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Evaluation on the effects of evapotranspiration estimations methods on drought frequency according to Reconnaissance Drought Index (RDI)

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Abstract

RDI is based on fitting a log-normal distribution to the data of ratio of precipitation to evapotranspiration (ETo) in selected periods. In this index value of ETo were calculated based on mean temperature by Thorenth-Waite (TW) method. In order to evaluate the effects of evapotranspiration estimations methods on drought frequency according to RDI, some meteorological parameters of 6 Synoptic Stations from arid and semi arid of Iran during 1958-2007, have been used. After some statistical tests, the values of RDI for any stations during the mentioned time were calculated. Then, from 11 empirical and semi empirical equations of ETo estimations, the best equation for any situations of lack of parameters in any stations were selected. Subsequently, time series of ETo from the best equation were prepared. After that the new RDI values so called RDI(Select) were established. Finally the frequency of different classes of drought according to RDI and RDI(Select) were compared. The results showed that the TW method, may underestimated ETo values about 610 mm.year-1 comparing to the actual in arid and semi arid regions. This underestimation leads to changing the frequency and/or displacement of different classes of drought. Displacement accrued in all classes at Tehran station and the frequency of moderate drought and normal situations were changed from 7 and 33 to 5 and 36 events respectively during a 50 years.

Keywords: Drought, Reconnaissance Drought Index (RDI), Evapotranspiration, empirical equations. Iran.

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Evaluation the effects of evapotranspiration estimations methods on drought frequency according to Reconnaissance Drought Index (RDI)

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ABSTRACT

Reconnaissance Drought Index (RDI) is based on ratio of precipitation to evapotranspiration (ET_o) for any period of time from 1 month to the entire year. In this index value of ET_o were calculated based on mean temperature by Thornthwaite (Th) method. In order to evaluate the effects of evapotranspiration estimation method on drought frequency according to RDI(Th) index, some meteorological parameters of 6 Synoptic Stations in arid and semi arid regions of Iran during 1958- 2007, have been conducted. After some statistical tests, the values of RDI for each station during the mentioned time were calculated. Then, from 11 empirical and semi empirical equations of ET_o estimations, the best equation for each situations of lack of variables in each stations were selected. Subsequently, time series of ET_o from the best equation were prepared. After that the new RDI values so called RDI(Select) were established. Finally the frequency of drought classes according to RDI and RDI(Select) were compared. The results showed that the Th equation, may underestimated ET_o values about 610 mm.year^{-1} comparing to the actual in selected stations. This underestimation leads to changing the frequency and/or displacement of drought classes. Displacement accrued in all drought classes at Tehran station and the frequency of moderate dry and normal classes were changed from 7 and 33 to 5 and 36 events respectively during 50 years.

Kay words: Drought, Reconnaissance Drought Index (RDI), Evapotranspiration, empirical equations, Iran.

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INTRODUCTION

Drought is a temporary climatic situation of a region and is different from aridity which is referred to lack of water in a region. In drought monitoring, different indices usage may leads to different results. Drought in comparison with the other disasters are of tremendous importance due to intensity, duration, spatial coverage, economic damages and long term effects (Jamshidi et al., 2009).

The complex drought phenomenon can be simplified into a drought index, which is a single number assimilating a large amount of water supply data. The index allows scientists to quantify climate anomalies in terms of intensity, duration, and spatial extent, making it easier to communicate the information to diverse users. A number of different indices have been developed to quantify a drought, each with its own strengths and weaknesses. They include the Palmer drought severity index (PDSI; Palmer 1965), rainfall anomaly index (RAI; van Rooy, 1965), deciles (Gibbs and Maher, 1967), crop moisture index (CMI; Palmer, 1968), surface water supply index (SWSI; Shafer and Dezman, 1982), national rainfall index (NRI; Gommes and Petrassi, 1994) and standardized precipitation index (SPI; McKee et al., 1993, 1995). Hayes (2000), Mishra and Singh (2010) gave a comprehensive review of drought index and concept.

