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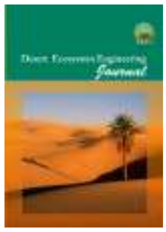

Spatial monitoring of drought in the Khatun Abad basin using SPI and remote sensing technique

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Abstract

Drought is a natural and recurrent phenomenon. It is considered 'a natural disaster' whenever it occurs intensively in highly populated regions, resulting in significant damage (material and human) and loss (socioeconomic). In this regard, this research aims to evaluate the drought of the Khatun Abad basin using the combination of NDVI (Normalized Difference Vegetation Index) and LST (Land surface temperature) MODIS sensors and an SPI indicator. For this purpose, the VHI index was calculated from the combination of VCI and TCI indices based on the 18-year time series (2000-2017) in June. Finally, drought zoning maps based on the VHI index were produced in five classes: very intense, intense, median, and mild and without drought. The evaluation of the time series derived from the VCI and TCI indices shows that there is a significant relationship between NDVI and LST variations. The results show that an extreme drought class is observed in 2017, covering an area of 46 km² from the plain involved with the extreme drought. This is despite the fact that the highest levels of severe drought class occurred in 2008 with an area of approximately 900 km². The total severe and extreme drought classes are observed in 2007, 2008 and 2017. In 2017, a total area of approxiamtely 844 km² from the Khatun Abad basin was involved with the drought, reaching 902 km² in 2008 and 809 km² in 2007. According to the results, the lowest level of drought in Khatun Abad in 2009 was 34 km² classified as a severe and extreme drought. Additionally, the results of the data analysis using the index SPI show that, the most severe drought in the region occurred in 2008. As a result, 33% of the area was severely subjected to drought, and 65% was placed in the middle class drought. In general, the research results indicate that drought changes in the Khatun Abad plain are not logical, and in different years, different drought intensities have been observed.

Keywords: Zoning, Drought, Remote Sensing, Khatun Abad Basin.

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1. Introduction

Natural disasters are part of the environment in which we live. They adversely affect the lives of a large number of people and cause considerable damage to economy, nature, and property worldwide. Economic losses and losses of life from natural disasters are staggering. Developing countries are more vulnerable to natural disasters, since people live in areas at high risk from natural disasters (e.g., unsafe urban areas), the housing is poorly built and can be easily damaged in the event of a disaster, countries are not equipped with early warning systems, and they have few assets and a weak social safety network to help them to cope with disasters. From 1991 to 2005, nearly 90% of disaster-related deaths and 98% of the people affected by disasters were in developing nations (Zorn, 2018).

Nearly 85% of all natural disasters are directly related or associated with extreme weather events (Kebede *et al.*, 2019). Every day, our planet experiences numerous extreme weather-induced disasters such as droughts, floods, hurricanes, tropical cyclones, heat waves, tornadoes, bushfires, and insect infestations. Among these, drought is the most damaging environmental phenomenon (Kogan, 1997). Drought is a hazardous and costly natural phenomenon with slow on-set having dreadful impacts on economy, social life and environment of a country or region. The fact that it is slow on-set and is not quite distinguishable in when is it started or when ended makes the phenomena difficult to study (El-Naqa & Hammouri, 2007). Drought appears when rainfall in a region is lower than the statistical multi-year average for that region over an extended time period (Mala *et al.*, 2014). It is a normal climatic event, but its effect varies from region to region. There are four types of drought, namely meteorological drought, agricultural drought, hydrological drought, and socio-economic drought (Rathore, 2009). Meteorological drought is deficiency of rainfall, which can be observed immediately (Panu & Sharma, 2002). Agricultural drought is measured in terms of deficiency in soil moisture, rainfall, ground water, and reduction in crop yield (Wilhite, 2000). Hydrological drought is deficiency in water availability in surface and subsurface water reservoirs. While, socio-economic drought is the final phase of drought caused by prolonging shortage in agricultural production and food, thereby affecting overall economy (Linsley *et al.*, 1975). Accordingly, drought is one of the most important natural hazards causing considerable damage in different areas each year, and it can cause famine. It is expected that drought will become worse with the overall climate change scenario and the drought affected areas are also expected to increase spatially. Generally traditional methods of drought assessment and monitoring rely on rainfall data, which are limited in the region, often inaccurate and, most importantly, difficult to obtain in near-real time. On the contrary, the satellite-sensor data are consistently available and can be used to detect the onset of drought, as well as its duration and magnitude (Thenkabail, 2004). Even crop yields can be predicted 5 to 13 weeks prior to harvests using remote-sensing techniques (Thenkabail, 2004). Vegetative conditions over the world are occasionally reported by the NOAA National Environmental Satellite Data and Information System (NESDIS) using the Advanced Very High Resolution Radiometer (AVHRR) data (Kogan, 2000). For this reason, much research has been conducted on the drought. For example, Nicolai-Shaw et al. (2017) studied drought event composite analysis using satellite remote-sensing MODIS based soil moisture on the global scale, and the results show that in many regions, long-term precipitation deficiencies are the driving factors of large negative soil moisture anomalies. At the peak of the dry period, large anomalies are found for precipitation, evapotranspiration, and temperature, while vegetation indices often show a delayed response. Furthermore, Safari Shad et al.

(2017) studied Drought Monitoring Using Vegetation Indices and MODIS Data in Isfahan Province, and the results show that the NDVI and VCI indices concerning MODIS sensor can be a good alternative to estimate the drought with respect to meteorological indices and consequently can offer a better idea on drought conditions in the study area. In another research, Ebrahimi et al. (2010) assessed drought in the arid regions of the central part of Iran, and their research results showed that, in the year 2002 compared to the year 1999, the amount of rainfall increased, vegetation fraction decreased and consequently, drought increased in the rangelands of the study area. This is due to existence of a severe drought and a decrease in the seeding of the rangeland vegetation in previous years (2000, and 2001). In addition, Berhan et al. (2011), in a research titled “Using Satellite Images for Drought Monitoring: A Knowledge Discovery Approach”, they state that, approximately 40% of the observed areas in Ethiopia exhibited negative deviation. In this study, the possibility of using the near real-time spatio-temporal Meteosat Second Generation (MSG) data for drought monitoring in food insecure areas of Ethiopia were tested, and promising results were obtained. Another study is the research made by Hammouri and El-Naqa titled “Drought Assessment Using GIS and Remote Sensing in Amman-Zarqa Basin, Jordan”, they recognized that the Amman-Zarqa basin had drought conditions. Furthermore, it was concluded that the combination of various indices offered a better understanding and better monitoring of drought conditions for semi-arid basins like the Amman-Zarqa basin.

