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Analysis of stream flow drought and deficiency in the west of Iran

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Abstract

Iran is located within the semi-arid and arid climatic zones, characterized by the consistent droughts and shortage of water resource. This paper aims to study the hydrological drought in Karkheh river basin known as one of the main water resources in the west of Iran, in order to hinder the undesirable effects of such events on water resources through understanding its mechanism. For the purpose of this study, 13 stations were selected in the river basin to investigate the hydrological drought, based on the constant and variable threshold level methods. Among the probability distribution methods involving Log-Normal, Weibull, Double exponential distribution, Gamma, Johnson, and Generalized Pareto (GP), the most suitable one was selected using the Chi-square test at each annual maximum series of deficit volume and drought duration. Furthermore, the occurrence probabilities of drought events as well as the return period of droughts were extracted according to the best-fitted probability distribution method. The results based on both constant and variable threshold level methods demonstrated the occurrence of droughts in the most of the studied periods even for a short time. Moreover, the largest deficit volume and the longest drought duration were occurred under both methods in the periods 1999-2000, and 2007-2008.The latest time step was identified as the most critical one within the study period.

Keywords: Frequency analysis, Stream flow drought, Stream flow deficiency

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1. Introduction

Drought is a natural phenomenon occurring when the precipitation is less than normal level. The event has happened frequently in recent decades comparing to other natural disturbances (Khazaei, 2003). There is no globally accepted definition of drought.

However, in general practice, the term can be divided into meteorological, agricultural, hydrological, and socio-economic droughts (Liu *et al.*, 2012 and Mirabbasi *et al.*, 2013). Among the aforementioned types of drought, investigating the hydrological drought is essential due to dependence of practices such as industrial activities, urban water, and electricity generation by power plants to the surface water resources (Vasilides *et al.*, 2011).

Hydrological drought declines water resources, lowers water quality, reduces irrigation water, destructs harvests, reduces electricity production, disturbs habitats, and creates problems in recreation, and socio-economic activities (Mishra and Singh, 2010)**.**Given the importance of hydrological drought, several studies have been conducted by different methods worldwide, e.g. Nalbantis and Tsakiris (2009), Fleig *et al.* (2010), Wen *et al.* (2011), van Huijgevoort *et al.* (2012) and Sung *et al.* (2013).

Having information on occurrence and return period of droughts can help policymakers and experts manage drought events. This is possible through using frequency analysis of drought parameters. Numerous studies have been conducted around the world on this topic, e.g. Mijuskovic- Svetinovic *et al.* (2008), Song and Singh, (2010), Nunez *et al.* (2011), Yoo *et al.* (2012).

Karkheh river basin is situated within seven provinces in the west of Iran. The agricultural practices and human settlements are mainly found in the valleys of the upper parts of the river basin and in the dry plains while the river basin is influenced by drought.

The main objective of this study is to investigate the hydrological drought in a drought-affected basin in order to provide useful information on water resources for enhancing the management of the river basin.

2. Materials and methods

Study site

Karkheh river basin is a watershed of 50768 km^2, located in the south west of Zagros Mountains, in central Iran, with latitudes and longitudes ranging from 30° 08´ to 35° 04´ and from 46° 06´ to 49° 10´, respectively. The river basin is divided into four sub-basins classified with code 21 (Eslamian *et al.*, 2012). A total number of 13 hydrometric stations were selected on the main tributaries of the river basin having maximum and minimum length of recorded data for 54 and 20 years, respectively. Figure 1 shows location of the study area and hydrometric stations, and Table 1 illustrates the characteristics of the stations.

