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Investigation of Lag Time Correlation between Agricultural and Meteorological Droughts

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Abstract

The most important natural hazard affecting agriculture in Lorestan province is the occurrence of drought and its consequences. Therefore, the main goal of this research is to investigate and determine the effects of drought on agriculture (irrigated and rainfed) in Lorestan province. To achieve this goal, a combination of field and statistical methods was used. The studied data include characteristics of rainfed and irrigated agriculture, characteristics of water resources, land use map, and drought indicators (meteorological and satellite) of Lorestan province. In order to investigate the relationship between the SPI index and each of the VCI, TCI, and VHI vegetation indices, the correlation coefficient between the indices was calculated and investigated, and a relationship was established between them through single and multiple linear regression. The correlation coefficient between the SPI drought index and TCI and VCI vegetation indices was estimated to be 0.77 and 0.70, respectively. Also, the correspondence between meteorological drought classes and vegetation cover was investigated using a mixed matrix. About the evaluation of the impact of agricultural drought on rainfed and irrigated agriculture, the results indicate that there is a positive and direct relationship between the values of the correlation index between the yield of rainfed and irrigated plants (especially wheat and barley) and the values of various drought indicators during the period of 1991-2017. In terms of time, the highest value of the correlation index between yield and drought index values is observed in the time scale of one to six months, and the correlation value decreases in longer time scales. One of the main reasons for these conditions is the physiological characteristics of different products. Based on the obtained results, in general, it can be said that the increase in drought and heat stress in Lorestan province has caused a decrease in yield and an increase in the water requirement of various aquatic crops.

Keywords: Correlation coefficient, Drought, Irrigated agriculture, Lorestan province, Rainfall, Rainfed agriculture.

1. Introduction

Drought is a complex phenomenon whose definition and understanding are sometimes different for different people according to different expertise (Tsakiris et al., 2013). Even though drought affects almost all sectors of the economy in different ways, each sector has its concept and criteria to measure the severity of drought. There may be many conflicting criteria in each sector. For example, in the agricultural sector, a hot and dry period may create a devastating drought for a grain farmer. While a fruit farmer needs this to ripen his fruit (Belayneh et al., 2016). Due to the existence of many risks, the occurrence of drought, and its impact on agriculture, few studies have been conducted in Iran on the evaluation of the impact of drought on agricultural products. This is even though the occurrence of this phenomenon in any part of Iran has the possibility of happening for several years, on the other hand, in some areas such as the southwest of Iran, agriculture is the main source of people's income. The investigation of climatic droughts that occurred in Lorestan province, Iran confirms that the probability of droughts that cover more than 80% of the province's surface is about 37% every year. In other words, such a drought may occur in Lorestan province once every three years (Zand, 2018). Now, if the possibility of widespread droughts (a drought that affects the entire Lorestan province) is taken into consideration, it is clear that such an event may occur in less than eight years. Therefore, even though Lorestan province is considered one of the rainiest regions of Iran, according to the studies carried out, it can be concluded that the occurrence of drought in this province is not only rare and random but also a common and recurring phenomenon (Zand, 2018). Singh et al. (2003) obtained drought-prone areas in India by using VCI and TCI indices. Ji et al. (2003) to better understand the relationship between normalized vegetation difference index and moisture availability, evaluated their research on monthly NDVI (1989-2000) during the growing season in the northern and central U.S. Great Plains. Rhee et al. (2010) proposed a remote sensing-based drought index, scaled drought condition Index (SDCI), to monitor agricultural drought in dry and wet regions using multi-sensor data.

This index was a combination of data, Land Surface Temperature (LST) and index data, Normalized Difference Vegetation Index (NDVI) obtained from the MODIS sensor, and TRMM tropical rainfall measurement satellite was used for rainfall data. Caccamo et al. (2011) investigated the capability of MODIS sensor data in drought estimation with, Enhanced vegetation index EVI index and Standardized Precipitation Index SPI index in Sydney basin during 2000-2009. The results showed a high correlation between SPI and EVI index in all time scales. Rahimzadeh et al. (2012) used three Vegetation Dryness Index (VDI), Temperature Vegetation Dryness Index (TVDI), and improved TVDI index (ITVDI) to investigate drought conditions in the semi-arid region of Hamedan and evaluated the results with monthly rainfall values. Based on that, they indicated that there is no significant relationship between VDI and soil moisture and rainfall, but since the ITVDI index improves with digital elevation model (DEM) and air temperature data, it monitors drought better. Shahabfar et al. (2012) conducted their study in order to investigate the relationship between rainfall (using ground indices Modified China Z Index (MCZI), China Z Index (CZI), Z) and remote sensing indices Modified perpendicular drought index (MPDI), perpendicular drought index (PDI), EVI, and VCI in the period of 2000-2005. The results of the linear regression analysis showed that all of these remote sensing indicators generally have a statistically significant relationship with the rainfall data. Mirmosavi et al. (2012) investigated the effect of drought on vegetation in Kurdistan province, Iran, and used meteorological and remote sensing data for this purpose. The results of their study showed that there is a high correlation between the average of NDVI and SPI indices (0.77) at a significance level of 0.01, and with a decrease of approximately -0.2 from the SPI index to an average of 1.2% (equivalent to 350 square kilometers), the level of weak vegetation increases. Ghaleb et al. (2015) monitored the drought of Lebanese vegetation in 2014 using a remote sensing technique. They used Landsat images with a spatial resolution of 30 meters to identify the vegetation condition index and the temperature condition index. Dmavandi et al. (2016) investigated the spatial monitoring of agricultural drought through the time series of NDVI and LST indices of MODIS data in Markazi Province, Iran. Examining the time series obtained from VCI and TCI showed that there is a significant relationship between NDVI and LST changes.

