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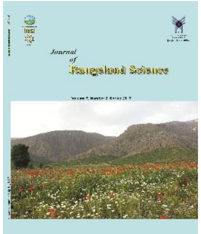

Research and Full Length Article:

Drought Monitoring Using Vegetation Indices and MODIS Data (Case Study: Isfahan Province, Iran)

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Abstract. Drought is a major problematic phenomenon mostly for semi-arid areas of Iran. During drought periods, reduction in vegetation levels causes such problems as soil erosion, surface runoff, flood risk, etc. Therefore, the assessment of drought effects on plant covers is the most important issue. This research was conducted in 2015 using the extracted vegetation indices from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor data during 2000-2008. In Esfahan province, monthly rainfall data from 25 stations were used to derive the Standardized Precipitation Index (SPI) at 3 month scale, March to September. SPI was used to validate three index results in drought estimation. The result of calculating SPI showed that droughts occurred in 2000, 2001 and 2008. The result of Pearson correlations between SPI and Vegetation Indices showed that the highest correlation was related to VCI index and the lowest correlation was related to TCI index. The result of NDVI index in 2000, 2001 and 2008 indicated that the poor vegetation cover was increasingly occurred. Based on the results of this study, it can be concluded that the NDVI and VCI indices concerning MODIS sensor can be a good alternative for estimating the drought with respect to meteorological indices and consequently can give a better idea on drought conditions in the study area. It was shown that remote sensing data can be practically useful in analyzing the drought events in Esfahan province.

Key words: Drought, Remote sensing, SPI, Vegetation indices, Isfahan province

Introduction

Drought is one of the most common natural disasters that can lead to a reduction in water supply, deteriorate water quality and finally crop failure (Riebsame *et al*., 1991). Drought effects on vegetation lead to significant consequences concerning livelihood and socio-economic development. Therefore, understanding drought is very important for ecologists, hydrologists, meteorologists, and related scientists. 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; Damavandi *et a*l., 2016). Remote sensing is superior to conventional methods for drought monitoring (Jain *et al*., 2009). Remote sensing and satellite sensors data can provide continuous datasets that may be used to detect the onset of drought as well as its duration and magnitude (Thiruvengadachari and Gopalkrishna, 1993; Chopra, 2006; Mu *et al*., 2013). Moderate Resolution Imaging Spectroradiometer (MODIS) data with proper spectral, temporal and spatial resolutions can be optimum for monitoring the droughts in large areas (Liu *et al.*, 2005; Patel *et al*., 2009). Using MODIS images facilitates near real-time monitoring of droughts. Images from other sensors are not used since there might be conflicts with the pixel resolution (Gopinath *et al*., 2014). Lots of vegetation index based on remote sensing data have been used to monitor vegetation with the most widely adopted NDVI (Choudhary *et al*., 2013). Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used indices based on drought indices (Gopinath *et al*., 2014). Currently, NDVI data play an important role in monitoring the vegetation drought (Kogan, 1995; Gu *et al*., 2007; Brown *et al*., 2008). NDVI minimizes the topographic and atmospheric effects (Rouse Jr *et al*., 1974; Mahmoud *et al*., 2016). Higher NDVI values reflect greater vigor and photosynthetic capacity (or greenness) of vegetation canopy whereas lower NDVI values for the same time period are reflective of vegetative stress resulting in chlorophyll reductions and changes in the leaves' internal structure due to wilting (Gu *et al*., 2008). Kogan (1990) suggested an approach to vegetation condition monitoring based on minimum and maximum NDVI values compiled per pixel over time. Kogan (1990) stated that available moisture and natural resources determine the NDVI minimum while other values including the historical maximum are determined by the weather. Kogan (1990) used this NDVI statistical range to develop VCI as an indicator of environmental stress. Several studies suggest that VCI captures rainfall dynamics better than the NDVI particularly in geographically nonhomogeneous areas (Mahyou *et al*., 2010). Kogan (1995) also proposed TCI. TCI is derived from brightness temperature in the NOAA-AVHRR 11 mm channel, and its algorithm is similar to that of VCI except for the fact that the relevant formula was modified to reflect the opposite to NDVI vegetation's response to temperature (Orhan *et al*., 2014). Zarei *et al*. (2013) used the images of an Advanced High Resolution Radiometer (AVHRR) to monitor the droughts in Iran during 1997-2005 (March-July). Their results revealed that satellite data had been successful for the early detection and monitoring of droughts. Feng (2014) generated VCI and TCI Indices from MODIS products. Results show that VCI and TCI indices provide the detailed spatial variability of drought intensity and thus enhance the understanding of relationships between drought conditions and land use/ land cover types. The aim of this study was to evaluate the NDVI, VCI, and TCI indices derived from MODIS images in order to monitor meteorological droughts in Isfahan province, Iran.

