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Full Length Research Paper

Comparison of the suitability of standardized precipitation index (SPI) and aggregated drought index (ADI) in Minab Watershed (Hormozgan Province/South of Iran)

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Drought is a climatic anomaly, characterized by shortage (lack) of rainfall, high evaporation and unsuitable distribution of rainfall. This study investigated and compared the aggregated drought index (ADI) and standardized precipitation index (SPI) for drought monitoring in Minab watershed in Hormozgan province in south of Iran. Precipitation data were used for SPI calculation. Four variables including precipitation, potential evaporation, temperature and peak discharge (4 available recorded data) were used for ADI calculations using principal component analysis (PCA). Results of SPI show that watershed has normal drought situation from 1980 to 2009. On the other hand, ADI shows capability to detect dry and wet years. Moreover, it has capability to detect historical drought. Overall, by considering the results, the ADI is more reliable than SPI for drought monitoring in the study area.

Key words: Drought, standardized precipitation index (SPI), aggregated drought index (ADI), Brentin, Minab, Hormozgan, Iran.

INTRODUCTİON

Drought is a temporary feature resulting from prolonged absence, or deficiency or poor distribution, of precipitation (Ogallo, 1994). Drought is a natural recurrent phenomenon, which occurs on a variety of different temporal and spatial scales, and significantly affects natural and socio-economic systems. The definition of drought is highly varied because of its strong dependency on time and space, and its variety of impacts. However, droughts may be classified as meteorological, agricultural, hydrological or socio-economical (Wilhite and Glantz, 1985; Hayes et al., 2010). Meteorological drought is associated with a precipitation shortage and is dependents upon its duration, which can result in agricultural (related to soil moisture) or hydrological drought (related to e.g. stream flow, ground water level, or reservoir storage). Socio-economic drought addresses the monetary effects of drought. A better understanding of drought is essential to develop an appropriate tool for prediction or forecasting of drought initiation and ending (Sharma, 1997; Chiew et al., 1998). This is essential for timely and appropriate implementation of measures to cope with a drought.

Although numerous interpretations of drought have been offered, the most significant determinant of drought is the amount of precipitation an area gets compared to normal (Edwards and Mckee, 1997). There are different types of drought classification based on the duration, severity and continuity of that, such as standardized precipitation index (SPI), aggregate drought index (ADI),

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surface water supply index (SWSI) and district regional stream deficiency index (RDI). This study focuses on the SPI and ADI for prediction of drought, and compares their suitability.

Standardized precipitation index

Mckee et al. (1993) developed the Standardized Precipitation Index (SPI) for monitoring drought conditions based on rainfall. Lloyd-Hughes and Saunders (2002) and Logan et al. (2010) have discussed the advantages and weaknesses of the SPI. Guttman (1998) provides a list of the advantages of the SPI:" the SPI is recommended as a drought index because it is simple, spatially consistent (invariant) in its interpretation, probabilistic so that it can be used in risk and decision analyses, and can be tailored to time periods of a user's interest (for example, three months for the life cycle of a crop, or several years for water storage)."According to these studies, regions with greater SPI spatial variability correspond to regions, which are less densely sampled. Moreover, if a few stations were located at medium and high elevations, a greater uncertainty would be expected at those regions. However, the spatial variability in the mountainous regions is often small, because the SPI is not affected adversely by the topography. The SPI can detect the high variation of drought in the period of the study. The SPI is computed by dividing the difference between the normalized seasonal precipitation and its long- term seasonal mean by the standard deviation. The formula for drought calculation is:

$$SPI=\frac{x_{ij}-\bar{x}}{S.d} \quad (1)$$

where, x is the seasonal precipitation at the i^{th} rain gauge and j^{th} observation, $\bar{x}$ the long-term seasonal mean and S.D is its standard deviation. The SPI is defined theoretically as the sub-areas under a normal (Gaussian) probability distribution function. It has many advantages over other drought indices which require more than two variables. It needs consideration only of two parameters, the arithmetic mean and the standard deviation.

