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COMPARISON OF METEOROLOGICAL INDICES FOR SPATIO-TEMPORAL ANALYSIS OF DROUGHT IN CHAHRMAHAL-BAKHTIYARI PROVINCE IN IRAN

Usporedba meteoroloških indeksa prostorno-vremenske analize suše u Chahrmahal-Bakhtyari oblasti u Iranu

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Abstract: Drought monitoring is important for risk assessment and management, as well as for effective action to prevent and reduce the effects of drought. Drought characteristics such as intensity, duration and extent can be analyzed by 14 different drought indices. Choosing drought indices should be based on available data and its quality and ability of the index to determine spatial and temporal characteristics of drought. The objective of the present study is drought monitoring by different indices, including China-Z index (CZI), Z-score, Standardized precipitation index (SPI) and Effective drought index (EDI) indices, and comparing the performance of drought indices in the Chaharmahal-Bakhtiyari province, duration 1980-2013.Results showed that SPI and CZI, Z-score have the strong relationships, particularly during normal years. Furthermore, the results of frequency analysis showed that the drought occurrence of during 1998- 2012 have been increased compared to 1983- 1998 period. CZI showed a similar behavior to the SPI, especially in normal and dry condition and EDI and Z-score showed similar results. Finally, the results of the present study showed that EDI index is more sensitive to detect the onset of drought, compared to other indices.

Keyword: Meteorological indices, Drought monitoring, Spatio-temporal analysis, drought frequency, Chahrmahal-Bakhtiyari Province.

Sažetak: Monitoring suše važan je za ocjenu i upravljanje rizicima kao i za pripreme i vođenje akcije za sprečavanje i smanjenje šteta od suše. Osobine suše, kao što su njezin intenzitet, trajanje i rasprostranjenost, opisane su upotrebom 14 različitih indeksa. Izbor indeksa koji opisuju sušu temelji se na raspoloživim podacima, njihovoj kakvoći i mogućnostima indeksa da odrede prostorne i vremenske osobine suše. Cilj rada je monitoring suše upotrebom različitih indeksa uključujući China-Z indeks (CZI), Z-score, standardizirani oborinski indeks (SPI) i efektivni indeks suše (EDI) i usporedba indeksa u Chahrmahal- Bakhtyari oblasti u razdoblju 1980. Ð 2013. Rezultati ukazuju na čvrstu vezu indeksa SPI, CZI i Z-score za vrijeme normalnih godina. Rezultat analize učestalosti pokazuje da je pojava suše u razdoblju 1998-2012 povećana u odnosu na razdoblje 1983-1998. CZI pokazuje slično ponašanje kao SPI u suhim i normalnim uvjetima, a EDI i Z-score pokazuju sličan rezultat. Konačno, studija pokazuje da je EDI indeks osjetljiviji za detekciju suše od drugih indeksa.

Ključne riječi: meteorološki indeksi, monitoring suše, prostorno-vremenska analiza, frekvencija suše, Chahrmahal- Bakhtyari oblast

1. INTRODUCTION

Drought is one of the most damaging natural events, so that, the annual economic damage of drought is estimated $6.2 billion on average in IRAN (UN, 2000). Droughts occurred in Somalia and Thailand, which together affected 8.9 million people in 2010 (Guha-Sapir, 2011). So, drought periods monitoring are important for risk assessment and management, as well as for effective action to prevent and reduce the effects of drought. Planning and risk management to cope with the adverse impacts of a drought event depends on information about its areal extent, severity and duration. So, on the one hand, understanding of drought has importance in water resources management and on the other one, required information in this field can be obtained through drought monitoring by drought indices, which provide quantitative information to decision makers about drought characteristics (Dogan *et al* ., 2012)

The choice of drought indices should be based on available data and its quality and ability of drought monitoring. A number of indices have been proposed for drought analysis, such as: Palmer (1965), Deciles (Gibbs and Maher, 1967), Soil Moisture Deficit Index (SMDI; Narasimhan & Srinivasan, 2005), Reconnaissance Drought Index (RDI; Tsakiris *et al.*, 2007), the China-Z index (CZI; Wu *et al*., 2001) All of these indices are normally continuous functions of the hydro-meteorological variable, precipitation, temperature, soil water, potential evapotranspiration, groundwater and stream flow etc. (WMO, 1975). Most of these indices are calculated according to meteorological variables such as rainfall and temperature. Most of the available drought indices have limited use under different climatic conditions and have been developed for specific conditions. For example, China Z-Index (CZI) was used by Wu *et al* (2001) in China and SPI (Edwards and Mckee, 1997) has adaptability to different time scales and climatic conditions, so it can be used widely and has been adopted as a monitoring tool in order to detect the early emergence of drought (Shukla *et al*. 2008). In addition, SPI can also be applied to other variables for deriving drought indices such as the standardized runoff index (SRI; Shukla and Wood 2008) and the standardized soil moisture index (SSI; Hao and AghaKouchak 2013) for meteorological-hydrological- agricultural drought monitoring. The study of drought monitoring can be found in several investigations. For instance, Morid *et al* (2006) compared seven drought indices in Iran and found that SPI and EDI have the capability of detecting drought onset. Jain *et al* (2015) compared the drought indices in the Ken

