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Evaluation of drought selected stations by Standardized Precipitation Index (SPI) on Wetland Gandoman

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Abstract
Drought is a natural reduction in the occurrence of continuous rainfall in the period of time that usually lasts for a season or more, and its effects impose irreparable damages to the human population, animals, plants and the environment every year in different climates. The aim of this study was to evaluate and compare the impact of meteorological drought by standardized precipitation index [SPI] on different time scales of the selected stations on wetlands Gandoman. in order to, the intensity and frequency of the drought of SPI3, SPI6 and SPI9 by monthly precipitation data over a 19 years statistical period from 1994 to 2012 were determined. And zoning maps was drawn based on the SPI%. Graphical method was used to analysis of the trend of changes the SPI12 and annual discharge average data. The results showed that all stations have been faced with the extremely and or very severe drought by the SPI3 in 1999. This situation occurred by SPI6 and SPI9 in 2008. SPI3, SPI6 and SPI9 showed severe wet at 2006 for all stations. The zoning maps of SPI% showed that Wetland Gandoman up to 29-35.5% by SPI3%, 25-31.5% by SPI6% and 26-29% by SPI9% has been affected by drought. Maps of different scales of SPI% caused the different directions in expanding drought. Trend changes was alternating by drought (SPI12) and the average annual discharge data and increasing the drought was accompanied by the reduction in discharge and vice versa.

Keywords: Drought, Standardized Precipitation Index (SPI), Time scales, Wetlands Gandoman

Introduction

Drought is a widely occurring phenomenon that arises from considerable deficiency in precipitation [1]. Drought is commonly defined as a below-normal water availability [2, 3] [4,5,6,7, 8].It affects and damages natural habitats, ecosystems, and many economic and social sectors [9]. Drought is a subtle and slowly-developing phenomenon, and it is difficult to declare the onset and end of drought with accuracy [10, 11]. The spatial extent of droughts is usually much greater than that of other natural hazards and the impacts are generally non-structural and difficult to quantify [12]. Wilhite and Glantz [4] defined four types of drought: meteorological or climatological, agricultural, hydrological, and socioeconomic. The definitions are generally accepted in the literature of drought science e.g. American Meteorological Society [13]. All droughts begin as meteorological droughts caused by precipitation deficits. A lasting meteorological drought can develop quickly into soil moisture shortage which results in reduction of agricultural production (agricultural drought). A prolonged meteorological drought can also develop further into hydrological drought – a deficit in surface water and/or groundwater supply, which reduces stream flow, groundwater, reservoir, and lake levels. Socioeconomic drought is defined in term of its consequences, associating with the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological drought [4].

Meteorological droughts indices are probably the most widely used indices in the drought literature. Many meteorological drought indices have been developed, including Palmer Drought Severity Index (PDSI) [14], the Drought Severity Index (DSI) [15], and the Standardized Precipitation Index (SPI) [16].
SPI has been widely used to evaluate drought events worldwide [16-18]. It is an index based on the probability of precipitation for any time scale. In addition, SPI is relatively simple, spatially consistent, and temporally flexible, thus making this index more reliable for providing early warning of drought and its severity and well suited for risk management [18-20]. The standardized precipitation index (SPI) [21] is often used to monitor moisture supply conditions
Wetlands are the aquatic-terrestrial ecotones that provide habitats for many species [22,23,3]. Changes in precipitation patterns can influence wetland hydrology by altering the timing and amount of atmospheric and groundwater inputs, which alters important abiotic features [e.g., water depth, solute concentration, temperature, drying rate of exposed substrates] that influence the composition of wetland plant, invertebrate, and vertebrate communities [24]. Wetland drought may not be linked to changes in local precipitation patterns, but could be more strongly related to recharge in distant regions with different climatic regimes, such as mountain headwaters [3]. Drought not only affects plants, aquatic animals and microorganisms in wetlands [25-28], but also influences the redox state of some elements, such as sulfur [29]. Drought changes the performance of wetland functions dependent on maintenance [ecosystem survival] flows [30]. Assessment of water resource variations is a pre-requisite to understand and adopt appropriate management strategies with the aim to avoid adverse environmental effects and reconcile conflicts between users [31]. Sorenson et al. [32] estimate the effect of climate change on wetlands in the north central United States Using the Palmer Drought Index (PDI). Withey and Cornelis van Kooten [33] studied the effect of climate change on optimal wetlands and waterfowl management in Western Canada. They relied on the Standardized Precipitation Index (SPI), which is a popular drought index based solely on precipitation. Bethke and Nudds [34] and Adams [2] argue that the best indicator of wetlands in the Canadian PPR is precipitation in the previous year.
The purpose of this study was to evaluate the effects of drought in the Gandoman wetland. The Standardized Precipitation Index (SPI) used to analysis spatial and temporal drought, to detect on a regional basis, drought frequency, drought intensity and drought duration. Trends of the number of wet and dry months decided by SPI were detected with Mann-Kendall technique.

2. Materials and methods

2.1 Study Region and Data

Gandoman wetland as a basin catchment of AqBolagh is located near the Choghakhour wetland in the Borujen city of Chaharmahal va Bakhtiari province. This wetland received the part of water outputted of the Choghakhour wetland. Standing water covers is about 700 hectares in the wetlands. The study area is located in the 51^0 3' to 51^0 6' longitude E with the latitude N of 31^0 48' to 31^0 51'. The region covers an area of 15.45 square kilometers (Fig 1).
Meteorological data required for this study were obtained from 5 stations (Table 1).
Gandoman wetlands located in the Borujen city, the average annual precipitation in the station was 32/253 mm in the period 1988-2013. Maximum of the annual precipitation in the water years of 2006 was equal to 393 mm, and a minimum of 112 mm related to the water years of 1999. More than 70% of the precipitation is happening in winter and autumn seasons in the Gandoman wetlands. Temperature is one of the main factors in the diagnosis of dry and wet periods. The average minimum temperature is positive in the 25 years period from 1988 - 2013 in April to September. The minimum temperature in other months of the year was negative. In this period, the mean maximum absolute temperature reached over 30 ° C in the months of July and August. It was during the months of January and February to 5C°.