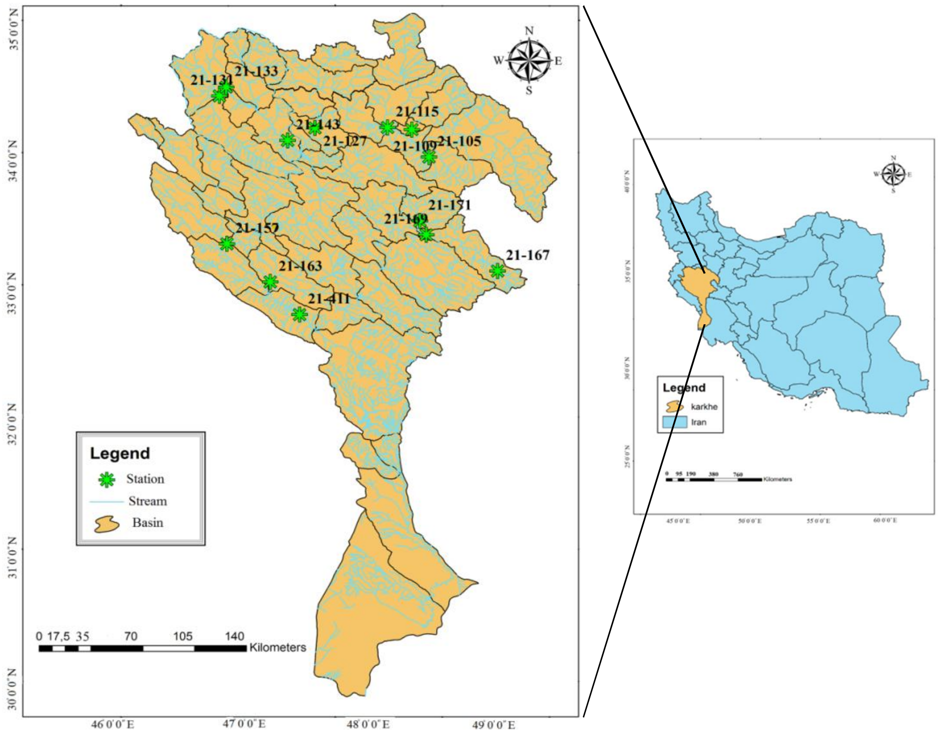


Figure 1. Location of the study area and hydrometric stations

Table 1. Characteristics of the selected hydrometric stations in Karkheh river basin

Code	Hyd. St.	Longitude	Latitude	River	Years with data
21-105	Sangsurakh	48°23′	34°22′	Gamasiab	1969-2008
21-109	Firuzabad	48°07′	34°21′	Toserkan	1954-2008
21-115	Doab	47°54′	34° 22′	Gamasiab	1969-2008
21-127	Polechehr	47° 26′	34° 21′	Gamasiab	1954-2008
21-131	Khersabad	46° 44′	34° 31′	Abmerk	1974-2008
21-133	Doabmerk	46° 47′	34° 33′	Gharesou	1954-2008
21-143	Ghurbaghestan	47° 15′	34° 14′	Gharesou	1956-2008
21-157	Dartoot	46° 41′	33° 45′	Abchenareh	1988-2008
21-163	Tang-siab	47° 12′	33° 23′	Darehdozdan	1974-2008
21-167	Dehno	48° 47′	33° 31′	Horrood	1988-2008
21-169	Kaka Reza	48° 16′	34° 43′	Horrood	1355-2008
21-171	Sarabseyed Ali	48° 13′	33° 48′	Doabaleshtar	1954-2008
21-411	Seymareh	47° 26′	33° 11′	Seymareh	1982-2008

(Tamab, 2012)

The method, known as theory of runs, usually examines the periods of upper and lower of a certain threshold (Hisdal and Tallaksen, 2000) such that when the value of a variable is less than the threshold in one or several consecutive time units, a negative run can be described by drought (Vrochidou *et al.*, 2013).

It is possible to select the threshold level with different methods while the selection is related to the type and water scarcity condition of study area (Dracup *et al.*, 1980). Moreover, using a very low threshold level for a large area with lack of long time series brings about too many zero-drought years. On the other hand, choosing the high threshold level yields the multi-year droughts (Tallaksen *et al.*, 1997). The threshold is properly explained in some practical programs. For instance, the threshold level can be defined as a certain percentile of the flow duration curve or the percent of the mean flow in the cases of permanent and periodic flows or, the regional scale, respectively (Fleig *et al.*, 2006).

For the purpose of this study, long-term daily discharge series were collected from 13 hydrometric stations located on the main tributaries of the watershed. The quality of data was then controlled while the missing data were corrected and reconstructed using Mann-Whitney test, run test, and regression analysis. A percentile of the flow duration curve (FDC) is used in order to select suitable threshold level based on using the daily data indicating the relationship between daily discharges and the probability of their occurrence$P(X \geq x)$ (Smakhtin, 2001; Ouyang, 2012). Threshold level can be considered as the values between 70% and 95% of the daily flow duration curve (Engeland *et al.*, 2004; Andreadis *et al.*, 2005; Wong *et al.*, 2011; Van Loon and Van Lanen, 2012; Hannaford and Buys, 2012). Accordingly, the threshold level of 70% was chosen in this research. The deficit volume (S_i) and duration of drought (d_i) are also suggested as parameters of drought (Eq. 1) (Yoo *et al.*, 2012; Vrochidou *et al.*, 2013; Giuntoli *et al.*, 2013). Figure 2 shows the drought parameters based on threshold level.

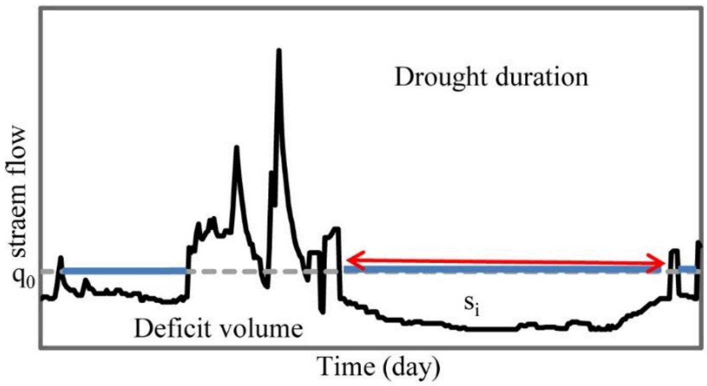


Figure 2. Drought parameters based on threshold level

$$DI_{(j)} = \begin{cases} 1 & \text{if } Q_j \leq \text{threshold} \\ 0 & \text{if } Q_j > \text{threshold} \end{cases} \qquad [1]$$

Where $DI_{(j)}$ stands for daily discharge deficit (m^3/s) on the j day and Q_j stands for daily discharge.

