A survey of temporal and spatial reference crop evapotranspiration trends in Iran from 1960 to 2005

**Mohammad Reza Kousari · Mohammad Amin Asadi Zarch ·
Hossein Ahani · Hemila Hakimelahi**

Abstract Reference crop evapotranspiration (ET_0) is one of the most important climatic parameters which plays a key role in estimating crop water demand and scheduling irrigation. Under global warming and climate change conditions, it is needed to survey the trend of ET_0 in Iran. In this study, ET_0 values were determined based on FAO-56 Penman-Monteith equation over 32 synoptic meteorological stations during 1960–2005; and analyzed spatially and temporally in monthly, seasonal and annual time scales. After removing the significant lag-1 serial correlation effect by pre-whitening, non-parametric statistical Mann–Kendall (MK) test was used to detect the trends. The slope of the changes was determined by Sen's slope estimator. In order to facilitate in trend analysis, the 10 moving average low pass filter were also applied on the normalized annual ET_0 time series. Annual ET_0 time series and filtered ones were then classified by hierarchical clustering in three clusters and then mapped in order to show the patterns of different clusters. Results showed that the significant decreasing trends were more considerable than increasing ones. Among surveyed stations, and on an annual time scale, the highest and lowest annual values of Sen's slope estimator were observed in Tabas with (+) 72.14 mm per decade and Shahrud with (−) 62.22 mm per decade, respectively. Results also indicated that the clustered map based on normalized and filtered annual ET_0 time series is in accordance with another map which showed spatial distribution of increasing, decreasing and non-significant trends of ET_0 on annually time scale. Exploratory and visual analysis of smoothed time series showed increasing trend in recent years especially after 1980 and 1995. In brief, the upward trend of ET_0 in recent years is a crucial issue with regard to the high cost of dam construction for agricultural aims in arid and semi-arid regions e.g. Iran.

M. R. Kousari (✉) · H. Ahani · H. Hakimelahi
Management Center for Strategic Projects, Fars Organization Center of Jahad Agriculture, Shiraz, Iran
e-mail: mohammad_kousari@yahoo.com

M. R. Kousari
Faculty of Natural Resource Management, Yazd University, Yazd, Iran

M. A. Asadi Zarch
School of Civil and Environmental Engineering, University of New South Wales, Sydney, Australia

1 Introduction

Besides the temperature and precipitation which play important role in climatic conditions, evapotranspiration as the third top climatic factor that controls the energy and mass exchange between terrestrial ecosystems and the atmosphere (Chen et al. 2006) should not be underestimated. Global land ET returns about 60 % of annual land precipitation to the atmosphere (Oki and Kanae 2006). Iran receives about 413 billion cubic meters precipitation annually, while more than 72 % is lost by evapotranspiration (Kousari and Ahani 2012). It is obvious that any change in evapotranspiration will affect the basins, natural resources, agricultural productions and as a result water resource programming.

Due to complex interactions amongst the components of the land–plant–atmosphere system, evapotranspiration is perhaps the most difficult among all the components of the hydrologic cycle (Xu and Singh 2005). While the continuous estimation of ET from meteorological data is virtually non-existent, the use of reference crop evapotranspiration (ET_0) to estimate the ET of crops is regularly practiced (Spano et al. 2009). Potential evapotranspiration, rather than actual evapotranspiration, is a common input for hydrologic models, because it offers an upper limit to evapotranspirative water losses (Douglas et al. 2009).

According to Yin et al. (2008) being an important component of the hydrological cycle, ET_0 will affect agricultural water use (Allen 2000; Hunsaker et al. 2002), ecosystem models (Fisher et al. 2005), aridity/humidity conditions (Wu et al. 2006), and rainfall-runoff estimation. There are several equations to calculate reference evapotranspiration. As stated by Alexandris et al. (2006) a review of literature (Amatya et al. 1995) clearly indicates that the evapotranspiration estimating Penman–Monteith (PM) method, having a strong theoretical basis, is superior to all other commonly used methods when the required data are available and reliable.

In order to importance of this factor, numerous studies have considered the trend analysis of ET_0 during past decades. Chen et al. (2006) surveyed the trend in time series (1961–2000) of Penman-Monteith potential evapotranspiration on the Tibetan Plateau and surrounding areas. For the Tibetan Plateau potential evapotranspiration has decreased in all seasons. Espadafor et al. (2011) surveyed ET_0 trends in South of Spain during 1960–2005. Results showed a positive trend in the last 45 years. Beside the ET_0, In regard to pan evaporation (evaporation from a standard water-filled dish and is the most widely used physical measure of the evaporative demand of the atmosphere (Lim et al. 2012)), Peterson et al. (1995) reported that pan evaporation had declined on average in the United States, former Soviet Union and parts of Asia from the 1950s to early 1990s. Several subsequent studies have largely confirmed these trends (McVicar et al. 2012). At individual sites, both increases and decreases in pan evaporation were commonly found (e.g. Chattopadhyay and Hulme 1997; Roderick and Farquhar 2004).

In Iran, Dinpashoh et al. (2011) examined the trends of ET_0 in monthly and annual time scales over the 16 weather stations located in the different regions of Iran. Both increasing and decreasing trends were statistically significant. The increasing trends were more severe than the decreasing trends. Kousari and Ahani (2012) investigated the trend of ET_0 computed by Penman-Monteith equation over 42 synoptic stations during last three decades (1975–2005). Although both downward and upward trends were observed, increasing trends had more frequency. Ahani et al. (2012) showed potential evapotranspiration had significant, mostly decreasing trends in the recent 50-year (1955–2005) at three large Iran's basins using the Mann–Kendall (MK) non-parametric test.

Under conditions of global warming, 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 (Ahani et al. 2012). Therefore, in this study, the ET_0 trend was analyzed from 1960 to 2005 over 32 synoptic meteorological stations, spatially and temporally by non-parametric MK test. ET_0 values were calculated based on FAO-56 Penman–Monteith (PM-56) method. Monthly, seasonal and annual maps of ET_0 trends have been presented in this work. Also, Sen's slope estimator was used in order to assess the amount of changes of ET_0 values in different time series. In addition, various types of agglomerative hierarchical clustering were employed in order to "bring together" similar annual ET_0 time series. Both initial and also normalized and filtered ET_0 were used as input for clustering. Finally in order to show the distributions of different clusters, the locations of stations were mapped. Integration among MK test, Sen's slope estimator, application of moving average low pass filter and clustering of ET_0 values have been followed in this study for more detailed investigation in regard to ET_0 trends in Iran.

