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Efficiency of Some Meteorological Drought Indices in Different Time Scales (Case Study: Tajan Basin, Iran)

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ABSTRACT Drought is a climatic phenomenon that causes much detrimental influence on ecological environments. This research investigates the performance of meteorological drought indices in different time scales in the Tajan basin in Iran. Indices undergone in this study include: Percent Normal Precipitation Index (PNPI), Z-Score Index (ZSI), Standard Precipitation Index (SPI), China Z Index (CZI), Modified CZI (MZCI), and Decile Precipitation Index (DPI). In this study, we used data of annual and monthly precipitation from meteorological stations in the basin. Drought indices were determined at time scales of 1, 3, 6, 9, 12, 18, 24 year of minimum precipitation with very intense drought and the method of correlation coefficients between drought indices values and monthly precipitation. The results showed that DPI was the best index at annual time scale, while at the time scale of 1,6,12 and 24-months, PNPI was the best index. MCZI was the best index for time scales of 9 and 48-months, and the ZCI had the maximum efficiency for a three-month scale.

Key words: *Drought, Drought indices, Precipitation data, Tajan basin*

1 INTRODUCTION

Successful water management to cope with water scarcity requires the understanding of respective governing processes and causes (Moreira *et al.,* 2008). Water scarcity results froma range of phenomena that may be produced by natural causes, such as aridity and drought, or it is induced by human activities, such as desertification and water demand (Paulo *et al.,* 2005). Drought is defined as a natural, but temporary, imbalance of water availability, consisting of a persistent lower-than-average precipitation, of uncertain frequency, duration and severity, unpredictability or difficulty to predict occurrence, resulting in diminished water resources availability, and reduced carrying capacity of the ecosystems (Dracup *et al.,* 1980). It is considered a major and frequent characteristic in all climates and its impacts are not limited to arid and semi arid regions.In addition, its impactsregularly can beobserved in humid regions. Drought is one of the natural hazards whose occurrence involvesdetrime0ntal impact on ecological environments. However, it causes many socio-economic and environmental damages. Drought receives less attention than other hydrological and meteorological phenomena. Drought may

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appear at climatic, hydrologic, agricultural and economic forms in spatial and temporal dimensions. Temporal and spatial complexities of drought make its assessment difficult; drought severity varies at spatial and temporal scales (Bonaccorso *et al.*, 2003; Vicente-Serrano *et al.*, 2006). Given the consequences and persistence of drought, it is important to assess drought severity, but precise quantification of drought is a difficultgeophysical process (Vasiliades and Athanasios, 2009). Because quantitative estimation and forecast of drought are important issues for politicians and scientists (Goddard *et al.*, 2003; Tadesse *et al.*, 2005), many indices have been submitted for evaluation and assessment of drought by scientists. Each index has been designed based on the variation between meteorological, hydrological and hydrogeological conditions and different calculation methods (Richard, 2002). Application of drought indices is necessary for monitoring and forecastingdrought.In addition, these indices allow us to evaluate drought risk (Sivakumar and Wilhite, 2002). Although none of these indices is superior to another, some function better than others dofor some specific applications and hydro-climate conditions. The suitability of a drought monitoring system is greatly influenced by an accurate selection of indices for drought identification, providing a synthetic and objective descriptionof drought conditions (Mendicino *et al.*, 2008). Therefore, it is essential thesuitability of different drought indicesbe assessed and the best index be selected. Afterwards, drought studies can be carried outbased on the selected index. Many drought indices, such as the China-Z index (CZI) (Wu *et al.*, 2001), are widely used while the Standardized Precipitation Index (SPI) (McKee *et al.*, 1993) has achieved world-wide popularity.

Several studies have been done to assess and quantify different aspects of droughts, such as spatial differences in drought hazard (Loukas and Vasiliades, 2004), the prediction of droughts with the use of atmospheric circulation indices (Tadess *et al.*, 2004; Piechota and Dracup, 1999), and the mitigation of drought effects (WMO, 2000). More efforts have been made to develop drought indices, allowing an earlier identification of droughts and their severity and areal extent (Vasiliades and Athanasios, 2009). In this study, the following indices will be investigated. Morid *et al.* (2006) compared the following seven DIs for drought monitoring in Tehran province, Iran: Percent of Normal (PN), Rainfall Deciles (RDs), Statistical Z Score (Z-Score), Standardized Precipitation Index (SPI), China-Z Index (CZI), Modified China-Z Index (MCZI), and Effective Drought Index (EDI). These DIs are all rainfall-based indices and are able to quantify both dry and wet cycles. Comparisons showed that SPI and EDI performed better in detecting the onset of drought, and these were recommended to the Tehran drought monitoring system. This study is enlightening and currently one of the most exhaustive comparison studies of DIs.