Hamzeh et al. (2016) studied the temporal and spatial monitoring of agricultural drought using remote sensing data from the Markazi province, Iran and examined the spatial and temporal patterns of drought using Modi's sensor satellite data between 2000 and 2013. The VCI index was selected as the best index to monitor the agricultural drought of Markazi Province, Iran. Firozi et al. (2018) investigated the sensitivity of two vegetation indices, NDVI and EVI, to droughts in arid and semi-arid areas (Sistan Plain, Iran). The results showed that in the sample dry year (2010-2011) a significant difference between these two indicators was observed in the normal vegetation class. Howitt et al. (2015) studied the economic effects of drought on agriculture in the California region and stated that the effects of drought are more pronounced in areas with limited groundwater so this event also affects the price of agricultural products. Kang et al. (2015) investigated the effect of climate change on the water productivity of harvesting systems in the Murray Darling basin of Australia and stated that climate change increases the amount of evapotranspiration and subsequently increases the yield of corn plants in south-eastern Australia.

Meroni et al. (2017) in research titled evaluation of the Standard Precipitation Index to provide an initial forecast of the seasonal vegetation status of the coastal region, by examining the relationship between the standard precipitation index and the z-score of the cumulative value of the Fraction of Absorbed Photosynthetically Active Radiation (ZCFAPAR) concluded that there is a significant linear relationship between these two variables in 32-66% of the studied area. Rimkus et al. (2017) studied the identification of drought in the Eastern Baltic region using the NDVI index. The effect of lack of precipitation on vegetation in water forests and extensive forests was analyzed using the SPI calculated for the time window of 1 to 9 months. Liu et al. (2020) to evaluate the drought used the composite index based on remote sensing to monitor the aridity of dry areas in northern China, Shandong province. Using multivariate linear regression, they extracted the MCDI index, which is a combination of soil moisture, LST, and NDVI, and then calculated the correlation coefficient between the SPEI index and MCDI, which is higher than the correlation coefficient between SPEI and individual indices (mode non-combined). They obtained the coefficients for the 1-month and 9-month time series, and the correlation coefficients were higher in the 9-month case. Therefore, they concluded that multivariate linear regression of the MCDI index is an effective method and indicator for drought monitoring in Shandong province, China (Liu et al., 2020).

According to the estimates made by the disaster headquarters of Lorestan governorate, Iran in the crop year 2013-2014, the drought caused 1300 billion rials of damage to the gardens and lands of the province. Drought has affected the amount of demand for agricultural inputs such as fertilizers, poisons, machinery, credits, etc., in addition, drought has hurt water resources, forests, pastures, and other natural resources of the province.

In Lorestan province, Iran, agricultural activities are carried out in both rainfed and irrigated forms and in the group of cereals, legumes, industrial and fodder plants, livestock, and aquatic animals. Therefore, drought events in this region have always had many adverse effects on the agricultural sector, and in recent years, this sector has been severely affected by the droughts that have occurred; Therefore, rainfall and its characteristics are of great importance in all aspects of agriculture in the study area, and the amount of the crop is strongly influenced by spring rainfall, especially in May, and in the meantime, the agricultural drought causes problems such as a decrease in household income (which has caused the amount of investment in this sector has also decreased), increasing unemployment among rural communities, migration, decreasing the number of livestock and decreasing the production of agricultural, horticultural, livestock and aquatic products. Therefore, in this study, the effect of drought on various aspects of the agricultural sector and natural resources of the study area (rainfed and irrigated farming) and its effects have been investigated and analyzed using a combination of field methods, remote sensing, and modeling.

2. Materials and Methods

2.1. Study Area

The studied area in this research is Lorestan province in the west of Iran. This province, with an area of 28,559 square kilometers in the west of Iran, covers 1.7% of the total area of Iran. Lorestan province is located between 32 degrees and 37 minutes to 34 degrees and 22 minutes north latitude and 46 degrees and 51 minutes to 50 degrees and 3 minutes east longitude. Lorestan province is bordered by Markazi and Hamadan provinces from the north, Khuzestan province from the south, Isfahan province from the east, and Kermanshah and Ilam provinces from the west. Figure 1 shows the location of Lorestan Province in Iran (Climatic Atlas of Lorestan Province, 2016).

