

Research Article

Spatio-temporal Characteristics of Droughts and Drought Trends in Qazvin Province of Iran

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Abstract: A study has been carried out to characterize the spatial patterns of droughts with different time scales as well as their trends in Qazvin province of Iran where droughts are recurrent phenomena. Thirty-five years (1971-2004) monthly rainfall data recorded at twenty rainfall stations are used for the study. Standardized precipitation index is used for the reconstruction of drought events from rainfall data in order to characterize the spatial and temporal distributions of droughts. A non-parametric trend test known as Mann-Kendall test is used to analysis the changes in rainfall and drought events. The results show that the north especially northwest part of the provinces most prone to droughts with different time spans and severities. Trend analysis shows significant changes in rainfall and droughts only in few stations sporadically distributed over the study area. It is expected that the study will be helpful in drought mitigation and adaptation planning in the area.

Keywords: GIS, Iran, standardized precipitation index, spatio-temporal pattern, trend analysis

INTRODUCTION

Droughts are very common in almost all countries around the world, especially those located in the arid and semiarid regions (Badripour, 2007; Shahid and Hazarika, 2010; Wang *et al.*, 2012a). Drought is a natural temporary deficit of water availability over a period due to low precipitation compared to the average (Pereira *et al.*, 2002). The effect of drought is often high compared to other natural disasters. Therefore, drought is considered as the costliest natural disaster in the globe (Vasiliades *et al.*, 2011). In contrast to other natural hazards (including floods) that are typically restricted to an area and occur over well-defined temporal intervals, drought is difficult to pinpoint in to time and space because it affects wide areas for a longer period (Vicente-Serrano *et al.*, 2012). Droughts are often recurring with certain spatial and temporal characteristics that vary significantly from one region to another (Tallaksen and van Lanen, 2004). Therefore, characterization of spatial pattern of drought at regional and local scales is one of the major steps for mitigation planning.

Droughts occurred several times in Iran in last few decades (UNA-IRAN, 2008) and caused severe damage to agriculture and economy. Drought during 1998-2001 affected 37 million people in 12 provinces out of 30

provinces of Iran and caused severe water and food shortages. The rainfall is changing due to climate change on both the global and the regional scales (Shahid and Khairulmaini, 2009). It has been projected that frequency of occurrence of droughts will increase in Iran due to climate change (Sayari *et al.*, 2013; Dastorani *et al.*, 2012). Therefore, characterization of droughts and understanding its trends at regional scale are very important.

Number of methods has been proposed for the characterization of droughts (Jr Heim, 2002; Keyantash and Dracup, 2002; Palmer, 1965; McKee *et al.*, 1993; Tabari *et al.*, 2013). Among those, the Palmer Drought Severity Index (PDSI) (Palmer, 1965), the standardized precipitation index (SPI) (McKee *et al.*, 1993) and the Drought Severity Index (DSI) (Tabari *et al.*, 2013) are widely used. A number of studies have been carried out to characterize droughts in different parts of Iran using various methods such as, evaluation of droughts in the northwest of Iran (Raziei *et al.*, 2009), temporal and spatial variability of drought in the western of Iran (Nikbakht *et al.*, 2013), hydrological droughts in the northwest of Iran (Daneshvar *et al.*, 2013), impacts of droughts on agricultural productions of Iran (Sayari *et al.*, 2013), meteorological drought in Iran (Asrari *et al.*, 2012), etc. However, little attention has been paid so far to characterize droughts at provincial level which

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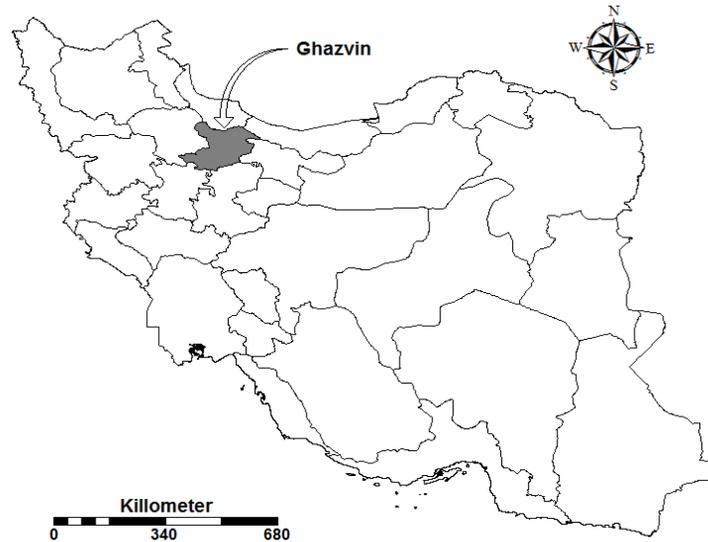


Fig. 1: Location of Qazvin Province in Iran

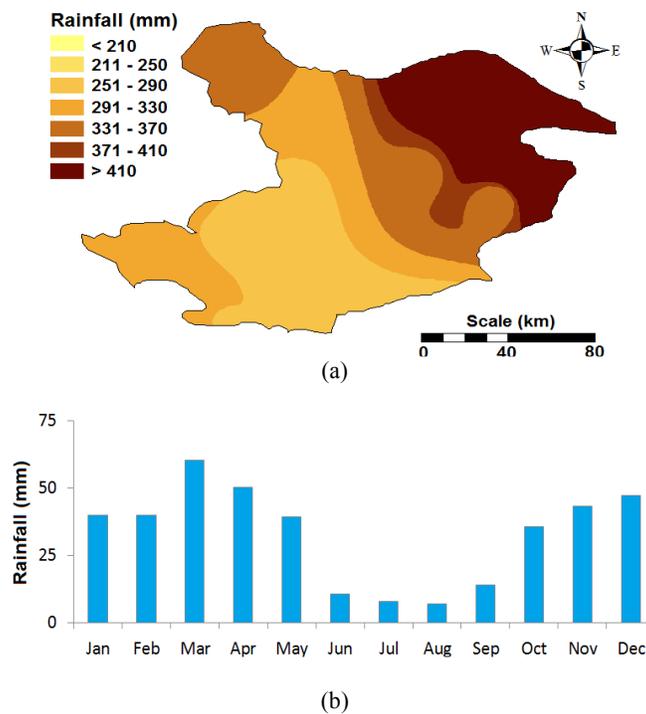


Fig. 2: (a) Spatial distribution of rainfall; (b) monthly distribution of rainfall

is extremely important to get more insights in to droughts at local level for effective mitigation and preparedness of droughts. The objectives of the present study are two folds:

- Characterization of spatial and temporal patterns of droughts in Qazvin province of Iran which is one of the drought prone regions of the country.
- Examine the trends in historical droughts with different time scales and severities in the area.