Materials and Methods

Study area

The study area (Isfahan province) is located in the central part of Iran that its area is about 214,503 km^2. It is stretched from 30º 6′ to 34º 58′ N and 49º 6′ to 55º 5′E. This region has a semi-arid climate with a low annual precipitation (130 mm) which generally occurs in winter from December to April) (Akbari *et al*., 2007). About 3% of total study area is cultivated (609250 ha) which 95 and 5% are assigned to the irrigated and rain-fed lands, respectively. The maximum and minimum temperature is 30 and 3°C in July and January, respectively (Akbari *et al*., 2007).

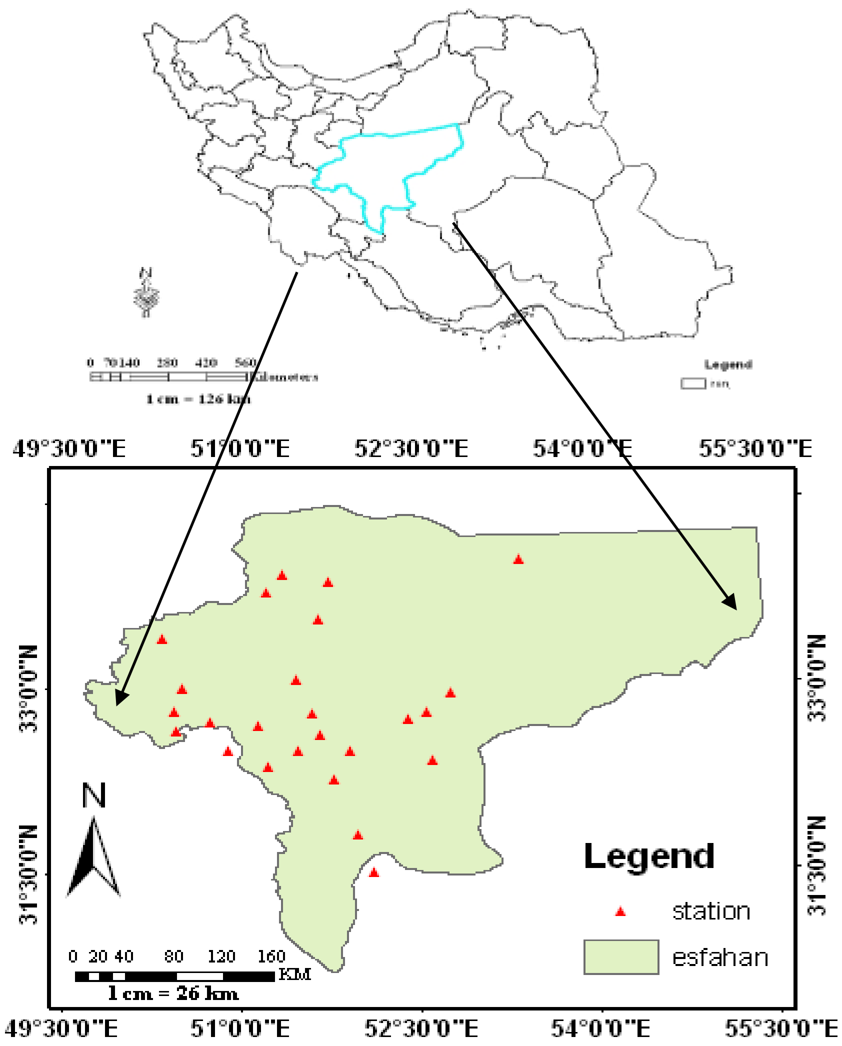


Fig. 1. Geography location of study area in Iran

MODIS Satellite Data

The MODIS data used in this study are from the Land Processes Distributed Active Archive Center (LP DAAC) and accessed from the Earth Observing System (EOS) Data Gateway during 2000 to 2008. Its detectors measure 36 spectral bands between 0.405 and 14.385 µm and it acquires data at three spatial resolutions - 250m, 500m, and 1,000m.

NDVI, VCI and TCI were calculated according to the equations (1), (2) and (3):

$$NDVI = \frac{P_{NIR} - P_{Red}}{P_{NIR} + P_{Red}} \quad (1)$$

$$VCI = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \times 100 \quad (2)$$

$$TCI = \frac{BT_{\max} - BT_i}{BT_{\max} - BT_{\min}} \times 100 \quad (3)$$

Where: NDVI= Normalized Difference Vegetation Index

P_{Red} and P_{NIR} are the reflectance for MODIS bands 1 (620–670 nm) and 2 (841–876 nm), respectively.

NDVI, $NDVI_{max}$ and $NDVI_{min}$ are the smoothed weekly NDVI, multiyear maximum NDVI and multiyear minimum NDVI, respectively for each grid cell.

BTi, BTmin and BT_{max} are the seasonal averages for weekly brightness temperature, multiyear absolute minimum BT, and maximum BT, respectively. Brightness temperature values were obtained from the thermal band (band 31). The MODIS Conversion Tool Kit (mctk) extension module to ENVI software was used. mctk extension converts emissivity values to brightness temperature. NDVI generally provides a broad overview of vegetation conditions and spatial vegetation distribution in a region. Vegetation drought is closely related with weather impacts. However, in NDVI, the weather component gets subdued by a strong ecological component. VCI separates the short-term weather-related NDVI fluctuations from the long-term ecosystem changes (Kogan, 1990, 1995). Therefore, while NDVI shows seasonal vegetation dynamics, VCI rescales vegetation dynamics between 0 and 100 to reflect relative changes from extremely bad to optimal in the vegetation conditions (Singh *et al*., 2003; Orhan *et al*., 2014). VCI and TCI characterize the moisture and thermal conditions of vegetation, respectively. To assess the indicators performance, the correlation between the average values of these indicators and average values of SPI was established in SPSS.