2.2. Studied Data

The data used to conduct this research includes field data, satellite data, and meteorological station data. Therefore, at first, by referring to the Meteorological Organization of Iran, the daily data of temperature, precipitation, and evapotranspiration of the synoptic stations of Lorestan province and its neighboring provinces were received from the beginning of its establishment until 2017. Among the synoptic stations of Lorestan province, Khorramabad, Aliguderz, Kohdasht, and Borujerd stations have a statistical period of 30 years or more, and other stations in the province have a statistical period of less than 30 years and in some cases less than 20 years.

Considering the nature of the research and the importance of the length of the statistical period in climate studies, after controlling the length of the statistical period of the stations, the same period of 30 years (1988-2017) was selected.

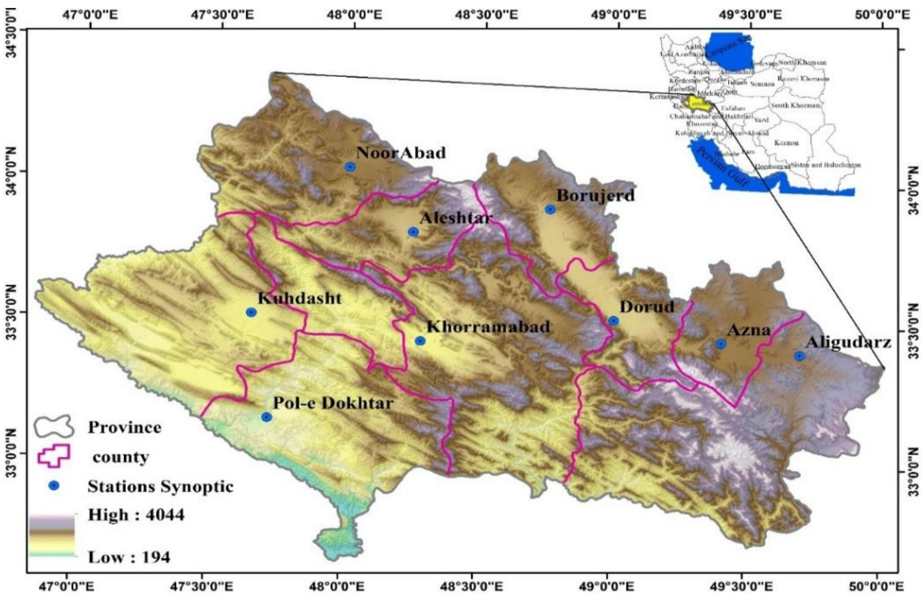

Fig. 1. The location of Lorestan province in Iran

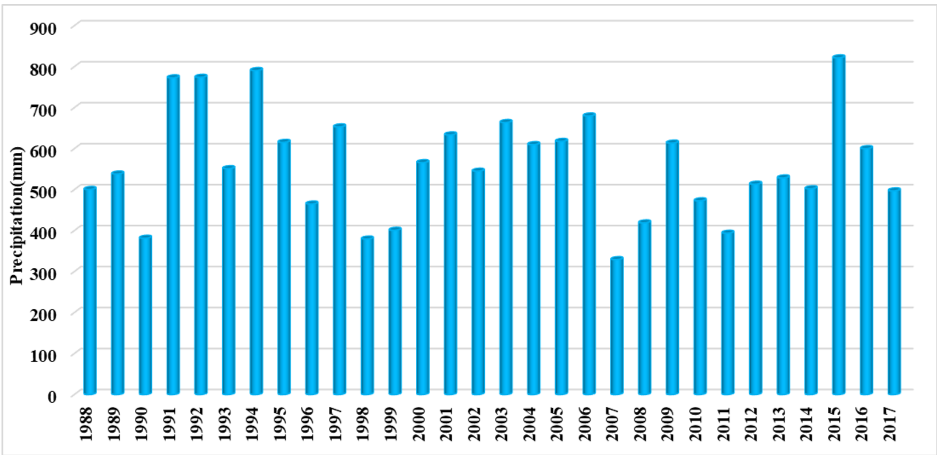

Fig. 2. The mean annual rainfall of Lorestan province during the period of 1988-2017

It is worth mentioning that during this same period, some of the synoptic stations of the province did not have a suitable statistical period, therefore, by using the normal ratio method and considering the stations around Lorestan province and Dez basin, data reconstruction was done. After reconstructing of studied data from 1988 to 2017 for the station of Lorestan province, 9 synoptic stations were selected as the best stations to calculate the meteorological drought (Fig. 1).