Like all other natural hazards, drought impacts can be mitigated through early detection (Sruthi & Aslam, 2015). Remote sensing and geographic information system play a crucial role in detecting, assessing and managing droughts as they offered up-to-date information on spatial and temporal scales (Brian *et al.*, 2012). To assess drought conditions in an area, different drought indices are used. Major drought indices use parameters such as rainfall, vegetation and land surface temperature, and soil moisture. (Mala *et al.*, 2014). Khatun Abad plain plays many important roles in the area, the first one is that this plain is an agricultural zone in the western part of Kerman province, and the agriculture depends on the precipitation amount. After that, this plain provides the water resources required by Sarcheshmeh Copper Company, and this factory is one of the most important industrial zones in Iran. These reasons show the importance of the research. The objective of this study is to assess the drought severity in the Khatun Abad plain using remote sensing and GIS.

2. Materials and methods

The study area known as the Khatun Abad plain is located in Kerman province with an area of 1339 square kilometers in 55° 14′ to 55° 49′ east longitudes and 29° 52′ to 30° 17′ north latitudes. The minimum and maximum altitudes of the plain are 1827 and 3073 m above sea level, respectively. Khatun Abad plain is located in the southeast of Iran, in the east of Shahr-e-Babak in the vicinity of Rafsanjan in the east and Sirjan in the south. Owing to the area topography, the climate condition of the plain is distinct in different parts. The average maximum rainfall in the northern and eastern highlands of the plain is 809 mm per year, while in a short distance in the central low altitude regions, the average minimum rainfall is 265 mm. Moreover, the average temperature at the highlands is -1 degree, and the mean maximum temperature in the central regions is 16 degrees.

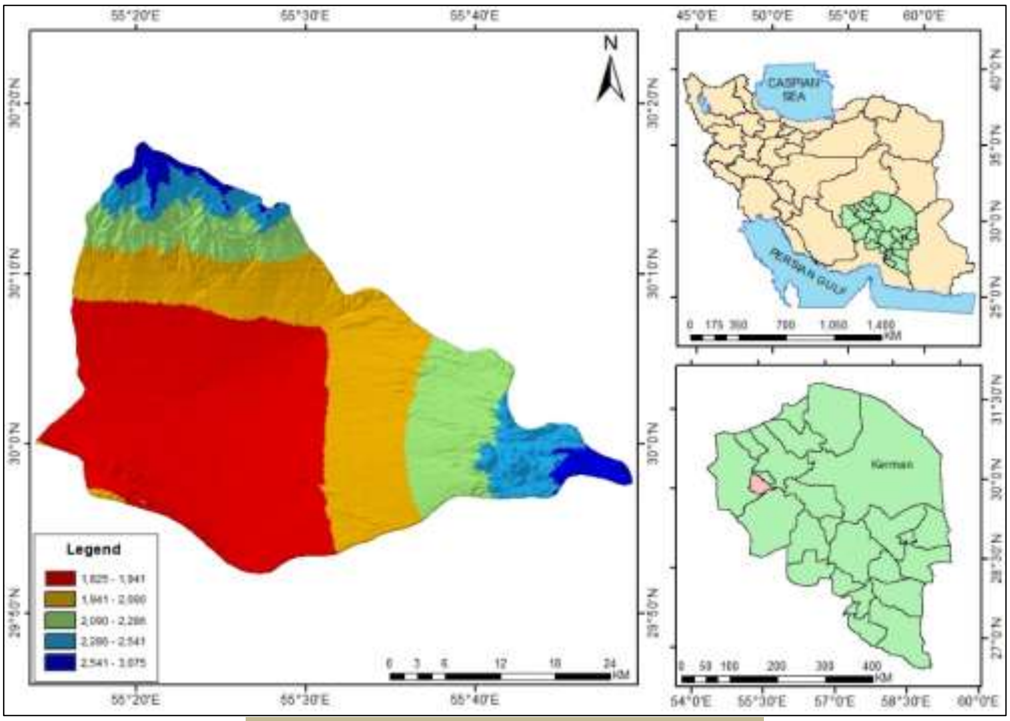

Figure 1: Location map of Khatun Abad area

The present study, which is an applied research, is conducted using the precipitation data obtained from the stations in the study area. The data are from 4 stations with monthly temporal separation in 18 years (from 2000 to 2017) and their null data were valued using existing functions before inserting in formulas.

Standard Precipitation Index (SPI) is based on the fact that precipitation shortage has different effects on underground waters, water resources, and soil moisture and snow coverage. The SPI calculates precipitation shortage for multi timescales (3, 6, 12, 24, 48 months). These timescales reflect drought impact on the existence of different water resources. The soil moisture condition reacts to times of rainfall abnormalities on a short scale, while underground waters, river flow and reserve resources react to rainfall abnormalities in a longer period. This index is calculated by the difference of precipitation from the average for a specific time scale and then divided by standard deviation (Mostafa Zade, 2016).

Since the precipitation for periods shorter than 12 months is not scattered normally, an adaptation and a method will be created, allowing the standardized precipitation index to be distributed normally. Therefore, on a time scale, the SPI average will be 0 and the standard deviation will be 1. This is an advantage, since the standard precipitation index will be normalized so that more humid climates and more dry climates would be presented similarly (Hanafi, 2011).

Table 1: SPI classification

CONDITION	INDEX
Extremely moist	2 and more
Very moist	1.5 – 1.99
Partly moist	1 – 1.49
Near normal	0 – 0.99
Partly dry	-1 – -1.49
Very dry	-1.5 – -1.99
Extremely dry	-0-2 and less

After collecting the data recorded in surrounding stations (Rafsanjan, Sirjan, Shahrbabak, Anar), all the data were inserted in the Excel by temporal and spatial separation, then, the SPI equation was applied to them. First, we collect total annual precipitation for each station; this means that all precipitation occurred during one year, then the average and standard deviation for the the precipitation in the whole period were computed, and in the last step, we can calculate the SPI index by the following equation:

$$\text{SPI}=\frac{total\ annual\ precipitation-precipitation\ average}{standard\ deviation}\quad Equation\ (1)$$

Afterward, we create a point layer in the ArcGIS software, which is the location of stations and a numeric field that is the number obtained from the previous equation for each year, and then we run the IDW interpolation model by inserting the created point layer as the input layer. Then, the required analyses, including the area of the classes, the severity and weakness of the rainfall, were conducted in different years.

