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Non-parametric trend analysis of the aridity index for three large arid and semi-arid basins in Iran

Hossien Ahani · Mehrzad Kherad ·
Mohammad Reza Kousari · Lieke van Roosmalen ·
Ramin Aryanfar · Seyyed Mashaallah Hosseini

Abstract Currently, an important scientific challenge that researchers are facing is to gain a better understanding of climate change at the regional scale, which can be especially challenging in an area with low and highly variable precipitation amounts such as Iran. Trend analysis of the medium-term change using ground station observations of meteorological variables can enhance our knowledge of the dominant processes in an area and contribute to the analysis of future climate projections. Generally, studies focus on the long-term variability of temperature and precipitation and to a lesser extent on other important parameters such as moisture indices. In this study the recent 50-year trends (1955–2005) of precipitation (P), potential evapotranspiration (PET), and aridity index (AI) in monthly time scale were studied over 14 synoptic stations in three large Iran basins using the Mann–Kendall non-parametric test. Additionally, an analysis of the monthly, seasonal and annual trend of each parameter was performed. Results showed no significant trends in the monthly time series. However, PET showed significant, mostly decreasing trends, for the seasonal values, which resulted in a significant negative trend in annual PET at five stations. Significant negative trends in seasonal P values were only found at a number of stations in spring and summer and no station showed significant negative trends in annual P. Due to the varied positive and negative trends in annual P and to a lesser extent PET, almost as many stations with negative as positive trends in annual AI were found, indicating that both drying and wetting trends occurred in Iran. Overall, the northern part of the study area showed an increasing trend in annual AI which meant that the region became wetter, while the south showed decreasing trends in AI.

H. Ahani · M. Kherad · M. R. Kousari (✉)
Management center for Strategic projects,
Cadastral Scientific Documentation Group,
Fars Organization Center of Jahad-Agriculture,
Shiraz, Fars, Iran
e-mail: mohammad_kousari@yahoo.com

L. van Roosmalen
National Centre for Groundwater Research and Training,
Flinders University,
GPO Box 2100, Adelaide, SA 5001, Australia

L. van Roosmalen
School of the Environment, Flinders University,
GPO Box 2100, Adelaide, SA 5001, Australia

R. Aryanfar
Meteorological Research Institute,
Shiraz, Fars, Iran

S. M. Hosseini
Eqlid Agricultural research station,
Eqlid, Fars, Iran

1 Introduction

Since Iran is located in arid to semi-arid regions of the world, water is a scarce resource. Therefore, water resource management is of great national importance, especially during spring and summer (April to September) when agricultural activity is high, but precipitation is low. Not only water scarcity, but also land degradation in Iran basins has become a major issue during the past decades, causing a decrease in soil fertility due to land use change, soil degradation and erosion, overgrazing of rangelands, and groundwater exploitation.

The uncertainty related to future climatic change caused by global warming presents another challenge for adaptive water resource management in the country. Regional climate projections for the Middle East can differ considerably from global climate model (GCM) projections due to different reasons such as: orographic effects, land–water interfaces, and variations in land cover, which are generally not well represented by the larger scale GCMs. For example, regional climate

model (RCM) simulations showed an increase in precipitation over Northeastern Iran in the late 21st century (Evans 2010). In contrast, an ensemble of GCMs simulated a decrease in precipitation (Evans 2009). The difference in the projections was because of the representation of a smaller scale phenomenon, called the Zagros mountain barrier jet (Evans 2008), in the RCM.

Trend analysis of the medium term change using ground station observations of meteorological variables can enhance our knowledge of the dominant processes in an area and contribute to the analysis of future climate projections. Recent studies in Iran focused on the long-term variability of temperature, precipitation, and relative humidity (Kousari et al. 2010; Kousari and Asadi Zarch 2010) and on drought (Bari Abarghouei et al. 2011). Evapotranspiration, as the third important climatic factor controlling the energy and mass exchange between terrestrial ecosystems and the atmosphere, has received less attention than precipitation (P) and temperature (Chen et al. 2006). Evapotranspiration is governed by a variety of parameters such as sunshine, temperature, wind, atmospheric humidity, soil moisture, and surface albedo. Evapotranspiration provides a sensitive tool for monitoring the changes of the energy and moisture that is transferred from the ground to the atmosphere (Chen et al. 2006). A number of equations to calculate evapotranspiration existed. In this study the potential evapotranspiration (PET) rates are estimated using the Penman–Monteith equation (Monteith 1965). The Penman–Monteith method has been the most reliable equation for estimating PET under various climatic conditions (Jensen et al. 1990). It reflects the changes of all meteorological factors affecting evaporation and plant transpiration. One of the main advantages of the PET concept is that it provides a standardized value, enabling a comparison between evaporative environments under different climatic settings. The Food and Agriculture Organization of the United Nations (FAO) performed a number of comparative PET studies during past decades (Allen et al. 1998; Doorenbos and Kassam 1986; Doorenbos and Pruitt 1977; Smith 1992) and the Penman–Monteith PET was calculated using global climate and land cover datasets in an assessment of agricultural land by Fischer et al. (2000).

Another important parameter in studying the climate in a region is the aridity index (AI) which is derived by dividing precipitation by PET. A classification system to characterize humid and arid areas using the annual AI was developed by UNESCO (1979). The UNESCO (1979) classification used the Penman formula to calculate PET. The drawback is the data required for this calculation method was not easily obtainable in most regions of the world. Therefore, another classification method was introduced by UNEP (1992), based on a simplified approach for calculating PET proposed by Thornthwaite (1948) (Tsakiris and Vangelis 2005). The UNEP index was also used by the FAO and subsequently became widely known as the AI (Tsakiris and Vangelis 2005).

Due to increasing challenges in water resources management caused by drought, soil degradation, and climate change, it is of interest to determine the trend in P, PET and the AI for the arid and semi-arid regions in Iran. Moreover, considering the fact that Iran has generally arid and semi-arid climate, the present precipitation in regard to high evapotranspiration is not sufficient to support producing reasonable crop yields in most parts. Therefore, any likely increase in aridity as a result of current or future climatic change can impose damaging consequences in agricultural productions and economy of the country. In this study the statistical Mann–Kendall (MK) test (Sneyers 1990) was used to determine whether a trend exists in monthly, seasonal, and annual P, PET, and AI data for 14 synoptic weather stations with observational time series of 50 years.

