Global and Planetary Change 100 (2013) 11–19

Contents lists available at SciVerse ScienceDirect

Global and Planetary Change

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

Moisture index for Iran: Spatial and temporal analyses

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ARTICLE INFO

Article history:
Received 21 May 2012
Accepted 27 August 2012
Available online 31 August 2012

Keywords:
moisture conditions
Thornthwaite index
precipitation
evapotranspiration
trend tests
Iran

ABSTRACT

Moisture indices, which account the balance between inputs and outputs of water, are typically used to determine the moisture conditions and the magnitude of water deficiency in a given area. This work studies the moisture conditions of Iran using the revised Thornthwaite moisture index, a ratio of evapotranspiration to precipitation, over the period of 1966–2005. Long-term trends in the moisture index were assessed by the Mann–Kendall test, the Sen's slope estimator and the Mann–Kendall rank statistic. According to the moisture index, arid and semiarid environmental conditions where the demand for water exceeds the water supply are dominant over the country. The results conclusively show that the significant trends in the moisture index are infrequent and found only at 8 out of the 41 study stations. The significant downward trends of the moisture index at Gorgan, Kermanshah, Khorram-Abad, Khoy, Sanandaj, Tabriz and Zanjan stations located in the north, northwest and west regions of Iran began in 1995, 1996, 1996, 1989, 1997, 1988 and 1986, respectively. Contrary to that, the significant upward trend at Dezful station started in 1973.

1. Introduction

In recent years, there has been a considerable concern about the possibility of climatic changes. Alteration in our climate is governed by a complex system of atmospheric and oceanic processes and their interactions (Rai et al., 2010). It was demonstrated that global surface warming has been taking place at the rate of 0.74 ± 0.18 °C over the period of 1906–2005. Projections by different Atmosphere–Ocean General Circulation Models (AOGCMs) and simpler climate models show that global warming by the end of the 21st century (2090–2099) relative to 1980–1999 can be up to 6.4 °C depending on the emission scenario (IPCC, 2007).

With global warming, a change in moisture conditions is predicted in some model scenarios which estimated that drought would persist in some areas (Wang, 2005; Paltineanu et al., 2007; Seager et al., 2007; Gao and Giorgi, 2008). It is projected that these areas will suffer from increased dryness, heat, water shortages, and reduced production (Schwartz and Randall, 2003). The moisture conditions are a balance between inputs of water (precipitation) and losses of water (evapotranspiration) on land surfaces. The moisture conditions are a limiting factor affecting plant growth and distribution under certain temperature (Zheng, 2000).

Owing to the changes of global temperature and precipitation over the earth's land surface, there is a likelihood of changes in the moisture conditions brought about by an intensification of the atmospheric hydrological cycle. Changes of the moisture conditions would influence ecological and agricultural water management, water resource utilization and desertification adaptation. However, so far there are not so many studies focused on the moisture condition changes as those on temperature and precipitation. This is one main deficiency in the current climate change research (Wu et al., 2006).

Typically, moisture indices are used to determine the moisture conditions and the magnitude of water deficiency in a given area. It can be derived from commonly available data like annual mean temperature and annual total precipitation, and thus is suitable for long-term studies (Grundstein, 2009). Basic understanding of moisture indices in arid and semiarid regions is essential for proper land management of these lands, in which it is characterized by a severe lack of available water. This has unfavorable effect on their quality and production (Abdulla, 2008).

There is a long history of evaluating the moisture conditions through the ratio of precipitation over temperature or evapotranspiration (De Martonne, 1926; Thornthwaite, 1948; UNESCO, 1979; UNEP, 1992). Using evapotranspiration parameter instead of temperature gives a more realistic estimate of water deficit and would be more representative of climatic variability conditions (Tsakiris and Vangelis, 2004; Khalili et al., 2011). The Thornthwaite moisture index (Thornthwaite and Mather, 1955) is an indicator of the supply of water in an area relative to the demand under prevailing climatic conditions (McCabe and Wolock, 1992). In the index, precipitation is compared with potential evapotranspiration which is a measure of water requirements to determine periods and quantities of water surplus and water deficit. The water deficiency represents the amount by which the precipitation fails to meet the demands of

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http://dx.doi.org/10.1016/j.gloplacha.2012.08.010

potential evapotranspiration (Rakhecha and Dhar, 1975). The index can be applied for climate classification, hydrological characterization for water management, environmental studies, and agricultural planning to define land use and agricultural practices (Dourado-Neto et al., 2010).

In several studies of climate change and water resources, the Thornthwaite moisture index has been used. Abdulla (2008) investigated the magnitude of water deficiency in the arid land in Iraq using the moisture deficit index (MDI). The results in general showed that the moisture index values were negative at Sulaimaniya and Mousl stations ranging from −56 to −73. Moisture deficit index ranges from −80 to −94 in Baghdad and Bassra stations. Grundstein (2009) used a modified form of the Thornthwaite moisture index to quantify climate variability over the continental United States. The results showed that the eastern half of the country has been getting wetter, even as temperatures have continued to increase in many areas.

The climate of Iran is generally becoming warmer and drier and shows remarkable variability and change (Soltani et al., 2011; Tabari and Hosseinzadeh Talaee, 2011b, 2011c; Shifteh Some'e et al., 2012). In this article we present a study of the moisture conditions in Iran for a period of 40 years (1966–2005). First, the Thornthwaite moisture index was calculated using meteorological data from 41 synoptic stations. Then, the trends in moisture index were analyzed by the Mann–Kendall test, the Sen's slope estimator and the Mann–Kendall rank statistic after eliminating the serial correlation effects from the data.

