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Characteristics of Drought in Three Recent Decades in North of Iran, Guilan Province

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Abstract: The drought monitoring in Guilan, particularly its intensity, duration, frequency and the extend area have been analyzed for the period '1966 – 2002' by SPI method. The results showed that droughts occurred periodically within the region and relatively regular cycles and frequency of the occurrence of drought was different at wet and dry stations. The highest frequency for each station is generally moderate and severe type in relation to wet stations. The correlation of SPI values in 19 stations distinguished a synchrony of the occurrence of drought in adjacent stations and its rate reduced with increasing distance. Finally, spatial-temporal pattern of drought after the monitoring indicated an occurrence of continuous and discontinuous droughts in study area which caused, provided the critical conditions for natural and human resources.

Key words: Guilan · Drought · Precipitation · SPI · Monitoring.

INTRODUCTION

With regard to technical and scientific progresses, the human has still been vulnerable against natural phenomena, including droughts and is seeking for methods which to recognize the occurrence of this phenomenon. This phenomenon has had multidimensional effects and has attracted most enthusiasts. Therefore, its recognition can present practical strategies. With regard to the importance of drought, extensive worldwide studies have been carried out. Tsakiris and Vangelis [1] in their study found that the regional drought could be estimated with its predictable consequences by various methods. They believed that public awareness of the occurrence, areal extent, intensity and the duration of drought are important for decision making. Therefore standardized precipitation index (SPI) in this viewpoint has the capability of global usage. This method could be done using simple computer routine calculations and also supports drought monitoring of a region and its spatial analysis in medium scale. Solaimani[2] showed that the monthly hydrometric and climatic data in ANN were ranged from 1969 to 2000. Also the results extracted from the comparative study indicated that the Artificial Neural Network method is more appropriate and efficient to predict the river runoff than classical regression model in Jarahi watershed. Gholami *et al.* [3] applied the HEC-HMS and Artificial Neural Network (ANN) to simulate the rainfall-runoff process over the Kasilian Watershed located in the north of Iran. They are believed the highest efficiency of this method and the desirable effect of optimized initial loss on increasing the accuracy of simulation in runoff and hydrograph. Sirdas and Sen [4] verified direct connection between duration and extent of drought by Run and Z- Score methods and Kriging interpolating in Trakya area of Turkey. Loukas *et al*. [5] evaluated the effects of climate change on severity of drought by use of SPI and GIS in the region of Thessaly, Greece. The results showed that the severity of annual drought is increased for all hydrological areas and SPI time scales, with the socioeconomic scenario SRES A2 being the most extreme. In this paper we used the standardized precipitation index for recognition, monitoring and determination of drought components (intensity, duration and frequency and areal extent) and it's zoning by GIS in Guilan province.

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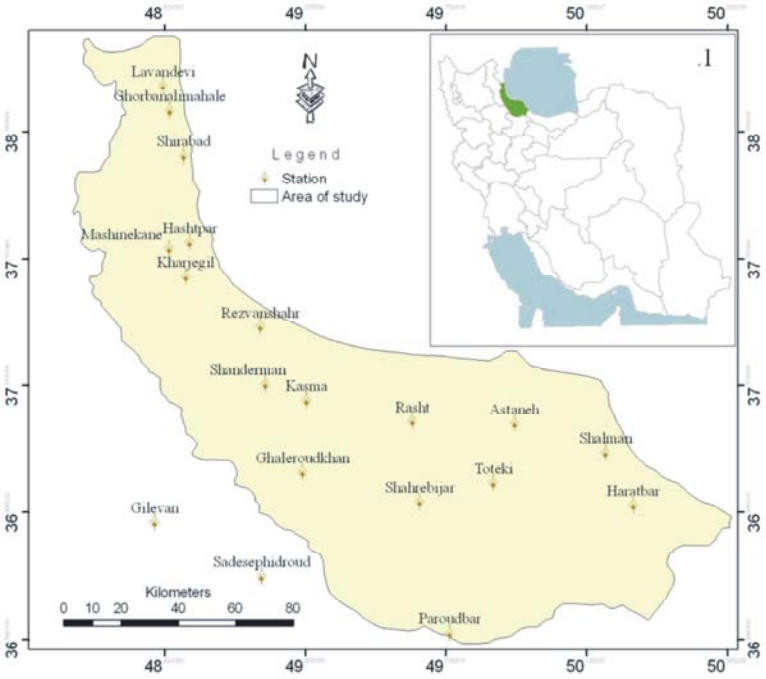

