Journal of the Earth and Space Physics, Vol. 42, No. 4, Winter 2017, PP. 49-61

Spatial analysis and investigation of Tele-connection patterns with drought in central Iran

Fatemi, M.[1], Omidvar, k.[2*], Mesgari, E.[3] and Narangifard, M.[4]

1. Ph.D. Graduated, Department of Physical Geography, Yazd University, Iran
2. Professor, Department of Physical Geography, Yazd University, Iran
3. Ph.D. Students, Department of Physical Geography, University of Sistan and Baluchestan, Zahedan, Iran
4. Ph.D. Students, Department of Physical Geography, Yazd University, Iran

(Received: 16 Mar 2016, Accepted: 18 Oct 2016)

Abstract

This study, by adopting an environmental approach to atmospheric circulation, estimates drought periods over a 20-year period (1992-2011) in 21 synoptic stations in Kerman, Yazd and Isfahan provinces, which share a long-term statistical period, using Standardized Precipitation Index (SPI). The data pertinent to 18 teleconnection patterns were derived and compared with climatic data of provinces under study and the relationship between major droughts in the region and these patterns was evaluated in accordance with correlation methods and multivariate regression model. According to the results, a total of 37.42% of annual SPI variation in Isfahan province, 51.09 % of SPI variation in Kerman province and 42.17% of SPI variation in Yazd province can be explained by these teleconnection patterns. Finally, the multivariate Scandinavian pattern (SCA) in Isfahan, East Atlantic (EA) pattern in Kerman and Tropical Southern Atlantic (TSA) pattern in Yazd were found to be the most effective patterns in explaining annual SPI changes in central Iran.

Keywords: Tele-connection, Standardized precipitation index, Kriging, Correlation, and regression models, Central Iran.

1. Introduction

Precipitation is a key meteorological element so that its decline from a standard threshold in a specific period can lead to the occurrence of drought. Drought is the most important extreme climatic phenomenon that gives rise to a plethora of environmental issues in most countries, especially Iran, which highlights the significance of annual and intra-decade changes for the improvement of water resources planning and management (Khorshiddost and Ghavidel Rahimi, 2008). Precipitation change at the global level poses serious risks to food security and economic development in the world.

Large parts of Iran, including the central terrains, being located in the arid and semi-arid climate, receive little rainfall and therefore are constantly faced with water shortages. The most important feature of the Iranian climatic regions is extreme changes in rainfall with precipitation oscillation playing an important role in limiting access to water resources (Ghavidel Rahimi et al., 2014). In connection with the drought events from a climatic point of view, understanding the reasons for this climatic variability that triggers such chronic disasters are of utmost importance.

The simultaneous deployment of a series of large-scale climatic patterns in the northern hemisphere called northern hemisphere teleconnection patterns (NHTP) that could be a key to the mystery of drought (Khosravi, 2004). NHTP are used to predict mean climatic conditions over a period, usually for several months or a year ahead. In other words, a combination of atmospheric and slow-paced changes in the ocean allows predicting climatic conditions over monthly, quarterly, yearly and even decade-long periods (Uppenbrink, 1997). The simultaneous NHTP between oscillations of climatic elements at a region are defined in terms of pressure and temperature variations at the sea level in other geographical regions (Wallace and Guzzler, 1981). Given that NHTP provides deeper understanding about the origins of precipitation and its fluctuations that cause drought and wet years. Efforts have been dedicated to identify effective models of

*Corresponding author: E-mail: komidvar@yazd.ac.ir

transplantation in recent years (Khorshiddost and Ghavidel Rahimi, 2008). There has been a host of invaluable studies on the effect of oscillations in rainfall patterns and drought in Iran and other parts of the world.

Studies have shown that the negative phase of the NAO pattern combined with an increase in winter precipitation and temperature reduction as well as its positive phase have contributed to the reduced rainfall, increased temperature and emergence of winter throughout Turkey (Türkeş and Erlat, 2005). Yetemen and Yalcin (2009) studied the relationship between the average monthly temperatures of Afyon region in Turkey and indicators of teleconnection patterns of North Caspian Sea, showing that in the positive phase of the North Caspian Sea pattern, the temperature have risen in mountainous area of Afyon region. Kutiel (2011) investigated the effects of North Caspian Sea Teleconnection Patterns on temperature and precipitation regimes in the Middle East concluding that the Middle East temperature regime was sensitive to different phases of North Caspian Sea Teleconnection Patterns. Global warming leads to a gradual deceleration of Walker Circulation to consolidate the flux of water vapor in the convection zone. If tropical oceanic regions are cooler, the Walker Circulation will be intensified to compensate for moisture flux (Di Nezio, 2011).

Rimkus et al. (2014) explored the climate patterns during drought periods in Lithuania. The results showed that the drought in the Baltic region was related to atmospheric circulation patterns. Negative phases of NAO/AO have caused severe droughts in the region. Peng et al. (2014) studied the probability of seasonal rainfall in China using a large-scale oceanic-atmosphere index on a monthly basis. The results showed that sea surface temperature index in West Pacific and Indian Oceans was more effective than El Niño-Southern Oscillation Index in terms of its prediction power. Azizi (2000) investigated the relationship between El Niño and dry and wet periods in Iran, finding a relatively strong relationship between annual rainfall in Iran and the Southern Oscillation Index (SOI). The monthly study revealed that the highest correlation between the monthly precipitation in Iran and its simultaneous southern oscillation index were observed in October. Ghayour and Khosravi (2001a.b) explored some signs and effects of ENSO on rainfall in the summer and fall in the southeast of Iran, demonstrating that in summer and during warm phases, summer drought conditions tend to persist and rainfall reaches its minimum in summer but in cold phases, unlike autumns, wet and humid conditions are above the normal level. Ghayour and Asakereh (2001) studied the effect of teleconnection pattern on Iranian climate showing that North Atlantic Oscillation Index (NAO) and the Southern Oscillation Index (SOI) had a noticable influence on the temperature in Jask region.

Khosravi (2004) assessed 20 macro-scale atmospheric circulation patterns of the North Hemisphere with SPI drought indices in Sistan and Baluchistan province in Iran with respect to their presence and intensity during different seasons and revealed that POL, PDO, NP, NOI, MEL had the highest correlation with the annual SPI index. Khourshiddoust and Ghavidel Rahimi (2006) demonstrated a positive correlation between Multivariate ENSO Index (MEI) and rainfall in stations of Eastern Azerbaijan province, showing that in all four seasons, the correlation was only significant in fall and there was no relationship between precipitation and El Niño and La Niña phenomena in other seasons. Salahi et al. (2007) showed that there was a weak negative and significant correlation between the annual rainfall in Tabriz, Ahar and Jolfa stations and the North Atlantic oscillation, especially in pervasive wet and drought periods.