2 Materials and methods

2.1 Study area

Iran, with about 1648000 square kilometers area, is located in Asia, approximately between 25°00′N and 38°39′N latitudes and between 44°00′E and 63°25′E longitudes. Generally, Iran is categorized as having arid (BW) and semi-arid (BS) climates based on the Koppen climatic classification (Ahrens 1998). The mean annual precipitation of Iran is about 224 mm. The two main mountain chains in Iran are Alborz and Zagros. Alborz Mountains extends from the north to the west and east Iran, while, Zagros Mountains extends from the northwest to the southern part of Iran (Dinpashoh et al. 2011). Mountainous basins and plains are the 53 and 47 % of total area of Iran, respectively (Asadi Zarch et al. 2011).

Figure 1 shows Iran's location and its boundaries in addition to the distribution of 32 synoptic stations used in this study. These stations have a good distribution with suitable period of weather data (46 years), which can support Evapotranspiration trend studies spatially and temporally. Table 1 indicates the general characteristic of 32 surveyed stations such as elevation, latitude, longitude and the average of ET_0.

2.2 Data collection and ET_0 computation

The climatic data were gathered from 32 synoptic stations of Iran Meteorological Organization (http://www.weather.ir) that included the average of minimum and maximum temperature, sunshine, the mean of relative humidity and wind. These 32 synoptic stations were selected because of having adequate data (1960–2005) to calculate PM-56 ET0. The quality of the data was checked prior to the analysis by plotting the time series and then inspecting visually for possible errors (Dinpashoh et al. 2011). This process was applied to all meteorological variables used in the study. The missing data was substituted with the corresponding long-term mean. ET_0 was estimated using the PM-56 equation (Allen et al. 1998). ET0 values were computed at the monthly time scale for each synoptic station and subsequently, seasonal and annual ET0 values were derived from the monthly values. Thermic seasons considered as winter that contains January, February and March; spring: April, May and June; summer: July, August and September; and autumn: October, November and December.
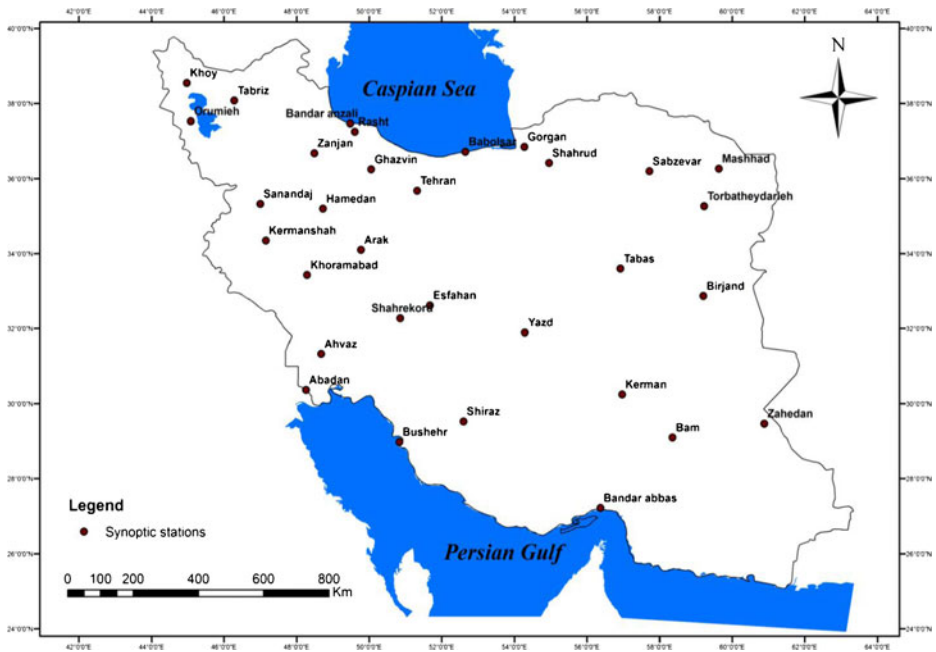
Fig. 1 The spatial distribution of 32 selected synoptic stations at Iran

2.3 Data processing

2.3.1 Trend analysis

The non-parametric rank-based MK test (Mann 1945; Kendall 1975) was considered to detect trends of ET_0 values in different time scales. According to Zhai and Feng (2008), it has a number of advantages such as (i) the data do not need to conform to a particular distribution, thus extreme values are acceptable (Hirsch et al. 1993), (ii) missing values are allowed (Yu et al. 1993), (iii) relative magnitudes (ranking) are used instead of the numerical values, which allows 'trace' or 'below detection limit' data to be included, as they are assigned a value less than the smallest measured value, and (iv) in time series analysis, it is not necessary to specify whether the trend is linear or not (Sneyers 1990; Yu et al. 1993). According to Dinpashoh et al. (2011), trends in ET_0 were detected using the MK test after the removal of the significant lag-1 serial correlation effect from all the ET_0 time series by pre-whitening.

For assessing the changes amount of ET_0 values using Sen's slope estimator, as stated by Ahani et al. (2012), if a time series presents linear trend, the true slope (change per unit time) can be estimated using a simple nonparametric procedure developed by Sen (1968). Sen's slope estimator the same as MK statistics is a well-known statistical test and more details in regard to these statistical functions can be found in Ahani et al. (2012), Dinpashoh et al. (2011) and Tabari and Hosseinzadeh Talaee (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 ET_0 time series.