In the next step, we used the normalized difference vegetation index (NDVI) products of MODIS sensor in Terra satellite with a 250m spatial resolution and a 16-day temporal resolution, as well as an LST product with a 1km spatial resolution and an 8-day temporal resolution from June 2000 to June 2017. For this purpose, the pre-processing operations such as molecular dispersion correction, ozone and dust absorption, Nadir correction, and angles of solar radiation were performed through the bidirectional reflectance distribution function (BRDF) model on the NDVI product. In addition, the corrections such as georeferencing, radiation calibration, removal of cloud shadow, atmospheric and water vapor temperatures were made by NASA on the LST product.

Climate characteristics of Khatun Abad plain

Climate is the recognition of weather conditions and the occurrence of meteorological parameters such as temperature and precipitation in a region and the contributing factors in the long term (Bakhtiari, 2003). Owing to the area topography, the climate condition of the plain is distinct in different parts. Table 2 shows the climatic characteristics of the Khatun Abad plain.

Table (2): Annual average of temperature and precipitation in the studied stations

Station / Year	Rafsanjan		Sirjan		Shahrbabak		Anar	
	P (mm)	Temp (◦C)	P (mm)	Temp (◦C)	P (mm)	Temp (◦C)	P (mm)	Temp (◦C)
2017	5.8	22.1	4.6	20.2	12.5	18.4	5	22
2016	3.71	19.6	16.5	17.9	18.4	15.9	3.65	19.2
2015	5.83	19.4	9	17.7	9.4	15.81	6.4	19.2
2014	8.14	19.2	13.12	17.17	13.36	15.4	9.3	18.8
2013	11.2	18.8	21.13	17.1	14.03	14.9	6.7	18.6
2012	5.57	19	5.93	17.3	9.44	15.4	4.5	18.7
2011	1.98	19	6.65	17.3	9.31	15.3	0.7	18.7
2010	8.05	18.7	13.97	17.5	8.75	15.6	2.8	18.6
2009	5.46	19.5	10.81	18.1	11.43	14.4	6.1	19.9
2008	4.01	19.2	6.17	17.9	3.37	15.8	3.8	18.8
2007	4.18	18.1	6.30	17.2	6.93	15.2	4	17.5
2006	5.99	18.2	10.79	17.1	9.10	15.3	3.93	17.8
2005	3.02	19.1	8.53	17.1	5.88	15.4	3.1	18.6
2004	9.11	18.2	13.98	17.5	16.03	15.5	7.33	18
2003	4.10	19.5	12.43	18.3	19.58	16.1	4	19.6
2002	12.58	19.3	7.84	17.9	11.38	15.6	3.21	19
2001	8.08	19.4	5.86	18	10.95	16.4	6.84	19.6
2000	7.88	18.7	4.31	17.5	7.69	15.4	3.11	18.3

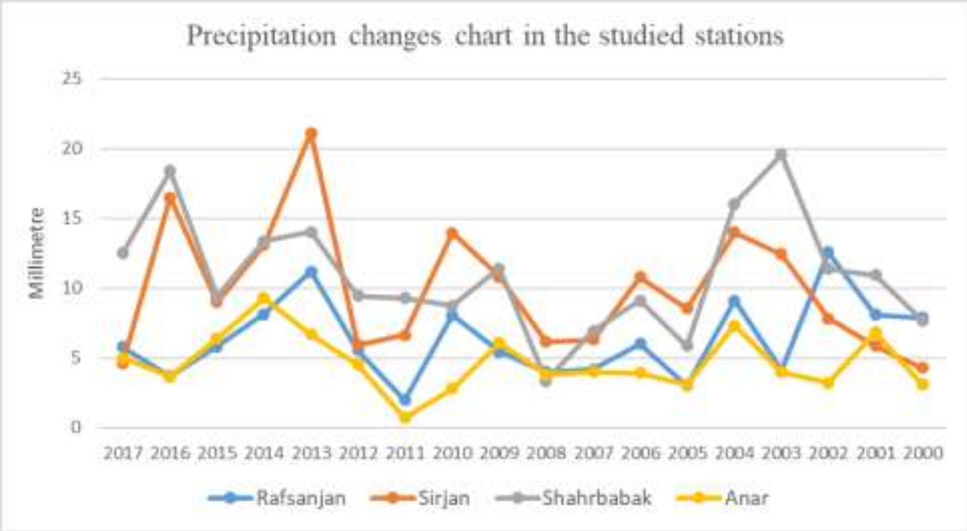

Figure 2: Precipitation changes chart in the studied stations

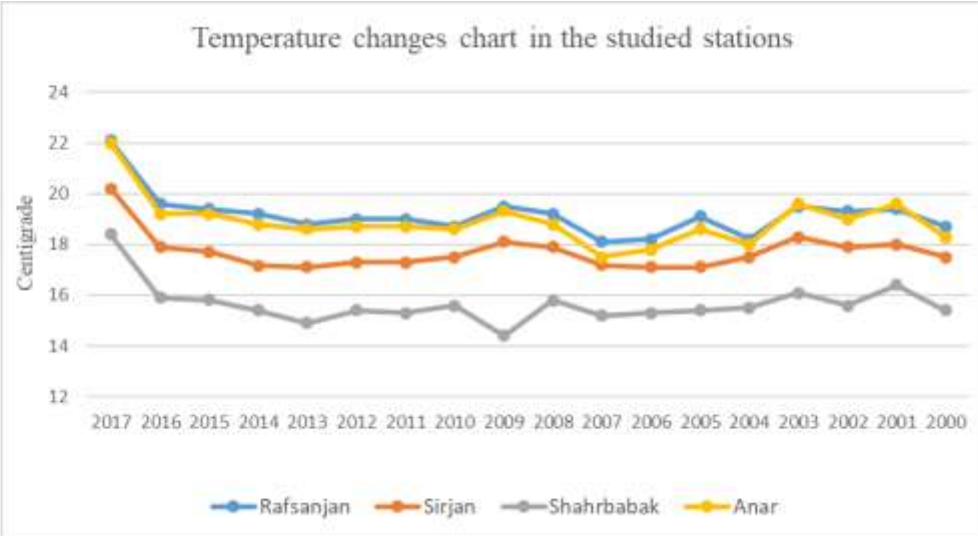

Figure 3: Temperature changes chart in the studied stations

Additionally, in this research, the climate of the study area was determined using the De Martonne method. This method is estimated according to the annual precipitation (mm) and average annual temperature based on the aridity index. Figure (2) shows the climatic zoning of the Khatun Abad plain.