Halabian and Mohammadi (2012) explored the relationship between monthly temperature in Bandar Abbas, Bushehr, Isfahan, Sanandaj, Tehran and Mashhad stations and ENSO indicator. The results indicated that only in two or three months, the correlation in the southern stations (Bushehr and Bandar Abbas) was greater than that of northern stations (Isfahan, Mashhad and Tehran). Zare Abyaneh and Bayat Varkesh (2012) investigated the impact of ENSO on monthly and seasonal temperatures in the southern Iran. Shirmohammadi et al. (2012) examined the relationship between ENSO phenomenon and seasonal rainfall in Khorasan provinces. Yousefi and Hajjam (2012) investigated the impact of ENSO on the climatic parameters of temperature and precipitation in Qazvin Plain using sequential correlation analysis (SCA) and other statistical methods. The results showed that during El Nino, the mean rainfall was greater in fall and yearly periods, but the mean temperature was lower in various seasons and yearly phases. On the contrary, during the La Niña phenomenon, the annual and seasonal (especially fall) precipitations were lower and the mean temperature in yearly and seasonal periods were higher than the average long-term figures.

Ghavidel Rahimi et al (2013) studied the effect of North Caspian Sea Teleconnection Patterns on temporal changes of rainfall in southern coasts of Caspian Sea. Darand (2014) monitored drought events in Iran using Palmer Drought Severity Index (PDSI) and its connection to Atmospheric-Oceanic Teleconnection Patterns, concluding that teleconnection patterns in fall showed stronger correlation with drought in Iran.

In this study, considering the importance of the of intermittent drought phenomenon in central Iran, which is severely influencing the sensitive ecosystem and the various aspects of life, attempts have been made to explore the influence of north hemisphere teleconnection patterns on the severity and extent of the droughts in Iran.

2. Data and method

The data used in this study consisted of daily precipitation data derived from synoptic stations in Isfahan, Kerman and Yazd over a shared statistical period. Table 1 presents the details of the selected meteorological stations and Figure (1) depicts the scatter of stations across the country. Central Iran is a steppe-like plateau characterized by extremely wet climate in the Northern regions Based on climatological conditions in Iran, four different seasons are distinguished including spring (first of March to end of May), summer (first of June to end of August), autumn (first of September to end of November) and winter (first of December to end of February) (Shahabfar et al., 2012; Fatemi et al., 2015). Periods of drought were calculated in seasonal and annual scales over a 20-year period (1992-2013) in 21 synoptic stations in Kerman, Yazd and Isfahan provinces, which shared a long-term statistical period, using SPI index. The data related to18 teleconnection patterns were derived in comparison with climatic data collected from provinces, and based on correlation and multivariate regression models, the relationship between major droughts in the region and these patterns were identified (Table 2). The correlation coefficients were investigated at significance levels of 0.05 and 0.01 and ultimately the patterns affecting SPI was determined.

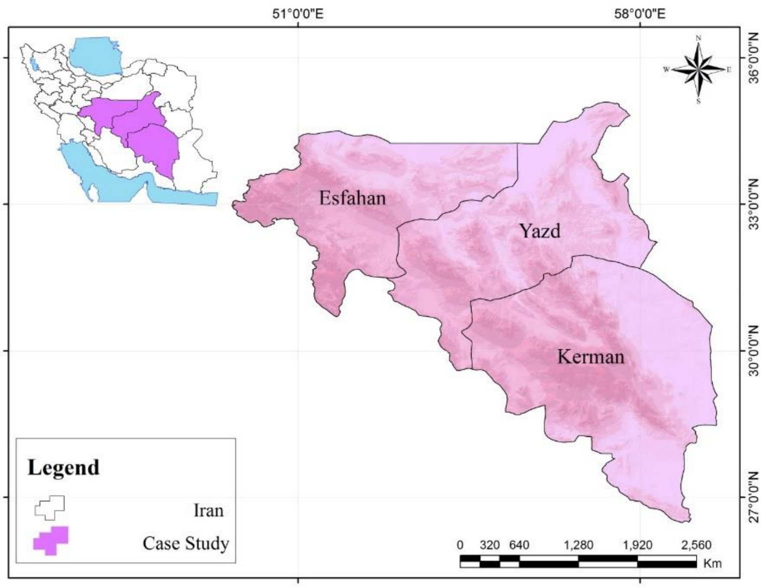


Figure 1. Study area including the related provinces

Table 1. Stations under study

Station	province	Longitude	Latitude	Height (m)
Khoor va Biabanak	Isfahan	°55 05'	°47 33'	845
Daran	Isfahan	°50 22'	°32 58'	2290
Eastern Isfahan	Isfahan	°51 52'	°40 32'	1543
Shahr Reza	Isfahan	°51 50'	°31 59'	1845.2
Kashan	Isfahan	°51 27'	°33 59'	982.3
Kabotar Abad	Isfahan	°51 51'	°32 31'	1545
Golpayegan	Isfahan	°50 17'	°33 28'	1870
Naeini	Isfahan	°53 05'	°32 51'	1549
Natanz	Isfahan	°51 54'	°33 32'	1684.9
Isfahan	Isfahan	°51 40 '	°32 37'	1550.4
Ardestan	Isfahan	°52 23'	°33 23'	1252.4
Anar	Kerman	°55 15'	°30 53'	1408.8
Baft	Kerman	°56 35'	°29 14'	2280
Bam	Kerman	°58 21'	°29 6'	1066.9
Sirjan	Kerman	°55 41'	°29 28'	1739.4
Shahrebabak	Kerman	°55 8 '	°30 6'	1834.1
Kerman	Kerman	°56 58 '	°30 15'	1753.8
Kahnouj	Kerman	°57 42'	°27 58'	469.7
Bafgh	Yazd	°55 26'	°31 36'	991.4
Robat Posht Badam	Yazd	°55 33'	°33 2'	1188
Yazd	Yazd	°54 17'	°31 54'	1237.2