The data processing of the studied data in the province showed that during the 30 years, the mean annual rainfall of the province was 561 mm, the maximum rainfall was 821.64 mm and the minimum was 329 mm, the standard deviation of the province's rainfall is 129.6 mm. In terms of time during the period, the amount of annual rainfall does not follow any particular order and the years with minimum and maximum rainfall are scattered during the period. The highest annual rainfall of the province was recorded with 821.64 mm in 2015 and the minimum was recorded in 2007 with 329.37 mm.

The characteristics of irrigated and rainfed agriculture in Lorestan province were prepared by the Planning and Program Unit of Lorestan Ministry of Agriculture Jihad, including type of crop, cultivation season, the area under cultivation of irrigated-rainfed lands, and the amount of production (in tons per hectare) at the village level. The 16-day MODIS product was used to calculate vegetation indices. The NDVI and LST indices were obtained from 2000 to 2017 from the NASA website (https://ladsweb.modaps.eosdis.nasa.gov/search/locate) in the 16-day interval of NASA's Terra satellite. This product provides a temporal and spatial comparison of global vegetation conditions and was used for monitoring. The data of this index is 16-day and the spatial resolution is 250 meters. To analyze the drought of rainfed lands in the period of June and July and for pasture lands, the period of April to September was considered. The time series was formed in the mentioned intervals. The land use map of Lorestan province was prepared based on satellite images and field information obtained from interviews with experts and farmers of the province to determine the pasture and cropland covers (Figure 3). As shown in figure 3, five main classes of pastures (good, medium, and poor), forest (dense, medium density, and low density), agriculture (rainfed and irrigated), and residential and irrigated areas have been identified in this map.

