The Efficiency of Meteorological Drought Indices for Drought Monitoring and Evaluating in Kohgilouye and Boyerahmad Province, Iran

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Abstract: *Drought is one of the most common natural events that have a great negative impact on agriculture and water resources. Recently, a new index for drought assessment and monitoring is presented called Reconnaissance Drought Index (RDI). RDI is calculated based on precipitation and potential evapotranspiration. In this study, indices of SPI (Standardized Precipitation Index) and RDI were calculated using 30 years meteorological data (1982 to 2012) for Kohgilouye and Boyerahmad Province located in iran. The negative values show the dry years of the historical record. It can be seen that the most sever drought occurred during the year 2007- 2010. Correlation analysis is performed to identify differences of the SPI and RDI in different time scales. Results show the presented correlation coefficients increase in the longer time scales such as (9 and 12 months). The Map of Spatial distribution of drought severity for 2010 obtained based on the SPI and RDI by means of geostatistics methods in the study area. It can be observed that East part of the watershed lie in the moderately class and the rest of area is generally characterized by severe drought. In this paper however it was shown that RDI can be used for monitoring purposes and to a certain extent for short period drought forecasting.*

Keywords: *Drought, Standardized precipitation index (SPI), Reconnaissance drought index (RDI), Kohgilouye and Boyerahmad*

I. Introduction

Drought as an environmental disaster is associated with a deficit of water resources over a large geographical area, which extends for a significant period of time (Rossi, 2000). It occurs in areas with high and low rainfall and all climate conditions. The different drought indices are presented for drought monitoring. They are useful tools for decision makers to identify weather abnormal conditions for a region (Wilhite et al., 2000).

There are many literatures on the drought evaluation by using different indices, models and water balance simulations (Jain et al., 2010). There are different indices for drought monitoring, such as: Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI), Percent of Normal Index (PN), Standardized Precipitation Index (SPI) (Mishra and Singh, 2010).

Along the various indices for meteorological drought monitoring, SPI were widely accepted and used (Shamsnia and Pirmoradian, 2009).The SPI was presented by McKee and his colleagues at Colorado State University . SPI is completely related to probability. This Index use precipitation as the most effective parameter in the calculation of the drought severity. The SPI is normally distributed so it can be applied to monitor wet as well as dry periods. During the last decade the SPI has become very popular due to its low data requirements. This index can be useful for drought monitoring and forecasting (Shamsnia et al., 2009). Recently, a new index for drought assessment and monitoring is presented called Reconnaissance Drought Index (Tsakiris et al., 2007). RDI is calculated based on precipitation and potential evapotranspiration. Precipitation alone cannot show the impact of drought on agricultural production and vegetation. Applying both of the P and PET in drought severity calculation and monitoring, increases the validity of the results (Tsakiris et al., 2007). Also, this index has a strong correlation with SPI (Asadi Zarch et al., 2011). The RDI was used in Greece (Tigkas, 2008), Cyprus (Pashiardis and Michaelides, 2008), Malta (Borg, 2009) and Iran (Khalili et al., 2011) for monitoring or analysis of historical droughts. To achieve this objective, we used Geostatistical tools to mapping. Geostatistical Analyst creates a continuous surface by using sample points taken at different locations. Using interpolation techniques are frequently used in recent years to mapping drought risk.

The Study Area

Drought is a common natural disaster in many countries as well as Iran. Previous studies show that Iran is exposing drought with different severities. To evaluate drought, Kohgilouye and Boyerahmad Province in the southwest of Iran were selected. This province is located in the southwest part of Iran, at 49° 57' to 51° 42 E longitude and 30° 9' to 31° 32' N latitude, with an area of 26416 Km2. Elevation in the study area ranges from 500 m to 4400 m. The climate is characterized by dry and warm summers, and cool wet winters. The annual mean of precipitation for the province ranges from 400 to 1300mm. Most of the annual average precipitation falls as rain during winter. The Location of study areas and monitoring station are shown in Figs 1.

Data used

Rainfall data were collected from 17 meteorological stations complied by the Meteorology Organization of Iran and Kohgilouye and Boyerahmad Regional Water Authority. After, annual rainfalls data during 30 years from 1982-2012 were chosen to later analysis. Missing data was computed by use of relationship between elevation and rainfall. To this order, linear regression was calculated in Spss software.

