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Research note

The RDI as a composite climatic index

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Abstract: Climatic changes in a geographical area may be detected by examining long timeseries of precipitation and potential evapotranspiration. From the point of view of water resources management, both of these variables influence directly the water availability and water demand, and therefore represent the climatic conditions of the studied area effectively. However, to avoid misinterpretations or non interpreted trends of these variables, simultaneous analysis of trends through a single index, incorporating both variables, is needed. The paper proposes the Reconnaissance Drought Index (RDI) (initial or normalised expressions) as a single climatic index for the detection of possible climatic changes. Using data for various reference periods (12, 6, 3 months) seasonal changes can be also detected. The merits of such an approach are presented in this contribution and examples using RDI as a climatic index are also illustrated.

Keywords: Reconnaissance Drought Index, climate change, water balance, precipitation, potential evapotranspiration, trends detection

1. INTRODUCTION

The climate of a region can be defined as the long-term pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables. Many recent studies show that there is an undergoing climate change. The effects of climate change over a long period are likely to influence water resources, agriculture, land use, environmental sustainability and the society. In this context climate change can intensify existing pressures and extreme events, thereby increasing risk, vulnerability and uncertainty of water systems (Loukas et al., 2008; WWAP, 2009).

Despite the fact that the causes of this climate change are not absolutely clear, according to the Intergovernmental Panel on Climate Change (IPCC, 2007), it is evident that there is a warming of the global climate system during the last few decades, with greater temperature increase at higher northern latitudes. Also, over the last century, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia but declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Other indicators of the climate change are the observed decrease in snow and ice extent, the rising sea level, etc. It should be noted, though, that there is always some level of uncertainty in projecting future conditions. For example, there is a high degree of confidence in projections that future temperature increases will be greatest in the Arctic and in the middle of continents (Karl et al., 2009).

From the above, it is obvious that precipitation and temperature can be key factors to characterise the climate of a region and indicate climate change, but these two factors exhibit varying trends in different regions of the world. Therefore, a composite index that incorporates both these factors can be very useful for primary climatic analyses.

Since the evapotranspiration is directly involved in the water balance studies, it is a more representative variable for replacing temperature in studies of water resources management under climatic change. Studying long timeseries of precipitation (P) and potential evapotranspiration (PET) of a geographical area may lead to one of 9 possible combinations (++, +0, +-, 0+, 00, 0-, -+, -0, --), in which + means increase, - means decrease and 0 means no change for the two variables studied. Having said that, one can conventionally try to check whether the detected changes are statistically significant.

Even so, from the water resources management point of view, in some of the above combinations it is difficult to conclude that these changes lead to a drier or wetter climate. For instance, which trend in the water availability is deduced by the observed increase of P and PET? For this reason a more effective procedure would be to study simultaneously the P and PET changes using a single index which will react positively if P is increasing or PET is decreasing. On the opposite the index will react negatively if P is decreasing or PET is increasing.

Such an index is the Reconnaissance Drought Index (RDI) which has been extensively used as a drought severity index in the past.

2. OVERVIEW OF THE RECONNAISSANCE DROUGHT INDEX (RDI)

2.1 Calculation of RDI

The Reconnaissance Drought Index (RDI) is based both on cumulative Precipitation (P) and potential Evapotranspiration (PET), from which one is measured and one is calculated determinant (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007a). RDI has three forms: the initial value (α_k), the normalised form (RDI_n) and the standardised form (RDI_{st}).

The initial value (α_k) of RDI is calculated for the i-th year in a time basis of k (months) as follows:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \; i = 1(1)N \text{ and } j = 1(1)k \tag{1}$$

in which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the j-th month of the i-th year and N is the total number of years of the available data.

The normalised form (RDI_n) is computed using the following equation:

$$RDI_n^{(i)} = \frac{a_k^{(i)}}{\overline{a_k^{(i)}}} - 1 \tag{2}$$

in which $\overline{a_k^{(i)}}$ is the arithmetic mean of $a_k^{(i)}$.

The values of α_k follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested (Tigkas, 2008; Tsakiris et al., 2008). By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of RDI_{st}:

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

in which y_i is the ln($a_k^{(i)}$), $\overline{y}$ is its arithmetic mean and $\hat{\sigma}_y$ is its standard deviation.

In case the gamma distribution is applied, the RDI_{st} can be calculated by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k (Tsakiris et al., 2008; Tigkas, 2008). For short reference periods (e.g. monthly or 3-months) which may include zero values for the cumulative precipitation of the period, the RDI_{st} can be calculated based on a composite cumulative distribution function including:

a) the probability of zero precipitation and

b) the gamma cumulative probability

Positive values of RDI_{st} indicate wet periods, while negative values indicate dry periods compared to the normal conditions of the studied area.