The threshold level can be selected constant or variable. Only a single threshold level is taken into account for the total time series of a discharge in the constant threshold level method. For the purpose of this research, Nizowka 2003 software (Jakubowski and Radczuk, 2003) was used to extract the drought parameters. Meanwhile, the variable threshold level changes seasonally, monthly, or even weekly during a year depending on how to define the unusual situation of a region (Stahl, 2001).The variable threshold method was then applied to determine stream flow deviations during both high and low flow seasons. It should be noted that periods with relatively low flow during the high flow season was not considered as drought. However, the events defined with the variable threshold, addressed stream flow deficiency or stream flow anomaly rather than stream flow drought (Hisdal and Tallaksen, 2000). Figure 3 shows the constant and monthly-based variable threshold levels.

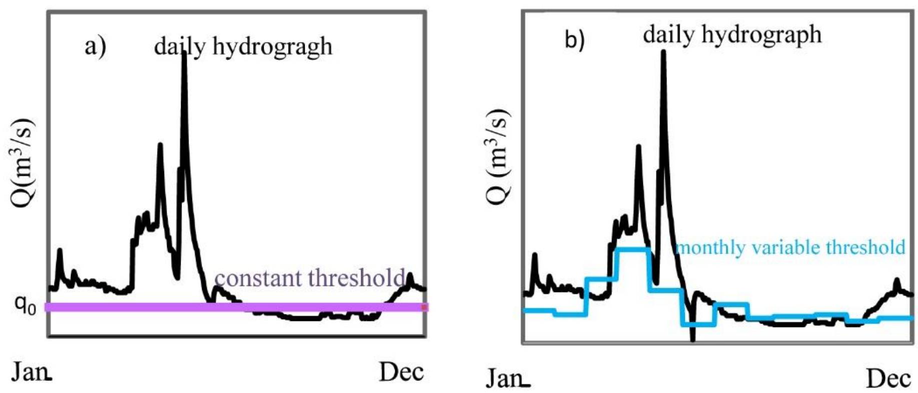


Figure 3. Threshold level method (a) constant (b) variable (monthly)

Generally, pooling procedures is required to remove the minor droughts and combining the dependent ones (Stahl, 2001; Pandy *et al.*, 2008; Van Loon and Van Lanen, 2012). There are three major methods to conduct the pooling procedure involving Sequent Peak Algorithm (SPA), Moving Average (MA), and the Inter-event Time (IT) (Fleig *et al.*, 2006). In the IT method (Zelenhasic and Salvai, 1987), which was utilized in this study, t_c is named critical time and if two dependent drought phenomenon occur with the time interval $(t_i < t_c)$ they are pooled. Under certain circumstances, duration and deficit volume are pooled **(**S_{pool}, d_{pool}**)** and computed as follows:

$$d_{pool} = d_i + d_{i+1} + t_i \quad [2]$$

$$S_{pool} = s_i + s_{i+1} \quad [3]$$

Where d_i and d_{i+1} stand forduration of events i and i+1, respectively.s_i and s_{i+1} represent deficit volumei and i+1, respectively. According to Fleig (2004) the value oft_c is 5 days.

2.3. Frequency analysis

Frequency analysis in hydrological drought aims to find the probability distribution of the deficit volume and duration of the drought that enable one to predict danger of the future droughts (Hisdal and Tallaksen, 2000). In the current study, the distribution function in a given time interval [*0,t*], e.g. one year was computed as follows:

$$F_t(x) = Pr(Z_t = 0) + \sum_{k=1}^{\infty} H_t^k(x)\, Pr(Z_t = k) \quad [4]$$

Where $Pr(Z_t=k)$ is the probability that *k* events occur in a given time interval and H_t^k is distribution function of all drought events within the time interval [*0, t*] (Fleig *et al.*, 2004). The frequency analysis of extracted Annual Maximum Series (AMS) of deficit volume and drought duration from constant and variable threshold methods was implemented in Nizowka 2003 and Easyfit software, respectively. The probability distributions of normal log, Pearson, Weibull, Double exponential, Gama, Johnson and Generalized Pareto Distribution (GP) were tested for fitting the AMSs of deficit volume and drought duration (Zelenhasic and Salvai, 1987).The best distributions were then selected based on X^2-test (Zelenhasic and Salvai, 1987) computed as follows:

$$X^2 = \sum_{j=1}^{k} \frac{\left(O_j - E_j\right)^2}{E_j} \quad [5]$$

Where Q_j is the numerical value of the observed data,E_j is the numerical value of expected data, and *k* is the number of serial intervals, according to probable occurrence derived from probability distribution $F_t(x)$. Different return periods of drought parameters were computed as follows:

$$T_{(x)} = \frac{1}{1 - F_t(x)} \quad [6]$$

Table 2 illustrates the computation methods of the applied distributions in this study.