2 Study area

Iran, with a total surface area of 1,648,000 km^2, is located in the southwest of the Middle East and can be divided in to six large basins: the Caspian Sea, Persian Gulf, Oroomieh, Central, Hamoon, and Sarakhs basins (Fig. 1). Iran is surrounded by two mountain ranges, namely Alborz which is located in the northern part and Zagros in the western part. Alborz and Zagros mountains avoid Mediterranean moisture bearing systems passing to the central and eastern part of the country, respectively. The Zagros mountain range is responsible for keeping the major portion of rain-producing air masses that enter the west and northwest which produce high amounts of rainfall (Sadeghi et al. 2002).

In this study, we focused on the trend in P, PET, and AI in three of the six basins, namely Central, Hamoon and Serakhs Basins. These basins cover more than 55 % of Iran's surface area and contain about half of the country's population. A number of major cities such as Tehran, Shiraz, Esfahan, Yazd, Mashhad, Kerman, and Zahedan are located in these regions. Water resources management is critical in these basins because the average annual P in most parts of the area is less than 150 mm and generally, the spatial and temporal distribution of P is very erratic. Fourteen synoptic weather stations are shown in Fig. 1. Some general characteristics of these stations and the climate zone status in aspect to aridity are shown in Table 1 (Kousari and Ahani 2011).

3 Materials and methods

3.1 Evapotranspiration and aridity index computation

The input data were derived from the Iranian Meteorological data website (http://www.weather.ir). These data were used to compute PET by Penman–Monteith equation for all the

Fig. 1 Map showing the six basins in Iran, the study area, and the location of the 14 synoptic stations used in this study

14 synoptic stations. Continuous total monthly P, the mean of monthly minimum and maximum temperature, the total monthly sunlight hours, the mean of monthly relative humidity and wind speed are available for at least 50 years in all the stations.

PET is estimated using the FAO Penman–Monteith equation (Allen et al. 1998):

$$\mathrm{ET}_0 = \frac{0.408\Delta(R_\mathrm{n} - G) + \gamma[900/(T+273)]\, U_2(e_\mathrm{s} - e_\mathrm{a})}{\Delta + \gamma(1 + 0.34\, U_2)}$$

where ET_0 is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (ms^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), $e_\mathrm{s} - e_\mathrm{a}$ denotes the saturation vapour pressure deficit (kPa), Δ is the slope vapour pressure curve (kPa °C^{-1}), and γ is the psychrometric constant (kPa °C^{-1}).

Monthly PET values were computed for each synoptic station and subsequently, seasonal and annual PET values

were derived from the monthly values. The monthly AI values were calculated using total monthly P and total monthly Penman–Monteith PET and seasonal and annual values were computed using the monthly values.

3.2 Mann–Kendall non-parametric test

The non-parametric rank-based MK statistics (Sneyers 1990) was used to detect trends in monthly, seasonal, and annual P, PET, and AI. As stated in Zhai and Feng (2008), this test has a number of advantages: (1) the data do not need to conform to a particular distribution, thus extreme values are acceptable (Hirsch et al. 1993), (2) missing values are allowed (Yu et al. 1993), (3) relative magnitudes (ranking) are used instead of the numerical values, which allows for 'trace' or 'below detection limit' data to be included, as they are assigned a value less than the smallest measured value, and (4) in time series analysis, it is not necessary to specify whether the trend is linear or not (Sneyers 1990; Yu et al. 1993; Silva 2004). The Z parameter is the output of the MK statistics. A positive value of Z indicates an upward trend and a negative value a

Table 1 General characteristics of the 14 synoptic stations surveyed. The altitude in meters above mean sea level (m asl), latitude and longitude, and the mean annual precipitation, potential evapotranspiration (PET), aridity index (AI) and climate zone status in aspect to aridity (http://www.weather.ir)

Station name	Altitude (m asl)	Coordinates		Mean annual precipitation (mm)	Mean annual PET (mm)	Mean annual AI (–)	Climatic zone
Arak	1708	49.77 E	34.10 N	342	1218	0.29	Semi-arid
Bam	1066	58.35 E	29.10 N	61	2089	0.03	Hyper-arid
Birjand	1491	59.20 E	32.87 N	171	1667	0.10	Arid
Esfahan	1550	51.67 E	32.62 N	123	1462	0.09	Arid
Ghazvin	1279	50.05 E	36.25 N	316	1290	0.25	Semi-arid
Kerman	1753	56.97 E	30.25 N	153	1788	0.09	Arid
Mashhad	999	59.63 E	36.27 N	255	1272	0.21	Semi-arid
Sabzevar	977	57.72 E	36.20 N	189	1756	0.11	Arid
Shahrud	1345	54.95 E	36.42 N	154	1316	0.12	Arid
Shiraz	1484	52.60 E	29.53 N	346	1648	0.21	Semi-arid
Tehran	1190	51.32 E	35.68 N	233	1595	0.15	Arid
Torbat	1450	59.22 E	35.27 N	275	1354	0.20	Semi-arid
Yazd	1237	54.28 E	31.90 N	61	1784	0.04	Arid
Zahedan	1370	60.88 E	29.47 N	91	1907	0.05	Arid

downward trend. In the present study, the significance of the trend is determined using a two-sided test at a significance level of 0.05. Note that a negative Z (downward trend) in the AI signifies drying of the area.

3.3 Time series serial correlation and pre-whitening

The presence of serial correlation in the time series, i.e., a relationship between values separated from each other by a given time lag, results in the null hypothesis of no trend of the MK statistics being rejected too frequently. Especially positive serial correlation has this effect, and therefore von Storch and Navarra (1995) suggested to 'pre-whiten' the time series before the MK statistics is applied. Pre-whitening a time series $(x_1, x_2, …, x_n)$ consists of computing the lag-1 serial correlation coefficient, r_1, which was done in MATLAB in this study and then generating the 'pre-whitened' time series as follows: $(x_2−r_1x_1, x_3−r_1x_2, …, x_n−r_1x_{n−1})$. However, in this study pre-whitening of the time series was only applied when the Durbin–Watson test (Durbin and Watson 1950, 1971) showed significant serial correlation in the surveyed time series at the 5 % level. The Durbin–Watson test is based on a statistic which uses the residuals (prediction errors) from a regression analysis to detect the presence of autocorrelation in the residuals. The null-hypothesis of the test is that the data are not autocorrelated against the alternative that there is a temporal relationship between values. Therefore, rejecting the null hypothesis means that the data must be pre-whitened before the application of the MK statistics. The Durbin–Watson test was applied to the monthly, seasonal, and annual time series and if the autocorrelation was not significant at the 5 % level, then the original time series was used in MK statistics.