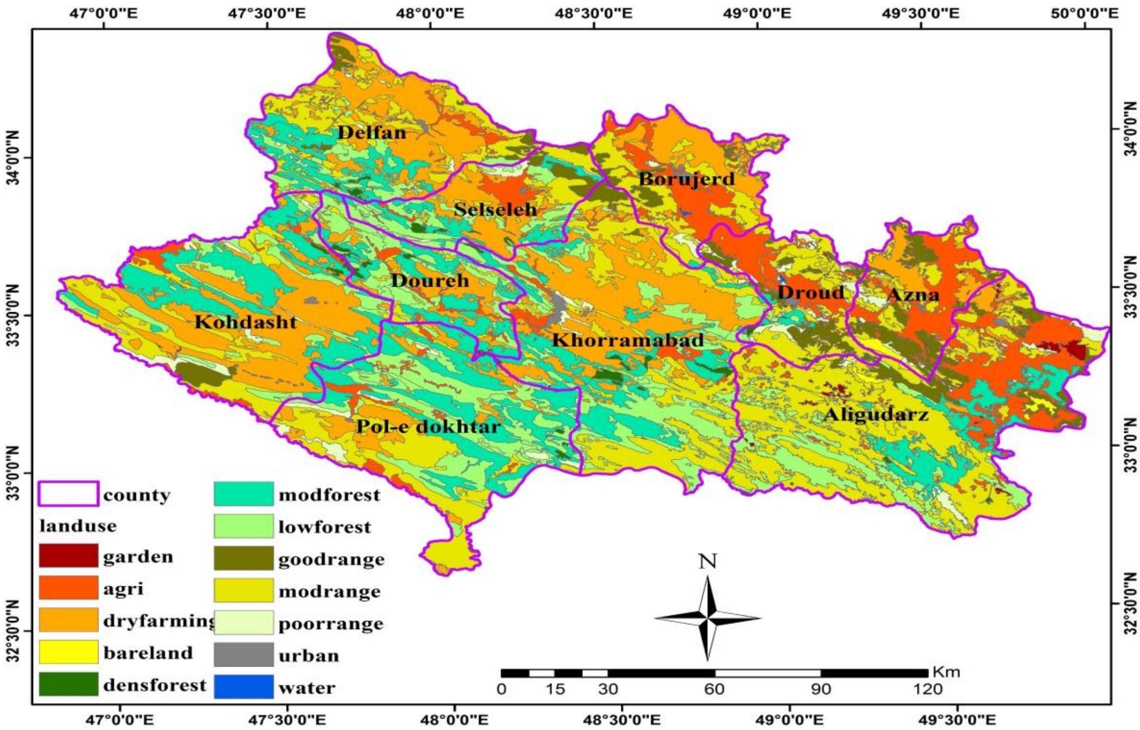

Fig. 3. Land use of Lorestan province, Iran, and its cities

2.3. Methodology

A combination of field, statistical, and remote sensing methods has been used to conduct the present research. At first, using field studies and interviews with local natives, as well as based on economic and social conditions, the status of water resources, and technical knowledge of farmers in the province, homogeneous areas were determined to save economic and time costs. After determining the homogeneous units, an interview card was prepared to know the irrigation conditions of the fields, the duration of irrigation, the type of water source feeding the fields, etc. After conducting library and field studies, the drought conditions of the studied province were calculated using SMI, SPI, SPEI, and RDI indices, based on the data of the synoptic station of Lorestan province and neighboring provinces from 1990 to 2017, and spatial and temporal changes occurred using their results. Drought was investigated in the time scales of 3, 6, 9, 12, 18, and 24 months at the province level. After calculating the named drought indices, at first all the used data were normalized between zero and one so that the value of one represents the maximum value of each index and zero is the minimum value of each index. In the following, the normalized values of the indices were produced using the PCA method, and the hybrid drought index was produced in the MATLAB software environment. To investigate the photosynthetic activity of plants and to detect the changes and biophysical interpretation of the main agricultural products of Lorestan province, the time series of images and the monthly MODIS-NDVI product (MODIS-13) of the Terra satellite during the period from 2000 to 2017 from the NASA website (https://ladsweb .modaps.eosdis.nasa.gov) was obtained and in the GIS environment, the basic information including the amount of cloudiness and the geometric characteristics of the image were examined and the problematic images were removed. Using the obtained images, vegetation indices NDVI, LST, VCI, TCI, and VHI were prepared for the entire Lorestan province. To use vegetation indices to investigate spatial and temporal changes of rainfed lands under the influence of drought, using single and multiple linear regression, a relationship was established between different indices of vegetation with SPI, and a linear equation was produced.

To calculate the SPI index, the non-parametric method of fitting the probability density function has been used. This method can be used in different climates and for different parameters. In calculating the SPI index, the probability density function or frequency is defined as below.

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (1)$$

$for: x > 0$

where α > 0 is the shape parameter, β > 0 is the scale parameter, x > 0 is the rainfall value, and Γ(α) is the gamma function (Andreadis et al., 2005).

The SPEI index was calculated based on the balance of climatic water resources, i.e. the difference between precipitation and evapotranspiration:

$$D = P - PET \quad (2)$$

where D is the balance of P and PET (precipitation and potential evapotranspiration respectively in millimeters). PET is usually calculated by Thornthwaite's method (Thornthwaite, 1948), which only requires monthly temperature data as well as geographic location. The NDVI index is obtained through the following equation:

DVI= (PNIR-PRED)/ (PNIR +PRED) (3)

where PNIR is a spectral reflection in the near-infrared and PRED is a spectral reflection in the visible part of the electromagnetic spectrum.

The Vegetation Condition Index (VCI), which is designed to remove the effect of climate and topography differences from the results of the NDVI index, is defined based on equation 4 below:

$$VCI_{ijk} = \frac{NDVI_{ijk} - NDVI_{i.min}}{NDVI_{i.max} - NDVI_{i.min}} \quad (4)$$

where $NDVI_{min}$ an $NDVI_{max}$ are calculated at monthly scale for a long-term period, the index j represents the desired month, i is the pixel number, and k is the desired month.

2.4. Temperature Condition Index (TCI)

The TCI index was also introduced by Kogan (1995), whose calculation algorithm is the same as the VCI index. In this index, it is assumed that the phenomenon of drought will reduce soil moisture and create thermal stress on the surface of the earth, which results in an increase in air temperature in dry years compared to normal years. This index is calculated based on equation 5:

$$\mathbf{TCI} = \frac{\boldsymbol{T_{max}} - \boldsymbol{T_i}}{\boldsymbol{T_{max}} - \boldsymbol{T_{min}}} \quad (5)$$

where T_{max} is the maximum temperature corresponding to any point or pixel in the study period, T_{min} is the minimum temperature corresponding to each point or pixel in the studied period, and T_i is the temperature value corresponding to each point or pixel at the studied period

2.5. Vegetation Health Index (VHI)

The vegetation health index was presented by Kogan (1995). This index is calculated based on Eq. 6 from the combination of Vegetation Condition Index and Temperature Condition Index. This index has a quasi-realistic approach to agricultural drought assessment. VCI and TCI indicators are fully described in the previous section.

$$VHI = 0.5 \times VCI + 0.5 \times TCI \qquad (6)$$

Considering that the contribution of humidity and temperature in the plant cycle is usually uncertain, the contribution of VCI and TCI indices in the VHI index is considered equal. Research shows that in high-latitude humid regions where vegetation is limited due to low air temperatures, this index should be used with caution. To investigate the effect of spatial and temporal changes in soil moisture on droughts in the study area, the standardized soil moisture index (SMI) based on GLDAS soil moisture data was used. The calculation and classification of drought in this index is the same as the SPI index, with the difference that soil moisture values are used instead of cumulative precipitation values.