Mckee *et al.* (1993) presented Standard Precipitation Index (SPI) of different periods 3,6,12 and 48 months for quantification of precipitation shortage and monitoring of drought situation. Wu *et al.* (2001) expressed three indices, including Standard Precipitation Index (SPI), China Z and Z-Score Index (ZSI) for the dry and humid climate in China and described their advantages and disadvantages by monthly precipitation data. They also attempted deferential deduction of Standard Precipitation Index and Modified CZI. The overall differences between these two indices reduced significantly compared to the difference between the SPI and CZI. Loukas *et al.* (2003) also calculated three indices, including Standard Precipitation Index (SPI), AnomalyRainfall Index, and Standard Index of Annual

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Precipitation (SIAP) at different time scales in Greece. All ofthe three indices had the same trend atthe 12-month time scale and agreed well with Palmer Drought Index (PDI). Loukas and Vasiliades (2005) presented the assessment of the Standardized Precipitation Index (SPI) for various time scales as an indicator of surface runoff and soil moisture drought at seven basins ranging from 133 to 6591 km^2. They found that SPI of 2- to 4-month time scales were good indicators of surface runoff drought, whereas the SPI of 1- to 3- month time scales represented the soil moisture drought better. Vicente-Serrano and Lopez-Moreno (2005) evaluated the SPI for various time scales as an indicator of runoff and reservoir storage in a mountainous basinin Spain. They provided empirical evidence that surface runoff responds to short SPI time scales (1–4 months). Smakhtin and Hughes (2007) assessed Decile Precipitation Index (DPI), Effective Drought Index (EDI) and SPI, in terms of long term average deviation and median deviation indices andanalyzed meteorological drought characteristics from monthly rainfall data. They could predict drought and its spatial distribution. Moradi *et al.* (2011) forecast the intensity, duration, frequency and extent of droughts in Fars province using SPI as a selective index, considering its capacity to facilitate accurate positional analysis between various regions of the drought extent. For this, precipitation data in 5 time scales of 3, 6, 12, 24 and 48 months were used, and the trends were assessed by using a time series analysis. Ezzine *et al.* (2014) assessed five indices, including SPI, NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Vegetation Index) SVI (Standardized Vegetation Index) and SWI (Standardized Water Index). Theresults show that the agreement between vegetation drought indices and meteorological drought indices is moderated to low, and the SPI is slightly more concordant with SWI compared to SVI in autumn and winter seasons. The validation approach indicated that the drought-affected areawas, according to SWI, highly correlated with cereal production. Likewise, a satisfactory correlation was revealed between SWI and in situ SPI. Caccamo *et al.* (2011) assessed the performance of MODIS-based reflectance spectral indices to monitor drought across forest and woodland vegetation types in Australia. A time series of eight spectral indices were created from 2000 to 2009 to monitor inter-annual changes in drought and were compared to the Standardized Precipitation Index (SPI). Results show that the Normalised Difference Infrared Index b and 6 (NDIIb6) provided themost suitable indicator of drought for the high biomass vegetation types considered. The NDIIb6 had the highest sensitivity to drought intensity andwas highly correlatedwith SPI at all time scales analyzed suggesting that variations in precipitation patterns have a stronger influence on vegetation water content than vegetation greenness properties. Spatial similarities were also found between patterns of NDIIb6-based droughtmaps and SPI values distribution. Dogan *et al.* (2012) compared Percent of Normal (PN), Rainfall Decile based Drought Index (RDDI), statistical Z-Score, China-Z Index (CZI), Standardized Precipitation Index (SPI), and Effective Drought Index (EDI) to identify droughts in a semi-arid closed basin (Konya) in Turkey. The comparison of time series of various DI values (numerical values of drought severity) instead of drought classes was advantageous for drought monitoring. SPI and CZI were more consistent in detecting droughts for different time steps. The response of DI and time step combination to the change of monthly and multi-monthly rainfall for a qualitative comparison of severities (drought classes) was investigated.