2.2 Applications of RDI

RDI has been used in several studies, mainly in the field of drought characterisation and monitoring. Drought severity can be assessed through the computation of the standardised form (RDI_{st}) for an easier interpretation of its results. This approach is extensively used mainly in arid and semiarid regions (Tsakiris et al., 2007b; Farajalla and Ziade, 2010; Asadi Zarch et al., 2011; Khalili et al., 2011; Kirono et al., 2011; Elagib and Elhag, 2011; Tigkas et al., 2012).

The severity of drought events increases when RDI_{st} values are becoming highly negative. Drought severity can be categorised in mild, moderate, severe and extreme classes, with corresponding boundary values of RDI_{st} (-0.5 to -1.0), (-1.0 to -1.5), (-1.5 to -2.0) and (< -2.0), respectively. RDI can be calculated for any reference period including several months of a hydrological year, though the most common reference periods are 3, 6, 9 and 12 months.

RDI has been also used for drought monitoring purposes (Tigkas, 2008; Pashiardis and Michaelides, 2008; Asadi Zarch et al., 2011; Mostafavi Darani et al., 2011) and for the design of drought meteorological monitoring networks as has been proposed by Tsakiris et al. (2008). Finally, drought and climate change impacts on water resources (Alexakis and Tsakiris, 2010; Tigkas et al., 2012; Tsakiris and Alexakis, 2013) and on agriculture (Tsakiris et al., 2010) have been investigated with the use of RDI.

3. RESULTS AND DISCUSSION

Meteorological parameters are used for characterising the climate of a region. In order to assess climate variations in a temporal scale, a climatic index could be useful for operational and management purposes. Such an index should be at least based on precipitation and temperature, the key factors for the identification of climate variations.

The initial value (α_k) of RDI is an adequate index for assessing the climatic conditions of a region, since it is based both on precipitation and potential evapotranspiration, the latter being directly related to air temperature.

Examples of the use of RDI as climatic index are now presented for illustration purposes. For instance Figure 1 presents the initial value of RDI, the α_{12} for two geographical areas in different climatic zones: the first for an area with humid climate, the second for an area with semi-arid climate. It is interesting to observe that α_{12} is significantly higher for the humid area for the entire timeseries associated with higher variability in comparison with the semi-arid area. It should be reminded that the average inter-annual RDI (α_{12}) coincides with the “aridity index” which is used for the climate characterisation (UNEP, 1992). Therefore, in order to detect the trend in the timeseries of annual RDI (α_{12}) one can use all appropriate methods for trend detection (e.g. Spearman test, Mann-Kendall test, Runs test, Durbin-Watson test, etc.). If the trend is statistically significant, then it can be assumed that there are strong indications of climatic change at annual basis.

Further, a more detailed detection of climatic change can be attempted by checking shorter reference periods than the entire year. In Figure 2 a 100-year timeseries of RDI for the first 6-month period (winter) and the second 6-month period (summer) of the hydrological year are presented. As known, due to the sharp decrease of precipitation in the summer months, the α_6 values of the summer are much lower than the values of winter. Obviously trends may be detected separately in the two time series giving more detailed information on possible seasonal climatic variations.