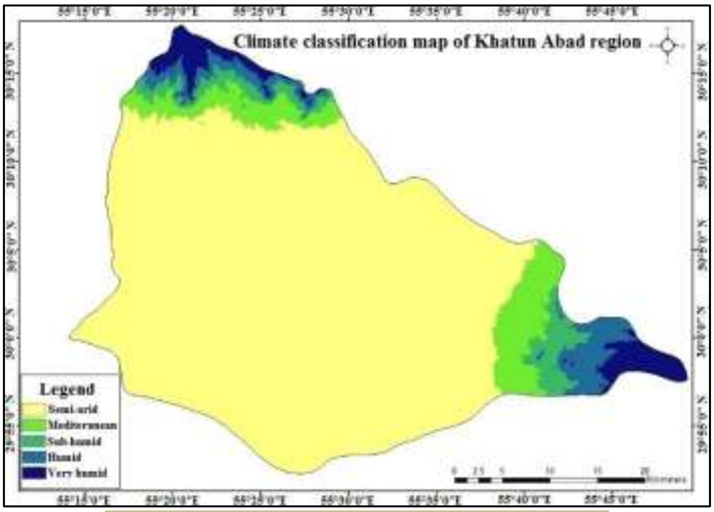

Figure 4: Khatun Abad climatic zoning map

Considering the topography of the area, the climatic condition of the Khatun Abad plain varies in different regions, so that the average maximum precipitation in the northern and eastern highlands of the plain is 809 mm per year, while a short distance farther in the central lowlands, the average minimum precipitation is 265 mm. Furthermore, the average minimum temperature at the highlands is observed by -1°, and the average maximum temperature in the central regions is 16°. Figures (3) and (4) show the precipitation and temperature maps of the region.

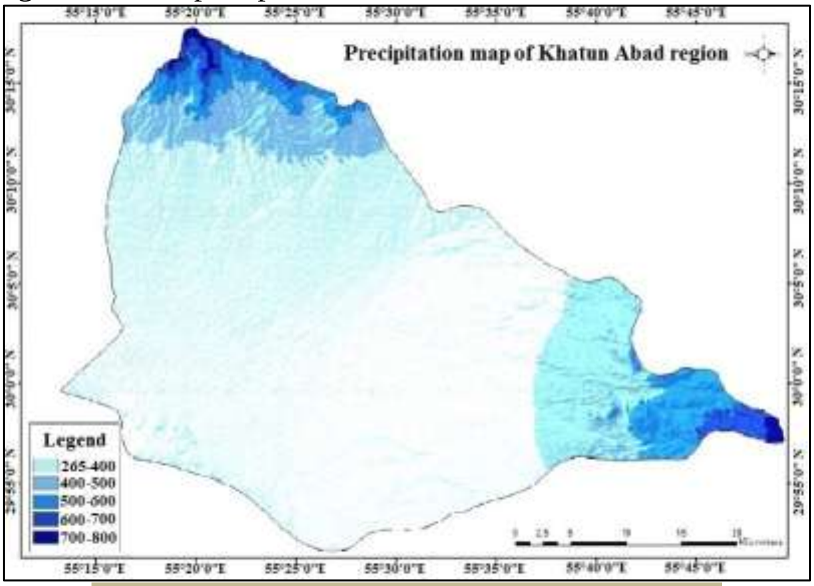

Figure 5: Precipitation map of the Khatun Abad region

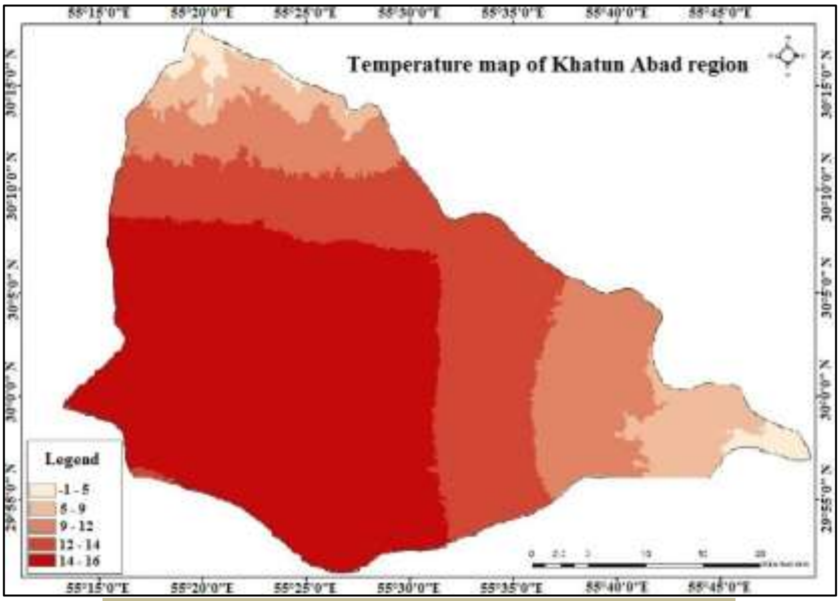

Figure 6: Temperature map of the Khatun Abad region

After adjusting LSD and NDVI for June, the files of the related class to this month were created from 2008 to 2017, and the minimum and maximum images were generated. Then, based on the relationship for each of the VCI and TCI indices, 18 images were prepared for each of the indices. The VHI index, which is the sum of the VCI and TCI indices, was prepared in the same number. Finally, the images from the VHI were classified into 4 classes, severe drought (10-20), moderate drought (20-30), mild drought (40-30) and not drought (>40) (Damavandi, 2016).