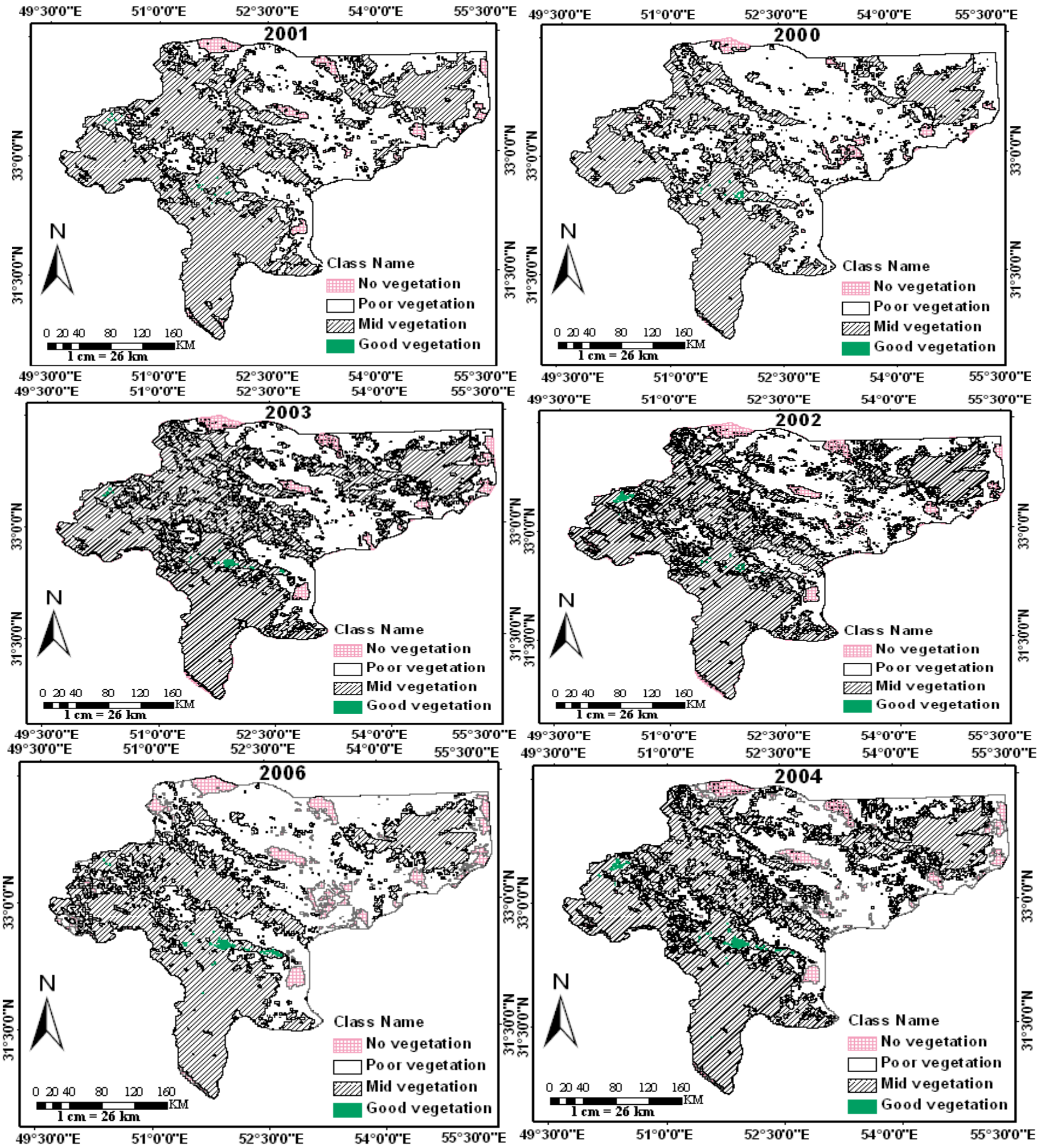
Results

Mapping agricultural vegetative drought

In the first step, all the MODIS satellite data are geo-referred with an image to image method. Region is located in the Zoon of 39 north all the images Convert into UTM 39N. True surface reflectance is derived from the top of the atmosphere apparent reflectance by performing the atmospheric correction. For each year, an image on May month was selected to produce vegetation drought indices during 2000 to 2008. Drought was not calculated for 2004-2005 because of clouds. The values of NDVI were calculated for each pixel of image. Vegetative drought was observed and understood through NDVI, VCI, and TCI indices. Fig. 2 shows an example of NDVI mapping during 2000-2008. NDVI varies between -0.1 and +0.1. Pixels with 0.0-0.05, 0.05-0.1, 0.1-0.5, and 0.5-1.0 values are classified as no vegetation, poor vegetation, moderate vegetation, and good vegetation, respectively (Orhan *et al*., 2014). According to Fig. 2, extreme