Aggregated drought index

ADI, which is developed by Keyantash and Dracup (2004), is a multivariate drought index that examines the bulk quantity of water across the meteorological, hydrological, and agricultural regimes of drought. In fact, ADI is anticipated to herald droughts, and it attempts to preserve a close connection between drought and basic elements of the hydrologic cycle. The most important input variables are stream flow, rainfall, reservoir storage volume, snow, potential evapotranspiration, soil moisture content and temperature in this index. ADI uses principal component analysis (PCA), because it involves more details of variance and standard data. PCA has been used extensively in atmospheric and hydrologic analysis to describe dominant patterns appearing in data (Lins, 1997; Barnston and Livezey, 1987; Hidalgo et al., 2000).

In this index, PCA was adopted as the numerical approach to distill the essential hydrologic information from the input dataset, which leads to the construction of the ADI. Computation of the Principal Components (PCs) requires constructing a square ($p \times p$, where p is the number of variables), symmetric correlation matrix to describe the correlations between the original data. The equation of ADI is:

$$Z = XE, \quad (2)$$

where, z is the $n \times p$ matrix of PCs; in which n is the number of observations, X is the $n \times p$ matrix of standardized observational data, and E is the $p \times p$ matrix of eigenvectors of PCA. As was reported by Keyantash and Dracup (2004), the ADI was considered as the PC, normalized by its standard deviation according to Equation 3:

$$ADIi,k = \frac{Zi1k}{\sigma} \quad (3)$$

where, $ADIi,k$ is the ADI value for month k in year i, $Z_{i,1,k}$ is the first principal component during year i, for month k, and σ is the sample standard deviation of $Z_{i,1,k}$ in overall years *i*.

Barua and Perera (2009) presented a comparative drought assessment between ADI and SPI. They have reported that ADI was able to detect historical droughts. Moreover, by considering their results it can discriminate drought from the aggregate prospective of metrological, hydrological and agriculture water shortage. In their study, the ADI showed smooth transitional characteristic where it's time series fluctuates smoothly during the droughts. On the other hand in their study, the SPI showed rapid fluctuations over the whole period. Moreover, it was unable to identify historical droughts.

The south of Iran is a drought- prone region (Razei et al., 2000). The frequent occurrence of drought in this region has resulted in significant social, economic and environmental impacts, emphasizing the region's vulnerability to natural hazards. Although drought occurrence in south of Iran is heterogeneous, it occurs almost every 5 to 6 years. Some studies such as Barkhordari and Khosroshahi (2006) have attempted to analyze the situation of drought in this region. They used a 5-year moving average method from 1971 to 2000, which showed that the region was wet from1975 to 1983 and 1991 to 2000, and dry from 1984 to 1990. This study adapted the ADI and SPI indices to the study area and

Figure 1. The Minab watershed study area in Hormozgan Province, Iran.

Table 1. Drought categorization values (Mckee et al., 1993).

Drought classes	SPI value
Extremely wet	<2
Very wet	1.5 to 1.99
Moderately wet	1 to 1.50
Near normal	-0.99 to 0.99
Moderately drought	-1 to -1.49
Severely drought	-1.5 to -1.99
Extremely drought	-2<

compared the suitability of them in predicting the drought in Brentin watershed in Minab in south of Iran.

MATERIALS AND METHODS

Study area

The Minab watershed is located at 54° 22' 07" E and 27° 11' 53" N in Hormozgan province with7495 km^2 in about 100 km northeast of Bandar Abbas city, the capital city of Hormozgan province (Figure 1). Mean elevation is about 760 m (varies from 130 to 2731 m). Most of the rainfall (65%) is in winter, and 11, 16 and 8% in spring, autumn and summer, respectively. A little rainfall (8%) is related to the monsoon mass effect, which comes from the Indian Ocean. Relative humidity is high in October and June and low in September and March. Temperature varies from 2-5 to 30-49°C and climate is arid to semi-arid. Geological formations are part of Zagros fold and the Makran mountains string, which is located in the southeast of Iran (Barkhordari, 2003). Based on the FAO international classification method (Dewan and Famouri, 1964) soils in the study area have been classified in six major groups. These include; leptosols, fluvisols, solonchaks, arenosols, regosols and cambisols (Barkhordari, 2003). Main vegetation types are *Astragalus* (shrub) and *Cymopogon* (grass), and the main land uses are agriculture and low elevated hills. The Minab River in Minab station is equipped with staff-gauge, peak discharge, synoptic and hydrometer stations, and limnograph from 1967 and Brentin station is equipped with a rain gauge and evaporimeter station.