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Khalili and BazrAfshan (2003) investigated some of the drought indices in several climates and concluded that DPI and SIAP indexarebest suited for meteorological drought assessment in Iran. Vafakhah and Rajabi (2005)compared suitabilityof five indices, including Percent Normal Precipitation Index (PNPI), Z-Score Index (ZSI), SPI,Rainfall Anomaly Index (RAI) and Decile precipitation Index (DPI), at 1, 3, 6 and 12 month time scale in the Bakhtegan basin in Iran and found that DPI and PNPI indices arebest suited. Ensafi Moghadam (2007) evaluated DPI, SPI, PNPI and ZSI indicesin the Daryache Namak basin and concluded that for drought condition analysis for a long-term period in this basin SPI, ZSI and PNPI are the best indices, respectively.

The Caspian region is one of the importantregionsin Iran.Because this region is considered as humid in all climatic classification systems (such as Domarten, Koeppen and Amberger) and drought effects become tangible in such climates slowly, ithas been disregarded by drought analysis so far. Hence, the investigation of drought's spatial and temporal trends is still lackingin this region. In order to do this, the most suitable index must be identified first. This study investigates suitability of some drought indices at various time scales in one of the Caspian basins, named Tajan.

2 MATERIALS AND METHODS

2.1 Study area

The Tajan watershed is situated between north longitudes of 53° 03´-54° 15´and the east latitude of 35° 55´-36° 46´, with an area of 2573 km^2 in Mazandaran province, Iran. This basin is borderedin the north by the Caspian Sea, in the south by the central Iran Basin, in the east by the Nekarood basin and in the west by the Babolrood basin (Figure 1). Elevation of general landscapes of the area ranges from -26 m to 1600 m above the mean sea level. The average annual rainfall and potential evapotranspiration by Thornth Waite method is 530 mm and 840 mm, respectively. The climatic class according to the Koeppen method is the humid class.

2.2 Data and gauging stations

In this research, four rain gauge stations where selected, in cluding Afrachal, Rig Cheshmeh, Solaiman Tangeh and Kordkheil. Characteristics and locations of these rain gauges are shown in Table 1. The stations have sufficient data and are operated by the Regional Water Organization of Mazandaran province.

Table 1 Characteristics of meteorological gauging stations in Tajan basin

Station name	Gauge type	Elevation (m)	Longitude	Latitude	Establishment year
Afrachal	Climatology	1200	E53° - 15′ - 00″	N36° - 14′ - 03″	1966
Rig Cheshmeh	Rain gauge	420	E53° - 10′ - 03″	N36° - 21′ - 60″	1969
Solaiman Tangeh	Climatology	400	E53° - 13′ – 52″	N36° - 15′ - 07″	1959
Kordkhil	Climatology	-5	E53° - 06′ - 17″	N36° - 42′ - 36″	1954