Table 2. Teleconnection patterns under study

1. **Multivariate ENSO Index (MEI)**
2. **East Atlantic (EA)**
3. **Western Pacific (WP)**
4. **Eastern Atlantic / Western Russia (EA /WR)**
5. **North Atlantic Oscillation (NAO)**
6. **Tropical / Northern Hemisphere pattern (TNH)**
7. **Northern Oscillation Index (NOI)**
8. **Tropical North Atlantic (TNA)**
9. **Tropical South Atlantic (TSA)**
10. **Arctic Oscillation (AO)**
11. **Pacific / North American (PNA)**
12. **Pacific Transfer (PT)**
13. **Asia-Pacific, North Pacific (EP / NP)**
14. **Pacific Decade Oscillation (PDO)**
15. **Southern Oscillation Index (SOI)**
16. **Scandinavian pattern (SCA)**
17. **Nino pattern transfer (TNI)**

a. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is one of the most commonly used indicators of meteorological drought monitoring and has been used extensively in the literature (Rahmani et al., 2015). Among all drought indices, the Standardized Precipitation Index, SPI, is the most popular and is now widely used throughout the world for drought analysis (e.g. Hayes et al., 1999; Raziei et al., 2009; Ibrahim et al., 2010; Mirabbasi et al., 2013). The Standardized Precipitation Index (SPI) was used for identifying dry periods and statistical investigation (Equation 1). This index was developed by Mckee et al. (1993), based on the following relation:

$$SPI = (Pik - Pi) / S \quad (1)$$

Where Pik = Amount of precipitation in ith station in the kth observation (mm)

Pi = Long-term mean precipitation of ith station (mm)

S = Standard deviation of long-term rainfall data for ith station

Positive values indicate precipitation higher than mean but negative values indicate the severity of the drought (Table 3).

3. Results

a. Evaluation of drought in central Iran based on SPI

According to SPI, drought periods and their intensity were determined and the frequency of drought periods in the area under study was evaluated on a continuum (mild, medium, severe, and extremely drought events) in an annual interval. Also, the zoning map of the annual drought for the respective provinces was drawn in GIS10.2 using Kriging interpolation method. In the cities under study, Kerman and Golpayegan with 5 mild drought events, Kabotar Abad, Natanz, Khoor and Biabanak, Kashan and Robat Posht Bam with 3 medium drought events, Robat Posht Bam with 3 severe drought events and Eastern Isfahan with 2 extreme drought events had the highest frequency of droughts in central Iran respectively (Fig. 2).

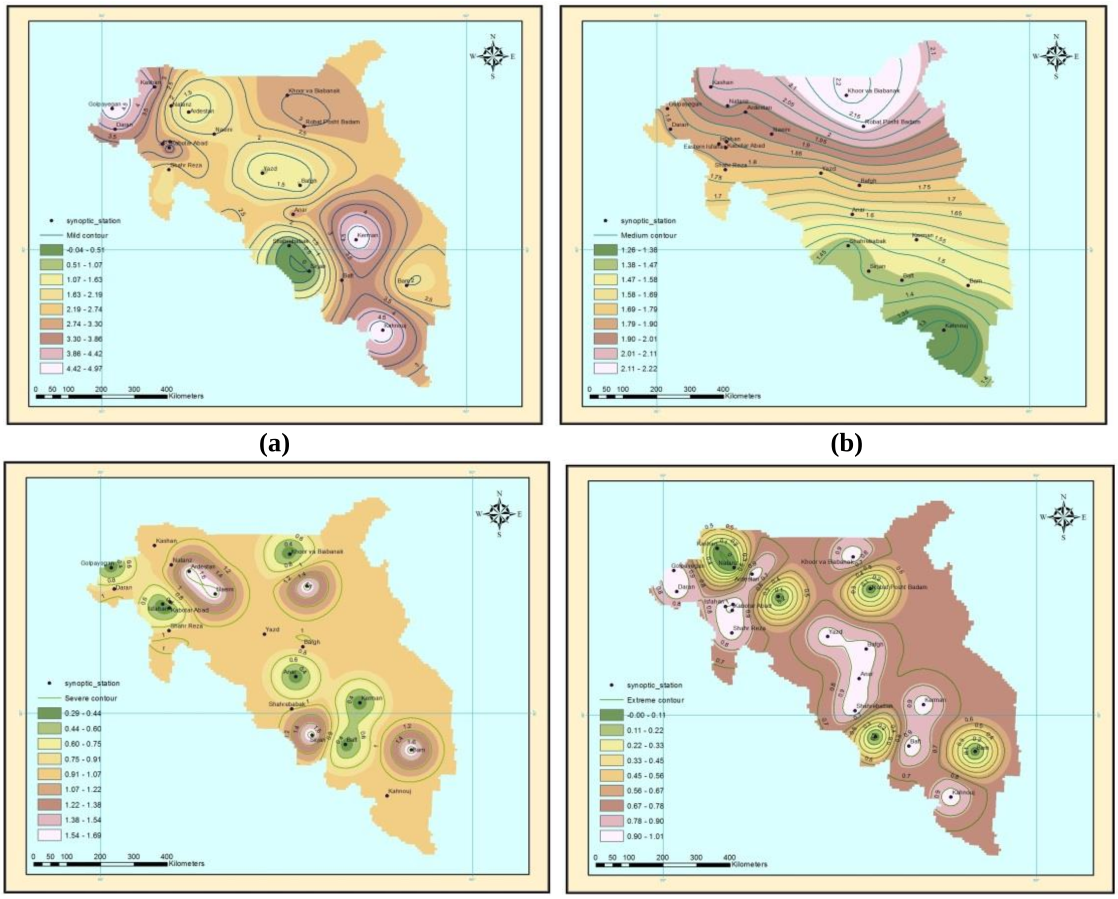
b. The relationship between tele-connection patterns and severity of droughts

Using correlation techniques, the relationship between variation in droughts intensity in central Iran and changes in teleconnection patterns were examined in all stations under study. The correlation coefficients were investigated at significance levels of 0.05 and 0.01 levels and the patterns affecting SPI were determined. The correlation between EPNP, SOI and MEI patterns in Isfahan and NAO, EA, EAWR, TNA and TSA patterns in Kerman were greater than other patterns at significant level of 0.01. In the city of Yazd, none of these patterns reached the level of significance. EAWR, SOI, PDO and TNI patterns in Isfahan, NAO, EA, EPNP, EAWR, POL, SOI, MEI, NOI, PDO, TNA and TSA patterns in Kerman and NAO, EA, EAWR and TNA patterns in Yazd were at significant level of 0.05.

On the other hand, correlation coefficients were also calculated during drought periods. Accordingly, SOI index in Isfahan station indicated a significant increase compared to the average drought index of province. Under this condition, most of the stations revealed a negative SOI pattern (a correlation coefficient of -0.647) indicating that during drought periods, the positive phases of this pattern augmented the severity of the drought. Kerman stations (TNA= -0.591, TSA= -0.585, NOI= -0.619 and SOI = -0.512) had a strong and significant correlation with drought indices, which was symptomatic of severe droughts in positive phases of this pattern. In Yazd station, (EA= -0.472, TNA= -0.467) patterns showed a significant negative correlation at the significant level of 0.05 with drought index during dry conditions in the region.

