Quaternary International 345 (2014) 158–166

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

A survey of temperature and precipitation based aridity indices in Iran

Hossein Tabari [a,*], P. Hosseinzadeh Talaee [b], S.S. Mousavi Nadoushani [c], Patrick Willems [a], Aldo Marchetto [d]

[a] Hydraulics Division, Department of Civil Engineering, KU Leuven, Kasteelpark Arenberg 40, BE-3001 Leuven, Belgium
[b] Young Researchers and Elite Club, Hamedan Branch, Islamic Azad University, Hamedan, Iran
[c] Department of Water Resources Engineering, Faculty of Water & Environmental Engineering, Power & Water University of Technology (PWUT), Tehran, Iran
[d] National Research Council, Institute for Ecosystem Study, Largo Tonolli 50, 28922 Verbania Pallanza, Italy

ARTICLE INFO

Article history:
Available online 24 April 2014

Keywords:
Climatic index
Climate classification
Spatial distribution
Temporal trend
Statistical techniques

ABSTRACT

In arid and semi-arid lands with warm climates, aridity and associated water scarcity is more severe because of greater populations and associated water use. The goal of this study was to explore the spatial and temporal variations of the de Martonne and Pinna aridity indices over Iran based on temperature and precipitation data from 41 stations for 40 years (1966–2005). The spatially interpolated maps of the aridity indices were prepared using the Ordinary Kriging technique in a GIS environment. The arid and semi-arid regions cover about 88% of Iran according to the de Martonne index, while about 96% of the country's areas are classified as dry and semi-dry based on the Pinna index. A strong relationship was found between the values of the de Martonne and Pinna indices, confirming their similar spatial distribution. Around 63% of the two indices series had a decreasing tendency. The significant decreasing trends of the aridity indices were observed mainly in the western and northwestern regions of the country. The relative changes of the aridity indices at the stations with significant decreasing trends were in the range of 18%–54%.

1. Introduction

Aridity, as defined by the shortage of moisture, is essentially a climatic phenomenon that is based on average climatic conditions over a region (Agnew and Anderson, 1992). Increased aridity, dryness, and desertification have become a major environmental problem affecting the living conditions of the people in the affected region in many countries of the world. Once the aridity or dryness of an area increased beyond a certain level, it becomes difficult to recover (Adnan and Haider, 2012).

Climatic indices are diagnostic tools used to describe the state of a climate system and understand the various climate mechanisms (Deniz et al., 2011). The aridity index is a climatic index which can be used for monitoring and prediction of drought (Nastos et al., 2013), and change in the aridity index would inevitably have impacts on the hydrological cycle, water resources management, and ecosystem in the region (Liu et al., 2012).

Generally, climate indices are derived from temperature and precipitation measurements. Temperature and precipitation data are climate indicators, and the sense of changes expected to accompany climate warming are reasonably well defined. In addition, records of temperature and precipitation are often longer and probably have a better chance of revealing a detectable change than alternative climate variables such as cloud cover, winds, and humidity (Toros et al., 2008). Whereas temperature and precipitation are very useful individual parameters to study climatic change, the overall expression and significance of climatic change in bioclimatic terms is better expressed by the aridity or humidity index (Kafle and Bruins, 2009). Climate change alters local dry/wet conditions and affects the regional agriculture sector (Du et al., 2013).

Changes in the aridity index have been studied in the literature. Baltas (2007) studied the spatial distribution of climatic indices in northern Greece during the period 1965–1995. The climatic indices used were the Johansson Continentality Index, the Kerner Oceanity Index, the de Martonne (I_{DM}) Aridity Index, and the Pinna Combinative (I_P) Index. The results showed that the Johansson index is preferable to the Kerner index owing to

* Corresponding author.
E-mail address: tabari.ho@gmail.com (H. Tabari).

http://dx.doi.org/10.1016/j.quaint.2014.03.061
1040-6182/

the former's distinct limit values separating continental from oceanic climates. It was also found that the I_{DM} led to a more precise definition of each station's climate due to its more climate categories, in contrast to the few climate categories of the I_P. Paltineanu et al. (2007) investigated the range of the I_{DM} aridity index in Romania, and determined its relationship with irrigation water requirements of representative crops of Romania. They found an inverse and strong correlation between the I_{DM} aridity index and crop evapotranspiration and irrigation water requirements of crops. Deniz et al. (2011) explored the spatial variability of the continentality, oceanity, and aridity indices in Turkey. The climatic indices were same as those used by Baltas (2007). They found a significant correlation of 0.91 between the I_{DM} and I_P indices. The extreme locations which were found using the I_{DM} were also addressed by the I_P. Croitoru et al. (2013) analyzed the indices of I_{DM} and I_P in order to identify critical areas in the most important agricultural regions of the extra-Carpathian areas of Romania over the period 1961–2007. They found that the trends calculated for I_{DM} index were mostly negative, but they were not statistically significant in the great majority of cases. For I_P, the trends were mainly positive, but also statistically insignificant.