Data sources

Data on rainfall, potential evapotranspiration and air temperature (Bureau of Meteorology of Iran, 2011) and peak discharge (Hormozgan Water Corporation Organization, 2011) were obtained for 30 years (1980-2009), and used for the selected indices calculation. There are three temperature gauges that measuring air temperature. Evaporation measuring stations were used to compute the monthly evaporation values for the selected watershed.Evaporation measuring station was inside of catchment area. Evaporation data had been used to calculate the evapotranspiration. The commonly used Thiessen polygon method (Thiessen, 1911) was used to calculate the monthly rainfall and evapotranspiration values for the watershed and stream flow data at Minab watershed were used in this study to compute average daily data for each month. These two data were considered as the watershed representative data, to account for the fluctuations in streamflow discharge.

Indices calculation and comparison

The SPI is calculated by taking the difference between amount of rainfall per months and precipitation average in time series divide by the standard deviation of rainfall in the time scale. To calculate the SPI, the equation 1 is used and results classified in seven classes according to Table 1 (Mckee et al., 1993).

The ADI is computed using Equations 2 and 3. To create a 30 × 4 matrix, where 30 is the number of years and four represents the variables precipitation, potential evaporation, temperature and peak discharge (4 available variables for calculation of this index). To calculate the Z value (the $n \times p$ matrix of PCs; in which n is the number of observations), X (the $n \times p$ matrix of standardized observational data) which has multiplied in E (the $p \times p$ matrix of eigenvectors). In this step, the matrix was multiplied to transpose matrix, and it was divided by the number of years to create symmetric 4 x 4 eigenvalues for time series. Finally, Z was divided by standard deviation.

In the developed matrix; P, Q, T and E, respectively, denote precipitation, peak discharge (stream flow), temperature and

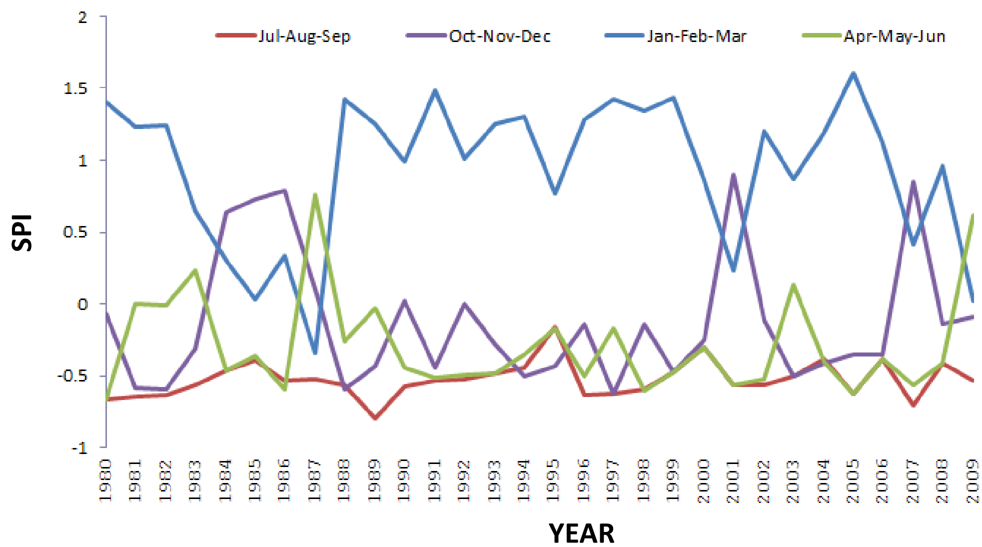

Figure 2. The SPI time series for Brentin Station (1980-2009).

potential evaporation. The 30 years of data P, E, Q and E are arranged columnar into a 4 × 30 matrix of observations "a". A strength of the correlation based PCA approach used for ADI that P, E, Q and E are reported in their original units of millimeter, cubic meters per second, centigrade and millimeter, respectively.