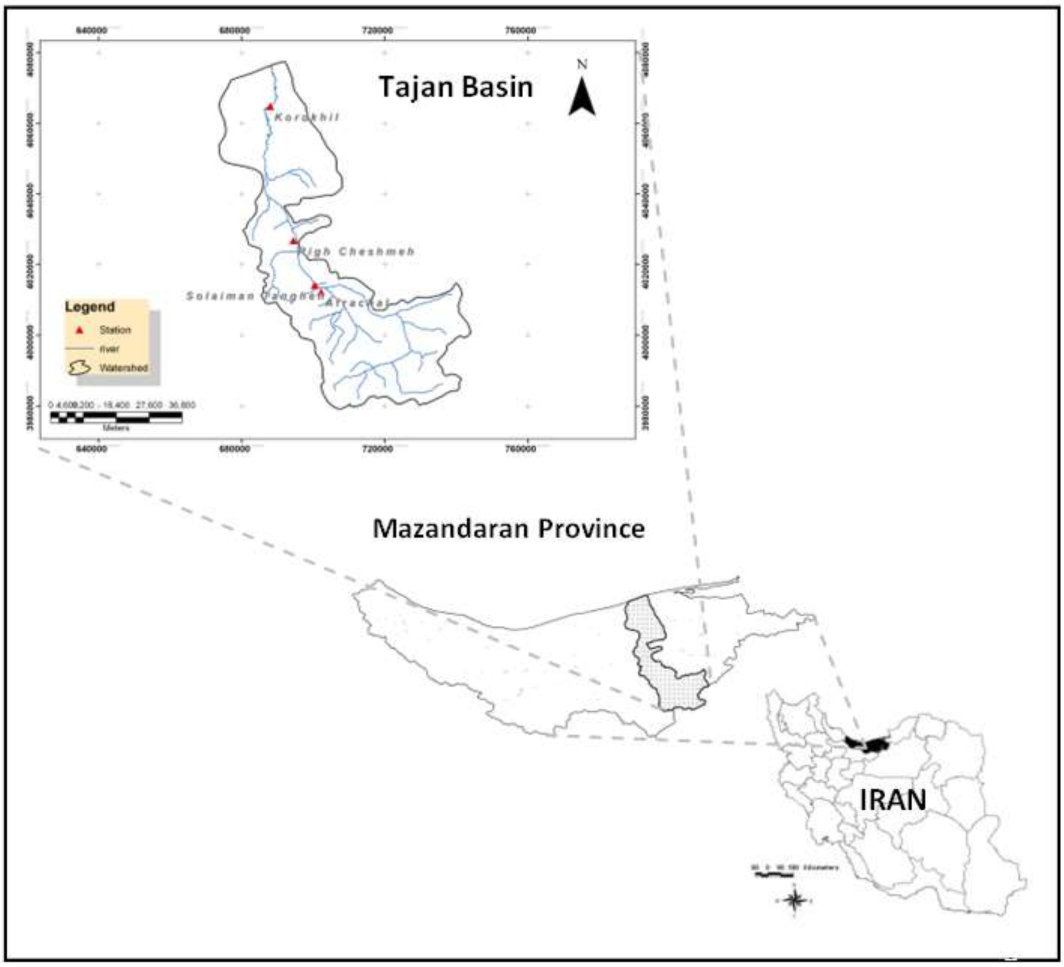

Figure 1 location of the Tajan basin and its meteorological stations in the Mazandaran province

2.3 Methods

First data homogeneity was tested and assured using Run test. After specification of a 39-year similar data period (1966-2005), normal ratio method was used for regeneration of three years missing data in Rig Cheshmeh station (DHV Consultants BV and DELFT HYDRAULICS, 1999; Alternate Hydro Energy Center, 2011). Then values for various drought indices were calculated for each station based on monthly and yearly precipitation by the Drought Indices Package (DIP) software package. Considering previous research, we assessed 6 indices including Percent Normal Precipitation Index (PNPI), Z-Score Index (ZSI), Standard Precipitation Index (SPI), China Z Index (CZI), Modified CZI (MZCI), and Decile Precipitation Index (DPI). Vafakhah and Rajabi (2005), Ensafi Moghadam (2007), Morid *et al.* (2006), Wu *et al.* (2001), Loukas and Vasiliades (2005), Smakhtin and Hughes (2007), Moradi *et al.* (2011), Dogan *et al.* (2012) and many other researchers have used these indices for drought investigation and confirmed the appropriacy of these indices.

2.3.1 Z-Score Index (ZSI)

For calculation of this index, equation (1) is used:

$$Z-Score = \frac{P_i - \overline{P}}{S} \qquad (1)$$

Where S is the standard deviation, P is the mean monthly precipitation and P_i is precipitation in a specific month. The more the value of this index, the more severe the drought. Table 2 presents various classes for the ZSI index.

2.3.2 Percent Normal Precipitation Index (PNPI)

When a region or season percent normal (PNPI) is considered alone, the utilization of this index will be very effective. PNPI index is calculated from equation (2):

$$PNPI = \frac{P_i}{\overline{P}} \times 100 \qquad (2)$$

Where P_i is precipitation in month or year and $\overline{P}$ is average monthly or annual precipitation. This index is always positive and has no theoretical limitations. Various classes of PNPI index are presented in Table 2.

2.3.3 Deciles Precipitation Index (DPI)

This index is applied to overcome some limitations of the PNPI index (e, f, …) and to recognize where in the gamut of successive decile of particular monthly or yearly precipitation a particular monthly or yearly precipitationis located (Khalili and Bazr Afshan, 2003). In this approach proposed by Gibbs and Maher (1967) the total monthly precipitations from a long recordis first ranked from highest to lowest to construct a cumulative frequency distribution. The severity of drought can be assessed by comparing the quantity of rainfall in a particular month or several months duration with the long time cumulative distribution of rainfall values for that time. Decile Indices (DI) classes are given in Table 2. In this paper, Box–Cox transformation was used to normalize monthly precipitation time series (McMahon, 1986).

