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Online at http://jdesert.ut.ac.ir

DESERT 14 (2009) 133-140

Spatio-Temporal Analysis of Drought Vulnerability using the Standardized Precipitation Index (Case study: Semnan Province, Iran)

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Received: 4 February 2008; Received in revised form: 25 April 2009; Accepted: 10 October 2009

Abstract

This study was conducted to identify drought event and its emerging regions in Markazi desert, Iran with focus on Semnan province in a 30 years statistical period. In this research, 61 stations having adequate data selected and used after extracting annual statistic from monthly and daily data. Standardized precipitation index values for each station were calculated and classified. The Results have shown that there was drought condition in 17 studied stations. Also among 44 stations with no drought condition, there was one humid year in 20 cases. Khareh sarlazor station has the first position of drought and humid condition among other stations, with 10 drought years and 5 humid years. The number of common years with normal condition is 3 years and the most extensive drought in 1999 has occurred in 10 dry stations and 1 very dry station. The existence of common trend of variation using study of correlation among stations has resulted in determination of 7 groups which these results can be useful according to temporal distance of one or two years in appearing drought in the same group of stations.

Keywords: Drought; Standardized Precipitation Index; Semnan; Iran

1. Introduction

Drought is one of the most damaging climate-related hazards. Drought is among the most multifaceted and least understood of all natural hazards, affecting more people than any other hazard. Although drought first appears as below-average rainfall within a normal part of climate, it can develop as an extreme climatic event and turn into a hazardous phenomenon that can have severe impact on communities and water-dependent sectors. Drought differs from most other natural hazards in many ways, especially in the sense that its onset and termination is difficult to predict (McKee et al., 1993). The response and mitigation to drought entail a careful planning of water resources, design of a contingency plan to reduce the impacts, and set up early warning systems to predict onset of drought occurrence. It develops in slow temporal pattern and its impacts may prolong for a long period even during wet periods (Wilhite and Glantz, 1985).

Iran has been affected by severe droughts in different times because of geographical location in drought belt and approximately tropical zone which has intensified arid and semi arid climatic condition. Drought and events such as flood and storm are natural events resulting from climatic factors, which affect some parts of the country each year. Identification of such events has been the only principled way for reduction of undesirable effects. Drought in comparison with other natural events has more geographical extension and may show all of its effects evidently and all at once. As a result, drought is

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different from events like flood, earthquake and storm. Other difference of drought and other natural events is that there is no exact definition for this event, and according to region conditions and study goals, researches have mentioned different definitions.

Yevjevich (1969) considered lack of comprehensive and brief definition of this event as the major obstacle in the way of performing researches. In addition to lack of definition, other problems in studying drought is different ways which cause researches result could not be combined and generalizable results to other regions. In spite of these problems, varieties of studies have been performed in other countries as well as Iran in this field, which indicate perception of importance of this event and its important effect on human societies. Farajzadeh (1995) in addition to studying of drought index in Iran has made zonation of the country based on drought classes.

Qayoor (1996) studied intensity, frequency and extension of Iran droughts. Azizi (2003) studied effect of drought on underground water sources in Qazvin plain. Ramazani (2005) studied drought problem in central part of Gilan province and has reported existence of drought in plain regions of mentioned area. Nosrati and Azarnivand (2002) in studying intensity, duration and drought return period in Atrak river basin and their results had shown drought intensity increase with increasing return period and its tendency to constant level with durability of drought period as result. Waid (1999) studied Spain drought periods in Europe. McKee et al. (1995) used standardized precipitation index for drought study and compared the results.

In studying drought, different methods and data can b used, however, these methods do not have absolute priority to each other and region of condition and study objective is final determinative of method type. Methods of studying drought are as follows:

A: Studying water balance

B: Analyzing flow

C: Analyzing precipitation

D: Studying synoptic index

E: Geomorphologic Studies (Historical droughts)

According to the study approach and drought evaluation, it is seen that precipitation factor has been used by most researches as the most important variable in identification of drought types (Climatologic, Hydrologic and Agricultural).

Ramazani (2005) used standardized precipitation index as well as other indices which are used in studying drought with determination of deviation from long-term precipitation average. He also introduced numbers, which are dimensionless and are used in annual humid and drought analyses. SPI uses only precipitation factor and has been widely used in many researches so far.