A comparison was carried out between SPI and ADI based on hydrological cycle and historical drought that in SPI using of a variable (precipitation) shows that it is affected by certain limitations, such as water supply and demands, hydrological boundaries ,rapid fluctuations thus, it cannot detect historical droughts. However, the ADI used four variables (precipitation, potential evaporation, peak discharge or stream flow and temperature) with the capability of detecting historical droughts.

RESULTS AND DISCUSSION

Table 2 shows the necessary data for calculating SPI and ADI. Available data entered in below matrix. Rainfall is the only required data for calculating SPI (Figure 2). Drought events were defined using Table 1. As Figure 2 shows, along a two-year period from 2004 to 2005, the highest value for this index is 1.6 in three months (January, February and March) and the lowest value for this index is 0.8 in 1998-1999 (July, August and September). Thus, the index takes the severe humid range in three months (January, February and March) and (July, August and September) to be a nearly normal. Overall, by considering to Table 1, the drought is near normal in the watershed with the SPI index.

The ADI index is presented in the following matrices and Figure 3. The matrix (4 columns × 30 rows) P, E, Q and T as mentioned are precipitation, potential evaporation, stream flow and temperature, respectively. The data in matrix "X" have their column means subtracted, and each element is divided by the column standard deviation. This expresses the original observations as a series of standardized anomalies, and the new series is referred to as "X". The correlations among the standardized anomalies are expressed in the symmetric, 4 x 4 correlation matrix "R":

X =

P	Q	T	E
15.1	19.75	27.9	284.7
5.83	13.57	26.9	295.9
22.88	42.78	26.3	277.5
7.51	18.76	27.6	271.4
5.63	13.21	27.4	323.6
4.77	7.98	26.8	340.1
4.95	6.14	27.5	325.1
9.8	18.87	27.1	317.2
5.86	12.63	26.1	305.3
4.39	8.5	26.8	321.6
6.97	29.12	25.6	334.1
11.84	21.13	24.6	247.4
9.11	26.09	25.7	245.5
31.86	33.65	26.1	250.1
3.78	7.44	25.9	274.3
3.95	10.01	26.0	265.1
18.65	61.11	25.7	241.8
8.5	23.15	26.4	238
12.94	44.94	26.8	244.3
6.17	18.9	26.4	263.6
6.8	18.41	26.7	283.2
1.56	4.25	27.0	287.3
0.74	11.46	26.9	271.4
0.98	6.74	27.2	269.2
1.23	3.91	26.7	273.4
10.5	37.31	27.3	253.7
0.80	7.78	27.2	355.8
1.37	12.9	27.2	243.4
1.39	17.2	26.2	259.6
1.83	18.3	26.7	256

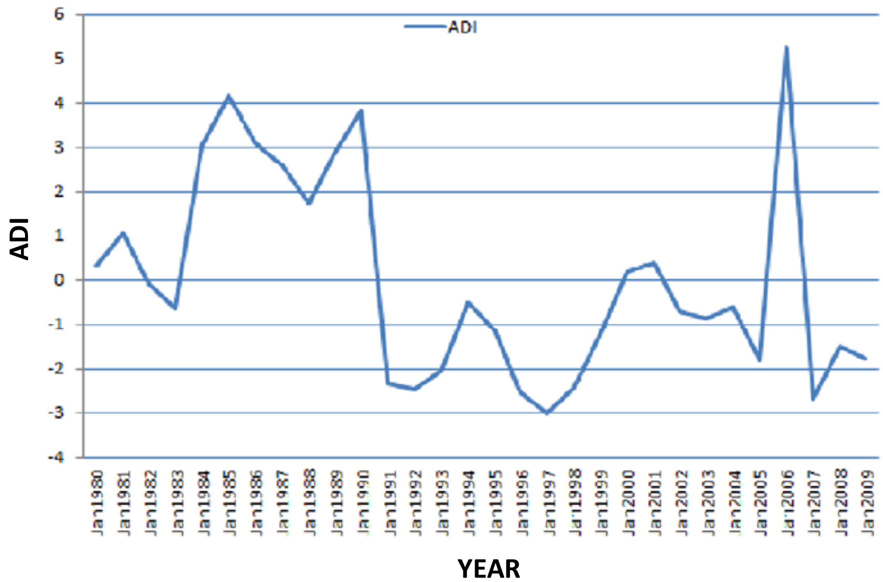

Figure 3. Time series of ADI for Minab watershed (Brentin station) from1980 to 2009.