Fig. 1: Location of the rain gauge station

Table 1. Drought classification by SPI value and corresponding event probabilities

Class	SPI value	% Probability
Extremely wet	<2	2.3
Severe wet	(1.5) - (1.99)	4.4
Moderately wet	(1) - (1.49)	9.2
Slight	0 - (0.99)	34.1
Slight	0 - (- 0.99)	34.1
Moderately Drought	(-1) - (-1.49)	9.2
Severe Drought	(-1.5) - (-1.99)	4.4
Extremely Drought	> -2	2.3

MATERIAL AND METHODS

This study conducted in Guilan province. This area located between 48°32´48½ to 50°36´45½E and 36° 33´42½ to 38° 27´ 02½N in south coast of Caspian Sea in north of Iran. Monthly precipitations data for 19 gauge rain stations are taken from the regional water bureau of Guilan province for the period 1978 – 2008. The elevation ranges from -28 to 4200m.s.l (Fig. 1).

In this study we used mathematical model of SPI. This model was presented by climatologists firstly. In terms of mathematic, SPI is based on probability of accumulative precipitation. Therefore data has been fitted with gamma probability distribution, then, transformed into the standard normal distribution to yield the SPI (Table 1).

This table also contains the corresponding probabilities of occurrence of each severity, these arising naturally from the normal probability density function. The monthly precipitation time series are modeled using different statistical distributions. The first is the gamma distribution, whose probability density function is defined as;

$$G(x) = \frac{1}{\alpha^{\beta}\Gamma_{\beta}}\int_0^x X^{\beta-1}e^{\frac{-x}{\alpha}}dx \quad (1)$$

Where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function. Fitting the distribution to the data requires α and β to be estimated by Edwards & McKee [6]. They suggested that estimating these parameters using the approximation of Thom for maximum likelihood as follows:

$$\alpha = 1/4U\,[1 + \sqrt{}\,(4U/3)] \quad (2)$$

$$\beta = X^{-} / \alpha \quad (3)$$

The gamma distribution is undefined for $x = 0$ and $q = P(x = 0) > 0$ where $P(x = 0)$ is the probability of zero precipitation, the cumulative probability becomes;

$$H(x) = q + (1 - q)G \quad (4)$$

The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI (Fig. 2).

The simplest method for calculation of SPI amounts is acquired from approximate conversion of Abramowitz and Stegun. The SPI amount for $0 < H(x) \leq 0.5$ will be equal to;

$$SPI = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \quad (5)$$

And for $0.5 < H(x) = 1$ will be equal to;

$$SPI = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \quad (6)$$

As;

$$t = \sqrt{(Ln[1/[(H(x))]^2])} \quad (7)$$

For $0 < H(x) = 0.5$ And;

$$t = \sqrt{(Ln[1/[(1 - H(x))]^2])} \quad (8)$$

For $0.5 < H(x) < 1$ is calculated. Constant amounts in formulas of 5 and 6 are equal with $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d2 = 0.189269$, $d_3 = 0.001308$. Therefore, SPI from t displacement with various formulas according to magnitude of displaced amounts of gamma is obtained. The obtained numbers for determination of droughts of 3, 6, 12, 18, 24 and 48 months are also used.