3.4 Sen's slope estimator

According to Ahani et al. (2012), if a time series presents a linear trend, the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). Sen's slope estimator the same as MK statistics is a well-known statistical test (Ahani et al. 2012; Dinpashoh et al. 2011; Tabari et al. 2011). The total change during the observed period was obtained by multiplying the slope by the number of years (Tabari and Hosseinzadeh Talaee 2011). In this study, Sen's slope estimator was applied on all AI time series.

4 Results and discussion

Figures 2 and 3 show the samples of P, PET and AI annual time series in some surveyed stations including: Arak, Bam, Ghazvin, Shahrud, Shiraz and Zahedan stations. All climatic zones (semiarid, arid and hyper arid) in the aspect of aridity can be covered by these stations. Moreover, the fitted lines (first order) on each time series are shown in these figures. The decreasing trend of P and increasing trend of PET resulted in a negative trend of AI, particularly in Arak station. However, decreasing trend of PET and increasing trend of P can lead to increasing trend of AI time series. These statuses occurred in Shiraz, Birjand and Shahroud Stations. In most cases, the AI trends showed the same trends as P, indicating that AI trend was mainly determined by the precipitation trend and to a lesser extent by PET.

As explained, the Durbin–Watson test was used to determine autocorrelation in the time series. The results of the serial correlation test were not presented in this article. The
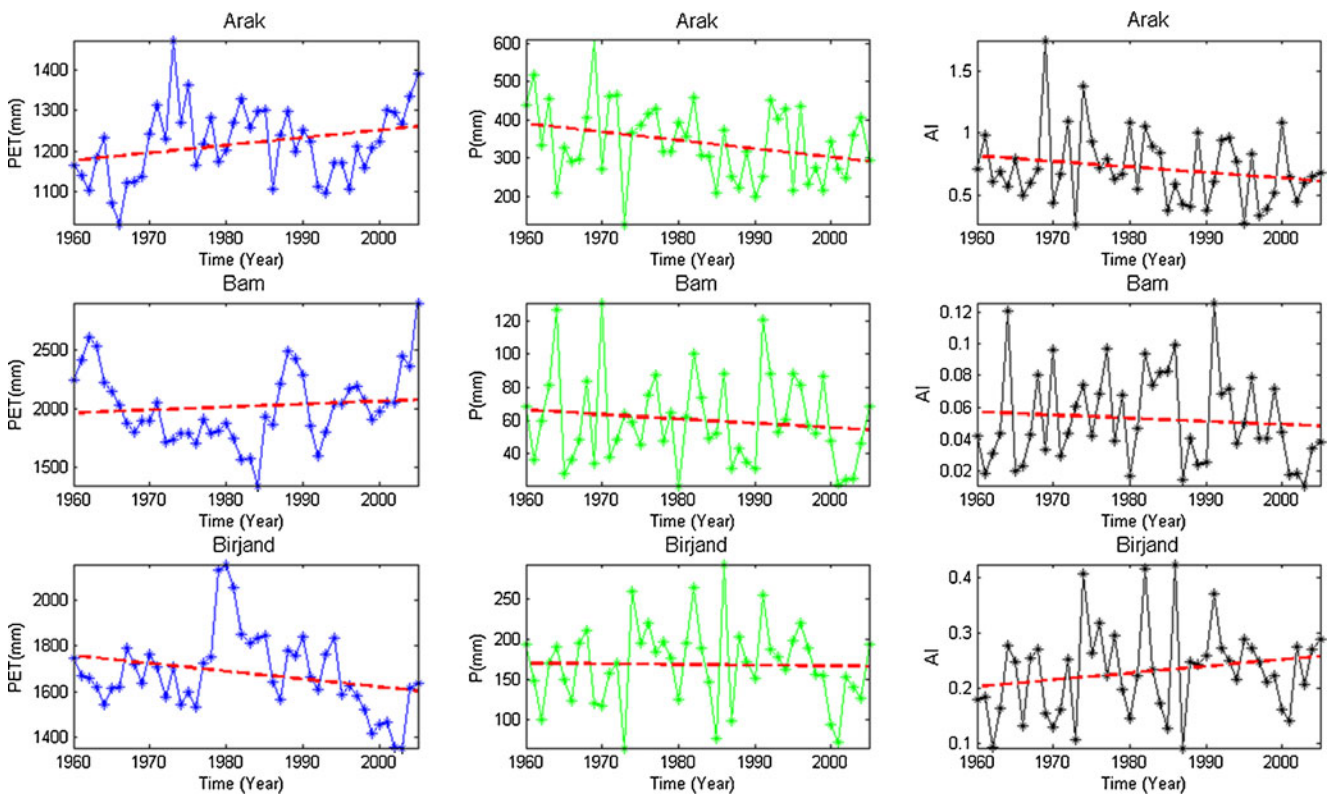
Fig. 2 Potential evapotranspiration (PET), precipitation (P) and aridity index (AI) annual time series in Arak, Bam and Birjand Stations
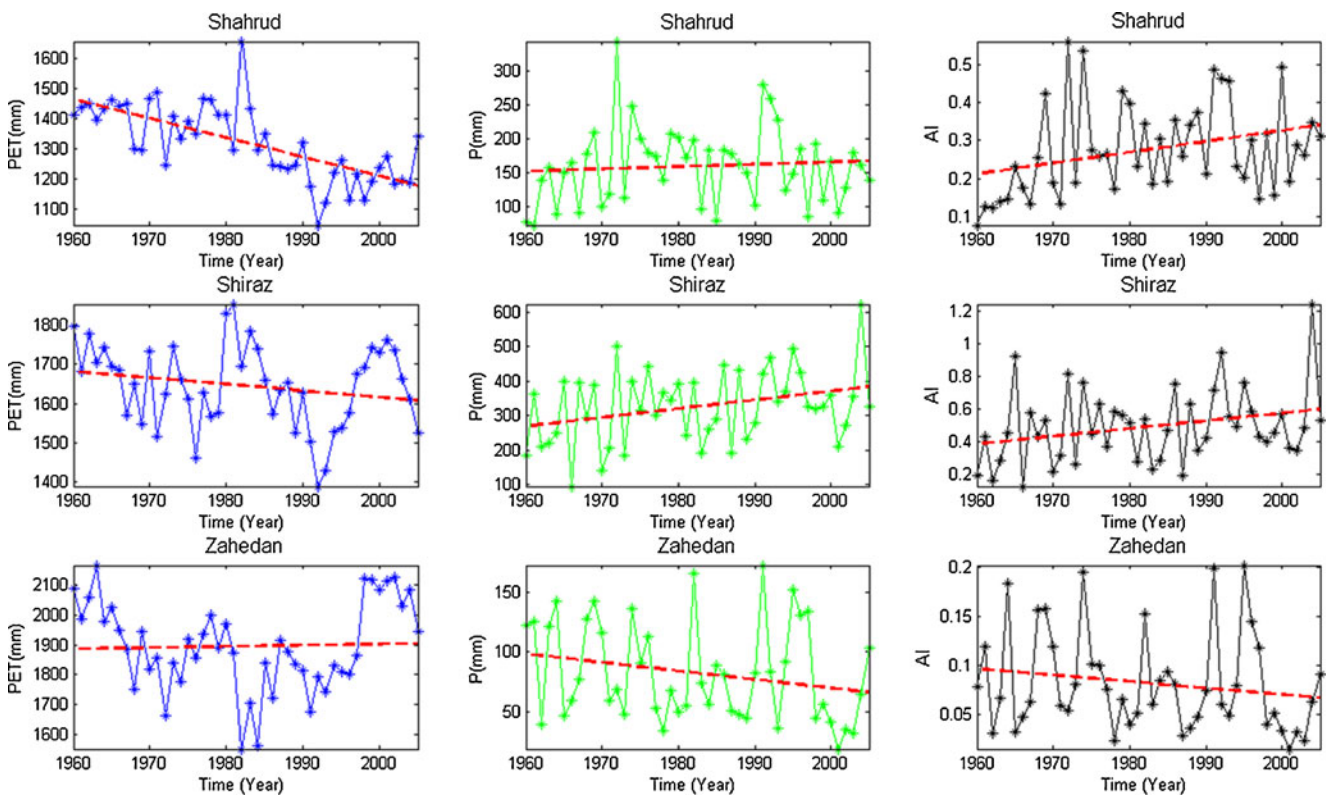
Fig. 3 PET, P and AI annual time series in Shahrud, Shiraz and Zahedan Stations

