this study. The Landsat TM sensors acquire temperature data and record this information. This information is in the form of digital number (DN) with a range between 0-255. Converting DNs to Kelvin degrees using a two-step process is possible. Converting the DNs to radiance values using the bias and gain values, specific to the individual scene of work is the first step. The formula used to convert DN to radiance is given as $CV_R=G(CV_{DN})+B$ where, CV_R is the cell value as radiance, CV_{DN} is the cell value digital number, G is the gain, B is the bias values. Converting radiance data to Kelvin degrees is the second step of the process. Application of the inverse of the Planck function to radiance data is adequate to compose temperature values. The formula to convert radiance to temperature for Landsat 5-TM was $T=K_2/ln((K_1*\varepsilon)/CV_R+1)$ where T is Kelvin degrees, CV_R is the cell value as radiance, ε is emissivity (typically 0.95). Also K_1 is 607.76 and K_2 is 1260.56 for Landsat 5-TM. (URL-4) Celsius=Kelvin-273.15 unit transformation is used to convert Kelvin values to Celsius.

NDVI is a quantitative method based on using spectral values from satellite imagery to get information on vegetation health and biomass density.

This indice commonly use photosynthetically active image wavelength portions, which are NIR&Red. The result of ratio based indice is an image with pixel values between -1 and +1. (Parmiggiani, 2006) High values of NDVI indicate healthy vegetation and high moisture and the low values of NDVI indicate unhealthy vegetation and low moisture. (Ozelkan, 2008) Thus NDVI results can be used as drought indices. The NDVI formula is *NDVI=(NIR-RED)/(NIR+RED)*. To compose NDVI for Landsat 5-TM data *NDVI=(Band4-Band3)/(Band4+Band3)* formula is used.

Table A. Landsat 5-TM Visualization Specialties

Electro Magnetic Region	Band No and Range(µm)	Spatial Resolution	Radiometric Resolution
Blue	1 (0.45-0.52)	30 m.	8 bit
Green	2 (0.52-0.60)	30 m.	8 bit
Red	3 (0.63-0.69)	30 m.	8 bit
Near Infrared	4 (0.76-0.90)	30 m.	8 bit
Mid Infrared	5 (1.55-1.75)	30 m.	8 bit
Thermal Infrared	6 (10.4-12.5)	120 m.	8 bit
Mid Infrared	7(2.08-2.35)	30 m.	8 bit

SPI is a way of measuring drought, negative values indicating drought, and positive values for wet conditions. SPI is a probability index that considers only precipitation. (URL-5) In SPI method, first of all the difference of significant precipitation (X_i, daily, annually, monthly) from average precipitation (X_i^{mean}, daily, monthly, annually) is obtained, then the difference is divided by standard deviation (σ) of the selected study time period. (Gülmez, 2010) The formula to obtain SPI value is $SPI=(X_i-X_i^{mean})/\sigma$. The SPI classification values are shown in Table B (URL-6). In this study the 1965-2010 precipitation data were examined to calculate daily SPI values.

Table B. Classification values for SPI

SPI Value	Drought Category
≥2.00	Extremely_wet
1.50_1.99	Very_wet
1.00_1.49	Moderately_wet
-0.99_0.99	Near_normal
-1.00_-1.49	Moderately_dry
0-1.50_-1.99	Severely_dry
≤-2.00	Extremely_dry

Table C. The LST&NDVI relations at 18 different points for 5 different dated images.

