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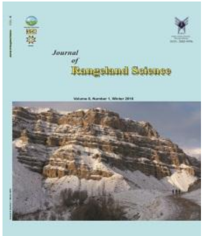

**Research and Full Length Article:**

# Assessment of Drought Severity Using Vegetation Temperature Condition Index (VTCI) and Terra/MODIS Satellite Data in Rangelands of Markazi Province, Iran

Ali Akbar Damavandi[A], Mohammad Rahimi[B], Mohammad Reza Yazdani[C], Ali Akbar Noroozi[D]

[A]Ph.D. Student in Combat Desertification, Semnan University, Semnan, Iran
[B]Assistant Prof., Semnan University, Semnan, Iran (Corresponding Author),
Email: mrahimi@profs.semnan.ac.ir
[C]Assistant Prof., Semnan University, Semnan, Iran
[D]Assistant Prof., Soil Conservation and Watershed Management Research Institute, Tehran, Iran

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**Abstract.** The drought caused a series of effects on many sectors of economy, especially natural resources. During two last decades, Iran has suffered from several severe to extreme agricultural droughts which caused significant decreases in rangeland and agriculture yields. This paper discusses the detection of agricultural drought severity over the rangelands of Markazi Province between 2000 and 2014 using remotely sensed data. Vegetation Temperature Condition Index (VTCI) is a near-real time drought assessment and monitoring approach which have been developed using Terra-MODIS normalized difference vegetation index (NDVI) and Land Surface Temperature (LST) products. VTCI is defined as the ratio of LST differences among pixels with a specific NDVI value in a sufficiently large study area. VTCI has capability of drought stress classification which therein lower VTCI is for drought and higher one for wet conditions. The ground-measured precipitation data from the synoptic stations of Markazi Province are used to validate the VTCI drought monitoring approach (11 stations). For this objective, after the calculation of Standardized Precipitation Index (SPI) with different periods and VTCI month of July during 2000 to 2014 (warm and cold edges from NDVI and LST scatter gram extracted), linear regression analysis between VTCI (15 maps) and SPI 1, 3,6,9,12,18 months were surveyed and finally, the best map was extracted. Based on the statistical analysis, higher correlations were found for July 2006 ($R^2$ =0.73 for warm edge and $R^2$=0.86 for cold edge) and the best linear correlation was created for SPI-18 month in July. Results showed that within VTCI classified map, moderate and low drought classes constituted most area of studied region. Also, the results showed that VTCI is closely related not only to recent rainfall events but also to past rainfall amount (18 month) indicating that VTCI is a better and near-real time drought monitoring approach for rangelands.

**Key words**: Drought, Rangelands, VTCI, Remote sensing, MODIS

## Introduction

Drought is a stochastic natural phenomenon that arises from considerable deficiencies in precipitation (Hayes *et al*., 2004). Among natural hazards, drought is known to cause extensive damages and affects a significant number of people (Wilhite, 1993). Drought produces a complex web of impacts which affects many sections of economy, especially rangeland section. Drought leads to a decline in food grain production depending upon the intensity, duration, and spatial coverage of drought stress. To reduce the damages of drought, it is crucial to characterize the droughts. Drought characterization enables such operations as drought early warning (Kogan, 2000) and drought risk analysis (Hayes *et al*., 2004), which allow the improved preparation and contingency planning. Iran is located in the arid and semi-arid regions and has high vulnerability to drought. In 2001 and 2002, the amount of damages in Iran was 2.5 and 1.7 billion dollar, respectively. Thus, monitoring of the most disastrous phenomena such as drought is a concern to the planners or decision makers from viewpoint of food security and trade as a whole (Damavandi and Panahi, 2013). In Iran, the point-based meteorological drought indices have been extensively used for drought monitoring, but sparse meteorological network and lack of timely availability of weather data always hinder the accurate and timely monitoring of regional drought.

