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Meteorological Drought Monitoring Using the Multivariate Index of SPEI (Case Study: Karun Basin)

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ABSTRACT: Considering the importance of drought in water resources management, the present study was conducted with the aim of drought monitoring using drought index SPEI due to its multi-scale nature and the ability to analyze at different time scales in selected meteorological stations in the Karun drainage basin. Another purpose of this research is to regionalize the SPEI index using cluster analysis method in order to homogenize the hydrologic basin. In this regard, 18 stations were selected based on the data homogeneity test and the determination of the length of the common statistical period. The SPEI drought index values were plotted in the form of sequencing graphs and their relationship with the correlation analysis was tested. The results showed that there is a positive and significant correlation of this index for all stations (0.5 to 0.95). Also, the frequency of dry and wet periods decreases by increasing the time scale, but their continuity increases. With the regionalization of the basin stations by cluster analysis, the stations were classified into 7 classes. The results of regionalization of the SPEI index also showed that the frequency percentage of the normal class is higher than the wet and dry classes.

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1- Introduction

Drought, as a natural disaster and inevitable phenomena, has often occurred in the vast area of many countries, especially in the warm and dry regions of the world. Studies show that 80 percent of the Iran has suffered from unprecedented drought between 1998 and 2001 and, the central, northern and northwestern parts of Iran have experienced up to 95% of drought [1]. The precipitation status, the limitation of water resources and climatic conditions in the country show the fact that, planning should be considered for the drought and the effects and consequences should not be dealt passively. It is undeniable that in the event of inefficient technical management and the use of inappropriate strategies, in addition to the loss of available resources and the exacerbation of the damaging effects of drought, the ground for the emergence of subsequent droughts is increasingly provided.

Rabets et al. [2] stated that the droughts of the summer of 2003 in the central parts of Europe were due to precipitation less than normal limit. However, the sharp increase in temperature (4 °C above the long-term average during June and July) caused an increase in losses in agricultural, natural resource sectors and significantly increased the evapotranspiration rate and water stresses. Precipitation and evapotranspiration are two basic parameters for meteorological drought monitoring. Hence, indicators that consider evapotranspiration in addition to precipitation have also capability of monitoring the climate change of current and future periods based on climate scenarios. Various precipitation and evapotranspiration parameters are used for drought monitoring that, the Palmer Drought Severity PSDI, the Reconnaissance Drought Index and the Standardized Precipitation Evapotranspiration Index are among them.

Sarano et al. [3] argued that Palmer's index, while having important benefits, has a weakness due to the fact that it cannot provide the short-term and long-term effects of drought through monitoring at different time scales. They also stated about the relatively new RDI index that, the ratio of precipitation to evapotranspiration in this index will not be defined when the amount of evapotranspiration equal to zero (in winter months in different parts of the world) and the range of applied ratios is considerably small, which cannot reflect the role of temperature.

While the SPEI index (Standardized Precipitation Evapotranspiration Index) has a higher utilization rate than other indicators and its main advantage is the ability to detect the effect of changes in evapotranspiration and temperature in relation to global warming. However, the quality of a drought index result can only be as good as the input data [4, 5]. Also Ability to incorporate both temperature and precipitation, SPEI may be a useful indicator of drought [6]. This is illustrated by Sarano et al. [7] using data from 11 regions located in different climatic regions of the world. Unlike the SPI, the SPEI index is able to show the main effects of temperature rise on water demand. The time scales of this index are like SPI up to 48 months. The SPI multiple numerical scales and

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its combination with the evapotranspiration parameter SPEI are also suitable for climate change studies. Tirivarombo et al. [8] used SPEI and SPI index to drought monitoring in Kafue Basin located in northern Zambia, where most of the socioeconomic livelihoods are dependent on water. They indicated that by comparing time series plots (1960-2015) of the two indices, both indices were able to pick up temporal variation of droughts.

The SPEI indicator is more powerful and efficient than other indicators due to the inclusion of water balance for determining drought and its control [9]. Livia et al. [10] compared SPEI and SPI (Standardized Precipitation Index) drought indices using COSMO model data in two basins of Slovakia. The results showed a low correlation between SPEI and SPI indices in the south of Slovakia at the three-month time scale. They also emphasized the important role of evapotranspiration and drought stress in the studied area in the summer.