Table 3. Severity of drought based on the standardized precipitation index (SPI)

SPI	Index value
2≥	Extreme wet year
1.5 to 1.99	Severe wet year
1 to 1.49	Mild wet year
-0.99 to 0.99	Normal
-1—1.49	Mild dry year
-1.5 to -1.99	Severe dry year
2≤	Extreme dry year



(a) (b)

(c) (d)

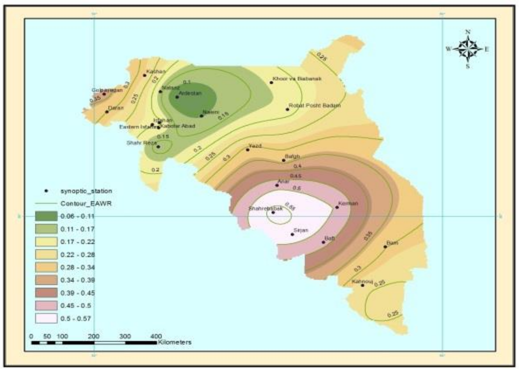
Figure 2. Frequency, extent and severity of SPI in the central Iran (1982-2013), (a) Mild drought, (b) Medium drought, (c) Severe drought and (d) Extreme drought

To examine the correlation between the most influential patterns and the drought intensity in different areas, the spatial distribution of coefficients was mapped ($p = 0.01$).

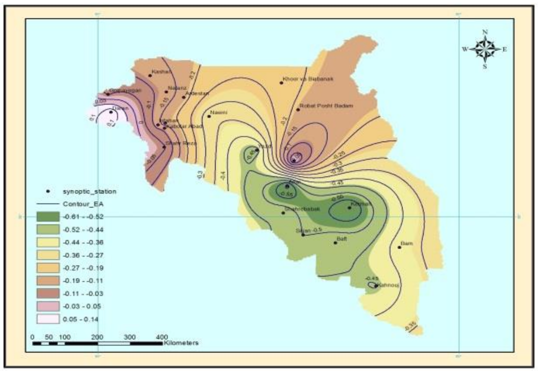
The Kriging interpolation method was used to interpolate of contours. According to Figure 3, the highest correlation between EA pattern and SPI was observed in central and northern parts of Yazd and the Northwest and West of Isfahan provinces, but the intensity of correlation between the relevant pattern and SPI index decreased in the peripheral areas. The greatest correlation between EPNP pattern and SPI was observed in north of Yazd province, northwest and west of Kerman province and northwest of Isfahan province, with the intensity of correlation with SPI tapering off in the surrounding areas. Moreover, the highest correlation between EAWR and SPI existed in central areas of Iran including northwest of Isfahan province and northwest and west of Kerman province. According to Figure (3), the greatest correlation between NAO and SPI was seen in northwest of Isfahan province, west of Yazd province and northwest and west of Kerman province.

The correlation between this pattern and SPI in Kerman province was stronger than other provinces, reflecting the impact of this pattern on drought events in the province. The greatest correlation between SOI teleconnection pattern and SPI was observed in northwest of Isfahan province and northwest of Kerman province, which followed a declining trend in the surrounding areas. The negative correlation coefficients of this pattern indicate that during drought conditions, the positive phases of the pattern intensify the severity of the drought.

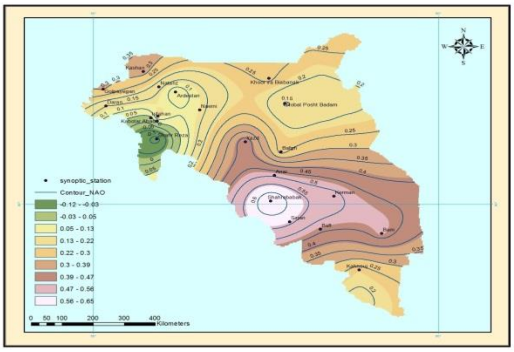
The highest correlation between TSA pattern and SPI existed in west and northwest of Yazd province and east and southeast of Isfahan province, with the intensity of association between above pattern and SPI declining in the peripheral areas. The negative correlation coefficients of the above pattern indicated that under drought conditions, the positive phases of the pattern strengthened the severity of the drought. The greatest correlation between TNA and SPI belonged to the northwest of Kerman province and south of Yazd province. The negative correlation coefficients of the above pattern revealed that during drought conditions, the positive phases of the pattern deepened the severity of the drought. The strongest correlation between MEI and SPI was seen in west and northwest of Kerman province, which the intensity of correlation tapering off in the surrounding areas.



