



# Application of effective drought index (EDI) in characterizing drought periods (case study: Tabriz, Bandar-e Anzali and Zahedan stations)

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## Abstract

In this study, drought characteristics of three stations namely Tabriz, Bandar-e Anzali and Zahedan are analyzed from 1951 to 2012 using the effective drought index (EDI). For this purpose daily precipitation records of each station are arranged in a distinct column of excel spreadsheet. Long-term daily average of the day (in daily scale) is substituted for missing data. In this study, effective precipitation index (EPI) is calculated, too. This is accomplished once for dummy duration (365 days) and once again for actual duration. Then daily mean effective precipitation (MEP) for each day of a year is calculated. Moreover, differences between effective precipitation (EP) and MEP are calculated and named DEP. Then standardized values of DEP (shown with SEP) are calculated, too. Precipitation needed for returning to normal condition (shown with PRN) is calculated for every station. At last, the EDI for each station in whole time period is obtained. In this study, time series including: (1) daily EPI (for dummy period of 365 days as well as actual duration), (2) MEP, (3) DEP, (4) SEP, (5) PRN and (6) EDI for every station are plotted. Results showed that years 2007–2008, 2007–2008 and 2001–2002 were known as the driest years in the 60 years time period, respectively, for Tabriz, Bandar-e Anzali and Zahedan stations. Based on the number of dry days occurred for each station it can be calculated that Bandar-e Anzali, Tabriz and Zahedan having the 2407, 1517 and 1338 dry days in the whole time period ranked in the first to third orders.

**Keywords** Tabriz · Bandar-e Anzali · Zahedan · Effective drought index · Precipitation

## Introduction

Drought refers to a period of time that water shortage occurs and, therefore, the environment and human life is disrupted. Of course, depending on regional and objectives of a research drought can take different definitions because the lack of water in different regions has different definitions. Drought forecasting is almost impossible and usually is a phenomenon that progress slowly. Therefore, well-timed detection in the early stages makes it possible to reduce the adverse effects on different parts of the environment, agriculture, water resources and so on.

Drought characteristics such as duration and severity of drought can be determined by drought indices. Scientists have proposed various indexes to assess this phenomenon. Drought index is a useful tool to assess drought

characteristics. Effective drought index (EDI) is a method, which is based on the cumulative daily precipitation by weighting method. This method is the only known way that determines daily dry and drought periods that last for several years.

In Iran, few studies were conducted on drought using the EDI index. Mogadassi et al. (2005a, b) monitored and evaluated drought conditions in Tehran in 1998–1999 using the EDI and assessed the sensitivity of mentioned index to length of period. They also conducted another study to monitor drought spells between 1998–1999 and 2000–2001 in Tehran using the standard precipitation index (SPI) and EDI by GIS tool (Mogadassi et al. 2005a, b).

Akhtari et al. (2006) conducted spatial analysis of drought by SPI and EDI using the rainfall observations of 43 stations in Tehran province. Morid and Paymozd (2007) studied drought in the period of 1998–1999 to 2000–2001 using the method known as Chang procedure in daily time scale and meteorological drought index (EDI) for Tehran province. Nowadays, the EDI is interested by many researchers. In the other countries, many researches have also been conducted