Drought indices are the quantitative measures that characterize drought levels by assimilating data from one or several variables (indicators) such as precipitation and evapotranspiration into a single numerical value that is more readily useable than raw indicator data (Zargar *et al*., 2011). Remote sensing observations have been used to monitor drought-related variables from a climatological viewpoint and also to assess and quantify the drought impacts from an ecosystem perspective (Aghakouchak *et al*., 2015). Satellite observations have been used to evaluate the drought impacts on ecosystems including vegetation health and growth by assessing the photosynthetic capacity of plants (Tucker and Choudhury, 1987; Asner and Alencar, 2010). Precipitation declines can lead to the reduced photosynthetic capacity and changes in the absorption of solar radiation in photosynthesis by plants. Combinations of satellite visible (VIS) and infrared (IR) images have been widely used to monitor the plant changes and water stress (Wardlow *et al*., 2012).

The most commonly used normalized difference vegetation index (NDVI) from remote sensing often falls short in real time drought monitoring (Park *et al*., 2004; Wang *et al*., 2004). Due to a lagged vegetation response to drought, NDVI cannot detect the drought events instantaneously. On the other hand, Land Surface Temperature (LST) is sensitive to water stress and has been identified as good indicator of water stress (Jackson *et al*., 1981; Goetz, 1997). Thus, accurate and real-time drought monitoring needs a combination of thermal and visible/near infrared wavelengths to provide information on vegetation and moisture conditions simultaneously. After the drought occurrence by the precipitation shortage, its impacts are usually first apparent in rangelands. A drought index which closely describes temporal and spatial variations of crop water use status must be suitable for drought monitoring. Satellite remotely sensed data offer considerable advantages and should be an integral part of monitoring drought, especially for temporal and spatial evolutions of drought (Wan *et al*., 2004). Since MODIS (Moderate Resolution Imaging Spectroradiometer) instrument on Terra satellite was launched in December 1999. The MODIS remotely sensed data can be used to produce NDVI imagery at 250m resolution, and to retrieve LST at the global scale. AVHRR NDVI and/or LST time series plots have been used to identify and monitor the drought evolution (Kogan, 2000; Liu and Ferreira, 1991; Chen *et al*., 1994; Liu and Kogan, 1996). Liu and Ferreira (1991) reported a good correlation between monthly total rainfall and monthly cumulative NDVI with a time lag of one month. Di *et al*. (1994) through a simulation approach found a good correlation between daily rainfall and daily NDVI with a time lag of 15 to 23 days. Wilks (1995) suggested that due to the obvious seasonal variations of climatic events, the use of standardized anomaly data instead of mean values was more suitable for investigating the annual NDVI departure from the normal ones. Chen *et al*. (1994) developed the Anomaly Vegetation Index (AVI) for monitoring the drought occurrence in China.

With drought incidence, land surface temperatures increase slightly earlier than plant cover decreases (Di *et al*., 1994). During dry conditions (there are less soil moisture availability), the rising leaf temperatures are good indicators of plant moisture stress and precede the onset of drought. This thermal response can occur even when plants are green as stomata closure to minimize water loss by transpiration results in a decreased latent heat flux. At the same time, due to the requirement that the energy flux must balance, there will be an increase in the sensible heat flux which may result in the increased leaf temperatures. This increase in leaf temperature can be used for stress detection in crops. This land surface energy flux balance finally results in high land surface temperatures (Bikash, 2006) Because of poor spatial resolution of meteorological data such as precipitation and land air surface temperature, especially in remote regions with difficult access and in some developing countries, the remotely retrieved NDVI and LST data can provide a valuable source of information for monitoring the drought (Wan *et al*., 2004). As mentioned above, the drought monitoring approaches with satellite remotely sensed data are based on NDVI, LST (or brightness temperature) and the single ratio of LST and NDVI. In this paper, the VTCI drought monitoring approach is further developed by the newly launched Terra-MODIS reflective and thermal infrared data, and applied to monitor the drought at a study area in Markazi Province, Iran. With the assumption that the shape of scatter plots of LST and NDVI is triangular at a regional level, the Vegetation Temperature Condition Index (VTCI) was developed for monitoring the drought occurrence, and has been applied in Markazi Province. However, these drought monitoring results are dependent on the methods of determining warm and cold edges of VTCI. The aim of this research was to detect the agricultural drought severity in the rangelands of Markazi Province, Iran during 2000 to 2014 using remotely sensing data.