Better understanding of droughts requires characterization of drought duration, frequency of occurrence and severity. Standardized Precipitation Index (SPI) (McKee *et al.*, 1993) can characterize droughts by their duration, frequency and severity and therefore, used in the present study to characterize the spatial and temporal patterns of droughts in Qazvin province. Considering the length of time series, non-parametric trend test has been proposed to examine the presence of trends in historical droughts. It is expected

that the study will help to understand the characteristics and the trends of droughts in more details which in turn will help planning mitigation and adaptation in the area.

AREA OF THE STUDY

Qazvin province is located in the northwest of the central plateau of Iran between longitude 48°45'E to 50°50'E and latitude 35°37'N to 36°45'N. The location of Qazvin province in the map of Iran is shown in Fig. 1. Climate of the province varies widely both spatially and temporally. Annual average rainfall in the province varies from 210 mm in west to more than 550 mm in mountains of Northeast. Figure 2 shows spatial and seasonal distribution of rainfall in area. Temperature varies between -5°C in winter to 35°C in summer. Qazvin is an agriculture based province of Iran. More than 80% of the land is used for cultivation. Therefore, droughts cause severe impacts on agro-based economy and people's livelihood.

MATERIALS AND METHODS

Thirty-five years (1971-2004) monthly rainfall records at twenty hydrometric stations located in and

around Qazvin province are used for the study. Location of rainfall recording stations is shown in Fig. 3.

The homogeneity of the rainfall records are analyzed by using the von Neumann ratio (Von Neumann, 1941), Standard Normal Homogeneity Test (SNHT) (Alexandersson, 1986) and the Range test (Buishand, 1982). The data sets of all the stations are found homogeneous. Standardized precipitation index is used for the reconstruction of drought events from rainfall data. Mann-Kendall test is applied to detect the trends in drought time series. Confidence levels of 90, 95 and 99% are taken as thresholds to classify the significance of positive and negative trends. The methods are discussed below in detail.

Standardized precipitation index: Standardized precipitation index (McKee *et al.*, 1993) is a widely used drought index based on the probability of precipitation for multiple time scales, e.g., 1, 3, 6, 9, 12, 18 and 20-month, respectively. It provides a comparison of the precipitation over a specific period with the precipitation totals for the same period for all the years included in the historical record. Consequently, it facilitates the temporal analysis of wet

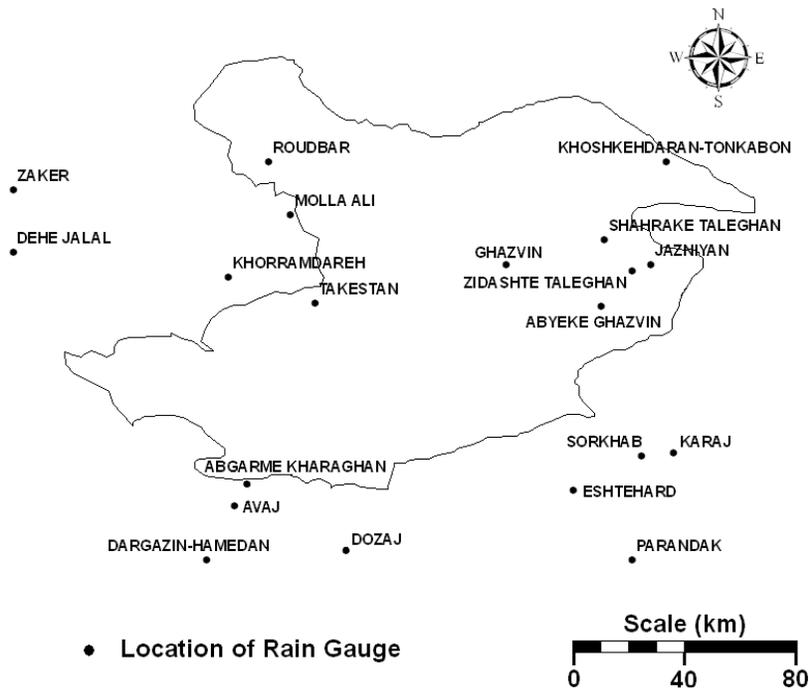


Fig. 3: Location of rain gauges in and around Qazvin Province of Iran

Table 1: Drought categories based on the classification of SPI values (after McKee *et al.* (1993))

| SPI | Category | Probability of occurrence |
|----------------|------------------|---------------------------|
| 0 to -0.99 | Dry event | 34.1% |
| -1.00 to -1.49 | Moderate drought | 9.2% |
| -1.50 to -1.99 | Severe drought | 4.4% |
| -2.00 and less | Extreme drought | 2.3% |

and dry phenomena. To compute SPI, historic rainfall data of each station are fitted to a gamma probability distribution function:

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \text{ for } x > 0 \quad (1)$$

where, $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, $x > 0$ is the amount of precipitation and $\Gamma(\alpha)$ defines the gamma function.

The maximum likelihood solutions are used to optimally estimate the gamma distribution parameters α and β for each station and for each time scale:

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right), \beta = \frac{\bar{x}}{\alpha} \quad (2)$$

where, $A = \ln(\bar{x}) - [\sum \ln(x)/n]$, $n =$ number of precipitation observations.

This allows the rainfall distribution at a station to be effectively represented by a mathematical cumulative probability function as given by:

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad (3)$$

Since the gamma function is undefined for $x = 0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

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

where, q is the probability of a zero. The cumulative probability $H(x)$ is then transformed to the standard normal distribution to yield the SPI (McKee *et al.*, 1993).