Thousmouth and Mensel [11] also analyzed the current and future drought conditions in Jordan and concluded that the six-month SPEI drought index had the highest relationship with soil moisture content and is the best indicator for explaining the annual variation of the Normalized Difference Vegetation Index (NDVI). Stag et al. [12] also compared the frequency distribution of SPEI and SPI drought indices in Europe. They identified the two-parameter gamma distributions and the general limit values for SPEI and SPI indicators, respectively. Considering the effect of temperature on the SPEI calculation, there is a significant difference between the values of the standard precipitation based index and the temperature-based evapotranspiration index, the efficiency and accuracy of the above indicator. Also Labudova et al. [10] compared the SPI and the SPEI using COSMO model data in two selected Slovakian river basins.

Considering the importance of evapotranspiration in water balance in arid and semiarid regions, standardized precipitation-evapotranspiration index can be used as an appropriate indicator in drought studies. Although more studies are needed at the time and space scales. By reviewing research data on drought analysis using various indicators, limited research has been made on the use of the SPEI index despite numerous records in the use of the SPI index, considering its newness in the world and in Iran, so far this index has not been considered seriously in the study and analysis of meteorological droughts. Accordingly and based on the importance of drought in water resource planning and management, the objectives of this research are:

Determination of SPEI drought index, 2) Assessment of the trend of changes of droughts in different parts of the basin and 3) Determination of homogeneous stations in terms of meteorological and agricultural drought indicators (regionalization of the SPEI index) by cluster analysis.

2- Material and methods

The Karun basin with a total area of 67297 square kilometers is one of the most important basins of the country in terms of water resources and the frequency of atmospheric precipitation, especially in the streams of this basin, has created a significant potential for surface water and groundwater resources. The Karun basin includes about 34% of the study area and 4.2% of the total area of the country (Figure 1). The Great Karun Basin consists of the Dez and Karun rivers located inside the middle Zagros Mountains and the geographical range is between 48° and 30‘, and 52° east longitude and 30° to 5’ 34° north latitude. About 67% of the basin area is mountainous and 33% is plain. The data required in this study, include daily precipitation, minimum temperature, maximum temperature, relative humidity, sunshine time and wind time, obtained from the Water Resources Management Company. After initial data analysis due to existing deficiencies and uncertainty about the accuracy of the data of some existing stations, based on the data homogeneity test, 18 stations with a statistical length of more than 30 years were selected. After determining the length of the common statistical period for the stations concerned, using different methods such as prediction and correlation between stations, restoration of statistical defects is performed.

