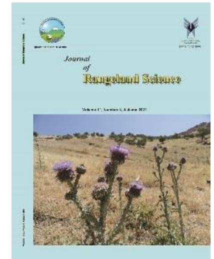

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Research and Full Length Article:

Drought Monitoring Using MODIS Land Surface Temperature and Normalized Difference Vegetation Index Products in Semi-Arid Areas of Iran

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Abstract. Reduction in vegetation cover and increasing land surface temperature are the most important consequences of drought which leads to land degradation. Therefore, the evaluation of drought effects on vegetation cover and its relationship with land surface temperature is very important. To that end, the objective of this study was to evaluate the relationship among vegetation cover, drought and land surface temperature in the north-west of Iran during 2001-2014. The annual (12 months) Standardized Precipitation Index (SPI) was calculated using monthly precipitation time series from 26 meteorological stations in the study area. Then, the interpolated maps of drought were produced using the Kriging method in the GIS environment. The Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) index were calculated from 2001-2014 using MODIS satellite images. Then, the Pearson correlation coefficient (R) was calculated to investigate the relationship among NDVI, LST and SPI. According to the results, the changes trend of mean NDVI was similar to drought trends over the years (2001-2014) and the NDVI values have experienced its greatest reduction in 2008 (NDVI=0.087). The results also showed that LST values had a significant inverse relationship with SPI and NDVI indices ($P<0.05$). So, Land Surface Temperature (LST) was the highest (LST=22.3) where SPI and NDVI were the lowest (SPI=0.04 and NDVI=0.087) and there was the most severe drought in these conditions. Therefore, mean NDVI and LST could be suitable alternatives for climate indicators in the monitoring and evaluation of drought events in semi-arid areas.

Key words: Remote Sensing, SPI, MODIS, North-West of Iran

Introduction

Global scale changes have altered the hydrological cycle and consequently, the frequency of the extreme events has been increased (Jentsch and Beierkuhnlein, 2008). Therefore, severity, duration and frequency of occurrence of drought events in the world scale are significantly increased, especially in the arid and semi-arid areas in recent decades (Dhawale *et al.* 2019; Solomon, 2007). Several studies (Parmesan, 2006; Sheffield *et al.* 2012) suggested that the impact of future droughts on the biochemical cycle would be more severe and can change the climate and ecosystem structure in the global (Dai, 2011) and local scales, respectively. As the result of such alterations, changes in the ecosystem productivity, water use efficiency and fluid dynamics are inevitable (Logan and Brunsell, 2015). On the other hand, drought with a certain return period as a common event in all climates (dry to wet) can affect the human population over the world. So, the impact of drought on the economic, social and environmental parts is significantly understandable (Wilhite, 2005; Begueria *et al*., 2010; Li *et al*., 2013). While there is no distinct and widely accepted definition of drought and various disciplines have their specific definition in general, drought is usually defined as a process which causes a reduction in precipitation volume and consequently, the deficit in the water supply of different parts (Wilhite, 1993). It has led to the use of indicators for analysis and monitoring drought in the last century. By using these indicators, severity, duration and spatial and temporal distribution patterns of drought can be investigated (Begueria *et al*., 2010; Vicente-Serrano *et al*., 2010).

The Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) are the most important indicators which are widely used by researchers in the detection of drought characteristics (Heim, 2002; Palmer, 1965; Palmer, 1968). In another definition of drought, Tucker and Choudhury (1987) noted that when drought occurs, due to the decrease in rainfall amount, the areal standard minimum growth rate of plants is also consequently reduced. In this definition, vegetation cover is defined as the natural or planted cover which can be recognized through spectral reflectance using satellite sensors. In fact, drought significantly affects the growth, production, structure, and the composition of the plants as well as the ecosystem functions (Jentsch, *et al*., 2011; Xia *et al*., 2014). Therefore, drought as an important factor can affect the quality and quantity of the vegetation (Ichii *et al*., 2002; Karabulut, 2003) and is capable to reduce plant cover in the area which is detectable through remote sensing techniques (Tucker, 1989; Al-Quraishi *et al*., 2020; Bushra *et al*., 2019; Hernina and Yandi, 2019; Klisch & Atzberger, 2016; Liu *et al*., 2018; Rajpoot and Kumar, 2019). In order to evaluate the quality and quantity of the vegetation cover over the years and also to overcome the problem and limitations of the field survey, the use of satellite imagery is a suitable alternative (Shamsipour *et al*., 2011; Fazel Dehkordi *et al*., 2015). In this regard, the use of remote sensing-based indices to study the vegetation cover changes has been increased. It should be noted that the Normalized Difference Vegetation Index (NDVI) is one of the widely used and most important remote sensing-based indices, which is used to investigate the plant drought and stress (Tucker and Choudhury, 1987; Tucker, 1989; Wessels, *et al.* 2007; Rhee, 2010; Vicente-Serrano *et al.* 2013; Li *et al.* 2015; Gutman and Radeloff, 2016).

The NDVI is based on the fact that the chlorophyll in the plant structure can absorb red light and the mesophyll layers of the leaf reflect near-infrared light. NDVI is strongly influenced by climatic condition that is more affected in the arid and semi-arid areas in comparison with the other areas (Pettorelli *et al*., 2005). Therefore, this indicator can be used as a robust tool in assessing the climate change and drought events (Dregne, 2002; Peters *et al.* 2002; Choubin *et al*., 2019).

Also, Land Surface Temperature (LST) is a suitable index of the energy balance at the Earth's surface that can prepare important information about the surface physical properties and climate. Goetz (1997) reported the negative correlation between LST and NDVI. Solangi *et al*. (2019) studied the relationship between LST and the Vegetation. Their results showed an inverse correlation between LST and vegetative cover, which indicated that crop cover decreases the LST and the ratio of LST/NDVI enhances during times of drought.