Precipitation is the primary factor controlling the formation and persistence of drought conditions, but evapotranspiration is also an important variable. Historical difficulties in quantifying evapotranspiration rates suggest that a general classification scheme is best limited to a simple measure of rainfall. Indeed, indices based solely on precipitation data perform well when compared with more complex hydrological indices (Lloyd-Hughes and Saunders, 2002).

RDI index was first presented in the coordinating meeting of MEDROPLAN by Tsakiris in 2004. Later and more comprehensive information on how to calculate the index, by Tsakiris & Vangelis, 2005 and Tsakiris et al., 2007 was published.

Tsakiris et al. (2007) were mentioned that usually droughts in the Mediterranean are accompanied by high temperatures, which lead to higher evapotranspiration rates. Therefore, the RDI is expected to be more sensitive index than those related only to precipitation, such as the SPI. The RDI is computed by fitting log- normal probability density function to the ratio of precipitation to (ET_o) over the time scale of interest.

Horvarth et al. (2010) have compared Thornthwaite method (considers bare soil) and Blaney– Criddle method (estimates evapotranspiration after specification of a given plant) of potential evapotranspiration, applied in computation of the Palmer Drought Severity Index. Monthly PDSI series in the April–October growing season of maize are analysed at five stations in Eastern Hungary for the period 1901–1999.

Jamshidi et al. (2009) have compared meteorological drought indices of SPI and RDI on 39 synoptic stations placed in different parts of Iran. The results of their study showed that the RDI is more sensitive than the SPI to climatic conditions and so the role of evapotranspiration in drought assessments could not be neglected. The results also showed that both indices behave in the same manner, but RDI due to use of potential evapotranspiration in similar climatic conditions is more sensitive. However, in some months increase or decrease in evapotranspiration will cause significant variation between the two indices.

The objective of this study is to compare eleven empirical and semi empirical ETo estimation on 6 synoptic stations placed in arid and semi- arid climate of Iran and evaluate the effects of evapotranspiration estimation methods on changing of drought frequency classes based on RDI Index.

MATERIALS AND METHODS

Site selected synoptic stations and dataset

Iran with an area about of 1'648'195 Km^2 lies along between 25° – 40° N and 44° - 64° E and located in the semi-arid regions of the Earth. In this study the data of 6 synoptic stations were used. The situation of these stations is shown in Fig. 1

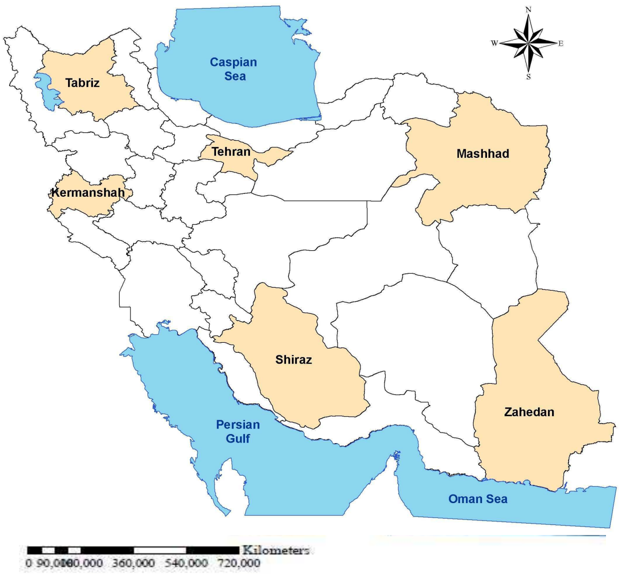

Figure 1. The location of selected synoptic stations in Iran

In this study in order to calculate evapotranspiration potential and RDI index, meteorological dataset consisted of monthly observations of maximum and minimum air temperature (T_{max} and T_{min}), mean relative humidity (RH), wind speed (U_2), sunshine hours (n) and Yearly rainfall amounts (P) from six synoptic stations of Mashhad, Tehran, Tabriz, Kermanshah, Shiraz and Zahedan in period of 1958 to 2007 were used. Meteorological dataset were obtained from I.R.Iran meteorological organization (http://www.irimo.ir).