2. Study area and data description

Iran, with an area of more than 1,648,000 km^2, is located in the southwest of Asia (approximately between 25°00′ N and 38°39′ N latitudes and between 44°00′ E and 63°25′ E longitudes). From the latitude point of view, the southern region of Iran is located in a tropical region and northern region is located in a subtropical region (Soltani et al., 2011).

Iran is surrounded by two mountain ranges, namely Alborz to the north and Zagros to the west, and the highest point of the country is located within the Alborz mountain range with an elevation of 5628 m above the mean sea level. These mountains avoid Mediterranean moisture-bearing systems from crossing through this region towards the east. The Zagros mountain range is responsible for the major portion of rain-producing air masses that enter the region from the western and northwestern sides, with relatively high amounts of rainfall (Sadeghi et al., 2002). The climate of the country is mainly arid or semi-arid, except the northern coastal areas and parts of western Iran. The arid and semi arid regions have an extremely continental climate with warm and dry summer and very cold winter especially in the central regions (Raziei et al., 2005).

For this study, meteorological datasets composing of 40 years of data (1966–2005) covering the whole Iranian region was collected from the Islamic Republic of Iran Meteorological Organization (IRIMO) (www.weather.ir). The stations of with at least 30-year records were chosen. The details and locations of the selected stations are given in Table 1 and Fig. 1. The quality of the data was checked by using the double-mass curve analysis (Kohler, 1949). The missing data were also substituted by the average between the data of the previous and the following year. When this standard was not possible to obtain, the recorded values in neighboring stations with high correlation (r greater than 0.8 at the 95% confidence level) were used to complete the climatic variable records. Moreover, the solar radiation gaps were filled using the Angstrom equation (Allen et al., 1998).

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \tag{1}$$

where R_s is the solar radiation (MJ m^{-2} day^{-1}), R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1}), n is the actual duration of sunshine (h), N is the maximum possible duration of sunshine or daylight hours (h), a_s is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0) and $a_s + b_s$ is the fraction of extraterrestrial radiation reaching the earth on clear days (n = N). Where sunshine data are lacking, the Hargreaves' radiation formula (Hargreaves and Samani, 1985) was used to estimate solar radiation.

$$R_S = k_{R_S}\sqrt{(T_{max} - T_{min})}R_a \tag{2}$$

where R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1}), T_{max} the maximum air temperature (°C), T_{min} the minimum air temperature (°C) and k_{R_S} is an adjustment factor equal to 0.16 for interior locations, where land mass dominates and air masses are not strongly influenced by a large water body, and 0.19 for coastal locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body. The calculation of R_a followed the procedure outlined in Allen et al., (1998).

Table 1
Geographic characteristics of the stations used in the study.

Station	Latitude (N)	Longitude (E)	Elevation (m a.s.l.)
1. Khoy	38° 33′	44° 58′	1103
2. Tabriz	38° 05′	46° 17′	1361
3. Oroomieh	37° 32′	45° 05′	1316
4. Bandar-Anzali	37° 28′	49° 28′	−26.2
5. Rasht	37° 15′	49° 36′	−7
6. Ramsar	36° 54′	50° 40′	−20
7. Gorgan	36° 51′	54° 16′	13
8. Babolsar	36° 43′	52° 39′	−21
9. Zanjan	36° 41′	48° 29′	1663
10. Shahroud	36° 25′	54° 57′	1345
11. Mashhad	36° 16′	59° 38′	999
12. Saghez	36° 15′	46° 16′	1523
13. Ghazvin	36° 15′	50° 03′	1279
14. Sabzevar	36° 12′	57° 43′	978
15. Tehran	35° 41′	51° 19′	1191
16. Semnan	35° 35′	53° 33′	1131
17. Sanandaj	35° 20′	47° 00′	1373
18. Torbateheydarieh	35° 16′	59° 13′	1451
19. Hamedan	35° 12′	48° 43′	1680
20. Kermanshah	34° 21′	47° 09′	1319
21. Arak	34° 06′	49° 46′	1708
22. Kashan	33° 59′	51° 27′	982
23. Khorram-Abad	33° 26′	48° 17′	1148
24. Birjand	32° 52′	59° 12′	1491
25. Isfahan	32° 37′	51° 40′	1550
26. Dezful	32° 24′	48° 23′	143
27. Shahrekord	32° 17′	50° 51′	2049
28. Yazd	31° 54′	54° 17′	1237
29. Ahwaz	31° 20′	48° 40′	23
30. Abadan	31° 11′	52° 40′	2030
31. Zabol	31° 02′	61° 29′	489
32. Kerman	30° 15′	56° 58′	1754
33. Shiraz	29° 32′	52° 36′	1484
34. Zahedan	29° 28′	60° 53′	1370
35. Bam	29° 06′	58° 21′	1067
36. Bushehr	28° 59′	50° 50′	20
37. Fassa	28° 58′	53° 41′	1288
38. Bandar-Abbas	27° 13′	56° 22′	10
39. Iranshahr	27° 12′	60° 42′	591
40. Bandar-Lengeh	26° 32′	54° 50′	23
41. Chahbahar	25° 17′	60° 37′	8

3. Methodology

3.1. Determination of moisture index

The moisture index devised in Thornthwaite and Mather (1955) and modified by Willmott and Feddema (1992) was used in this study. It is a dimensionless index that is bounded from −1 to 1.