Table 1 General characteristic of 32 surveyed synoptic stations

Station name	Longitude °E	Latitude °N	Elevation (m)	Annual ET0 (mm)
Abadan	48.25	30.37	6.6	2217.8
Ahvaz	48.67	31.33	22.5	1989.7
Arak	49.77	34.1	1708	1222
Babolsar	52.65	36.72	−21	886.9
Bam	58.35	29.1	1066.9	2040.3
Bandar abbas	56.37	27.22	98	1865.5
Bandar anzali	49.47	37.47	−26.2	840
Birjand	59.2	32.87	1491	1681.5
Bushehr	50.83	28.98	196	1690.8
Esfahan	51.67	32.62	1550.4	1394.6
Ghazvin	50.05	36.25	1279.2	1222.9
Gorgan	54.27	36.85	133	924.1
Hamedan	48.72	35.2	1679.7	1332.4
Kerman	56.97	30.25	1753	1667.7
Kermanshah	47.15	34.35	1318.6	1394.6
Khoramabad	48.28	33.43	1147.8	1329.9
Khoy	44.97	38.55	1103	948
Mashhad	59.63	36.27	999.2	1271.9
Orumieh	45.08	37.53	1315.9	1040
Rasht	49.6	37.25	−6.9	795.9
Sabzevar	57.72	36.2	977.6	1615
Sanandaj	47	35.33	1373.4	1278.6
Shahrekord	50.85	32.28	2048.9	1132.9
Shahrud	54.95	36.42	1345.3	1274.3
Shiraz	52.6	29.53	1484	1640.5
Tabas	56.92	33.6	711	1638.7
Tabriz	46.28	38.08	1361	1338.5
Tehran	51.32	35.68	1190.8	1577.1
Torbatheydarieh	59.22	35.27	1450.8	1355.8
Yazd	54.28	31.9	1237.2	1742.7
Zahedan	60.88	29.47	1370	1870.2
Zanjan	48.48	36.68	1663	1136

2.3.2 Clustering and mapping clusters

In this study, we used cluster analysis to "bring together" similar annual ET_0 time series in different stations. Various steps were followed to prepare as input to these methods. In fact two types of annual ET_0 time series were applied for clustering. For finding the time of fluctuations as well as facilitating the trend analysis in time series, both initial annual ET_0 data and also normalized and filtered ones have been considered. In fact, for removing the shorter term fluctuations from the time series to observe and detect the presence of longer term variations for trend analysis, besides using initial ET_0 data for clustering, the normalized and filtered time series were applied as input for clustering. The 10-year moving

average low-pass filter (Kiely 1999) was considered for this purpose. More detail about this moving average can be found in Kousari and Asadi Zarch (2010).

The cluster analysis methods are largely based on hierarchical, non-hierarchical and linkage methods (Sahin and Cigizoglu 2012). In this study agglomerative hierarchical clustering was applied. Agglomerative hierarchical clustering begins with all objects in individual clusters and then iteratively merges the two most similar clusters until all objects are in the same cluster (Earle 2010).

There are a range of methods for assessing similarity of objects or groups with cluster analysis, and different approaches will highlight different aspects of a dataset (Mckenna 2003; Johnston 1976). In this study, similarity or dissimilarity between every pair of objects in the data set were surveyed using the four methods specified by distance including Euclidean distance, Standardized Euclidean distance, Correlation (One minus the sample correlation between points), One minus the sample Spearman's rank correlation between observations (MathWorks 2001). Furthermore, determination of the linkages or grouping the objects into a binary, hierarchical cluster tree was done based on Average or Unweighted average distance (UPGMA), Centroid distance (UPGMC), Complete or Furthest distance, Weighted center of mass distance (WPGMC), Single or Shortest distance, Ward or Inner squared distance (minimum variance algorithm) and Weighted average distance (WPGMA) methods (MathWorks 2001).

Different combinations of the mentioned methods both for distance and linkages computation were tested. Since there were 4 distance computation methods and 7 methods were used for determining the linkages, totally 28 combinations were formed and investigated. Considering to Cophenetic correlation coefficient (C) (Farris 1969), suitable combinations were selected and the related dendrograms were presented.

It should be mentioned that determination of an optimal number of clusters is a difficult task (Lin and Wu 2007). Moreover, different choices of clustering methods often lead to different clustering results even though the same data sets are analyzed (Nathan and McMahon 1990). In this study by exploring in dendrograms which were selected based on C, three clusters for annual ET_0 and also normalized and filtered one were presented (maximum numbers of clusters were set to three). Then, in order to show distribution of the different clusters, they were mapped.

3 Results

Table 2 indicates ET_0 results based on the application of MK test (Z parameter) in monthly time series and Table 3 shows the same results in seasonal and annual time scales. * illustrates the including upward trends (Z parameter more than 1.96) and downward trends (Z parameter less than −1.96), $\alpha<0.05$. Both downward and upward trends can be seen in these two tables. In monthly analysis, about 73 % of Z factors show non-significant trends, while 10 and 17 % have increasing and decreasing trends, respectively. On the other hand, in seasonal investigation, 68, 20 and 12 % of Z factors show non-significant, upward and downward trends, respectively. In annual time scale, 72, 12 and 16 % of Z factors indicate non-significant, increasing and decreasing trends, respectively. It can be concluded that the number of significant downward trends are more considerable than significant upward trends.

To show the spatial distribution of ET_0 trends in monthly time scale, the Z values in Table 2 were mapped (Figs. 2 and 3). Generally it can be found out that the frequencies of downward trends are more considerable than upward ones. Clearly, the number of non-significant trends is considerable. This feature is more obvious in January, February, March,

Table 2 Z factor derived by application of the MK test on monthly ET$_0$ data for all synoptic stations. Z values more than 1.96 represent upward significant trends, less than −1.96 show the decreasing trends at α<0.05

Station name	Jan	Feb	Marc	Apr	May	Jun	July	Agu	Sep	Oct	Nov	Dec
Abadan	-2.76*	-0.64	-1.00	1.42	1.17	1.82	2.29*	1.42	1.59	-0.34	-0.19	-2.35*
Ahvaz	-0.27	1.68	-0.28	1.14	0.69	1.32	2.50*	2.36*	0.09	-0.58	0.45	-1.34
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
Babolsar	2.79*	1.57	1.55	2.82*	0.89	1.48	1.55	2.61*	2.44*	2.18*	1.77	1.75
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
Bandar abbas	-2.79*	-1.21	-2.89*	0.00	-0.64	-0.56	-0.25	-1.00	-2.73*	-2.59*	-1.46	-2.32*
Bandar anzali	0.70	0.70	1.17	1.25	-0.72	-0.76	0.74	1.07	0.76	1.48	0.83	-0.91
Birjand	-2.50*	-0.42	-2.63*	-0.91	-0.87	-1.40	-0.60	-0.87	-2.18*	-3.30*	-1.44	-2.51*
Bushehr	-1.74	-1.31	-2.16*	0.59	2.34*	1.84	-0.07	-0.62	-0.69	-0.59	-1.27	-3.03*
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*
Gorgan	0.26	-0.89	-0.28	0.49	-1.09	-0.34	-0.60	-0.87	-1.28	0.15	-0.21	-0.54
Hamedan	-0.30	-0.25	-0.04	1.18	0.34	1.61	1.22	1.69	1.32	-0.17	-1.12	-0.51
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*
Kermanshah	1.19	1.53	0.01	2.63*	1.81	0.38	-0.81	-0.71	-1.48	-0.50	0.77	0.09
Khoramabad	-1.09	-0.21	-2.12*	-1.20	0.03	1.93	2.87*	1.85	0.73	0.00	-2.02*	-1.73
Khoy	0.21	1.59	1.07	1.95	0.28	0.26	-0.48	-0.71	-0.93	0.30	-0.70	-1.44
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
Orumieh	1.67	2.96*	1.14	3.07*	0.69	0.54	0.54	0.01	0.34	0.69	0.68	-0.73
Rasht	-0.02	0.13	1.29	0.59	-0.42	0.59	0.32	1.00	-0.57	0.32	-1.36	-0.98
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*
Sanandaj	0.74	1.36	0.89	1.57	0.57	0.67	1.01	0.01	-1.42	-1.05	-1.53	0.04
Shahrekord	1.46	1.14	-0.19	1.48	1.40	3.53*	3.04*	2.14*	1.67	0.38	1.42	1.00
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