II. Method

Calculation of meteorological indices

The Standardized Precipitation Index

The standardized Precipitation Index (SPI) is one of the indices that were presented for drought monitoring. It is calculated in short-term (3, 6 and 9 months) and long-term (12, 24 and 48 months) periods. In any time scale, the SPI mean may reach zero in a location and its variance become equal to 1.Using the SPI, quantitative definition of drought can be established for each time scale. A drought event for time scale i is defined here as a period in which the SPI is continuously negative and the SPI reaches a value of -1.0 or less. The drought begins when the SPI first falls below zero and ends with the positive value (Mckee et al., 1993). The SPI is calculated by using the following equation:

$$SPI = \frac{P_i - \bar{P}}{S} \qquad (1)$$

Where P_i and $\bar{P}$ are the precipitation and average precipitation of selected period, S is standard deviation of precipitation.

The Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) is calculated in three stages: Initial value of RDI (a_0), normalized RDI (RDIn) and standardized RDI (RDIst). Initial value may be calculated for each month, seasons (3-month, 4-month, etc.) or hydrological year. The a_0 is calculated by using the following equation (Tsakiris et al., 2007; Asadi Zarch et al., 2011)

$$a_0^{(i)} = \frac{\sum_{i=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \; ; i = 1(1)N \; and \; j = 1\,(1)12 \qquad (2)$$

Where $P_{ij}$and PET_{ij} are the precipitation and potential evapotranspiration of the jth month of the i_{th} hydrological year. Hydrological year is starting from October in Iran. N is the total number of years of the available data.

A second step, the Normalized RDI(RDI_n)is computed using the following equation for each year, in which it is evident that the parameter a_0 is the arithmetic mean of a_0 values (Tsakiris et al., 2007; Asadi Zarch et al., 2011).

$$RDI_n^{(i)} = \frac{a_0^{(i)}}{\bar{a}} - 1 \qquad (3)$$

The third step, the Standardized RDI(RDI_s), is computed following a similar procedure to the one that is used for the calculation of the SPI: The equation for the Standardized RDI is:

$$RDI_{st(k)}^{(i)} = \frac{y_k^i - \bar{y}_k}{\hat{\sigma}_{yk}} \qquad (4)$$

Where y_k is the $ln(a_0; \bar{y}_k)$ is its arithmetic mean of y_k , and $\hat{\sigma}_{yk}$ is its standard deviation.

The RDI is based on the ratio of two aggregated quantities which are precipitation and potential evapotranspiration. It can be estimated for all time scales. However 3, 6, 9 and 12 month are suggested since they are more useful for comparing different locations (Tsakiris and Vangelis, 2005).

Estimation of potential evapotranspiration for drought monitoring using RDI

Several methods have been suggested for PET estimation. The Penman–Monteith (PM) equation is one of the standard methods of calculating PET by using meteorological data. It is remarkable that the international scientific community has accepted this equation as the exact method (Jabloun and Sahli, 2008). Although PM equation in different climates has shown positive results, but because of the full meteorological data requirement such as minimum and maximum air temperature, minimum and maximum relative humidity, solar radiation and wind speed, its widespread use is limited. In some studies for drought monitoring using RDI, alternative methods such as Thornthwaite method and Blaney-Criddle equation has been used for PET estimation (Kanellou et al., 2010). Therefore in this research was used the Calibrated Thornthwaite method (Ahmadi and Fooladmand, 2008) for Kohgilouye and Boyerahmad Province. The Calibrated Thornthwaite equation is :

$$PET = 16(10\frac{T_{eff}}{I})^a \qquad (5)$$

Where PET is mm month^{-1},T_{eff} is the effective monthly temperature (°C). I is a thermal index imposed by the local normal climatic temperature regime, and the exponent a is a function of I.

Effective temperature is calculated as (Camargo et al., 1999):

$$T_{eff} = K(T_{ave} + A) \qquad (6)$$

$$A = T_{max} - T_{min} \qquad (7)$$

Where T_{min}, $T_{max}$and $T_{eff}$are the minimum, maximum and effective monthly temperature (°C) respectively. $K$is the calibrated coefficient.