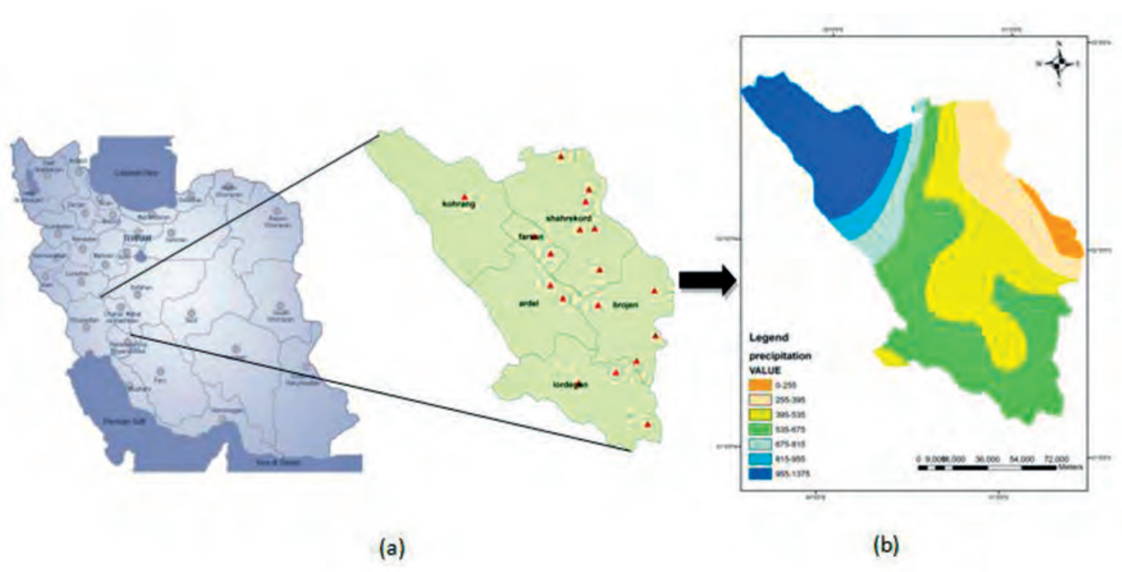

Figure 1. Location of study area and spatial distribution of meteorological stations (a), the map of precipitation mean during 1980-2012 (b).

Slika 1. Položaj područja istraživanja i razmještaj meteoroloških posataja (a), karta srednje količine oborine 1980-2012 (b).

Table 1. Mean annual rainfall (mm) stations in study area

Tablica 1. Srednja godišnja količina kiše (mm) na postajama promatranog područja.

No	Station	Longitude (E)	Latitude (N)	Elevation (m)	Mean annual rainfall (mm)
1	Shahr-e Kord	50° 84'	32° 29'	2050	3.242.175
2	Emam chaie	51° 30'	31° 75'	2285	563.205
3	Dezak	50° 96'	32° 09'	2054	441.313
4	Pole zamankhan	50° 90'	32° 50'	1883	329.04
5	Ardal	50° 66'	32° 01'	1875	554.74
6	Boroojen	51° 30'	31° 98'	2260	254.93
7	Kohrang	50° 13'	32° 46'	2365	1375.75
8	Farokhshar	50° 93'	32° 30'	2073	294.85
9	Farsan	50° 56'	32° 26'	2059	497.62
10	Gordbishe	51° 19'	31° 62'	2030	595.28
11	Jonaghan	50° 66'	32° 17'	2027	626.16
12	Khanmirza Aluni	50° 06'	31° 56'	1867	497.97
13	Lordegan	50° 83'	31° 50'	1611	558.89
14	Mal-e Khalifeh	51° 25'	31° 30'	1762	592.02
15	Naghan	50° 74'	31° 94'	2109	469.55
16	Oergan	50° 95'	31° 90'	2410	537.67
17	Saman	50° 87'	32° 44'	2075	333.254
18	Yan cheshme	50° 72'	32° 67'	2238	352.77
19	Ben				333.78

River Basin. Iran located in arid and semi-arid regions, so drought monitoring has become an important tool for the risk management. The objective of the present study is to investigate the most appropriate index for drought monitoring in Chaharmahal-Bakhtiyari province, South West, Iran. For this purpose, four drought indices (CZI, Z-score, SPI and EDI) are compared in terms of their performances.

2. DATA AND METHOD

2.1 Study area

Chaharmal-Bakhtyari province is located at 32°32' N, 50°85' E and has a total area of 16421 km^2. Precipitation varies from 254.9 mm at Broojen station in the eastern and northeast parts to 1375 mm at Koohrang station in the western and northwest parts, but mean annual precipitation is 560 mm. Ten stations were used to evaluate the drought indices. The locations of the meteorological stations in this study and their details are shown in Fig. 1 and Table 1, respectively.

Average temperature exceeds 5.4 °C and the average elevation of the province is about 2066 m above mean sea level (MSL). Continuous daily and annual rainfall data of 10 stations for a period of 32 years from 1980 to 2012 are obtained and used in the present analysis. Then quality control was conducted by homogenization and normalization tests (World Meteorological Organization).

In the present study, four drought indices were selected, Z-score, CZI, EDI, and SPI. Annual and daily meteorological data were recorded. Selected indices calculated different aspects of drought based on only precipitation data.