Table 2 (continued)

Station name	Jan	Feb	Marc	Apr	May	Jun	July	Agu	Sep	Oct	Nov	Dec
Tabas	0.01	0.13	0.64	3.30*	4.32*	3.57*	3.81*	3.22*	2.83*	1.07	1.15	0.15
Tabriz	0.78	2.91*	1.36	3.11*	0.47	−1.03	−2.40*	−3.06*	−2.01*	1.28	0.68	−1.18
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
Torbatheydarieh	−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
Zanjan	2.47*	1.29	0.59	3.22*	0.87	3.57*	4.66*	4.96*	5.33*	4.90*	2.79*	1.53

Significant trends (95 %) indicated by asterisks

Table 3 Z factor derived by application of the MK test on seasonal and annual ET_0 data for all synoptic stations. Z values more than 1.96 represent upward significant trends, less than −1.96 show the decreasing trends at $\alpha<0.05$

| Station name	Winter	Spring	Summer	Autumn	Annual
Abadan	−2.03*	1.69	2.31*	−1.14	1.46
Ahvaz	−0.05	1.40	1.67	−0.09	1.32
Arak	−0.25	2.24*	1.97*	−0.28	1.63
Babolsar	1.75	2.10*	2.89*	2.02*	2.40*
Bam	−0.32	1.48	0.62	−0.21	0.67
Bandar abbas	−2.71*	−0.79	−1.75	−2.08*	−1.81
Bandar anzali	1.00	−0.66	0.58	0.71	0.11
Birjand	−2.56*	−1.57	−1.18	−2.51*	−2.01*
Bushehr	−2.27*	2.65*	−0.85	−3.00*	−1.11
Esfahan	−2.22*	−3.24*	−5.47*	−4.17*	−5.23*
Ghazvin	−2.12*	−5.25*	−5.16*	−3.94*	−4.90*
Gorgan	−0.44	−0.73	−0.52	−0.52	−0.32
Hamedan	−0.59	1.05	1.56	−0.32	1.42
Kerman	−1.56	−2.36*	−3.00*	−2.63*	−2.67*
Kermanshah	1.18	1.89	−0.99	0.00	0.22
Khoramabad	−1.63	0.01	1.38	−1.26	0.00
Khoy	1.54	0.85	−0.73	−0.81	−0.13
Mashhad	1.77	1.95	1.75	1.73	1.85
Orumieh	1.87	1.46	0.22	0.56	0.91
Rasht	0.45	−0.11	0.91	−0.98	0.02
Sabzevar	−1.65	−1.71	−1.65	−2.20*	−1.52
Sanandaj	1.19	1.07	−0.01	−1.44	0.21
Shahrekord	0.45	2.47*	2.75*	1.31	2.73*
Shahrud	−4.11*	−3.58*	−4.12*	−6.92*	−5.49*
Shiraz	−0.47	0.46	−2.49*	−3.43*	−1.46
Tabas	0.15	3.90*	3.38*	0.73	3.40*
Tabriz	1.46	0.52	−3.06*	0.24	−1.03
Tehran	−0.19	−0.34	−0.28	−1.51	−0.78
Torbatheydarieh	−1.19	0.64	2.10*	−1.05	1.56
Yazd	−1.75	−1.69	−1.56	0.42	−1.36
Zahedan	0.64	−0.38	−0.26	0.75	−0.03
Zanjan	1.09	2.85*	5.39*	4.24*	4.74*

Significant trends (95 %) indicated by asterisks

May, and October while, both significant downward and upward trends in other months are notable. Spatial distribution of the ET_0 trends on a monthly time scale does not show specific trend and concentration in any parts of the country. But it can be said that to some extent, northern parts of Iran show more significant trend in the most cases than other regions and central parts.