As the precipitation rate is fitted to a gamma distribution for different multiple time scales for each month of the year, the resulting function represents the cumulative probability of a rainfall event of a station for a given month of the dataset and at different multiple time scale of interest. This allows establishing a classification values for SPI. McKee *et al.* (1993) classified wet and dry events according to SPI values as given in Table 1. Detail of the SPI algorithm can be found in (McKee *et al.*, 1993, 1995).

Mann-Kendall trend test: In Mann (1945) and Kendall (1975), the data are evaluated as an ordered time series. The net result of all such increments and decrements yields the final value of S. If $x_1, x_2, x_3 \dots x_i$ represent n data points where x_j represents the data point at time j , then the Mann-Kendall statistic, S can be calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \quad (5)$$

where:

$$\text{sign}(x_j - x_k) = \begin{cases} 1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases}$$

The probability associated with S and the sample size, n , are then computed to statistically quantify the significance of the trend. Normalized test statistic Z is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad (6)$$

At the 99% significance level, the null hypothesis of no trend is rejected if $|Z| > 2.575$; at 95% significance level, the null hypothesis of no trend is rejected if $|Z| > 1.96$; and at 90% significance level, the null hypothesis of no trend is rejected if $|Z| > 1.645$. More details of Mann-Kendall test can be found in Sneyers (1990).

Spatial interpolation: Kriging is used for the mapping of spatial pattern of droughts and their trends from point data. Geo-statistical analysis tool of ArcMap 9.1 (ESRI Virtual Campus Web Course, 2004) is used for this purpose. Kriging is a stochastic interpolation method (Journel and Huijbregts, 1981; Isaaks and Srivastava, 1989), which is widely recognized as the standard approach for surface interpolation based on scalar measurements at different points. Studies show that Kriging gives better global predictions than other methods (Van Beers and Kleijnen, 2004). Kriging is an optimal surface interpolation method based on spatially dependent variance, which is generally expressed as semi-variogram. Surface interpolation using kriging depends on selection of semi-variogram model and the mathematical function to fit the model. Depending on the shape of semi-variograms, different models are tested for best fitting.

Hydrological investigation over a large area requires assimilation of information from many sites each with a unique geographic location (Shahid *et al.*, 2000). GIS maintains the spatial location of sampling points and provides tools to relate the sampling data contained through a relational database. Therefore, it can be used effectively for the analysis of spatially distributed hydro-meteorological data and modeling. In the present paper, GIS is used to show the spatial variation of droughts and their trends.

RESULTS AND DISCUSSION

The occurrence of droughts in the study area is identified from SPI time series' of multiple-time scales. In the present study, SPI for six- and twelve-month time

steps are computed to study the characteristics of seasonal and annual droughts. The six-month SPI is used to describe the seasonal droughts i.e., droughts during dry or wet seasons. While the twelve-month SPI is used to characterize annual droughts occur due to rainfall deficit in the whole year.

Droughts in qazvin: Representative six-month SPI time series' at AbyekGhazvin, Ghazvin, Roudbar and Takestan stations are shown in Fig. 4. Analysis of six-month SPI time series' at different stations located in and around Qazvin province reveals that severity of six-month time scale droughts varies from station to

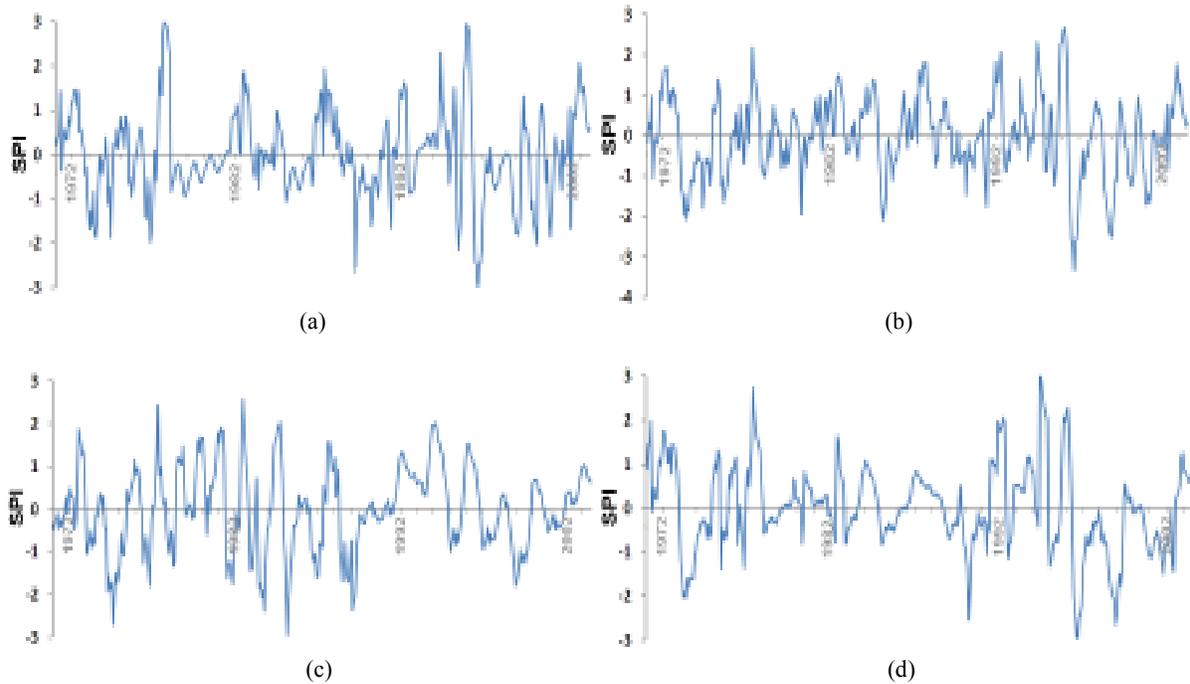


Fig. 4: Six-month SPI time series at (a) AbyekGhazvin; (b) Ghazvin; (c) Roudbar; and (d) Takestan stations of Qazvin Province of Iran