2.2 Standardized Precipitation Index

The SPI is the transformation of precipitation time series into a standardized normal distribution according to McKee *et al.* (1993). For calculation of SPI at different time scales, gamma probability distribution was used. Classified SPI values as presented in Table 2, utilized to define drought intensities associated with a particular SPI value. Other studied indices have an almost similar range of numerical values. Positive and negative values of SPI demonstrated greater and less than mean precipitation, respectively. SPI index indicates diversion values upper or lower than average, it can be used for spatial analysis of drought, then the different station can be compared which ignored differences between their normal precipitations. Aanalysis of frequency and duration of drought is possible using SPI index.

2.3. China-Z index (CZI) and Z-Score

The CZI is based on Wilson-Hilferty cube-root transformation (Kendall and Stuart, 1977).
CZI index is computed as:

$$CZ_i = \frac{6}{C_s}\left(\frac{C_s}{2}\emptyset_i + 1\right) - \left(\frac{6}{C_s}\right) + \left(\frac{C_s}{6}\right) \quad (1)$$

$$C_s = \frac{\sum_{i=0}^{n}(x_i - \bar{x})^3}{n \times \sigma^3} \quad (2)$$

$$\emptyset_i = \frac{x_i - \bar{x}}{\sigma} \quad (3)$$

Where i is the current month, C_s is the skewness coefficient, n is a total number of months, is the standard variate, and X_i is precipitation in i^{th} month. The Z-score index is defined by Heim & Kotil (1996), which is calculated by subtracting the long-term mean from an individual rainfall value then divided the difference by standard deviation. In addition, when rainfall data is incomplete, use of CZI index can be preferred over SPI index (Wu *et al.*, 2001). Because of simple calculation, Z-score index has been used in many studies, (Akhtari *et al.*, 2009; Komuscu, 1999; Patel *et al.*, 2007; Tsakiris and Vangelis, 2004; Dogan *et al.*, 2012)

2.4. The effective drought index (EDI)

Byun and Wilhite (1999) proposed the effective drought index (EDI), to determine the start and the end of drought duration and severity of drought (Akhtari *et al.*, 2009; Kalamaras *et al.*, 2010; Roudier and Mahe, 2010; Lee *et al.*, 2012). It was extended for monthly drought monitoring (Smakhtin and Hughes, 2004; Pandey *et al.*, 2008; Deo and Byun, 2014). Drought severity Classification of the EDI and SPI is similar; based on EDI index, effective precipitation (EP) is calculated by a time dependent reduction function of daily/monthly precipitation.

The EDI enables comparing one location's drought severity to another location's, regardless of climatic differences. Use of EDI has been tested in several drought studies (Kim *et al.* 2009; Morid *et al.* 2006). Byun and Wilhite (1999) defined effective precipitation as a function of current month's rainfall and weighted rainfall over a defined preceding period computed using a time dependent reduction function.

The following equations were used for EDI calculations.

$$EDI_j = \frac{PRN_j}{ST(PRN_j)} \quad (1)$$

$$PRN_j = \frac{DEP_j}{\sum_{N=1}^{j}(\frac{1}{N})} \quad (2)$$

$$DEP = EP - MEP \quad (3)$$

Table 2. Different categories of various drought indices based on index value

Tablica 2. Različite kategorije indeksa suše na temelju vrijednosti indeksa.

Values	SPI	EDI	CZI	Z-score	Class	Symbol
3	≥ 2	≥ 2.5	≥ 2	≥ 2	Extremely wet	EW
2	1.5 to 1.99	1.5 to 2.49	1.5 to 1.99	1.5 to 1.99	Severely wet	SW
1	1 to 1.49	0.7 to 1.49	1 to 1.49	1 to 1.49	Moderately wet	MW
0	-0.99 to 0.99	-0.69 to 0.69	-0.99 to 0.99	-0.99 to 0.99	Normal	N
-1	-1 to -1.49	-0.7 to -1.49	-1 to -1.49	-1 to -1.49	Moderately dry	MD
-2	-1.5 to -1.99	-1.5 to -2.49	-1.5 to -1.99	-1.5 to -1.99	Very dry	VD
-3	≤ -2	≤ -2.5	≤ -2	≤ -2	Extremely dry	ED

Where, ST (PRN) is the standard deviation of each day's PRN; EP becomes the valid accumulation of precipitation for 365 days from a particular date and MEP is the mean of each day's EP.

$$EP_i = \sum_{n=1}^{i}[(\sum_{m=1}^{n} P_m)/n] \quad (4)$$

Here i is the duration of summation and P_m is the precipitation of m - 1 days before.

3. RESULTS AND DISCUSSION

Drought indices which have the similar range of numerical values are comparable. For comparison of drought indices such as CZI and Z-Score with the SPI index for 10 stations, Pearson correlation coefficient (R^2) was used (Table 3).

Table 3. The range of the Pearson's correlation coefficients of the regression line for every index

Tablica 3. Raspon Pearsonovih koeficijenata korelacije za liniju regresije pojedinih indeksa.