Time Scales

In this study, Monthly SPI and RDI were calculated using the monthly precipitation and evapotranspiration data of 17 stations in Kohgilouye and Boyerahmad Province. SPI and RDI values were calculated in the period of hydrological years from 1982 to 2012 for the time scales of 1, 3, 6, 9 and 12 months. Because of data limitations, SPI with time scales longer than 24 months may be unreliable. The RDI_{st} behaves similar to the SPI. Drought classification of these indices is shown in Table 1. The values from -0.5 to -0.99 and +0.5 to +0.99 considered as nominal class of mild drought and slightly wet (Shamsnia and Pirmoradian, 2009).

III. Results and discussions

Correlation analysis between RDI and SPI

The correlation coefficients (r) between SPI and RDI for each area and each time scales are described in Table 2. Results show the presented correlation coefficients increase in the longer time scales such as (9 and 12 months). The maximum value of r between SPI and RDI was obtained for 12-month time scale and the minimum value for 1-month time scale in all areas (Table 2). In time Scale 9 and 12 months in all stations, correlation coefficient (r) is more than 0.9. Because SPI index is related to precipitation parameters for drought assessment, the results show that precipitation parameters are more effective in drought with a longer time scale. By contrast, the effect of potential evapotraspiration parameters that were used in the RDI index will be reduced by increasing the time scale. The wet, drought and normal periods have more fluctuation on the short time scales such as 1, 3 and 6 months, because of the low number of effective months and effects of other meteorological parameters on the severity of drought. In other words, changes of dry and wet periods on short time scales, in addition to precipitation, depend on the evapotraspiration and the other weather parameters.

Identification of Drought Events

Fig 2 shows the annual SPI and RDI in the yasuj station for the period 1982 to 2012. The negative values show the dry years of the historical record. It can be seen that the most sever drought occurred during the year 2007- 2010.

Drought Maps

Drought maps were produced using the estimated annual values of SPI and RDI. Also, By means of kriging method spatial severity of drought was mapping. Fig 3 and 4 shows Spatial distribution map of SPI and RDI in 2010 in the study area. It can be observed that north and west parts of the area lie in the extremely class and the rest of area is generally characterized by severely and moderately drought. Such spatial drought map can be useful to forecast drought in the further studies. In most cases, the results from both indices are similar. However, in some cases, depending on the local conditions, the results from RDI are more sensitive.

IV. Conclusions

SPI and RDI were calculated in a period of 30 years data (1982 to 2012) for Kohgilouye and Boyerahmad Province. Correlation analysis is performed to identify the differences of the standardized precipitation index (SPI) and the reconnaissance drought index (RDI). From the presentation of some popular indices for drought assessment it seems that SPI is becoming the most widely used index. This is probably due to its simplicity, universality and to its least data demanding nature. In this paper however it was shown that water deficit cannot be estimated only on the input (e.g. precipitation) but also on the output variable (water consumption). Based on the logic a new index, RDI was purposed using data of two determinants, precipitation and potential evapotranspiration. It can be more effectively associated with hydrological and agricultural drought. Also it is an ideal index to study the effects of climate instability conditions. Due to its easy calculation RDI can be used for monitoring purposes and to a certain extent for short period drought forecasting.

References

[1] Ahmadi, S.H. and Fooladmand, H.R. (2008). Spatially distributed monthly reference evapotranspiration derived from the calibration of Thornthwaite equation: a case study, South of Iran. Irrig Sci. 26:303–312.
[2] Asadi Zarch, M.A., Malekinezhad, H., Mobin, M.H., Taghi Dastorani, M. and Kousari, M.R. (2011). Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran. Water Resour Manag. 25(13):3485-3504.
[3] Borg, D.S. (2009). An application of drought indices in Malta, case study. European Water. 25/26:25-38/
[4] Kanellou, E., Domenikiotis, C., Tsiros, E. and Dalezios, N.R. (2008). Satellite-based drought estimation in Thessaly. European Water, 23/24:111-122.
[5] Kanellou, E., Domenikiotis, C., Tsiros, E. and Dalezios, N.R. (2008). Satellite-based drought estimation in Thessaly. European Water, 23/24:111-122.
[6] Khalili, D.,Farnoud, T., Jamshidi, H., Kamgar-Haghighi, A.A. and Zand-Parsa, Sh. (2011). Comparability analyses of the SPI and RDI meteorological drought indices in different climatic zones. Water Resour Manag. 25(6): 1737-1757.
[7] Jabloun, M. and Sahli, A. (2008). Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data. Application to Tunisia. Agric Water Manage. 95:707–715.
[8] Jain, S.K., Keshri, R., Goswami, A. and Sarkar, A. (2010). Application of meteorological and vegetation indices for evaluation of drought impact: a case study for Rajasthan, India. Natural Hazards. 54: 643-656.