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in this regard. For instance, some of the most important studies are referred. Byun and Wilhite (1999), in enumerating the disadvantages of other indices, introduced new indices namely mean effective precipitation (MEP), effective precipitation (EP) and EDI and then explained them. They also applied these indices in the high plains of the United States during the 1960–1996 and compared the results with previous drought reports. They concluded that the EP-related indexes (including EDI) are suitable for practical use. Furthermore, they found that all of the new indices derived from the EP in the study area have reasonable results. Among the indices, EDI is known as the best indicator for evaluating the severity of drought in global scale and precipitation needed for returning to normal condition (PRN) was known as the most appropriate index in areas with restricted time series. Morid et al. (2007) compared accuracy of the drought index namely: deciles, normal percentage index, SPI, the index of Chinese Z, modified Chinese Z, Z Index Score and EDI for monitoring drought in Tehran province. They conclude that modified China Z Index (MCZI) and percentage of normal (PN) indices are not suitable to assess drought in Tehran. Deciles Index (DI) showed large sensitivity to temporal and spatial variations of rainfall during wet periods. EDI responded quickly to emergency dryness situations rather than SPI and DI and indicated the development of dry conditions better than other indices. While the need for daily rainfall data series is known as a limitation of this index. Kim et al. (2009) evaluated the two meteorological indices consisting of EDI and SPI for Seoul station in South Korea in the period of 1807–2006 to choose a best index. They also presented some indices such as CEDI, AEDI, YAEDI for the purpose of improving the EDI index. They compared and evaluated the strengths and weaknesses of these two indices. Byun and Kim (2010) compared the performance of EDI and SPI indices in Seoul, South Korea. In the mentioned study, the time scales of 1, 3, 6, 9, 12 and 24 months were selected for SPI index. The minimum value of EDI versus SPI was plotted as a scatter plot to evaluate the accuracy of drought indices. The results indicated that there is not any significant correlation between the two mentioned indices, but in long-term time span SPI index behavior was same as EDI. It can be concluded that in short-term time span SPI underestimates drought intensity. Wambua et al. (2014) examined the performance of SPI and EDI indices in drought prediction using artificial neural network in the upstream of Tana River basin. The results indicated that at the beginning of the period both indices cannot predict drought with good accuracy, but over time that the number of data given to software get more and more accuracy of the indices in drought modeling increases. By comparing the obtained correlation coefficient between the calculated and observed indices, it can be realized that EDI in comparison with SPI show higher correlation with software-observed data and

thus performs well in drought prediction. Jain et al. (2015) compared the SPI, EDI, Z-score, Z Chinese, RD and RDDI indices to determine the most appropriate one in the Ken River Basin, located in central India. All selected indices with different lag times were used to calculate the drought severity. The results showed that all indices in the time span of 1 month cannot be able to estimate the dry length with good accuracy. Furthermore, they concluded that in 9-month time span all indices had reasonable capabilities. It can be concluded that because EDI index does not have a certain time interval, its correlation with other indices in all time periods (both short and long time) are good. The best correlation was achieved in the time period of 9 months. This index predicts drought spell earlier than other indices and this is a prominent advantage for a drought index. The aim of this study is applying EDI in three different climate of Iran and comparing the results with each other and some of other similar studies.

## Materials and methods

In this study, three stations were selected for analysis from different climates of Iran, which are Tabriz, Bandar-e Anzali and Zahedan.

Tabriz is the capital city of East Azerbaijan province having the semi-arid climate. The geographical coordinates of Tabriz is 38° and 36'N, and 46° and 49'E and its altitude is about 1348 m above the sea level. Its weather is very cold in winter, and hot and dry in summer. The annual mean air temperature of Tabriz is about 9.1 °C; its annual mean precipitation is about 300 mm.

The second station selected for this study is Bandar-e Anzali having the humid climate.

Bandar-e Anzali is located in the Caspian Sea shoreline, which is located in Guilan province. It is located in 49°28'N longitude and 37°28'E latitude. Its altitude is –24 m. The mean annual rainfall of this station is about 1892 mm. The largest monthly precipitation of this station belonged to the September. The mean annual relative humidity of this site is varied from 71 to 97% and the annual mean air temperature is about 16.2 °C.

The third station selected for this study is Zahedan having the hyper-arid climate.

Zahedan is capital city of Sistan–Baluchestan province located in the southeast of Iran. Its geographical location is 60°51'E, and 29°30'N. Its altitude is about 1385 m above mean sea level. Its annual mean rainfall is about 72 mm. The average of annual maximum air temperature is about 37 °C whereas the absolute minimum air temperature is recorded as –12.6 °C. The average annual relative humidity of this station is about 33%.