Also, there are other indices such as Temperature Condition Index (TCI), Transformed difference vegetation index (TDVI), Standardized Water-level Index (SWI) and Vegetation Condition Index (VCI) that were used in different researches (Rezaei Banafsheh *et al*., 2015; Du *et al*., 2018; Naik & Somni, 2019). Hamzeh *et al*. (2017) investigated agricultural drought using remote sensing-based indices such as VCI, TCI, TDVI, SWI and NDVI in Markazi province, Iran. According to their results, VCI index was selected as the best index for monitoring agricultural drought in Markazi province. Rezaei Banafsheh *et al*. (2015) applied remote sensing- indices of NDVI and VCI to assess drought in East Azerbaijan Province, Iran. Their results indicated that using the VCI and NDVI indices are excellent method for evaluating the agricultural droughts through the Remote Sensing. According to the above-mentioned issues, drought can be detectable using remote sensing techniques. However, the most of researches were performed in local scale and did not consider different regions with various values of precipitation and temperature. Therefore, the main objective of this research was to evaluate meteorological drought and its relationship with vegetation cover and land surface temperature using remote sensing techniques in wide area in the North-West of Iran.

Materials and Methods

Study area

The research study area that lies between 44° to 49° E longitudes and 33° to 40° N latitudes covers six provinces including Ardabil, East and West Azerbaijan, Zanjan, Kurdistan and Kermanshah is located in the North West of Iran and has semi-arid climate. The elevation of the study area varies from 14 to 4788 m above the sea level and covers a total area of 181300 km^2 (Fig. 1). The mean annual temperature and precipitation are 9°C and 303 mm in Ardebil station, 11.5°C and 341 mm in Oroomiyeh station, 10.94°C and 336 mm in Zanjan station, 13.4°C and 458.4 mm in Sanandaj station, 14.25°C and 445.1 mm in Kerrmanshah station and 12.5 °C and 289 mm in Maragheh station, respectively. The study area includes the Urmia Lake (between West Azerbaijan and East Azerbaijan provinces).

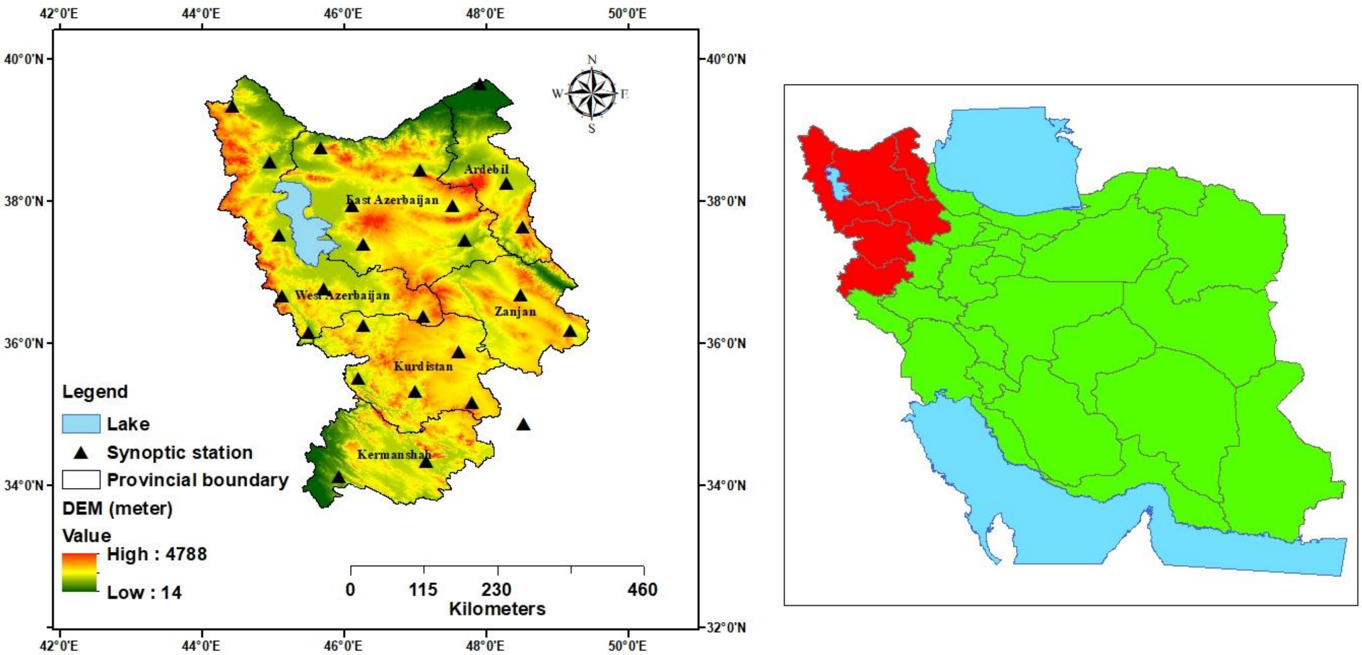

Fig. 1. The location of the study area in Iran

Methodology

This study was carried out in three major steps: i) The mapping of Standardized Precipitation Index (SPI) using 26 meteorological stations existing in the study area ii) extracting NDVI from MODIS satellite images iii) extracting LST from MODIS satellite images iv) assessing the relationship between meteorological drought (SPI), LST and NDVI.

Standardized Precipitation Index (SPI)

In order to detect drought events, monthly rainfall time series from 26 meteorological stations were used to calculate the annual SPI. After normalizing data using Kolmogorov-Smirnov test and assessing their homogeneity, the SPI was calculated using the monthly precipitation time series with the DIP (Drought Index Package) software package. Then, the Kiriging interpolation method was applied to produce SPI maps. Due to the availability of satellite images over the 2001-2014, the SPI maps were also prepared for this time period. Table 1 shows the SPI classification (Mckee *et al*., 1993).