Vafakhah and Rajabi (2005) have compared SPI with other indices including Percentage of normal precipitation (PNPI), Precipitation Deciles (DPI), Precipitation Abnormality and Z index in Bakhtegan basin and have reported DPI and PNPI indices that have less standardized deviation and more average.

Hayes (2000) has evaluated SPI index in comparison with Palmer index is more sensitive. In the current study, the major issue is studying distribution of drought periods in a spatio-temporal scale in different areas of Central Desert.

Therefore, with analyzing the results, possibility of return period's determination can be studied. It is clear that to pursue the goal. The possibility of challenge with drought unflavored effects is easier and necessary preparation measure can be made in sensitive regions.

2. Materials and Methods

Semnan province has 90,985km^2 (5.5% area of the country). Latitude in this province varies from 34°17' to 37°30' northern and longitudes from 51°58' to 57°58' eastern. A narrow strip in parallel northern frontier of the province is mountainous area and the rest includes desert plains and salty desert pans.

The Central Desert area or Namak Desert is the greatest internal watershed of Iran plateau that has an area of about 200,141km^2. Average elevation of the Desert varies from 650 m a.s.l. in west to 850 m a.s.l. in the east. Klinsely (1973) has stated the most of these areas has 100mm or less precipitation. Northern foot a mountain which are considered as desert above frontier, constituted 150 mm isohyte and show very pressured isohyte between 200 to 450 mm of annual precipitation in narrow and sloped strip above this line which involve a few area.

The Standardized Precipitation Index (SPI) proposed by McKee et al. (1993) to quantify the precipitation deficit for multiple time scales. These time scales reflect different water resources. In this study the SPI was calculated on 3-, 6- and 12-month time scales, which correspond to the past 3, 6, 12 months of observed precipitation totals respectively. These time scales reflect the soil moisture conditions (minor scale) or the underground waters, river flows and lake water levels (large time scales). The SPI is defined for each of the above time scales as the difference between monthly precipitation on 3-, 6- and 12-months time scale, (xi) and the mean value ($\bar{x}$), divided by the standard deviation (s),

$$SPI = \frac{x_i - \bar{x}}{s}$$

Where (x_i) is the monthly rainfall amount and $\bar{x}$, s are the mean and standard deviation of rainfall calculated from the whole time series of monthly values. Considering that, the monthly precipitation data may consist of many zero values it is expected that precipitation values do not follow the normal distribution. Thus, one must perform initially a transformation of the data in order to follow a normal distribution (Geerts, 2002; Hayes et al., 1999; Hayes, 2000; Edwards and McKee, 1997; Komuscu, 1999). Therefore, a theoretical cumulative probability distribution function is adjusted on the precipitation data. Edwards and McKee (1997), applied the two parameter gamma distribution for the calculation of SPI, while Guttman (1999), applied the Pearson type III distribution. Thus, the cumulative distribution of the precipitation data is transformed to a normal distribution with a mean value of 0 and a standard deviation of 1. In this way, the calculated SPI values are percentages of the standard deviation, while the extreme values have about the same low frequency of occurrence in all places for a long period. However, based on this methodology it is difficult to identify locations that are more ‘‘drought prone’’ than others (Hayes et al., 1999). McKee et al. (1995) and Komuscu (1999) defined various drought intensities, for all time scales together with their corresponding probabilities. Later on, Agnew (2000) suggested a new classification scheme for drought classes by adopting slightly different thresholds. Thus, the SPI is a tool for the investigation of drought by taking into accounts its intensity and duration. Because the SPI values fit a normal distribution, its thresholds can be combined with the corresponding probabilities. According to Edwards and McKee (1997) values less than -2.0 (extreme drought) are expected to appear 2 to 3 times in 100 years.

Precipitation in formation of all central desert stations were obtained from beginning of establishment till 2001 obtained from Water Resources Researches Organization and Semnan province Regional Water Company. This information was registered daily and monthly and yearly statistics were extracted for performing this study. Only 61 of 184 stations were determined considerable according to number of available data. These stations had at least 16 years data.