## Materials and Methods

### Study area

Markazi Province is located in center of Iran (lat 33˚- 23′ to 35˚-33′N and long 48˚-51′ to 51˚-05′E). Markazi Province is limited from north to Tehran, Alborz and Qazvin, from south to Isfahan and Lorestan, from west to Hamadan and from east to Qom province. Based on last country divisions of Iran, Markazi Province has 12 counties, 32 cities, 23 units and 1394 villages. Its area is about 29127 $km^2$ that comprises about 1.85 percent of Iran area. Altitudinal range is 3390 m (Adineh Koh in Shazand County) to 950 m a.s.l. (Saveh Plain). Mean annual rainfall is 290 mm and mean annual temperature is 13 °C (Markazi Office of Meteorology) (Fig. 1).

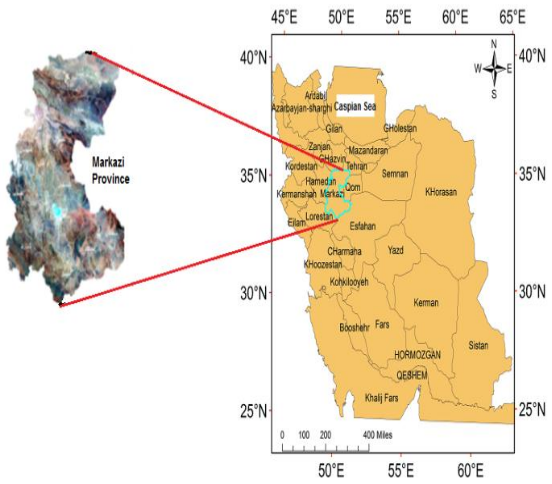


**Fig. 1.** Geographic location of study area

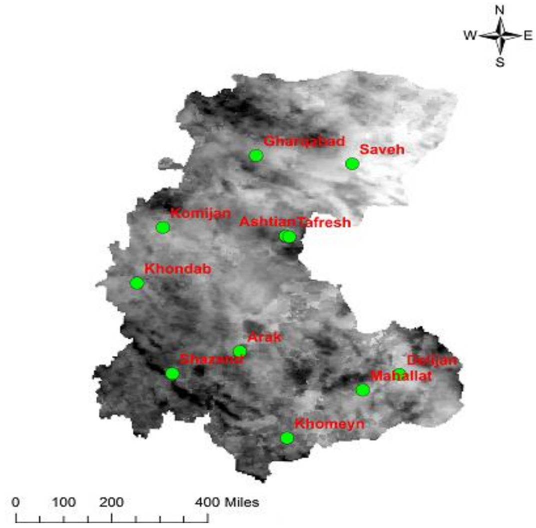


**Fig. 2.** location of synoptic stations

## Data

Drought causes serious challenges in much of Markazi Province, especially in the areas where variability in annual rainfall is high.

Therefore, there is a considerable interest in the indices that monitor the agricultural drought. Most of the study area is covered by the rangelands (70%) and croplands (26%). Other land cover types are stony and salt pan and residential lands.

Monthly synoptic measured surface data are obtained from National Climatic Data Center.

The data include elevation, latitude and longitude of meteorological stations and total monthly precipitation. We selected synoptic stations with records of precipitation for at least 30 years and fully recorded data for every month from July 2000 to August 2014. The 16-day Terra MODIS composites of NDVI and 8-day LST were selected for this study.

The compositing period is from July $28^{th}$ to August $30^{th}$, 2000 to 2014 (day 209 and 225 for NDVI and day 209 to 233 for LST of the each year).

The spatial resolution for the NDVI and LST data is about 250 and 1km in nominal, respectively (226m and 855m actually).

## Methods and Data Processing

### VTCI definition

This index has been used as an effective agricultural drought index to monitor the spatial pattern of vegetation over a region (Equations 1 & 2). Vegetation temperature condition index is calculated as below (Wang *et al*., 2004; Wan *et al*., 2004):

$$VTCI = \frac{LST_{NDVIi.max} - LST_{NDVIi}}{LST_{NDVIi.max} - LST_{NDVIi.min}}$$

(Equation 1)

Where

$$LST_{NDVIi.max} = a + bNDVI_i$$

$$LST_{NDVIi.min} = a' + b' NDVI_i$$

(Equation 2)

Where $LST_{NDVIi.max}$ and $LST_{NDVIi.min}$ are maximum and minimum land surface temperatures of pixels which have same $NDVI_i$ value in a study region, respectively. $LST_{NDVIi}$ denotes land surface temperature of one pixel whose NDVI value is $NDVI_i$. Coefficients of $a$, $b$, $a'$ and $b'$ can be estimated from a large area where soil moisture at surface layer should span from wilting point to field capacity at pixel level. In general, the coefficients are estimated from the scatter plots of LST and NDVI in the area. The shape of t scatter plot is normally triangular at a regional scale

(Gillies *et al*., 1997; Wang *et al*., 2004) if the study area is large enough to provide a wide range of NDVI and surface moisture conditions.

