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# Monitoring agricultural drought in Iran using time series of vegetation health index

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**A B S T R A C T**

In this study, in order to examine the severity of drought risk in Iran during 18-year period (2001-2018), we used rain meteorological data of 176 synoptic meteorological stations, ground surface temperature product (MOD11C3) and vegetation product (MOD13C2) of Moderate Resolution Imaging Spectro radiometer (MODIS). The study results show that the highest drought severity occurred in 2001 and 2003, in 2001 in spring 85.8% and in the summer of 2003, 93.8% of the country was affected by different degrees of drought. During the 18-year period, the highest percentage of drought was related to mean (45.3%), mild (25%), and severe (8.9%) classes, and no drought (20.79%), respectively. The results indicate that in the whole country, there is no severe drought region in the studied period. According to the map of the rainy regions, Iran's rainfall is highly dependent on the roughness, latitude and frequency of the arrival of synoptic systems in the region. The spatial rainfall map in Iran is well suited to VHI drought maps. The regions that receive less than 100 mm of rainfall represent the real deserts of the country. In these regions, severe drought conditions occur. The rainy regions between 100 and 200 mm, in terms of drought conditions, are in the mean class of drought. The rainy regions with a range of 200 to 300 mm are in the mild class of drought and rainy regions with more than 300 mm are usually not affected by drought stress.

**A R T I C L E  I N F O**

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## 1. Introduction

One of the natural characteristics of climate is drought, in general drought occurs when the amount of annual rain is lower than the mean long-term rain of a region. In other words, drought has occurred when the amount of water in water resources of a region is significantly reduced in a continuous period of time (Vyas et al., 2015). The occurrence of drought in a region has irreparable environmental, economic and social impacts (Tallaksen et al., 2004). This risk, which is seen in three climate, hydrology and agriculture forms, is one of the most important natural disasters that causes annually loss in many parts of the world. In the past, the conventional approach to drought monitoring has been based on climatic observations of meteorology and the use of climatic indicators. The distribution of stations especially in arid regions of Iran, lack of long-term statistics in many stations, lack of synoptic stations with long statistical period as well as point-based methods based on climatic statistics have caused some limitation in the study of drought. Over the past few decades, satellite images have provided a comprehensive spatial and temporal view of the ground surface and helped researchers in various fields of study. So far, many drought monitoring models have been presented using these images, which are generally based on vegetation, ground surface temperature; moisture and reflection indicators in the visible and infrared regions. The most important factors affecting drought are soil moisture and vegetation. Therefore, it is necessary to study how soil spectral behavior and vegetation percentage are important in estimating drought.

The change in vegetation effective by the effect on transpiration of plants, surface albedo, radiation power and superficial roughness on energy balance. Determining vegetation percentage using traditional harvesting methods does not provide a complete view of vegetation of the whole region, and will cost a lot of time and cost. In addition, there may be human error in determining the percentage of vegetation using traditional methods, but satellite images provide a comprehensive picture of the time and place of the ground surface and its various covers, which use it to reduce time and cost as well as increase accuracy. MODIS, Aster, ETM+, OLI, IRS, ALOS, and AVHRR sensors' data can be considered as the most important data sources that have been used in drought studies. Huete, with a review of studies conducted on the relationship between soil and vegetation patterns in the southern part of the US, using NDVI of AVHRR, mentioned positive results in this regard. According to Luzano Garcia et al., Huete reported a clear relationship between soil set and biomass expansion in the studied regions using NDVI and AVHRR data (Huete, 2004). In his study, Sharma evaluated drought in Karnataka Province of India using two methods. In this study, rainfall data was used during the statistical period of 1970-2003 to calculate the standard rainfall index and NOAA / AVHRR / NDVI satellite images to calculate vegetation index in India. Finally, the two methods were compared and it was concluded that the accuracy of NDVI is higher (Sharma, 2006). Vicente and Serrano in their study using NOAA / AVHRR / NDVI satellite data and drought indicators, predicted wheat and barley production in one of the arid regions of Europe (Here valley in Spain). This prediction has been for February and the months before harvest. The study results showed that these predictions can be useful for managing product production at the domestic level (Vicente and Serrano, 2006). Liu and Wu studied the agricultural drought in Central China using NDVI derived from MODIS. Their study results showed that this index could be used in different time and spectral ranges of regional, continental and global drought (Liu and Wu, 2008). Guyia et al. used NDVI from SPOT4 and SPOT5 satellites to study the extent, severity and continuity of drought throughout Portugal over the period 1999-2006. The severity of drought on vegetation was determined. In past decades, drought of 1999, 2002, and most notably 2005 has been identified (Gouveia et al., 2009). Funk and Budd examined agricultural drought using MODIS / NDVI in Zimbabwe and concluded that this index was suitable for accurate agricultural drought monitoring (Funk and Budd, 2009). Zhang et al. in the northern part of China studied drought by employing PCI, SMCI, VCI, PSMCI, PTCI and MIDI derived from MODIS, TRMM and AQUA satellite data compared to SPI. The results showed that MIDI had a better performance than drought monitoring drought indicators for drought monitoring (Zhang et al., 2013). Martha et al. (2016) investigated the relationship between the performance of Brazilian agricultural products and the evaporative stress index, using Modused images from 2003 to 2013. The results showed that evaporative stress index along (ESI) with the two LAI and LST indicators could be the basis of a physical model for determining the effect of drought on agricultural products (Martha et al., 2016). Xiang et al. (2016) by monitoring drought and its effect on agricultural products in China basin using DSI concluded that the relationship between vegetation and estimation of evapotranspiration in winter and summer wheat was different. PSI will be more effective for drought proof in the cold season and winter wheat (Xiang et al., 2016). Among other researchers who worked on MODIS data-based indicators to monitor drought in agricultural and semi-arid regions of the world we can mention Huete et al. 2002; Caccamo et al. 2011; Thenkabail et al. 2004; Cammalleri et al. 2009; Sruthi and Mohammed Aslam, 2005; Garcia-Leon et al. 2019; Aulia et al.,2016; Joachim et al. 2016; Their study results indicate that Modus data is suitable for drought determination.