(Reconnaissance Drought Index (RDI

The Reconnaissance Drought Index (RDI) is based on the ratio between precipitation and potential evapotranspiration amounts. It appears in three forms: the initial value α_0, the Normalized (RDI_n) and the Standardized (RDI_{st}). The initial value (α_0) is presented in an aggregated form using a monthly time step and may be calculated on a monthly, seasonal or annual basis. The α_0 for the year I and a time basis j (months) is calculated as:

$$\alpha_0^{(i)} = \frac{\sum_{j=1}^{12} p_{ij}}{\sum_{j=1}^{12} ET_{ij}}, \quad i = 1:N \quad and \quad j = 1:12 \tag{1}$$

Where P_{ij} and ET_{ij} are the precipitation and potential evapotranspiration in month j of Year i and N is the total number of years of the available data.

The second term in calculating the index, RDI values normalized (RDI_n) are calculated using values for the various α_0 the previous step, according to equation (2) are calculated.

$$RDI_n^{(i)} = \frac{\alpha_0^{(i)}}{\bar{\alpha}_0} - 1 \tag{2}$$

The initial formulation of the RDI_{st} used the assumption that the α_0 values follow the lognormal distribution and RDI_{st} is calculated as:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y} \tag{3}$$

In which $y^{(i)}$ is the ln($\alpha_0^{(i)}$), $\bar{y}$ is arithmetic mean and $\hat{\sigma}_y$ is its standard deviation of $y^{(i)}$ (Tsakiris et al., 2007).

The Standardized RDI (RDI_{st}), behaves similarly to the SPI and therefore the interpretation of the results is similar since the same thresholds as SPI (Edwards & McKee, 1997) can be used.

Estimation of ET_o in lack of measurement data

In RDI index, the ET_o values were calculated by means of mean temperature based on the Thornthwaite (Th in the followings) equation, But this equation underestimates ET_o values comparing with the actual values, spatially in arid and semi-arid regions (Jensen et al., 1990). There for in this study, ET_o values were calculated using Th and selected methods. The ET_o value in selected method was calculated via the best empirical or semi empirical equations based on the parameters available for each month. In other words, if in a certain month, all parameters that needed for FPM equation are available, the ET_o value was calculated via this equation, Otherwise based on the available parameters, was calculated using the best empirical or semi empirical equations. How to determine the best equation in each situation of lack of meteorological parameters is given in the following section.

FPM equation is used as standard method in a region where the lysimetric data are not avaialbe. This equation required the parameters of T_{max}, T_{min}, RH, U_2 and sunshine hours. In Majority of synoptic stations of Iran, some requirement meteorological parameters of FPM were not measured in first years of construction of station. In this situation for accurate estimation of ET_o value seme- empirical semi- empirical equations that require less meteorological parameters should be useful.

Equations and parameters required consist of six empirical equation FAO Penman Monteith (FPM), Hargreaves and Samani (HS), Turc (T), Priestley and Taylor (PT), Thornthwaite (Th) and Makkink (MK) and 5 semi empirical equation PT_{Rsest}, T_{Rsest}, MK_{Rsest}, FPM_{Rsest} and $FPM_{RsRHest}$ been used to estimate ET_o.

In Table 1 the semi empirical equation of FPM_{Rsest}, T_{Rsest}, MK_{Rsest} and PT_{Rsest} were modified from the empirical equations of FPM, T, MK and PT, that the solar radiation values are estimated based on temperature data. In addition, FPM_{RsRHes} is the modified form of FPM that in which solar radiation and relative humidity values are estimated based on temperature data.