PET time series showed autocorrelation for most of the surveyed time series (monthly, seasonal, annual), while significant trends for precipitation and the AI autocorrelation was rarely found. These results are in accordance with the results of Tabari et al. (2011) in which positive serial correlations were found for temperature (annual maximum, minimum, and mean air temperatures) but not for precipitation.

Tables 2 and 3 show the results of the MK statistics (Z parameter in the MK statistics) in all synoptic stations for monthly P and PET, respectively. In these tables, the asterisk (*) indicates a significant trend at the 0.05 significance level.

Monthly Z factors of P showed that significant trends occurred just in nine cases. Half of them were seen in April and 25 precent in March. Most of the months had upward trends; while, during April there was no upward trend. In May the frequency of downwards were more and in September both trends were equal. By considering the stations we realized that Yazd had two significant months which was the most significant number. Most of the stations had more frequency of increasing trends than decreasing ones; however, Zahaden was in contrast and Arak and Bam had equal numbers.

The significant downward PET trends were detected in most of the months in some stations such as Esfahan, Ghazvin, Kerman, and Shahrud (Table 3). However, these stations are distributed throughout the study area (Fig. 1), and it is not possible to relate this decrease to a specific region. Mashhad, Torbat Heydariieh, Shiraz, Bam, and Arak stations showed a significant positive trend for a few different months. Furthermore, significant increases in PET for some months were accompanied with decreasing (though

not always statistically significant) trends in other months for the same station. Thus, the decreasing trend in PET at some of the stations was more consistent than the positive trend in PET at the other stations.

The results of the MK statistics on the seasonal and annual PET and P data for all synoptic stations are shown in Table 4. The seasons are as follows: winter (January–March), spring (April–June), summer (July–September), and autumn (October–December). For the seasonal values, PET showed significant, mostly decreasing trends, which result in a significant negative trend in annual PET at five stations. Only a few seasonal P values are significant and they have generally negative trends during spring and summer; meanwhile, for annual values only one station showed significant negative trends.

The results of the MK statistics on the monthly AI (Table 5) showed both increasing and decreasing trends with no consistent signal for specific months or stations with few statistically significant trends. Similar results were found for monthly precipitation trends, athough April did show decreasing trends in precipitation for all stations (Table 2) which resulted in negative trends in AI for most stations during this month (Table 5).

The monthly AI Sen's outcomes are presented in Table 6. It indicated that Shiraz with (+) 1.95 changes per decade had the highest upward trend in January. In December, the highest frequency of high increasing trends were seen. The trends in January had one negative and two positive values. In February, there was only one high negative trend. The values in the rest of the months were low.