Table 2. The available data for calculating ADI and SPI.

Year	Precipitation (mm)	Peak discharge (L/s)	Temperature (°C)	Potential evaporation (mm)
1980	15.10	19.75	27.9	284.7
1981	5.83	13.57	26.9	295.9
1982	22.88	42.78	26.3	277.5
1983	7.51	18.76	27.6	271.4
1984	5.63	13.21	27.4	323.6
1985	4.77	7.98	26.8	340.1
1986	4.95	6.14	27.5	325.1
1987	9.80	18.87	27.1	317.2
1988	5.86	12.63	26.1	305.3
1989	4.39	8.50	26.8	321.6
1990	6.97	29.12	25.6	334.1
1991	11.84	21.13	24.6	247.4
1992	9.11	26.09	25.7	245.5
1993	31.86	33.65	26.1	250.1
1994	3.78	7.44	25.9	274.3
1995	3.95	10.01	26.0	265.1
1996	18.65	61.11	25.7	241.8
1997	8.50	23.15	26.4	238
1998	12.94	44.94	26.8	244.3
1999	6.17	18.9	26.4	263.6
2000	6.80	18.41	26.7	283.2
2001	1.56	4.25	27.0	287.3
2002	0.74	11.46	26.9	271.4
2003	0.98	6.74	27.2	269.2
2004	1.23	3.91	26.7	273.4
2005	10.50	37.31	27.3	253.7
2006	0.80	7.78	27.2	355.8
2007	1.37	12.90	27.2	243.4
2008	1.39	17.20	26.2	259.6
2009	1.83	18.30	26.7	256

$$R = \left(\frac{1}{29}\right) \times X^T \times X = \begin{bmatrix} 109.742 & 221.58 & 207.75 & 2135.42 \\ 221.58 & 263.06 & 525.76 & 5373.08 \\ 207.75 & 525.76 & 733.75 & 7737.08 \\ 2135.42 & 5373.51 & 7737.08 & 82579.12 \end{bmatrix}$$

where, X^T is a transpose matrix. Principal component analysis is performed on R, and eigenvalues for the time series are determined as:

$e_{1=}$ [0.0257 0.0648 0.0930 0.9932] ^{T}

The eigenvectors as unit vectors are derived through PCA. In this study, PCA was adopted as the numerical approach to distill the essential hydrologic information from the input data set, which leads to the construction of the ADI as:

$$\text{ADI} - \left(\frac{1}{14.01}\right) \times aa \times ei - vec,$$

where, ei-vec is simply e_1 and aa was replaced instead of $\mathbf{X}$ in Equation 1.