Table 1. Classification of Standardized Precipitation Index (McKee *et al*., 1993)

Classification	SPI values
Extremely wet	SPI> 2
Very wet	1.5<SPI<1.99
Moderately wet	1<SPI<1.49
Near normal	-0.99<SPI<0.99
Moderately dry	-1.49<SPI<-1
Severely dry	-1.99<SPI<-1.5
Extremely dry	SPI< -2

Normalized Difference Vegetation Index (NDVI)

The study of the vegetation cover carried out using NDVI which has been derived from the Terra MODIS satellite imagery (MOD13A2). MOD13A2 produces the Normalized Difference Vegetation Index with 1 km spatial resolution and monthly time scale (earthexplorer.usgs.gov). NDVI is very sensitive to the change in vegetation cover and in relation of weather and soil effects, except in the cases where the vegetation is low and less sensitive. The NDVI is calculated using Equation 1 (Rouse *et al*., 1974).

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \qquad \text{(Equation 1)}$$

Where:
NIR =the near infrared band reflection
R = the red band reflection (Lu, 2015).
Theoretically, the NDVI values range from -1 to +1 (Fang *et al.* 2004; Amiri *et al*., 2013). In the high and low density of vegetation cover, the NDVI tends to 1 and -1, respectively (Yin and Williams, 1997). Previous studies have shown that the NDVI is usually used as a vegetation indicator for evaluating vegetation growth conditions (Thenkabail, 2002; Pandey, 2002). So, value of this index in the area with very low density of vegetation (sparse vegetation) is low (near to -1) and in the area with high density of vegetation, it is high (near to +1).

Land Surface Temperature (LST)

The MODIS derived MOD11C3 LST data is applied. MODIS Land Surface Temperature (LST) products provide per-pixel temperature and emissivity values. This level-3 MODIS global Land Surface Temperature (LST) and Emissivity data are composed of the LST product (MOD11C3) with a spatial resolution of 0.05 degrees and temporal resolution of monthly in sinusoidal projection represented as the average values of clear-sky LSTs during monthly periods.
The unit of LST values is Celsius degree. Land Surface Temperature (LST) images in monthly scale were downloaded during 2001-2014.

Studying the relationship among drought, LST and vegetation cover

In order to detect the effects of drought, the means of the NDVI and LST were calculated in the annual time scale for each of the drought periods. Then, based on the derived indices, the effects of different drought conditions on vegetation cover and its relationship with land surface temperature were analyzed. Also, mean NDVI, LST and SPI were developed "during" 2001-2014 and finally, the correlation among these three variables was detected through the Pearson correlation coefficient (R). Fig. 2 shows the conceptual framework of the methodology of this research.

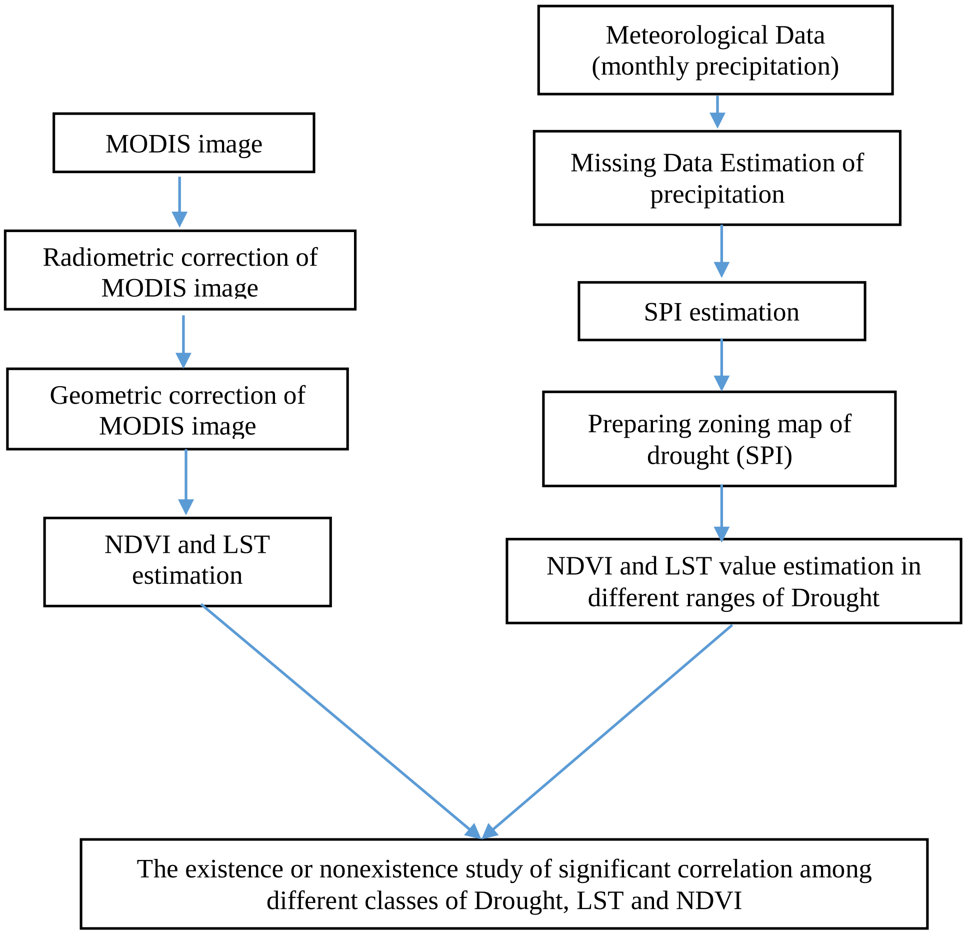

Fig. 2. The flow chart of the study methodology

Results

Meteorological Drought

In this study, monthly rainfall time series from 1984 to 2014 (30 years) were used to calculate the Standardized Precipitation Index (SPI) which is applied for detection of drought condition in the study area. However, due to the large volume of the SPI results and also temporal compliance with NDVI and LST indices, results are reported for 2001-2014 period for SPI, NDVI and LST (Fig. 3).