The VTCI is related not only to NDVI changes in the region, but also to LST changes of pixels with a specific NDVI value. It can be physically explained as the ratio of temperature differences among the pixels (Fig. 3). The numerator of Equation (1) is the difference between maximum LST of pixels and LST of one pixel while the denominator of Equation (1) is the difference between maximum and minimum LSTs of pixels. In Figure 3, $LST_{max}$ can be regarded as the 'warm edge' where there is less soil moisture availability and plants are under dry conditions and $LST_{min}$ can be regarded as the 'cold edge' where there is no water restriction for the plant growth (Gillies *et al*., 1997; Wang *et al*., 2004). The value of VTCI ranges from 0 to 1 and lower value of VTCI leads to higher occurrence of drought.

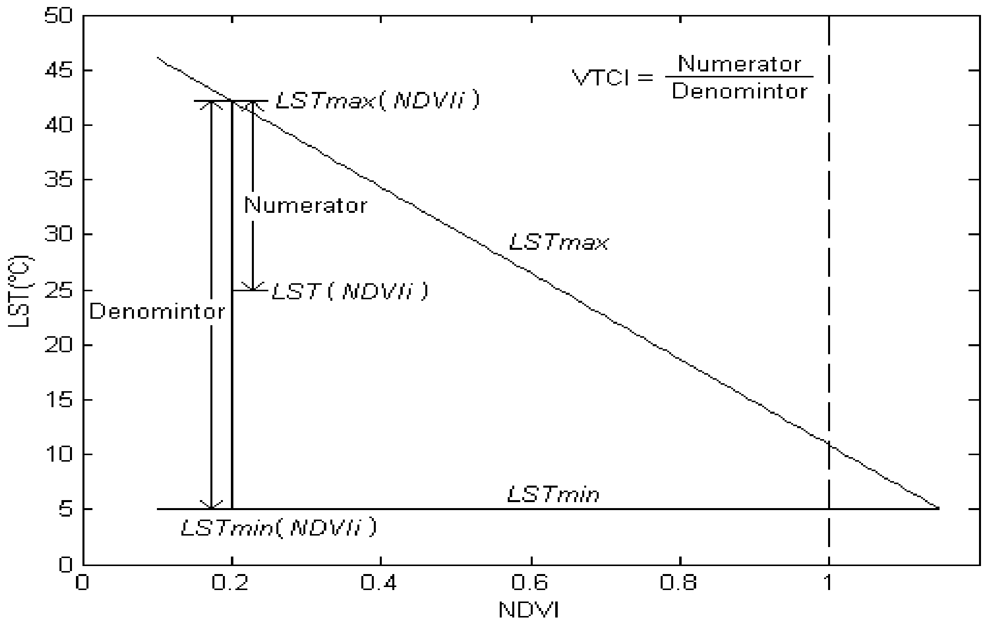


**Fig. 3.** NDVI/LST feature space relationships

## Data processing

After the perception of 16-day composite NDVI and 8-day LST product based on MODIS Terra, we generated MODIS data including geo location, re-projection, calibrated radiance, cloud masking, atmospheric temperature and water vapor using ENVI 4.7 and ArcGIS 10.2.2 software. The retrieved LST and NDVI data are stacked in the ENVI software and 2-D scatter gram of LST and NDVI. Pixels of warm edge (max) and cold edge (min) of points were separated and their values for NDVI and LST in ArcGIS were extracted. Afterward, the equation of each warm and cold line in EXCEL was calculated. At the end, we get a linear regression between VTCI and NDVI, LST and SPI for mapping the VTCI drought stress classes for each year using ArcGIS software.