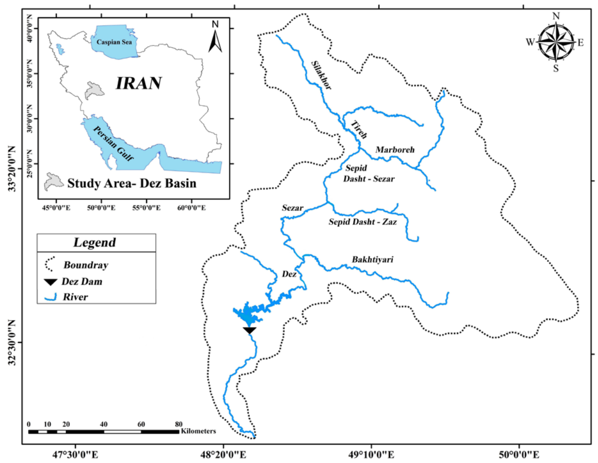

Figure 1. Location of the Karun basin in Iran

2- 1- Drought Index

Over the past decades, researchers have developed various indicators to monitor the drought situation and examine the quantitative effects that it has caused. In this study, SPEI drought index was used to monitor moisture periods. The effects of increasing the temperature in an increase in the drying rate of an area is far more than reducing precipitation. Accordingly, precipitation-evapotranspiration and standardized drought index can be used as an appropriate index for determining drought [7]. Three variables of precipitation, temperature and evapotranspiration potential are considered in this index. One of the limitations of the SPI index is the lack of considering water balance based on evapotranspiration. While the SPEI index considers the water balance in calculating the drought index, based on precipitation and potential evapotranspiration. In contrast to SPI, the SPEI index is able to show the main effects of temperature rise on water demand. The time scale of this index is similar to that of SPI and the classification of drought status is similar to the SPI index using Table 1. The SPI multiple numerical scales and its combination with the evapotranspiration parameter are also suitable for SPEI for climate change studies. The method for calculating the SPEI index is the same as the SPI index, but the difference of precipitation and potential evapotranspiration (PET) in the SPEI index is used. This is in fact a reflection of the climate balance of the water balance which is considered in the SPEI Index. Based on the results of Moorwitz [13], based on the similarity of simple and complex methods for potential evapotranspiration, Serano et al. [3] used the Torrent White method for this purpose. The SPEI index is derived from relationships 1 through 7.

$$PET = 16K\left(\frac{10T}{I}\right)^{m} \tag{1}$$

$$m = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} \tag{2}$$

$$i = \left(\frac{T}{5}\right)^{1.514} \qquad K = \left(\frac{N}{12}\right)\left(\frac{NDM}{30}\right) \tag{3}$$

Where, T is the average monthly temperature in degrees Celsius, m is the coefficient of dependence on I, I of the heat index or the sum of the 12-month index i, K is the correction factor in terms of the geographical month and latitude, NDM is the number of days in a month and N is the maximum number of hours of radiation. Thus, having potential evapotranspiration, the difference in precipitation (P) and (PET) for the i^{th} month is obtained.

$$D_i = P_i - PET_i \tag{4}$$

Based on the results obtained by Sarano et al. [7] it has been found that, logistic distribution with better efficiency in determining the probability density function or pdf of time series D, based on the logarithmic logistic distribution, has been calculated according to the following equation, due to its proportionality with the data with skewness and the longer sequence in the end domain of distribution.

$$f(x)=\beta/\alpha+((X-\gamma)/\alpha)^{\beta-1}\,[(1+((X-\gamma)/\alpha)\beta)]^{-2} \tag{5}$$

Where, α, β and γ are the scale, shape, and principal parameters for the values of D in the domain $\infty >$ D$< \gamma$ [7]. The probability weighted moment method has been used as a powerful and simple method in order to calculate the logarithmic logistic distribution parameters. The distribution function of the D series is also obtained according to the following equation.

$$F(x) = \left[1+\left(\frac{a}{X-\gamma}\right)^{\beta}\right]^{-1} \tag{6}$$

The SPEI index as the standardized values (F(x)) is calculated in this way.

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{7}$$

Where $w = \sqrt{(-2\ln(P))}$ for $P \le 0.5$ and P is the probability of higher values of D set. The values $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$ are specified. The SPEI index is a standard variable and therefore can be compared with other SPEI values in position and time. The SPEI value of zero equals the values of 50% of the cumulative probability D. Since the SPEI index is based on the development concepts of the SPI index, positive values of SPEI indicate that the water balance is positive and its negative values indicate a negative water balance and indicates the period of drought. In fact, the drought begins when the index values reach -1 and end with the positive.

Table 1. Different classes of drought severity based on the SPEI index [4]

Drought and wet degree	Index values
Very severe wet	Index ≥ 2
Severe wet	1.5 ≤ Index < 2
Moderate wet	1 ≤ Index < 1.5
Close to normal	-0.99 ≤ Index ≤ 0.99
Moderate drought	-1.5 < Index ≤ 1
Severe drought	-2 < Index ≤ -1.5
Very severe drought	Index ≤ -2

2- 2- Determination of homogeneous regions in terms of drought Index

Cluster analysis is used in this research in order to determine the homogeneous regions in terms of drought indicators. Thus, homogeneous stations created by each group of agricultural and meteorological indicators are determined by cluster analysis method and then examined. Overall, in general, homogeneity of stations is examined by cluster analysis and the stations examined in the Euclidean space differentiate the ecological parameters.

In order to determine homogeneous stations in terms of meteorological and agricultural drought indicators (SPEI regionalization), SPEI drought index is located in separate groups in the mentioned scales. Then, cluster analysis is performed using hierarchical methods such as ward method and SPSS software. Finally, comparing these indices makes it possible to determine the hydrological homogeneous regions in terms of drought effectively. Separation of the study area into homogeneous regions increases the accuracy and reduces errors in regression models in non-statistical areas.