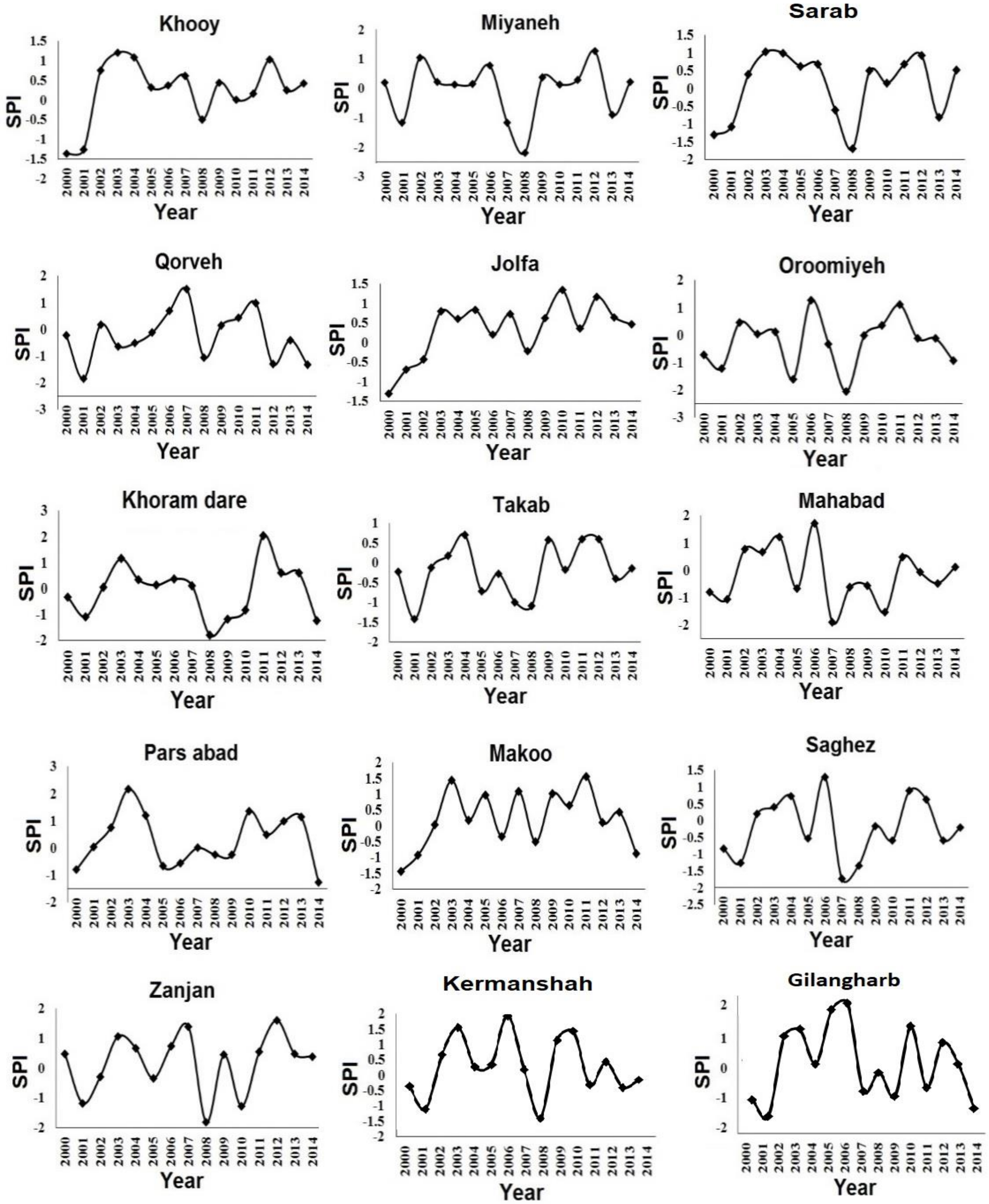

Fig. 3. The SPI values in different stations in study area

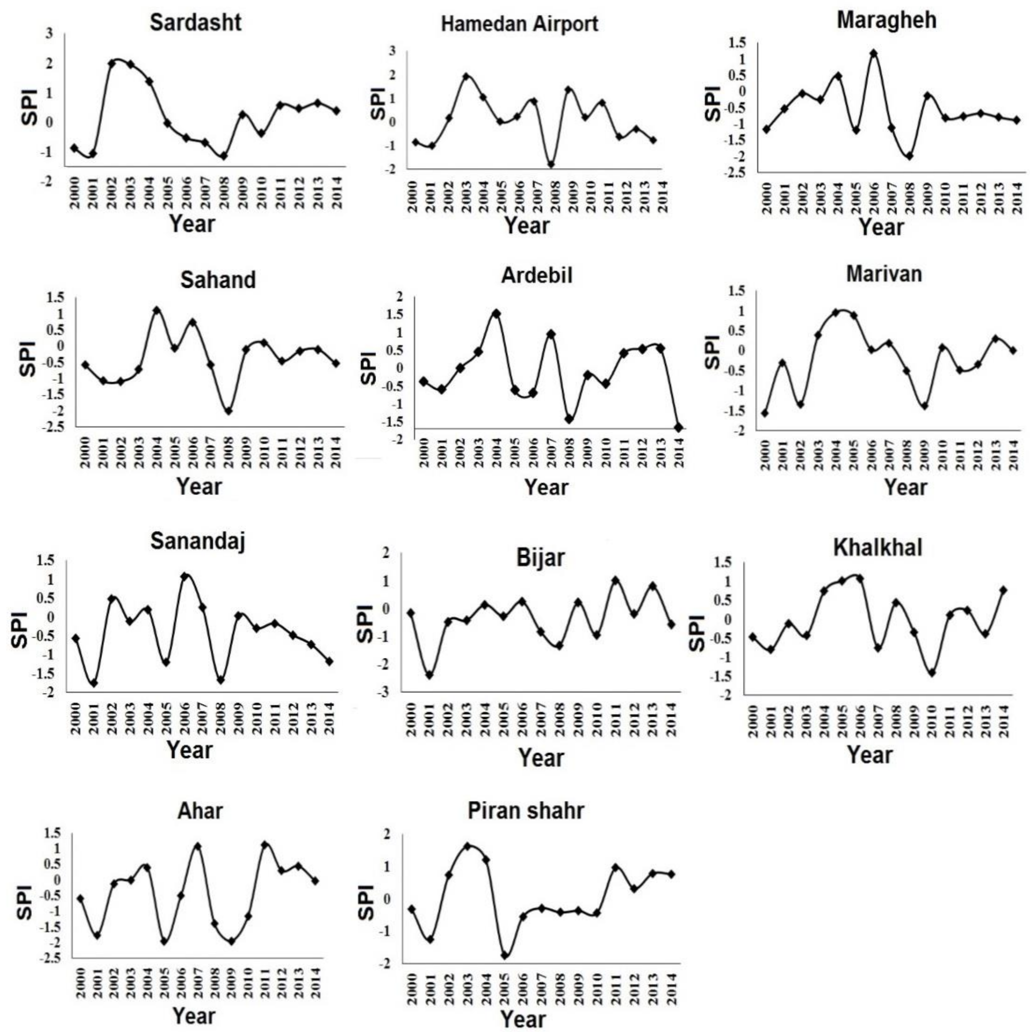

Fig. 3. Continued

According to the results, in the most of stations, the highest severe drought condition was related to 2001 and 2008, which is in accordance with the global scale drought events. Ardabil, Kermanshah and Pars Abad stations have experienced severe drought conditions in 2014, PiranShahr in 2005 and Makoo in 2000. According to Fig. 3, in terms of the wet condition, the majority of stations in 2003, 2007 and 2011 had the least amount of drought. After calculating SPI for all stations in the study area, the annual interpolated maps of this index were produced during 2001-2014 (Fig. 4).