**Effective drought index** To better monitor the drought, selecting the time scale is of particular importance. The main advantage of EDI compared to other known indices is the daily time scale of this index. It should be noted that only required data by this method are daily precipitation data. EDI computational steps are briefly mentioned below. The first step is choosing dummy duration, which can be chosen as 365-day or 15-day period. After selection of dummy period calculation, process begins according to the following steps.

**Daily effective precipitation** Understanding the concept of effective precipitation or EP is essential for better analysis of drought using the EDI. The amount of EP is calculated with summation of daily rainfall values using the function, which decreases with time. In fact, the EP that is calculated for each day is a function of certain daily precipitation and the rainfall of previous days, so the recent day's precipitation get large weight in the EP comparing the last far day's. Obviously, the calculations for EP for the first year will be impossible, so the total number of EPs is equal to  $\{(number\ of\ years - 1) \times 365\}$ .

Byun and Wilhite (1999) proposed different functions to calculate the EP but according to the recommendation of Mogadassi et al. (2005a, b) the following equation is found to be the most proper relationship in the similar studies:

$$EP_i = \sum_{n=1}^i \left[ \left( \sum_{m=1}^n P_m \right) / n \right], \quad (1)$$

where  $i$  is the dummy period and  $P_m$  is the total precipitation received in the past  $m$  days.

**Mean of effective precipitation** As mentioned before, for every day of a year, the total number of EP<sub>*i*</sub>s is equal to the number of years minus one multiplied by 365. For each day of a year MEP<sub>*i*</sub> is calculated by average of the EP<sub>*i*</sub> values of a same day for years in time period.

**Differences between the EP<sub>*i*</sub> and MEP<sub>*i*</sub>** Differences between the EP<sub>*i*</sub> and MEP<sub>*i*</sub> for the  $i$ th day is calculated by the following equation:

$$DEP_i = EP_i - MEP_i, \quad (2)$$

where MEP<sub>*i*</sub> is the long-term average of EP, and EP<sub>*i*</sub> is the effective precipitation (mm) for the  $i$ th day. The positive value of DEP<sub>*i*</sub> means that water is stored in the considered time and site whereas negative values of DEP<sub>*i*</sub> implies that water is drawn in certain time from the site.

**Standardized DEP<sub>*i*</sub> (SEP<sub>*i*</sub>)** To compare the results of different areas regardless of climate conditions, DEP<sub>*i*</sub> values should be standardized using the following equation:

$$SEP_i = \frac{DEP_i}{ST(EP_i)}, \quad (3)$$

where ST(EP<sub>*i*</sub>) is the standard deviation of the EP (mm) for each day of the dummy period and SEP<sub>*i*</sub> is the standardized value of DEP<sub>*i*</sub> (mm).

**Dry period and actual duration** It is clear that negative values of DEP<sub>*i*</sub> and SEP<sub>*i*</sub> indicate that precipitation is lower than normal and thus there is a drought spell in the period. Dry period refers to a time that these two mentioned parameters consecutively be negative. The actual dry duration is calculated by adding dummy duration and dry period. Actual duration is calculated for every day of the studied time period.

**Precipitation needed for a return to normal (PRN<sub>*j*</sub>)** Regarding to the actual duration, the amount of precipitation needed for returning to normal conditions is calculated by a iterating the calculation process of previous steps. Thus, for each day of the time period with actual duration in hand, the values of EP<sub>*i*</sub>, MEP<sub>*i*</sub> and DEP<sub>*i*</sub> are recalculated again. The only difference between the calculations of this stage with that of the previous steps is in its time duration (dummy or actual). In the first stage, calculation is performed with dummy duration, whereas at this stage, calculations are obtained with actual duration that were calculated in the previous steps. After calculating the DEP<sub>*i*</sub> for every day with actual duration, the precipitation needed for returning to the daily normal (PRN<sub>*j*</sub>) conditions can be obtained using the following equation:

$$PRN_j = \frac{DEP_j}{\sum_{N=1}^j \left( \frac{1}{N} \right)}, \quad (4)$$

where  $j$  is the index for actual duration and PRN<sub>*j*</sub> is the amount of precipitation needed for returning the normal condition (mm).