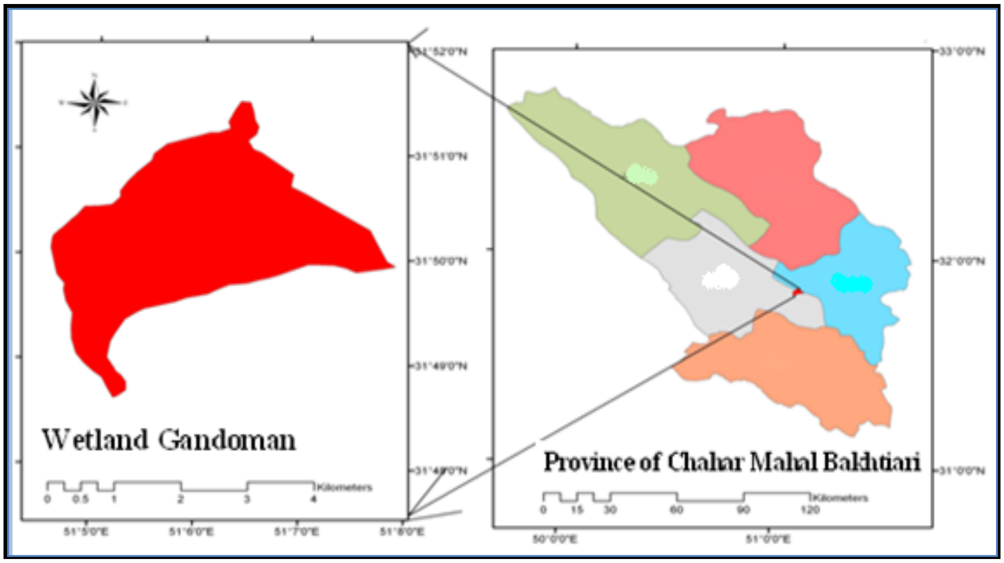

Figure 1: The study area in Chahar Mahal Bakhtiari

Table 1: Situation from synoptic stations

station	Longitude	latitude	Altitude
Boroujen	$51^{0}18'$	$31^{0}59'$	2260
Saman	$50^{0}56'$	$32^{0}27'$	2075
Lordegan	$50^{0}50'$	$31^{0}30'$	1611
MalKhalife	$51^{0}15'$	$31^{0}18'$	1762
Naghan	$50^{0}44'$	$31^{0}56'$	2045

2.2 Standardized Precipitation Index (SPI)

Usually, expressions of precipitation departure from normal over some period of time reflect one of the primary causes of drought [35]. This section presents an analysis of droughts that have occurred in the region. The standardised precipitation index (SPI) method developed by is used for the temporal analysis of droughts. This method is simple and straight forward since precipitation is the only meteorological variable used. An advantage of this method is the utility of various time periods in drought assessments. A standardized precipitation series is calculated using the arithmetic average and the standard deviation of precipitation series. For a given X1, X2, Xn series, the standardized precipitation series, SPIi, is calculated from the following equation:

$$\mathrm{SPI_i} = \frac{X_I - \bar{X}}{S_x} \qquad [1]$$

where$\bar{X}$ is the average and S_x is the standard deviation of the precipitation series. Negative values obtained from this
equation indicate precipitation deficits (drought events), while positive values stand for precipitation excesses (wet events). In its original version, a long-term precipitation record at a station is fitted to a probability [gamma] distribution, which is then transformed into a normal distribution so that the mean SPI is zero. The index values are therefore the standardized deviations of the transformed rainfall totals from the mean. The SPI may be computed with different time steps (1 month, 3 months, 24 months). to facilitate the assessment of the effects of a precipitation deficit on different water resources components (groundwater, reservoir storage, soil moisture, streamflow). Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Drought periods are represented by relatively high negative deviations. Normally, the ‘‘drought’’ part of the SPI range is arbitrary split into moderately dry (-1.0 > SPI > -1.49), severely dry (-1.5 > SPI > -1.99) and

extremely dry conditions (SPI < -2.0). A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again. Six different drought categories are defined for Iran by as given in Table 2.

Table 2: Probability of occurrence and classification and evaluation of different standardized precipitation indices

values category of SPI	SPI values category
>2	Extremely wet
1.5-1.99	Severe wet
1-1.49	Moderate wet
0.5-0.99	Slight wet
-0.49-(+0.49)	Normal
-0.99- (-0.5)	Slight drought
-1.49- (-1)	Moderate drought
-1.99-(-1.5)	Severe drought
-2>	Extremely drought

For this study, precipitation data of stations, Borougen, Lordegan, Naghan, Saman, Mal Khalifeh were collected over 19 years from 1993 to 2012. Using the above data calculated standardized precipitation index [SPI] with different time steps, 3 month, 6 months and 9 months. In order to calculation of standardized precipitation index (SPI) used the software SPI_SL_6.exe. Zoning maps standardized precipitation index (SPI) plotted with Software ArcGis 9.3. Software from SPSS version 19 was used for drawing graphs. The trend of changes using graphical method of drought and discharge determined by the standardized precipitation index (SPI12) and the annual average discharge. So that on the basis of nearby the weather station to hydrometric stations; be drawn the change trend of SPI12 of Boroujen with average discharge data of TagargAb, Malkhalifeh with KorehBas, Lordegan with Armand and Zarin Derakht, Saman with KohSokhteh and Tangedarkesh o varkesh and Naghan with Behesht Abad, KohSokhteh and Tangedarkesh o varkesh.

3. Results

3.1 Changes of the standard precipitation index(SPI3, SPI6 and SPI9)

The values of SPI index 3, 6 and 9 months shows the changes of the the standard precipitation index during 1994 - 2012 in the area of Boroujen (Fig 2).

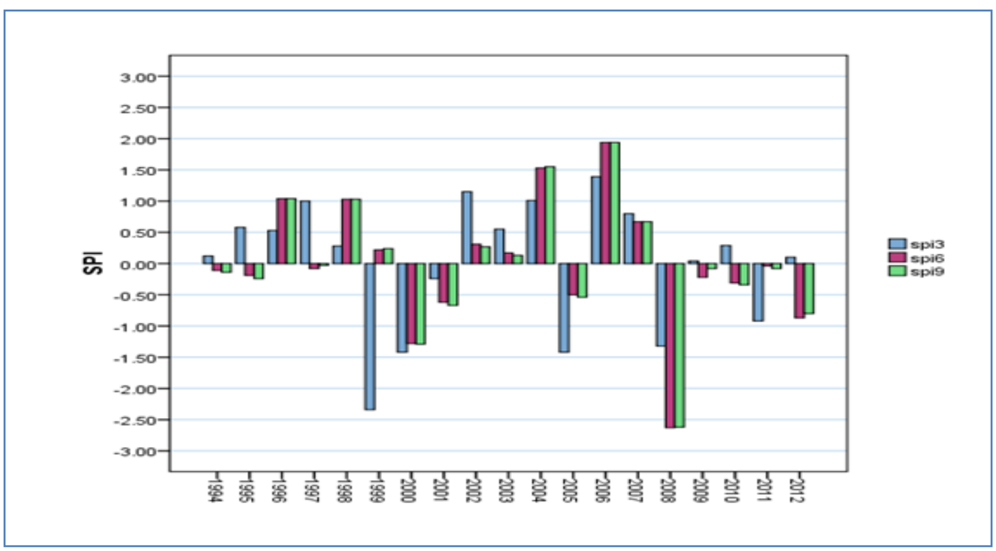

Figure 2: Changes of the Standardized Precipitation Index (SPI3, SPI6, SPI9) in Borujen stations (1994 – 2012)