RESULTS

Average of precipitation in 19 stations varied from lowest amount (21.92 mm) in Paroudbar up to most amounts (129.41mm) in Toteki station during the period. Comparison of monthly precipitation series of each station with its average indicated that stations have suffered from drought repeatedly. Likewise, comparison of observed occurrence probability percentage with normal probability distribution indicated that there is a difference between them, because probability percentage of drought and wetness had not conformity with normal probability distribution and did not follow it, completely. At first it must be said that sum of probability percentage of wetness occurrence is more than the sum of droughts probability percentage in four classes (> 50%) and asymmetry between occurrence probability of drought and wetness is completely indicated this issue. Severe droughts had less occurrence frequency in relation to extreme droughts which is changed from 17.5% (Paroudbar) up to 38.33% (Haratbar). Also frequency and occurrence probability of Moderate droughts were changing between the two levels (17.5 up to 38.33%) in other stations. In addition, comparison of occurred droughts with normal distribution suggested a significant change in various stations. Likewise, the occurrence probability of slight and moderate droughts in relation to severe and extreme droughts was more. Because the most frequency of droughts were the type of slight ($0 < SPI \leq 0.99$) and the rarest droughts were the extreme type ($SPI \leq -2$) in all stations (Table 2).

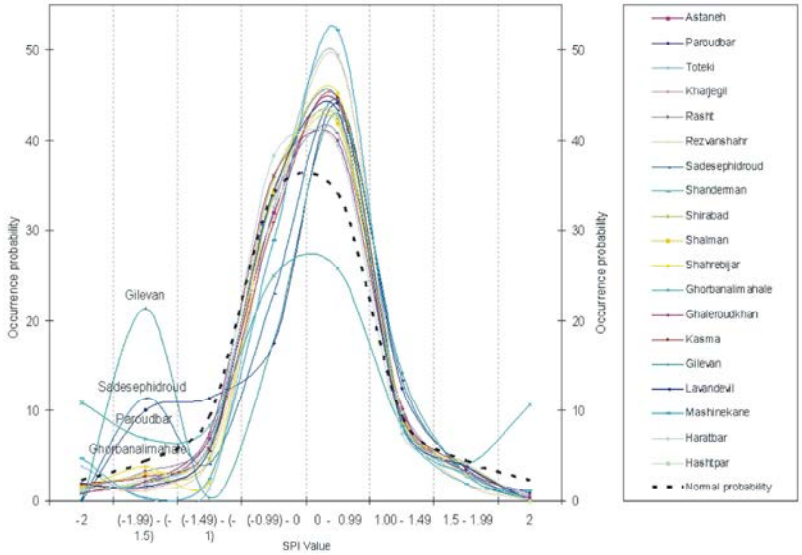

Fig. 2: Example of a probability transformation from a fitted gamma distribution to the standard normal distribution

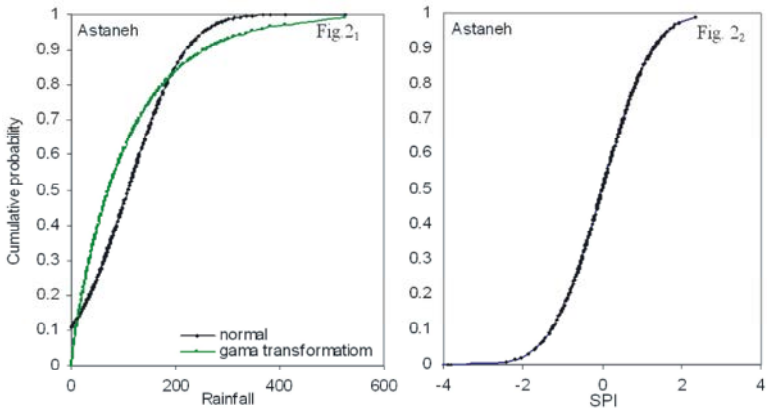

Fig. 3: The comparing of drought occurrence probability with SPI normal probability in the stations