## 2. Material and Methods

### *2.1. Study area*

The present study is in the Middle East geographic area in Iran. Iran with a total area of 1648195 square kilometers and a population of more than 78 million persons is located on a large part of the Iranian plateau, with 25 to 45 degrees north latitude and 44 to 63 degrees east longitude of the Greenwich meridian. The long and continuous mountains on the sidelines is surrounded by shallow holes. The mean altitude of Iran is more than 1200 meters. The lowest internal point is about 187 meters in Lut desert and its highest peak is Damavand with a height of 5671 meters in Alborz Mountains.

176 synoptic meteorological stations with a statistical period of 2000-2017 were used to identify the Iranian rainy regions. The mean 18-year rainfall of each station was calculated and then, using IDW interpolation method, using GIS, the map of the Iranian rainy region was prepared. In order to create VHI time series for drought evaluation, we took NDVI (mod13c2) and LST (mod11c3) products of MODIS Terra satellite on a monthly scale since April to September (growing vegetation months) since 2001 to 2018 (https://earthdata.nasa.gov). Then, using toolkit of software Envi, while performing geometric corrections, the values of vegetation indicators and surface temperature were extracted in different months. At the next stage, VCI was calculated based on NDVI values, temperature condition index (TCI) based on LST values and vegetation health index (VHI) based on equations 1-3.

*2.2. Vegetation Condition Index (VCI)*

This index was presented by Kogan (1955) and based on NDVI. This method shows the percentage of the most prevailing vegetation changes. So, if VCI value is close to zero, drought is severe. This index is calculated according to equation 1, (Rizqi et al., 2016; Bhuiyan, 2004).

$$VCI = \frac{(NDVI - NDVI_{Min})}{(NDVI_{Max} - NDVI_{Min})} \times 100 \qquad (1)$$

Where $NDVI_{Max}$ is the maximum of NDVI and $NDVI_{Min}$ is the minimum of NDVI for the time period in which $NDVI_{Min}$ and $NDVI_{Max}$ are the minimum and maximum of NDVI values for a month, respectively. VCI is designed to eliminate the effect of climate and topography differences on NDVI results.

*2.3. Temperature Condition Index (TCI)*

This index was presented by Kogan (1955). The computational algorithm of this index is similar to VCI, but its equation is defined to reflect the thermal response of vegetation. TCI is based on absolute temperature and is calculated using thermal bands and equation 2.

$$TCI = \frac{(LST_{Max} - LST)}{(LST_{Max} + LST_{Min})} \times 100 \qquad (2)$$

Where $LST_{Max}$ and $LST_{Min}$ are the mean of the maximum and minimum temperature, respectively and LST is the ground surface temperature in the studied month (Kogan, 1990).

*2.4. Vegetation Health Index (VHI)*

This index is a combination of VCI and TCI for displaying drought stress, the combined effect of moisture and thermal stress (Rojas et al., 2011; Kogan, 2001).

$$VHI = 0.5(VCI) + 0.5(TCI) \qquad (3)$$

Finally, various drought severities are proposed according to Table 1 (Kogan, 2002: Rizqi et al., 2016).