## Results

### Determination of 'warm edge' and 'cold edge'

One important issue in using VTCI approach for monitoring the droughts is to determine whether the study area is large enough to provide a wide range of NDVI and LST. In the study area, main land cover types are rangelands and croplands, and other land cover types include salt land and stony land. A method to analyze wet and dry conditions is to use the scatter plot of LST and

NDVI. Figure 4 is the scatter plots of the MODIS 16-day NDVI and LST 8-day data. The straight lines are drawn in the scatter plots based on the scatter plot of the whole study area, the upper and lower limits of scatter plots represent the 'warm edges' ($LST_{max}$), and 'cold edges' ($LST_{min}$), respectively.

All the warm and cold edges in the scatter plots (Fig. 4) seem to be well defined. On the whole, the same 'warm edge' and 'cold edge' are used in calculating VTCI for all land cover types over the whole study area. After estimating $a$, $b$, $a'$ and $b'$ from the selected 'warm edge' and 'cold edge' for the studied years (July 2000-2014), the best correlation (Equation 3) was achieved for 2006 (Fig. 5). A linear relation for this year was give as follows:

$$LST_{NDVI\ i.max} = 325.91 - 11.463NDVI_i$$
$$LST_{NDVI\ i.min} = 305.78 + 7.8353 \times NDVI_i$$
(Equation 3)

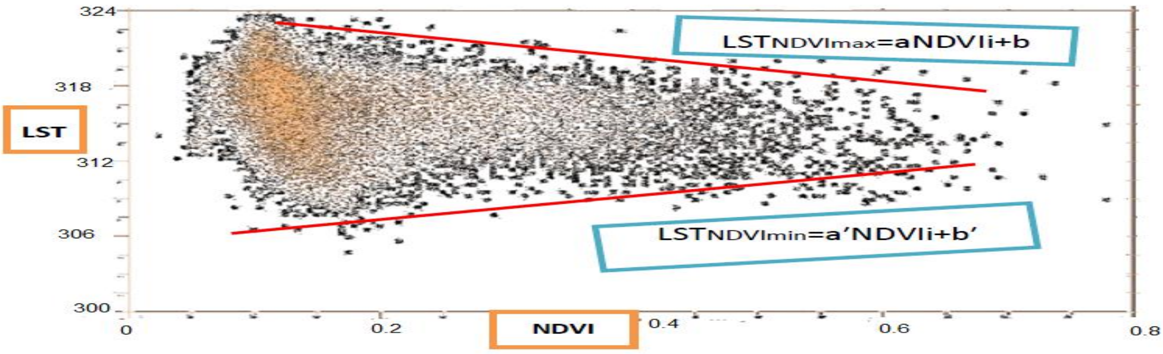


**Fig. 4.** Scatter plot of LST and NDVI in study area (July, 2006)

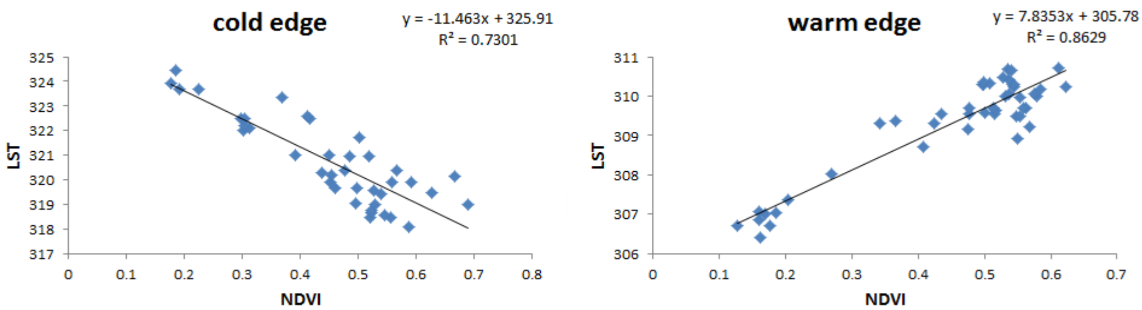


**Fig. 5.** Linear regression of warm and cold edges in the study area (July, 2006)

Table 1 shows a, b, a′ and b′ and their $R^2$ for the studied years:

**Table 1.** Correlation coefficients of warm and cold edge equations

| Year | a | b | $R^2$ | a′ | b′ | $R^2$ |
|---|---|---|---|---|---|---|
| 2000 | 1.2863 | 320.81 | 0.03 | 0.2524 | 313.41 | 0.006 |
| 2001 | -7.9018 | 325.05 | 0.25 | 4.3348 | 311 | 0.16 |
| 2002 | -7.3436 | 324.49 | 0.2 | 2.5681 | 310.45 | 0.11 |
| 2003 | -2.8022 | 322.32 | 0.03 | 2.1819 | 309.81 | 0.07 |
| 2004 | -2.8446 | 323.18 | 0.05 | 1.6561 | 311.46 | 0.03 |
| 2005 | -10.531 | 326.74 | 0.7 | 3.8588 | 309.02 | 0.14 |
| 2006 | -11.463 | 325.91 | **0.73** | 7.8353 | 305.78 | **0.86** |
| 2007 | -8.3935 | 321.13 | 0.15 | 4.7661 | 306.62 | 0.2 |
| 2008 | 10.59 | 323.3 | 0.22 | 6.4729 | 307.3 | 0.25 |
| 2009 | -7.0652 | 321.79 | 0.15 | 4.6013 | 308.86 | 0.13 |
| 2010 | -8.6095 | 322.4 | 0.21 | 7.9686 | 306.35 | 0.7 |
| 2011 | -8.8924 | 322.33 | 0.3 | 5.2343 | 309.36 | 0.17 |
| 2012 | -8.0537 | 323.58 | 0.17 | 2.2566 | 310.74 | 0.03 |
| 2013 | -3.3636 | 322.99 | 0.06 | 2.4986 | 310.64 | 0.02 |
| 2014 | -10.799 | 324.1 | 0.3 | 1.6057 | 309.96 | 0.02 |

Using the (Equations 1 and 3), we got the VTCI image of the study area. Then, this image has been categorized into 5 drought classes consisting of 1-very high, 2-high, 3-moderate, 4-low and 5-no drought. The final map of classified droughts based on VTCI in July 2006 showed that moderate and low drought classes had constituted the most area (Fig. 6).

## Relations between VTCI and Precipitation

After the calculations of SPI-1, 3,9,12 and 18 periods for July in 11 synoptic stations and their averages, the linear correlation of these pointed drought indices with VTCI for July was estimated (Fig. 7). Results show that a linear correlation between VTCI and SPI-18month (Table 2) is better than other SPIs. VTCI value in 2000 had a very high drought stress, 2005 and 2008 had a moderate stress of drought, and the other desired years had a high stress of drought. These results are in accordance with those reported for Iranian drought conditions that Iran Climatology Research Institute published. VTCI is significantly correlated with cumulative SPIs amount in July. These results suggest that VTCI is closely related not only to recent rainfall events but also to past rainfall amount indicating that VTCI might be a better index for the drought assessment. Based upon the results of this research, July 2006 had the best conditions using VTCI, and SPI 18-month and had the best correlation with VTCI (Table 3).