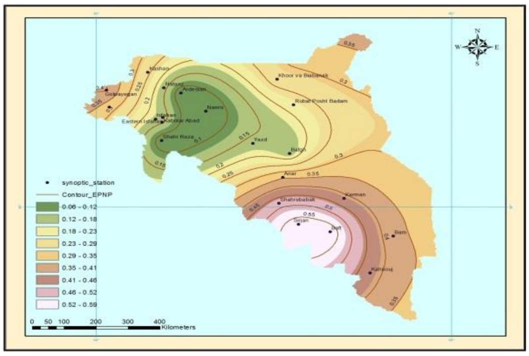
EA/WR



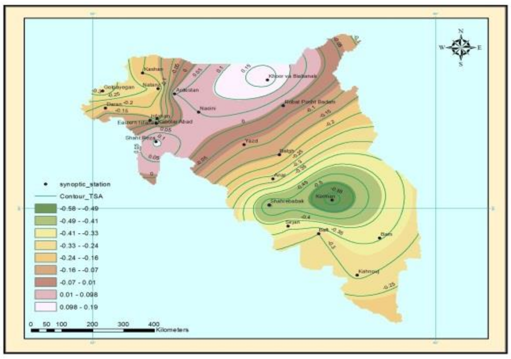
EA



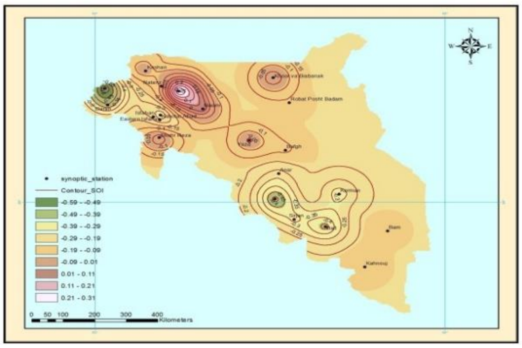
NAO



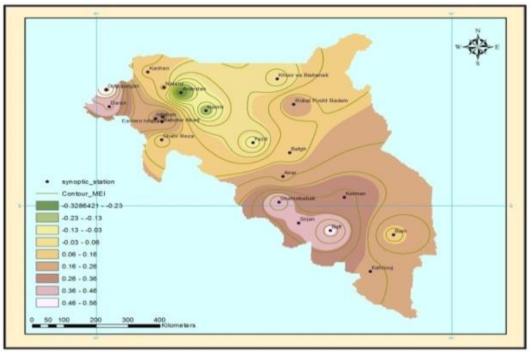
EP/NP



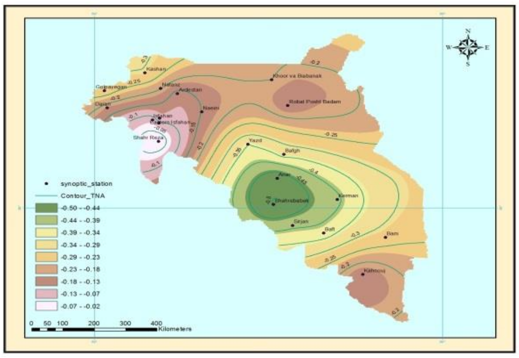
TSA



SOI



MEI



TNA

Figure 3. Map of SPI correlation with EA, EA / WR, EP / NP, NAO, SOI, TSA, TNA, MEI patterns at significant level

of 0.01

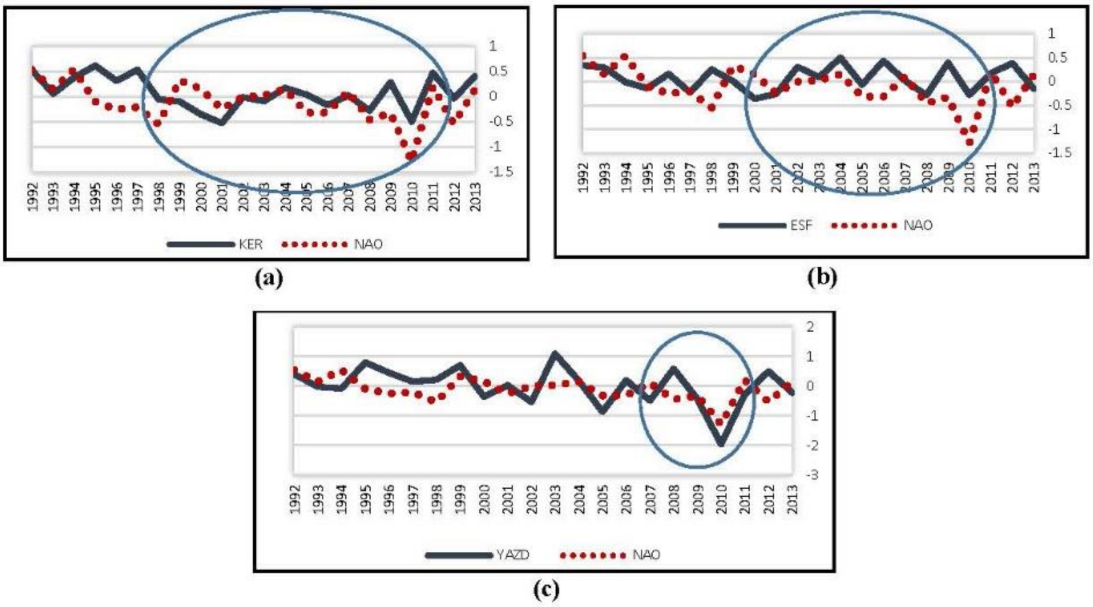


Figure 4. Diagram of SPI annual changes in (a)Kerman, (b)Isfahan and (c) Yazd and NAO pattern

Figure (4) depicts the overlapping of time series of SPI variation and NAO teleconnection pattern over the specified time period in Kerman, Yazd and Isfahan stations. The overlapping of SPI time-series and NAO patterns represents the absolute subordination of dry year and wet year frequency of this pattern in Kerman station (1999- 2013) Isfahan station (2002-2011) and Yazd station (2008-2011). Moreover, the severe drought of 2010 is associated with an unusual and extremely low NAO index.

Figure (5) depicts the variation of drought severity index in Isfahan, Kerman and Yazd stations with respect to TNA index. In the period marked by the circle, the greatest harmony between oscillations of patterns and drought severity was observed in Kerman (1996-2006), Isfahan (1996-2004) and Yazd (-1994-1998) stations. Further, the year 2010 was considered as an unusual year in all stations when TNA took a different direction and the droughts grew in intensity as the pattern intensified.

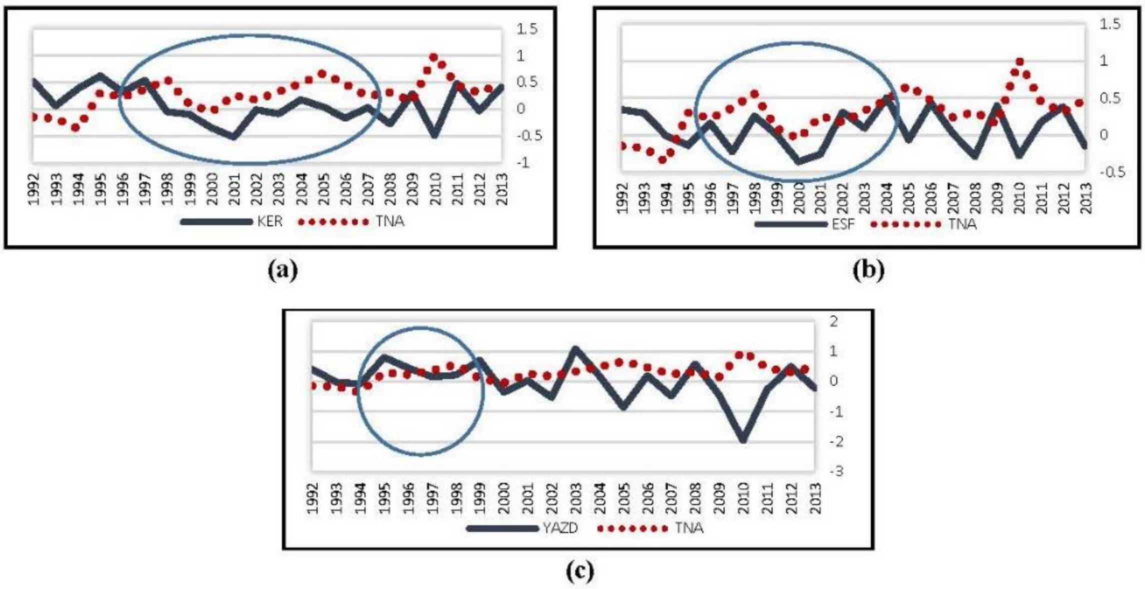


Figure 5. Diagram of SPI annual changes in (a)Kerman, (b)Isfahan (c) Yazd and TNA pattern