**Table 1.** Classification scheme for drought mapping

| Drought classes | VHI |
|---|---|
| Extreme drought | < 10 |
| Severe drought | 10-20 |
| Moderate drought | 20-30 |
| Mild drought | 30-40 |
| No drought | >40 |

## 3. Results and discussion

According to Fig. 1, rain spatial behavior of Iran is such that the amount of rain from the southeast to the northwest is increased. The roughness and latitude trend plays a very important role in spatial borders and differences between the regions. The rainfall varies from 32 to 1789 mm. In general, from the point of view of rainfall, Iran can be divided into 7 rain classes.

A. The rainy region less than 100 mm

This region covers 23.26% of Iran's total area. The main area of this region is the central and eastern deserts in the southeastern and central parts of Iran.

B. The rainy region of 100 to 200 mm

This region covers a very low rainfall area (less than 100 mm) like a belt. It covers about 527912.1771 square kilometers of Iranian area. It starts from southern Iran and extends to the eastern slopes of Zagros Mountains, the southern slopes of Alborz Mountains and the southern highlands of Khorasan, and a small part of Khuzestan plain is also covered by it.

C. The rainy region of 200 to 300 mm

This region is about 291177.9187 square kilometers, equivalent to 17.9 percent of Iran's total area. This is distributed in 3 separate parts including: 1) Khuzestan plain in southwest Iran, 2) shores and off-shores of Persian Gulf in Bushehr Province extending to the slopes of Zagros and Alborz Mountains and finally reaching the northeastern part of Iran and 3) Northwest of Iran in the area and around Urmia Lake.

D. The rainy region of 300 to 400 mm

This region covers about 13.64% of Iran's total area, which is 291177.9187 square kilometers. This is a long belt from north to the south of Golestan Province, and its width is narrowed in Tehran, the highlands of Azerbaijan, the eastern slopes of Zagros Mountains, northern plain of Khuzestan, and highlands of Azerbaijan are in this region.

E. The rainy region of 400 to 500 mm

This rainy region with an area of 220933.37 square kilometers is distributed in two separate regions including 1) the western part of Caspian Sea, Astara, which is like a belt and extends to the southern Alborz Mountains, Golestan Province (east of Caspian Sea) and 2) the western part of the country and the western slopes and highlands of Zagros.

F. The rainy region of 500 to 600 mm

This region is mainly distributed as spots in 3 separate parts, which include the eastern Caspian off-shore and the narrow part of Alborz Mountains, Koohrang highlands of Zagros and part of the western part of the country in Kurdistan and Ilam Provinces. It covers an area of 2.4% of the country's total area.

I. The rainy region of greater than 600 mm

The region range is from 600 to 1789 mm. And only 2.6% (43100.61 km²) covers the area of Iran including the northern coast of the country, highlands of Zagros (Koohrang) and a small area west of Kurdistan and West Azerbaijan Provinces.