3. Results and Discussion

In the matter of evaluating the impact of drought on rainfed agriculture, the results include three parts, the first part is the result of the evaluation of rainfall data with ground and station observations. In this regard, the calculated values of the SPI meteorological drought index were examined and the risk of drought was calculated. In the second part, the results of the calculation of vegetation indices NDVI, LST, VCI, TCI, and VHI were examined. In the end, the relationship between the meteorological drought index and the vegetation drought index was investigated. Multiple regression relations between the SPI index and TCI, VCI, and VHI indices were calculated and the correlation coefficient and p-value were obtained for each relationship with a significance level of 5%. The obtained results are shown in Table 1. As seen in Table 1, in all three regression relationships, because the p-value is less than 0.05, it indicates that the regression model was appropriate and the SPI variable can significantly predict the changes of TCI, VCI, and VHI variables and TCI, VCI, and VHI variables are influence.

Table 1. Multiple regression equations between SPI and vegetation indices TCI, VCI and VHI

vegetation indices	regression equations	R	p-value
June TCI	- 17.18 SPI (April) - 18.5 SPI (November) + 82.47 SPI (November) - 230 SPI (December) + 201 SPI (February) + 23.21 SPI (March) + 42.57	0.77	$1.74e^{-32}$
June VCI	1.4SPI (April) + 0.46SPI (May) - 0.63SPI (June) + 0.09SPI (October) - 0.27SPI (November) - 1.15SPI (November) + 0.87	0.70	$2.13e^{-27}$
May VHI	- 53.9 SPI (April) - 33.6 SPI (May) + 114 SPI (June) - 2 SPI (October) + 4.95 SPI (November) + 0.42 SPI (November) + 51.87	0.80	$1.43e^{-42}$

The relationship between the yield of irrigated crops and drought in the long term: Considering that there was no clear relationship between the yield of irrigated crops with drought and wet conditions prevailing in the studied region based on the statistics published by the Ministry of Agriculture Jahad in studied providence, in this part the relationship between the amount The performance of irrigated crops was investigated with the values of drought indices in different cities of Lorestan province. Figure (3) shows the correlation between wheat and barley yields in Lorestan province with various drought indicators used in this research. Indices such as NDVI, Standardized NDVI or SNDVI, SPI, RDI, SPEI, SMI1 (at a depth of 0 to 10 cm), SMI2 (at a depth of 10 to 40 cm), SMI3 (at a depth of 40 to 100 cm), SMI4 (at a depth of 100 to 200 cm) that all these indices are in time series of 1, 3, 6, 9, 12, 18, 24 months, VCI, TCI and VHI index and finally the hybrid drought index based on PCA which this series is also in time scales of 1, 3, 6, 9, 12, 18, 24 months. The red dashed lines that appear horizontally on the chart show the range of each indicator. Since some indicators have different time scales (such as SPI), they have also assigned a larger range.vIn the range of indicators with a time scale, the column charts belong to the time series of 1, 3, 6, 9, 12, 18, and 24 months, respectively. Within the polygon of each city and in each water year, the average drought indices were adapted and then correlated with the yield of rainfed wheat and barley in the cities. Figure (4) shows the relationship between various drought indicators with the yield of wheat and barley. As shown in the figure, there is a direct relationship between the yield of wheat and barley crops with different drought indicators. That is, with an increase in the amount of precipitation and soil moisture, the yield also increases, and with a decrease in the amount of precipitation and soil moisture, the yield of barley and wheat plants decreases. Among the examined indices, the PCA index has a higher correlation with wheat yield, which decreases with the increase of the time scale.