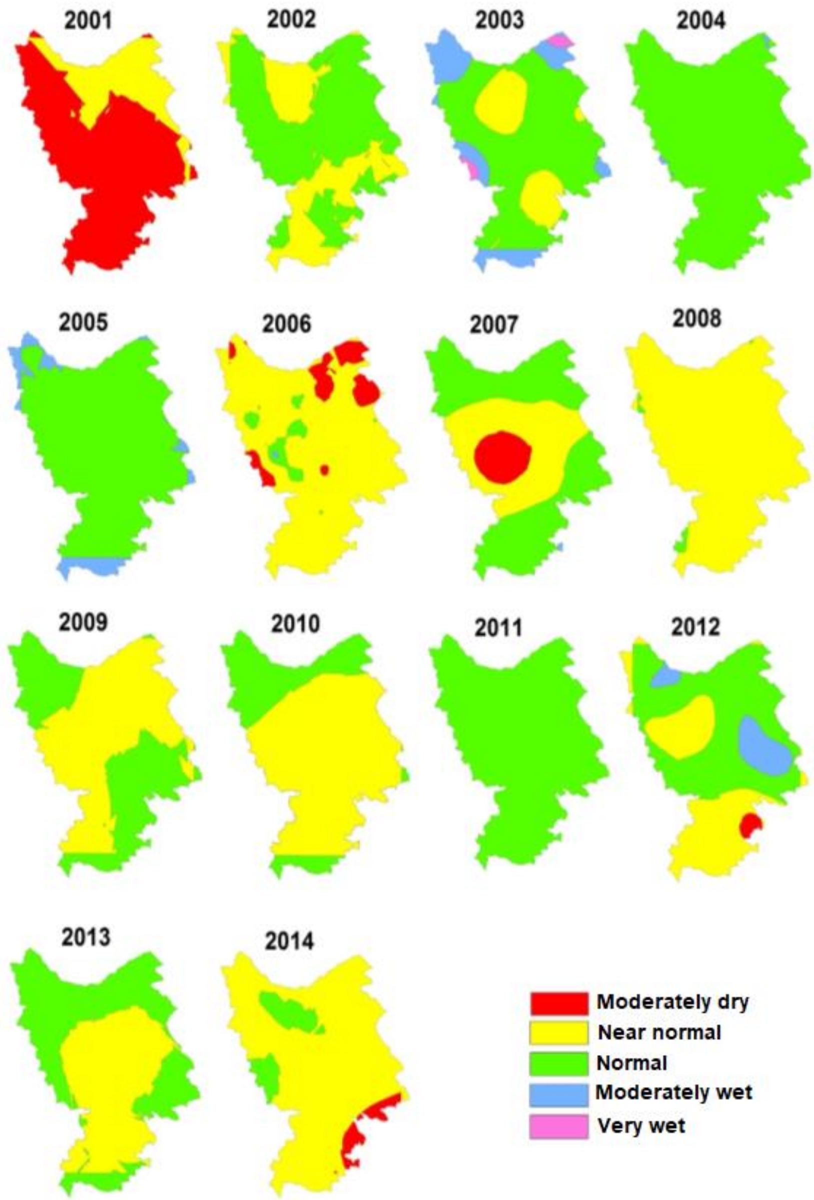

Fig. 4. The mapping of SPI in 2001-2014 period

The interpolated SPI maps (Fig. 4) show that in 2001, southern and northern parts of the study area have experienced moderate drought and near normal conditions, respectively. During 2002-2005 compared to 2001, drought severity was decreased. While drought severity was increased from 2006 to 2008. From 2009 to 2011, the affected areas by normal drought conditions had increased. In 2012, southeast, northern and western parts of the study area were affected by the moderate drought, normal and moderately wet conditions, respectively. From 2012 to 2014, drought conditions were increased and affected all of the study area.