c. The results of regression models

Overall, according to the regression model and 18 tele-connection patterns data in central Iran, including Isfahan, Kerman and Yazd provinces, 37.42 % of SPI variation in Isfahan Province, 51.09% of SPI variation in Kerman province and 42.17% of SPI variation in Yazd province could be explained. As shown by the multiple regression coefficients (R= 0.6.8), this pattern indicates the relatively strong relationship between intensity of dry years and wet years in Isfahan province. Similarly, the multiple regression coefficient (R= 0.710) shows the relatively strong relationship between variation in the intensity of dry years and wet years in Kerman province. Finally, the multiple regression coefficient (R= 0.642) suggest the relatively strong relationship between variation in the intensity of dry years and wet years in Yazd province (Table 4). Moreover, the analysis of variance and model analysis indicate a significant difference between the explained values and remaining (Table 5). However, the results vary from region to region. In Isfahan province, only a small share of SPI variation could be explained by the above patterns compared to Yazd and Kerman provinces so that in Kashan station, the patterns explained only 26.6% of the variation in the central Iranian. In Kerman province, the largest share of SPI variation could be explained by the above patterns compared to Isfahan and Yazd provinces so that in in Kerman station, the patterns explained a maximum of 63.8% of the variation in the central Iranian.

To determine the pattern that had the highest effect on the intensity variation of dry and wet years, the stepwise regression model was selected. The results of the average index for Isfahan, Yazd and Kerman provinces are shown in Table (6). According to the results, the multivariate Scandinavian patterns (SCA) in Isfahan province, the Eastern Atlantic (EA) in Kerman province and the Tropical South Atlantic (TSA) in Yazd province in central Iran had the greatest power in explaining SPI variation in central Iran. The analysis of variance showed significance of ratio test between regression values and the residuals.

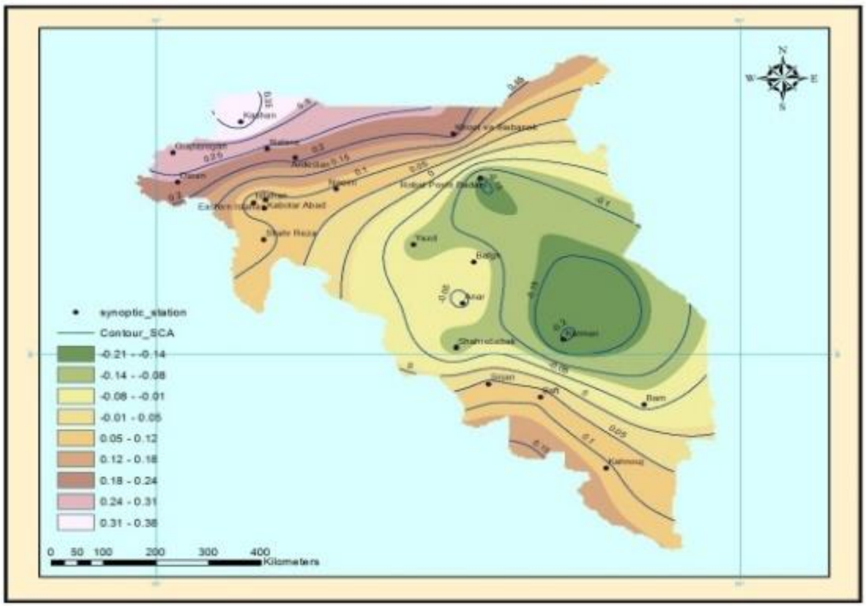
In most of the provincial stations under study, the above patterns were identified as the most influential factors. Figure 6 depicts the distribution of the most effective patterns in the province of Isfahan, Yazd and Kerman. Accordingly, the SCA pattern in Isfahan province, EA pattern in Kerman and TSA pattern in Yazd provinces were selected by the model (Figure 6). At the provincial level of Isfahan, Kerman and Yazd, various patterns were selected at stations by the model, especially EA/WR and NAO, and patterns such as TNA, SOI and MEI reached the level of significance in many stations. Also, in some areas, such as Bafgh, Robat Posht Badam, and Khoor and Biabanak, none of the patterns reached the significant level required by the model.

Table 4. The results of the regression model for the annual SPI in central Iran and northern hemisphere teleconnection patterns

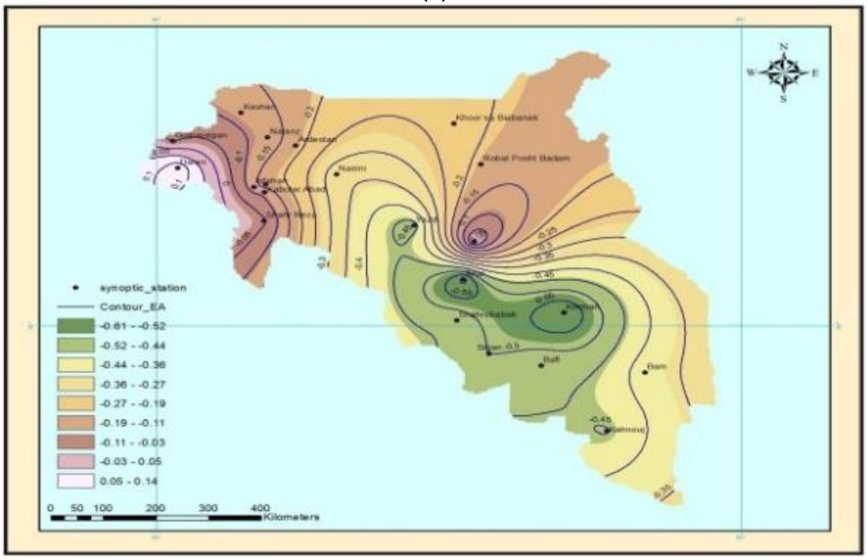
Province	Standard error of estimate	Percentage of variation explained	Multivariate regression coefficient
Isfahan	0.81	37.42	0.61
Kerman	0.70	51.09	0.71
Yazd	0.76	42.17	0.64

Table 5. Analysis of variance between the distribution of the annual SPI in provincial stations of Yazd, Kerman and I or Isfahan as explained by the model and the unexplained values (remaining) - A significance level of 0.05 was considered