2.1. Normal Difference Vegetation Index (NDVI)

Many researchers have been able to determine vegetation condition using vegetation indices, including NDVI. The NDVI is based on the fact that healthy vegetation has a low reflectance in the visible portion of the electromagnetic spectrum due to chlorophyll absorption and other pigments, and high reflectance in the Near Infrared (NIR) owing to the internal reflectance by the mesophyll spongy tissue of a green leaf. NDVI can be calculated using pixel's reflectance values of red (visible) band and the NIR band of a satellite sensor, and is represented by the following equation, where NIR is band 1 reflection (620-670 Nanometer) and Red is band 2 reflection (841-876 Nanometer) (Damavandi et al., 2016):

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}$$
$Equation$ (2)

NDVI values range from –1 to +1 (Berhan et al., 2011). Owing to the high reflectance in the NIR portion of the electromagnetic spectrum, healthy vegetation is represented by high NDVI values between 0.05 and 1. Conversely, non-vegetated surfaces (such as water bodies) yield a negative NDVI value. Bare soil areas have NDVI values, which are closest to 0 due to the high reflectance in both visible and NIR portions of the electromagnetic spectrum (Li et al., 2004).

2.2. Vegetation Condition Index (VCI)

Although the NDVI has been extensively used in the past for vegetation monitoring, it is often very difficult to interpret regarding vegetation conditions, especially when comparing different climate regions to each other. To overcome this difficulty, Kogan (1995) created the Vegetation Condition Index (VCI) comparing the NDVI of the present month to the maximum and minimum NDVI (which is calculated using long-term records of RS images). VCI separates the short-term signal from the ecological signal (Wan et al., 2004).

$$VCI = \frac{NDVIi - NDVImin}{NDVImax - NDVImin} \times 100$$
Equation (3)

where NDVImax and NDVImin are calculated by long-term RS images, VCI is calculated using the above equation. The condition of the ground vegetation presented by the VCI is measured as a percent. A 50% VCI value reflects fair vegetation conditions, whereas values in the range 50-100% indicate optimal or above normal vegetation conditions. A VCI value of 100% means that the NDVI value for the selected month (week) is equal to the NDVI max, which in turn means that the optimal conditions for vegetation are provided (Berhan, 2011). Different degrees of drought severity are represented by any VCI value below 50%. Kogan (1995) identified extreme drought conditions to be those below a VCI threshold of 35%. He also suggested that further research would be conducted to categorize drought severity for VCI values ranging from 0 to 35%. A VCI value close to 0% reflects an extremely dry month and an NDVI value that is close to its long-term minimum. Low VCI values persisting over several consecutive time intervals indicate the development of drought.

2.3. Temperature Condition Index (TCI)

During the rainy season in general, it is common for overcast conditions to prevail for up to three weeks. When conditions last longer than this, the weekly NDVI values tend to be depressed, giving the false impression of water stress or drought conditions. To remove the effects of contamination in the satellite assessment of vegetation conditions, Kogan (1995, 1997) suggested the use of a Temperature Condition Index (TCI). The TCI is calculated much in the same way as the VCI, but its formulation is modified to reflect the vegetation's response to temperature (i.e. the higher the temperature, the more extreme the drought). TCI is based on brightness temperature (BT) representing the deviation of the current month's temperature from the recorded maximum. Using meteorological observations, as well as the relationship between ground surface temperature and moisture regimes, drought-affected areas can often be detected before occurrence of biomass degradation. Hence, TCI plays a key role in drought monitoring and is represented by Kogan (1997):

$$TCI = \frac{LSTmax - LSTi}{LSTmax - LSTmin} \times 100$$
Equation (4)

2.4. Vegetation Health Index (VHI)

Although VCI and TCI are characterized by varying moisture and thermal conditions of vegetation, Vegetation Health Index (VHI) represents overall vegetation health. Kogan

(2001) assigned five different drought classes to VHI to construct drought maps more properly: (Owrangi et al., 2011). VHI is computed using the following equation:

$$VHI = (0.5\ \times VCI)(0.5\ \times TCI)$$

Equation (5)

3. Results

3.1. Standard Precipitation Index

In the present study conducted based on the precipitation gradient and SPI index difference, 6 years were chosen as sample years that raster analysis in the ArcGIS software is applied to them.