SPI	Z-Score	CZI	EDI
Kohrang	0.982	0.969	0.571
Yancheshme	0.9814	0.9996	-
Pole zamankhan	0.9725	0.9997	0.4065
Shahrekord	0.9885	0.9936	0.576
Dezak	0.9708	0.9703	0.503
Broojen	0.962	0.9987	0.4109
Emam chaie	0.9656	0.9367	0.655
Lordegan	0.9828	0.9443	0.423
Jonaghan	0.9826	0.9822	-
Naghan	0.983	0.9903	0.477

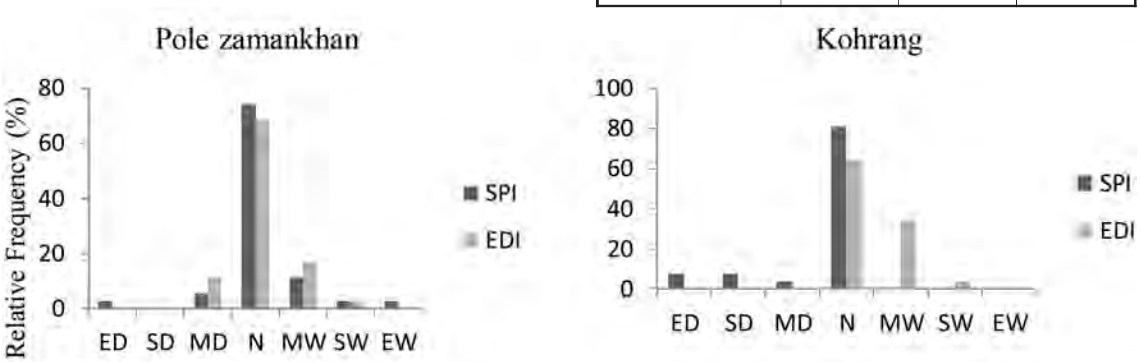

Figure 2. The drought frequency histogram of the SPI and EDI indices for the Kohrang and Pole Zamankhan stations

Slika 2. Histogram frekvencije suše za SPI i EDI indeks za postaje Kohrang i Pole Zamankhan.

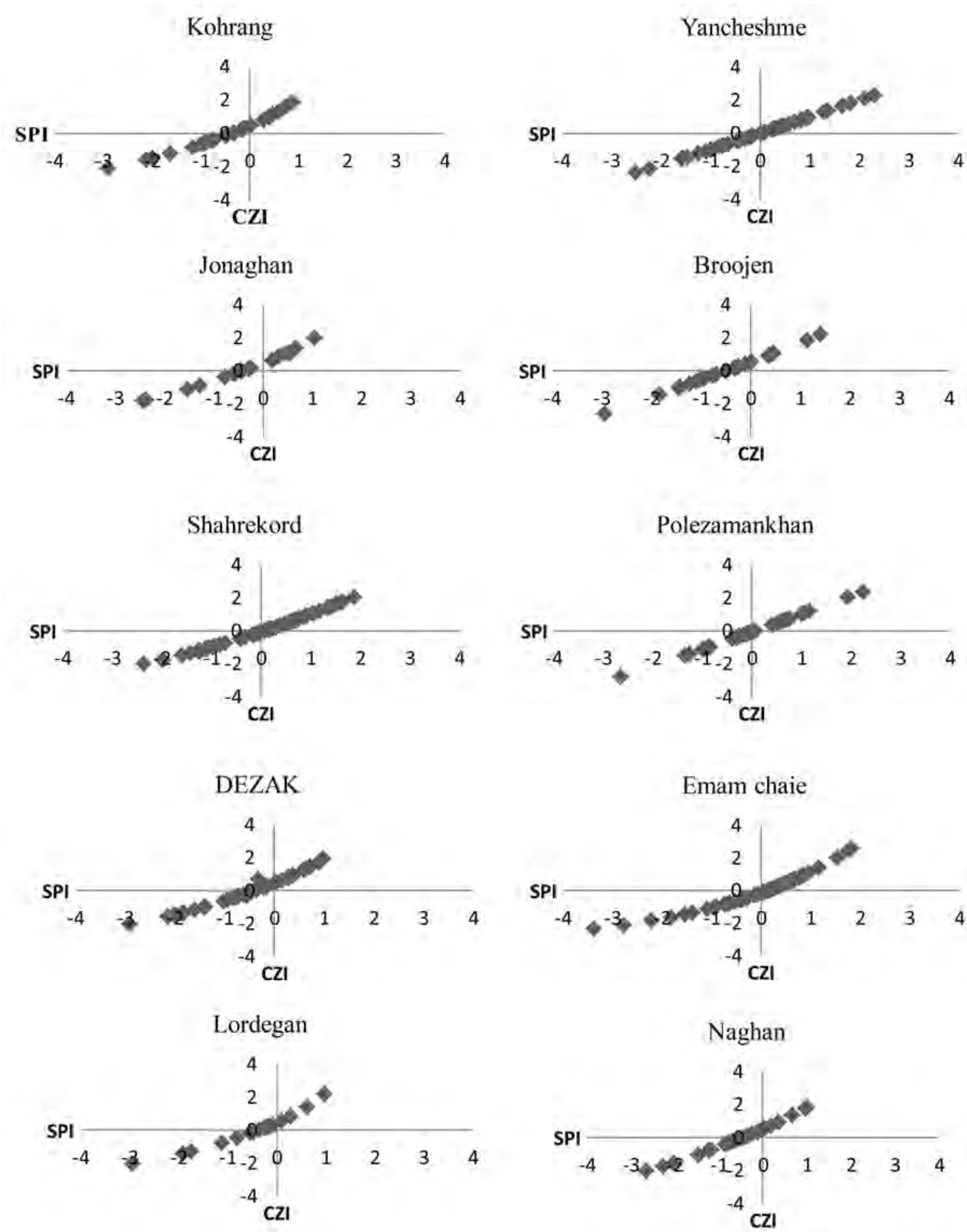

Figure 3. The linear regression values between SPI and CZI

Slika 3. Vrijednosti linearne regresije za SPI i CZI.