Table 2. Computation methods of the applied distributions in this study

Function	Formula
Normal log	$f(x) = \frac{1}{(x-S)\sigma\sqrt{2\pi}} e^{\frac{(\ln(x-s)-\mu)^2}{2\sigma^2}}$ x>S
Pearson	$f(x) = \frac{\lambda^{\beta}(x-\varepsilon)^{\beta-1} e^{\lambda(x-\varepsilon)}}{x\Gamma(\beta)}$ $0 \leq x < +\infty$
Weibull	$f(x) = \alpha\lambda(x-S)^{\alpha-1} e^{-\lambda(x-S)^{\alpha}}$ x>S
Double exponential	$f(x) = \alpha e^{-\alpha(x-\mu)} e^{-e^{-\alpha(x-\mu)}}$
Gama	$f(x) = \frac{\alpha^{\upsilon}}{\Gamma(\upsilon)}(x-S)^{\upsilon-1} e^{-\alpha(X-1)}$ x>S
Johnson	$f(x) = \frac{1}{\sqrt{2\pi}\sigma}\frac{b-a}{(x-a)(b-x)} \exp\left[\frac{1}{2\sigma^2} \left(\ln\frac{x-a}{b-x} - \mu\right)^2\right]$ b>x>a
Generalized Pareto	$f(x) = \frac{1}{\alpha}\left[1 - k\frac{x-s}{\alpha}\right]^{\frac{1}{k}-1}$ x>S

Figure 4 illustrates the steps taken in this study.

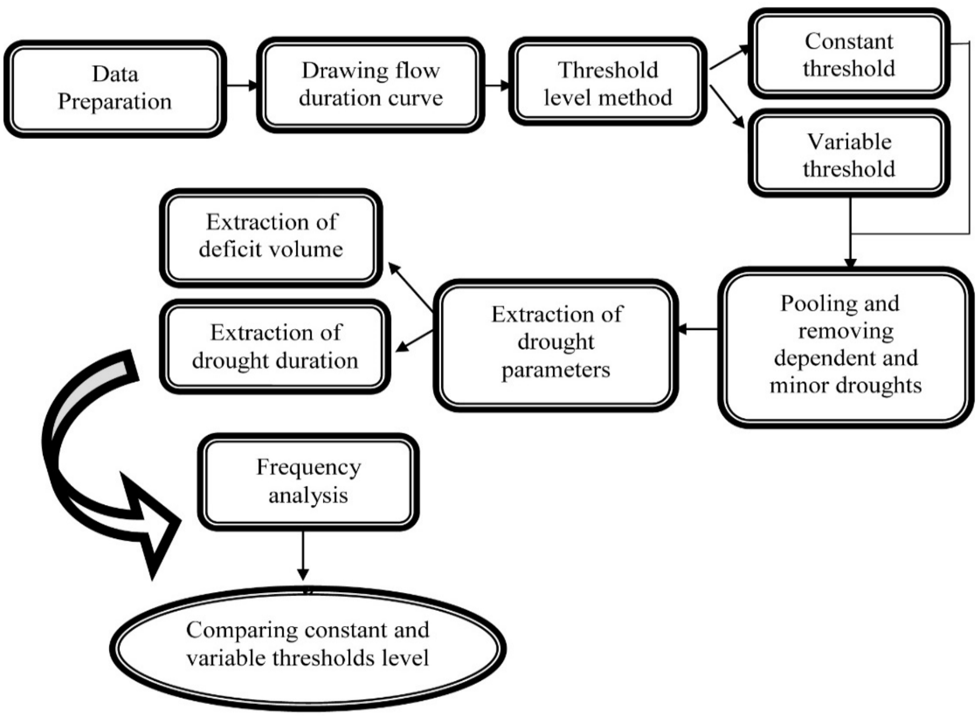


Figure 4. Flowchart of the main steps of research in this study

3. Results and Discussion

The parameters including deficit volume, drought duration, and date of occurrence were determined for each station. The results based on both constant, and variable threshold level methods showed that the basin experienced drought for most of the years even for a short period.

Comparison of the results obtained from constant and variable threshold level methods showed the inclination of the variable threshold level method to increase, (Figures 5 and 6). This is mainly due to capability of the variable threshold level method to show the stream flow deficits during the high and low flow seasons. A stream flow rate may be called stream flow deficiency though it is not considered drought in spite of the rate being lower than the usual during a certain season (Stahl, 2001). This deficiency might be due to delayed onset of snowmelt.