and severe droughts occurred in 2008 and 2000. Increasing of poor vegetation and decreasing of moderate and good vegetation are seen for 2000, 2001 and 2008 (Fig. 2). After the calculation of NDVI, VCI was computed using band math in ENVI software. Based on the drought levels (Table 1), extreme, severe, moderate, slight and normal droughts were obtained by the means of density slice. Fig. 3 is the VCI from which we can see that most of the areas are in drought in 2000 and 2008. TCI was calculated using the brightness temperature. Fig. 4 is the TCI from which we can see that most of the areas are in drought during 2000-2004.

Table 1. SPI, VCI, and TCI classification schemes **(**Bhuiyan *et al.*, 2006**)**

Drought classes	classification schemes	
	SPI value	VCI & TCI
Extreme drought	-2<	10>
Severe drought	-1.49 to -2	10 to 19.9
Moderate drought	-1.5 to -0.99	20 to 29.9
Mild drought	-1 to 0	30 to 39.9
No drought	0>	40≥



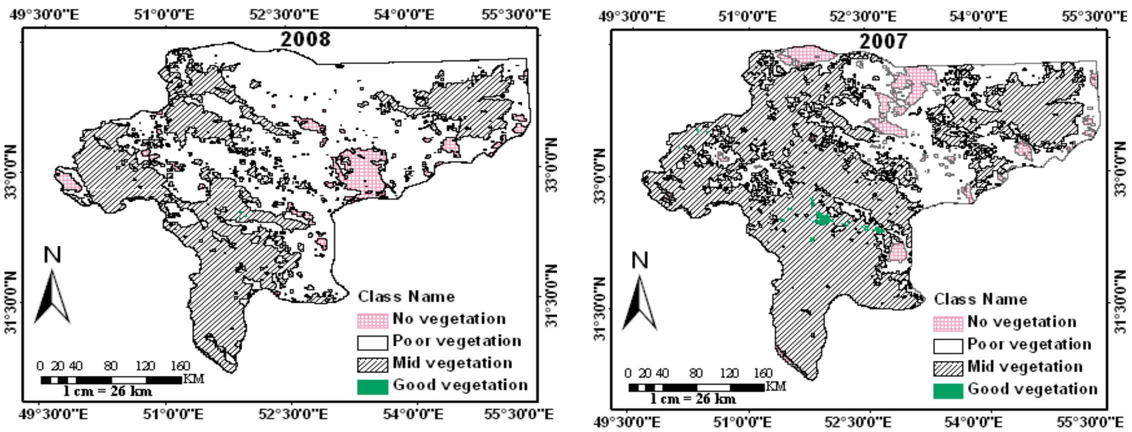
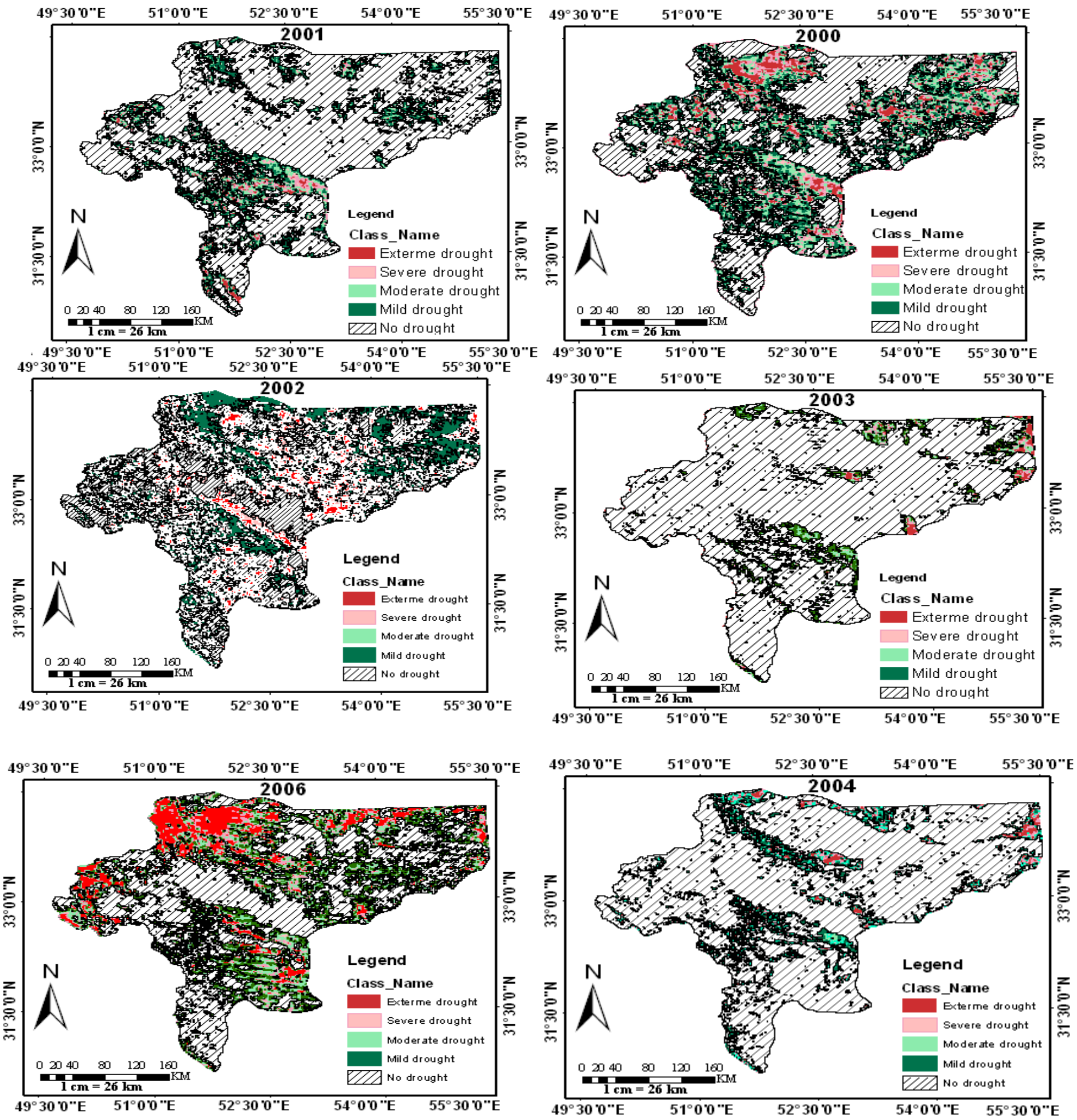