Fig. 5 shows the mapping of NDVI during 2001-2014. The mean annual NDVI in different classes of SPI is shown in the Table 2. According to Table 2, since drought is a temporary phenomenon, the wet and dry conditions did not spatially affect the NDVI values. For example, in 2001, the mean NDVI value in the moderately dry zone was higher than in the near normal zone. Also, in 2007, the mean NDVI value in the moderately dry zone was higher than moderately wet zone. Therefore, the changes of NDVI values in different drought zones do not follow any particular rules.

Table 2. Mean NDVI in different ranges of drought

Class	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Moderately dry	0.07	0	0	0	0	0.03	0.13	0	0	0	0	0.08	0	0.03
Near normal	0.04	0.04	0.03	0	0.12	0.09	0.06	0.06	0.06	0.16	0.08	0.02	0.13	0.10
Normal	0	0.09	0.09	0.11	0.01	0.02	0.05	0.01	0.03	0.04	0	0.061	0.06	0.05
Moderately wet	0	0.01	0.02	0.01	0	0.15	0.11	0	0	0	0	0.02	0	0
Very wet	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0

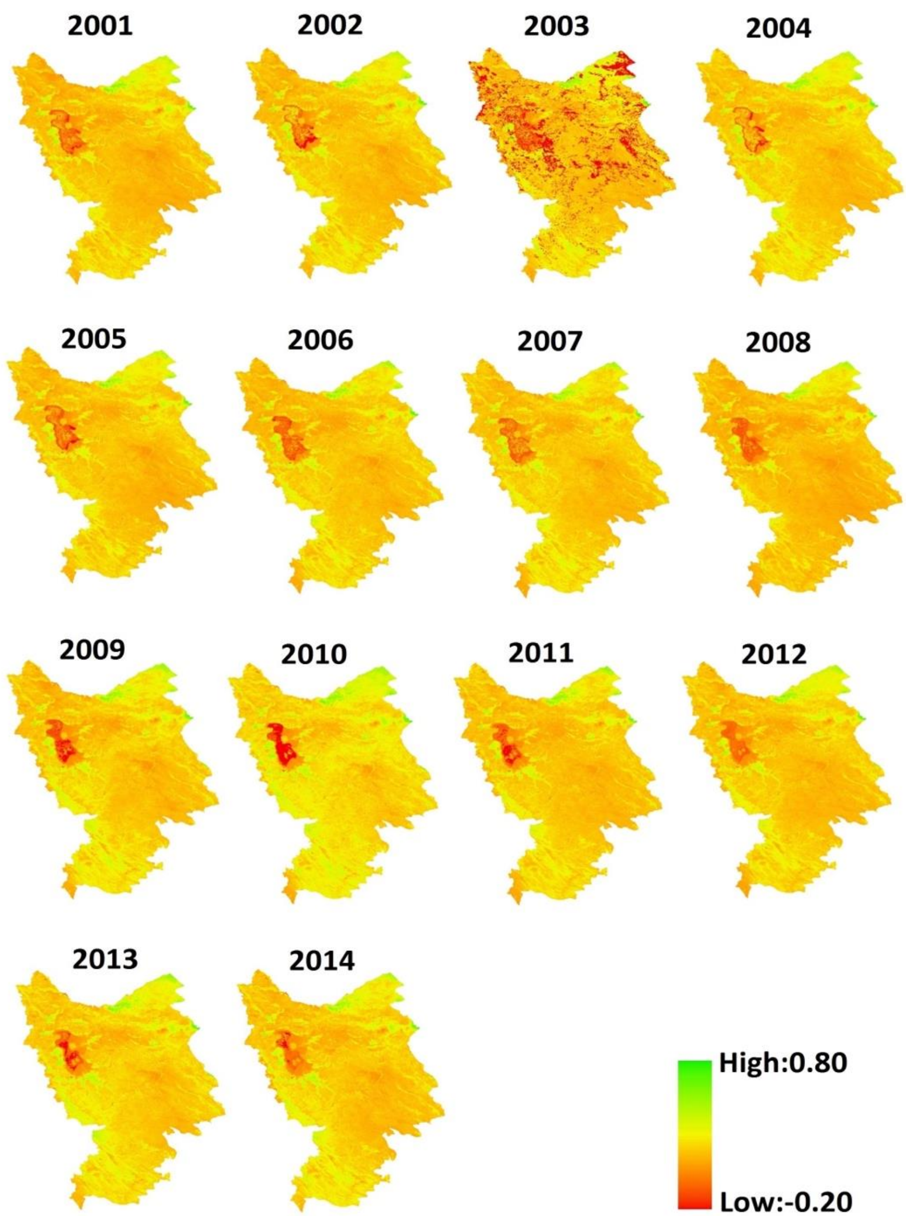

Fig. 5. The mapping of NDVI in 2001-2014 period

Figs. 5 and 6 show the mapping of NDVI and LST in 2001-2014 period, respectively. The mean NDVI and LST of whole study area for each year was obtained using zonal statistics command in ArcGIS 10.2.2. Also, weighted average drought for each year was extracted in the same way and was compared with the mean values of the NDVI and LST (Table 3).