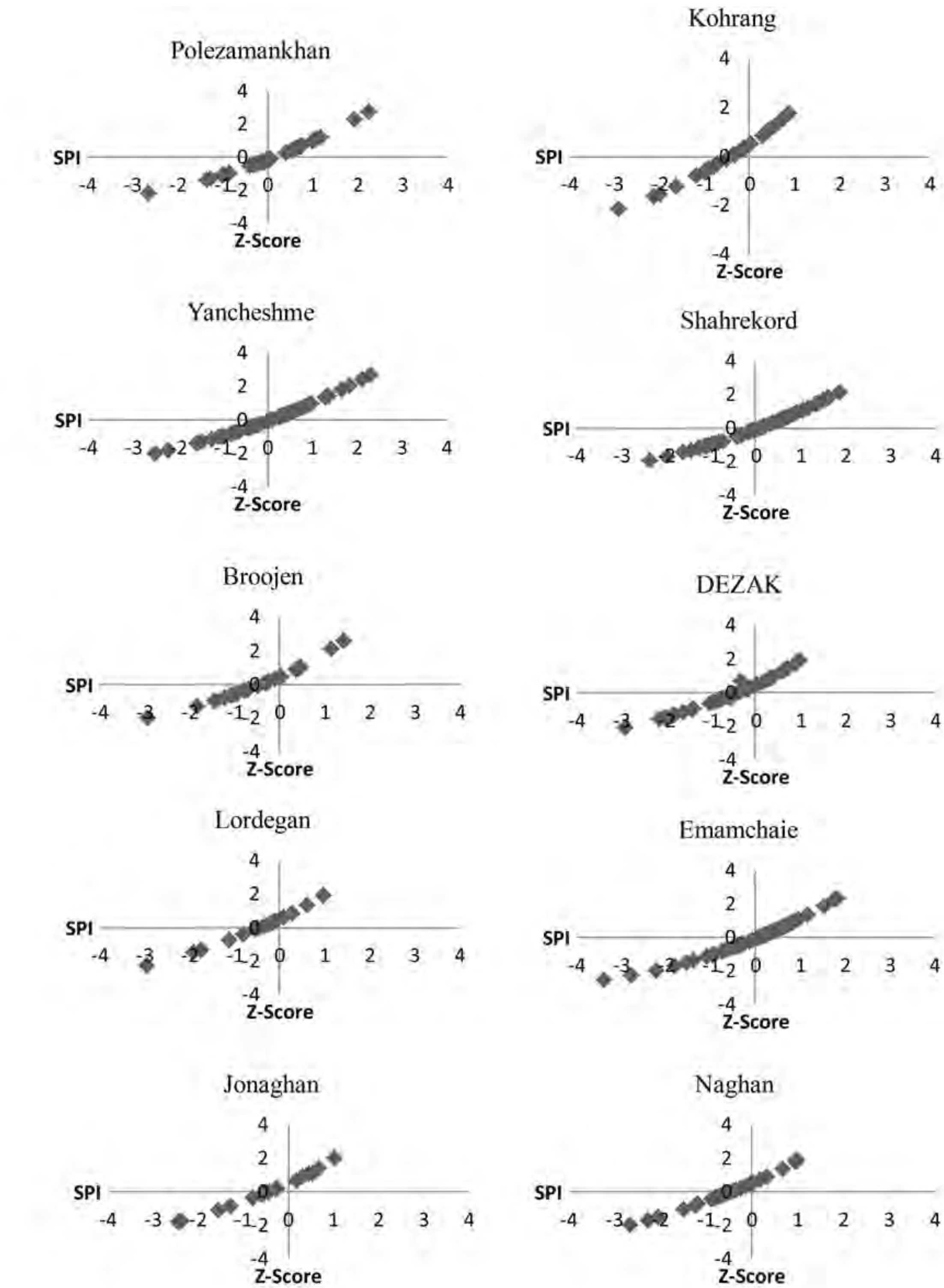

Figure 4. The linear regression values between the SPI and Z-score

Slika 4. Vrijednosti linearne regresije za SPI i Z-score.