[9] McKee, T.B., Doesken, N.J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales, Preprints, 8th conference on applied climatology, January 17 22, Anaheim, California, pp 179–148

[10] Mishra, A.K. and Singh, V.P. (2010). A review of drought concepts. Journal of Hydrology. 391: 202-216.

[11] Pashiardis, S. and Michaelides, S. (2008). Implementation of the standardized precipitation index (SPI) and the reconnaissance drought index (RDI) for regional drought assessment: A case study for Cyprus. European Water. 23/24: 57-65.

[12] Rossi, G (2000). Drought mitigation measures: a comprehensive frame work. In Drought and Drought Mitigation in Europe. J. Voght and F. Somma (eds), Kluwer Academic Publishers, Dordrecht.

[13] Shamsnia, S.A. and Pirmoradian, N. (2009). Rectification of the Standardized Precipitation Index (SPI) Classification for Drought Evaluation in Fars Province (IRAN). 2nd India Disaster Management Congress. National Institute of Disaster Management. 4-6 November.

[14] Tigkas, D. (2008). Drought Characterisation and monitoring in regions of Greece. European Water. 23/24:29-39.

[15] Tsakiris, G., Pangalou, D. and Vangelis, H. (2007). Regional drought assessment based on the reconnaissance drought index (RDI). Water Resource Management. 21:821-833.

[16] Wilhite, D., Sivakumar, M. and Wood, D. (2000). Early Warning Systems for Drought Preparedness and Drought Management. Proceedings of an Expert Group Meeting, 5-7 Sep, Lisbon, Portugal.WMO TD No. 1037.

Table 1. Drought classification according to the SPI and RDI_{st} values

SPI and RDI_{st} value	Category
2 or more	Extremely wet
+1.5 to +1.99	Severely wet
+1 to +1.49	Moderately wet
+0.5 to +0.99	Slightly wet
-0.49 to +0.49	Normal
-0.5 to -0.99	Mild drought
-1 to -1.49	Moderately drought
-1.5 to -1.99	severely drought
-2 and less	Extremely drought

Table 2. Correlation coefficient (r) of the SPI and RDI in different time scales

Row	Station	Time Scales (Month)				
		1	3	6	9	12
1	Yasuj	0.838	0.965	0.979	0.990	0.992
2	Dashtroom	0.521	0.746	0.899	0.948	0.985
3	Dehnoo	0.640	0.831	0.954	0.977	0.991
4	Patave	0.532	0.764	0.842	0.971	0.989
5	Abchirak	0.615	0.856	0.941	0.983	0.997
6	Nazmakan	0.654	0.832	0.932	0.955	0.984
7	Tolchega	0.543	0.683	0.742	0.886	0.979
8	Ghaleraesi	0.725	0.846	0.921	0.964	0.993
9	Bibihakime	0.626	0.754	0.878	0.943	0.996
10	Likak	0.537	0.622	0.774	0.865	0.947