Fig. 2. NDVI Map during the 2000 to 2008 years in the area



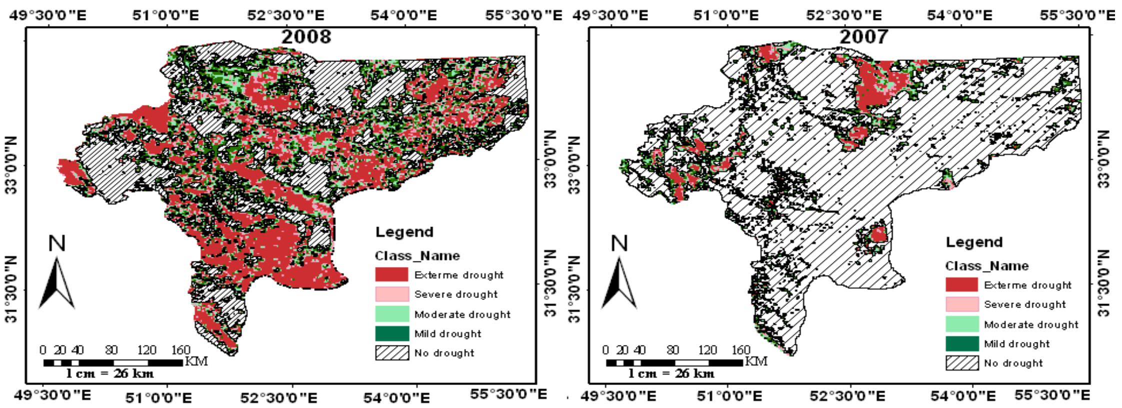
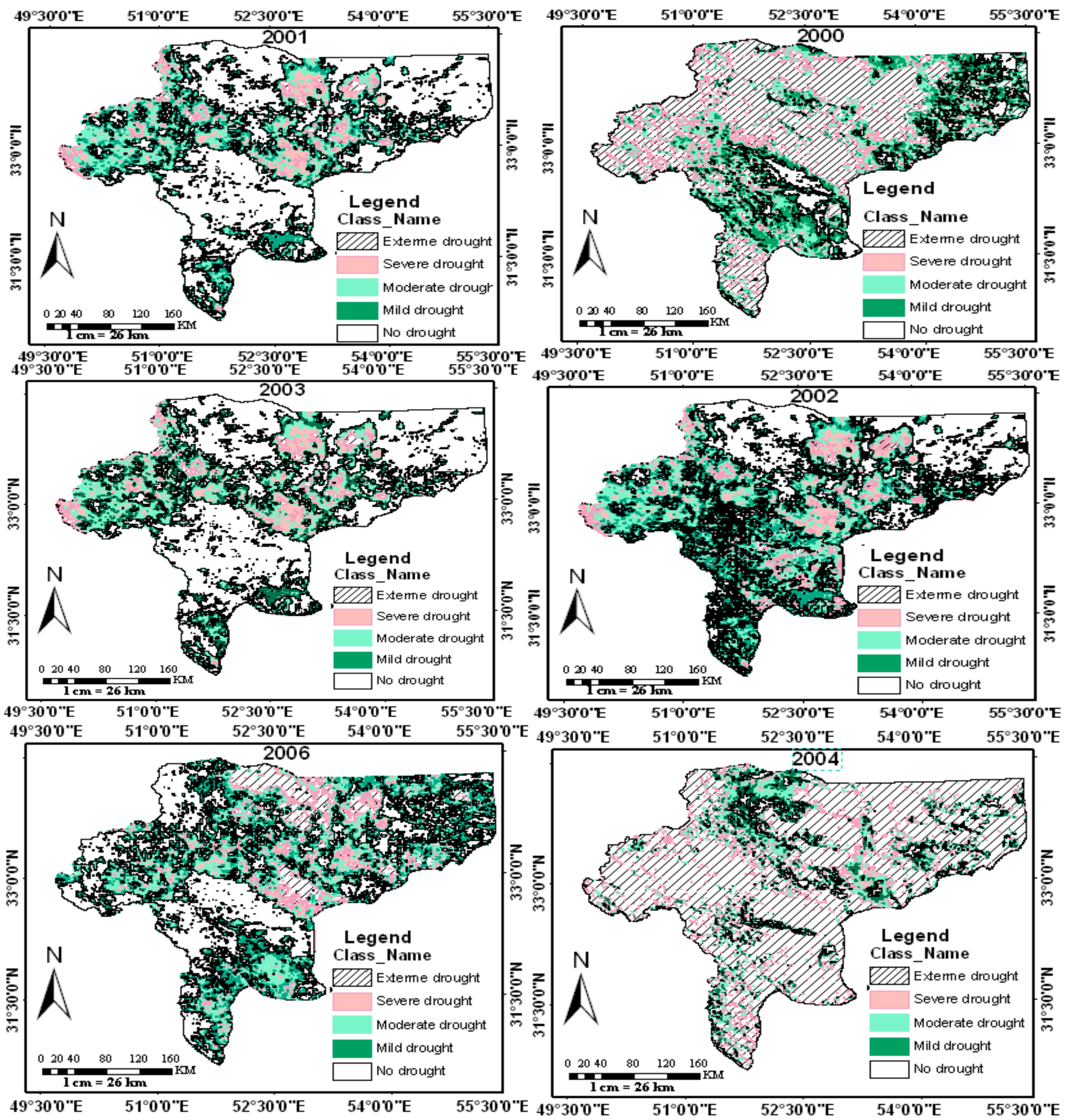