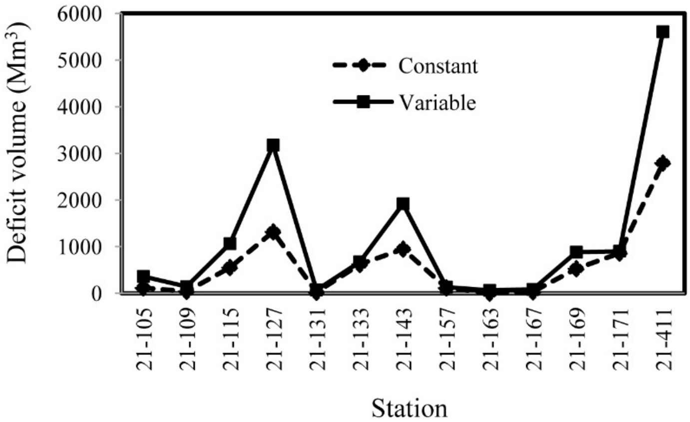


Figure 5. Deficit volume in constant and variable threshold method

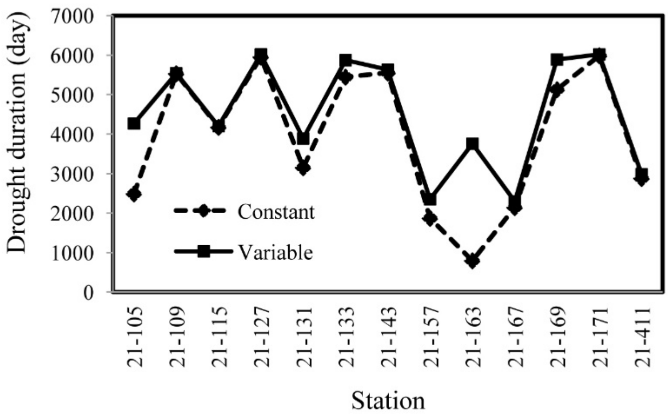


Figure 6. Drought duration in constant and variable threshold method

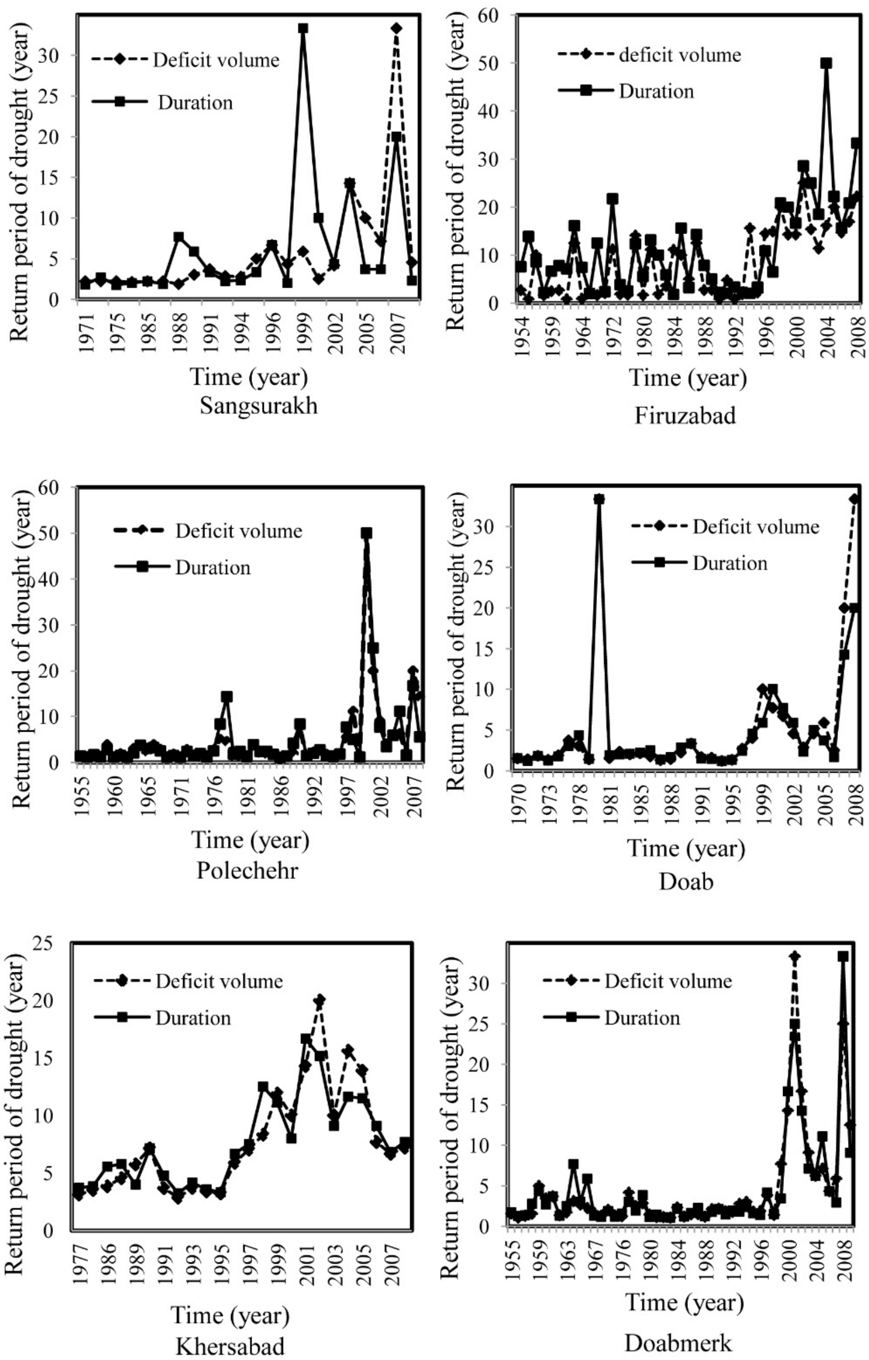
The achieved results of comparing both constant and variable threshold level methods based on the independent-samples t-test (Bihamta and zareh chahuki, 2008) demonstrated that there was no significant difference between the two methods (Table 3). It means, both methods can be used to analyze the drought, but the results of variable threshold level method are independent from seasonal regional climatic characteristics. The findings can be attributed mainly to actual meteorological situation that are therefore suited for linking to atmospheric circulation (Stahl, 2001). This is significant in order to manage water resources towards diminishing the damages of drought.