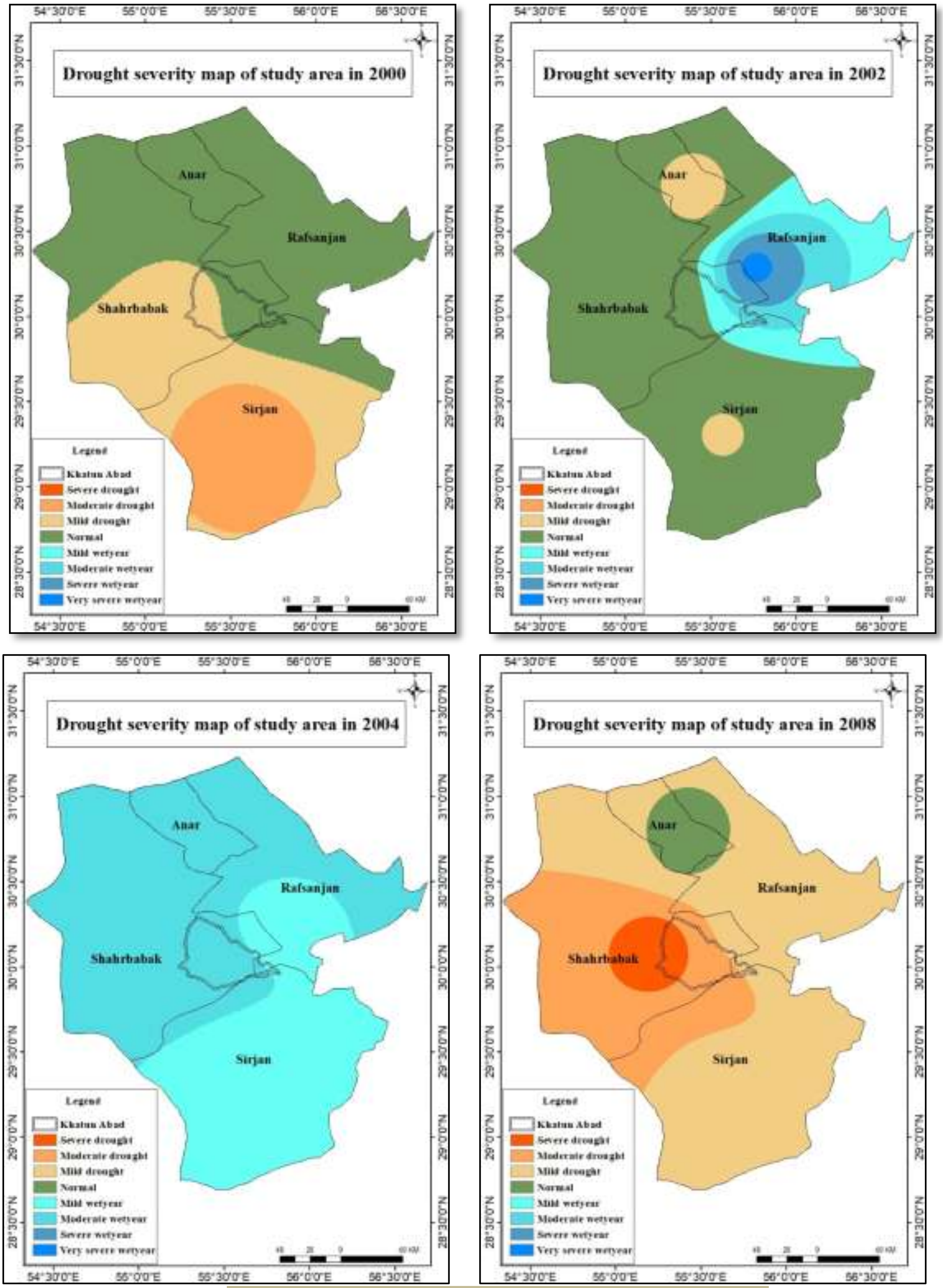

Figure 7: Drought severity maps in 2000, 2002, 2004, 2008

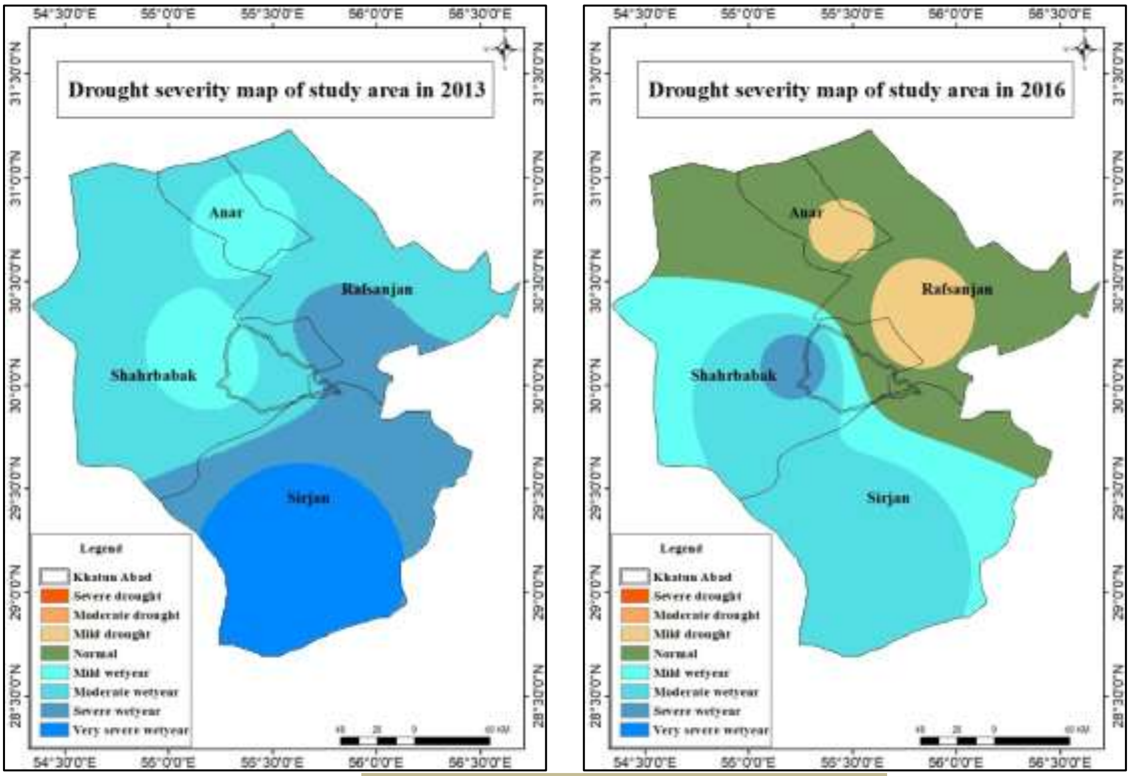

Figure 8: Drought severity maps in 2013, 2016

As shown, the plain drought level has a severe fluctuation in the study period such that the precipitation of the region during a 4-year period become so low that climate condition descends from moderate wet periods to moderate drought and again after 5 years and increasing precipitations, we can see moderate and severe wet periods. All of these precipitation fluctuations and climate changes show global warming at upper levels. These fluctuations are dangerous to preservation of water resources, and their next result will be risk of manufacturing industries based in the plain and surrounding cities, since the industry's required water is provided from the Khatun Abad plain.

3.2. Remote Sensing analysis

Figure (5) shows the map of drought classes and Figure (6) shows the diagram of the drought class area from 2000 to 2008 in the study area. According to the research findings, 2008 and 2017 had the highest drought, and 2009 had the least drought in the study area. In general, the drought in the Khatun Abad basin does not show a consistent trend; for example, while 2007 and 2008 experienced a severe drought, 2009 was normal in terms of drought. Then, since 2006, the drought has had an increasing trend in the region and reached the peak in 2008. However, the intensity of the drought in 2009 was lower than that in the rest of the years.