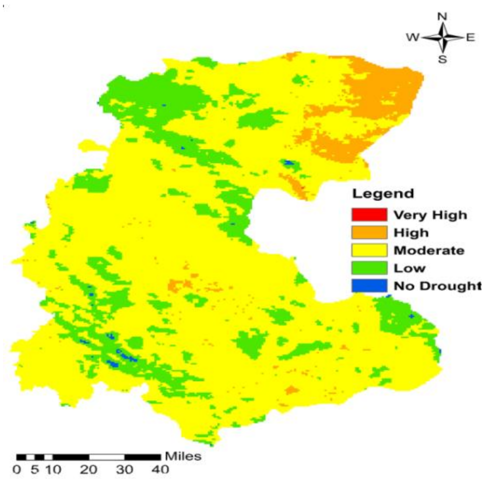


**Fig. 6.** VTCI drought classes map

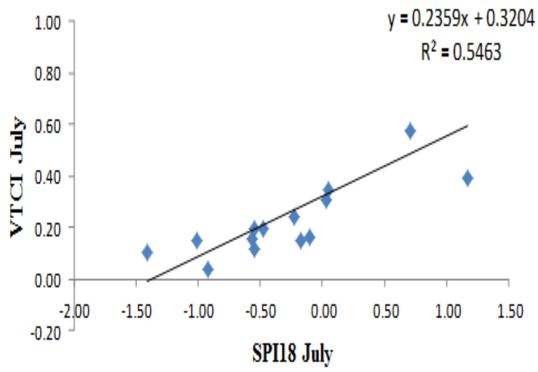


**Fig. 7.** Correlation of VTCI and SPI-18 month in July (2000-2014)

**Table 2.** Values of SPI 1, 3, 6,9,12, 18 and VTCI for July

| Year | spi1 | spi3 | spi6 | spi9 | spi12 | spi18 | VTCI |
|---|---|---|---|---|---|---|---|
| 2000 | 0.68 | -0.78 | -1.77 | -1.29 | -0.89 | -1.41 | 0.20 |
| 2001 | 0.65 | 0.24 | -0.89 | -0.21 | -0.04 | -1.01 | 0.26 |
| 2002 | 0.68 | -0.36 | 0.19 | 0.51 | 0.46 | -0.10 | 0.38 |
| 2003 | 0.61 | 0.40 | 0.82 | 0.90 | 0.70 | 0.71 | 0.37 |
| 2004 | 0.61 | 0.85 | 0.73 | 1.02 | 0.76 | 1.17 | 0.39 |
| 2005 | 1.06 | 0.59 | 0.11 | 0.34 | 0.24 | 0.55 | 0.48 |
| 2006 | 0.67 | -0.08 | -0.62 | -0.14 | -0.30 | -0.17 | 0.35 |
| 2007 | 1.43 | 1.01 | 0.69 | 0.31 | 0.46 | 0.03 | 0.30 |
| 2008 | 0.62 | -0.20 | -1.40 | -0.91 | -1.29 | -0.57 | 0.45 |
| 2009 | 0.62 | 0.13 | -0.05 | -0.34 | -0.17 | -0.92 | 0.33 |
| 2010 | 0.60 | -0.83 | -0.14 | -0.37 | 0.10 | 0.05 | 0.25 |
| 2011 | 0.73 | -0.25 | 0.16 | -0.42 | -0.46 | -0.55 | 0.32 |
| 2012 | 0.71 | -0.07 | -0.30 | -1.16 | -0.41 | -0.23 | 0.34 |
| 2013 | 0.72 | -0.14 | -0.54 | -0.67 | -0.39 | -0.55 | 0.40 |
| 2014 | 0.71 | 0.29 | -0.10 | 0.02 | 0.01 | -0.48 | 0.39 |

**Table 3.** Correlation coefficient between SPI periods and VTCI

| | spi-1 | spi-3 | spi-6 | spi-9 | spi-12 | spi-18 |
|---|---|---|---|---|---|---|
| VTCI | 0.2 | 0.41 | 0.22 | 0.36 | 0.29 | 0.54 |

## Discussion and Conclusions

Drought is a recurring phenomenon so that the assessment of its spatial and temporal variations is necessary for many sections such as natural resources and rangelands. Iran in two recent decades has experienced droughts with different intensities. VTCI can be physically interpreted as the ratio of LST differences among the pixels with a specific NDVI value in a large area to provide wide ranges of NDVI at the surface layer. This study explored the integration of vegetation represented by NDVI and surface temperature measurements (LST) for deriving the vegetation temperature condition index (VTCI) based on the interpretation of LST-NDVI space. The role of satellite-derived VTCI for monitoring and assessing the agricultural drought in a regional scale has been shown by the meteorological integration based on SPI. It was observed that the VTCI is an ideal index to monitor the agricultural drought. This case study is carried out to validate the VTCI index approach using ground measured precipitation data over the study area covering Markazi Province, Iran. Consequences of this research showed that VTCI is related not only to recent rainfall events, but also to past rainfall amounts. These results are consistent with those presented by the studies done by Wan *et al*. (2004) and Aghakouchak *et al*. (2015). The produced map showed that moderate and low drought classes had covered the most area in this year.