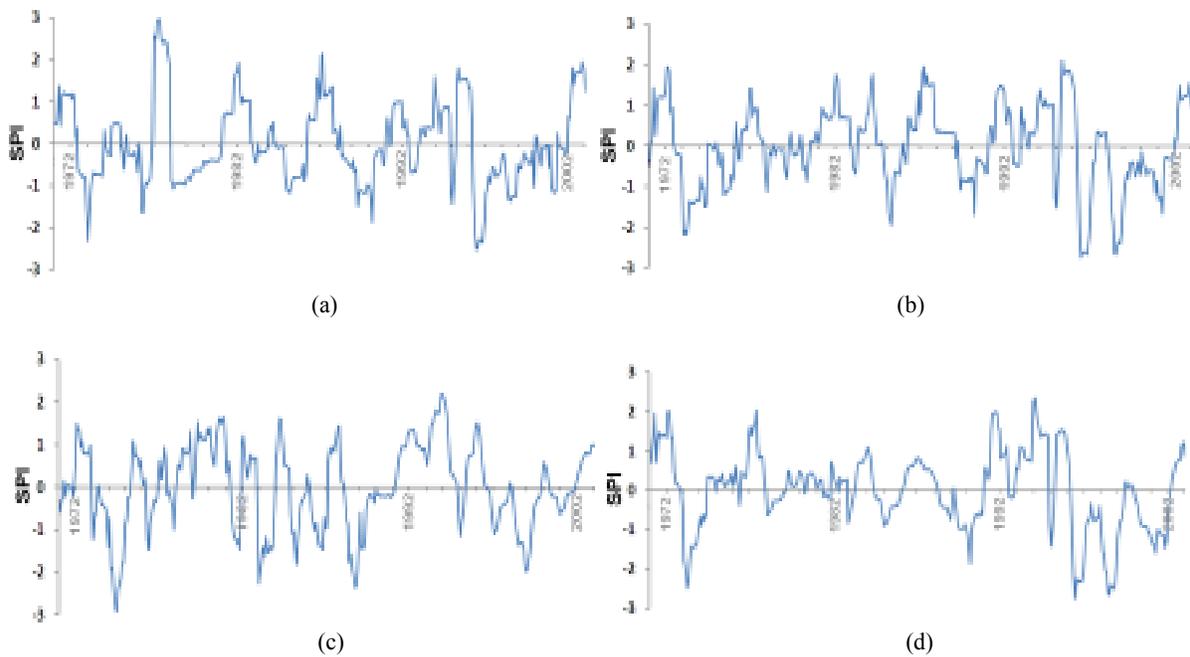


Fig. 5: Twelve-month SPI time series at (a) AbyekGhazvin; (b) Ghazvin; (c) Roudbar; and (d) Takestan stations of Qazvin Province of Iran

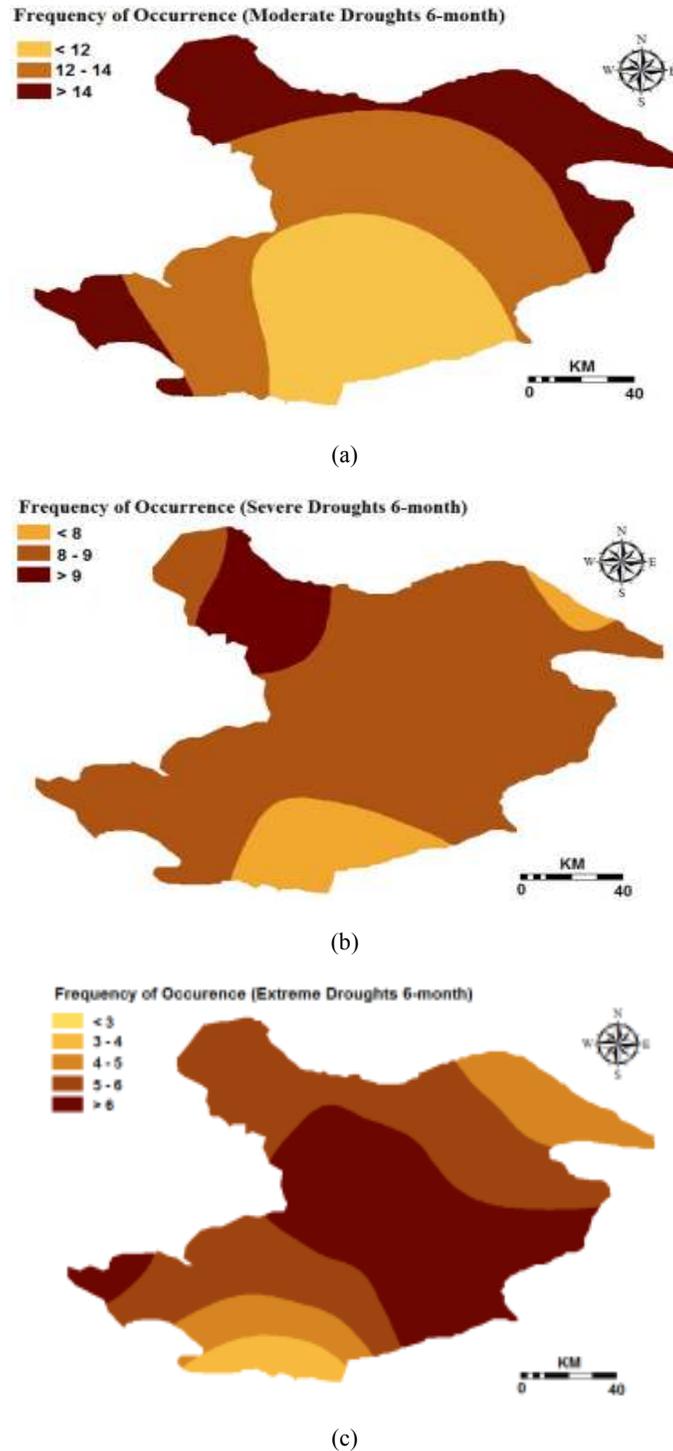


Fig. 6: Spatial distribution of the frequency of occurrence of (a) moderate; (b) severe; and (c) extreme droughts at six-month time step in Qazvin Province of Iran

station. Major droughts having six-month time span occurred in 1973, 1989, 1996 and 1998. The SPI values in those years were less than -2.0 in most of the stations. It means that most parts of the province were affected by extreme droughts for six-month in those years.