Table 3. Comparison of the results of two drought methods using t-test

Drought parameters	Independent-samples t-test
Deficit volume	0.11^{ns}
Drought duration	0.17^{ns}

ns: not significant

Afterwards, the best probability distribution was determined to fit the annual maximum series of deficit volume and drought duration in each station. For series of deficit volume and drought duration extracted from constant threshold method, the best distribution was not found to fit the data series in Tang-siab station. The largest return period (59 years) was observed in Doabmerk station for the year 1973 while the least return period (14 years) was observed in Dehno station for the year 1999, based on deficit volume analysis (Figure 7). Likewise, the largest return period (50 years) was seen in Polechehr station for the year 2000 and the least return period (14 years) was seen in Dehno station for the year 1999, based on the duration analysis (Figure 7). Furthermore, Polechehr station experienced the largest return period (100 years) for the year 2008 whilst Sarabseyed Ali station experienced the least return period (20 years) for the year 1999, based on the deficit volume analysis (Figure 8). In addition, Khersabad station experienced the longest return period (50 years) for the year 2008 whereas Daroot station experienced the shortest return period (13 years) for the year (2008), based on the duration analysis (Figure 8).


Deficit volume
Duration
Return period of drought (year)
Time (year)
Sangsurakh
deficit volume
Duration
Return period of drought (year)
Time (year)
Firuzabad
Deficit volume
Duration
Return period of drought (year)
Time (year)
Polechehr
Deficit volume
Duration
Return period of drought (year)
Time (year)
Doab
Deficit volume
Duration
Return period of drought (year)
Time (year)
Khersabad
Deficit volume
Duration
Return period of drought (year)
Time (year)
Doabmerk