With considering in time series σ = 14.01 inserting numbers for all variables,

$$\text{ADI}=\frac{1}{14.01}\begin{bmatrix} 7.51 & 0.55 & 1.27 & 4.04 \\ -1.75 & -5.62 & 0.27 & 15.24 \\ 15.29 & 23.58 & -0.32 & -3.15 \\ -0.07 & -0.43 & 0.97 & -9.25 \\ -1.95 & -5.98 & 0.77 & 42.94 \\ -2.81 & -11.21 & 0.17 & 59.44 \\ -2.63 & -13.05 & 0.87 & 44.44 \\ 2.21 & -0.32 & 0.47 & 36.54 \\ -1.72 & -6.59 & -0.52 & 24.64 \\ -3.19 & -10.69 & 0.17 & 59.44 \\ -0.61 & 9.92 & -1.02 & 53.44 \\ 4.25 & 1.93 & -2.02 & -33.25 \\ 1.52 & 6.89 & -0.92 & -35.15 \\ 24.27 & 14.45 & -0.52 & -30.55 \\ -3.80 & -11.75 & -0.72 & -6.35 \\ -3.63 & -9.18 & -0.62 & -15.55 \\ 11.06 & 41.91 & -0.92 & -38.85 \\ 0.91 & 3.95 & -0.22 & -42.65 \\ 5.35 & 25.74 & 0.17 & -36.35 \\ -1.41 & -0.29 & -0.22 & -17.05 \\ -0.78 & -0.78 & 0.07 & 2.54 \\ -6.02 & -14.94 & 0.37 & 6.64 \\ -6.84 & -7.73 & 0.27 & -9.25 \\ -6.60 & -12.45 & 0.57 & -11.45 \\ -6.35 & -15.28 & 0.07 & -7.25 \\ 2.91 & 18.11 & 0.67 & -26.95 \\ -6.79 & -11.42 & 0.58 & 75.14 \\ -6.22 & -6.3 & 058 & -37.25 \\ -6.2 & -2 & -0.42 & -21.05 \\ -5.75 & -0.9 & 0.07 & -24.65 \end{bmatrix} \times \begin{bmatrix} 0.026 \\ 0.065 \\ 0.093 \\ 0.99 \end{bmatrix} = \begin{bmatrix} 0.31 \\ 1.05 \\ -0.09 \\ -0.65 \\ 3.01 \\ 4.16 \\ 3.09 \\ 2.6 \\ 1.71 \\ 2.85 \\ 3.83 \\ -2.35 \\ -2.46 \\ -2.05 \\ -0.51 \\ -1.16 \\ -2.55 \\ -3 \\ -2.45 \\ -1.21 \\ 0.17 \\ 0.4 \\ -0.7 \\ -0.88 \\ -0.6 \\ -1.81 \\ 5.26 \\ -2.67 \\ -1.51 \\ -1.76 \end{bmatrix}$$

Finally, using the ADI equation, it was found a column that related to 30 years. For example, 0.31 for January 1980 and -1.76 for January 2009. Considering it, we determine the ADI equation.

Figure three shows that drought events in 1997 and 2007 were considerably more intense than in other years, particularly the drought event in 1997 which with the value of "-3" can be considered as a historical drought in the study area. According to Figure 3, the high values for 1985, 1990 and 2006 can be considered as the wet years in the study area.

In Figure 2, SPI shows rapid fluctuations over the whole study period. In conclusion, with the SPI, it is difficult to identify the historical drought for 1997 or even for 1982-83, 1987-88 (January, February and March) and 1982-83, 1986-87 and 2000-01 (October, November and December), whereas ADI clearly identified these droughts.

Although SPI gave some indication of drought conditions during dry periods, it gave misleading information that the drought has ended showing higher SPI values (or wet spells) during the drought, because of high rainfall values over a month or two.

As Smakhtin and Hughes (2004) reported, the SPI suffers from certain limitationsbecause it is a rainfall-based drought index and it does not represent wider dry circumstances. In contrast ADI uses several data sources.

Obviously, because of the greater number of parameters and variables, it's accuracy is high. Thus, the ADI is considered to be amore efficient indicator than the SPI. On the other hand, according to observations, it can be concluded that ADI is the most aggregated index in this basin because of having more variable. A similar conclusion has been made by Kaskin and Sorman (2010) who reported that ADI is a useful tool that explaining meteorological, hydrological and agricultural droughts together.

Drought assessment has been a challenge amongst drought studies and decision makers. There is ongoing debate that drought is just a deficiency in rainfall and could therefore be defined with a single variable. Others believe that rainfall is not sufficient to define wider drought conditions. From the results of this study, using the SPI, which usually have been affected by drought, can be used for analyzing by considering rainfall fluctuations. However, results in comparison with the results of ADI are not completely efficient.

On the other hand, the ADI is constructed separately for each month, based on four hydrologic variables.

Although up to seven variables have been used to calculate this index, due to lack of data for variables such as soil moisture content and snow water content in this study region only four variables were used. The use of ADI and spell it into time series is determined as the wet and dry periods, and the most value of drought in Minab watershed is in 1997 year and it considered as a historical drought.

To sum up, between the two indices, it can be concluded that for all forms of physical (hydrological, agricultural, etc.) droughts the ADI has more reliable results in comparison with the SPI with respect to the parameters used in this study for the study region (Brentin station). It may, because of the ADI employmore parameters, while SPI use only one parameter.

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