Representative twelve-month SPI time series' at AbyekGhazvin, Ghazvin, Roudbar and Takestan stations are shown in Fig. 5. Analysis of twelve-month SPI time series' at different stations located in and around Qazvin province reveals that major droughts with twelve-month time span also occurred in the years

1973, 1989, 1996 and 1998. The SPI values were also below -2.0 in those years means that the province was affected by extreme droughts with twelve-month time span in the years 1973, 1989, 1996 and 1998.

Spatial distribution of drought: The areas vulnerable to droughts at different time scales are identified on the basis of their percentage of occurrences. The percentage of drought occurrences is computed by taking the ratio of drought occurrences in each time step to the total drought occurrences in the same time step and drought category (McKee *et al.*, 1993). Spatial distribution of

the percentage of occurrences of moderate, severe and extreme droughts at six-month time scale is shown in Fig. 6.

The spatial distribution of moderate droughts (Fig. 6a) indicates that they tend to occur in north and west parts of the province at 6-month time scale. The central- south part of the province experiences moderate droughts with lower frequencies at 6-month time scale. Distribution of severe droughts (Fig. 6b) shows a similar pattern like moderate droughts. The north and west parts of the province are found to be most potential for severe droughts at 6-month time

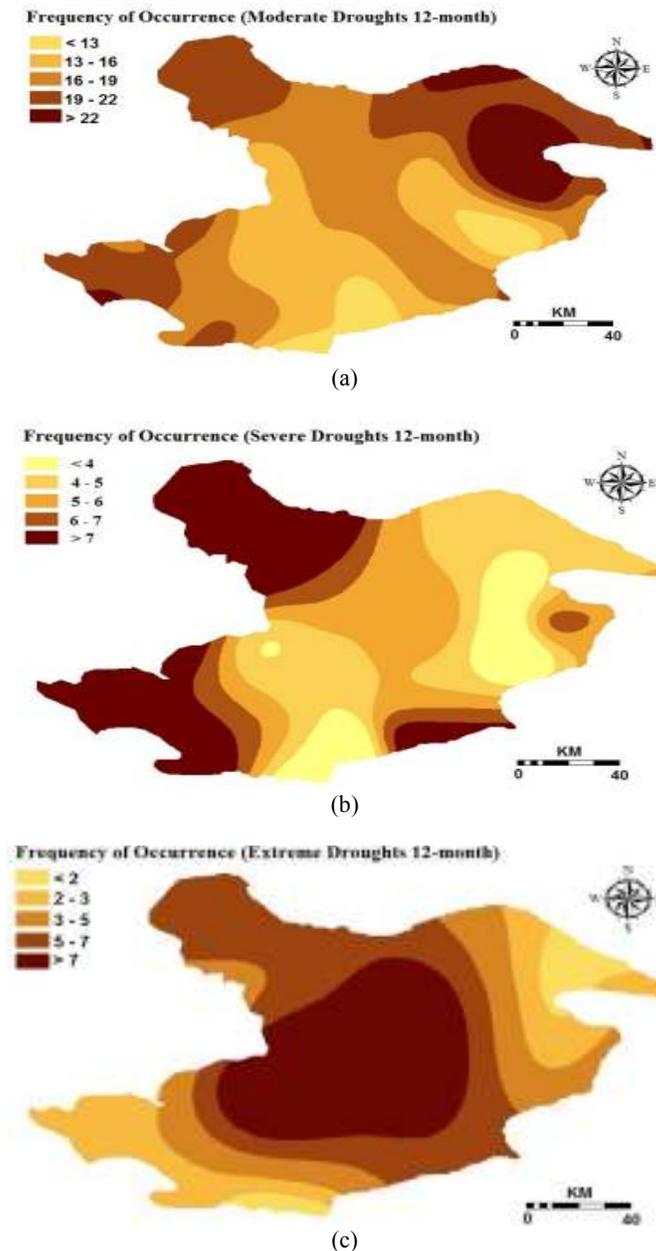


Fig. 7: Spatial distribution of the frequency of occurrence of (a) moderate; (b) severe; and (c) extreme droughts at twelve-month time step in Qazvin Province of Iran

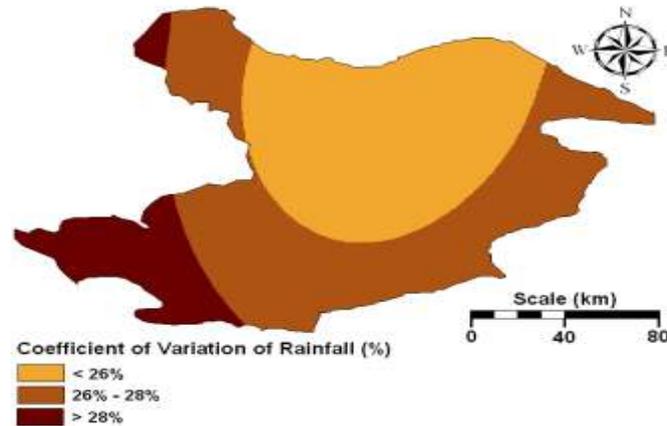


Fig. 8: Coefficient of variation of annual average rainfall in Qazvin Province of Iran

span. Figure 6c shows that the pattern of extreme droughts is different from moderate and severe droughts at 6-month time scale. Extreme droughts at 6-month time scale occur more frequently in the central part of the province. The north and the west parts of the province are also vulnerable to extreme droughts at 6-month time scale. On the other hand, the southern part of the province is less prone to extreme droughts at 6-month time scale.

With the increase of time scale from 6-month to 12-month, drought occurrence areas are found to change in Qazvin province. The spatial distributions of the percentage of occurrences of moderate, severe and extreme droughts at twelve-month time scale are shown in Fig. 7. The spatial distribution of moderate droughts at twelve-month time step (Fig. 7a) indicates that they tend to occur in northeast, northwest and southwest parts of the province. The southeast part experiences moderate droughts with lower frequencies at 12-month time scale. Distribution of severe droughts (Fig. 7b) shows that northwest and west parts of the province are most potential for severe droughts at 12-month time scale. Figure 7c shows that the pattern of extreme droughts at 12-month time scale is similar to extreme droughts at 6-month time scale. Extreme droughts at 12-month time scale are most frequent in the central part of the province. The northwest part of the province is also vulnerable to extreme droughts at 12-month time scale.