Table 7 gives us the information of annual and seasonal MK and Sen's results. In regard to Sen's slope results,

Table 2 Z factor derived by application of the MK statistics monthly P data for all synoptic stations

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Arak	−1.74	−1.89	0.91	−0.95	−0.11	0.74	1.09	1.55	−0.26	0.99	0.05	−0.73
Bam	0.30	−0.47	−0.55	−2.11*	−0.20	0.39	0.96	0.88	−0.23	1.10	−0.60	−0.95
Birjand	0.13	0.33	1.51	−3.04*	0.14	1.08	0.88	−0.78	1.19	−0.84	0.11	1.22
Esfahan	1.55	−0.10	2.32*	−0.79	−0.06	1.66	1.14	0.69	−0.07	0.63	0.41	1.29
Ghazvin	−1.26	0.43	1.82	−0.09	0.20	−1.59	1.64	−0.33	−0.34	0.73	1.16	1.21
Kerman	−0.09	−0.95	−0.10	−1.81	−2.26*	0.56	0.98	0.78	0.69	1.71	0.70	1.17
Mashhad	1.69	0.62	0.49	−1.58	−0.03	0.91	0.78	0.70	0.52	−0.60	0.56	0.96
Sabzevar	1.48	0.59	1.51	−1.03	−0.11	1.05	0.54	1.29	0.71	0.29	0.59	0.76
Shahrud	0.27	0.24	1.11	−0.49	−0.87	1.37	0.59	0.72	0.38	−0.48	0.52	1.57
Shiraz	1.41	0.50	1.51	−1.87	0.01	1.80	−0.33	0.86	1.10	0.59	0.19	1.50
Tehran	1.11	0.16	2.05*	−0.11	0.79	−0.51	1.31	0.56	−0.49	0.67	0.55	1.50
Torbat	0.09	0.32	1.14	−2.17*	0.21	1.15	1.22	2.49*	0.34	0.49	1.06	0.58
Yazd	2.08*	−1.52	0.28	−2.37*	0.00	1.22	1.44	−0.27	−1.58	0.00	1.27	1.65
Zahedan	−0.66	−1.43	−0.89	−1.70	−0.82	0.39	1.01	0.42	−0.88	0.44	−0.70	−0.32

Z values of more than 1.96 represent upward significant trend, while values less than −1.96 show decreasing trend at $\alpha < 0.05$

*Significant trend at the 0.05 level

Table 3 Z factor derived by application of the MK statistics monthly PET data for all synoptic stations

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Arak	−0.19	0.00	−0.64	0.89	1.25	3.06*	2.96*	1.65	1.16	0.17	0.23	−1.27
Bam	−0.32	0.54	−0.87	3.22*	0.83	0.77	0.34	1.01	0.19	0.48	−0.19	−1.77
Birjand	−2.50*	−0.42	−2.6*3	−0.91	−0.87	−1.40	−0.60	−0.87	−2.18*	−3.30*	−1.44	−2.51*
Esfahan	−0.68	−0.23	−3.57*	−0.93	−2.65*	−4.65*	−4.79*	−4.58*	−3.56*	−3.26*	−2.63*	−3.11*
Ghazvin	−1.91	−1.19	−2.22*	−2.10*	−3.64*	−5.26*	−5.68*	−4.49*	−5.02*	−3.53*	−3.29*	−2.92*
Kerman	−0.83	−0.36	−1.95	−1.26	−0.89	−3.18*	−3.39*	−3.36*	−3.14*	−2.20*	−2.08*	−2.96*
Mashhad	1.57	1.31	0.89	3.51*	1.22	1.59	2.53*	1.36	1.73	1.52	1.93	1.42
Sabzevar	−0.42	−0.42	−1.76	−0.93	−1.09	−1.87	−2.47*	−1.57	−1.05	−1.73	−2.85*	−2.18*
Shahrud	−5.09*	−3.05*	−3.79*	−3.07*	−3.75*	−2.58*	−2.06*	−3.73*	−5.23*	−5.86*	−6.23*	−6.76*
Shiraz	0.21	−0.09	−0.66	2.10*	0.77	−1.85	−1.77	−2.06*	−3.22*	−3.24*	−1.91	−1.50
Tehran	0.93	0.38	−0.81	1.08	−0.59	−1.57	0.28	−0.01	−2.02*	−1.08	−1.44	−0.98
Torbat	−0.57	−0.38	−1.69	0.91	−0.03	0.45	2.65*	2.26*	1.14	−0.15	−0.91	−2.42*
Yazd	−0.72	−0.11	−2.02*	−0.50	−1.71	−2.18*	−1.65	−1.71	−0.17	0.13	0.69	−0.40
Zahedan	1.65	1.00	−0.99	0.42	0.36	−0.09	0.19	−0.58	−0.58	−0.62	1.20	1.50

Z values of more than 1.96 represent upward significant trend, while values less than −1.96 show decreasing trend at $\alpha < 0.05$

*Significant trend at the 0.05 level

autumn contained the highest value; whereas, in winter the most frequent high values including increasing and decreasing were observed. There was not any high value in annual time scale. According to Table 7, significant positive trends in annual AI were occurred in three of the 14 stations.

Figures 4 and 5 show point maps of the annual and seasonal Z parameters of the MK statistics for AI in the 14 synoptic stations. These figures show the spatial distribution of AI trends and facilitate the identification of regions within the study area that show statistically significant trends. Generally, the northern part of the study area showed an increasing trend in annual AI which meant that the region became wetter, while the south showed decreasing trends in AI. In spring, decreasing trends in AI were found in most stations which were four in the south. Summer and autumn generally showed an increase in AI with significant increases occurring in the north. The spatial distribution of trends in winter was similar to the annual trend except Yazd and Shiraz stations where fewer significant trends occur.

Table 4 Results of the MK statistics on seasonal and annual PET and precipitation for all synoptic stations

Station name	PET					Precipitation				
	winter	spring	summer	autumn	annual	winter	spring	summer	autumn	annual
Arak	−0.25	2.24*	1.97*	−0.28	1.63	−1.48	−1.24	0.95	−0.23	−1.95
Bam	−0.32	1.48	0.62	−0.21	0.67	−0.66	−1.68	1.09	−0.49	−0.61
Birjand	−2.56*	−1.57	−1.18	−2.51*	−2.01*	0.96	−3.24*	0.49	1.17	−0.23
Esfahan	−2.22*	−3.24*	−5.47*	−4.17*	−5.23*	2.37*	−0.47	1.22	1.44	1.99*
Ghazvin	−2.12*	−5.25*	−5.16*	−3.94*	−4.90*	0.81	−0.49	0.64	1.57	1.03
Kerman	−1.56	−2.36*	−3.00*	−2.63*	−2.67*	−1.35	−2.02*	0.45	1.62	−1.27
Mashhad	1.77	1.95	1.75	1.73	1.85	1.88	−0.85	1.83	0.37	0.96
Sabzevar	−1.65	−1.71	−1.65	−2.20*	−1.52	2.20*	−0.88	1.16	0.90	1.55
Shahrud	−4.11*	−3.58*	−4.12*	−6.92*	−5.49*	0.81	−0.44	0.74	0.38	0.66
Shiraz	−0.47	0.46	−2.49*	−3.43*	−1.46	1.89	−1.90	0.16	1.69	1.78
Tehran	−0.19	−0.34	−0.28	−1.51	−0.78	1.35	0.19	1.01	1.57	1.69
Torbat	−1.19	0.64	2.10*	−1.05	1.56	0.93	−1.26	2.73*	1.23	0.80
Yazd	−1.75	−1.69	−1.56	0.42	−1.36	1.26	−1.92	0.55	1.89	0.53
Zahedan	0.64	−0.38	−0.26	0.75	−0.03	−2.75*	−1.59	0.35	−0.11	−1.76