2.3.4 Standardized Precipitation Index (SPI)

The SPI was developed by McKee *et al.* (1993). This index has been applied in order to determine drought duration and severity (Paulo *et al.*, 2003). In its original version, a long precipitation record at a station is fitted to a probability (gamma) distribution, which is then transformed into a normal distribution so that the mean SPI is zero. The index values are therefore the standardized deviations of the transformed rainfall totals from the mean (Smakhtin and Hughes, 2007). The SPI may be computed in different time steps (1 month, 3 months, 24 months, etc.) to facilitate the assessment of the effects of a precipitation deficit on different water resources components (soil moisture, groundwater, stream flow, reservoir storage). Positive SPI values indicate precipitation higher than the median and negative values indicate precipitation lower than the median of long-term precipitation records. Drought periods are characterized by relatively high negative deviations. A drought event starts when SPI value reaches a negative value and ends when SPI becomes positive again (Table 2) (McKee *et al.*, 1993).

Table 2 Classification of drought classes for different indices

Drought Category	Rank	Index value				
		PNPI	**DPI**	**ZSI**	**SPI**	**ZCI and MZCI**
No drought	0	>80%	40-100%	-0.25-+0.25	0<	>0
Slight drought	1	70-80%	30-40%	-0.52- -0.25	-0.99-0	-0.99-0
Moderate drought	2	55-70%	20-30%	-0.84- -0.52	-1.49- -1	-1.49- -1
Severe drought	3	40-55%	10-20%	-1.25- -0.84	-1.99- -1.5	-1.99- -1.5
Extreme drought	4	<40%	<10%	< -1.25	< -2	< -2

2.3.5 China Z index (CZI)

Kendall and Stuart (1977) stated that China Z Index is based on the Wilson–Hilferty cube–root transformation. In CZI, it is supposed that rainfall data fit the Pearson Type III distribution. CZI equation can be written as:

$$CZI_i = \frac{6}{C_s}\left(\frac{C_s}{g}\varphi_i + 1\right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6} \tag{3}$$

$$C_s = \frac{\sum_{i=1}^{n}\left(p_i - \bar{p}\right)^3}{n \times \sigma^3} \tag{4}$$

$$\varphi_i = \frac{p_i - \bar{p}}{\sigma} \tag{5}$$

Where I factor is the current month, Cs factor is expressed as coefficient of skewness, φi is standard deviation, also called the Z-Scores, and x_i index is monthly precipitation (Wu *et al.*, 2001).

2.3.6 Modified CZI (MCZI)

In Modified China Z Index, mean rainfall has been changed to Median precipitation (equation 4 and 5) as done for the calculation of the CZI (Wu *et al.*, 2001).CZI and MCZI drought severity classes are also presented in Table 2.

In order to assess the efficiency of drought indices in annual time scale, regarding coincidence of theyear with the minimum annual precipitation (reflecting a severe meteorological drought) with a drought class in that year we can choose the most suitable index. The indices for particular meteorological stations were ranked according to the drought class. The class "extreme drought" for rank 4, the class "severe drought" for rank 3, and so forth. The class "no drought" was ranked 0. This was repeated for each index.

Evaluation of drought indices in various monthly time scales was also performed. For achieving this purpose, first qualitative description of drought indices were quantified.Afterward,the Spearman rank correlation coefficientwere used between quantitative values of drought indices in each month and monthly precipitation value for each index and station. These calculations were performed by SPSS 24 software.Thenarithmetic means of correlation coefficients were calculated in all stations for each index and time scale. Finally, an efficacious index was selected for each time scale based on the highest degree of correlation coefficient.

3 RESULTS

Severities of meteorological drought were calculated using different indices for the Tajan basin in a 39-year period (1966-2005). The minimum annual precipitation and the

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associateddrought severity classes for each indexand the four stations are presented in Table 3. The class “extreme drought” in the year with the minimum precipitation was identified by the DPI for all four stations (100 % score). The score is 75 % for ZCI and 50 % for SPI and ZCI. The PNPI and MZCI were not identified for the year with the minimum precipitation.

The DPI index is the most suitable index for drought studies in the Tajan basin when the annual precipitation is used. The sequence of the indices using this approach is DPI, ZSI, SPI and ZCI, PNPI and MZCI, respectively.