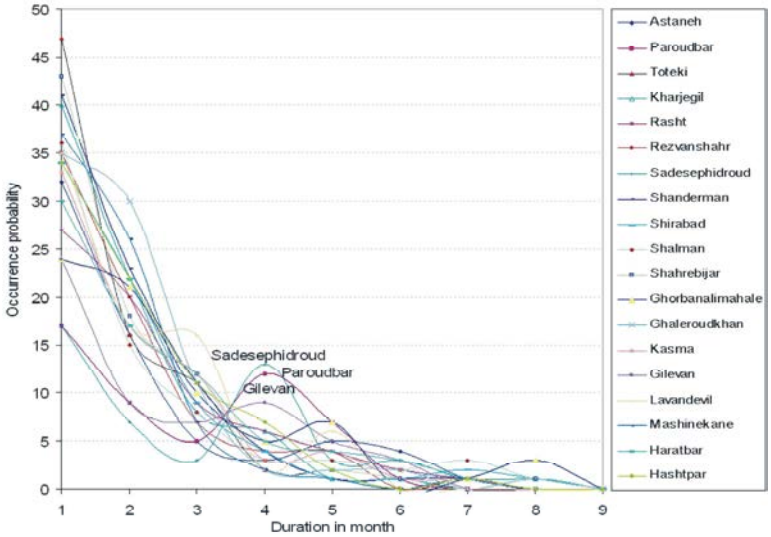

Fig. 4: The observed frequency of drought occurrence in the difference time ranges

The irregularity is seen in probability distribution of severe and extreme droughts in some of stations and it shows a decrease and increase of occurrence probability of short – term and long–term droughts, respectively. Thus, occurrence probability trend of short – term to long - term droughts in Paroudbar, Sadesephidroud, Ghorbanalimahale and Gilevan in relation to other station are somewhat different. The obtained results show that 1, 2, 3 and 6, 7, 8, 9 month droughts frequencies has maximum and minimum occurrence in all stations, respectively. In addition, the one month droughts have most frequency in Toteki (47 times) and least frequency in Paroudbar and Sadesephidroud (17 times) (Table 3, Fig. 3 and 4). But it has not come true about two month's droughts and droughts frequency with other duration was irregular and did not follow an especial rule. The droughts frequencies are also not equal from 1 to 9 months and did not follow linear trend.

The relation between duration and frequency was nonlinear trend in all of stations and in spite of reduction in frequency from 1 to 9 months; second peak was seen in 4 and 5 month frequency. Totally, R^2 was more than 0.7 and the relationship between duration and frequency was logarithmic and followed it (Table 4). The correlation coefficient of SPI was high in neighbor stations and its rate changed from minimum (0.09) up to maximum (0.89).There are a strong correlation coefficient from east to west and north to south. The SPI coefficients aren't heterogeneous and occurrence times of droughts are similar in all adjacent stations. There is also a significant difference in correlation coefficient between northern slope (wet climate) and southern slope (arid and semiarid climate) stations that indicated non synchronism of drought occurrence in two regions (Table 5). In Spatial analysis of droughts it is obvious that most part of Guilan province in February 1984 has been faced with drought