Based on index values of SPI in this statistical period, the drought was extremely on the SPI3 of 1999. As well as the extremely drought was obtained in 2008 by SPI6 and SPI9. Borujen station was confronted with moderate drought in all three time scales (SPI3, SPI6 and SPI9) in 2000. Moderate SPI3 related to the years of 2005 and 2008. Values of SPI6 and SPI9 showed the slightly drought in 2001, also SPI3 was normal. Slightly drought obtained by SPI3 of 2011, but slightly drought in 2012 related to SPI6 and SPI9. In regard to SPI3, SPI6 and SPI9 the situation was normal in 1994, 2009 and 2010. Values of index SPI of the other years studied showed different severity of wet. Given the amount of SPI6 and SPI9 located in status of severe wet 2006 year.
Changes of the standardized precipitation index (SPI3) provided of 1994-2012 in Lordegan stations (Fig 3). Situation of extremely drought was obtained by SPI6 and SPI9 in 2008. Drought situation in the station indicates that severe drought with SPI3 obtained for 1999. Moderate drought in 2000 and 2008 created of SPI3. Drought was slightly of SPI6 and SPI_9 in 1995, 2000, 2009 and 2012 as well as, slightly drought observed of SPI3 in 2011. In other years, Normal or wet situation obtained by calculating SPI so that SPI3 was indicative of severe wet of 2002.

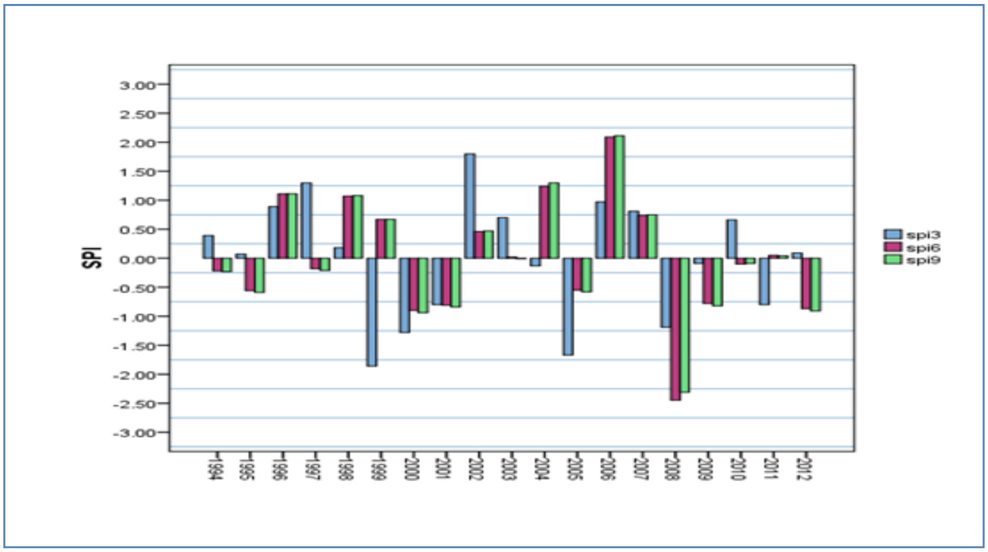

Figure 3: Changes of the Standardized Precipitation Index (SPI3, SPI6, SPI9) in Lordegan stations (1994 – 2012)

SPI6 and SPI9 revealed very severe wet of 2006.
Changes of the Standardized Precipitation Index (SPI3, SPI6, and SPI9) in Samna stations (1994 – 2012) (Fig 4) revealed that extremely drought of SPI6 and SPI9 in 2008. 1999 and 2008 of SPI3 faced with severe drought. Moderate drought observed of SPI3 in 2000. The calculation of SPI indicated that drought is moderate for all three time scales in 2001. Slightly drought obtained of SPI6 and SPI9 in 2000 and 2012. Drought was slightly of SPI3 in 2011. In cases where the Standardized Precipitation Index [SPI] was higher than -0.5 showed the normal or wet station. In this station the very severe wet related to 2006 of SPI6 and SPI9. Very severe wet of SPI6 and SPI9 was belonged to 2006.
Changes of the Standardized Precipitation Index (Fig 5) show that extremely drought happened by SPI6 and SPI9 in 2007 and SPI3 and SPI6 in 2008. Severe drought related to 1999 of SPI3. Drought was moderate of SPI9 in 1994, SPI6 in1999, SPI3 in 2011 and SPI9 in 2012. Slightly Drought observed of SPI3 in 1994, SPI9 in 1997, and SPI6 in 2000. In other cases, the situation was normal or wet. Very severe wet obtained of SPI9 in 1998 and SPI6 in 2005. The moderate drought estimated by SPI9 in 1994, SPI6 in 1999, SPI9 and SPI6 in 2000 and SPI3 in 2011. Drought was slightly of SPI3 in 1994, SPI9 in 1997, SPI3 in 1999 and 2000, SPI3 and SPI6 in 2001, SPI9 in 2005, SPI3 and SPI6 in 2011. In other cases, SPI provided the normal or wet situation at this station.
Change of the Standardized Precipitation Index (SPI) (Fig 6) suggests that the severe drought in Naghan stations related to SPI6 and SPI9 in 1994 and SPI3 in 1999. SPI6 and SPI9 estimated the moderate drought for 2000. Calculation of the SPI6 and SPI9 in 1999, SPI3 in 2004, SPI6 and SPI9 in 2008 and 2009 revealed the slightly drought. The normal and wet situation found in other cases so that, severe wet was calculated by the SPI6 and SPI9 in 2005 and as well as SPI3 in 2006.