3- Results and discussion

3- 1- Investigation of the variation trend

The results of calculating the SPEI index for each station resulted in the zoning map of the Karun basin for representation of drought in the region. Also, the charts of the variation of each indicator can be seen at a specific time interval at each station. The SPEI index for selected stations was calculated separately for different months and only the results of some stations have been presented due to the similarity of the survey and validation of the indicators. Figures 2 to 7 show the evaluation of SPEI index for the time scale of 3 (short term), 9 (medium term) and 24 (long term) months for the Hana and Arabhasanabad stations. The reason for choosing the two stations is different geographic location and comparison of the two stations in the type of drought forecast. At the Hana station, according to Figures 2-4 (SPEI index fluctuations in 3, 9, and 24-month periods), it is found that in the 3-month period, alternative drought and wet periods have been observed. 11 drought periods have occurred during the 9-month period of the SPEI index, its most severe period is in October 2008 and its longest period is from 2007 to 2008. In the 24-month period of the SPEI index, there were 3 drought periods that, the longest of them was from February to December 2010, and the most severe was in September 2008.

At Arab Hassanabad Station, according to Figures 4 to 6, it is known that in the 3-month period, like the Hana station, drought and wet periods have been alternating at this station. Nine drought periods have been observed in the 9-month period of the SPEI index, its most severe period is associated with October 2008 and its longest period is from November 2007 to November 2008. There were 3 drought periods in the 24-month period of the SPEI index that, the longest in May 2007 to September 2011 and the most severe in December 2010. It should be noted that the results of calculations in the 10 selected stations of 18 stations (stations with more than 30 years of statistics) showed that, Hana, Sulgan, Susan, Tang-e-Bakhtiari and Dez Dam stations have close estimates of severe drought occurrences by the SPEI index and provide a similar drought trend. But at the stations of Arabhassanabad, Avangaran, Rum Plain, Kazemabad and Lali Band sorkhi, there was no high agreement on the prediction of severe drought events by the index. Although a similar trend has been observed in drought and wet occurrences by the aforementioned.

The frequency of dry and wet periods in the short term scales is high. Increasing the time scale of dry and wet period frequency decreases, but their continuity increases. Results of the 24-month SPEI index at 10 stations indicated that, at most stations, the longest droughts have been recorded during the period from 1986 to 2011 and this situation has been repeated more or less at most stations in the years 2011-2013. Although the highest drought intensity based on this index has been different for different years in different stations of Karun basin, it does not follow a specific pattern. The most severe drought occurrences were observed in the 10 stations of Arab-Hasanabad-2010, Avargan-2012, Dasht-e-rum-2000, Hana-2008, Kazemabad-2010, Lali Band sorkhi-2008, Dez dam-2008, Sulgan-2008, Susan-1998, and Tang-e-panj-Bakhtiari-2011. It should be noted that the severity of drought calculated using the SPEI index is rarely lower than the numerical value of 2. The reason for this is the factorial of temperature in determining the drought in this index. In other words, in addition to precipitation, the temperature increase also has a high effect in the study area.