Parameters of the mathematical expressions: T_{mean} is the mean daily air temperature (°C), T_{max} is the maximum daily air temperature (°C), T_{min} is the minimum daily air temperature (°C), N_m is corrected coefficient, I is heat index, a is exponent coefficient , λ is the latent heat of evaporation (MJ kg^{-1}), Δ is the saturation vapour curve slope (kPa $^oC^{-1}$), R_n is the daily net radiation (MJ m^{-2} d^{-1}), G is the daily soil heat flux density (MJ m^{-2} d^{-1}), R_s is the daily solar radiation (MJ m^{-2} d^{-1}), Ra is the daily extraterrestrial radiation (MJ m^{-2} d^{-1}), R_{sest} is the estimated daily solar radiation (MJ m^{-2} d^{-1}), a = 1.26, g is the psychometric constant (kPa $^oC^{-1}$), u_2 is the wind speed at 2m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), ea is the actual vapour pressure (kPa), es(Tmin) is the saturation vapour pressure at the minimum daily air temperature (kPa), $e_s(T_{max})$ is the saturation vapour pressure at the maximum daily air temperature (kPa), RH is the daily relative humidity (%).

Based on the meteorological parameters required to calculate ET_o value, equations of Table 1 were divided into three different groups including: Temperature and/or relative humidity based equations (group 1), Solar radiation based equations (group 2) and FPM analogous equations (group 3). Classification of ET_o estimation equations based on required meteorological parameters are shown in Table 2.

Table 1. Summary of ET_o estimation equations used in this study

Group	Model	Equation	estimated parameter	Mathematical Expression
Reference equations	FPM	FAO Penman-Monteith	None	$FPM = \frac{0.408\,\Delta\,(R_n - G) + \gamma\left(900/(T_{mean} + 273)\right) U_2 (e_a - e_d)}{\Delta + \gamma\,(1 + 0.34\,U_2)}$
ET_o equation	Th	Thornthwaite	None	$Th = 16 N_m \left(\frac{10 T_{mean}}{I}\right)^a$
	HS	Hargreaves and Samani	None	$HS = 0.0023 \frac{R_a}{\lambda}\left(T_{mean} + 17.8\right)\sqrt{T_{max} - T_{min}}$
	PT	Priestley and Taylor	None	$PT = \frac{a}{\lambda}\frac{\Delta}{\Delta + \gamma}\left(R_n - G\right)$
	MK	Makkink	None	$MK = 0.61 \frac{\Delta}{\Delta + \gamma}\frac{R_s}{\lambda} - 0.12$
	T	Turc	None	$T = a_T 0.013 \frac{T_{mean}}{T_{mean} + 15} + \frac{23.8856 R_s + 50}{\lambda}$ $RH \geq 50 \rightarrow \; a_T = 1$ $RH < 50 \rightarrow \; a_T = 1 + \frac{50 - RH}{70}$
ET_o equations with estimated parameters	FPM_{Rsest}	Penman-Monteith	Solar radiation	$R_{sest} = 0.16 R_a \sqrt{T_{max} - T_{min}}$
	T_{Rsest}	Turc	Solar radiation	
	MK_{Rsest}	Makkink	Solar radiation	
	PT_{Rsest}	Priestley-Taylor	Solar radiation	
	$FPM_{RSRHsest}$	Penman-Monteith	Relative humidity and Solar radiation	$e_a = 0.611 \exp \frac{17.27 T_{min}}{T_{min} + 237.3}$ *insted of* $e_a = \frac{RH}{100}\left[\frac{e_s(T_{min}) + e_s(T_{max})}{2}\right]$

Table 2. Classification of ET_o estimation equations based on Meteorological data requirement

	equation	Meteorological data requirement
Temperature and/or relative humidity based equations (group 1)	Th	$T_{mean}, T_{max}, T_{min}$
	PT_{Rsest}	$T_{mean}, T_{max}, T_{min}$
	MK_{Rsest}	$T_{mean}, T_{max}, T_{min}$
	HS	$T_{mean}, T_{max}, T_{min}$
	T_{Rsest}	$T_{mean}, T_{max}, T_{min}$, RH
Solar radiation based equations (group 2)	PT	$T_{mean}, T_{max}, T_{min}$, Rs
	MK	$T_{mean}, T_{max}, T_{min}$, Rs
	T	$T_{mean}, T_{max}, T_{min}$, Rs, RH
FPM analogous equations (group 3)	FPM_{Rsest}	$T_{mean}, T_{max}, T_{min}$, U_2, RH
	$FPM_{RsRHest}$	$T_{mean}, T_{max}, T_{min}$, U_2

For each station to calculate ET_o value by using the selected method, the months which have all meteorological parameters that needed by the Penman-Monteith were implemented for the period of January 1990 to December 2007. Then the ET_o values were calculated by means of 11 different equations (Table 1) in the mentioned period and used FPM as standard method, the root mean square error (RMSE) was calculated for different equations. After that, based on the RMSE criteria, for each

station in each group the best equation determine to estimate the ET_o values.