Figure 4: Changes of the Standardized Precipitation Index (SPI3, SPI6, SPI9) in Saman stations (1994 – 2012)

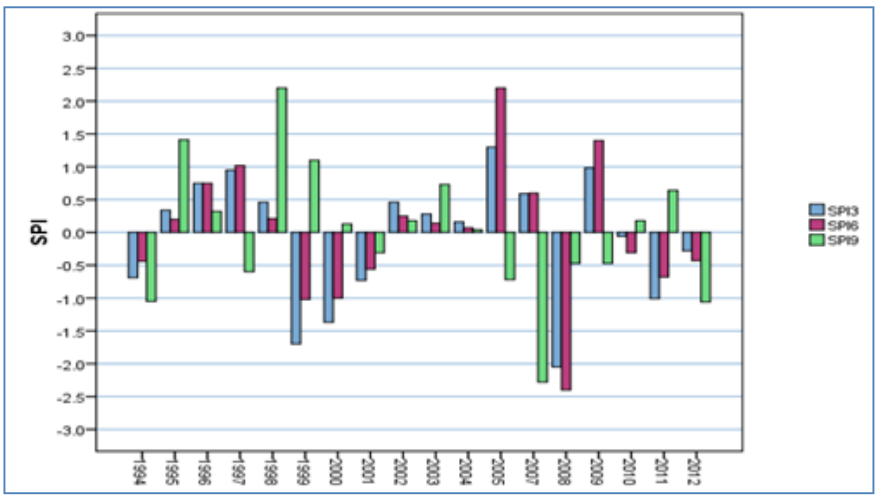

Figure 5: Changes of the Standardized Precipitation Index (SPI3, SPI6, SPI9) in MalKhalife stations (1994 – 2012)

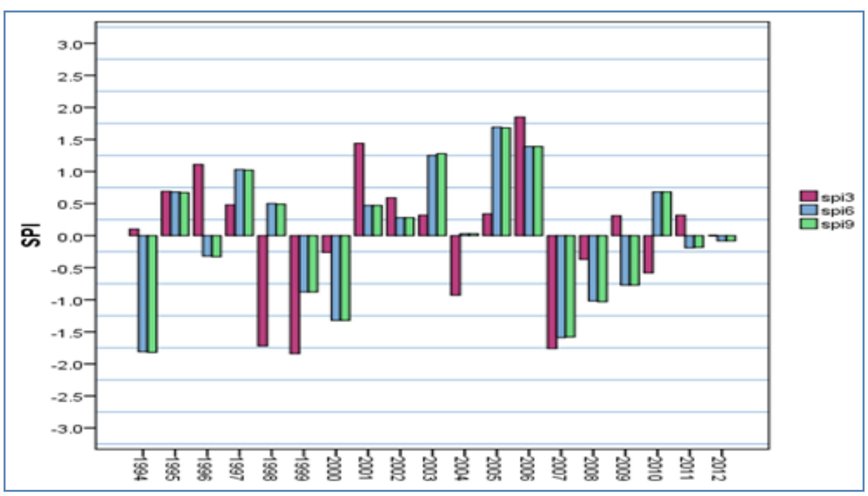

Figure 6: Changes of the Standardized Precipitation Index (SPI3, SPI6, SPI9) in Naghan stations (1994 – 2012)

3.2 Zoning maps of drought

Zoning maps of the drought were drawn on the Percent of standard precipitation index (SPI3%, SPI6% and SPI9%) of five-station Borujen,Lordegan, Saman,MalKhalife and Naghan in the statistical period 1994 to 2012. Table 3 shows the percent of classes of the severity drought of selected stations in wetlands Gandoman.

Table 3: Percent of the standard precipitation index (SPI) of selected stations on wetlands Gandoman

Severity drought classes	SPI3%	SPI6%	SPI9%
Extremely drought	2-2.5	1-1.5	2-3
severe drought	2-3	2-4	4-6
Moderate drought	12-15	12-14	6-8
Slight drought	13-15	10-12	10-12
Normal	40-45	40-45	40-45
Slight wet	15-20	6-8	20-25
Moderate wet	5-6	8-10	4-8
severe wet	1.7-3.4	4-8	3-4
Extremely wet	3.3.3	2-4	4-5.3

3.2.1 Situation drought (SPI3%) on Gandoman wetlands

In general, on the based percent of drought the Gandoman wetlands faced with 2-2.5% extremely drought. The extremely drought reached to 3-3.5% in Naghan station (Fig 7). Situation of severe drought based on percent was 2-3% in the Gandoman wetlandsas well as the severe drought reached to 6-6.8% in Lordegan station (Fig8). Situation of the Moderate drought reached to 12-15 % in Gandoman wetlands (Fig 9). The slightly drought situation in Gandoman wetlands was 13-15%. Wetland Gandoman 40-45% revealed the normal situation for drought according to the percent (Fig 10).