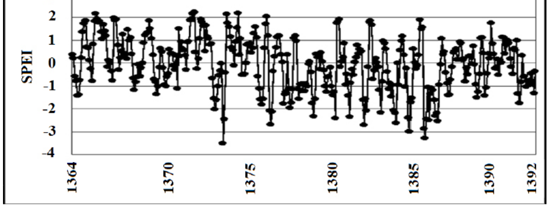

Figure 2. Changes in the SPEI Index at Hana Station

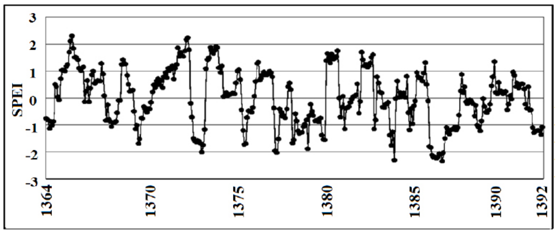

Figure 3. Nine-month SPEI index changes at the Hana station

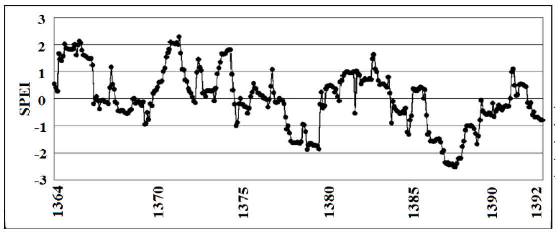

Figure 4. 24-month SPEI index changes at the Hana station

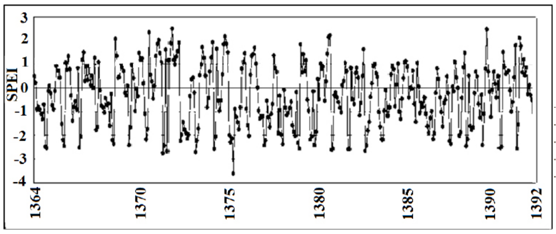

Figure 5. SPEI Index changes at Arbhassanabad Station

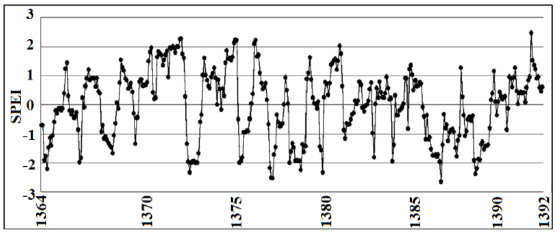

Figure 6. Nine-month SPEI index changes at the Arab Hasanabad Station

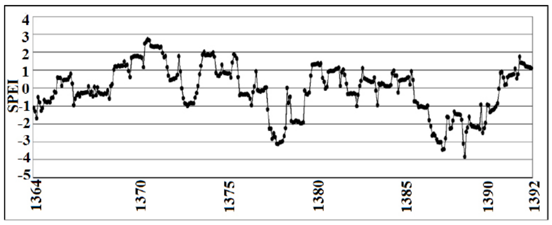

Figure 7. 24-month SPEI index changes at the Arab Hasanabad Station

The highest total number of drought events, especially severe/very severe droughts, has been identified by the SPEI index, which indicates the effective contribution of evapotranspiration to drought monitoring. Also, Figure 8 shows the graphs for comparing the SPEI index in time scales of 6 (short term), 12 (medium term) and 24 (long term) months for Susan station. The results show that the frequency of dry and wet periods is high in short-term time scales. Increasing the time scale, the frequency of dry and wet periods decreases, but their continuity increases.

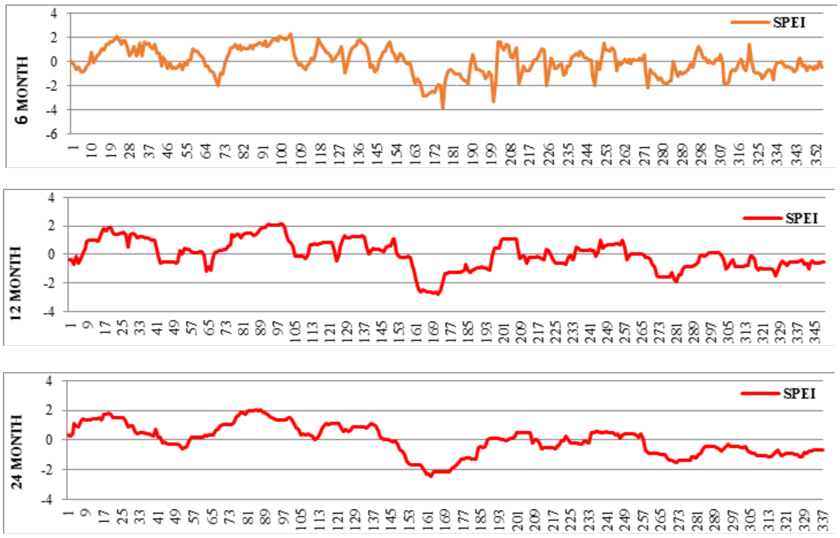

Figure 8. SPEI index values for time scales of 6, 12 and 24 months at Susan station