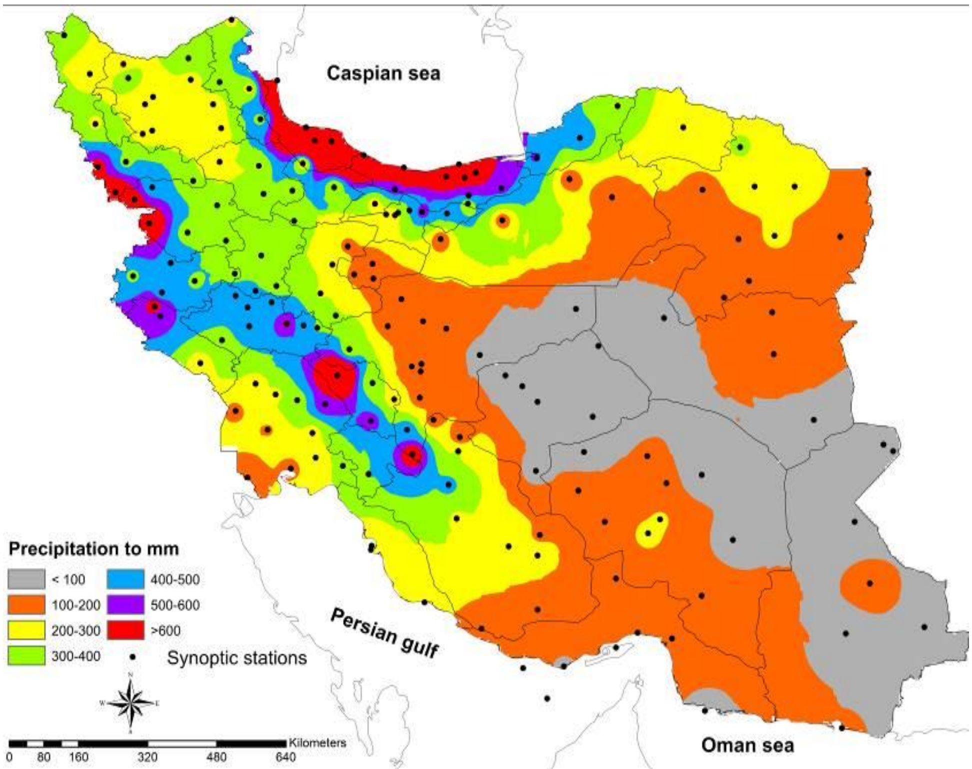


**Fig.1.** The spatial Distribution Map of Iran's rain

*3.1. Study of drought conditions in spring months*

In order to study drought condition on vegetation, given that vegetation growth and decay stages in Iran are since April to September, so 18-year drought condition was studied only for these 6 months. Due to the large number of drought-related images in different months (108 images) over the course of 18 years, only a few months' images have been taken into consideration for drought classes as shown in Figures 5 and 9. The results of all years of drought classes are expressed in Figures 2, 3, 4, 6, 7, and 8. In April, the general trend of severe drought class is descending. In 2001, with an area of 282120 square kilometers, southern, southeast, eastern and central parts of the country, and parts of the center of the country, are affected by severe drought. The smallest part of severe drought is in 2013 with an area of 74,748 square kilometers that is Lut desert and parts of the western Sistan - Baluchistan Province. In contrast to severe drought class, the trend of moderate drought class is ascending. On average, over the course of 18 years, 38.84% of the country's total area is affected by moderate drought, with a total area of 752069 km² in 2008 and an area of 480730 km² in 2007 with the highest and lowest mean drought area, respectively. The mild drought class on average covers about 21.71% of the country's total area, which generally includes mountainous regions and hillsides. The regions with no drought cover about 31 percent of Iran's total area that are mostly Zagros Mountains, northwest and north of Iran. In May, on average 73% of Iran's total area is affected by drought stress with different severities. So that about 11.78% of the country's total area had severe drought, 43.2% of the country's total area had moderate drought and 17.88% of the country's total area had mild drought. In this month, in general severe drought class is characterized by a descending trend, and moderate, mild, and non-drought classes are characterized by an ascending trend, with the difference that the moderate drought class has a higher uptrend than other classes. In May, the moderate drought class in all studied years has become more exposed than other classes (Figure 3). The regions with severe drought have been expanding in the years when the rainfall was less than the mean of the regions, and the non-drought class in low rainfall years is only limited to the northern region and the narrow belt in the northwest of the country (Fig. 5).