These results indicated that VTCI is a near-real time drought monitoring approach. VTCI is time-dependent and usually region-specific, and is better to be used during the plant growing seasons. One issue in applying VTCI approach is how to determine its ‘warm edge’ and ‘cold edge’ (Wan *et al*., 2004). The major advantage of VTCI is that it captures information about the drought stress conditions solely by satellite measurements. Results of this research are in agreement with those reported by Wang *et al*. (2004) who studied Guanzhong Plain, PR China and the southern Great Plains, USA. However, this index has a limited applicability in cloudy conditions since surface temperature is highly sensitive to cloud cover. For avoiding the point-based quantitative drought monitoring approaches, further studies should be focused on developing a quantitative drought monitoring index by remotely sensed data, and choosing an appropriate model to forecast the droughts using the time series of VTCI. The results of this study can serve as a guide for agricultural drought researchers to assess the vast natural resources and agricultural lands of the country. The procedures described in this paper can be considered as a good method for the real time assessment of agricultural droughts.

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# ارزیابی شدت خشکسالی با استفاده از شاخص وضعیت حرارتی پوشش گیاهی(VTCI) بوسیله داده های سنجنده مودیس در استان مرکزی، ایران

علی اکبر دماوندی[الف]، محمد رحیمی[ب]، محمد رضا یزدانی[ج]، علی اکبر نوروزی[د]

[الف]دانشجوی دکتری بیابان زدایی، دانشکده کویرشناسی دانشگاه سمنان، ایران
[ب]استادیار دانشکده کویر شناسی دانشگاه سمنان، ایران (نگارنده مسئول)، پست الکترونیک: mrahimi@profs.semnan.ac.ir
[ج]استادیار دانشکده کویر شناسی دانشگاه سمنان، ایران
[د]استادیار پژوهشکده حفاظت خاک و آبخیزداری سازمان تحقیقات، آموزش و ترویج کشاورزی، ایران

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**چکیده.** خشکسالی سبب ایجاد مجموعه‌ای از اثرات نامناسب در بخش‌های مختلف اقتصادی و خصوصا منابع طبیعی تجدید شونده می‌گردد. در دو دهه گذشته، ایران متحمل چندین خشکسالی شدید کشاورزی بوده که سبب کاهش جدی محصولات مرتعی و کشاورزی گردیده است. این مقاله به بررسی شدت خشکسالی کشاورزی در مراتع استان مرکزی در بین سال‌های ۲۰۰۰ تا ۲۰۱۴ با استفاده از داده‌های سنجش از دوری می‌پردازد. شاخص وضعیت حرارت پوشش گیاهی (VTCI)، شاخصی با رویکرد نزدیک به واقعیت با استفاده از شاخص پوشش گیاهی اختلاف نرمال شده (NDVI) و درجه حرارت سطح زمین (LST) سنجنده MODIS ماهواره Terra است. شاخص VTCI شاخصی مبتنی بر نسبت اختلاف‌های LST در میان پیکسل‌هایی با NDVI بخصوص در یک منطقه نسبتا وسیع است. این شاخص می‌تواند تنش‌های حاصل از خشکسالی را طبقه‌بندی نماید. برای این منظور ایستگاه‌های سینوپتیک استان مرکزی (۱۱ ایستگاه) برای تولید شاخص بارندگی استاندارد شده (SPI) در دوره‌های ۱-۳-۶-۹-۱۲ و ۱۸ ماهه برای ماه جولای و شاخص‌های ماهواره‌ای NDVI و LST برای همین ماه از سال ۲۰۰۰ تا ۲۰۱۴ انتخاب شدند. به دنبال آن تعداد ۱۵ شاخص VTCI تولید گردید و معادلات لبه گرم و سرد از منحنی‌های مثلثی ایجاد شده استخراج گردید. نقشه حاصل از تنش خشکسالی که بر اساس رابطه سال ۲۰۰۶ دارای بیشترین همبستگی بود، تولید شد. در ادامه همبستگی میان شاخص VTCI و شاخص SPI در دوره‌های ۱-۳-۶-۹-۱۲و۱۸ ماهه بررسی گردید که بهترین رابطه مربوط به SPI ۱۸ ماهه منتهی به جولای(مرداد) بوده است ($R^2$=0.73 برای لبه گرم و $R^2$=0.86 برای لبه سرد). همچنین در نقشه حاصل از طبقه بندی بوسیله VTCI، غالب منطقه مطالعه را طبقات خشکسالی متوسط و ملایم تشکیل می‌دهند. نتایج این تحقیق نشان داد که این شاخص علاوه بر رطوبت فعلی به رطوبت قبلی نیز وابسته می‌باشد.

**کلمات کلیدی:** خشکسالی، مراتع، VTCI، سنجش از دور، مودیس