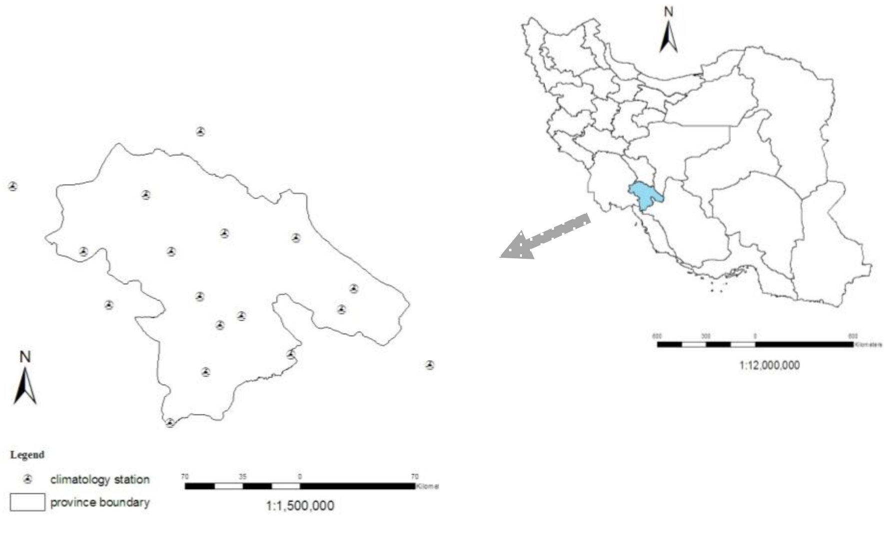

Fig 1. Regional map of Iran , location of study area and monitoring stations

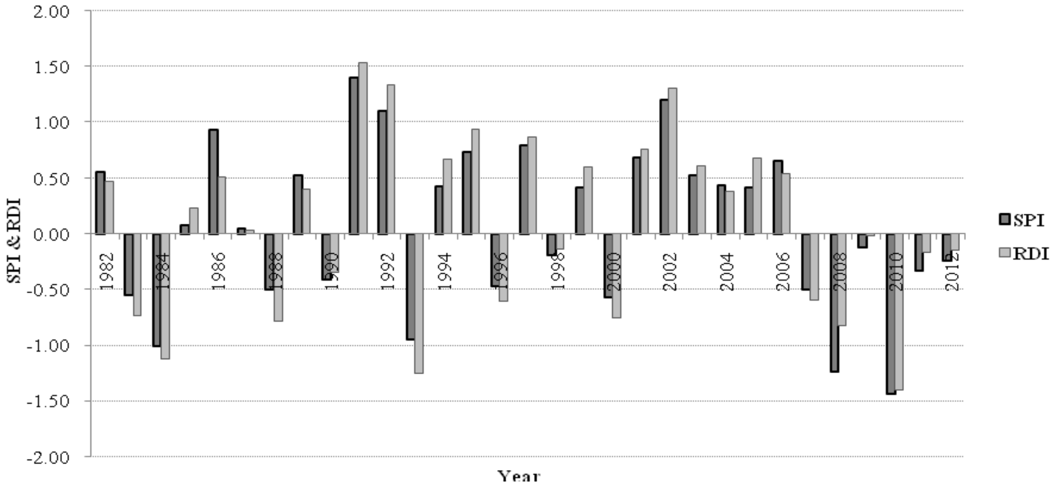

Fig 2. Annual SPI & RDIst for each hydrological year (Oct-Sep) for yasuj station

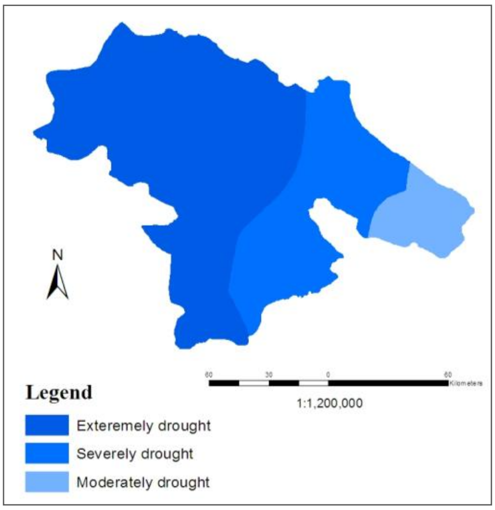

Fig 3. Spatial distribution map of SPI in 2010 in the study area

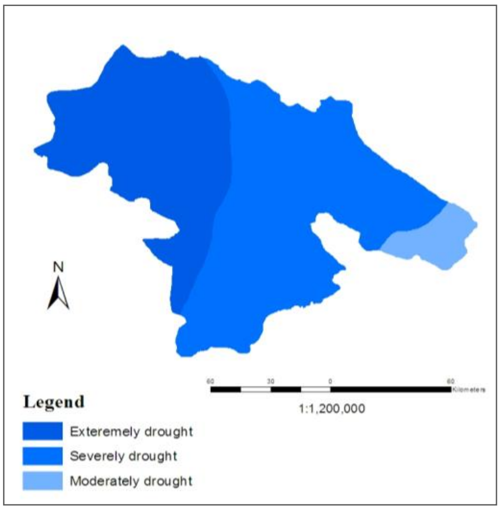

Fig 4. Spatial distribution map of RDI in 2010 in the study area