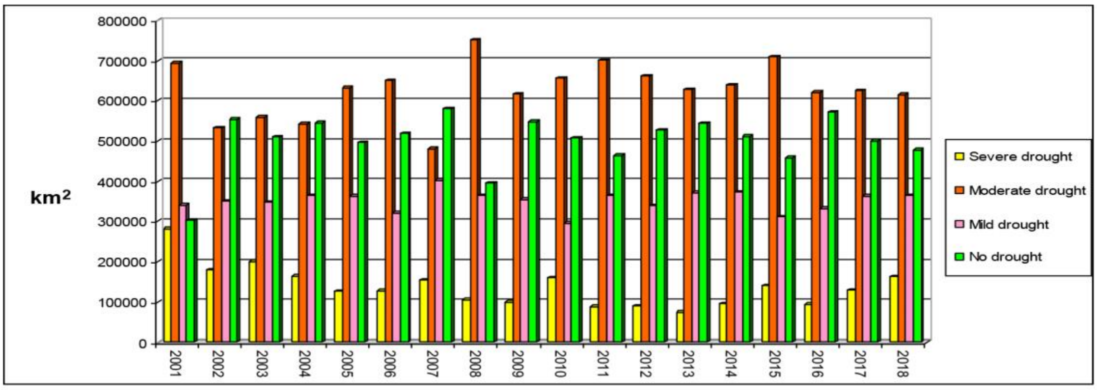


**Fig. 2.** Drought classes based on VHI in April

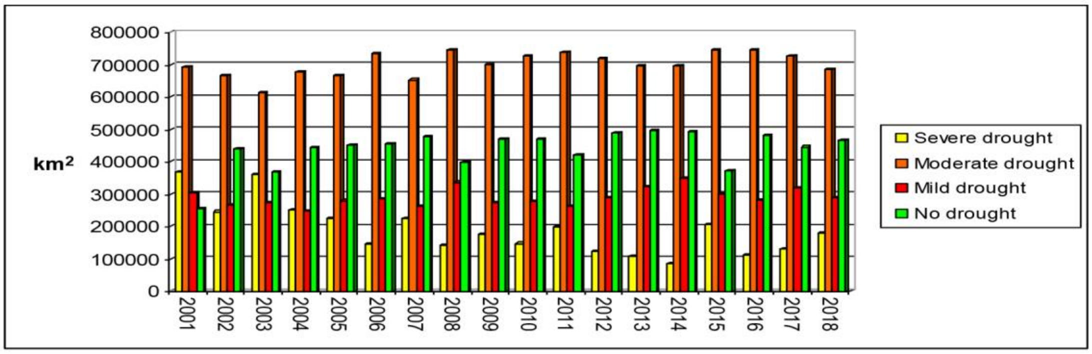


**Fig. 3.** Drought classes based on VHI in May

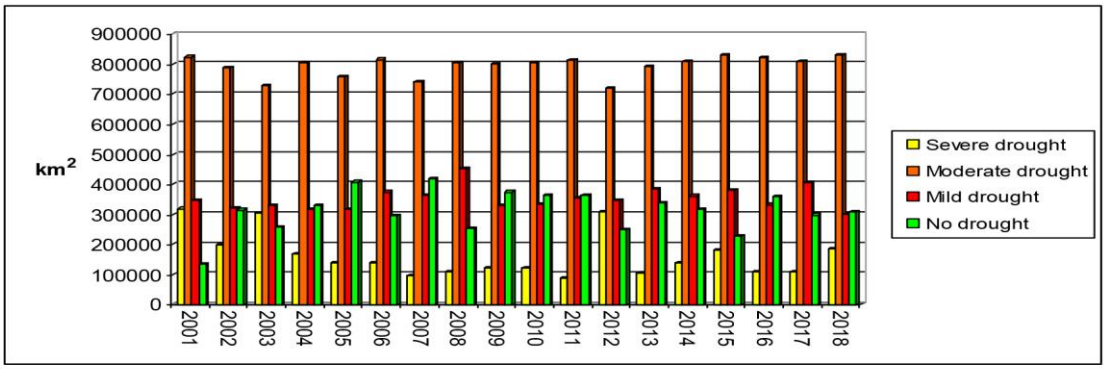


**Fig. 4.** Drought classes based on VHI in June

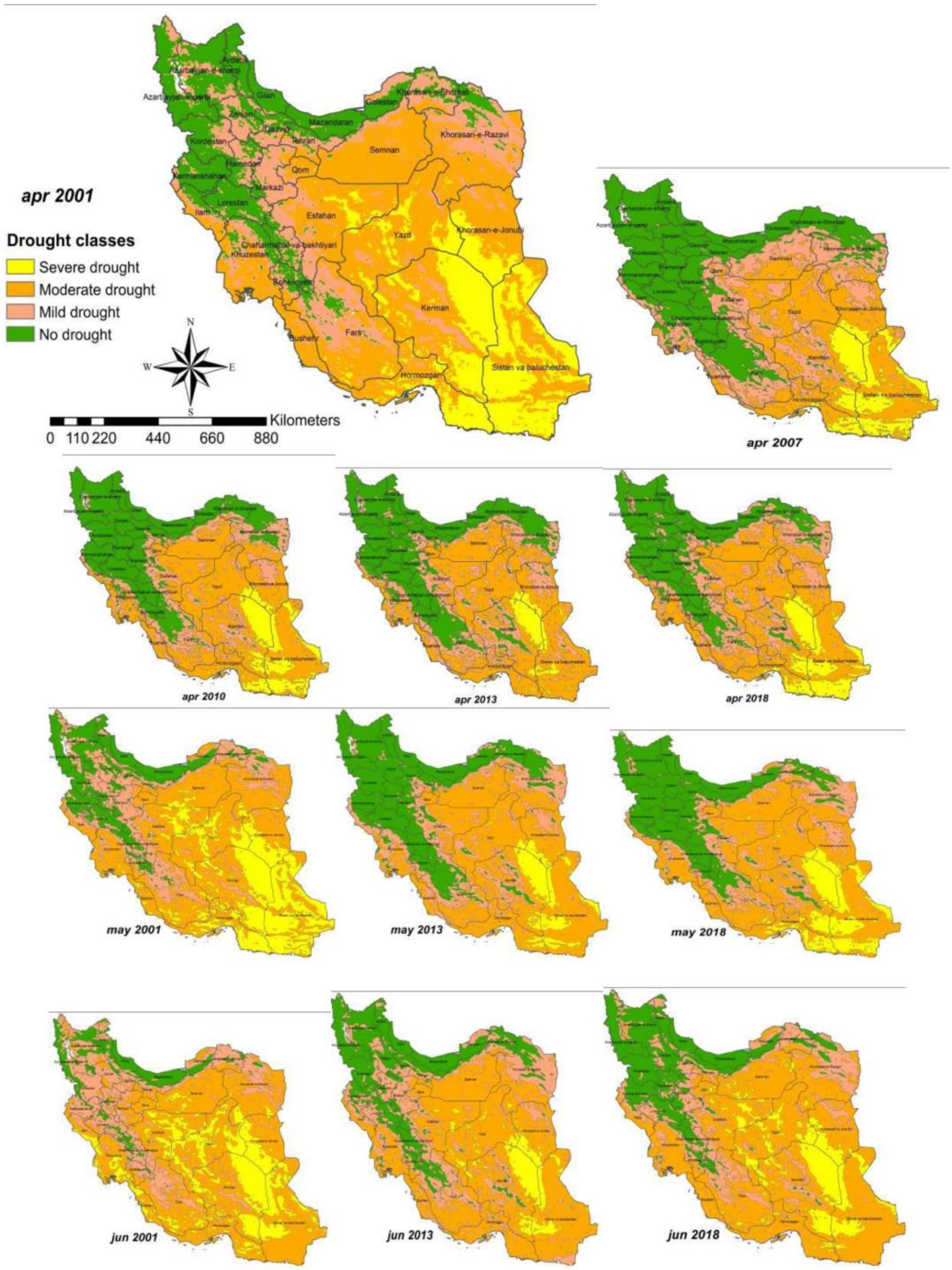


**Fig. 5.** Drought conditions in the spring months based on VHI classification

### *3.2. Summer drought conditions*

The rainfall in the summer is very low except for the northern belt of the country and partly in the south-east of Iran. The summer is a dry season in Iran, and rainfall is severely reduced. Severe drought of this season occurs in eastern regions (Sistan - Baluchistan, Kerman, and South Khorasan Provinces), central regions (Kerman, Yazd, Isfahan and Provinces) and southwest regions (Khuzestan Province). However, in the years when more rain occurs, the severity of drought is reduced (Figure 9).

In July, the most severe drought was in 2003, 23.8% of the country was affected by severe drought, 49.9% had moderate drought, 19.9% had mild drought, and only 6.5% of the country's area had no drought (Fig. 6). During the 18-year statistical period, on average, moderate and mild drought were more frequent, affecting 48% and 29% of the country's area, with 15% severe drought, 85 percent of Iran's total area in July was affected by drought stress (Fig. 6).

In August, non-drought reduced compared to July by about 1 percent and reached 14 percent. The regions with no drought include the northern parts of the country (Golestan, Mazandaran, Gilan, and Ardebil Provinces) and the northwest parts of the country (small parts of East and West Azerbaijan Provinces) and southwest parts of the country (parts of Chaharmahal e Bakhtiari Province). Lut desert, Jasmourian and parts of the country's center throughout the year had severe drought. The most severe drought occurred in this month in 2003, involving about 1533554.75 square kilometers of Iranian total area (Figure 7).

In September, rain is expected to increase somewhat over July and August, thus, vegetation growth has increased non-drought region, which has increased by about 4.5% to non-drought region, and reached about 18.5%. This class includes the northwest mountains, Alborz and Zagros Mountains. In the same month as in previous months, moderate and mild drought classes are more prevalent than other classes. The severe drought class is limited in most cases to Lut desert and Jasmourian region in Kerman, Sistan - Baluchestan and South Khorasan Provinces (Figure 8).