Table 2: Comparing of observed probability distribution with SPI probability

Class	Extremely wet	Severe wet	Moderately wet	Slight	Slight	Moderately drought	Severe drought	Extremely drought
SPI value	2<	(1.5)-(1.99)	(1) - (1.49)	0 - (0.99)	0 - (- 0.99)	(-1) - (-1.49)	(-1.5) - (-1.99)	-2>
Normal probability	2.3	4.4	9.2	34.1	34.1	9.2	4.4	2.3
Stations	Observed occurrence probability to percent							
Astaneh	0.278	3.056	10	44.167	31.944	6.944	1.944	1.667
Paroudbar	0.833	3.611	12.5	44.167	17.5	11.389	10	0
Toteki	0.278	2.778	9.444	49.444	32.5	1.389	0.278	3.889
Kharjegil	0	3.333	9.444	44.722	33.889	5.556	1.389	1.667
Rasht	0.556	3.056	10.278	40.833	33.611	6.944	3.333	1.389
Rezvanshahr	0.278	1.944	9.722	49.167	31.389	4.444	1.111	1.944
Sadesephidroud	0.278	3.056	13.333	44.444	23.056	4.167	11.389	0.278
Shanderman	1.111	1.944	8.889	44.722	34.167	6.111	2.222	0.833
Shirabad	0.556	4.167	9.167	42.5	35.833	4.722	2.222	0.833
Shalman	0.556	3.889	8.889	41.944	34.444	5.556	3.056	1.667
Shahrebijar	0.278	3.056	9.722	45.278	34.167	2.222	3.889	1.389
Ghorbanalimahale	10.556	4.167	8.333	25.833	25	8.333	6.944	10.833
Ghaleroudkhan	0.833	3.333	9.167	40	36.111	7.5	2.222	0.833
Kasma	0.278	3.889	9.722	44.722	30.833	5.833	2.778	1.944
Gilevan	0.278	3.056	14.167	43.056	17.778	0.278	21.389	0
Lavandevil	0.833	3.889	8.333	43.333	34.444	5.556	1.667	1.944
Mashinekane	0.000	3.056	8.333	52.222	28.889	2.5	0.278	4.722
Haratbar	1.111	4.167	7.5	39.444	38.333	6.111	1.944	1.389
Hashtpar	0.833	3.056	9.722	42.778	33.611	6.389	2.5	1.111

Table 3. Drought occurrence frequency in identified durations in the study area

	Duration / month								
Stations	Period	1	2	3	4	5	6	7	8	9
Astaneh	1978 -2008	32	16	5	3	5	4	1	0	0
Paroudbar	1978 -2008	17	9	5	12	7	1	0	0	0
Toteki	1978 -2008	47	16	11	2	2	1	0	0	0
Kharjegil	1978 -2008	40	22	8	6	1	1	0	1	0
Rasht	1978 -2008	27	20	9	6	4	2	1	0	0
Rezvanshahr	1978 -2008	35	20	7	4	4	0	1	0	0
Sadesephidroud	1978 -2008	17	7	3	13	3	3	1	1	0
Shanderman	1978 -2008	41	23	11	4	1	1	1	0	0
Shirabad	1978 -2008	34	22	9	4	1	1	2	1	0
Shalman	1978 -2008	36	15	8	3	3	2	3	1	0
Shahrebijar	1978 -2008	43	18	12	2	2	1	0	1	0
Ghorbanalimahale	1978 -2008	24	21	10	5	7	0	1	3	0
Ghaleroudkhan	1978 -2008	35	30	11	2	2	2	0	1	0
Kasma	1978 -2008	33	17	12	3	4	1	1	0	0
Gilevan	1978 -2008	24	9	7	9	5	3	0	0	0
Lavandevil	1978 -2008	35	17	16	2	6	0	0	0	0
Mashinekane	1978 -2008	37	26	7	2	1	0	1	0	0
Haratbar	1978 -2008	30	17	12	5	4	3	1	0	0
Hashtpar	1978 -2008	34	22	13	7	2	0	1	0	0

based on defined classes and main core of drought lies in east of province. The conditions are completely changed from February to March and witness dominated too. In this time, core of witness intensity located in the Astaneh area and most part of province is encountered with slight wetness. Again, slight and moderate droughts conditions dominated in April and it repeated in May. Afterwards, the critical conditions dominated in June, because its effect doubles with increasing temperature. In addition, the drought core lies in the Sephidroud valley and the same condition repeated in July too and is displaced from east to west in August. The most important issue is drought duration and extent (from April to August) which caused critical conditions in this area. In continuation, a witness condition dominated in the September. It is completely clear a small part of east and west be faced with drought in March 1993. After that, all of the area encountered with drought In April. The condition changed in May and then wetness