Figures 4 and 5 exhibit the spatial distribution of Z values in Table 3 in seasonal and annual time scales, respectively. As it can be seen in Table 3, in winter and autumn the downward significant trends are more than upward ones while summer and nearby spring show more considerable upward trends. In annual time scale and according to Fig. 5, clear
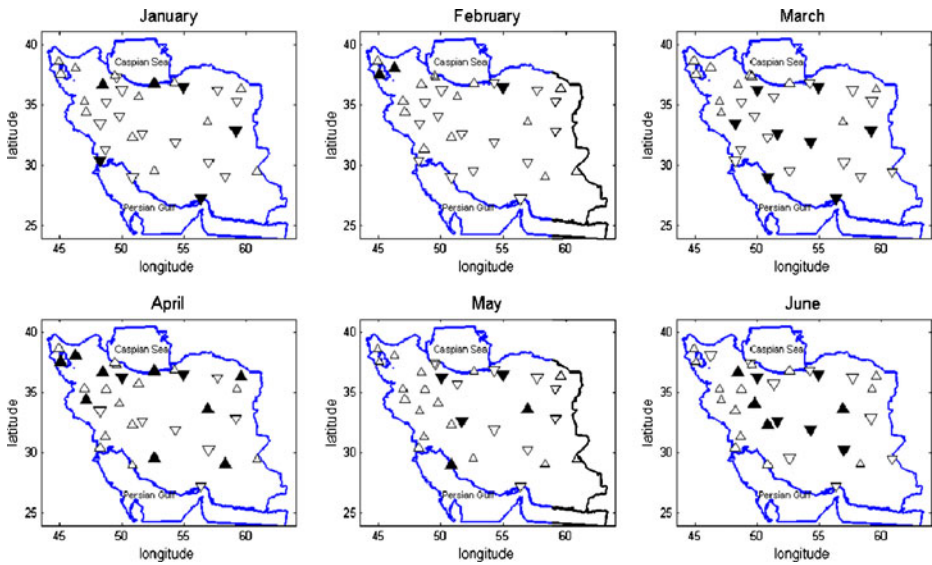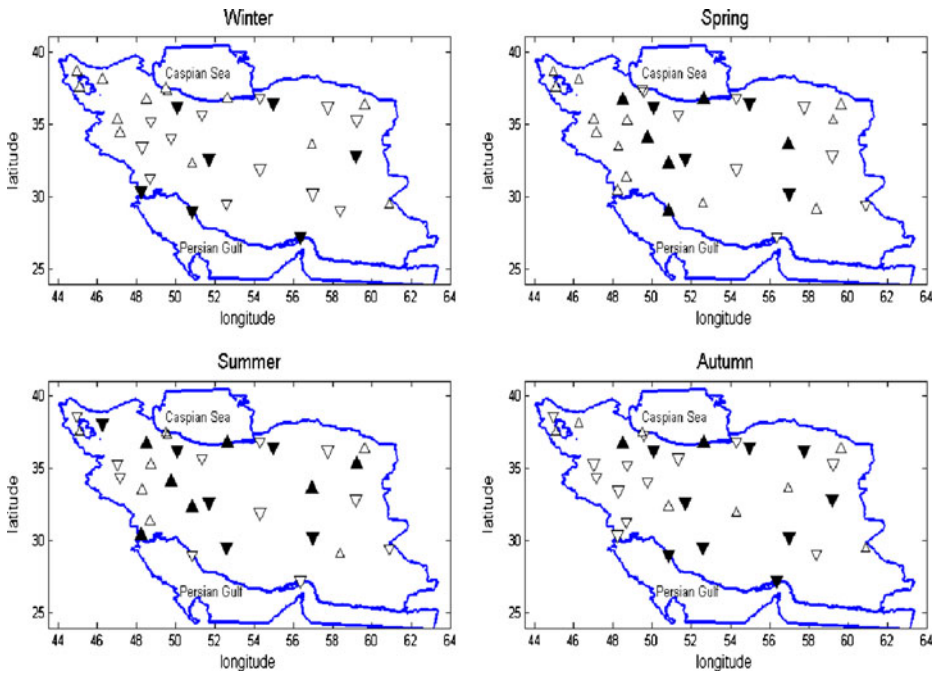
Fig. 2 Spatial distribution of increasing, decreasing and non-significant trends in monthly ET_0 in January to June. Solid up pointing triangles show positive (*increasing*) significant trend at 95 %. Solid down pointing triangles show (*negative*) decreasing significant trend at 95 %. *Open triangles* represent non-significant trends

decreasing trends of ET_0 can be found in most parts of the country except western and southestern parts. In addition, significant trends (both downward and upward types) spatially distributed in the northern and especially central parts of Iran.
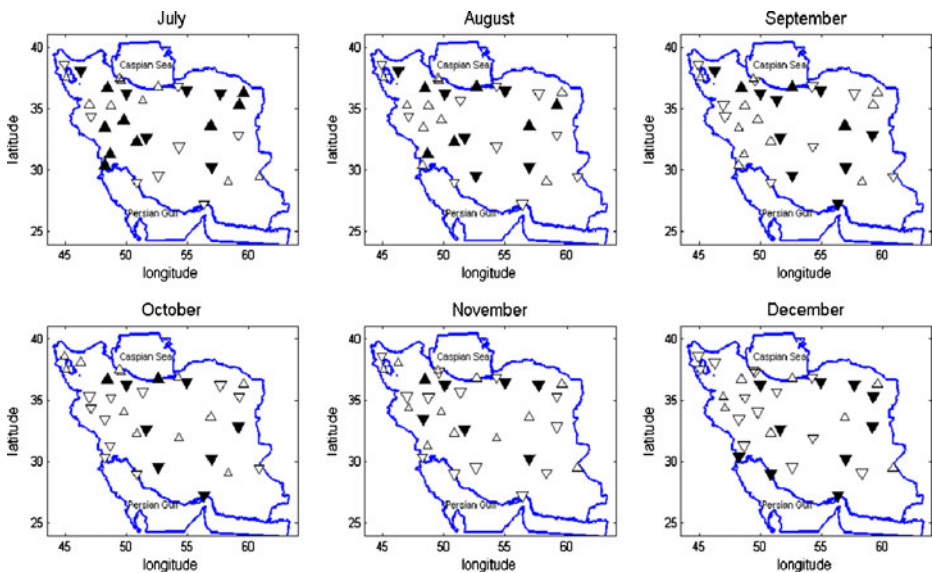
Fig. 3 Spatial distribution of increasing, decreasing and non-significant trends in monthly ET_0 in July to December

Fig. 4 Spatial distribution of increasing, decreasing and non-significant trends in winter, spring, summer and autumn seasons
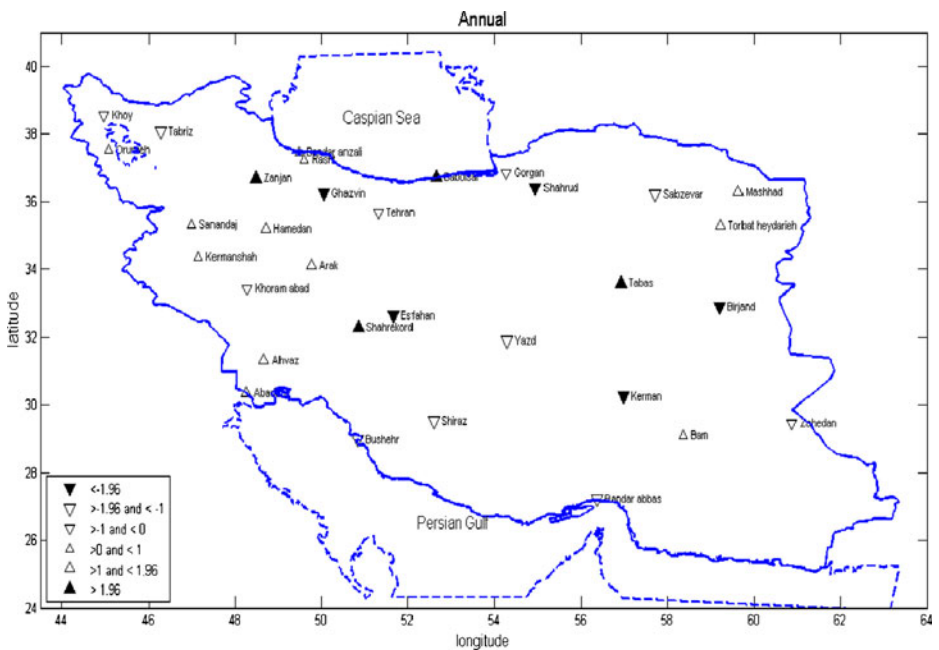
Fig. 5 Spatial distribution of increasing, decreasing and non-significant trends in ET_0 in annually time scale