Reconstruction of incomplete stations statistic was done using linear regression. Statistical correlation was determined using SPSS software and producing 61×61 matrix and comparison of each station with others. Usually each station with other stations showed correlation in confidence level of 95 or 99% among which station that had the highest coefficient was selected for reconstruction. Correlation was not observed in some cases, so after reconstruction of statistic and completing stations, correlation coefficient was studied again and reference station was selected for each incomplete station. Annual SPI values in each station were calculated and were classified using Table 1.

Table 1. Wet and drought period classification according to the SPI Index

	Index value	Class	Probability	ΔP
Non Drought	SPI ≥ 2.00	Extremely wet	0.977–1.000	0.023
	1.50 ≤ SPI < 2.00	Very wet	0.933–0.977	0.044
	1.00 ≤ SPI < 1.50	Moderately wet	0.841–0.933	0.092
	−1.00 ≤ SPI < 1.00	Near normal	0.159–0.841	0.682
Drought	−1.50 ≤ SPI < −1.00	Moderate drought	0.067–0.159	0.092
	−2.00 ≤ SPI < −1.50	Severe drought	0.023–0.067	0.044
	SPI < −2.00	Extreme drought	0.000–0.023	0.023

For better understanding of changes process of 3, 5 and 7 years average SPI values were calculated in each station and figure were compared with each other.

3. Results

Over 30 years data period the stations did not show drought in 15 years. Amongst 15 years 1993, 1984 and 1998 in all stations were normal. Remained 12 years were humid years in all stations. Within 15 years which drought was registered in stations, 8 years drought is absolute; it means there was no drought condition station through the region. In remained 7 years, of drought and humid years were seen in different stations. The most extensive drought and humid years have occurred geographically in 1999 (11 dry station) and 1991 (14 humid stations), respectively (Figure 1).

Observation of 7 years moving average figures in each station determine clearly the increasing and decreasing process and humid and drought periods. The existence of geographical relation of drought occurring was studied with considering SPI values change correlation. Results indicate more droughts occurring in stations which are in higher elevations. Of 24 stations, which had normal precipitation in all statistical period, 17 stations namely, more than 70% of them were part of low precipitation 24 stations with annual precipitation average of 79mm (Hosein-Abad Miamey) to 167mm (Daruneh).

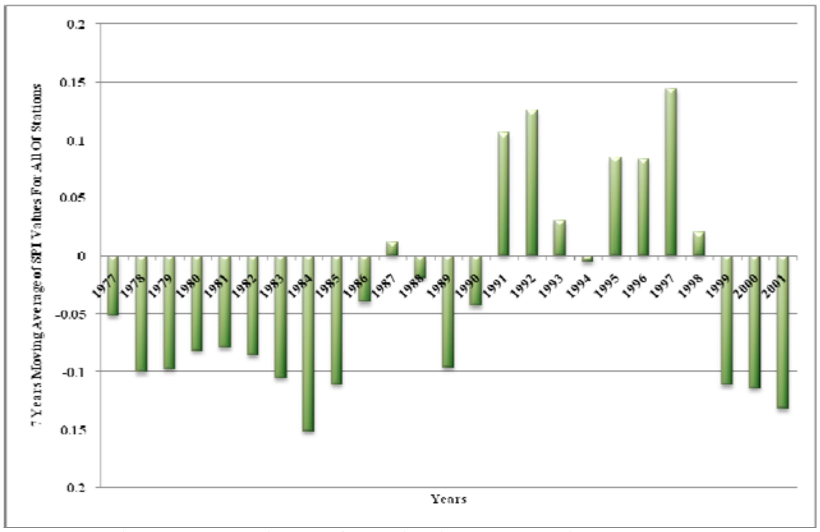


Fig. 1. Long-term changes of SPI values in Semnan Province (1971–2001)

Study of existence of statistical correlation between 7 years moving average values of different stations and figures showed that 7 groups are detectable from others by clear and separate process. The minimum correlation coefficient was 75%. The stations location place was shown on the map. Correlation matrix was calculated in SPSS software in stations grouping and stations, which had correlation coefficient values above 75%, placed in one group. In this manner, seven groups were separated but 11 other stations including Sfaraien, Ejeh, Bala Khosh, Esfarain, Beshruyeh, Pirdeh, Jelizjand, Hatiteh, Daruneh, Ali Abad, Shamgan, Mehdi Shahr had no statistical correlation with none of other stations (Table 2).