Fig. 3. VCI index map during the 2000 to 2008 years in the area



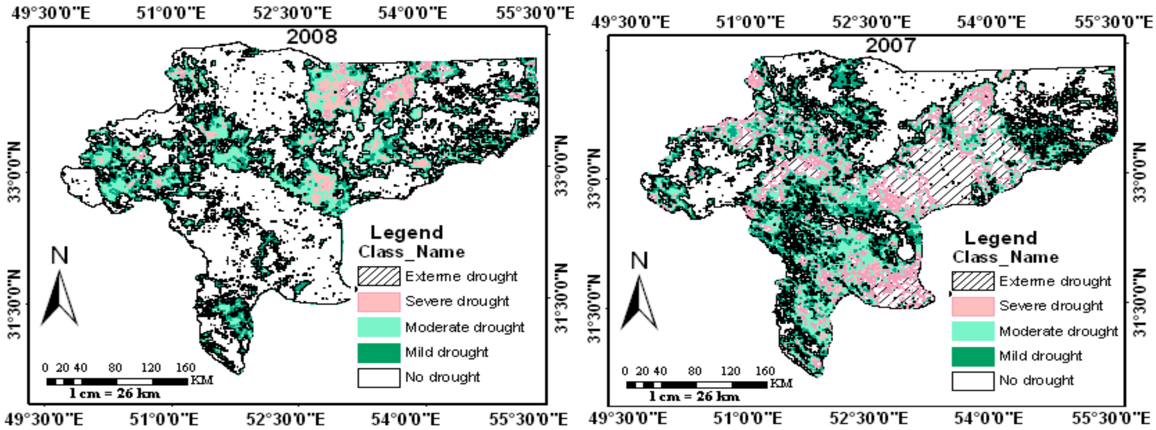
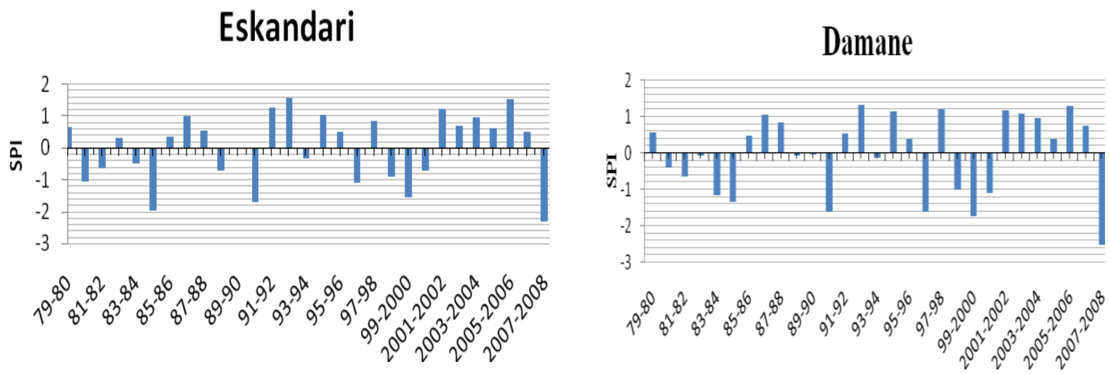