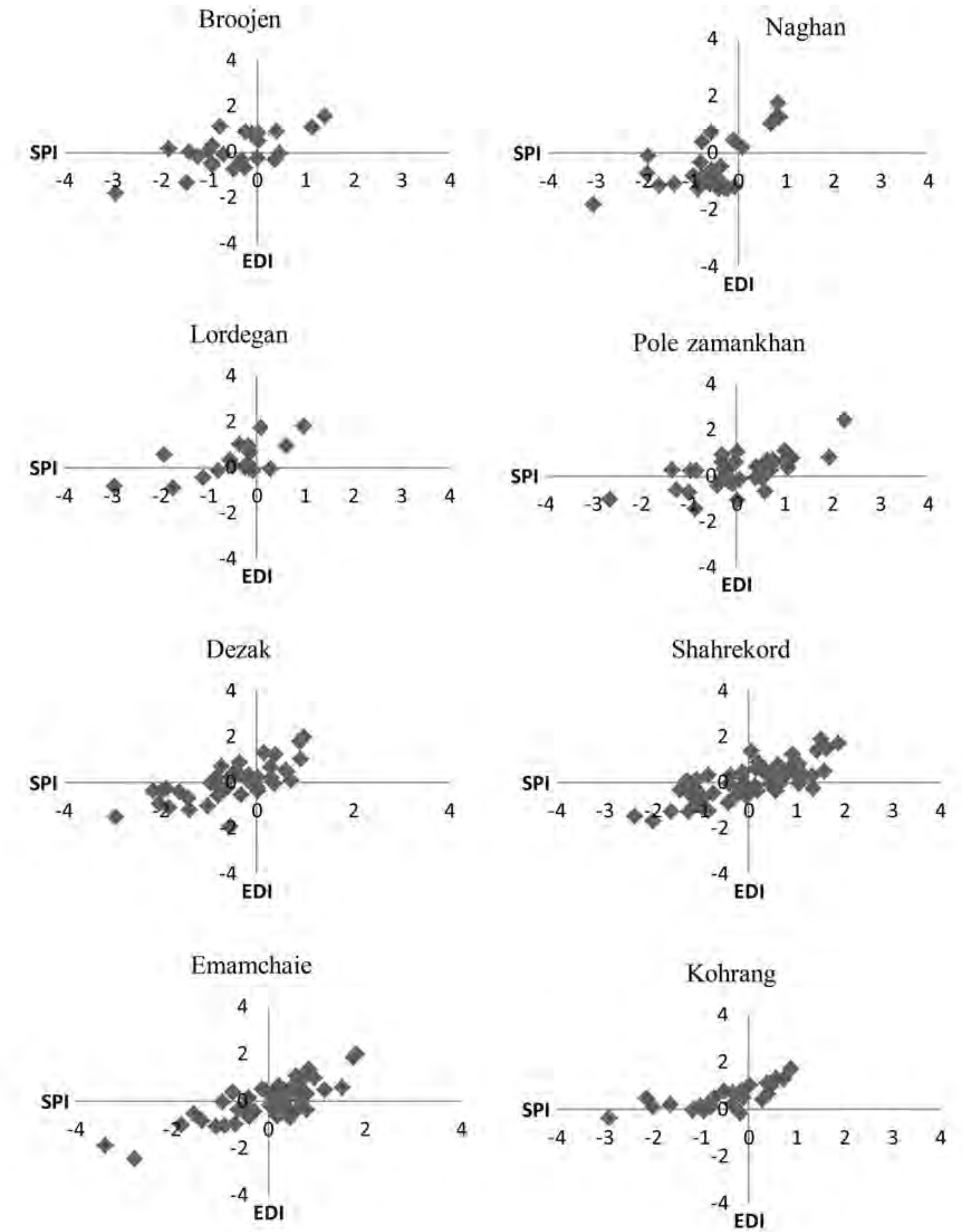

Figure 5. The linear regression values between the SPI and EDI

Slika 5. Vrijednosti linearne regresije za SPI i EDI.

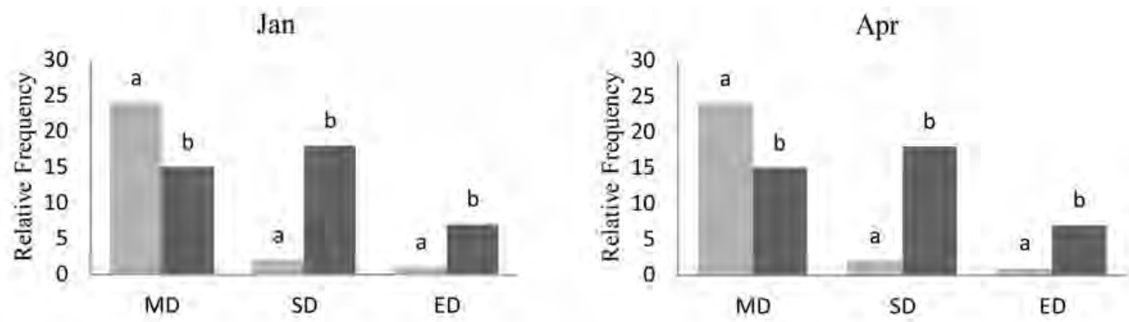

Figure 6. Histograms for the drought frequency classes of the SPI1 (a: 1983-1998 b: 1998-2013)

Slika 6. Histogrami frekvencije suše za SPI1 (a: 1583. - 1998. b: 1998. - 2013.).

3.1. Comparison of the CZI and Z-Score with the SPI

The drought severity is calculated using SPI, Z-Score, CZI and daily EDI. Then correlation coefficients (R^2) were calculated for SPI index with the CZI, Z-Score and EDI in annual time scale in study areas. The linear regression values between SPI and CZI from 1980 to 2012 have been shown in Fig. 2. Linear regressions between the annual values of selected drought indices in the present study indicate that SPI and CZI have a strong relationship, especially during normal years. So that, the R^2 values for studying stations were in 0.93 (in Emam chaie station) to 0.99 range. Also, the correlation between Z-Score and SPI was good (Table 3 and Figure 3). The R^2 values of Z-Score with SPI were in the range of 0.96 (in Broojen and Emam chaie stations are located in the eastern and southeast parts of the province) to 0.98 (for the stations are located in the northern parts of the study area).

Table 4. Relative frequencies (%) for different categories of drought by SPI1

Tablica 4. Relativne frekvencije (%) za različite kategorije suše po SPI1.