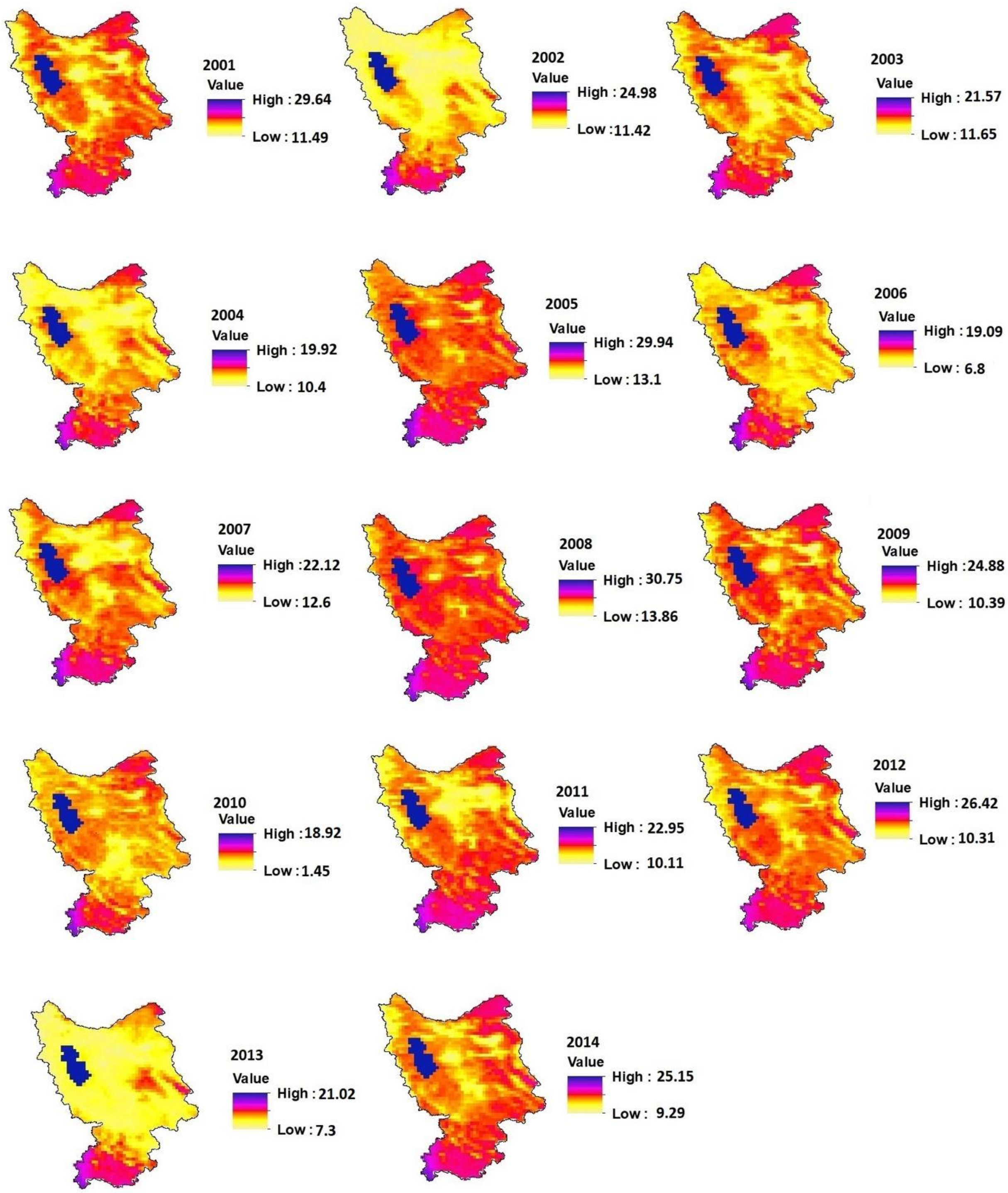

Fig. 6. The mapping of LST in 2001-2014 period

The changes trend of mean NDVI, LST and SPI has been shown in Fig.7. According to the results, the NDVI values have experienced its greatest reduction between 2008 (mean NDVI=0.087) and 2009 (mean NDVI=0.09). The highest mean NDVI values belong to 2002 and 2010. Generally, the NDVI trends revealed that this index value has fallen up to 2008 and after that the index values have been increased up to 2010. In 2010, this index has received the highest value in the study period. The index value has fallen again up to 2011 and after 2011, the index value has increased up to 2013 and finally, in the 2014, it has taken a downward trend. According to the results, the NDVI results verified drought trends over the years. So,

The most severe drought occurred in 2001 (SPI=0.02), 2005 (SPI=0.07), 2008 (SPI=0.04) and 2011 (SPI=0.06). The lowest severe drought and the most NDVI also occurred in 2010 (SPI=0.14 and NDVI=0.14) (Fig. 7).

Also, the changes trend of LST was in accordance with SPI and NDVI (Fig. 7). LST had an inverse relationship with NDVI and SPI. So, LST had received the most values in 2001, 2005, 2008 (LST=19.1, 21.52, 22.3, respectively) where NDVI and SPI had the least values. Also, LST had received the least values in 2004, 2006, 2010 and 2013 (LST=15.16, 12.94, 10.18 and 14.16, respectively) where NDVI and SPI had the most values. According to the results, Land Surface Temperature (LST) was the most where SPI and NDVI were the lowest and there was the most severe drought in these conditions.

Table 3. The mean values of the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and Standardized Precipitation Index (SPI)

Year	SPI	LST	NDVI
2001	0.02	19.1	0.1
2002	0.07	18.2	0.125
2003	0.07	16.61	0.106
2004	0.12	15.16	0.116
2005	0.07	21.52	0.104
2006	0.08	12.94	0.108
2007	0.05	17.36	0.094
2008	0.04	22.30	0.087
2009	0.06	17.63	0.09
2010	0.14	10.18	0.14
2011	0.06	16.53	0.099
2012	0.08	18.36	0.109
2013	0.1	14.16	0.121
2014	0.09	17.22	0.114