**Effective drought index** The value of precipitation deficiency from the normal situation indicates the severity of drought, so PRN<sub>*j*</sub> can be considered as the severity of drought. Therefore, in different climate conditions, it is needed to standardize the PRN<sub>*j*</sub> amount. In fact, EDI<sub>*j*</sub> is the standardized value of the PRN<sub>*j*</sub> and is introduced as the severity of the drought, which is calculated using the following equation:

$$EDI_j = \frac{PRN_j}{ST(PRN_j)}, \quad (5)$$

where ST(PRN<sub>*j*</sub>) is the standard deviation of the PRN<sub>*j*</sub> time series. EDI<sub>*j*</sub> (mm) shows the drought conditions independent of climate conditions. After calculating the EDI<sub>*j*</sub> values for each day of a year (365 days), classification of drought is performed using the following criteria (Kim et al. 2009):

If the amount of EDI is less than or equal to  $-2$ , it is considered as the most severe drought.

If  $-2 < EDI \leq -1.5$ , it is considered as the severe drought.

If  $-1.5 < EDI \leq -1$ , the drought is the moderate type.

And if  $-1 < EDI \leq +1$ , the situation of the period is normal considering the rainfall.

Figure 1 shows the computational steps of EDI as a flowchart. It should be noted that all the above indices are calculated by a code written by the authors in Matlab.

## Results and discussion

Figure 2 shows daily EP with dummy and actual duration. As it can be deduced from the mentioned figure that the highest amount of EP in Tabriz station is around 835 mm, which is experienced on the 19th April, 1969. Comparing the maximum amount of EP for Tabriz station with corresponding value of Tehran Mehrabad station reported by Mogadassi et al. (2005a, b) it can be concluded that maximum EP in Tabriz station is two times more than of Tehran. Also, according to Byun and Wilhite (1999), the maximum

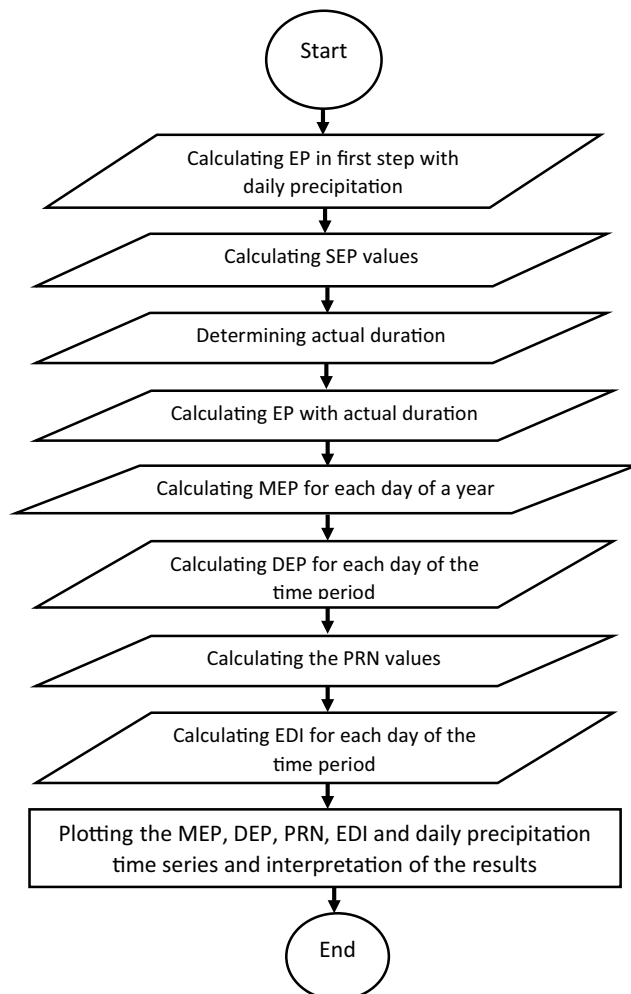
value of EP for the Nebraska station in United States is approximately twice of the corresponding amount of Tabriz.