Spatial distribution of annual ET_0 in Fig. 5 shows the concentration of significant trends (in most cases downward trends) in the central, northern and southern parts of the country. In fact, frequent non-significant but downward trends can be seen in the southern parts.

According to Table 4, Tabas Station with (+) 18.85 mm per decade had the highest upward trend of the monthly Sen's values during July, while the least downward one was observed in Sabzevar station with (−) 10.92 mm per decade during July. The annual and seasonal time scale Sen's slope results are shown in Table 5. On one hand, the most and the least annual values were observed in Tabas with (+) 72.14 mm per decade and Shahrud with (−) 62.22 mm per decade, respectively. On the other hand, Tabas with (+) 38.66 mm per decade had the highest seasonal results during summer and Ghazvin with (−) 21.13 mm per decade had the lowest values during spring.

Figure 6 shows four dendrograms in regard to Euclidean distance, Squared Euclidean distance, Correlation, Spearman methods for annual ET_0 time series. In these combinations, the Average is most appropriate method as linkage except Correlation procedure that has fitted in Centroid linkage method. In the title of each dendrogram, C also has been shown. The magnitude of this value should be very close to 1 for a high-quality solution. As it can be seen, for annual ET_0 and based on Cophenetic correlation coefficient, Spearman and Average methods are the best combination (C equals to 0.778). While, by exploring and visual investigation on the dendrograms, Euclidean distance and Squared Euclidean distance with Average method as linkage show more distinguished clusters than others. Although these combinations showed very similar dendrograms, since the Squared Euclidean distance and Average method have more Cophenetic correlation coefficient (C equals to 0.715) than Euclidean distance one (C equals .0712), that was selected as optimum combination for clustering.

Figure 7 indicates three clusters of annual ET_0 time series derived based on Squared Euclidean distance and Average method. As it can be seen, most time series are located in the first and third clusters. Fluctuations in all time series are obvious and some of them show considerable difference in range during the surveyed time. The locations of these clusters have been shown in Fig. 8. This figure indicates that most stations are in third cluster distributed in the north, north west and north eastern parts of Iran. The central parts of the country and also southern regions have been covered by the first cluster which has more average ET_0 (around 1,800 mm) than third cluster with average around 1,200 mm. Just three stations named Bam (in central parts), Abadan and Ahvaz located in the south east of the country are in the second cluster.

Figure 9 indicates four dendrograms in regard to Euclidean distance, Squared Euclidean distance, Correlation, Spearman methods for normalized and filtered annual ET_0 time series. In contrast by the results for raw annual ET_0 time series presented in Fig. 6, for the Euclidean and Squared Euclidean distances, the Centroid method linkage is introduced as appropriate method. While, for Correlation and Spearman methods the Average is introduced as linkage method. Based on the C and also investigation of the dendrograms, the combination of Spearman and Average methods was selected for the most accurate clustering than other surveyed combinations (C equals to 0.777).

Figure 10 indicates three clusters of normalized and filtered annual ET_0 time series derived based on Spearman and Average method. This figure shows the first and second clusters contain most stations. In contrast to Fig. 7, due to application of low pass filter on ET_0 time series, these clusters do not show considerable fluctuations. In fact this type of data lets us to facilitate trend analysis and investigate more long term changes during time series. The results are more clear when this figure will be analyzed with Fig. 11 which indicates the distribution of the three clusters through the country. First of all, this map differs from the one produced by clustering based on initial annual ET_0 data. This figure shows that most stations saw decreasing trends until 1982, then increasing trends began toward 2000 which according to Fig. 10, have been classified in cluster 1. Based on Fig. 11, mentioned time

Table 4 Sen's slope estimator results in monthly time scale (mm per decade)