Fig. 4. TCI index map during the 2000 to 2008 years in the area

Calculation SPI Index and assessment MODIS Indicators

Rainfall data have been monthly collected from 25 rain gage stations in and around Isfahan Province (Fig. 1). This study has used a 3-month SPI to quantify the precipitation deficit for 1999-2009 because the 3-month SPI has large fluctuations whereas in a long-term scale, the fluctuations are reduced (Thenkabai *et al*., 2003). It can be interpreted that a short-term SPI is very sensitive to moisture conditions so that with the smallest variation in the monthly rainfall, SPI responds quickly indicating the SPI ability as a powerful tool for monitoring humidity and short-term changes (Bedagh Jamali *et al*., 2005). Since precipitation data are mostly skewed, precipitation data were normalized using a gamma function in order to compute SPI. Classification of SPI maps has been carried out using the method proposed by McKee *et al.* (1995). SPI diagrams for the selected stations in the study area are shown in Fig. 5. According to Fig. 5, in 10 years later, extreme drought occurred during 2007-2008 for all the desired stations. In the other years, severe to extreme droughts occurred during 1999-2000 and 2000-2001; it is in accordance with the evaluation results of NDVI and VCI indicators. A summary of Pearson analysis is presented in Table 2. Both NDVI and VCI showed a significant relationship with the 3-month SPI. Interestingly, TCI showed the negative correlation with SPI.