In another method, in order to evaluate the efficiency of these indices, Spearman rank correlation coefficient was used between quantitative values of drought indices and monthly precipitation values. Results of arithmetic means of correlation coefficients in all stations for each index and time scale are shown in Table 4 and Figure 2. Spearman correlation coefficient analysis showed 1% significant level (P**) in all analyses of stations and time scales. Considering the results of these methods, PNPI index with the highest mean of Spearman correlation coefficients is the most efficacious index in 1, 6, 12 and 24 month time scales.

Table 3 Drought severity classes for each index and for the four stations

Station	**Minimum precipitation (mm)**	**Water year**	**Study indices**					
			ZSI	**PNPI**	**DPI**	**SPI**	**ZCI**	**MZCI**
Afrachal	452.1	1985-86	3	3	4	2	2	2
Rig Cheshmeh	439.5	1970-71	4	2	4	4	4	2
Solaiman Tangeh	317.5	1985-86	4	3	4	4	4	2
Kord Khil	426.7	1974-75	4	2	4	3	3	3
Rank			second	fourth	first	third	third	fifth

Table 4 Arithmetic mean values of Spearman rank correlation coefficient in various stations

Drought index	**Time scale (month)**							
	1	**3**	**6**	**9**	**12**	**18**	**24**	**48**
SPI	0.824	0.548	0.416	0.322	0.318	0.275	0.235	0.153
ZSI	0.864	0.655	0.419	0.319	0.317	0.281	0.232	0.147
CZI	0.865	0.531	0.394	0.315	0.318	0.282	0.237	0.147
MCZI	0.620	0.401	0.376	0.350	0.313	0.273	0.224	0.190
PNPI	0.883	0.641	0.425	0.297	0.321	0.288	0.248	0.155
Efficacious Index	PNPI	ZSI	PNPI	MCZI	PNPI	PNPI	PNPI	MCZI

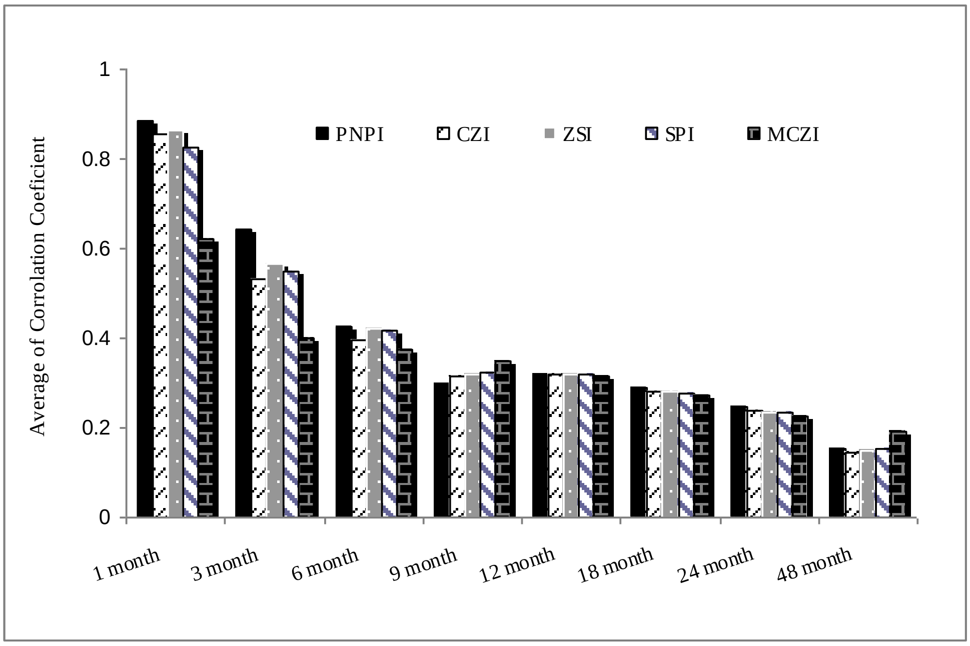

Figure 2 Diagram of Average amounts of Spearman rank correlation coefficient in various stations

4 DISCUSSION

The results of this study are in agreement with Vafakhah and Rajabi (2005) on the DPI as the best index when annual precipitation is used. Results of this study conformed Loukas *et al.* (2003) in that three indices including Standard Precipitation Index (SPI), Anomaly Rainfall Index and Standard Index of Annual Precipitation (SIAP) had the same trend in 12-month time scale. With regard to Tables 3 and 4, it could be concluded that SPI and ZCI had the same value in each method. This confirms the findings of Wu *et al.* (2001). Identification of efficacious indices by coincidence of minimum annual precipitation with drought severity categories in this study was in agreement with Khalili and Bazr afshan (2003) who identified DPI index as the best index. However, identification of SIAP disagreed with the result of this research. The findings of Ensafi moghadam (2007) differed from the present results. This difference is due to the difference between climates of their case study and the Tajan Basin and data period.