Muğla			08.06.1985		14.06.1987		07.06.2002		26.06.2003		13.06.2010		
Point	latitude	longitude	NDVI	LST	NDVI	LST	NDVI	LST	NDVI	LST	NDVI	LST	
1	622725	4119525	0,1353	35,8909	0,1468	34,4137	0,1491	17,1197	0,2256	36,8521	0,26	29,93	Muğla Down Town
2	622365	4118475	0,3035	37,6256	0,1699	38,0331	0,1786	25,6886	0,2538	39,6966	0,29	33,15	
3	619005	4118535	0,2387	36,8982	0,2292	36,3042	0,219	27,754	0,2716	38,5298	0,3	31,79	
4	621345	4118955	0,0822	37,8071	0,0803	36,3959	0,0975	25,2919	0,1453	39,9649	0,14	33,53	
5	619395	4118235	0,2189	38,5751	0,2177	36,8063	0,2291	28,2414	0,2921	39,1147	0,32	32,17	
6	620535	4120935	0,2556	37,2612	0,3357	33,4361	0,2798	23,135	0,3866	33,6229	0,33	27,9	
7	621795	4119435	0,1607	35,6155	0,1416	35,7077	0,1351	21,1462	0,2046	37,5802	0,22	30,6	
8	620505	4120425	0,1578	36,9436	0,1227	37,398	0,1081	27,6077	0,0943	40,0536	0,1	33,95	
1	657315	4067295	0,3487	40,4977	0,3349	37,1233	0,2697	32,4272	0,261	41,0296	0,33	34,41	Dalaman
2	658065	4071915	0,3336	39,3386	0,2501	35,9375	0,2788	34,6457	0,2986	35,7986	0,3	33,25	
3	658185	4071585	0,1429	43,0975	0,1122	39,3385	0,1055	38,3041	0,0989	42,8801	0,11	36,49	
4	658755	4071375	0,2431	42,0899	0,1179	39,651	0,1887	38,1664	0,2001	42,4422	0,24	36,17	
5	662445	4074045	0,208	44,098	0,1932	39,963	0,2732	36,0745	0,2681	40,4547	0,26	33,76	
6	662685	4073745	0,0385	45,0891	0,0876	39,2038	0,1194	36,1665	0,097	41,253	0,14	34,55	
1	675945	4067055	0,3657	28,2414	0,3862	37,1256	0,5361	31,3157	0,5485	33,8546	0,52	30,17	Fethiye
3	673155	4069845	0,2032	40,8534	0,1898	38,3493	0,2275	35,7523	0,2305	37,1713	0,21	33,06	
4	674715	4069815	0,0996	46,2941	0,1144	39,1147	0,1258	36,8064	0,09	40,6327	0,11	36,26	
5	684525	4062075	0,2601	41,6508	0,3233	32,3564	0,4159	37,2171	0,4477	32,7331	0,39	30,36	
Correlation coefficients (ρ)			-0,4407		-0,50823		0,190227		-0,80359		-0,63315		

4. RESULTS

LST&NDVI images (Figure 2) were obtained from 08.06.1985, 14.06.1987, 07.06.2002, 26.06.2003, 13.06.2010 dated Landsat 5-TM band satellite images. Especially June images were chosen to examine to analyze the temporal change due to drought. Black color shows low and white color shows high temperature values for thermal image. Black color show unhealthy and drought and white color show healthy and wet vegetation areas for NDVI images. For all images, same 18 control points (8 point from Muğla Down Town, 6 point from Dalaman and 4 point from Fethiye) were determined around the meteorological stations to get sample for LST&NDVI.(Table C) The negative correlation was seen between LST&NDVI when their relation was examined for each image except 2002. Image of 2002 was cloudy over Muğla Down Town, and it caused LST values to be low. Thus the cloudy weather distorts the relationship that is indicated in this study. When the Muğla Down Town data was eliminated and only Dalaman & Fethiye data were used for 2002, the correlation became negative as others. Correlation coefficients (ρ) between LST&NDVI are respectively $\rho_{08.06.1985=}$ -0.4407, ρ_{1987}= -0.50823, $\rho_{07.06.2002}$= 0.190227, $\rho_{26.06.2003}$= -0.80359, $\rho_{13.06.2010}$= -0.63315. When cloudy Muğla Down Town data is eliminated for 2002, the $\rho_{07.06.2002}$ is -0.63954 and this shows the cloud effect for this study. Coefficients of determination (R^2) for regression analyze between LST&NDVI are respectively $R^2_{08.06.1985}$= 0.1942, $R^2_{14.06.1987}$ = 0.2583, $R^2_{07.06.2002}$ = 0.0362, $R^2_{26.06.2003}$ =0.6458, $R^2_{13.06.2010}$ = 0.4009. When cloudy Muğla Down Town data is eliminated for 2002, the $R^2_{07.06.2002}$ is 0.409 and this is the evidence of cloud effect for this study. The negative ρ value is the determinative factor for drought determination, if the negative correlation is high, R^2 value is high, indicating drought is high.