Stations with the same symbol in the map have similar trend of changes in amount of precipitation during the study period, which is shown in Figure 3.

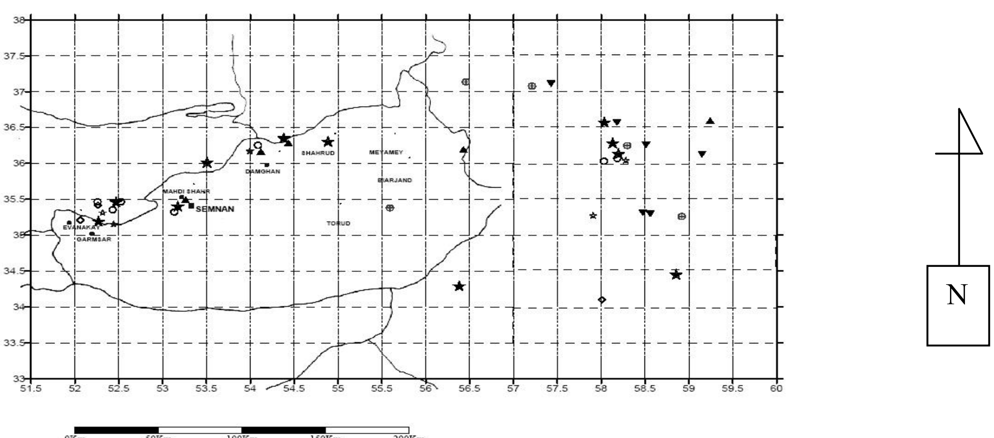
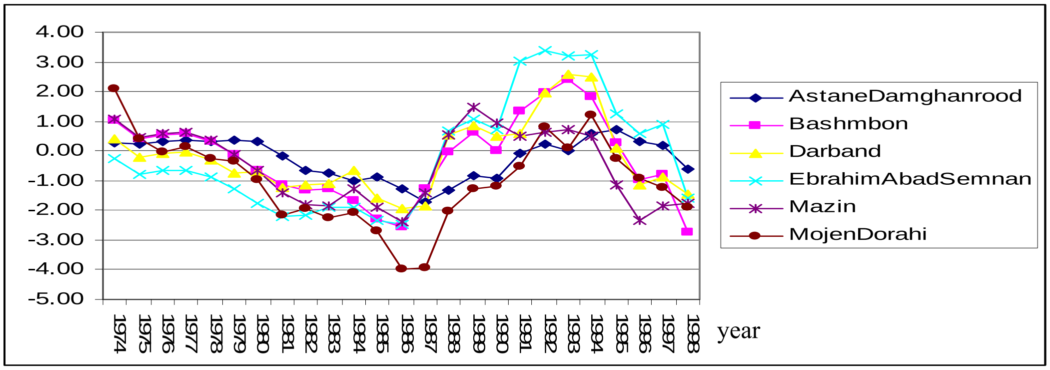