	Jan		Apr	
	15-Jan	15-Feb	15-Jan	15-Feb
Extremely dry (ED)	25.92 %	6.45 %	3.7 %	17.5 %
Severely dry (SD)	29.63 %	22.58 %	7.4 %	45%
Moderately dry (MD)	44.44 %	70.96 %	88.88 %	37.5 %

3.2. Comparison of the EDI and SPI

Results of drought frequency for Kohrang and Pole Zamankhan stations have been shown in Fig4 (synoptic stations were selected). It is obvious that the normal class for EDI is smaller than for SPI. While an amount of the EDI in other classes are higher than the SPI values. The EDI could be able to detect gradual increment in droughts that cannot be detected by the SPI.

For comparison between the EDI and SPI in monthly time scale, firstly the EDI values were computed in daily time scale, then average daily values were computed for monthly EDI in order to compare between EDI and SPI. The scatter plot of the EDI and SPI has been shown in Fig. 5. As Shown in Table 3, the correlation between SPI and EDI is weak.

For more accurate analysis, the percentage of relative frequencies of drought on January and April months, as a median severity of drought and growing months, were compared for 1983-1998 and 1998-2013 periods. Table 4 and Fig 6 show relative frequency of SPI index during 30 year period, the first half of the period (from 1983 to 1998) and the second half of the period (from 1998 to 2013) at January and April. For evaluation the changes of drought for 30 years, the period was divided into two parts. The percentage of drought frequency showed that the frequency of droughts events in the second half of the period (from 1998 to 2013) have been increased in comparison with the first half (from 1983 to 1998).

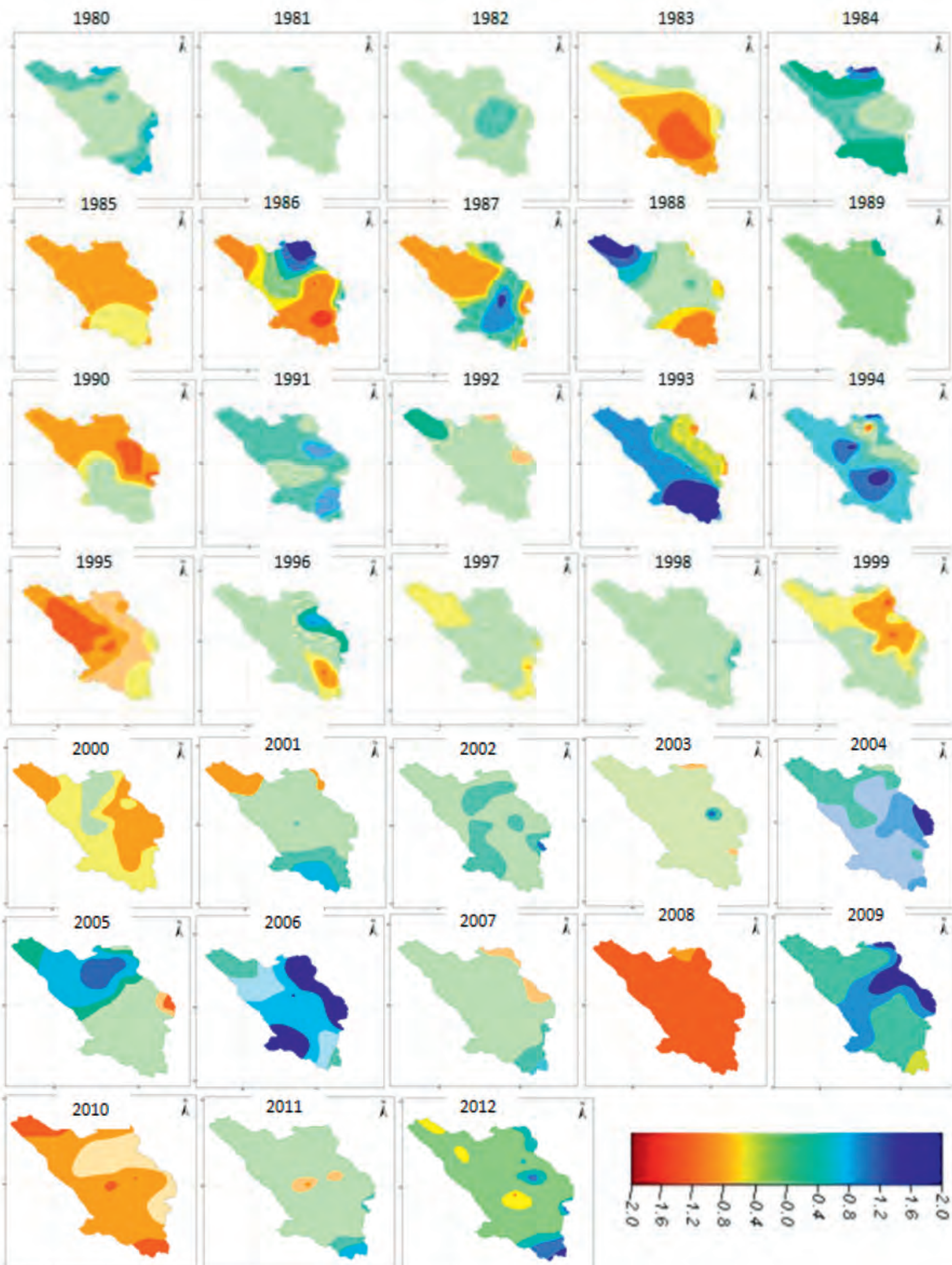

Figure 7. Spatial distribution of annual drought indices with the best correlation to standardized precipitation index (SPI) for the CZI index

Slika 7. Prostorna raspodjela godišnjeg indeksa suše u korelaciji sa standardiziranim oborinskim indeksom (SPI) za CZI indeks.