Station name	Jan	Feb	Marc	Apr	May	Jun	July	Agu	Sep	Oct	Nov	Dec
Abadan	−2.47	−0.68	−2.15	3.24	5.12	6.63	10.56	7.39	5.03	−0.82	−0.14	−2.90
Ahvaz	−0.26	1.72	0.29	3.62	5.18	9.43	12.96	11.65	1.84	−1.77	0.93	−1.68
Arak	−0.16	0.02	−1.01	1.80	2.27	4.89	5.46	3.64	2.32	0.85	0.20	−0.86
Babolsar	0.85	0.62	0.90	2.72	0.77	1.76	2.56	4.29	2.13	1.32	0.68	0.50
Bam	−0.42	0.21	−1.71	8.10	5.16	1.69	0.10	4.09	1.11	1.69	−0.50	−2.15
Bandar abbas	−2.63	−1.26	−5.07	0.01	−1.33	0.09	−0.55	−1.94	−3.45	−3.16	−2.51	−3.04
Bandar anzali	0.30	0.41	0.76	1.15	−0.87	−0.89	0.99	1.98	0.64	1.06	0.30	−0.17
Birjand	−2.06	−0.62	−3.28	−0.56	−1.64	−3.24	−2.91	−4.15	−4.62	−5.35	−2.28	−1.74
Bushehr	−1.32	−0.95	−3.50	0.78	4.03	2.69	0.23	−0.57	−0.44	−0.59	−1.51	−2.66
Esfahan	−0.69	−0.34	−5.53	−1.95	−5.04	−7.64	−10.88	−9.89	−6.22	−4.98	−2.24	−1.76
Ghazvin	−1.20	−1.35	−3.56	−2.99	−7.91	−9.55	−10.50	−7.61	−7.18	−4.65	−3.05	−1.78
Gorgan	0.31	−0.24	−0.16	0.39	−0.84	−0.68	−1.54	−0.88	−1.15	−0.11	0.09	−0.09
Hamedan	−0.34	−0.22	−0.03	2.65	1.08	4.32	2.73	4.27	2.05	−0.20	−0.78	−0.48
Kerman	−0.85	−0.90	−3.69	−2.59	−1.83	−6.12	−8.14	−9.24	−6.45	−5.04	−2.84	−3.31
Kermanshah	0.79	1.93	1.10	4.21	3.86	1.00	−0.97	−1.59	−3.60	−0.63	0.86	−0.14
Khoramabad	−0.55	0.13	−2.63	−1.40	1.51	7.06	10.57	8.26	2.90	1.36	−1.22	−1.04
Khoy	0.11	1.34	1.28	2.08	0.50	1.21	−0.42	−0.80	−0.64	0.32	−0.34	−0.72
Mashhad	1.32	1.49	1.57	4.22	2.06	3.76	6.01	4.78	3.08	2.60	1.30	1.00
Orumieh	0.63	1.57	1.84	3.33	1.13	1.71	1.15	0.39	1.04	0.90	0.48	−0.18
Rasht	−0.06	0.15	0.86	0.52	−0.31	0.67	0.42	1.10	−0.43	0.16	−0.54	−0.49
Sabzevar	−0.50	−0.95	−4.22	−1.48	−3.57	−5.45	−10.92	−8.41	−4.41	−6.06	−3.79	−2.30
Sanandaj	0.40	1.33	1.59	2.46	1.51	0.75	2.17	−0.48	−2.32	−1.17	−1.39	0.04
Shahrekord	0.93	0.72	−0.24	2.22	1.82	4.71	5.35	3.97	2.01	1.17	1.24	0.64
Shahrud	−3.15	−3.16	−4.89	−4.11	−7.06	−4.46	−3.94	−6.61	−7.88	−7.89	−5.87	−4.55
Shiraz	0.18	−0.13	−1.17	4.55	2.22	−2.92	−3.40	−3.09	−5.14	−4.10	−2.76	−1.27

Table 4 (continued)

Station name	Jan	Feb	Marc	Apr	May	Jun	July	Agu	Sep	Oct	Nov	Dec
Tabas	0.00	0.29	0.59	7.02	10.64	12.62	18.85	14.59	5.59	2.48	1.51	0.21
Tabriz	0.46	1.70	2.93	4.08	0.84	−2.17	−7.54	−5.94	−3.59	2.83	0.60	−0.40
Tehran	1.04	0.42	−1.39	2.20	−1.49	−2.35	0.51	0.43	−1.72	−1.78	−1.36	−0.83
Torbatheydarieh	−0.25	−0.30	−1.91	0.94	−0.03	1.23	7.62	4.74	1.55	−0.27	−0.57	−0.80
Yazd	−1.19	−0.15	−3.45	−0.68	−4.97	−4.55	−6.80	−5.23	−0.77	0.45	0.41	−0.27
Zahedan	1.95	2.26	−2.22	1.07	0.98	−0.40	−0.29	−0.96	−1.19	−0.78	2.00	2.49
Zanjan	1.29	1.15	0.60	4.15	1.94	6.64	8.70	11.28	8.78	6.16	1.98	1.05

Table 5 Sen's slope estimator results in seasonal and annual time scales (mm per decade)

Station name	Sen' slope estimator				
	Winter	Spring	Summer	Autumn	Annual
Abadan	−5.90	13.91	21.67	−3.91	29.34
Ahvaz	1.36	19.82	27.67	−0.24	56.88
Arak	−0.34	10.15	11.31	0.62	21.41
Babolsar	2.45	4.58	9.10	2.11	16.50
Bam	−1.97	14.36	10.90	−1.28	26.16
Bandar abbas	−8.83	−0.98	−6.51	−8.08	−28.39
Bandar anzali	1.43	−1.72	3.05	1.17	3.51
Birjand	−6.10	−5.10	−13.09	−8.82	−34.76
Bushehr	−6.44	8.63	−1.05	−5.73	−3.88
Esfahan	−7.14	−12.01	−27.74	−8.59	−53.86
Ghazvin	−6.24	−21.13	−25.29	−9.77	−59.90
Gorgan	−0.32	−1.12	−1.51	−0.75	−3.43
Hamedan	−1.85	7.90	8.59	−0.85	16.14
Kerman	−4.82	−13.19	−25.56	−11.07	−50.31
Kermanshah	3.34	8.90	−6.87	−0.03	4.71
Khoramabad	−4.67	3.88	17.03	−2.75	5.75
Khoy	2.24	3.99	−1.12	−0.78	3.28
Mashhad	3.43	10.85	14.31	4.87	38.10
Orumieh	3.68	5.39	0.77	1.15	9.75
Rasht	0.77	−0.20	1.92	−0.90	0.15
Sabzevar	−5.79	−10.92	−20.40	−11.72	−41.70
Sanandaj	2.28	5.67	0.27	−3.47	5.14
Shahrekord	0.92	9.86	11.18	2.16	24.15
Shahrud	−11.16	−15.44	−17.75	−18.84	−62.22
Shiraz	−1.48	1.78	−11.90	−9.10	−18.32
Tabas	0.45	28.78	38.66	4.51	72.14
Tabriz	4.33	3.23	−17.59	2.08	−12.76
Tehran	−0.52	−1.13	−1.01	−3.57	−6.90
Torbatheydarieh	−2.54	2.71	13.27	−1.86	11.64
Yazd	−6.19	−13.94	−14.65	0.10	−36.18
Zahedan	1.17	−2.78	−2.56	3.60	−8.92
Zanjan	3.09	11.39	27.97	9.93	51.59

series have been located along the borders of Iran except southeast ones, while most of central parts have been classified in cluster 2, where the ET_0 values show decreasing trends toward 1990 and then increasing trends between 1990 and 2000.