The results of this study on the effectiveness of the SPEI index have consistency with other studies. Using two SPI and SPEI drought indicators in studying the effects of warming on droughts and water resources in Spain, the results showed that, precipitation and potential evapotranspiration increased from 1930 to 2006 and the results of the two drought indicators were similar [7]. Although precipitation plays a special role in drought timing, but the effect of temperature is significant and it exacerbates the drought phenomenon and ultimately leads to a sharp decline in water resources and this explains the relationship between meteorological and hydrological droughts. Considering the combined effects of precipitation and evapotranspiration, the SPEI drought index has a high potential for displaying changes in water resources compared to other drought indicators.

3- 2- Regionalization of the SPEI index and the determination of homogeneous stations

The hierarchical clustering method was used to determine the homogeneous stations for different drought indicators. For this purpose, SPEI index was calculated on a monthly basis and its results were used for clustering. According to the dendrogram diagram of Figure 9, the rain gage and synoptic stations of the Karun basin have been classified in seven classes. Gotvand and Kazemabad stations have been considered in class 1, stations of Rum plain, Yasuj, Patavah, Hana, Avangaran, Sulgan in Class II, Barangard, Izeh, Beheshtabad, Laliband Sorkhi, Dez Dam and Tang-e Bakhtiari stations in Class 3, Arab Hassanadd station in class Four, Dezful Dam Station in Class 5, Abbaspour Dam Station in Class Six and Susan Station in Class 7. According to the SPEI index, due to the interference of temperature and evapotranspiration, the intensity of the dry and wet years has decreased and the trend of the droughts of the three stations is getting closer. For this reason, the distance between these stations in the dendrogram of rain gage and synoptic stations has decreased based on the SPEI index (Figure 9).

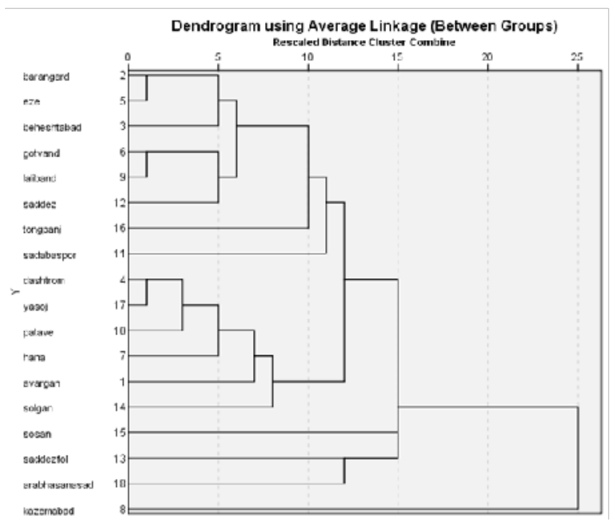

Figure 9. Dendrogram diagram of SPEI drought index clustering between stations

One station from each class was selected as the representative of that class that, Barangard from class (1), Gotvand from Class (2), Tangpanj-Bakhtiari from Class (3), Shahid Abbaspour Dam from Class (4), Dashtrom from Class (5), Susan from Class (6) and Kazemabad dam station from Class (7) were selected and the frequency of different drought levels was studied. The results of Figure 10 show that in all classes, the highest frequency percentage of drought classes is in the normal class. In other words, the frequency percentage of the normal floor is higher than the frequency percentage of wet and dry classes. Also, the total frequency percentage of dry class is equal with the sum of the frequency percentage of wet class which means that during the period of 30 years, the Karun basin area is balanced in terms of drought and wet occurrence. Among the dry classes, the average drought frequency percentage is more than the severe and very severe drought. In other words, the number of months affected by severe drought is lower than in the months of severe and moderate drought.