By comparing both actual and dummy duration it can be realized that amount of EP values with actual duration is greater than corresponding EP with dummy duration (365 days).

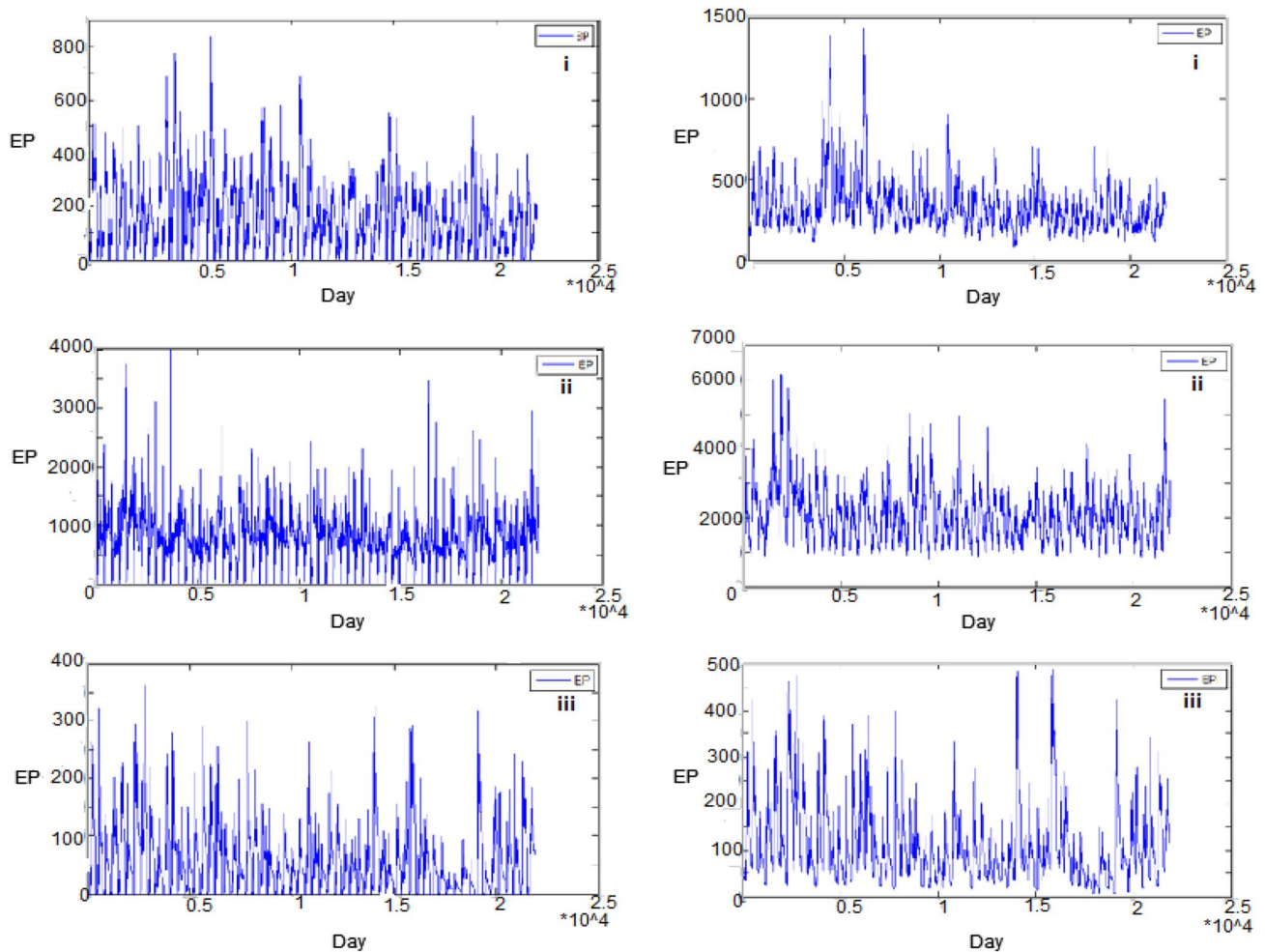
Figure 3 shows the MEP and PRN value diagram for the selected stations. It can be concluded that MEP of Tabriz station during the second decade of October to the second decade of December as well as the second decade of April to the middle of May was relatively too large. The greatest amount of mean of effective daily precipitation was about 472 mm, which corresponds to the 24th May. According to the findings of Byun and Wilhite (1999) reported for the Nebraska in United States, this was approximately 1000 mm, which is about 12.2 times larger than of Tabriz station. This value for Mehrabad station in Tehran during the hydrological year 1999–2000 was about 440 mm (Mogadassi et al. 2005a, b), which is close to the corresponding value of Tabriz station. In Tabriz station, the amount of rainfall for returning the normal conditions on some days of the studied period reached nearly 40 mm. On wet days that there is no need for additional precipitation to compensate dryness, the amount of excess precipitation rarely reaches to 150 mm. The results showed that through the studying period in the time domain of middle of 1963 until the end of 1968 steadily PRN values were positive. In fact, such years with positive PRN values can be known as wet years for Tabriz station (Table 1).