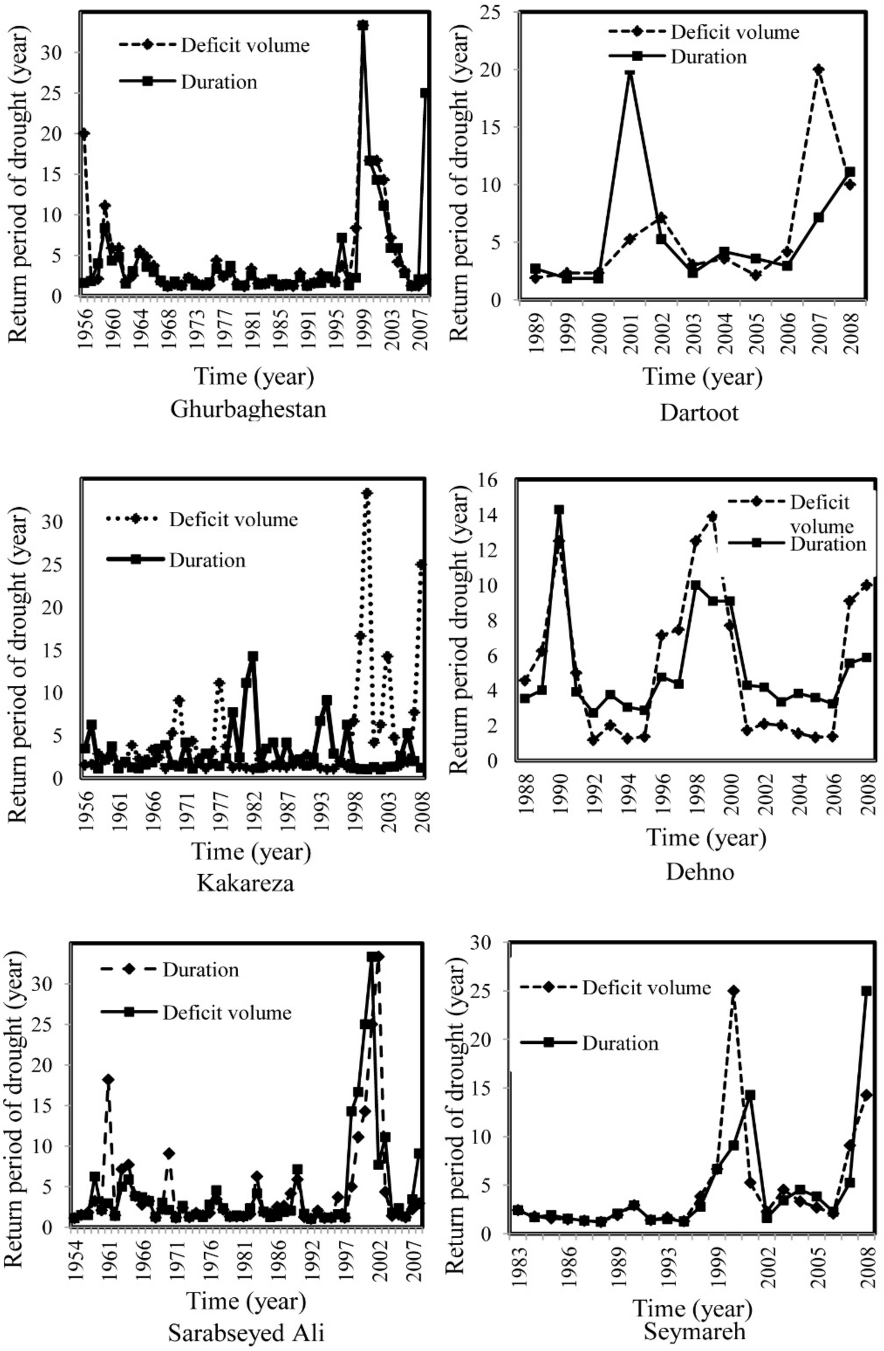
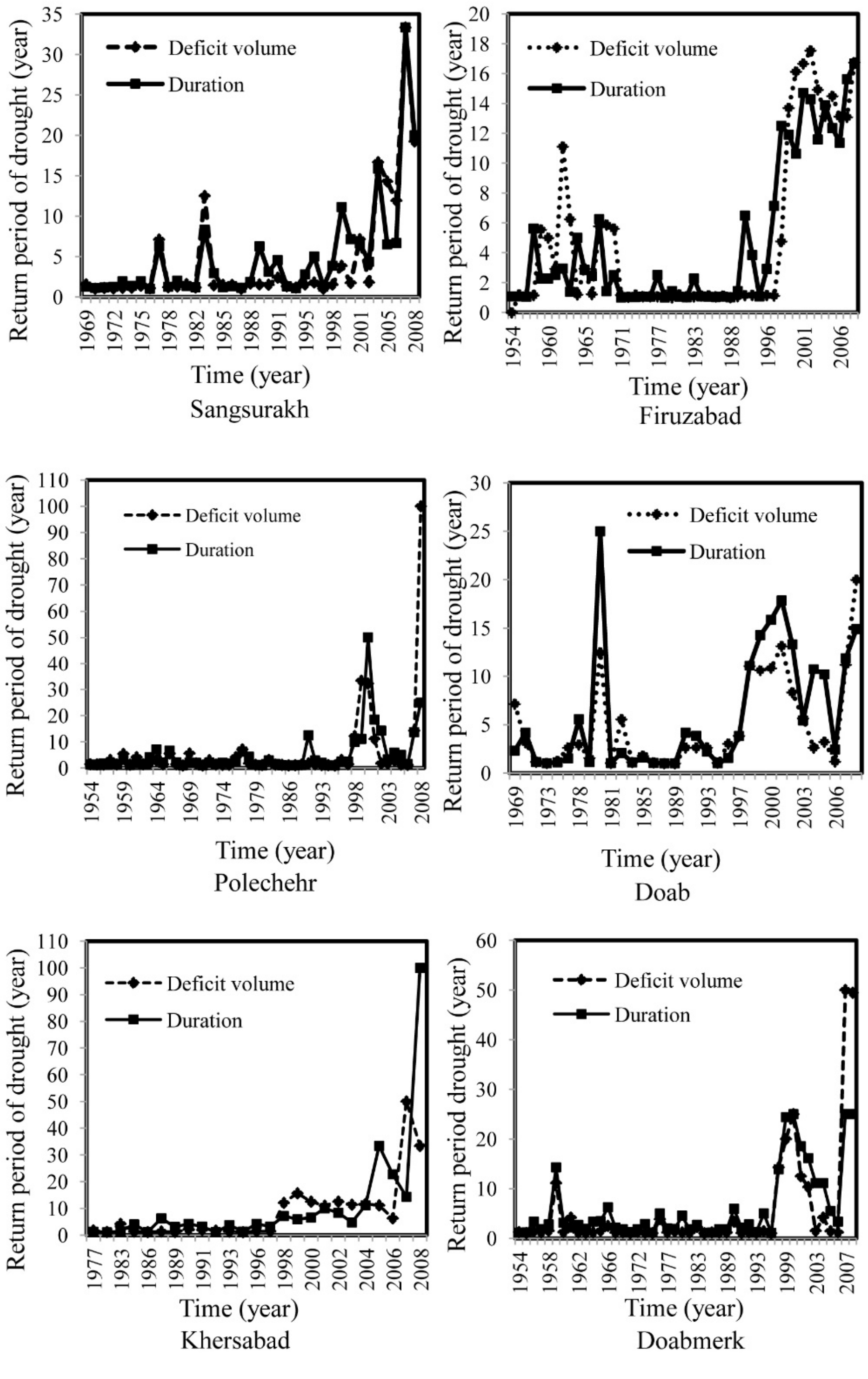


Figure 7. Various return periods of drought parameters in constant threshold method


Deficit volume
Duration
Return period of drought (year)
Time (year)
Sangsurakh
Deficit volume
Duration
Return period of drought (year)
Time (year)
Firuzabad
Deficit volume
Duration
Return period of drought (year)
Time (year)
Polechehr
Deficit volume
Duration
Return period of drought (year)
Time (year)
Doab
Deficit volume
Duration
Return period of drought (year)
Time (year)
Khersabad
Deficit volume
Duration
Return period drought (year)
Time (year)
Doabmerk