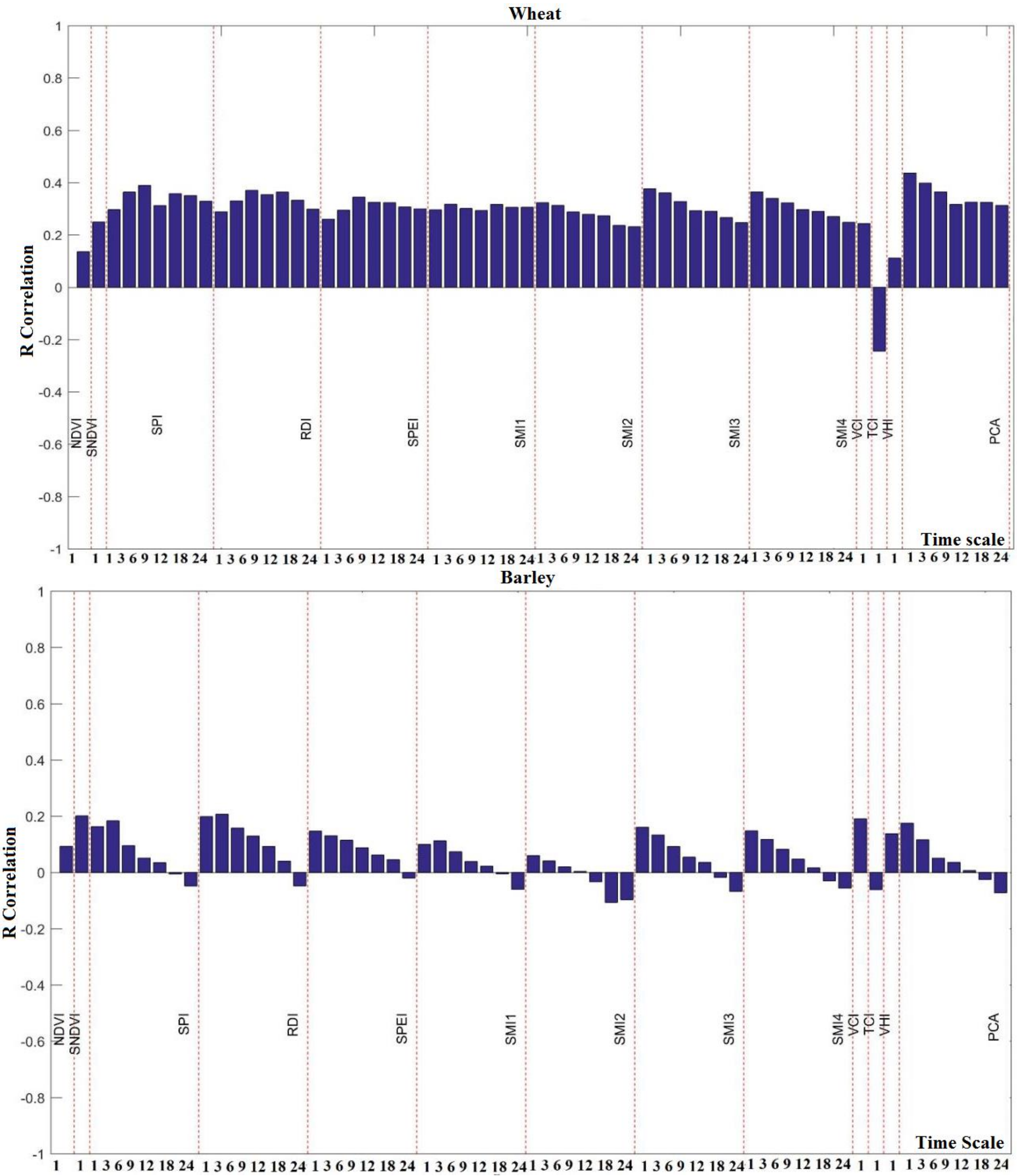

Fig. 4. Correlation index (R) of drought indices with wheat and barley yield in Lorestan province

The results of the investigation of the relationship between meteorological drought index and vegetation indices can be summarized as follows:

a: According to the results of SPI meteorological drought index calculation, dry, normal, and wet years were obtained for Lorestan province in 2008, 2013, and 2016 respectively.

b: In examining the relationship between the drought risk index and topographic and meteorological variables (altitude and mean values of rainfall), it was found that the risk of drought has an inverse relationship with these variables, and as the height of the land increases, the risk of drought decreases.

c: The results of examining the relationship between the meteorological drought index and TCI index showed that in 2008, the highest Pearson correlation coefficient was for SPI with a 9 and 12-month time scale, and the value of this correlation was much higher for SPIs in October and November than in other months. It could mean that if the amount of rainfall is suitable in October and November, the growth of rainfed crops in spring will be very good, and also the lack of rain in October and November of the previous year will cause a decrease or lack of growth of crops in the spring. The results of examining the relationship between SPI and VCI showed that the highest correlation coefficient of VCI is for SPI with a 9-month time scale and related to November. Also, the results of multiple regression between these two indicators showed that the correlation coefficient between 9 and 12 months of SPI is higher than other time scales of SPI and like the results of TCI. These results show that the lack of rainfall in November of the provirus year, can affect the reduction of rainfed crops.

d: The results of examining the relationship between VHI and SPI showed that, like the two indices of VCI and TCI, the highest correlation coefficient is related to SPI in October and November, and the multiple regression between SPI in the months (April, May, June, October, November, and December) showed the highest correlation coefficients with VHI for 9 and 12 months of SPI time scale. These results mean that if there is a drought and a lack of rainfall in October and November, then we will face a decrease in crops, and the vegetation will be more affected by the rainfall of the previous 9 and 12 months.

e: Based on the obtained results, Vegetation indices TCI, VCI, and VHI were investigated in May and June (June in the colder regions of the studied province due to the later growth of vegetation and other areas in May). Because the main growth of the product is in these two months, and if the product faces a decrease and lack of growth, it will be determined in these two months, and checking these two months is more important than other months. The regression relationships were investigated and all three relationships resulting from the regression of TCI, VCI, and VHI with SPI were found to have a significance level of less than 0.05, which indicates the appropriateness of the regression model and the variables of SPI in different months have been able to predict the changes of TCI, VCI and VHI variables and influence them significantly.