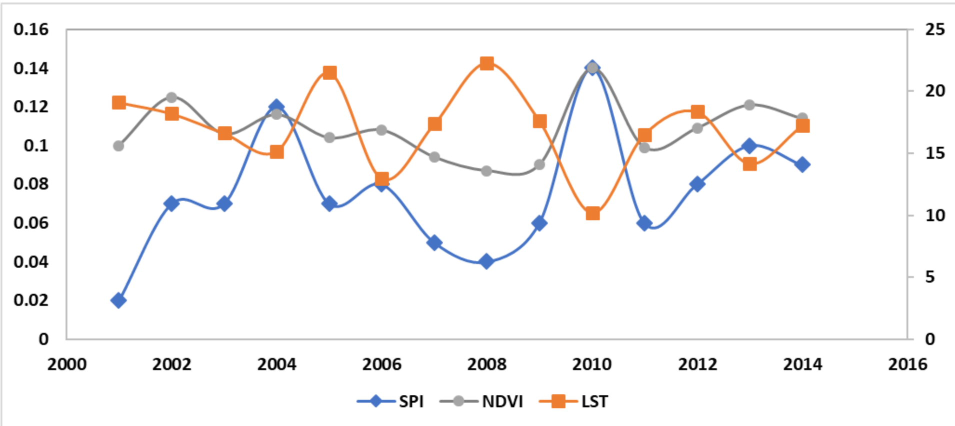

Fig.7. The changes trend of mean NDVI and SPI and LST

The correlation among the SPI, the NDVI and the LST values was calculated using Pearson's correlation coefficient (R) (Table 4). Results showed a positive correlation between SPI and NDVI (R=0.812, P<0.01), an inverse correlation between LST and SPI (R=-0.512, P<0.05) and an inverse correlation between LST and NDVI with (R =-0.589, P<0.05).

Table 4. Correlation among the Standardized Precipitation Index (SPI), the Normalized Difference Vegetation Index (NDVI) and the Land Surface Temperature (LST) values

	SPI	NDVI
NDVI	0.812**	
LST	-0.512*	-0.589*

*, **. Significant at 1 and 5 % probability levels, respectively.

Discussion and Conclusion

Continuous monitoring of drought, especially in the arid and semi-arid areas is important due to its impact on ecosystems. Due to spending much time and cost on one hand and lack of sufficient data on the other hand, such monitoring cannot be done regularly.

Decreasing vegetation cover and increasing land surface temperature (LST) is significantly related to drought which leads to land degradation. NDVI and LST are known as the most important remote sensing-based indices that can be applied to investigate drought (Vicente-Serrano *et al.* 2013; Gutman and Radeloff, 2016; Lu *et al*., 2019; Dhawale *et al*., 2019). To that end, the main objective of this study was to find an alternative solution for monitoring drought. Results revealed that the most severe droughts have happened in 2001, 2005 and 2008 which are in accordance with the global scale drought events (Spinoni *et al*., 2014).

According to the results, the changes trend of mean NDVI and LST was similar to drought trends over the years. The both of the mean NDVI and SPI values had experienced the most decrease in 2001 & 2008 and the most increase in 2010. The results of Liu and Kogan (1996), Ji and Peters (2003), Son *et al*. (2012), Lotsch *et al*. (2003), Wu *et al*. (2010), Dutta *et al*. (2013), Rimkus *et al.* (2017), Lu *et al.* (2019) and Dhawale *et al*. (2019) confirm this correlation.

The results obtained based on Pearson's correlation coefficient showed that LST values had an inverse significant relationship with SPI and NDVI indices. So, Land Surface Temperature (LST) was the highest where SPI and NDVI were the lowest and there was the highest severe drought in these conditions, which was accordance to the findings of Ozelkan *et al*. (2011) and Dhawale *et al.* (2019). Therefore, mean NDVI and LST could be suitable alternatives for climate indicators in monitoring and evaluating drought events in the arid and semi-arid areas. The framework of this study which includes correlation of SPI, NDVI and LST can be used to forecast drought and prepare early warning system.

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پایش خشکسالی با استفاده از محصولات دمای سطح زمین و شاخص تفاضل پوشش گیاهی MODIS در مناطق نیمه خشک ایران

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چکیده. کاهش میزان پوشش گیاهی و افزایش دمای سطح زمین، یکی از مهم‌ترین پیامدهای خشکسالی است که سبب سیر قهقرایی زمین و تخریب اراضی می‌گردد. لذا ارزیابی اثرات خشکسالی بر روی پوشش گیاهی و ارتباط آن با دمای سطح زمین، از اهمیت زیادی برخوردار است. در این راستا، این مطالعه با هدف بررسی ارتباط پوشش گیاهی، دمای سطح زمین و خشکسالی شمال غرب ایران در طول دوره ۱۳۹۳-۱۳۸۰ انجام گردید. جهت بررسی خشکسالی هواشناسی، شاخص بارش استاندارد شده (SPI) سالانه براساس سری زمانی بارش ماهانه حاصل از ۲۶ ایستگاه باران‌سنجی موجود در منطقه محاسبه گردید. سپس نقشه پهنه‌بندی مقادیر شاخص سالانه SPI در محیط سیستم اطلاعات جغرافیایی (GIS)، توسط روش درون‌یابی کریجینگ تهیه گردید. شاخص تفاضل پوشش گیاهی NDVI و شاخص دمای سطح زمین (LST) برای بازه زمانی ۱۳۹۳-۱۳۸۰ براساس تصاویر ماهواره‌ای مودیس به دست آمدند. سپس همبستگی بین مقادیر NDVI، LST و SPI، از طریق ضریب همبستگی پیرسون (R) بررسی شد. بر طبق نتایج، روند تغییرات NDVI میانگین، مشابه با روند تغییرات خشکسالی در طول سال‌های مورد مطالعه (۱۳۸۰-۱۳۹۳) بود و بیشترین کاهش شاخص NDVI در سال ۱۳۸۷ (NDVI=۰/۰۸۷) بوده است. همچنین نتایج حاصله نشان داد که مقادیر LST دارای یک رابطه معنی‌دار معکوس با شاخص‌های NDVI و SPI، در سطح احتمال ۱ درصد می‌باشد. به‌طوری‌که دمای سطح زمین (LST) ، زمانی‌که SPI و NDVI دارای کمترین میزان بودند (SPI=۰/۰۴ و NDVI=۰/۰۸۷)، دارای بیشترین مقدار بود (LST=۲۲/۳) و در این شرایط بیشترین شدت خشکسالی موجود بود. بنابراین میانگین NDVI و LST می‌توانند جایگزینی مناسب برای شاخص‌های اقلیمی در ارزیابی و پایش خشکسالی‌ها در مناطق نیمه خشک باشند.

کلمات کلیدی: سنجش از دور، SPI، MODIS، شمال غرب ایران