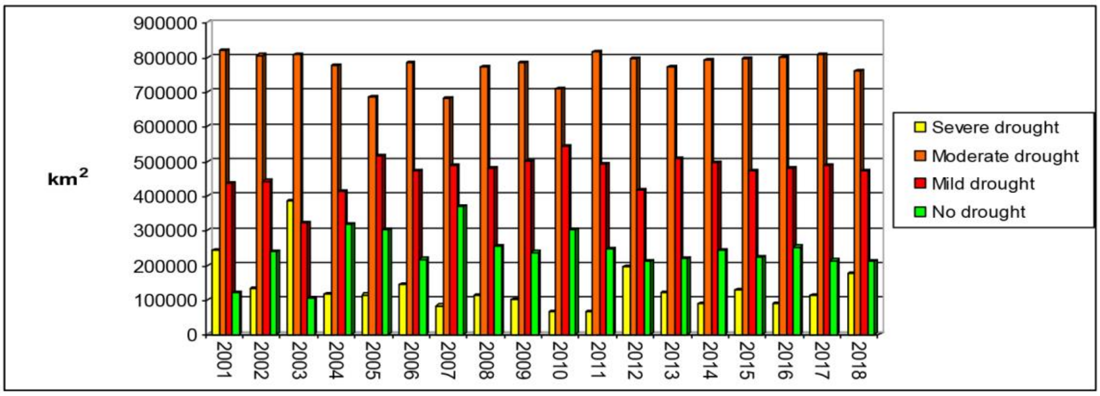


**Fig. 6.** Drought classes based on VHI in Jul

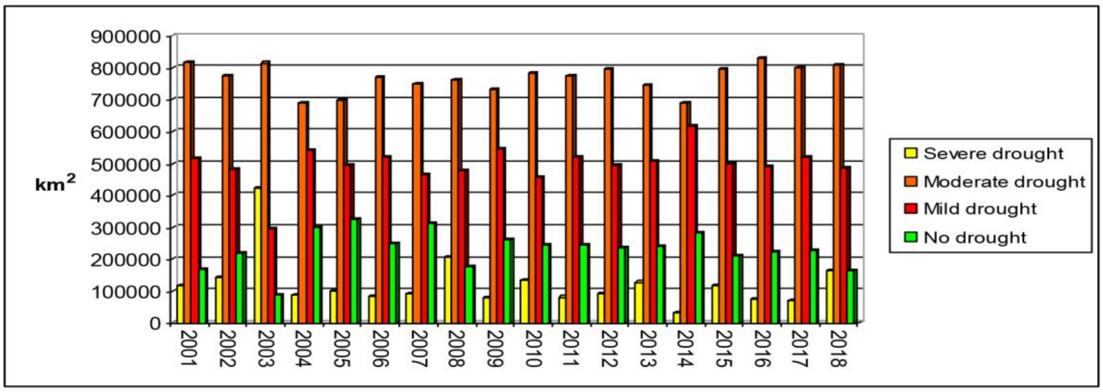


**Fig. 7.** Drought classes based on VHI in Aug

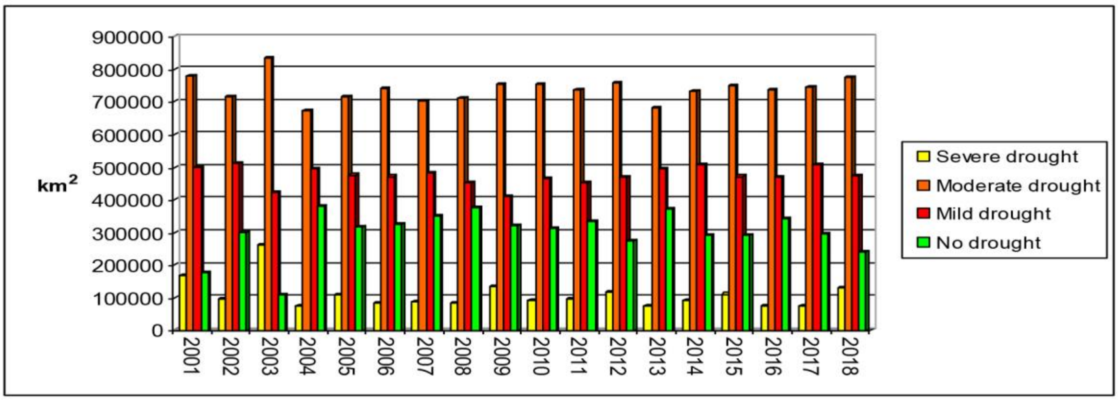


**Fig. 8.** Drought classes based on VHI in Sep

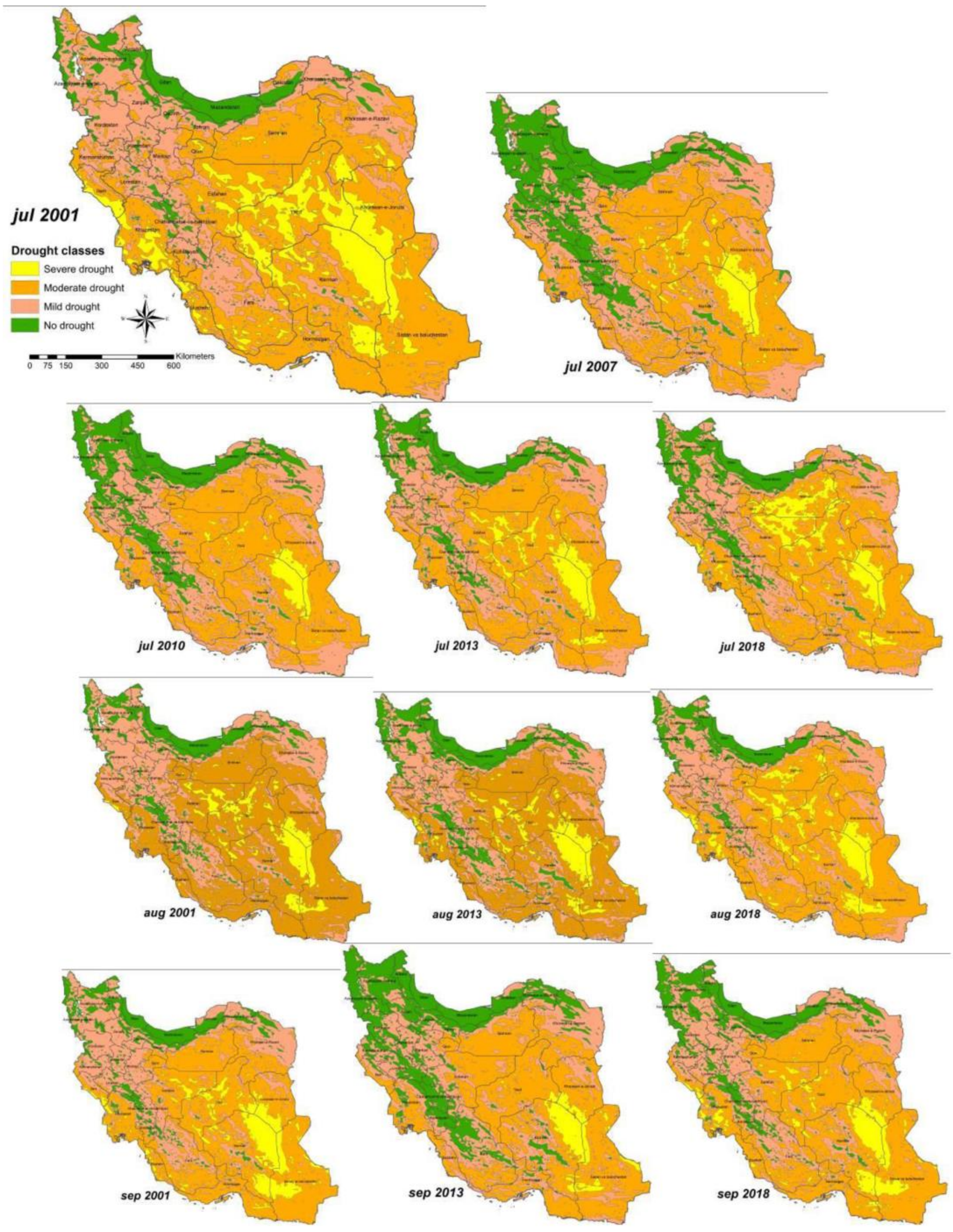


**Fig. 9.** Drought conditions in the summer months based on VHI classification

## 4. Conclusion

Considering the widespread and interactive effects of the climate on various production sectors - environmental factors, today drought is considered as one of the most important environmental challenges of the 21st century. Drought is a natural disaster that affects agriculture, economy and social aspects of the community. This phenomenon is gradual in such a way that its beginning and end is unknown. Its continuity may range from several months to several years and the area covered by it varies over time. For this reason, the need to monitor it is felt more (Bhuiyan, 2004). Iran is classified as arid and semi-arid region in the world's climatic zone (IPCC, 2007). The historical evidence and weather data as well as the country's climate predictions show occurrence of the phenomenon of climate change and drought in recent decades and this trend continuity in the future. In this study, in order to study the severity of drought risk in Iran in 18-year period (2001-2018), we collected rain meteorological data of 176 synoptic meteorological stations and then using IDW method and software GIS, Iran rain map was drawn. In order to map drought severity maps in plants' growing seasons, MODIS ground temperature product (MOD11C3) and vegetation product (MOD13C2) were obtained from WWW.USGS.ORG since 2001 to 2018. Drought indicators of Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and, finally, Vegetation Health Index (VHI) were calculated for each month in plants' growth seasons (April, May, June, July, August, and September). In the spring of 2001 and summer of 2003, the most severe drought conditions