Fig. 2. Spatial position of stations with similar longterm changes of SPI

Table 2. Characteristics of the stations used in the study

Station	Code	Longitude (Degrees, inutes)	Latitude (Degrees, inutes)	Symbol	Station	Code	Longitude (Degrees, inutes)	Latitude (Degrees, inutes)	Symbol
Amirieh	47-210	35.17	52.48	○	Arieh	47-043	36.27	58.41	✶
Chahar deh Damghan	47-216	36.25	54.12	○	Bastam	47-044	36.29	55	✶
Hosein abad Forest	47-045	36.03	58.26	○	Bonkuh	47-015	35.18	52.25	✶
Mohammad abad Neishaboor	47-122	36.07	58.42	○	Drjezin	47-023	35.39	53.2	✶
Najaf dar	47-016	35.47	52.2	○	Firoozkuh	47-005	35.45	52.46	✶
Khier abad Semnan	47-038	35.33	53.13	○	Hosein Abad meiami	47-404	36.34	54.47	✶
Anzeha	47-009	35.36	52.38	○	Janat abad forest	47-120	34.44	59.17	✶
Taghoon	47-093	36.25	58.41	⊗	Neishaboor	47-050	36.12	58.48	✶
Tarood	47-110	35.38	55.57	⊗	Seh	47-091	36	53.55	✶
Sankhast	47-063	37.14	56.48	⊗	Yaqhobieh	47-132	34.28	56.57	✶
Senobar	47-071	35.26	59.06	⊗	Zarandeh	47-095	36.56	58.31	✶