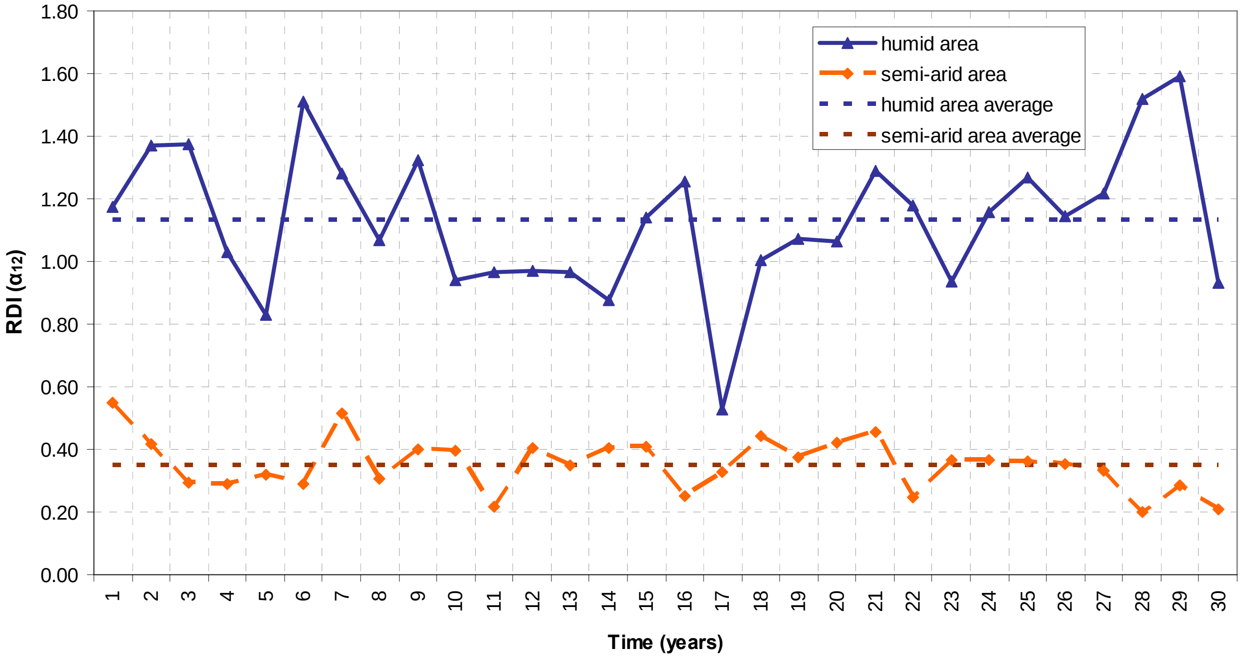


Figure 1. The initial value (α_{12}) of RDI for a time series of 30 years for a humid and a semi-arid area (dashed line represents the average of α_{12} for each area).

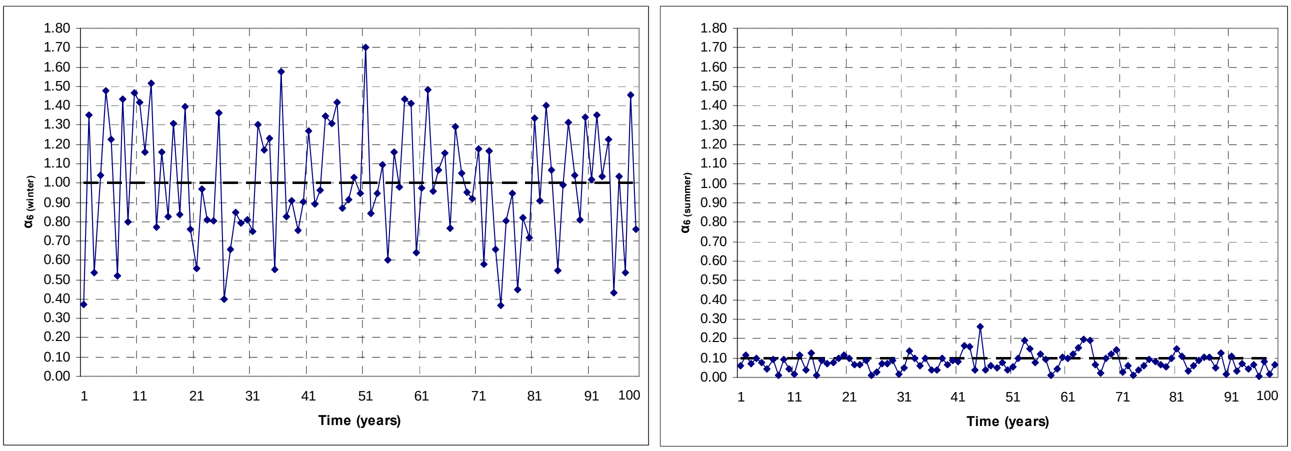


Figure 2. The initial values (α_6) of RDI for a time series of 100 years a) for the winter season (October-March) b) for the summer season (April-September) (dashed line represents the average of α_6).

In the above examples the initial value of RDI was used as the climatic index incorporating both cumulative precipitation and potential evapotranspiration. However, the normalised expression of RDI could be used also for the detection of significant trends, therefore showing strong indications of climatic change. For illustration purposes Figure 3 represents the annual normalised RDI_n of an area for a timeseries of 100 years. Finally, Figure 4 is presented to show the timeseries of normalised values of RDI for the two 6-month periods (October-March) and (April-September) of the same area.

It is important to note that although the standardised expression of RDI is not influenced significantly by the method of potential evapotranspiration calculation, the initial and the normalised forms of RDI are directly influenced by the various methods. Therefore, attention should be paid to the method of calculation of PET. In case adequate long timeseries of data of several meteorological variables are available, the researchers should use the widely accepted FAO Penman-Monteith method (Allen et al., 1998). However, if precipitation and air temperature data are the only readily available data, then the Hargreaves method or the simplified version of FAO Penman-Monteith method using only temperature, could be used (Vangelis et al., 2013).