In this study in order to assess the role of these two methods, the values of ET_o were estimated by the Thornthwaite (Th) and selected methods. Then by fitting log- normal probability density function to the ratio of precipitation to ET_o (Th and selected methods), the indices of RDI (Th) and RDI (Select) were calculated and the effects of evapotranspiration estimation methods on changing of drought frequency classes were examined.

RESULT AND DISCUSSION

Results of different methods of estimating ET_o in RDI

Result of compression different ET_o estimation equations in three groups at selected stations is shown in Table 3. According to this table, along with equation of group 1 and group 2 for all six selected stations, the HS equation has a low error value. In addition, FPM_{Rsest} equation is most accurate in third group of equations for all stations.

Table 3. Result of compression different ET_o estimation equations in three groups at selected stations

Station	Group 1					Group 2			Group 3	
	Th	HS	PT_{Rsest}	MK_{Rsest}	T_{Rsest}	PT	MK	T	FPM_{Rsest}	$FPM_{RsRHest}$
Mashhad	1.370	0.451	1.104	1.323	2.653	0.940	1.133	2.564	0.164	0.737
Tehran	1.448	0.704	1.422	1.747	2.928	1.177	1.447	2.747	0.345	1.125
Tabriz	2.377	0.858	1.419	1.718	3.010	1.182	1.413	2.870	0.174	1.080
Kermanshah	1.536	0.643	0.855	0.673	2.208	1.080	1.064	2.421	0.222	0.208
Shiraz	1.531	0.559	0.977	1.046	2.456	0.913	0.971	2.417	0.089	0.522
Zahedan	2.222	0.654	1.849	1.690	3.010	1.865	1.716	3.029	0.081	0.949

The value of difference between Th and selected method of ET_o estimation is given in Fig 2. According to this fig. for the period of 50 years, Th equation, may underestimated ET_o values about 610 $mm.year^{-1}$ comparing to the actual in selected stations.

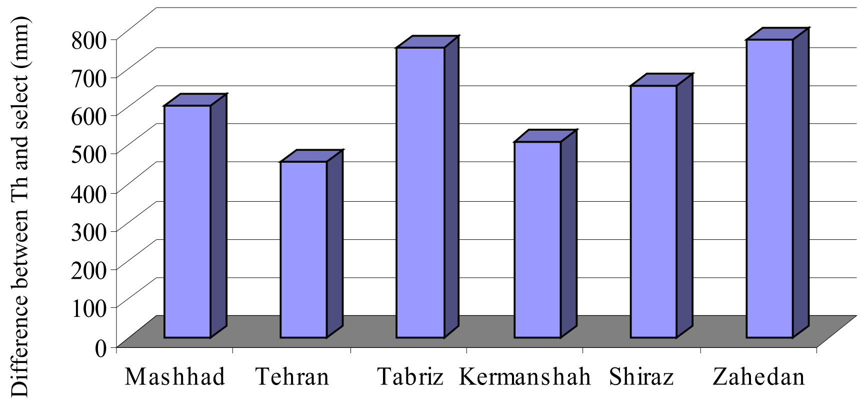

Fig 2. Difference of estimation values between Th and select method (mm)

It can be seem that, difference between the values of estimated ET_o in different method can lead to changes in frequency of drought classes. The results of Frequency of drought classes based on ET_o estimation method (Th and selected) according to RDI index were given in Table 4.