Table 4: Equations of occurrence frequency with drought duration in monthly scale

Stations	Duration - Frequency correlation	Equations
Astaneh	$R^2 = 0.8683$	y = -13.525Ln(x) + 26.572
Paroudbar	$R^2 = 0.7799$	y = -7.519Ln(x) + 16.362
Toteki	$R^2 = 0.8422$	y = -19.671Ln(x) + 36.759
Kharjegil	$R^2 = 0.8987$	y = -18.009Ln(x) + 34.395
Rasht	$R^2 = 0.9587$	y = -13.075Ln(x) + 26.264
Rezvanshahr	$R^2 = 0.9041$	y = -15.829Ln(x) + 30.404
Sadesephidroud	$R^2 = 0.6706$	y = -6.7359Ln(x) + 14.915
Shanderman	$R^2 = 0.9105$	y = -18.779Ln(x) + 35.822
Shirabad	$R^2 = 0.9047$	y = -15.755Ln(x) + 30.632
Shalman	$R^2 = 0.8596$	y = -14.816Ln(x) + 28.963
Shahrebijar	$R^2 = 0.8735$	y = -18.568Ln(x) + 35.19
Ghorbanalimahale	$R^2 = 0.9077$	y = -11.856Ln(x) + 24.753
Ghaleroudkhan	$R^2 = 0.8746$	y = -17.766Ln(x) + 34.493
Kasma	$R^2 = 0.9299$	y = -14.906Ln(x) + 29.091
Gilevan	$R^2 = 0.8938$	y = -9.967Ln(x) + 20.511
Lavandevil	$R^2 = 0.9095$	y = -16.023Ln(x) + 31.236
Mashinekane	$R^2 = 0.8685$	y = -17.691Ln(x) + 33.387
Haratbar	$R^2 = 0.9633$	y = -13.714Ln(x) + 27.507
Hashtpar	$R^2 = 0.9472$	y = -16.267Ln(x) + 31.694

Table 5: Correlation coefficient of SPI values in the stations

Station	Lavan-devil	Ghorbana-limahale	Shirabad	Hashtpar	Mash-inekane	Kharjegil	Rezvan shahr	Shand-erman	Kasma	Ghaler-oudkhan	Gilevan	Sadesep-hidroud	Paro-udbar	Rasht	Shahr-ebijar	Toteki	Astaneh	Shalman	Haratbar
Lavandevil	1.0																		
Ghorbanalimahale	0.8	1.0																	
Shirabad	0.7	0.7	1.0																
Hashtpar	0.8	0.8	0.7	1.0															
Mashinekane	0.6	0.5	0.5	0.6	1.0														
Kharjegil	0.7	0.7	0.7	0.8	0.6	1.0													
Rezvanshahr	0.5	0.5	0.5	0.6	0.5	0.6	1.0												
Shanderman	0.6	0.7	0.6	0.8	0.5	0.8	0.6	1.0											
Kasma	0.7	0.7	0.6	0.8	0.5	0.8	0.6	0.9	1.0										
Ghaleroudkhan	0.6	0.7	0.6	0.8	0.5	0.8	0.6	0.8	0.8	1.0									
Gilevan	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.1	1.0								
Sadesephidroud	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.8	1.0							
Paroudbar	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.3	0.3	0.2	0.8	0.9	1.0						
Rasht	0.6	0.6	0.5	0.7	0.5	0.6	0.6	0.7	0.8	0.8	0.3	0.4	0.4	1.0					
Shahrebijar	0.5	0.5	0.5	0.6	0.4	0.6	0.4	0.7	0.7	0.7	0.3	0.3	0.3	0.7	1.0				
Toteki	0.4	0.5	0.5	0.5	0.4	0.6	0.4	0.5	0.6	0.6	0.2	0.3	0.2	0.6	0.5	1.0			
Astaneh	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.7	0.8	0.7	0.3	0.4	0.4	0.9	0.7	0.6	1.0		
Shalman	0.6	0.6	0.6	0.7	0.5	0.6	0.6	0.7	0.8	0.7	0.2	0.3	0.3	0.8	0.6	0.6	0.8	1.0	
Haratbar	0.6	0.6	0.6	0.7	0.5	0.7	0.5	0.7	0.7	0.8	0.0	0.1	0.1	0.7	0.6	0.6	0.6	0.8	1.0