Ivanaki	47-004	35.21	52.04	◊	Dehnamak	47-028	35.15	52.44	☆
Ivanaki 2				◊	Jondagh				☆
Yahrkahnak	47-022	35.42	52.25	◊	Karizayarj abad	47-073	35.17	58.17	☆
Garaneh	47-176	34.1	52.28	◊	Roodbar amqhan	47-212	36.17	54.07	☆
Eysh abad	47-041	36.19	58.5	▼	Simin dasth hebleh rood	47-011	35.31	52.31	☆
Dizbad alia	47-079	36.06	59.17	▼	Rooh abad	47-039	36.04	58.56	☆
Fadihe	47-156	35.23	58.55	▼	Damghan rood Astoneh	47-027	36.16	54.06	▲
Namagh	47-158	35.25	58.46	▼	Bashm bon	47-972	35.49	53.16	▲
Nushirvan	47-136	37.04	57.36	▼	Darban	66-010	36.59	59.43	▲
Yangajeh	47-049	36.5	58.15	▼	Maziran	47-128	36.19	56.48	▲
					Majn dorahi	47-033	36.28	54.39	▲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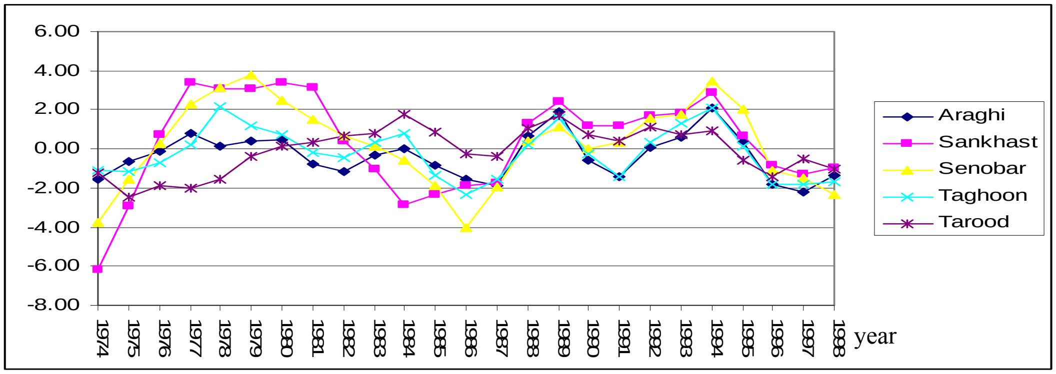
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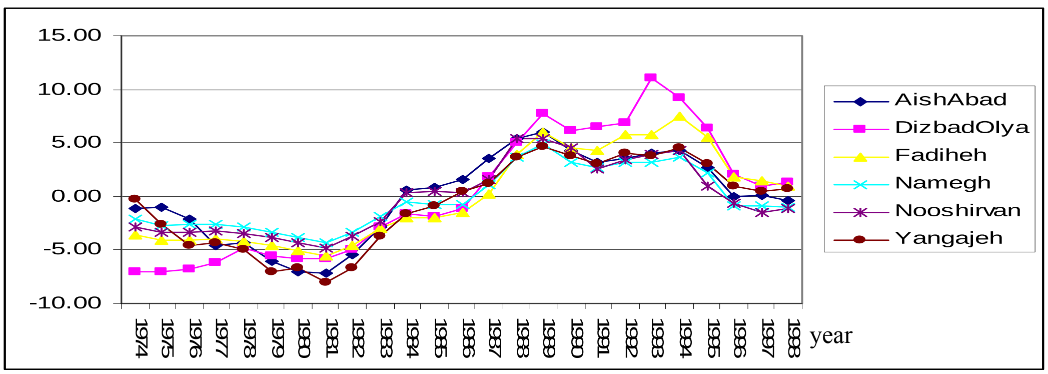
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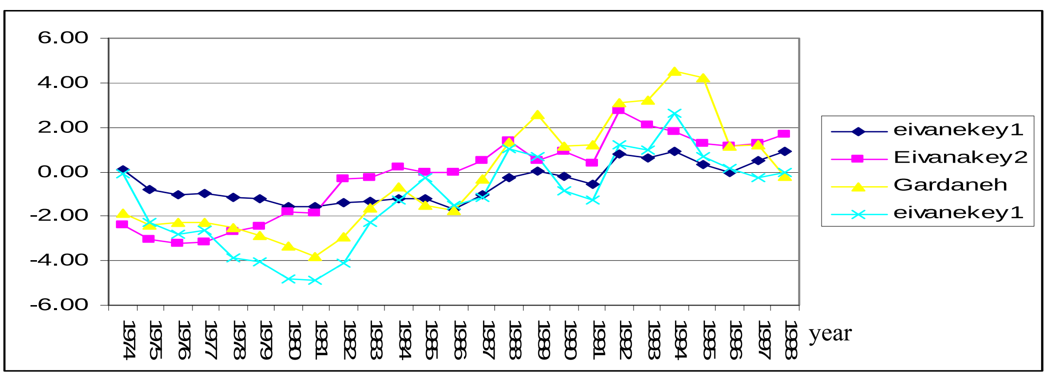
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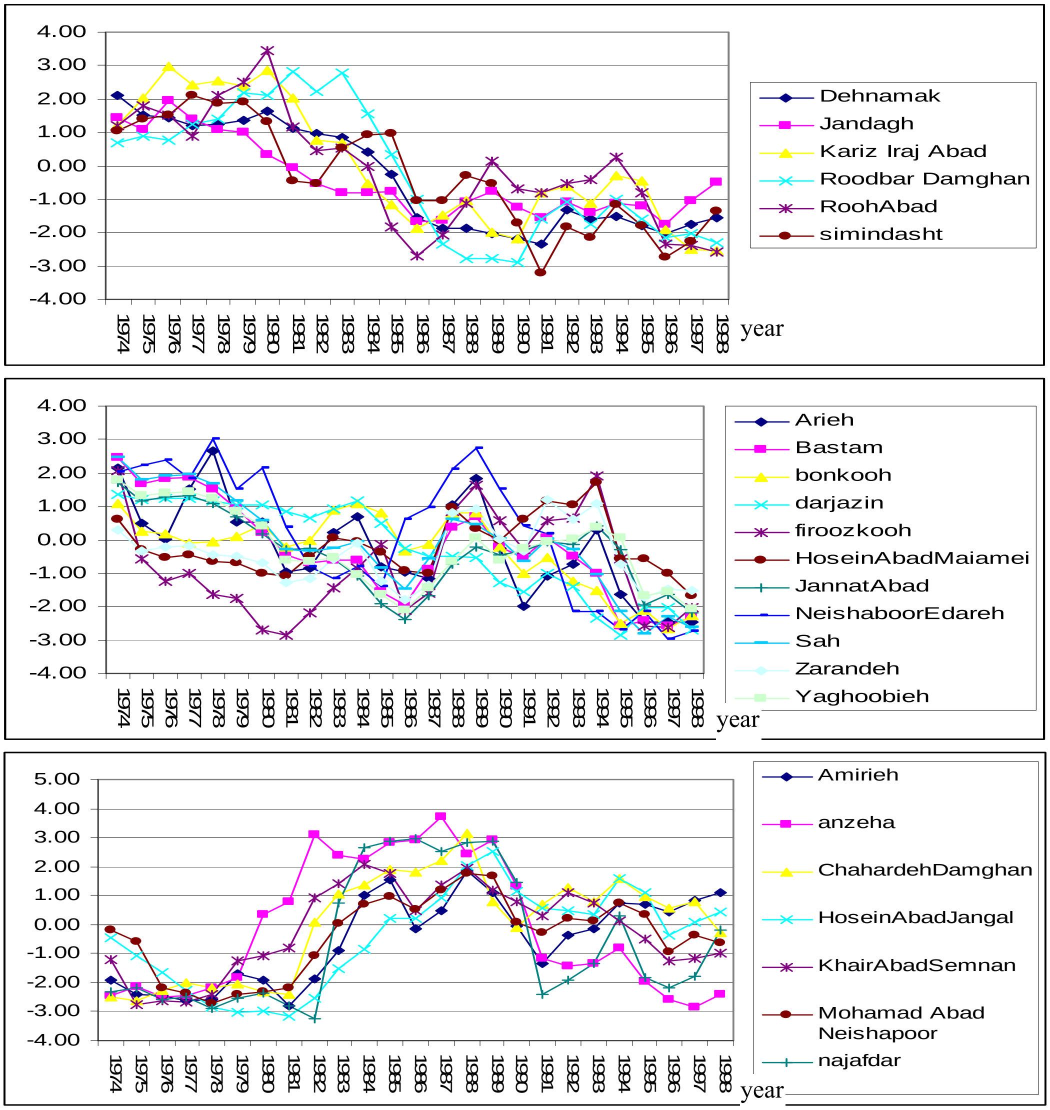