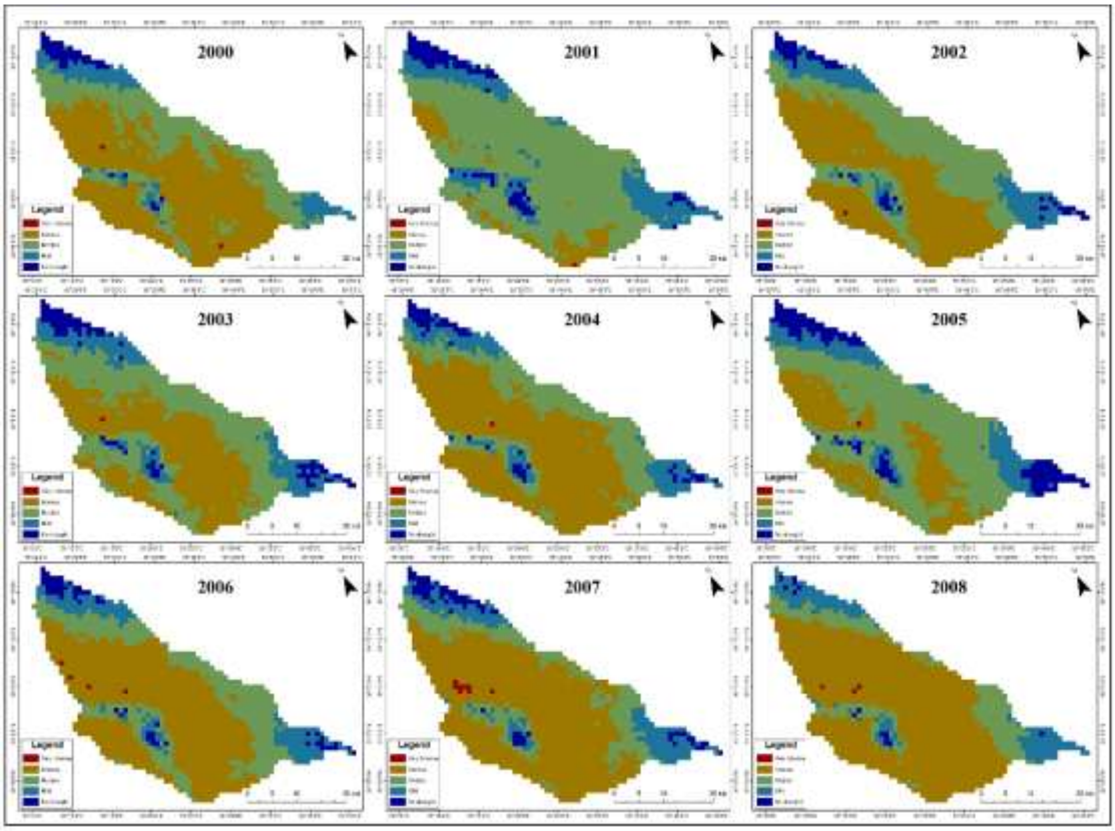

Figure 9: Drought class map from 2000 to 2008

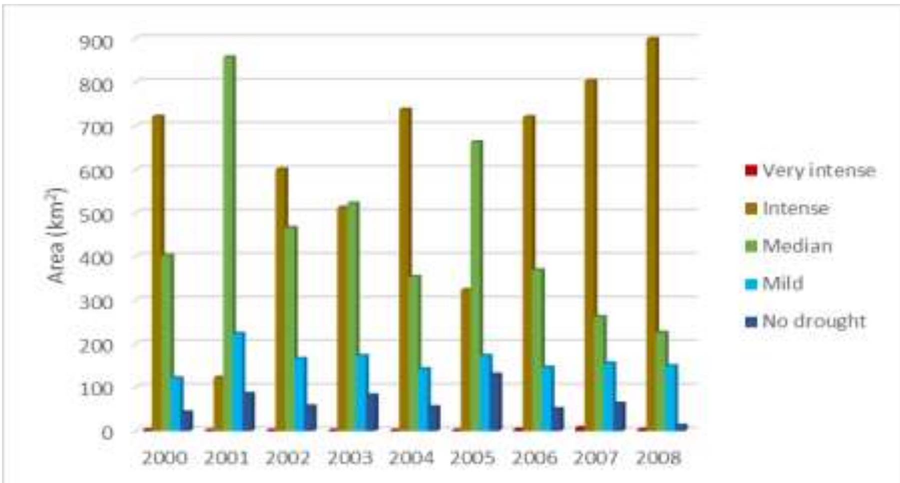

Figure 10: Diagram of the drought class area from 2000 to 2008

Figure (7) also shows the zoning map of the drought classes in the study area from 2008 to 2017, and Figure (8) shows the diagram of the area for each of the classes in the aforementioned years.