Recently, changes in the aridity index in Iran were analyzed in several studies. Tabari and Aghajanloo (2013) and Shifteh Some'e et al. (2013) analyzed the UNESCO index, utilizing ratio of precipitation (P) over reference evapotranspiration (ET_o), in Iran. In another study, Tabari and Hosseinzadeh Talaee (2013) investigated the moisture conditions of Iran using the revised Thornthwaite moisture index, a ratio of evapotranspiration to precipitation. The overall results showed that similar to the precipitation variations in Iran (Modarres and da Silva, 2007; Tabari and Hosseinzadeh Talaee, 2011; Soltani et al., 2012; Shifteh Some'e et al., 2012), the significant trends of the moisture index are not evident at the majority of the stations.

This study attempts to analyze simple aridity indices based on only temperature and precipitation for the regions where full meteorological data may not be available for ET_o estimation. Thus, the aridity indices of de Martonne and Pinna were calculated by using monthly temperature and precipitation data from 41 meteorological stations in Iran. We focused on the spatial and temporal variations of aridity indices for the period 1966–2005. The temporal trend in the aridity indices was examined using the Mann–Kendall test modified by Hamed and Rao (1998). Additionally, the cumulative sum test was utilized for change point detection in aridity indices time series.

2. Materials and methods

2.1. Dataset

The data used in this study are monthly records of temperature and precipitation provided by the Islamic Republic of Iran Meteorological Organization (www.weather.ir/). In this study, 43 weather stations with a minimum record length of 40 years were considered. Only stations with less than 5% of missing values in relation to the total weather station data for the whole study period were selected. Therefore, two stations (Jask and Tabass) were excluded from the study and a total of 41 stations across the country were used to calculate the aridity indices over the period 1966–2005. A statistical summary of precipitation and air temperature at the considered stations is presented in Table 1 and the spatial distributions of the selected stations are shown in Fig. 1.

Table 1
A statistical summary of precipitation and air temperature at the considered stations.

Station	Precipitation		Air temperature	
	Mean (mm)	Standard deviation (mm)	Mean (°C)	Standard deviation (°C)
Abadan	167.9	58.9	25.5	0.73
Ahwaz	246.7	83.7	25.4	0.86
Arak	333.9	96.8	13.8	1.12
Babolsar	925.0	158.0	17.1	0.69
Bam	59.1	26.3	23.1	0.80
Bandar-Abbas	183.3	118.0	26.9	0.59
Bandar-Anzali	1775.3	341.6	16.2	0.67
Bandar-Lengeh	143.1	96.5	26.6	0.62
Birjand	169.7	52.3	16.4	0.77
Bushehr	268.2	113.1	24.7	0.66
Chahbahar	110.3	98.4	26.2	0.48
Dezful	416.5	127.7	24.0	0.60
Fassa	299.9	122.7	19.3	0.85
Ghazvin	324.3	87.3	13.9	1.06
Gorgan	595.9	106.4	17.7	0.71
Hamedan	328.7	82.7	10.8	0.92
Iranshahr	111.7	57.4	26.8	0.64
Isfahan	125.0	39.4	16.4	0.65
Kashan	137.1	52.3	19.1	0.85
Kerman	142.6	49.2	15.7	0.80
Kermanshah	464.3	125.6	14.4	0.90
Khorram-Abad	510.6	124.9	16.9	1.13
Khoy	298.2	85.1	11.9	1.19
Mashhad	261.1	74.1	14.3	1.17
Oroomieh	335.2	106.1	11.2	1.03
Ramsar	1208.7	286.8	16.0	0.70
Rasht	1379.4	252.1	16.0	0.83
Sabzevar	199.5	56.6	17.7	0.99
Saghez	503.9	131.8	11.1	1.18
Sanandaj	465.5	126.3	13.4	0.93
Semnan	142.6	54.4	18.1	0.71
Shahrekord	331.9	85.1	11.8	0.85
Shahroud	166.1	56.7	14.7	0.88
Shiraz	333.6	107.0	17.9	0.90
Tabriz	280.3	74.2	12.6	0.99
Tehran	241.5	69.7	17.5	0.92
Torbateheydarieh	281.2	77.2	14.2	0.75
Yazd	61.1	27.0	19.2	0.82
Zabol	60.9	31.1	22.1	0.76
Zahedan	79.6	40.6	18.5	0.73
Zanjan	305.6	74.6	10.9	0.92

2.2. Aridity indices

Aridity is the degree to which a climate lacks effective, life-promoting moisture; the opposite of humidity, in the climate sense of the term (American Meteorological Society, 2006). An aridity index is defined as the numerical indicator of the degree of dryness of the climate at a given location and it classifies the type of climate in relation to water availability. The higher the aridity indices of a region, the greater water resources variability. The increasing aridity represents a higher frequency of dry years over an area (Deniz et al., 2011). In this study, the de Martonne aridity index and the Pinna combinative index were calculated for Iran based on temperature and precipitation data for the period 1966–2005.

The I_{DM}, developed by de Martonne (1925), is calculated by the following equation:

$$I_{DM} = \frac{P}{T + 10} \quad (1)$$

where I_{DM} is the de Martonne aridity index, P is the annual mean precipitation in mm and T is the annual mean air temperature in °C. The climatic classification based on the I_{DM} values is shown in Table 2.