The analysis of the occurrence of droughts of different categories and time scales indicate that western part of the province is most vulnerable to droughts. Extreme droughts are found to occur most frequently in the central part of the province. The southern part especially the southeast part of the province is less vulnerable to droughts.

Spatial distribution of coefficient of variation of rainfall or rainfall reliability of Qazvin province is shown in Fig. 8. The figure shows that year to year variation of annual rainfall in the western part of the

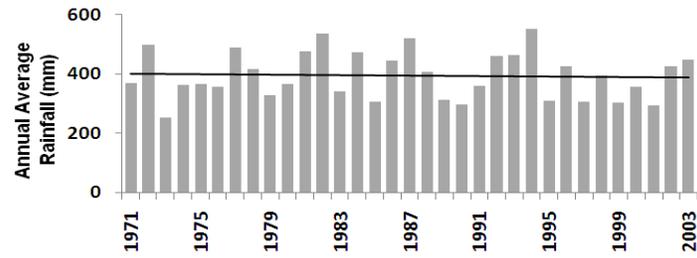
province is very high. Rainfall in the western part is also low compared to other parts of the province.

Therefore, it can be remarked that low rainfall and high variation in annual rainfall have made the western part of Qazvin province highly prone to droughts.

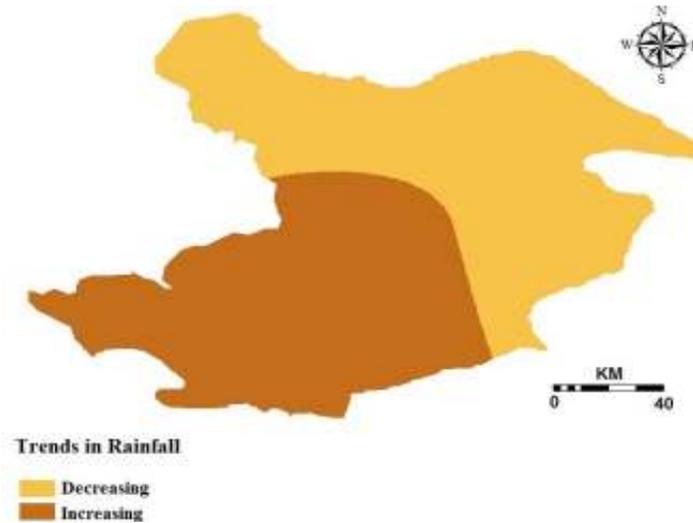
Trends in rainfall: The annual rainfall data of 20 stations located in and around Qazvin province are averaged to get the time series of annual average rainfall of the area for the period 1971-2004 as shown in Fig. 9a. The mean annual rainfall over the time period 1971-2004 in Qazvin was approximately 394.7 mm. Average year to year variation of rainfall was 20.2%. The trend analysis of annual average rainfall time series by Mann-Kendall test reveals no significant change in annual average rainfall in Qazvin province of Iran.

Annual rainfall trends at each station are calculated and interpolated to prepare the map of annual rainfall trends in Qazvin which is shown in Fig. 9b. Significant changes are found only at three stations out of 20 stations in the province. Rainfalls at two stations located in the southern part of the province are found to increase at 95% level of confidence. On the other hand, rainfall at a single station located in the northeast part of the province is found to decrease significantly at 95% level of confidence. Spatial distribution of rainfall trends (Fig. 9b) shows non-significant increase and decrease of rainfall in the south and north parts of the province.

Trends of drought events: The standardized precipitation index is designed to flexibly present the incremental rainfall excess or deficit at any time scale of interest (McKee *et al.*, 1993). In the present study, SPIs at six- and twelve-month time periods are analyzed to assess the trends of dry or droughts events in Qazvin province of Iran.



(a)



(b)

Fig. 9: (a) Trends in annual average rainfall; and (b) Spatial distribution of the trends in annual rainfall in Qazvin Province of Iran

Six- and twelve-month SPI time series' for the period 1971-2003 calculated at each station of Qazvin are averaged to get the six- and twelve-month average SPI time series' of Qazvin over the study period. Trend analysis by using Mann-Kendall trend test show no significant change on average six- and twelve-month SPI values in the province. Trends in six- and twelve-month SPIs at each station are also calculated and interpolated to understand the spatial pattern in the trends of droughts with various severities in the study area.

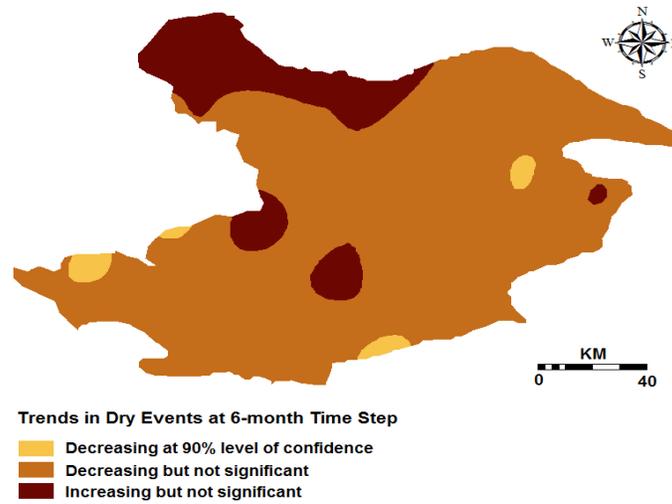
Figure 10 shows the spatial pattern in the trends of dry events ($SPI < 0$), moderate droughts ($SPI < -1.0$) and severe droughts ($SPI < -1.5$) at six-month time scale in the study area. As extreme droughts at six-month time scale is very rare, its trend is not calculated in the present study. It can be seen from Fig. 10a that no significant change in dry events at six-month time scale in the study area except in few pockets sporadically distributed over the province where the dry events are found the decrease significantly at 90% level of confidence. Spatial pattern in the trends of moderate and severe droughts at six-month time scale (Fig. 10b

and c, respectively) shows no significant change at any stations of the province.