Fig. 3. Tend of longterm SPI changes in similar stations

Considering studied temporal period, which has been extracted from statistic of all stations, showed that during 30 years period of studying humid year in view of intensity, duration and frequency had priority than occurred droughts. In addition, in case of 1999 drought, the results indicate its short time, while 1983-86 drought periods had much more stable duration with less intensity.

4. Discussion and Conclusion

Standardized Precipitation Index, which has been used according to the obtained results compared to the same researches in common statistical period, determined drought processes and precipitation increase and decrease. Water year drought in 1998-99 could be mentioned, Azizi (2003) has reported that average annually precipitation was 26% lesser than 30 years average and 11% lesser compared to water year in 1997-98, which include through Iran and has concluded its result in Qazvin plain. In addition, Climatology National Organizations report 1998 has mentioned this drought effects including 70% reduction of dryland crops and 10% of irrigated crops, reduction of 2.4 million ton of wheat production and 400,000 ton of rice production. This drought can be used, as a useful tool, in studying SPI index sensitivity level in the region.

The results showed average of all studied stations in 1999 in this area has been about 60% using 30 years precipitation average. The calculated SPI was the least recorded level and was 54% drier than the second drought year

1996. So, sensitivity of this index was evaluated. Vafakhah and Rajabi (2005), Farajzadeh(1995) and McKee et al (1995) have recommended SPI for long-term drought studies, which are effective on water resources.

While studying the stations separately, attempts have made for identification of drought geographical distribution. Results in this field indicate more intensive changes in stations located in mountainous parts that have higher average precipitation. Also studying annual precipitation variance indicated this point that lesser annual precipitation average is accompanied range amplitude decrease and data variances. In this field occurrence of the greatest drought years in Khareh Sar Lazour station and Dizabad Olia stations with annual precipitation of 401 and 316mm respectively could be suggested, which are the first and ninth in view of precipitation average. Kharehsar Lazour station is located in Firouzkouh area had the greatest humid year. Studying long-term average of annual precipitation and number of humid and drought years is shown that all stations which had more than one abnormal year (drought or humid), had precipitation higher than 185mm.

5. Recommendations

Studying weather stations of the province indicate existence of 90% of them in piedmont areas so importance of province arid and semi-arid regions of the province is recommended, station establishment studies to be performed in southern areas of the province and a plan to be made for establishment of synoptic stations.

Comparison and adding up of the results is difficult and impossible because of difference in methods. Because of geographical location of Iran in the world drought belt and scarcity of water resources supply for the country and increasing population, it is recommended that a model to be planned proportional to geomorphologic and atmospheric conditions special for mountainous surrounding areas Iran's plateau for drought prediction. Semnan province has suitable characteristics for primary studies in the country.

Establishment of the country drought database, which involves research results of all researches, is a solution that can be considered until introduction of native model of drought predication and awareness system.

Determination of drought crisis index in different geographical regions of the country is the most necessary most necessary need of the country. This index could direct researches to prove regions and to be a suitable basis for comparison of results. Also it could be used for crisis management improvement and challenge with social and economical effects of drought.

Acknowledgement

The financial support of International Desert Research Center of the University of Tehran for this research is acknowledged.

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