Apart from the above, for a reconnaissance detection of trends in the timeseries of initial values of RDI, it can be argued that the influence of the PET calculation method is generally small.

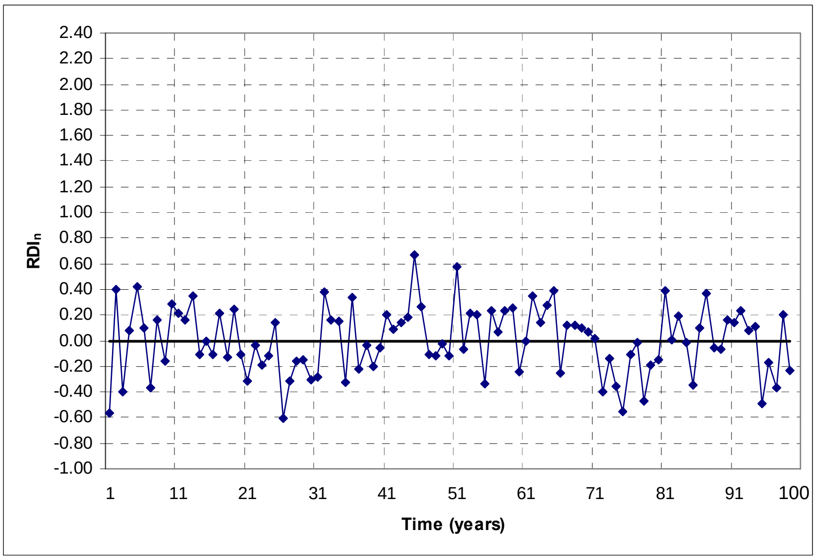
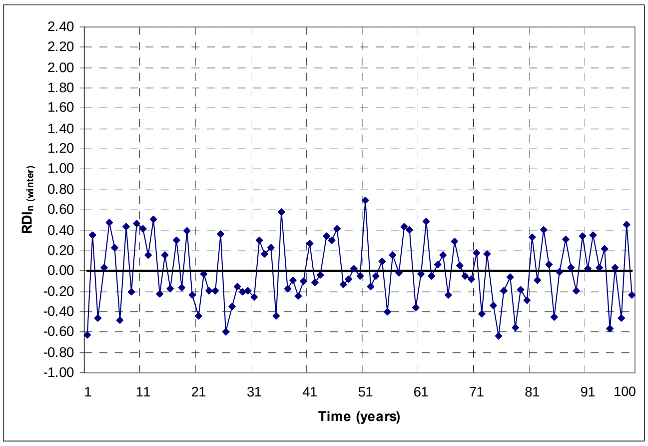


Figure 3. The annual normalised RDI_n for a time series of 100 years.



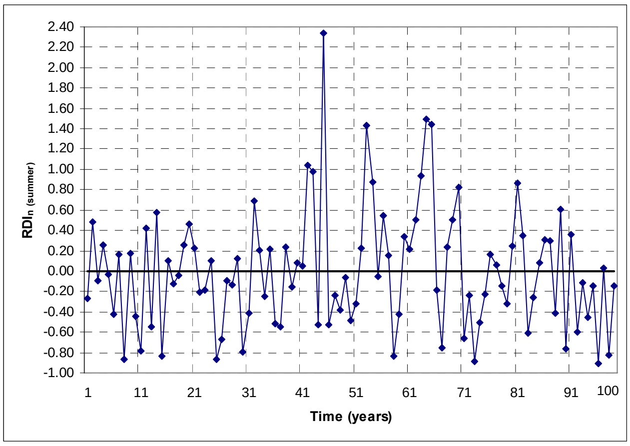


Figure 4. The normalised RDI_n for a time series of 100 years a) for the winter season (October-March) b) for the summer season (April-September).

4. CONCLUDING REMARKS

This Research Note proposes the Reconnaissance Drought Index as a climatic index for detecting possible climatic changes of a geographical area. The main advantage of this approach is that RDI incorporates both precipitation and potential evapotranspiration in a single index.

The Note also illustrates RDI timeseries of different durations (e.g. 12-month, 6-month etc.) for the detection of possible seasonal climatic changes.

Using the initial or the normalised expression of RDI a more reliable trend of climate variations can be detected than by using timeseries of precipitation and potential evapotranspiration separately. It is expected that this needs to be thoroughly documented through the future papers on the subject.

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