Table 4. Frequency of drought classes based on Th and selected method in selected stations

station	Drought Index	Number of frequency of drought classes						
		EW	SW	MW	N	MD	SD	ED
Mashhad	RDI(Th)	1	3	2	37	4	2	1
	RDI(Se)	0	4	5	34	3	3	1
Tehran	RDI(Th)	1	2	4	33	7	2	1
	RDI(Se)	0	3	3	36	5	1	2
Tabriz	RDI(Th)	2	2	3	35	5	2	0
	RDI(Se)	1	3	5	33	6	1	1
Kermanshah	RDI(Th)	1	3	5	32	6	1	1
	RDI(Se)	1	1	6	33	5	1	2
Shiraz	RDI(Th)	0	2	4	37	5	0	2
	RDI(Se)	0	3	4	34	7	1	1
Zahedan	RDI(Th)	0	3	9	30	4	2	1
	RDI(Se)	0	2	8	30	6	2	1

The number of transform of frequency and displacement of drought classes by using selected method for ET_o estimation for each stations is given in table 5. Based on these results, displacement has occurred in all drought classes at Tehran station. In this station frequency of normal and moderate dry classes transform from 33 to 36 and 7 to 5 respectively. A total of transform frequency at Mashhad station is equal to10 events and the highest transform is related to moderate wet and normal events with 3 classes transformations. The numbers of transform in frequency of drought classes in other stations were change from 6 to 2 events.

Table 5. number of change frequency and displacement of drought classes by using select method for ET_o estimation

Station	Number of displacement in each of drought classes							Total
	EW	SW	MW	N	MD	SD	ED	
Mashhad	1	1	3	3	1	1	0	10
Tehran	1	1	1	3	2	1	1	10
Tabriz	1	2	2	2	1	0	1	8
Kermanshah	0	2	1	1	1	0	1	6
Shiraz	0	1	0	3	2	1	1	8
Zahedan	0	1	1	0	2	0	0	4

REFERENCE

1- Edwards, D.C., McKee, T.B., 1997. Characteristics of 20th century drought in the United States at multiple time scales. Climatology Report Number 97(2), Colorado State University, Fort Collins, Colorado.

2- Hayes, M.J., 2000. What is Drought? Climate Impacts Specialist, htpp://www.drought.unl.edu.

3- Horvath, S., Szep, I.J., Makra, L., Mika, J., Pajtok-Tari, I., Utasi, Z., 2010. Effect of evapotranspiration parameterization on the Palmer drought severity index. Physics and Chemistry of the Earth 35, 11–18.

4- Jamshidi, H., Khalili, D., Kamgar-Haghighi, A.A., Zand-Parsa, S., 2009. RDI as the appropriate index of drought monitoring system in water resources management in Iran. International conference on water resource: emphasis on regional development, Shahrood, Iran.

5- Jensen, M.E., Burman, R.D., Allen, R.G. 1990. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practices, American Society. Civil Engrs, New York, NY, 360 P.

6- Landeras, G., Ortiz-Barredo, A., Lopez, J.J., 2008. Comparison of artificial neural network models and empirical and semi-empirical equations for daily reference evapotranspiration estimation in the Basque Country (Northern Spain). Agricultural water management 95, 553–565.

7- Lloyd-Hughes, B., Saunders, M.A. 2002. A drought climatology for Europe. International Journal of Climatology, 22: 1571–1592.

Mishra, A.K., and Singh, V.P. 2010. A review of drought concepts. Journal of Hydrology, 391: 202–216.

8- Richard, R., Heim, J.R., 2002. A review of twentieth- century drought indices used in the United States. American meteorological society. 1149-1165.

9- Tsakiris, G., Pangalou, D., Vangelis, H., 2007. Regional drought assessment based on the Reconnaissance Drought Index (RDI).Water Resource Manage 21,821–833.

10- Tsakiris, G., Vangelis, H. 2004. Towards a drought watch system based on spatial SPI. Water Resources Management 18, 1-12.

11- Tsakiris, G., Vangelis, H., 2005. Establishing a drought index incorporating evapotranspiration. Eur Water 9, 1–9.