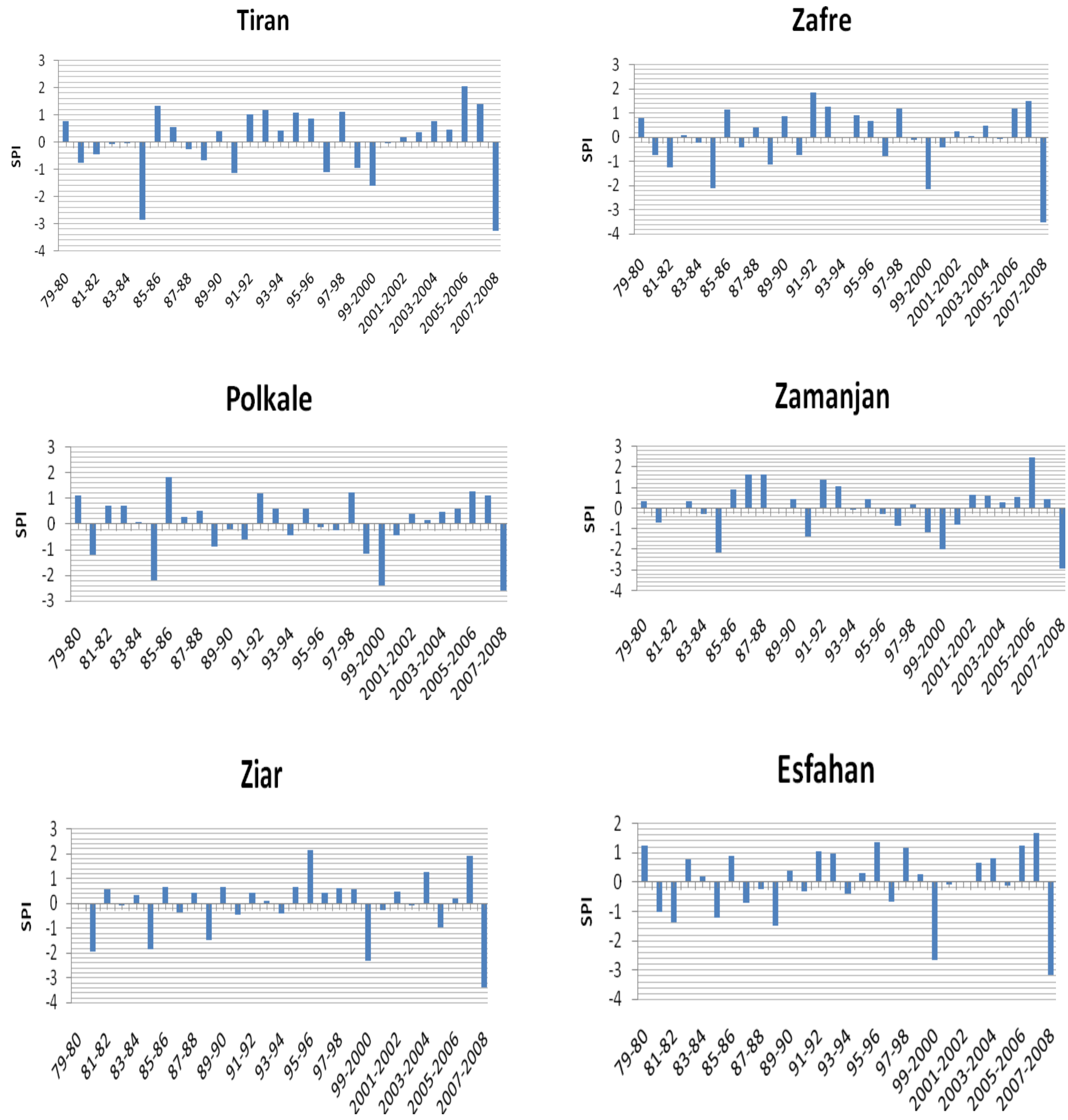


Fig. 5. SPI diagrams for selected stations in the study area

Table 2. Correlation coefficient between SPI-3 and annual NDVI, TCI and VCI indices

Index	SPI
SPI	1
NDVI	0.701
TCI	-0.65
VCI	0.719

Discussion

Drought affects not only agricultural productions and water resources but also the vegetation cover of a region and promotes the desertification**.** Today, the identification of drought effect on plant vegetation as temporal and spatial has been possible with drought indices defined by remote sensing images. Two main aims of this research were as follows: the efficiency assessment of vegetation indices in the estimation of drought and second, the use of more powerful and widely MODIS sensor data.

Considering the satellite images, number of sampling points is greater than number of ground stations; thus, the use of remote sensing knowledge is recommended. According to the VCI Index, 2008 and 2000 have the most severity, respectively. Also, with respect to TCI, 2004 and 2000 had the most severity, respectively. As it can be seen, the results of indicators are different. So, a criterion should be used for evaluating the efficiency of these indicators. SPI associated with vegetation was chosen as a measure. Correlation between VCI and SPI was equal to + 0.71 which indicates a strong positive correlation. Therefore, the VCI index has shown a more accurate and better method for the estimation of drought. Finally, we can conclude that the NDVI and VCI indices and MODIS sensor can be good alternatives in estimating the drought with regard to the meteorological indices. The relationships between MODIS, NDVI and VCI have been demonstrated in the literature (Dabroska *et al*., 2002; Koltunov *et al*., 2009). According to the Ramesh *et al.* (2010), VCI and TCI indices are used for the estimation of vegetation drought and monitoring. VCI coupled with TCI should be employed as a tool to monitor both drought and excessive wetness. Thus, we can say that VCI and TCI are found to be dependent on the region and also weather and ecological conditions.

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پایش خشکسالی با استفاده از شاخص‌های گیاهی در تصاویر ماهواره‌ای MODIS (مطالعه موردی: استان اصفهان)

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چکیده. خشکسالی پدیده بسیار مشکل‌زا برای بسیاری از نواحی نیمه خشک ایران است. در طی دوره-های خشکسالی کاهش سطوح پوشش گیاهی منجر به بروز مشکلاتی برای فرسایش خاک، رواناب سطحی، خطر بروز سیل و ...، می‌شود. بر این اساس، ارزیابی اثرات خشکسالی بر روی پوشش گیاهی از اهمیت زیادی برخوردار است. پژوهش حاضر در سال ۱۳۹۴ با استفاده از تصاویر ماهواره‌ای MODIS طی دوره آماری ۲۰۰۰ تا ۲۰۰۸، انجام شد. به منظور محاسبه نمایه بارش استاندار (SPI) در مقیاس سه ماه (فروردین تا شهریور) آمار ماهانه بارش ۲۵ ایستگاه در استان اصفهان، مورد استفاده قرار گرفت. شاخص SPI به منظور اعتبار سنجی سه شاخص برآورد کننده خشکسالی بکار برده شد. نتایج محاسبه شاخص SPI نشان داد که در سال‌های ۲۰۰۰، ۲۰۰۱ و ۲۰۰۸ خشکسالی به وقوع پیوسته است. نتایج حاصله از همبستگی پیرسون بین شاخص‌های گیاهی و شاخص زمینی (SPI) نشان داد، بیشترین همبستگی مربوط به شاخص VCI و کمترین همبستگی مربوط به شاخص TCI می‌باشد. نتایج شاخص NDVI نشان داد که سطح پوشش گیاهی ضعیف در طی سه سال ۲۰۰۰، ۲۰۰۱ و ۲۰۰۸ گسترش پیدا کرده است. بنابر نتایج این تحقیق، می‌توان نتیجه گرفت که شاخص‌های VCI و NDVI استخراجی از سنجنده MODIS می‌تواند گزینه‌ای مناسب برای برآورد خشکسالی نسبت به شاخص‌های آب و هواشناسی باشد و در نتیجه ایده بهتری راجع به شرایط خشکسالی در منطقه مورد مطالعه می‌دهد. در نهایت این تحقیق نشان داد که داده‌های سنجش از دور می‌تواند عملا" در آنالیز وقوع خشکسالی در استان اصفهان مفید باشد.

کلمات کلیدی: خشکسالی، سنجش از دور، SPI، شاخص‌های گیاهی، استان اصفهان