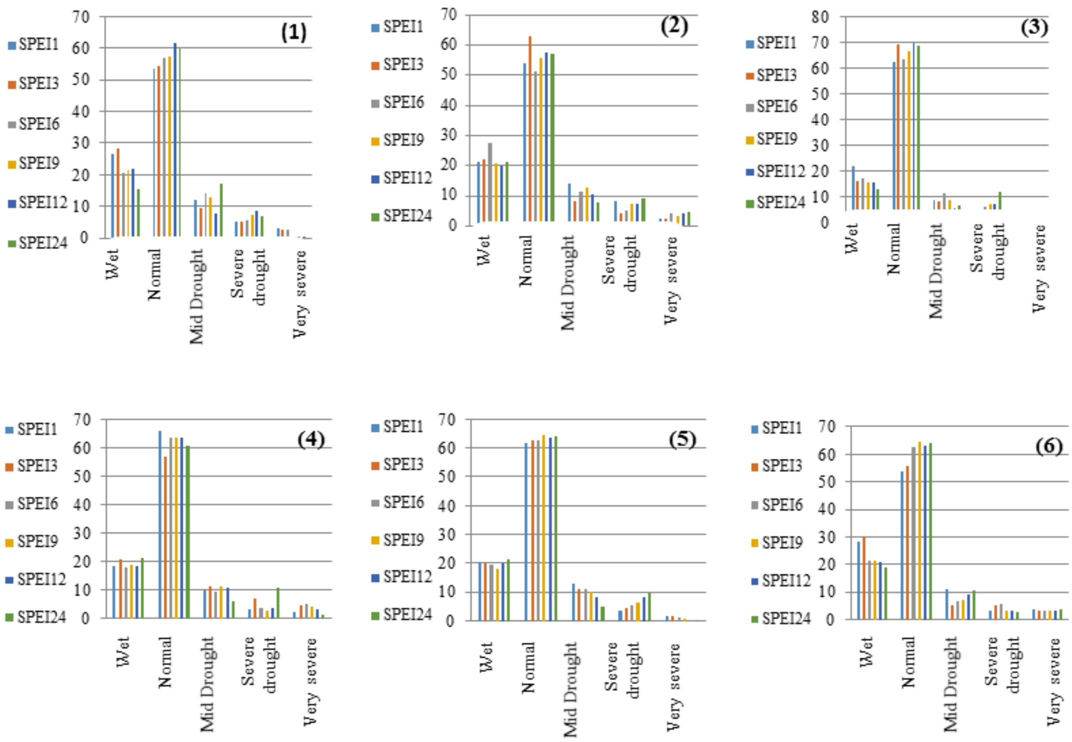

Figure 10. Frequency of different drought categories in classes 6-1

4- Conclusion

The present study was conducted to monitor the drought SPEI and to determine the homogeneous hydrologic regions in the Karun basin. The results of calculations in the 10 selected stations from 18 stations (stations with more than 30 years of statistics) showed that, Hana, Sulgan, Susan, Tang-panj-Bakhtiari stations and Dez Dam stations have a close estimate of severe drought events by the SPEI index and the process of similar drought changes. However, at the stations of Arabhassanabad, Avangaran, Rum Plain, Kazemabad and Lali-Band sorkhi, there was no high consistency in the estimation of severe drought events by the mentioned index, although the trend is almost the same in both drought and wet events. Also, in most stations, October 2008 has been estimated as the most severe drought period in the Karun basin.

The frequency of dry and wet periods in the short term scale is high. Increasing the time scale, the frequency of dry and wet periods decreases, but their continuity increases. The results of the 24-month SPEI index showed that in most stations, the longest droughts were recorded during the period from 2007 to 2011. Also, observations showed that at most stations, the correlation coefficient between indicators increases with increasing time period. In general, SPEI index shows drought classes well, which can be a reason for the SPEI index sensitivity to precipitation change and considering the temperature variable on this index. In this regard, it can be argued that increasing temperatures in the future could not be ignored. In the Karun basin, the results of drought monitoring showed that the estimated drought was higher in SPEI according to the SPEI index and almost the entire basin is in severe drought conditions and this rate is increasing from the east to west to the basin. But the normal conditions in autumn have been presented by the index. The results of the regionalization of the homogeneous stations led to the classification of the rain gage and synoptic stations of the basin in 7 classes. The stations' clustering results are close to each other based on indicators. Also, the results showed that in all classes, the highest frequency percentage of drought classes is associated with the normal class and due to equal the total frequency percentages of dry class with total frequency percentage of wet class, the Karun basin has balance in the trend of drought and wet occurrence.

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