Table 5. Severity of different dry and wetness categories detected by five indices during 1980-2013

Tablica 5. Stupanj opasnosti različitih kategorija suše i vlažnosti opažen pomoću pet indeksa u razdoblju 1980. - 2013.

duration	CZI	Z-score	MCZI	SPI	EDI
1980	Near normal	Moderately wet	Moderately dry	Near normal	moderately wet
1981	Near normal	Near normal	Moderately dry	Near normal	Near normal
1982	Near normal	Near normal	Moderately dry	Near normal	Near normal
1983	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately Dry
1984	Near normal	Near normal	Moderately dry	Near normal	Near normal
1985	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1986	Very wet	Very wet	Moderately dry	Very wet	Very Wet
1987	Near normal	Near normal	Moderately dry	Near normal	Moderately wet
1988	Near normal	Near normal	Moderately dry	Near normal	Near normal
1989	Near normal	Near normal	Moderately dry	Near normal	Near normal
1990	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately Dry
1991	Moderately wet	Moderately wet	Moderately dry	Moderately wet	Moderately wet
1992	Near normal	Near normal	Moderately dry	Near normal	Moderately wet
1993	Very wet	Very wet	Moderately dry	Moderately wet	Moderately wet
1994	Near normal	Moderately wet	Moderately dry	Near normal	Moderately wet
1995	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1996	Moderately wet	Moderately wet	Moderately dry	Moderately wet	Moderately wet
1997	Near normal	Near normal	Moderately dry	Near normal	Near normal
1998	Near normal	Near normal	Moderately dry	Near normal	Near normal
1999	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
2000	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
2001	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
2002	Near normal	Near normal	Moderately dry	Near normal	Near normal
2003	Near normal	Near normal	Moderately dry	Near normal	Near normal
2004	Moderately wet	Moderately wet	Moderately dry	Moderately wet	Moderately Wet
2005	Near normal	Moderately wet	Moderately dry	Near normal	Moderately Wet
2006	Extremely wet	Very wet	Moderately dry	Very wet	Severely wet
2007	Near normal	Near normal	Moderately dry	Near normal	Near normal
2008	Extremely dry	Severely dry	Moderately dry	Extremely dry	Moderately dry
2009	Moderately wet	Moderately wet	Moderately dry	Moderately wet	Moderately Wet
2010	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2011	Near normal	Near normal	Moderately dry	Near normal	Near normal
2012	Near normal	Moderately wet	Moderately dry	Near normal	Moderately Wet
2013	Near normal	Moderately wet	Moderately dry	Near normal	Moderately Wet

The frequency of severely (SD) and extremely drought (ED) events were increased in the second half of the analyzed period while for decreasing trend observed for moderately drought (MD) events. For instance, the frequency of moderate drought was 88.9 % and 70.9 % in the April and January, respectively.

Considering the strong correlation between SPI and CZI index (Table 3) reflection of change drought condition spatially by CZI index for a period of 1980-2012 have been drawn using GIS. Figure 7 shows drought pattern in Chaharmal-Bakhtiyari province. It is evident that a wet condition from 1980-1982 turned into a dry condition from 1983 to 1987. Then in 1990 and 1999 drought occurred partly in the northern part of the province. Droughts occurred in 1995, 2000, 2008 and 2010, while most of the province is under the normal condition in the central and northwest parts.

Table 5 represents the severity of different condition by CZI, Z-score, SPI and EDI indices in Shahrekord Synoptic Station. CZI showed a similar behavior to the SPI, especially when the normal and dry years. EDI and Z-score showed similar results. For instance, during 1999-2001, CZI and SPI showed the normal period while EDI and Z-score showed moderately dry years. Finally, results showed that the EDI index is more sensitive to detect the onset of drought, compared to the other indices.

4. CONCLUSIONS

In this study, four drought indices (SPI, the Z-score, CZI, and the EDI) were evaluated for monitoring and detecting drought periods in Chaharmal-Bakhtiyari Province, Iran.

Linear regressions between the annual values of the SPI, Z-score, CZI and EDI from 1980 to 2012 indicate that SPI and CZI, Z-score have the strong relationships, particularly during normal years. The degree of these relationships is possibly related to climatic region and time scales (Shahabfar and Eitzinger, 2013). According to results, by considering the good relationship between selected indices with SPI, CZI and Z-score could be used instead of SPI, when limitation of availability of long term data. EDI is calculated in daily time scale, therefore it can be able to detect gradual increment in droughts that cannot be detected by the SPI. This index is more sensitive to emerging drought condition compared to other indices (Morid *et al*., 2006; Byun and Kim, 2010; Bazrafshan *et al*., 2002). The EDI index is capable drought monitoring and describing characteristics of drought conditions, albeit existence of precipitation data in daily time scale is one of the limitations to using the EDI index. Having regards to the effects of climate change, lack of assuring about severe drought condition or duration in several parts of the world is associated with climate change or variability of climatic factors and requires evaluation in a longer period. Totally, the occurrence of meteorological droughts is inevitable, but monitoring and prediction of drought can be resulted to alleviate adverse impacts of drought (Livada, 2007).

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