The 1965-2010 June precipitation data were examined to calculate daily SPI values. The SPI period contains the LST&NDVI period. First of all, the difference of significant precipitation (X_i, daily precipitation of the satellite imaging date) from average precipitation X_i^{mean}, then the difference is divided by standard deviation (σ, by using daily precipitation data from 1965-2010) of the selected study time period (June 1965-2010).

Table D. SPI results

The amount of daily precipitation at data acquisition date			
Date	**Muğla**	**Dalaman**	**Fethiye**
08.06.1985	0	0	0
14.06.1987	0	0	0
07.06.2002	0	0	0
26.06.2003	0	0	0
13.06.2010	No data	0	No data
SPI Values			
Date	**Muğla**	**Dalaman**	**Fethiye**
08.06.1985	-0,36754	-0,42012	-0,22183
14.06.1987	-0,36754	-0,42012	-0,22183
07.06.2002	-0,36754	-0,42012	-0,22183
26.06.2003	-0,36754	-0,42012	-0,22183
13.06.2010	No data	-0,42012	No data

There is no precipitation on the date of data acquisition of Landsat 5-TM. The daily $SPI_{08.06.1985}$, $SPI_{14.06.1987}$, $SPI_{07.06.2002}$, $SPI_{26.06.2003}$, $SPI_{13.06.2010}$ are shown in Table D. The values are less than 0 so the values are in near normal SPI class but they are near to moderately dry. The drought analyze results that were derived from two different method is directly proportional. The meteorological stations of Muğla and Fethiye have been closed since 2007. There is a lack of meteorological data after 2006 and it is impossible to make drought analyze by meteorological data. At this point the negative correlation between LST&NDVI can be used as a drought analyze as in this study.