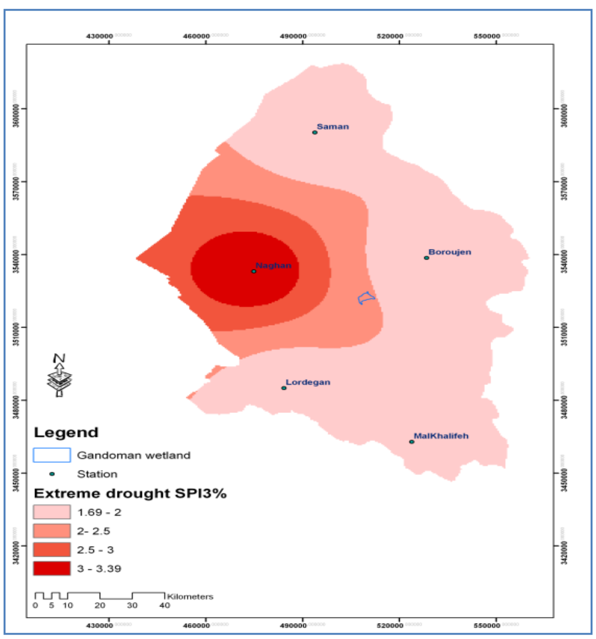

Figure 7: Zoning map of very severe drought SPI3%

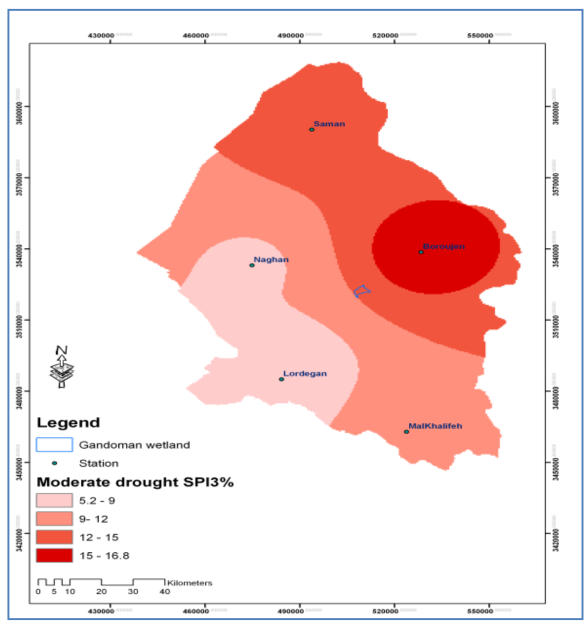

Figure 9: Zoning map of moderate drought SPI3%

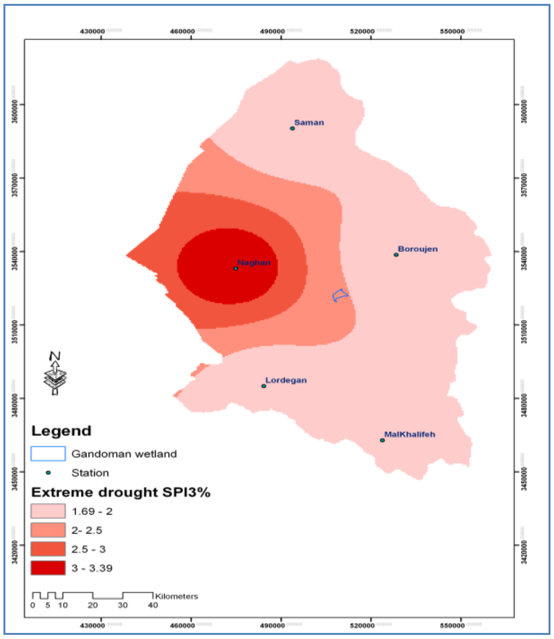

Figure 8: Zoning map of severe drought SPI3%

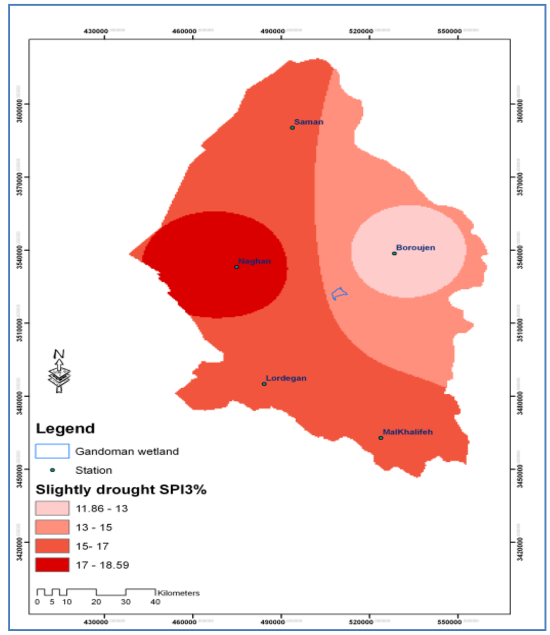

Figure 10: Zoning map of slightly drought SPI3%

3.2.2 Situation drought (SPI6%) on Gandoman wetlands

Based on the calculation of the percentage of the drought (SPI6%) was prepared zoning maps. According to this maps of wetland Gandoman was faced with 1-1.5% extremely drought, 2-4% severe drought, 12-14% moderate drought, 10-12% slightly drought and the normal condition was 40-45% (Fig 11,12,13 and 14).