occurred, so that in the spring of 2001, 85.8% and in 2003 summer 93.8% was affected by various levels of drought. According to VHI, non-drought class is reducing since April to August, and somewhat increasing in September. The percentage of non-drought class per month is 14.3, 14.6, 19.2, 27 and 30.9 and finally 18.53 percent in September. According to drought severities' comparison, the highest drought duration in all vegetation growth months was for moderate drought (45.3% of the area of Iran), mild drought (25% of the area of Iran) and severe drought (8.9% of the area of Iran), respectively. The mean rain in the studied period is 276.69 mm, which is a low rainy region relative to the global mean. While 56% of the country's area has less than 200 mm rain. According to the map of the rainy regions, Iran's rainfall is highly dependent on the roughness, latitude and frequency of the arrival of synoptic systems in the region. A rainfall spatial map that shows the amount of rain received in different locations is well suited to drought maps (VHIs). So that regions with less than 100 mm of rainfall are representative of the real deserts of the country. In these regions (in most of the statistical period) severe drought conditions occur. The rainy regions of 100 and 200 mm, in terms of drought conditions, have moderate drought. It seems that severe and moderate drought in this region is due to tropical high pressure during the warm period of the year as well as due to being located in the slopes of Zagros Mountains, which prevent the arrival of Western systems to this region greatly. The regions with rainfall between 200 and 300 mm are subject to mild drought. However, the extent of this drought class is expected to double in summer compared to spring. The rainy regions of more than 300 mm are usually not affected by drought stress, and only in those years where these regions had less than normal rainfall, parts of these regions are affected by mild drought.

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