According to the EDI values results showed, in Tabriz station, the number of days with the most severe drought last for only 22 days (equivalent to 0.1% of the total days of the time period, i.e., 21,900 days). Most of mentioned days in Tabriz belonged to the autumn season. According to the classification of EDI, the number of days with EDI values in the range of severe drought is about 146 days (about 0.66% of the total time period). The maximum number of days having severe drought also occurred in autumn. During the study period, there are 1349 days (which is equivalent to 6.15% of the total time period days), and Tabriz experienced moderate drought. The rest of the days of the time period and according to the values of EDI, the normal condition or even better than the normal condition dominated in Tabriz. Figure 4 shows the graphs of EDI parameter of three selected stations.

The hydrological year of 2007–2008 was known as the first rank of driest year in Tabriz station. Totally, 182 days experienced drought in Tabriz. 126 out of the 182 days experienced the moderate drought whereas other 56 days experienced severe drought. It is worthy to mention that there is no very severe drought in this year. The second rank of dry year can be attributed to the hydrological year 2000–2001, in which 1, 19 and 154 days, respectively, showed the most severe drought, severe drought and



**Fig. 1** Flowchart of the computer code to calculate the effective drought index



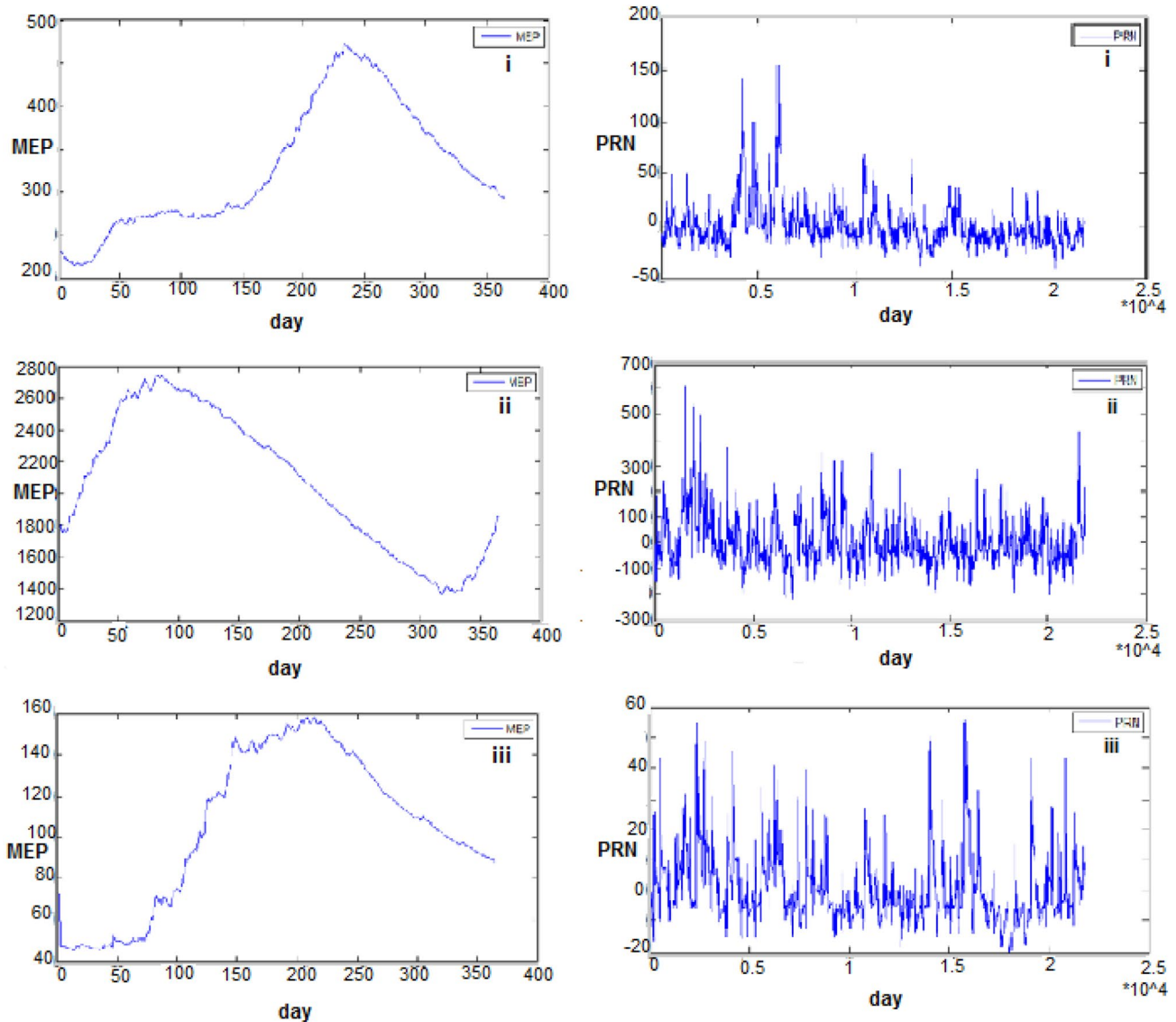
**Fig. 2** Graphs of effective daily precipitation with actual and dummy duration (in mm). **i** Tabriz station, **ii** Bandar-e Anzali station and **iii** Zahedan station. Note that the graphs in right column refers to actual duration and that in left column refers to the dummy duration

moderate drought. The third rank of dry year is related to the 1990–1991 having the total number of 171 dry days. 21 out of the total 171 days faced with severe drought. Ranking of dry year for this station performed based on the number of days that drought observed. In other words, ranking is not performed according to the severity of drought. It is obvious to mention that the impact of the most severe drought on water resources is more than the moderate droughts.

Effective drought index at Tehran Mehrabad station in 1998–1999 year in the most of days of time period is reported to be negative (Mogadassi et al. 2005a, b). Comparison of the annual data with several hydrological years is incorrect, because the time period used in the two distinct cases are not compatible with each other. Also, EDI values for Nebraska region shows fluctuations which appears to be below the zero line, so in the most of cases, this area has experienced drought (Byun and Wilhite 1999) (Table 2).