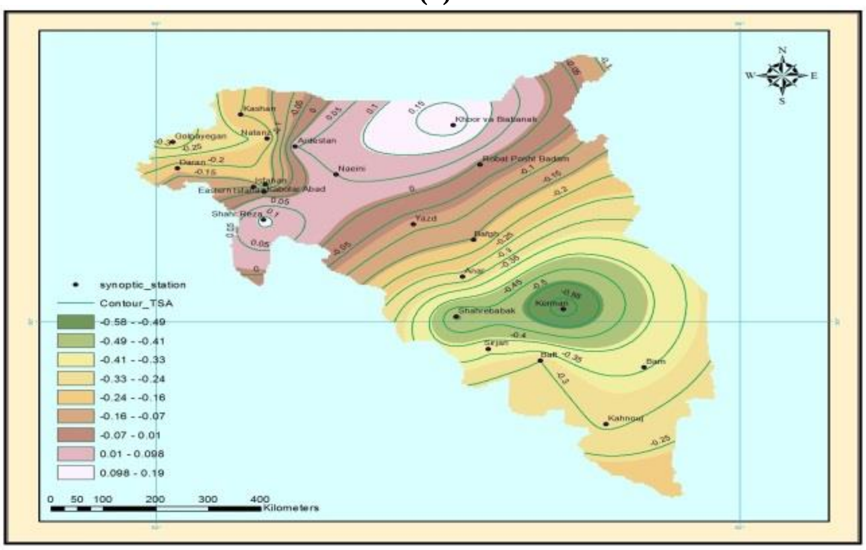
Level of significance	Coefficient F	Mean squares	Degree of freedom	Sum of squares		
		3.72	1	3.72	Regression	
0.045	4.915	0.757	13	9.87	Residuals	Yazd province
			14	13.56	Sum	
		5.56	1	6.68	Regression	
0.01	11.72	0.51	13	6.51	Residuals	Kerman province
			14	13.19	Sum	
		4.24	1	4.24	Regression	
0.03	6.48	0.68	11	7.85	Residuals	Isfahan province
			12	12.09	Sum	



(a)



(b)



(c)

Figure 6. The most effective patterns in (a) SCA in Isfahan, (b) EA in Kerman and (c) TSA in Yazd provinces

Table 6. The results of stepwise regression model between the annual drought index in Yazd, Kerman and Isfahan provinces stations

	Standard error of estimate	Percentage of variation explained	Multivariate regression	Model
Yazd	0.69	37.7	0.614	**TSA**
Kerman	0.68	57.8	0.760	**EA**
Isfahan	0.79	35.4	0.595	**SCA**

4. Conclusion

Drought, as a normal, recurrent climatic condition with complicated mechanism, is one of the least known natural disasters that may occur in any climatic condition. Considering the recent drought events in the Iran and the deterioration of water crisis, especially in the area under study, the necessity of further research in this area is felt. Also, the evaluation and monitoring of drought with reliable indices as well as its relationship with large-scale atmospheric patterns is the first step in the mitigation and management of this natural phenomenon.

Thus, this study set out to explore the relationship between dry and wet years in Isfahan, Kerman and Yazd provinces and large-scale northern hemisphere atmospheric circulation patterns (teleconnections) using a variety of methods. The results showed the relationship of these patterns with drought in central Iran. In the present study, Standardized Precipitation Index (SPI) was used as a measure for the severity of the drought.

Using statistical methods such as correlation and linear multiple regression models, the most effective patterns and the mechanism of their effect was determined.

Of a total of 18 teleconnection patterns with respect to their existence and severity of activity during different seasons, it was found that EPNP, SOI and MEI patterns in Isfahan, NAO, EA, EAWR, TNA and TSA patterns in Kerman had the strongest impact at a significant level of 0.01, but none of these patterns reached the level of significance in Yazd province. Moreover, EAWR, SOI, PDO and TNI patterns in Isfahan, NAO, EA, EPNP, EAWR, POL, SOI, MEI, NOI, PDO, TNA and TSA patterns in Kerman and NAO, EA, EAWR and TNA in Yazd province were significant at significance level of 0.05. As discussed earlier, there are regional differences in this regard, but the impact of teleconnection patterns on the severity of droughts in the abovementioned stations was not symmetrical. In other words, some patterns were more noticeable and active under drought conditions. The results of this study are in line with the findings of Khosravi (2004), in which MEL, NOI, NP, PDO and POL patterns had the most significant correlation with the SPI in Sistan and Baluchistan province. The overlapping of SPI time series and NAO pattern represents the absolute subordination of dry year and wet year frequency of this pattern in Kerman station (in the period 1999-2013), Isfahan station (in the period 2002-2011) and Yazd station (in the period 2008-2011).

Moreover, the severe drought of 2010 was accompanied with an unusually low NAO index. The variation of Palmer Drought Severity Index in Isfahan, Kerman and Yazd stations with respect to TNA index revealed that in Kerman province (in the period 1996-2006), Isfahan province (in the period 1996-2004) and Yazd province (in the period 1994-1998) the greatest harmony between pattern oscillations and intensity of droughts was observed.

The year 2010 was considered as an unusual year in all the stations when TNA took a radically different direction and drought severity deteriorated with pattern intensification. On an annual basis, approximately 37.42, 51.09 and 42.17% of SPI variation in Isfahan, Kerman and Yazd provinces can be explained by the models respectively.

To determine the patterns that had the greatest effect on the severity of the dry and wet years was selected by the model, the stepwise regression models were used. According to the results, the multivariate Scandinavian (SCA) pattern in Isfahan province, Eastern Atlantic (EA) pattern in Kerman province and the Tropical South Atlantic (TSA) in Yazd province in central Iran were the most effective patterns that explained annual SPI variation. As reported by Khosravi (2005), in the winter drought patterns, North Pacific (NP) pattern plays a more significant role, explaining 60% of variation in winter drought severity.

The drought~~s~~ events in central Iran are linked to droughts in northern Scandinavian, West Africa and the Azores. Thus, a deeper understanding of regional droughts and its relationship with large-scale atmospheric patterns can help adopt appropriate measures to efficiently handle natural and water resources.

References:

Azizi, Gh., 2000, El Niño and dry and wet periods in Iran, Geographic Studies, 38, 71-84.

Darand, M., 2014, Drought monitoring in Iran by palmer severity drought index (PDSI) and correlation with oceanic atmospheric teleconnection patterns, Geographical Research Quarterly, 29(115), 67-82.

Di Nezio, P., 2011, Mechanisms of tropical pacific climate change: Beyond the bjerknes feedback, Ph.D. Dissertation of University of Miami, scholarly Repository.