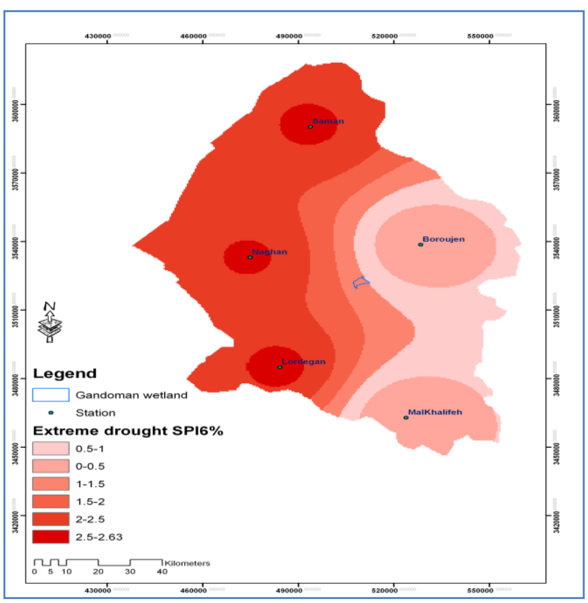

Figure 11: Zoning map of very severe drought SPI6%

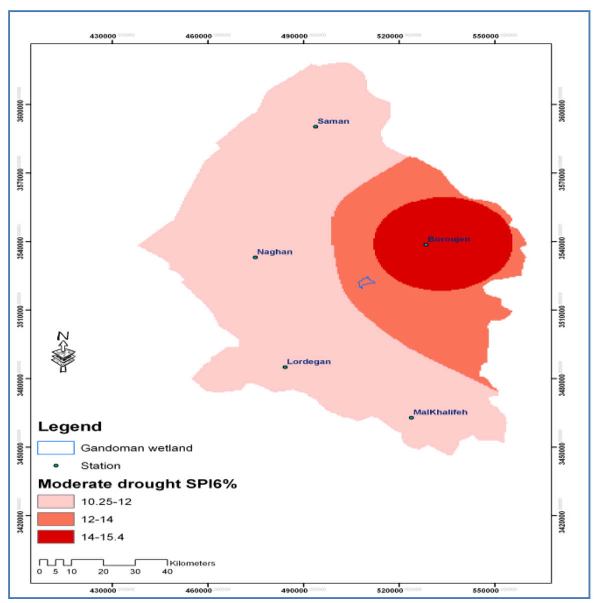

Figure 13: Zoning map of moderate drought SPI6%

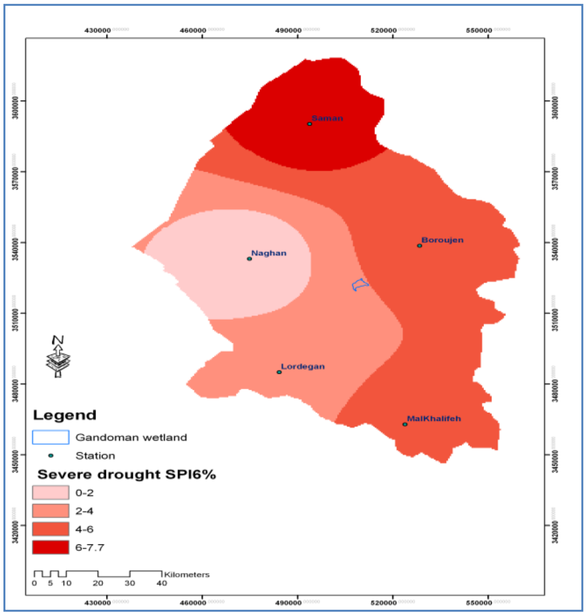

Figure 12: Zoning map of severe drought SPI6%

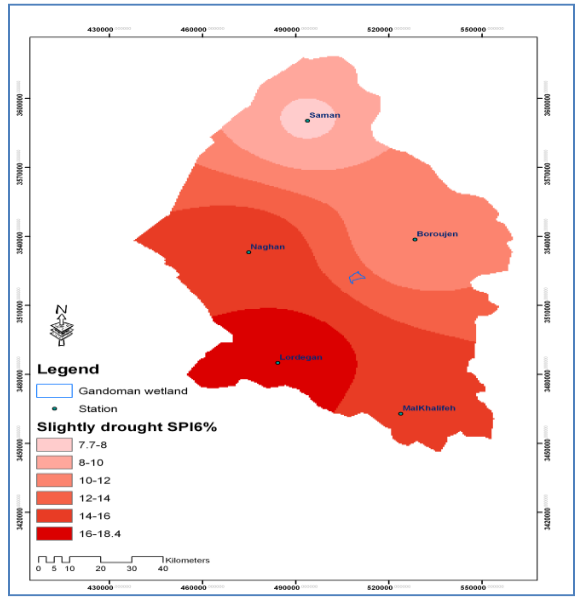

Figure 14: Zoning map of slightly drought SPI6%

3.2.3 Situation drought (SPI9%) on Gandoman wetlands

The zoning maps of drought percent (SPI9%) indicated that wetland Gandoman included 2-3% extremely drought, 4-6% severe drought, 6-8% moderate drought,10-11.7% slightly drought. As well as zoning maps prepared on the basis of SPI9% showed the 45-40% normal status for wetlands Gandoman (Fig 15,16,17,18 and Table 3).