Spatial distribution in the trends of dry events and moderate droughts at twelve-month time scale are shown in Fig. 11a and b, respectively. As the severe and extreme droughts at twelve-month time scale is very less, there trends are not calculated in the present study. It can be seen from Fig. 11a that dry events at twelve-month time scale have decreased only at a small pocket in the southwest part of the province. No significant change has occurred in rest of the province. Figure 11b shows that severe droughts at twelve-month time scale have decreased significantly in the southwest part of the province.

From the above analysis, it can be remarked that dry events or droughts has not change significantly in most parts of the province over the time period 1971-2003. Significant changes have been noticed only in few pockets sporadically distributed over the study area.

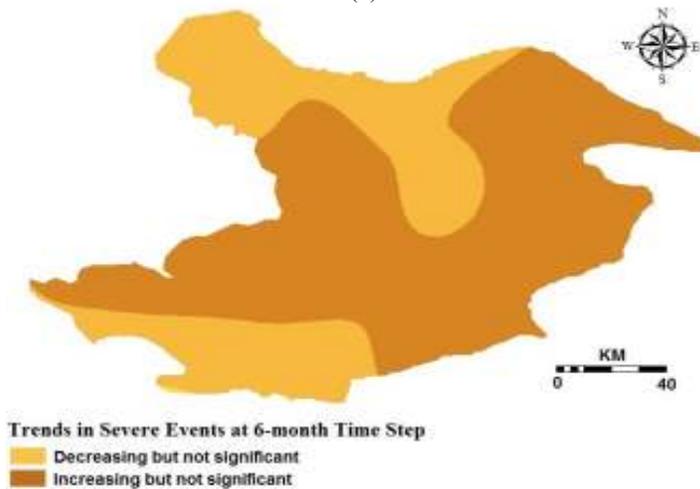
With the global climate change, land temperature is rising in most parts of the world. Rising temperature has caused a change in precipitation in many parts of the world. IPCC projections for precipitation suggest



(a)

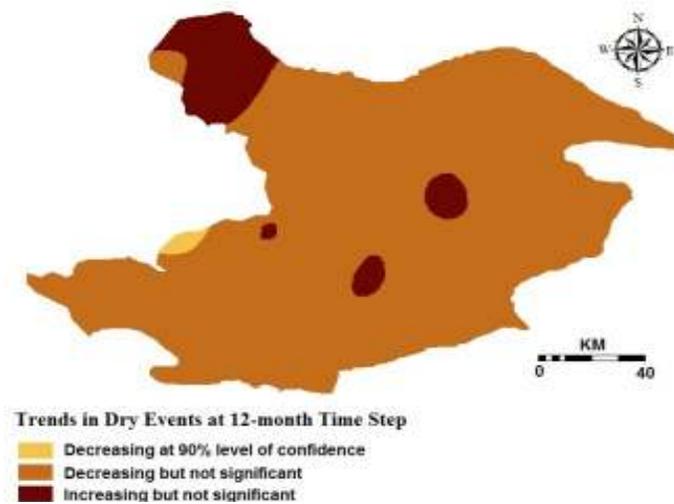


(b)

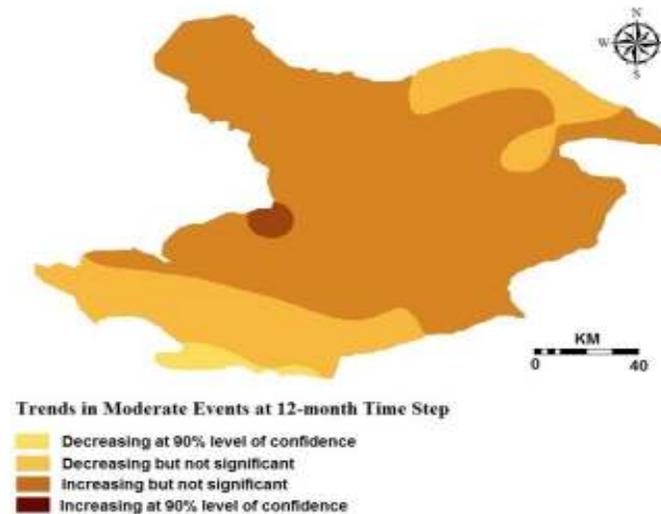


(c)

Fig. 10: Spatial distribution of the trends of (a) dry events; (b) moderate droughts; and (c) severe droughts at six-month time step in Qazvin Province of Iran



(a)



(b)

Fig. 11: Spatial distribution of the trends of (a) dry events; and (b) moderate droughts at twelve-month time step in Qazvin Province of Iran

that Iran will likely experience decrease in precipitation both in summer and winter (IPCC, 2007). This is explainable since Iran is located on the desert belt of the northern hemisphere (Farzipour, 2011). The analysis of data shows still there is no evidence in the changes of rainfall or droughts in the province. However, if the precipitation decreases in near future due to the effect of global climate change, it might have severe implications on drought severity and frequency in the province.

CONCLUSION

Drought is a major concern in Iran which has been projected to increase in future due to climate change. The spatial and temporal characteristics of

meteorological droughts in Qazvin province of Iran have been studied by reconstructing historical drought sat six- and twelve-month time steps by using SPI. This study reveals that north-west part of the province is most prone to droughts. As it is not possible to change the natural course of droughts, actions at political and institutional levels are necessary to build capacity and reduce people's vulnerability to droughts. The major outcome of the study is the production of drought hazard maps of Qazvin province. As understanding the frequency and severity of water stress is essential for adaptation and mitigating planning (Wang *et al.*, 2012b), it is expected that the study will be beneficial to a number of stakeholders of the province particularly disaster management, agricultural organizations and development/planning authorities.