## Conclusions

Average daily precipitation in Tabriz, Bandar-e Anzali and Zahedan stations are, respectively, 0–3.5, 0–45 and 0–2 mm per day and the maximum value of daily precipitation of the stations is, respectively, 60, 360 and 55 mm per day. Most of the precipitation received in the mentioned three stations is experienced in April, November and February, respectively. Also, maximum daily EP obtained in Tabriz, Bandar-e Anzali and Zahedan, respectively, was about 835, 4000 and 363 mm. It is concluded that EP is independent of daily precipitation and its fluctuation pattern is similar to the daily precipitation perturbation. According to Fig. 2, mean values of EP calculated by actual duration were greater than corresponding values calculated with dummy duration (365 days). The reason for this is attributing more weights for rainfall occurred for the considered day and its adjacent previous days. Due to the effect of the earliest day's precipitation in calculating

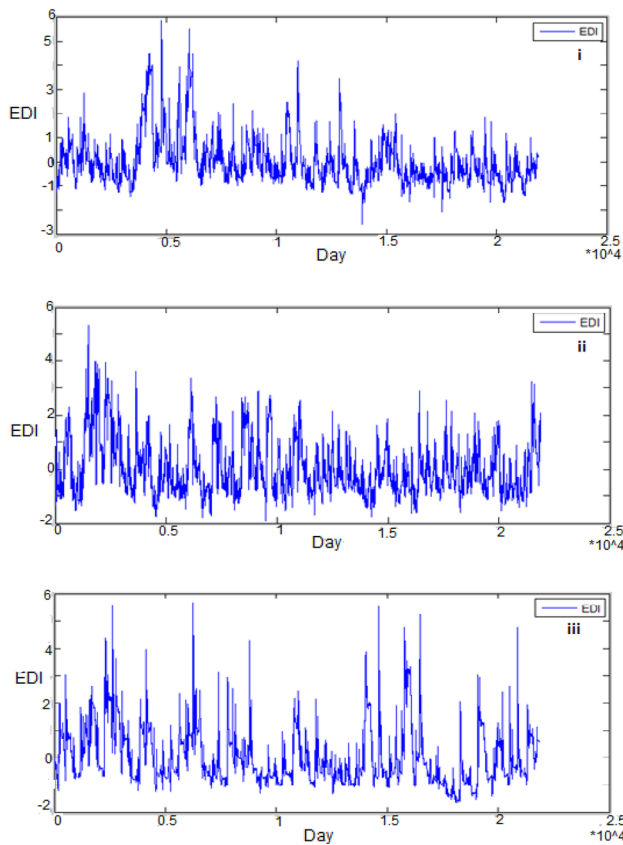


**Fig. 3** MEP (left column) and PRN (right column) values of the selected stations. **i** Tabriz, **ii** Bandar-e Anzali and **iii** Zahedan

**Table 1** Maximum and minimum values of calculated DEP and PRN of the selected stations

Station	Parameter	Minimum	Maximum
Tabriz	DEP	-266.29	1051.2
Tabriz	PRN	-41.12	153.43
Bandar-e Anzali	DEP	-1457.8	4235.5
Bandar-e Anzali	PRN	-225.12	608.26
Zahedan	DEP	-129.01	363.72
Zahedan	PRN	-19.92	55.19

the EP, the station's climate is drier, and the range of EP parameter decreases. In this study, the maximum value of DEP as well as the minimum value of that belonged to humid station among the selected stations. Furthermore, it can be concluded that if the maximum amount of DEP in a specific station be large, in contrast minimum value of DEP would be small. Also, the amount of precipitation needed for returning to the normal condition (PRN) in Bandar-e Anzali station was more than that of Tabriz. Similarly and in Tabriz station, the amount of rainfall needed for returning to the normal condition was more than of Zahedan. Generally, PRN values of humid stations were more than that of the arid and semi-arid stations.



**Fig. 4** Graphs of EDI values of the three selected stations **i** Tabriz, **ii** Bandar-e Anzali and **iii** Zahedan

**Table 2** Number of dry days for the selected stations using the EDI

Station	Most severe drought	Severe drought	Moderate drought	Total dry days
Tabriz	22	146	1349	1517
Bandar-e Anzali	–	2222	185	2407
Zahedan	–	231	1107	1338

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