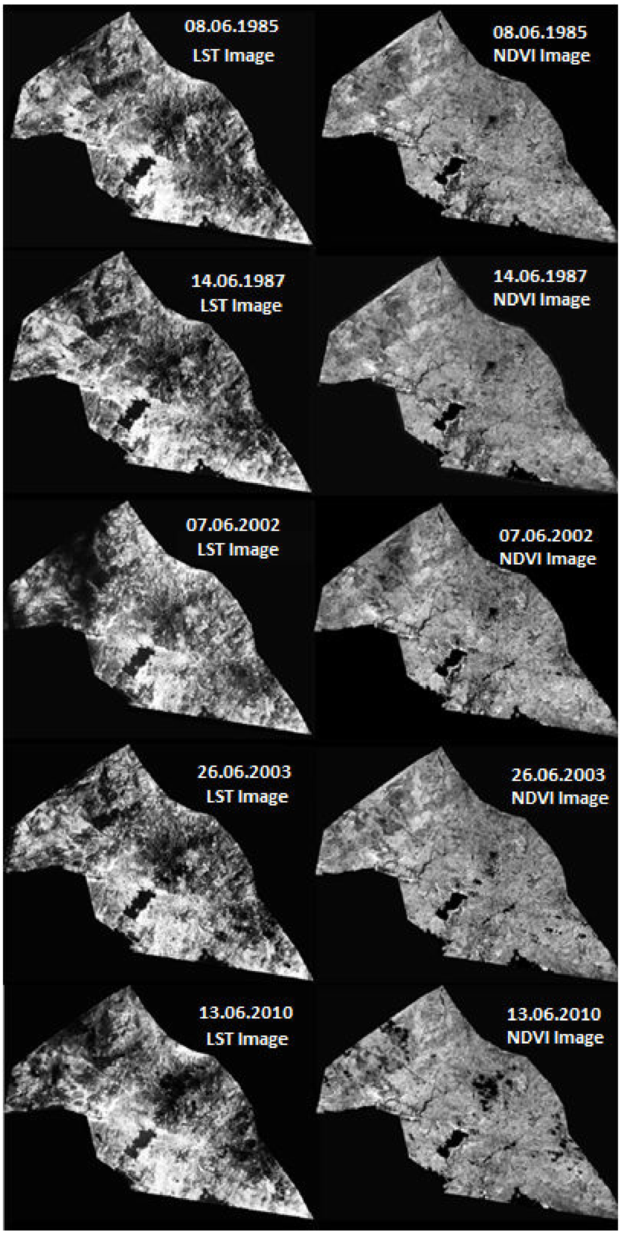

Figure 2. LST&NDVI images of the study area.

5. CONCLUSION

By examining the relationship of NDVI&LST, the regional drought is verified by SPI analysis. The reverse correlation found between LST&NDVI values which is an indicator of drought, can be used in drought analysis if meteorological data is not available.

As a result of closure of Muğla and Fethiye metrological station after 2006, it is not possible to make drought analysis. Dalaman meteorological station is currently working. When the application performed with the data acquired from the active station located in Dalaman is extended for the duration till 2010, it is seen that it is possible to determine the drought by using NDVI&LST method.

Muğla is an important tourist region however it is under severe drought and fire risks. The lack of metrological data is the major problem in drought analysis. This study shows, for this kind of situations, this method may be used to determine drought analysis.

REFERENCES

A. Karnieli, N. Agam, R.T. Pinker, M. Anderson, M.L. Imhoff, G.G. Gutman, N. Panov, A. Goldberg, "Use Of NDVI And Land Surface Temperature For Drought Assessment: Merits And Limitations", Journal Of Climate Volume: 23, Issue: 3, Pages: 618-633, 2010.

E. Özelkan, C. Örmeci, "Risk Assessment Of Forest Fires By Using Satellite Data With Remote Sensing Techniques", EARSEL, Istanbul, Turkey, 2–5 June 2008, Volume 0, 2009.

F. Parmiggiani, G. Quarto, G. Marra, D. Conte, "NDVI Fluctuations From 1995 To 2006 in South Italy And North Africa: A Search For Or A Climate Change Indicator", Remote Sensing For Agriculture, Ecosystems, Hydrology 8, Volume 6359, September 2006

Ö.F. Durdu, S.P. Gülmez, " Investigating Spatial Distribution Of Meteorological Drought In The Büyük Menderes River Basin Using Standardized Precipitation Index", I. National Symposium On Agricultural Structures And Irrigation", Kahramanmaras, Turkey, 28.5.2010.

S. Sirdas, Z. Sen, "Meteorological Drought Modeling And Application To Turkey", Journal Of Istanbul Technical University, Volumet:2, No:2, 95-103 April 2003

T.T. Van, L.V. Trung, H.T. Lan, "Application Of Thermal Remote Sensing in Study On Surface Temperature Distribution Of Ho Chi Minh City", Vietnam 7th Fıg Regional Conference Spatial Data Serving People, 19-22 October 2009.

URL-1, Wikipedia Free Encyclopedia, 04.01.2011 http://tr.wikipedia.org/wiki/Mu%C4%9Fla_(il)

URL-2, World Geography, 04.01.2011, http://www.cografya.gen.tr/tr/mugla/iklim.html

URL-3, United States Geological Survey, Earth Resources Observation and Science (EROS) Center http://eros.usgs.gov/#/guides/landsat_tm

URL-4, Landsat DN_to_Klevin, 2010, The Yale Center For Earth Observation, September 2010, http://www.yale.edu/ceo

URL-5, NOAA Satellite And Information Services Climate Of 2010 – December, National Climatic Data Center, 04.04.2011, http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html

URL-6, North American Drought: A Paleo Perspective, Standard Precipitation Index (SPI), 04.01.2011, http://www.ncdc.noaa.gov/paleo/drought/drght_spi.html