REFERENCES

- Alexandersson, H., 1986. A homogeneity test applied to precipitation data. *J. Climatol.*, 6: 661-675.
- Asrari, E., M. Masoudi and S.S. Hakimi, 2012. GIS overlay analysis for hazard assessment of drought in Iran using Standardized Precipitation Index (SPI). *J. Ecol. Field Biol.*, 35(1): 323-329.
- Badripour, H., 2007. Role of Drought Monitoring and Management in NAP Implementation. In: Sivakumar, M.V.K. and N. Ndiang'Ui, (Eds.), *Climate and Land Degradation*. Springer, Berlin, Heidelberg, pp: 565-582.
- Buishand, T.A., 1982. Some methods for testing the homogeneity of rainfall records. *J. Hydrol.*, 58(1-2): 11-27.
- Daneshvar, M.R.M., A. Bagherzadeh and M. Khosravi, 2013. Assessment of drought hazard impact on wheat cultivation using standardized precipitation index in Iran. *Arab. J. Geosci.*, 6(11): 4463-4473.
- Dastorani, M.T., A.R. Massahbavani, S. Poormohammadi and M.H. Rahimian, 2012. Assessment of potential climate change impacts on drought indicators (Case study: Yazd station, Central Iran). *Desert*, 2: 157-166.
- ESRI Virtual Campus Web Course, 2004. Creating, Editing and Managing Geodatabases for ArcGIS 8.3. Retrieved from: campus.esri.com/index.cfm. (Accessed on: March, 2005)
- Farzipour, B., 2011. Climate change impacts on forest fires in Iran: Issues in global warming. Technical Document No. 1404, University of Toronto.
- IPCC, 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
- Isaaks, H.E. and R.M. Srivastava, 1989. *An Introduction to Applied Geostatistics*. Oxford University Press, New York.
- Journel, A.G. and C. J. Huijbregts, 1981. *Mining Geostatistics*. Academic Press, New York.
- Jr Heim, R.R., 2002. A review of twentieth-century drought indices used in the United States. *B. Am. Meteorol. Soc.*, 83: 1149-1165.
- Kendall, M.G., 1975. *Rank Correlation Methods*. Griffin, London.
- Keyantash, J. and J.A. Dracup, 2002. The quantification of drought: An evaluation of drought indices. *B. Am. Meteorol. Soc.*, 83: 1167-1180.
- Mann, H.B., 1945. Nonparametric tests against trend. *Econometrics*, 13: 245-259.
- McKee, T.B., N.L. Doesken and J. Kleist, 1993. The relationship of drought frequency and duration to time scales. Proceeding of the 8th Conference on Applied Climatology. Anaheim, California.
- McKee, T.B., N.J. Doesken and J. Kleist, 1995. Drought monitoring with multiple time scales. Proceeding of the 9th Conference on Applied Climatology. Dallas, TX.
- Nikbakht, J., H. Tabari and P.H. Talaee, 2013. Streamflow drought severity analysis by Percent of Normal Index (PNI) in northwest Iran. *Theor. Appl. Climatol.*, 112(3-4): 565-573.
- Palmer, W.C., 1965. *Meteorological Droughts*: United States Department of Commerce. Weather Bureau, Research Paper No. 45.
- Pereira, L.S., I. Cordery and I. Iacovides, 2002. Coping with Water Scarcity. UNESCO IHP VI, Technical Documents in Hydrology No. 58, UNESCO, Paris.
- Raziei, T., B. Saghafian, A. Paulo, L. Pereira and I. Bordi, 2009. Spatial patterns and temporal variability of drought in Western Iran. *Water Resour. Manag.*, 23(3): 439-455.
- Sayari, N., M. Bannayan, A. Alizadah and A. Farid, 2013. Using drought indices to assess climate change impacts on drought conditions in the northeast of Iran (case study: Kashafrood basin). *Meteorol. Appl.*, 20(1): 115-127.
- Shahid, S. and M.K. Hazarika, 2010. Groundwater droughts in the northwestern districts of Bangladesh. *Water Resour. Manag.*, 24(10): 1989-2006.
- Shahid, S. and O.S. Khairulmaini, 2009. Spatio-temporal variability of rainfall over Bangladesh during the time period 1969-2003. *Asia-Pac. J. Atmos. Sci.*, 45(3): 375-389.
- Shahid, S., S.K. Nath and J. Roy, 2000. Ground water potential modeling in a soft rock area using GIS. *Int. J. Remote Sens.*, 21(9): 1919-1924.
- Sneyers, R., 1990. On the Statistical Analysis of Series of Observation. World Meteorological Organisation (WMO), Technical Note No. 143, Geneva, pp: 192.
- Tabari, H., J. Nikbakht and P.H. Talaee, 2013. Hydrological drought assessment in northwestern Iran based on stream flow drought index (SDI). *Water Resour. Manag.*, 27(1): 137-151.
- Tallaksen, L.M. and H.A.J. van Lanen, 2004. *Hydrological drought: Processes and estimation methods for streamflow and groundwater*. Elsevier, Amsterdam, pp: 579.
- UNA-IRAN, 2008. *Climate Change and Iran*. United Nations Association of Iran, UNA-IRAN: Technical Document No. 1.
- Van Beers, W.C.M. and J.P.C. Kleijnen, 2004. Kriging interpolation in simulation: A survey. Proceeding of the 2004 Winter Simulation Conference. IEEE, Piscataway, NJ, pp: 113-121.
- Vasiliades, L., A. Loukas and N. Liberis, 2011. A water balance derived drought index for Pinios River Basin, Greece. *Water Resour. Manag.*, 25: 1087-1101.

- Vicente-Serrano, S.M., J.L. López-Moreno, S. Beguería, J. Lorenzo-Lacruz, C. Azorin-Molina and E. Morán-Tejeda, 2012. Accurate computation of a stream flow drought index. *J. Hydrol. Eng.*, 17(2): 318-332.
- Von Neumann, J., 1941. Distribution of the ratio of the mean square successive difference to the variance. *Ann. Math. Stat.*, 13: 367-395.
- Wang, X.J., J.Y. Zhang, S. Shahid, A. ElMahdi, H. Ruimin, B. Zhen-xin and M. Ali, 2012a. Water resources management strategy for adaptation to droughts in China. *Mitigation Adaptation Strategies Global Change*, 17(8): 923-937.
- Wang, X.J., J.Y. Zhang, S. Shahid, A. ElMahdi, R.M. He, X.G. Wang and M. Ali, 2012b. Gini coefficient to assess equity in domestic water supply in the Yellow River. *Mitigation Adaptation Strategies Global Change*, 17(1): 65-75.