*Significant trend at the 0.05 level

Table 5 *Z* factor derived by application of the MK statistics monthly AI data for all synoptic stations

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Arak	−0.85	−1.69	0.74	−1.01	−0.37	0.65	0.99	1.49	−0.29	0.96	−0.11	−0.28
Bam	0.41	−0.45	−0.32	−2.24*	−0.34	0.41	0.96	0.84	−0.25	1.12	−0.46	−0.72
Birjand	0.53	0.32	1.74	−3.06*	0.28	1.05	0.88	−0.78	1.20	−0.74	0.38	1.55
Esfahan	1.61	0.18	2.46*	−0.63	0.00	1.69	1.17	0.71	−0.07	0.64	0.64	1.46
Ghazvin	0.27	0.70	1.93	0.23	0.66	−1.36	1.74	−0.18	−0.20	1.15	1.46	1.55
Kerman	0.00	−0.62	0.04	−1.64	−2.03*	0.60	1.00	0.77	0.71	1.65	0.84	1.42
Mashhad	0.78	0.19	0.11	−1.63	−0.11	0.82	0.73	0.50	0.50	−0.78	0.36	0.19
Sabzevar	1.59	0.93	1.61	−0.70	0.00	1.02	0.57	1.24	0.74	0.46	1.13	1.27
Shahrud	1.16	0.71	1.69	−0.23	−0.49	1.47	0.65	0.81	0.53	−0.03	0.92	2.76*
Shiraz	1.50	0.57	1.64	−1.85	−0.01	1.80	−0.36	0.88	1.08	0.64	0.26	1.50
Tehran	0.61	0.06	1.69	−0.34	0.79	−0.45	1.31	0.58	−0.52	0.76	0.63	1.36
Torbat	0.19	0.11	1.31	−1.97*	0.19	1.09	1.22	2.48*	0.36	0.54	1.07	1.06
Yazd	1.94	−1.40	0.50	−2.22*	0.13	1.20	1.44	−0.27	−1.58	0.08	1.18	1.62
Zahedan	−0.87	−1.38	−0.98	−1.56	−0.92	0.58	1.01	0.42	−0.88	0.49	−0.69	−0.39

Z values of more than 1.96 represent upward significant trend, while values less than −1.96 show decreasing trend at $\alpha < 0.05$

*Significant trend at the 0.05 level

5 Discussion

Prior to the trend analysis, as Kousari and Asadi Zarch (2010) concluded an increasing trend in temperature in arid and semi-arid regions of Iran, an increasing trend in PET was expected. However, the PET shows declining trends at many stations. Roderick and Farquhar (2002) concluded that as the average global temperature increases, it was generally expected that the air will become drier and that evaporation from terrestrial water bodies would increase. Paradoxically, terrestrial observations throughout the Northern Hemisphere over the past 50 years generally showed the reverse trend (Roderick and Farquhar 2002). Roderick and Farquhar (2002) showed that

the decrease in evaporation was consistent with what one would expect from the observed large and widespread decrease in sunlight hours resulting from an increase in cloud coverage and aerosol concentration.

Peterson et al. (1995) reported that pan evaporation declined (on average) in the United States, the former Soviet Union and some parts of Asia from the 1950s to the early 1990s. Roderick and Farquhar (2005) referred to several subsequent studies that have confirmed these trends regionally, though at individual sites, both increases and decreases in pan evaporation occurred. Chen et al. (2006) found that for the Tibetan Plateau as a whole, PET had decreased in all seasons and the mean annual evapotranspiration decreased by 13.1 mm

Table 6 Results of Sen's slope estimator (changes per decades) on monthly AI for all synoptic

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Arak	−1.17	−1.38	0.45	−0.48	−0.06	0.00	0.00	0.00	0.00	0.05	−0.07	0.35
Bam	0.02	−0.03	−0.02	−0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Birjand	0.31	0.20	0.55	−0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75
Esfahan	0.91	0.03	0.46	−0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.71
Ghazvin	0.54	0.68	0.78	0.07	0.11	−0.01	0.00	0.00	0.00	0.14	0.80	2.05
Kerman	−0.03	−0.21	0.01	−0.13	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Mashhad	0.79	0.08	0.06	−0.52	−0.02	0.00	0.00	0.00	0.00	−0.04	0.09	0.30
Sabzevar	1.35	0.41	0.53	−0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.88
Shahrud	0.76	0.26	0.46	−0.03	−0.05	0.02	0.00	0.00	0.00	0.00	0.13	1.56
Shiraz	1.95	0.32	0.69	−0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75
Tehran	0.64	0.04	0.50	−0.05	0.04	0.00	0.00	0.00	0.00	0.03	0.25	1.12
Torbat	0.19	0.18	0.89	−0.57	0.02	0.00	0.00	0.00	0.00	0.00	0.23	1.58
Yazd	0.30	−0.17	0.04	−0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
Zahedan	−0.22	−0.25	−0.07	−0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7 Results of the Sen's slope estimator (changes per decades) and MK statistics on seasonal and annual AI for all synoptic stations