Fatemi, M., Omidvar, K., Beiglou, K. H. B. and Narangifard, M., 2015, Using principle component analysis in identifying synoptic patterns of wet periods in Central Iran, Earth Science & Climatic Change, 6, 309. doi:10.4172/2157-7617.1000309.

Ghavidel Rahimi, Y., Farajzadeh, M. and Kakapur, S., 2014, The effect of the teleconnection pattern of North-Caspian Sea on autumn rainfall oscillations in west and northwest parts of Iran, Journal of Geography and Planning, 18(49), 217-230.

Ghavidel Rahimi, Y., Hatami Zarina, D. and Rezaei, M., 2013, The role of the teleconnection pattern in the upper atmosphere of the North Sea–Caspian Pattern in precipitation changes in the southern coasts of Caspian Sea, Journal of Applied Research of Geographic Sciences, 31(31), 29-46.

Ghayour, H. and Khosravi, M., 2001a, Impacts of El Niño/southern oscillation (Enso) on summer and autumnal precipitation anomalies in south east of Iran, Geographical Research Quarterly, 16(3), 141-174.

Ghayour, H. and Khosravi, M., 2001b, Study the effect of the graft around the climate case study: the effect of North Atlantic oscillations and the Southern oscillation on mean monthly temperature changes Jask, Journal of Geographical Research, (63-64), 93-113.

Ghayour, H. and Asakereh, H., 2001, A study of the effect of teleconnection pattern on the climate of Iran (case study: the effect of North Atlantic oscillation and the Southern oscillation on monthly mean temperature variations in Jask), Geographical Research, 17(1), 93-113.

Halabian, A. H. and Mohammadi, B., 2012, The relation of monthly temperature of some sample stations in Iran with different ENSO indices, Geographical Space, 12(38), 1-19

Hayes, M. J., Svoboda, M. D., Wilhite, D. A. and Vanyarkho, O. V., 1999, Monitoring the 1996 drought using the standardized precipitation index, Bulletin of the American Meteorological Society, 80(3), 429-438.

Ibrahim, K., Zin, W. Z. W. and Jemain, A. A., 2010, Evaluating the dry conditions in Peninsular Malaysia using bivariate copula, ANZIAM Journal, 51, 555-569.

Khosravi, M., 2004, A survey on the relations of the northern hemisphere large scale circulation patterns with Sistan & Baluchistan annual droughts, Journal of Geography and Development, 167-188.

Khosravi, M., 2005, The effect of teleconnection patterns on the continuous winter droughts in Sistan and Baluchistan Province, Journal of Geography and Regional Development, 4, 27-54.

Khourshiddoust, A. M. and Ghavidel Rahimi, Y., 2008, Investigating monthly precipitation variations of Ahar station in relation with teleconnection patterns, Sarzamin Geographical Quarterly, 20, 65.

Khourshiddoust, A. M. and Ghavidel Rahimi, Y., 2006, the evaluation of the effect of ENSO feature on variability of seasonal precipitation in eastern Azerbaijan province using multivariate ENSO index (MEI), GEOGRAPHICAL research quarterly, 38(57), 15-26.

Kutiel, H., 2011, A review on the impact of the North Sea–Caspian Pattern (NCP) on temperature and precipitation regimes in the Middle East, in survival and sustainability (pp. 1301-1312). Springer Berlin Heidelberg.

Mckee, T. B., Doesken, N. J. and Kleist, J., 1993, The relationship of drought frequency and duration to time scales, in: Proc. 8th conference on applied climatology, January 17-22, 179-184.

Mirabbasi, R., Anagnostou, E. N., Fakheri-Fard, A., Dinpashoh, Y. and Eslamian, S., 2013, Analysis of meteorological drought in northwest Iran using the Joint Deficit Index, Journal of Hydrology, 492, 35-48.

Peng, Z., Wang, Q. J., Bennett, J. C., Pokhrel, P. and Wang, Z., 2014, Seasonal precipitation forecasts over China using monthly large-scale oceanic-atmospheric indices, Journal of Hydrology, 519, 792-802.

Rahmani, A., Golian, S. and Brocca, L., 2015, Multiyear monitoring of soil moisture over Iran through satellite and reanalysis soil moisture products, International Journal of Applied Earth Observation and Geoinformation.

Raziei, T., Saghafian, B., Paulo, A. A., Pereira, L. S. and Bordi, I., 2009, Spatial patterns and temporal variability of drought in western Iran, Water Resources Management, 23(3), 439-455.

Rimkus, E., Kažys, J., Valiukas, D. and Stankūnavičius, G., 2014, The atmospheric circulation patterns during dry periods in Lithuania, Oceanologia, 56(2), 223-239.

Salahi, B., Khourshiddoust, A. M. and Ghavidel Rahimi, Y., 2007, Linking between oscillations of north Atlantic atmospheric-oceanic circulation and droughts in east Azerbaijan, geographical research quarterly, 39(60), 147-156.

Shahabfar, A., Ghulam, A. and Eitzinger, J., 2012, Drought monitoring in Iran using the perpendicular drought indices, International Journal of Applied Earth Observation and Geoinformation, 18, 119-127.

Shirmohammadi, Z., Khani, A., Ansari, H., Alizadeh, A. and Mohammedan, A., 2012, The relationship between ENSO phenomenon and with the limit values of seasonal rainfall in the province of Khorasan, Journal of Soil and Water Conservation, Gorgan University of Agricultural Sciences, 19(1) 61-79.

Türkeş, M. and Erlat, E., 2005, Climatological responses of winter precipitation in Turkey to variability of the North Atlantic oscillation during the period 1930-2001, Theoretical and Applied Climatology, 81(1-2), 45-69.

Uppenbrink, J., 1997, Seasonal climate prediction, Science, 277(5334), 1952.

Wallace, J. M. and Gutzler, D. S., 1981, Teleconnections in the geopotential height field during the Northern Hemisphere winter, Monthly Weather Review, 109(4), 784-812.

Yetemen, O. and Yalcin, T., 2009, Climatic parameters and evaluation of energy consumption of the Afyon geothermal district heating system, Afyon, Turkey. Renewable Energy, 34(3), 706-710.

Yousefi, N. A. and Hajjam, S., 2012, Exploring the impact of ENSO on temperature and precipitation (case study: Qazvin plain), Journal of Geographic Space, Islamic Azad University of Ahar Branch, 39, 195-210.

Zare Abyaneh, H. and Bayat Varkesh, M., 2012, The impact of ENSO on monthly and seasonal temperature changes in the southern parts of Iran, Natural Geographical Research, 44(2), 67-84.