As shown in Table 4 and Figure 2, Arithmetic mean amounts of Spearman rank correlation coefficient was high in short term time scales; and the longer time scales become, the less Spearman rank correlation between precipitation data and index values will be. This finding was completely in agreement with Loukas and Vasiliades (2005). Therefore the results suggest that drought studies by indices can be performed inshort-term time scale, obviating the need to using long-term time scales.

5 CONCLUSION

This research investigates the performance of meteorological drought indices in different time

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scales. Indices applied in this study include Percent Normal Precipitation Index (PNPI), Z-Score Index (ZSI), Standard Precipitation Index (SPI), China Z Index (CZI), Modified CZI (MZCI), and Decile Precipitation Index (DPI). Drought indices were determined at time scales of 1, 3, 6, 9, 12, 18, 24 and 48-months. The results showed that DPI was the best index at annual time scale and the sequence of the indices using this approach is DPI, ZSI, SPI and ZCI, PNPI and MZCI, respectively, while at the time scale of 1, 6, 12 and 24-months, PNPI was the best index. MCZI was the best index for time scales of 9 and 48-months, and the ZCI had the maximum efficiency for scale of 3 months. This investigation showed that the use of an appropriate time step is as important as the type of DI used to identify drought severities. It could be suggested that drought-zoning maps be provided with these chosen indices, and then these maps should investigate the drought spatial distribution.

The study was based on the freely available short-time series data. It demonstrated how to overcome the lack of data for drought characterization and monitoring in some developing countries, where data are unavailable or access to them is still costly or difficult. Further investigations are required in order to establish a comprehensive early warning and drought monitoring system. This can be reached by integrating thermal time-series data and soil moisture parameters that .can be linked to a model.

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کارایی تعدادی از شاخص‌های خشکسالی هواشناسی در مقیاس‌های مختلف زمانی (مطالعه موردی: حوزه آبخیز تجن)

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چکیده خشکسالی پدیده‌ای اقلیمی است که اثرات زیان‌آور زیادی روی محیط‌های اکولوژیکی دارد. این تحقیق به بررسی کارایی شاخص‌های خشکسالی هواشناسی در مقیاس‌های مختلف زمانی در حوزه آبخیز تجن می‌پردازد. شاخص‌های درصد نرمال بار بارندگی (PNPI)، شاخص عدد استاندارد (ZSI)، شاخص بارندگی استاندارد (SPI)، شاخص اندیس Z چین (ZCI)، شاخص ZCI اصلاح شده (MZCI) و شاخص دهک‌های بارندگی (DPI) در این مطالعه مد نظر قرار گرفته‌اند. در این مطالعه از داده‌های بارندگی سالانه و ماهانه ایستگاه‌های هواشناسی موجود در حوزه استفاده شد. شاخص‌های خشکسالی در مقیاس‌های زمانی ۱، ۳، ۶، ۹، ۱۲، ۱۸ و ۲۴ سال از بارندگی کمینه با خشکسالی‌های بسیار شدید و روش ضرایب همبستگی بین مقادیر شاخص‌های خشکسالی و بارندگی مشخص گردید. نتایج حاصله نشان داد، در مقیاس زمانی سالانه، شاخص DPI و در مقیاس‌های زمانی ۱، ۶، ۱۲ و ۲۴ ماهه، شاخص PNPI مناسب‌ترین شاخص بوده‌است. هم‌چنین برای مقیاس‌های زمانی ۹ و ۴۸ ماهه شاخص MCZI، و برای مقیاس ۳ ماهه شاخص ZSI دارای بیش‌ترین کارایی بوده‌اند.

کلمات کلیدی: حوزه آبخیز تجن، خشکسالی، داده‌های بارش، شاخص‌های خشکسالی