dominated. Likewise, the central areas (Sephidroud valley) involved become drought in June and the condition to be completely wet in July, but drought occurred in August again. In continuation, September was an arid month and drought covered all of area with weak intensity. Finally the alternative occurrence of dry - wet periods was drought characteristic in this period. Furthermore, the indicated that wetness has occurred in February 2007 and drought covered the area in March, completely. After that the drought observed with high intensity in April. The effect of drought is doubled in May and the condition changed in June and slight wetness becomes overcome. Of course it must be said that in more than fourth – fifth of this month, very arid conditions have been prevailed and heavy rainfall in end of June have caused changes in spatial pattern. Moreover, with regard to rainfall in the previous month, drought occurred in August again and in continuation, wet and drought conditions are restricted to shore region and south slopes of Alborze mountains in east of province of the September (Fig. 5).

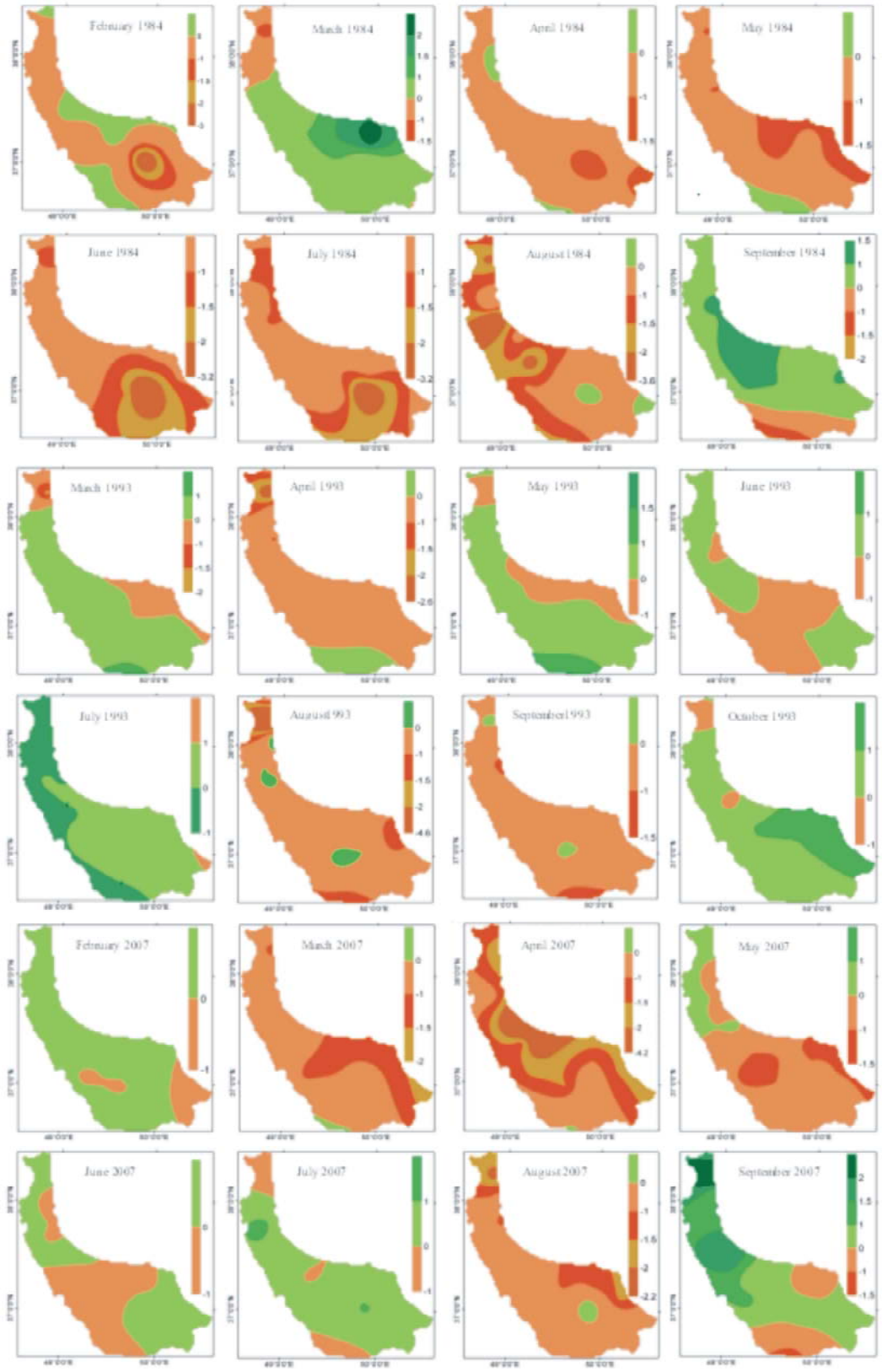

Fig. 5: Areal distribution of drought intensity for historical droughts that occurred in the study area

DISCUSSION

The obtained results of drought characteristics (intensity, duration, frequency and extend area) showed that the drought - wetness occurrence probability followed of normal probability density function and droughts occurrence probability in all stations is also more than wetness occurrence probability. In addition, frequency of severe drought occurrence in relation to slight drought is less. The short – term droughts have most frequency and in some of the stations, there are irregularities in probability distribution of severe and extreme droughts (i.e. Sadesephidroud and Gilevan with severe drought occurrence probability 11.39% and 21.39%). Besides, frequency of drought periods are reduced from low intensities (0 to -0.99) to higher intensities (-1.5 to -1.99 or more) except Paroudbar, Sadesephidroud, Ghorbanalimahale and Gilevan Because the frequency of droughts in four stations mentioned above ($-1.5 \geq SPI \geq -1.99$) are increased in relation to other stations and droughts occurrence probability ($-1.5 \leq SPI \leq 1.5$) in most stations is higher than 85% and 90% (except Ghorbanalimahale). Occurrence probability of drought and wetness out of defined range ($-1.5 > SPI > 1.5$) in all stations is variable between 10 to 20%. Thus, the occurrence probability of slight to moderate droughts has been more than severe and extreme droughts and there is a possibility that the one drought or wetness will occur with intensity more than defined range during the 8 to 10 months. The sequence of drought indicated regular fluctuations of this phenomenon in stations because the drought has occurred with various intensities in the area and by regard to local factors intensities are somewhat variable. In addition, relationship between duration -frequency is nonlinear decreasing trend in all stations because in spite of reduction in frequency from 1 to 9 months, the second peak in drought frequency was seen in months 4 and 5. The correlation in many stations has been found more than 0.7 and relation of duration-frequency is logarithmic and follows it. Monitoring of this phenomenon in 19 stations indicated an accurate fitting of precipitation with gamma distribution function and with performed modeling; drought intensity could be estimated with this model (SPI). The correlation in adjacent stations is up and with increasing distance reduced, which it is importance in spatial-temporal difference of drought intensity. Finally, the spatial - temporal pattern of drought indicated that this phenomenon has been occurred in the area repeatedly. According to the researchers viewpoints (Tsakiris and Vangelis, 2004; Sirdas and Sen, 2003) awareness of occurrence, intensity and duration of drought is effective in forecasting it and droughts could be forecasted and managed better. In this study, the all drought characteristics are recognized in area. The main point in investigation of drought by SPI method is ignoring daily time scale for precipitation which in the EP method, this defect has been removed.

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