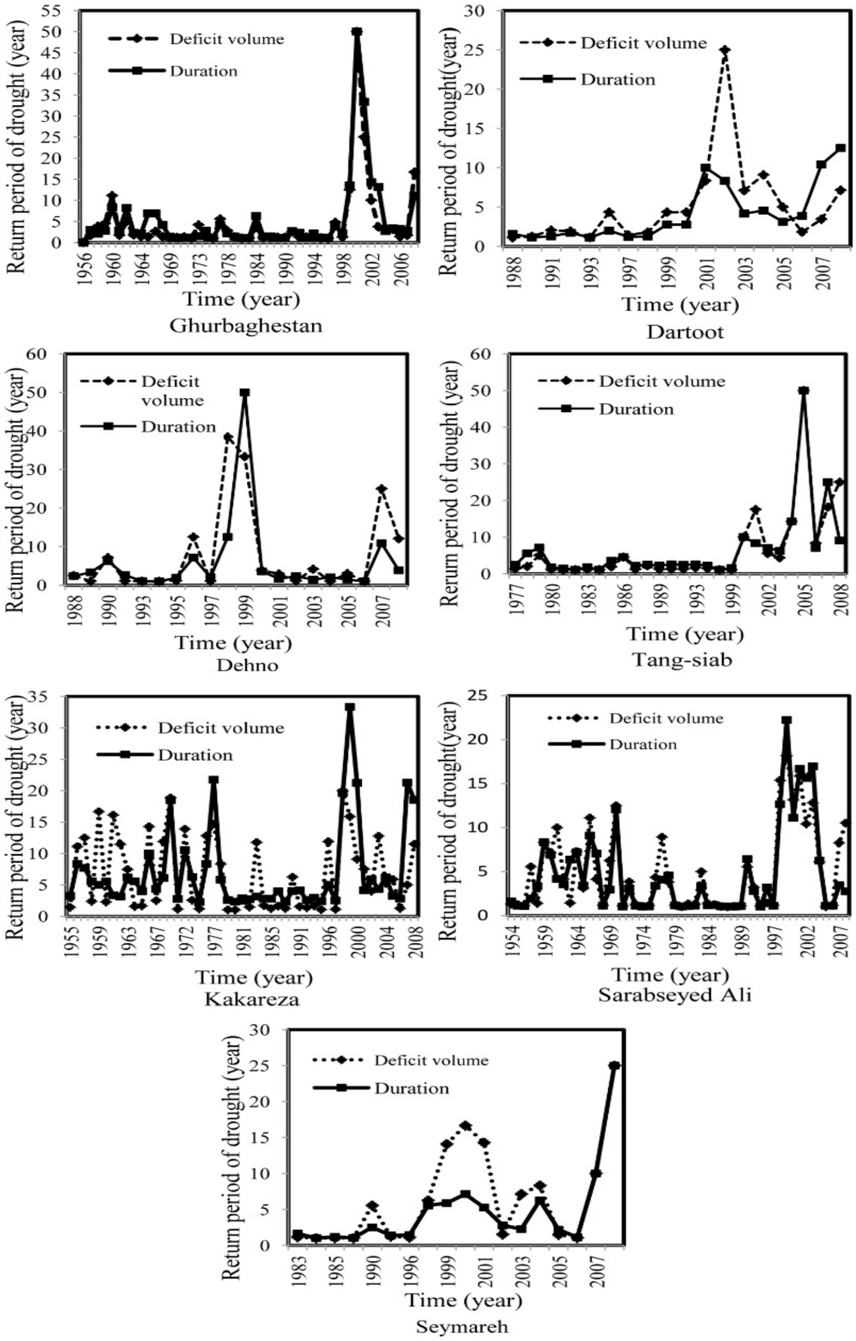


Figure 8. Various return periods of drought parameters in variable threshold method

Results of the frequency analysis indicated that the largest deficit volume and the longest drought duration were occurred in periods 1999-2000 and 2007-2008based on both constant and variable threshold level methods (Figures7 and 8). The latest time step was identified as the most critical one within the study period due to occurrence of extensive climate changes in most parts of Iran during this period. The outcomes are in line with the findings of Kariminazar *et al.* (2010), and Kaznowska (2011).

Our results indicated that there were some differences in return periods of droughts (Figures 7 and 8). The reason is that the statistical distributions for deficit volume and drought duration were not the same in each station while the temporal variations were the same.

5. Conclusions

This research successfully applied useful techniques for analyzing the hydrological drought known as constant and variable threshold level methods at a drought-affected watershed in Iran. This is important, taking into account that there is shortage of documentation regarding the variable threshold level method, especially knowing that there is no evidence of such research in Iran. Hence, this research provides a way to conduct further researches in this domain.

The findings of this research revealed that the whole Karkheh river basin is under the hydrological drought risk. Moreover, the constant and variable threshold level methods were found useful means to assess stream flow drought and deficiency, respectively. We suggest that through adopting the techniques such as improving the traditional rainwater harvesting systems, waste optimum management, construction and improvement of water structures, preventing extraction of more ground water, and undertaking the correct water consumption culture, droughts can be made more manageable.

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