Station name	MK statistics					Sen's slope estimator				
	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
Arak	−1.51	−1.20	0.68	0.04	−1.25	−1.20	−0.27	0.00	0.02	−0.36
Bam	−0.53	−2.03*	1.01	−0.35	−0.49	−0.04	−0.04	0.00	0.00	−0.01
Birjand	1.08	−2.73*	0.47	1.51	1.33	0.34	−0.20	0.00	0.30	0.12
Esfahan	2.16*	−0.47	1.38	1.86	2.23*	0.54	−0.02	0.00	0.41	0.21
Ghazvin	0.97	0.11	1.17	2.44*	2.25*	0.51	0.02	0.01	1.31	0.58
Kerman	−0.91	−1.69	0.69	1.62	0.53	−0.22	−0.08	0.00	0.19	0.03
Mashhad	0.81	−1.34	1.71	0.04	0.05	0.46	−0.20	0.00	0.03	0.06
Sabzevar	1.87	−0.89	1.20	1.31	1.34	1.08	−0.06	0.00	0.40	0.33
Shahrud	1.50	0.00	0.89	2.31*	2.82*	0.47	−0.01	0.01	0.57	0.34
Shiraz	1.46	−1.84	0.17	1.65	1.63	1.08	−0.11	0.00	0.83	0.40
Tehran	0.53	−0.09	1.09	1.55	1.06	0.28	−0.01	0.00	0.56	0.18
Torbat	0.57	−1.59	2.61*	1.48	1.12	0.72	−0.21	0.00	0.63	0.28
Yazd	1.17	−1.76	0.47	2.01*	1.51	0.11	−0.04	0.00	0.14	0.06
Zahedan	−2.39*	−1.51	0.33	−0.42	−1.50	−0.37	−0.02	0.00	−0.02	−0.07

*Significant trend at the 0.05 level

per decade (2.0 % of the annual total) for the period 1961–2000. In this study, the decreasing trend in PET was seen in Iran which confirms the findings of other studies.

In addition, the study of Dinpashoh et al. (2011) and Kousari and Ahani (2011) showed that both statistically significant increasing and decreasing trends were observed in the annual and monthly ET_0. They indicated the ET_0 increasing trends were more pronounced than the decreasing ones. It should be mentioned that the number of surveyed stations and data length period were different from our
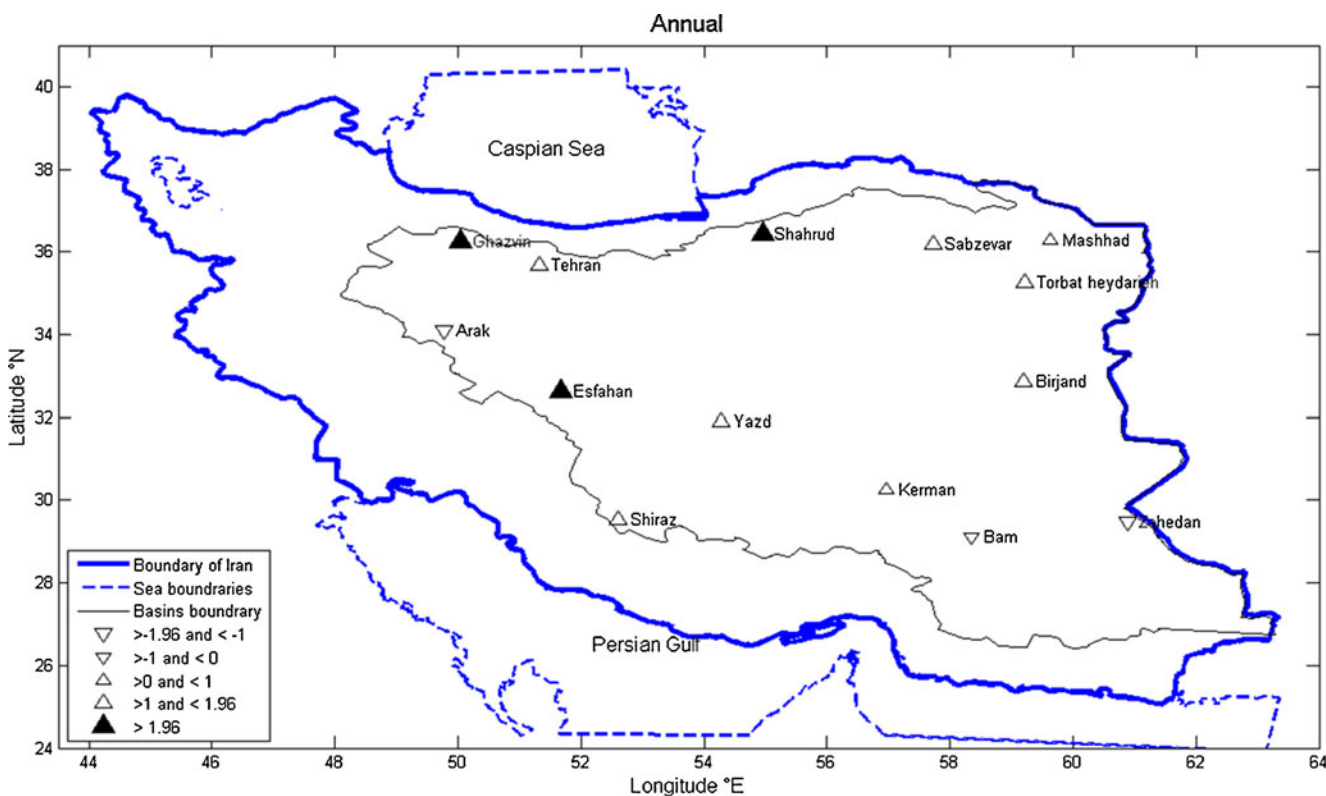
Fig. 4 A point map of the Z parameter of the Mann–Kendall (MK) statistics for the annual aridity index for the 14 synoptic stations
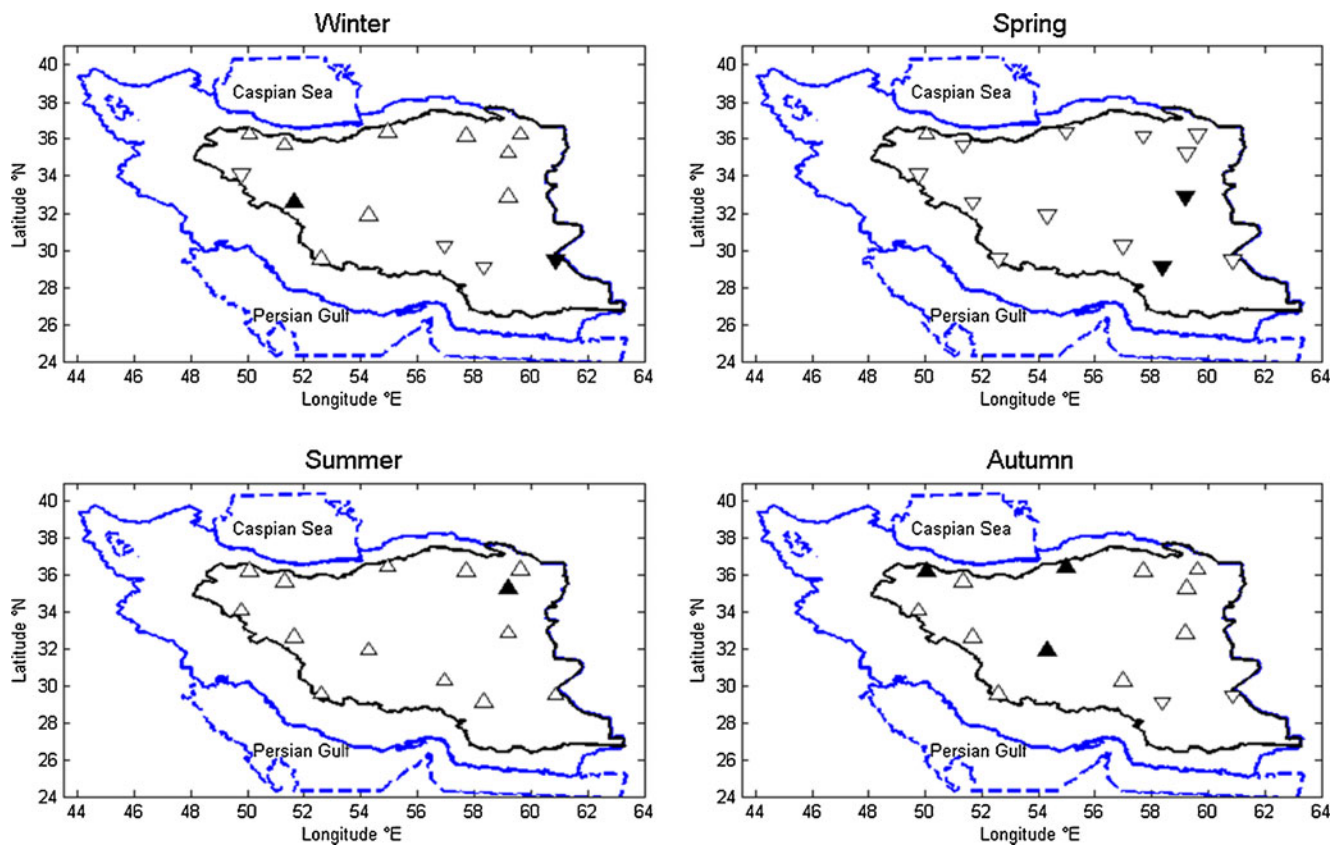
Fig. 5 A point map of the Z parameter of the MK statistics for the aridity index in spring for the 14 synoptic stations