In the literature review, there was often a good correlation between vegetation indicators and vegetation drought indicators with meteorological drought. Damavandi et al. (2010) found a good relationship between VHI and meteorological drought indicators. Quiring et al. (2010) found a significant relationship between SPI at 6- and 9-month with VCI. Dutta et al. (2015) also found a good relationship between VCI and SPI in India. Also, in the second half of the growing season, Rimkus et al. (2017) evaluated the relationship between VCI and SPI as positive, which indicates the relationship between the two types of drought, vegetation, and meteorological, and the results of this research also prove this. In the study conducted by Liu et al. (2020), the relationship between the meteorological drought index and vegetation indices for nine months obtained higher correlation coefficients, which are close to the results of the current research. Malaksabet et al. (2015) found a relatively good correlation between SPI and VCI index (0.6-0.5), and also the research results of Zambrano et al. (2016) and Mirahsani et al. (2018) also showed a good correlation between SPI and VCI, which is close to the results of the current research.

4. Conclusion

Water shortage and drought are one of the biggest challenges that Iran's agricultural development will face now and in the future. Estimates of food needs show that if a suitable strategy for water management and preparation to reduce the effects of drought is not adopted in the agricultural sector, the water and land potentials of the country will not provide the food needs of Iran. The calculation and analysis of drought indicators in order to monitor the drought conditions of Lorestan province, Iran from 1991 to 2017 showed that the increasing trend of drought and the repetition of long-term cycles of drought and wet years are evident in Lorestan province. Based on the results of SPEI and RDI drought indices, which include potential evapotranspiration in their calculations, three cycles of drought and wet years are observed during the studied period. The first cycle is before 2001, which ends in a significant drought around 2001. In the next step, this cycle peaked again and ended in a significant depression in 2007. Although this period of wet year is less intense than the previous wet year that happened in 1994. The occurrence of long-term droughts during the years 2008 to 2015 is evident, and we witnessed the creation of drought again in 2017. The decrease in the severity of droughts and the increase in the duration of droughts and their severity can indicate climate changes in recent years. The results of examining the relationship between the performance of rainfed and irrigated plants with various drought indicators in Lorestan province, Iran from 1991 to 2017 showed that the correlation between the yield of rainfed plants and higher values of drought indices is positive, although the correlation index is different in different time scales. The positive correlation values between the yields of rainfed plants with different drought indicators indicate the direct relationship and influence of the yield of rainfed plants on the amount of precipitation and moisture in the soil, which increases with the increase of precipitation and soil moisture and decreases with the decrease of precipitation and moisture in the soil. About the mentioned issues, the solutions to face the agricultural drought in Lorestan province can be stated as follows:

According to available official informations, the average yield of rainfed cereals in the studied province is about one to one and a half tons per hectare. Therefore, by applying scientific methods and developing knowledge-based agriculture, it is possible to increase the average grain yield in drylands by at least five hundred kilograms. With the same current resources, by maintaining the level of grain production in the province, up to 30% of the land devoted to grain cultivation can be freed and devoted to the cultivation of fodder plants or legumes. Improving the cultivation pattern in the studied province and using projects such as planting one-year fodder plants such as various species of vicia sativa, lathyrus, and medicago in the crop rotation of 130,000 hectares of rainfed grain cultivation (ley-farming) can increase the capacity and help the production of fodder in the dry lands of the province. According to available official statistics, the average yield of rainfed cereals in the province is about one to one and a half tons per hectare. Therefore, by applying scientific methods and developing knowledge-based agriculture, it is possible to increase the average grain yield in drylands by at least five hundred kilograms. With the same current resources, by maintaining the level of grain production in the province, up to 30% of the land devoted to grain cultivation can be freed and devoted to the cultivation of fodder plants or legumes. Another point that should be noted is that from the conditions of increasing soil moisture and reducing droughts in recent years (wet years in general), it should be done in the direction of issues such as supplying and feeding groundwater, producing agricultural products, establishing tree seedlings or plants in the fields of natural resources. Also, the lack of soil moisture, like what happened after 2009, may happen again, and in such a case, the implementation of structural operations of natural resources compared to biological operations, as well as smartening and establishing new irrigation systems and increasing water productivity is preferred. The results of questionnaires as well as interviews conducted with farmers and experts in the region show that most of the questioned farmers as well as other farmers believe that the main solution to reduce drought damage is possible by using new methods of irrigation and planting drought-resistant crops. Other solutions proposed by the participating farmers and other farmers in the region to reduce drought damage are timely planting of crops (correction and revision of the crop calendar of various crops) and water supply. In general, drought is an undeniable fact that has affected all aspects of human life. Therefore, to intelligently face and adapt to such a serious threat, a national, comprehensive, and interactive determination between all stakeholders and agents is necessary.

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