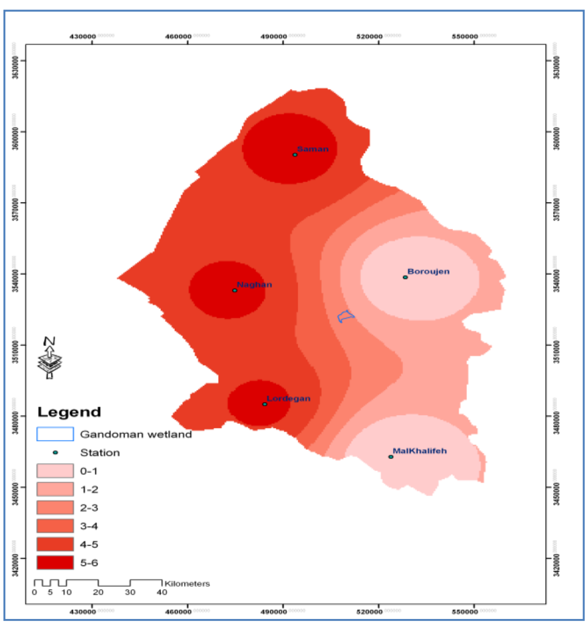

Figure 15: Zoning map of extremely drought SPI9%

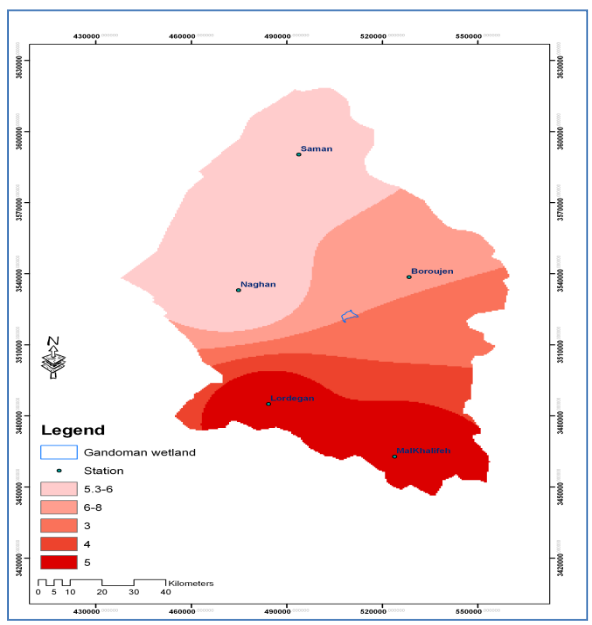

Figure 17: Zoning map of moderate drought SPI9%

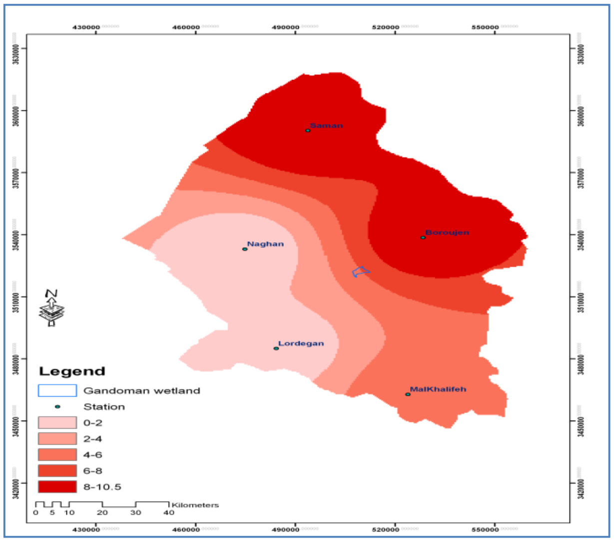

Figure 16: Zoning map of severe drought SPI9%

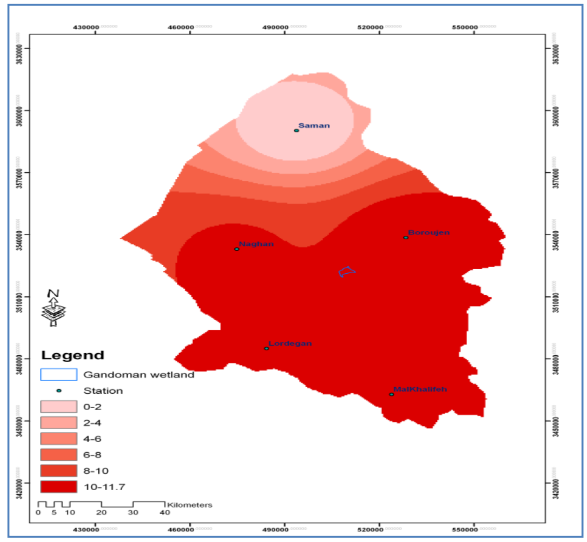

Figure 18: Zoning map of slightly drought SPI9%

3.3 Trend changes of annual average discharge data with SPI12 (1994 to 2012)

Trend discharge changes of TagargAb stations with SPI12 of Borujen station showed that the drought and discharge alternately increased and decreased in this statistical period so that, with increasing drought can be seen reduction of discharge and vice versa (Fig 19). Trend discharge changes of Lordegan station with discharge data of Zarrin Derakht found that matches the trend of change of discharge and drought SPI12. Trend changes SPI12 of the Lordegan meteorological station with discharge data the Armand showed that with a little change in the drought the changes of discharge are significant. Trend of changes obtained by the Zarrin Derakht was more accurate (Fig 20). Trend changes of the Malkhlifeh meteorological station with discharge of Koreh Bas showed alternatively increasing and decreasing (Fig 21) as well as the trend of change SPI12 of Saman station with discharge data of Kohe Sokhteh and Tangedarkesh o Varkesh showed alternatively increasing and decreasing (Fig 22). Trend discharge changes of stations Kohe Sokhteh and Tangedarkesh o Varkesh and Behesht Abad compared with SPI12 of Naghan. All stations clearly showed discharge changes compared with the drought however, changes in the discharge of Behesht Abad Station is much more the drought in Naghan Station (Fig 23). The continuing drought is minimal at all stations.

4. Discussions

Comparison of the changes trend and the frequency of droughts in selected stations showed that after the two or three consecutive wet years happen two or three consecutive dry years as well as drought occur immediately after the wet years and vice versa. Severe or very severe drought was occurred by SPI3 at all stations. This situation caused by a drastic reduction in rainfall in spring. Very severe drought and severe by the SPI3, SPI6 and SPI9 observed in 2008 for all stations except the station Naghan. Severe wet belonged to 2006 in all three time scales. Zoning maps based on percent of the standardized precipitation index (SPI) in all three time scales showed that 45-40% situation normal in Gandoman wetlands. The situation of wetlands Gandoman drought of SPI3 was in the range 29-35.5% and the range 25-31.5% of drought was obtained of SPI6% as well as the drought range of SPI9% was equal to 26-29%. In the case of the SPI3% the very severe and severe drought located in range of 2-5.5%,3-5.5% of SPI6% and 6-9% of SPI9%. So droughts of extremely and severe in scale 9 months (SPI9%) showed higher occurrence in Gandoman- wetland however, the seasons of spring and summer caused the droughts of the severe and very severe to 5.5%. The trend of increasing and decreasing changes of discharge and SPI12 observed in stations. The trend of changes showed that the continuing drought is minimal. One of the reasons is due to its proximity to the mountains and elevated regions. This caused the regime snow rain, and this gradual melting snow will reduce the severity and duration of drought in other seasons.