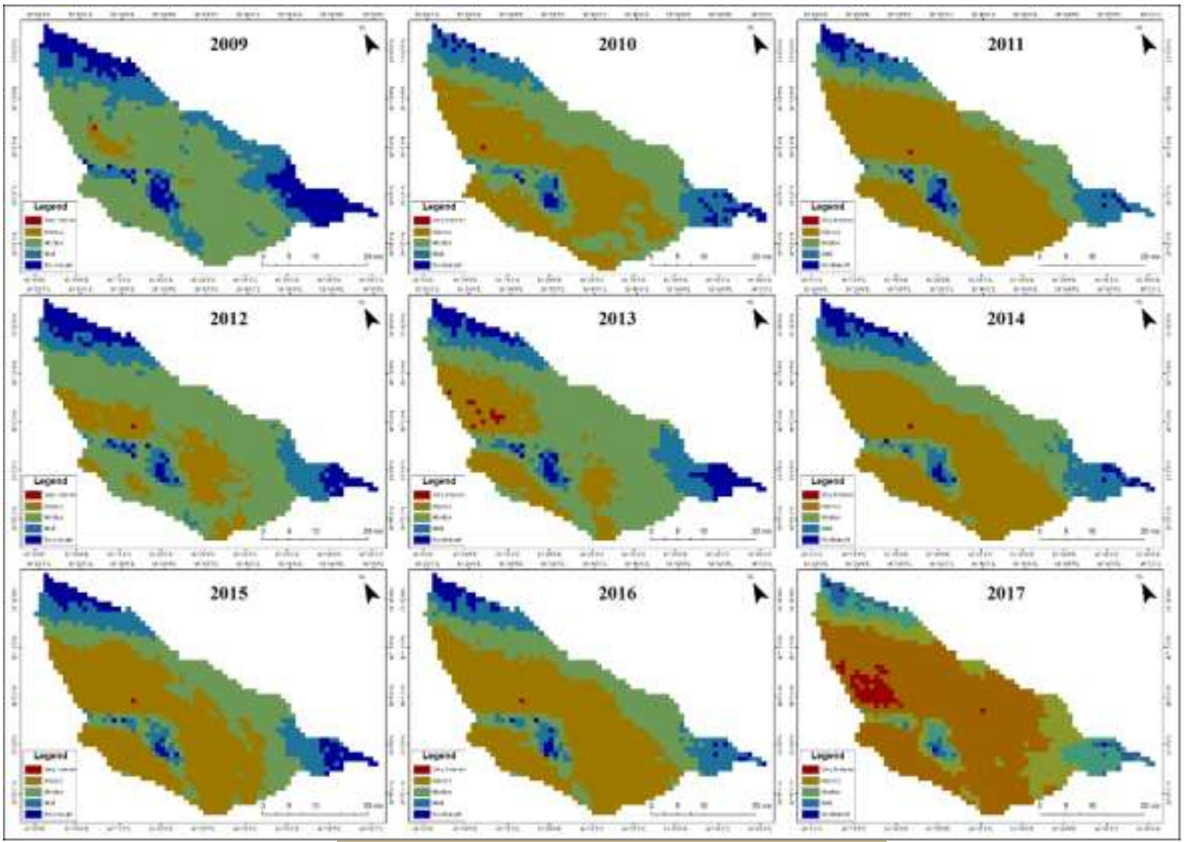

Figure 11: Drought class map from 2009 to 2017

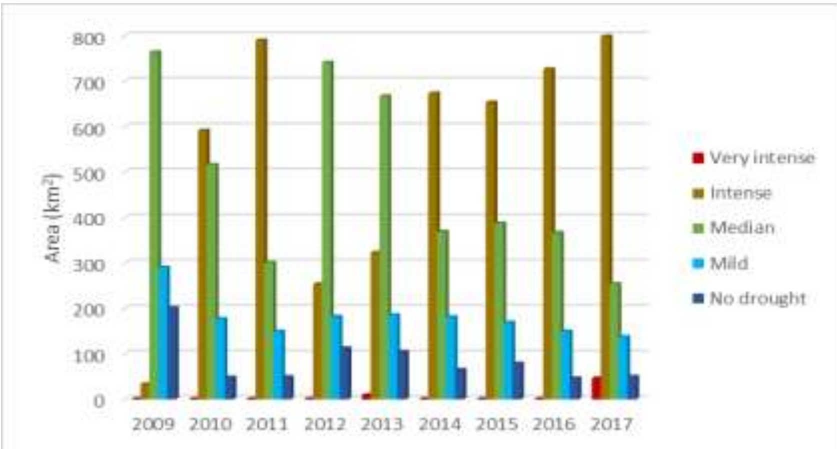

Figure 12: Diagram of the drought class area from 2009 to 2017

4. Discussion and Conclusion

Generally, precipitation is the most important factor in the occurrence of drought. The results of various studies in the world show that the satellite indices along with the land-based meteorological indices can effectively monitor the drought trend. In recent years, researchers have attempted to simultaneously consider the factors contributing to the drought study process. This idea is the foundation of some indices such as SPI, NDVI, and LST. Generally, the results show that the combined indices outperform the individual ones.

The results of the data analysis using the index SPI show that, in 2000, 59% (793 km²) of the Khatun Abad plain was in normal precipitation conditions, and the rest 41% (549 km²) was in mild drought, which means it has a lower amount of precipitation than the region long-term rainfall. This ratio in 2002 is like this 55.5% (745 km²) in the normal class, 29.5% (396 km²) in the mild wet period and 15% (201 km²) was in the moderate wet period class. In 2004, it was also a wet period in the plain, when 96.65% (1297 km²) of the region experienced a moderate wet period, and the rest 3.35% which is approximately 45 km² of the plain area was in the mild wet period class. However, in 2009, it was a completely different situation, and the plain faced drought, 2% (27 km²) was in mild drought, 65% (863 km²) was in moderate drought, 33% (452 km²) was in the severe drought class. Khatun Abad plain has a wet year during 2013, so that 37.48% (503 km²) from the plain area had a mild wet period condition, 60.65% (814 km²) a moderate wet period, and the rest 1.86% (25 km²) was a severe wet period. In addition, in 2016, it was a wet year such as the previous sample year, the ratios are 29.21% (382 km²) normal condition, 26% (348 km²) mild wet period, 29.43% (395 km²) moderate wet period, and 15.42 (207 km²) severe wet period. Generally, calculating the severity of drought in the sample years using the SPI index implies that it was a drought in the plain.

Furthermore, the present study evaluates the spatial variability of vegetation and land surface temperature due to the drought in the form of combined indices based on the TCI, VCI and VHI time series in the Khatun Abad plain from 2000 to 2017. The results of this study indicate that the effects of drought on ground surface temperature and vegetation are different and follow many factors such as the type and characteristics of vegetation and the temperature conditions. The VHI index is one of the most important combined indices to assess the drought intensity in different regions owing to the ability to simultaneously display the effects of drought on the vegetation and ground surface temperature. The results of the drought zoning in the study area using the VHI index indicate that in the study period in the Khatun Abad plain, an extreme drought class is observed in 2017, covering an area of 46 square kilometers from the plain involved with the extreme drought. Nevertheless, the highest levels of severe drought class occurred in 2008 with an area of approximately 900 square kilometers. The total severe and extreme drought classes are observed in 2007, 2008 and 2017. In 2017, a total area of approximately 844 square kilometers from the Khatun Abad plain was involved with the drought, reaching 902 square kilometers in 2008 and 809 square kilometers in 2007. According to the results, the lowest level of drought in Khatun Abad in 2009 was 34 square kilometers classified as a severe and extreme drought. In general, the drought intensity zoning maps developed by the combined indices can be used for the systematic planning to monitor, control and prevent the increase of drought trends in different regions and have a significant impact on the reduction of the damage caused by drought. The results of the present study were compared to other researcher's results. For instance, Pourkhosravani (2016) showed that Sirjan did not have an intense drought in a similar period, and another study by Hammouri (2007) in Jordan indicated that this country faced drought conditions during 2007. Moreover, he suggested the use of a mixture of indices to analyze drought under semi-arid conditions like his study area, Zarqa basin. Another study by Luisa Amalo conducted in Java, Indonesia investigated the role of three drought indices (VCI, TCI, VHI) and showed the accuracy of these indices. Finally, he suggested that the use of these indices was a more accurate method. Moreover, Damavandi (2014) demonstrated that the benefits of remote sensing indexes like VHI could overcome the weaknesses of point methods; therefore, this case helps planners and decision-makers to predict drought. All these items show the importance of remote sensing methods for drought monitoring. The results of the mentioned studies are consistent with those of the present study.

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