research (e.g., Kousari and Ahani surveyed ET_0 time series during 1975 and 2005). Obviously, the length of time series is a key parameter in trend detection. As a result, although few significant trends (especially for AI) were detected in this study, it is anticipated that considering shorter period (e.g., investigation of P, PET and AI time series during 1970 and 2005 or further time), more significant AI trends will be identified. It was concluded that AI trends was more sensitive to P trends than PET ones.

Sen's slope estimator results showed that the AI changes in cold months were more considerable than warm months. Considering the fact that most precipitation, although erratic, occur in cold months in Iran, it is clear that when the precipitation is low the AI changes are negligible. However, the erratic precipitation causes considerable changes in AI during monthly time scale investigations. Since Sen's slope estimator was applied to AI average values in seasonal and annual time scales, the seasonal and annual slopes were less than monthly time scale Sen's results.

Although most of the trends in this study did not exhibit any significant trend, in some cases both decreasing and increasing trends of AI were found. As Misra et al. (2012) stated, the increasing global mean surface temperature trend is regarded as a strong evidence of global warming due to increasing greenhouse gases. However, regional surface temperature trends

may have different warming rates or even cooling trends relating to land cover/land use changes (Kalnay and Cai 2003; Pielke et al. 2007; Findell et al. 2009; McCarthy et al. 2010) such as urbanization and irrigation (Kueppers et al. 2007; Puma and Cook 2010). In regard to P, PET and AI trends, the regional effects can be anticipated. In other words, both decreasing and increasing trends beside the insignificant ones can be detected in the extent area such as the surveyed wide basins in Iran.

6 Conclusions

In this study, a trend analysis of monthly, seasonal, and annual precipitation, PET, and AI was performed for 50 years of data from 14 synoptic stations in Iran. A trend analysis of the monthly data did not show a consistent decreasing or increasing trend in AI for a specific station or month. However, in some stations the AI in April decreased (indicating a drying trend), which resulted from the decrease in P during this month. The generally decreasing trend in PET indicated a wetting trend. However, at some stations the decreasing trends in PET were accompanied with decreasing trends in precipitation. The northern part of Iran showed generally increasing trends in annual AI while the south trend towards drier conditions.

The decreasing trend in PET requires further analysis to determine which parameters are contributing to the decrease in PET despite the increase in temperature in the region. A sensitivity analysis of the parameters of the Penman–Monteith equation for PET under Iran climate conditions can increase our process understanding of PET in Iran. Subsequently, a trend analysis of the most sensitive parameters of PET can shed some light on the cause of increasing and decreasing trends in PET in the study area.

This study has shown that both P and PET can have a significant impact on whether an area becomes wetter or drier. As feedbacks exist between P and PET, it is not a straightforward matter to determine whether and to what extent a former positive or negative trend will influence the latter or vice versa. Hence, it was clearly beneficial in this study to determine the combined impact using an AI. This investigation of the historical trend in P, PET, and AI can now for example be used in a comparison with future climate change projections for this part of Iran.

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