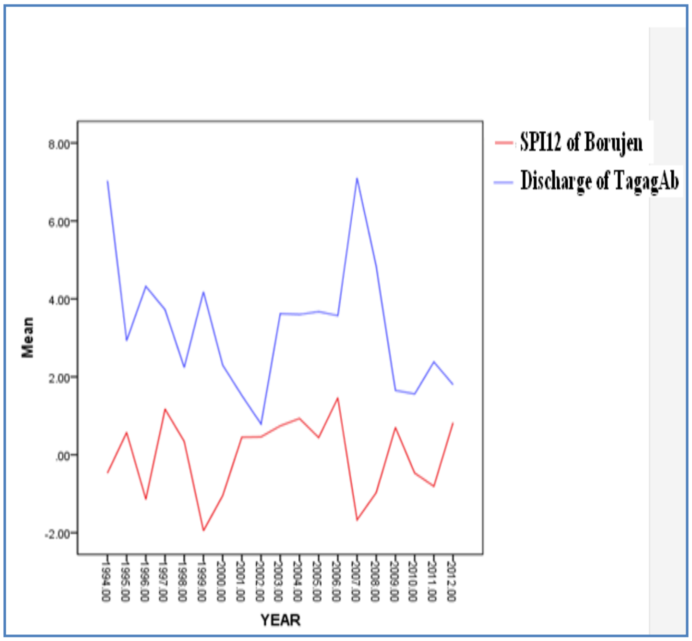

Figure 19: Trend of changes SPI12 with annual average discharge

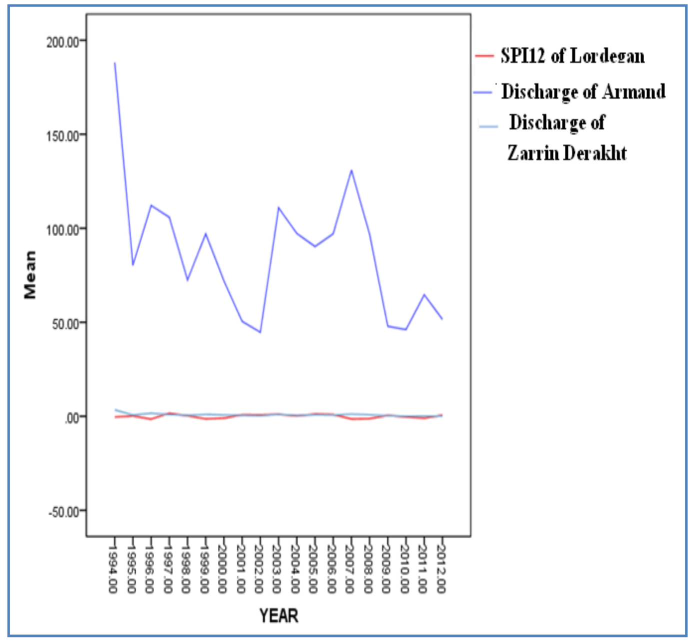

Figure 20: Trend of changes SPI12 with annual average discharge

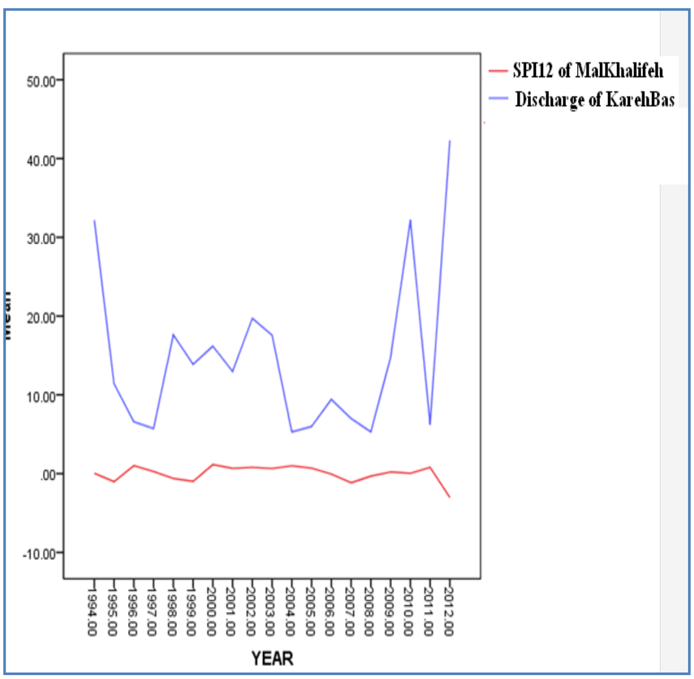

Figure 21: Trend of changes SPI12 with annual average discharge

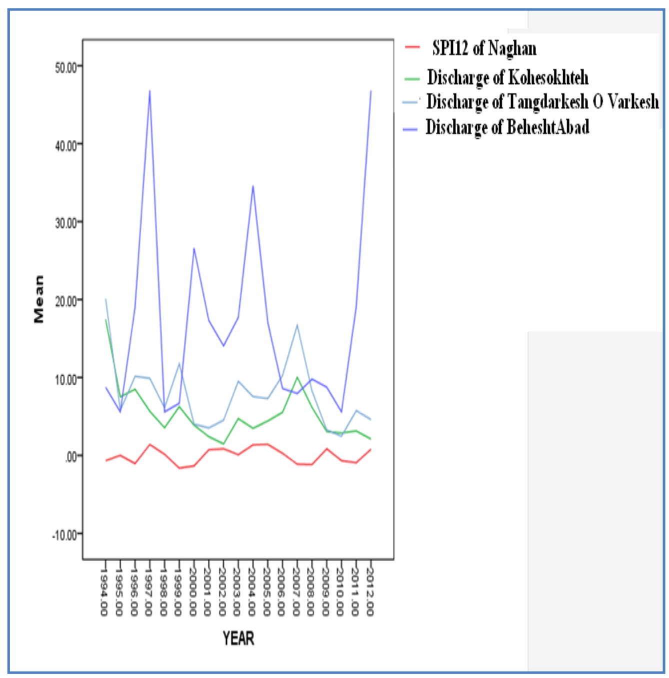

Figure 22: Trend of changes SPI12 with annual average discharge

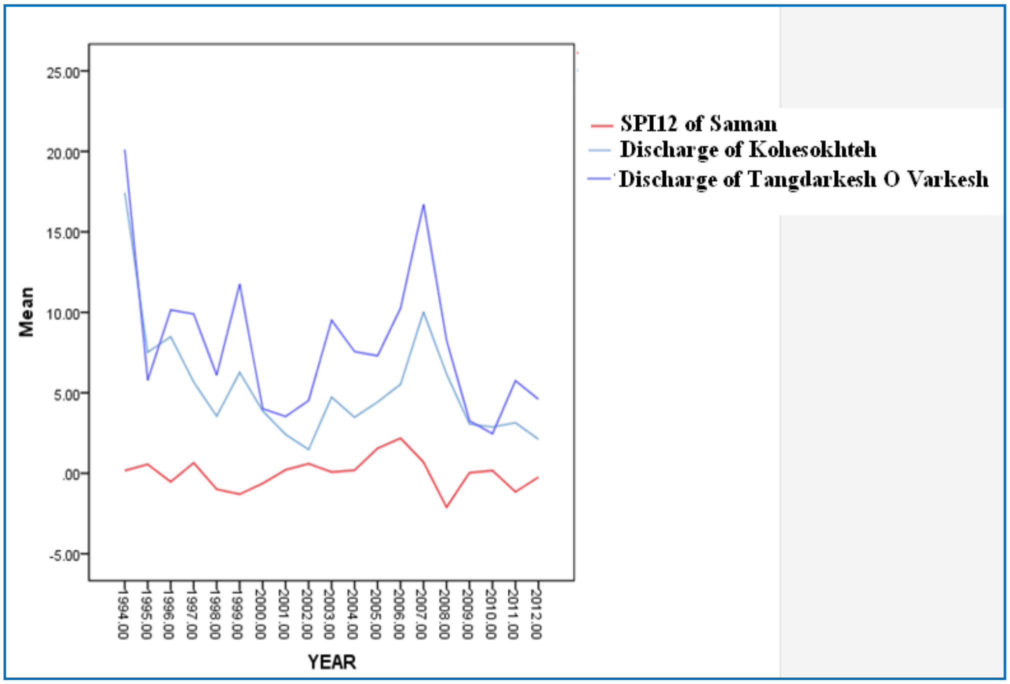

Figure 23: Trend of changes SPI12 with annual average discharge

Conclusion

Changes of the Standardized Precipitation Index (SPI) in three time scale SPI3, SPI6 and SPI9 examined of 5 synoptic stations of Borujen, Lordegan, Malkhalifeh, Saman and Naghan calculated during the period from 1994 to 2012. The results showed fluctuations of the extremely drought and wet by SPI in different stations. All the stations had been affected by drought at different time scales. Calculation of standardized precipitation index in three different time scales (SPI3, SPI6 and SPI9) in different stations showed that station had been moderately wet from 1996 to 1998. And in 4 stations (Lordegan, MalKhalifeh, Naghan and Saman) observed the severe droughts in the scale 3 and 6 months (SPI6 and SPI9) in 1999, in the same year Borujen Station faced with extremely drought in scale 3 months (SPI3). The slightly drought in 2009 and 2012 observed on scale of 3, 6 and 9 months of the Borujen and Lordegan stations. Generally, the use of standardized precipitation index at different time scales showed that the droughts and wet periodically repeated in the region. The zoning maps of the SPI% showed that events the extremely droughts of SPI3% are reached to the maximum limit in the West to the South-West. It was greatest in the time scale of 6 months (SPI6%) in the North-West to South-West and the North. In the North-West to South-West and North-East the largest expansion of extremely and severe drought related to SPI9%. Trend of changes of the average discharge data and SPI12 showed the alternating changes of increasing and decreasing so that , increasing the drought coincided with reduction in discharge, and vice versa.

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