4 Discussion and conclusion

Results showed that the significant negative trends are more considerable than the significant positive ones. The same results about declining trend have been derived in other parts of the
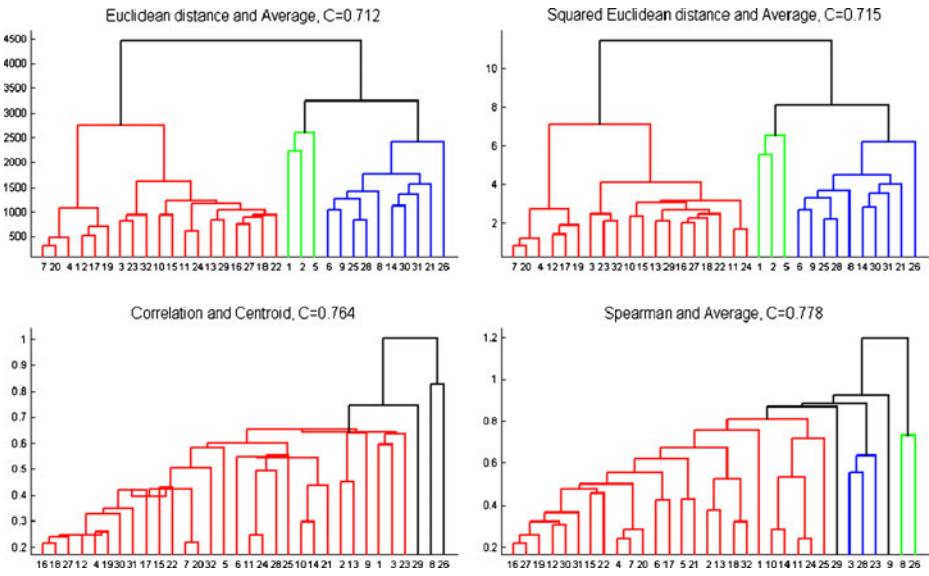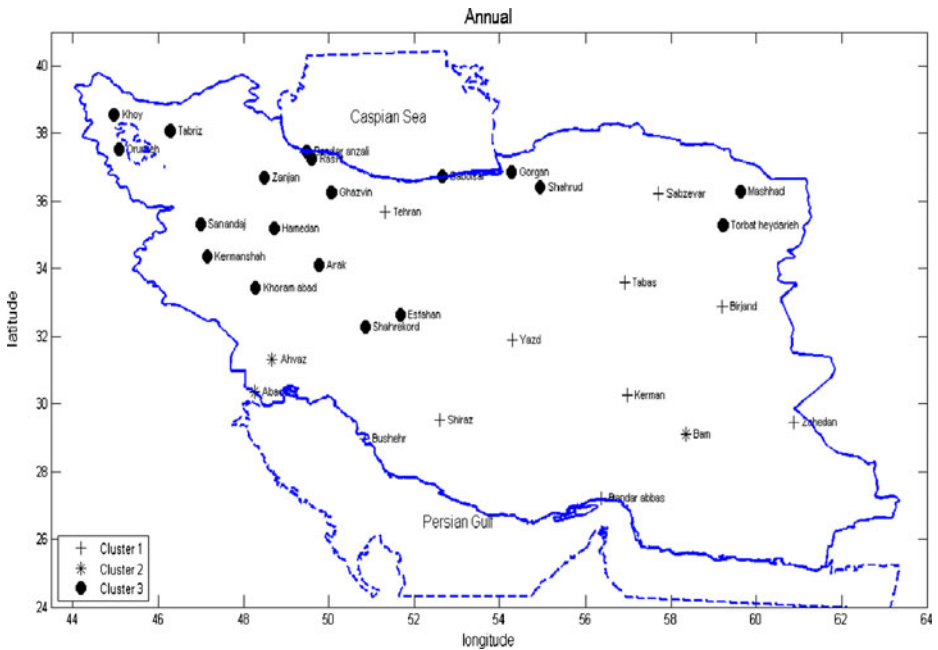
Fig. 6 Dendrograms showing the hierarchical clustering results of 32 ET0 annual time series in synoptic stations based on Euclidean distance, Squared Euclidean distance, Correlation and Spearman methods. *-The numbers x axis are representative of the stations number in accordance to Table 1. For example 1 is representative Abadan station and 2 for Ahvaz one

world. Roderick and Farquhar (2002) reported that as the average global temperature increases, it is generally expected that the air will become drier and evaporation from
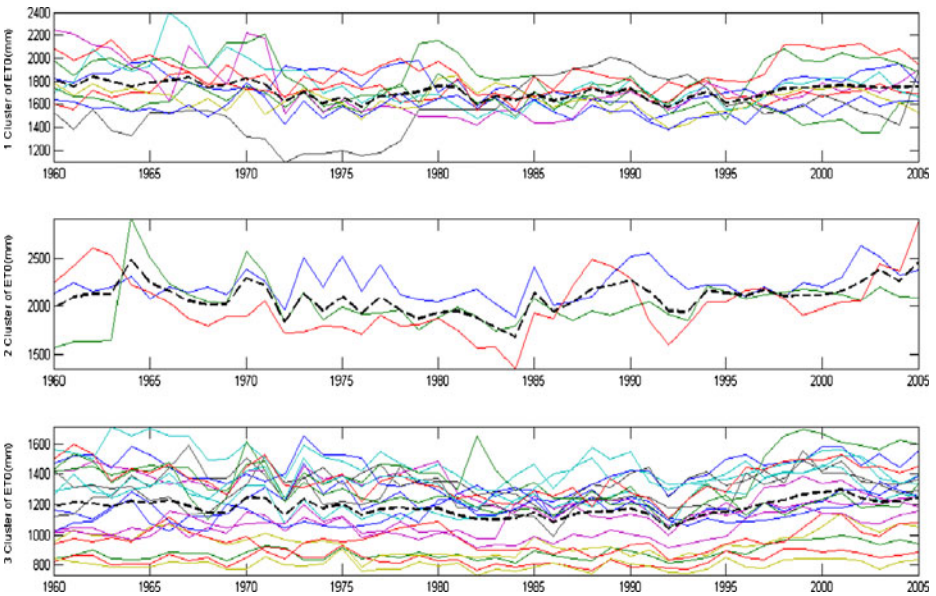
Fig. 7 Three clusters of ET_0 in relation to annually time scale based on combination of Euclidean distance and average methods. *- Each *colored line* represents the time series of one station. *- The *dashed lines* show the average of time series in each clusters

Fig. 8 Spatial distribution of three clusters in annual time scale and based on combination of Euclidean distance and average methods. +, *, ● represent cluster 1, cluster 2 and cluster 3, respectively
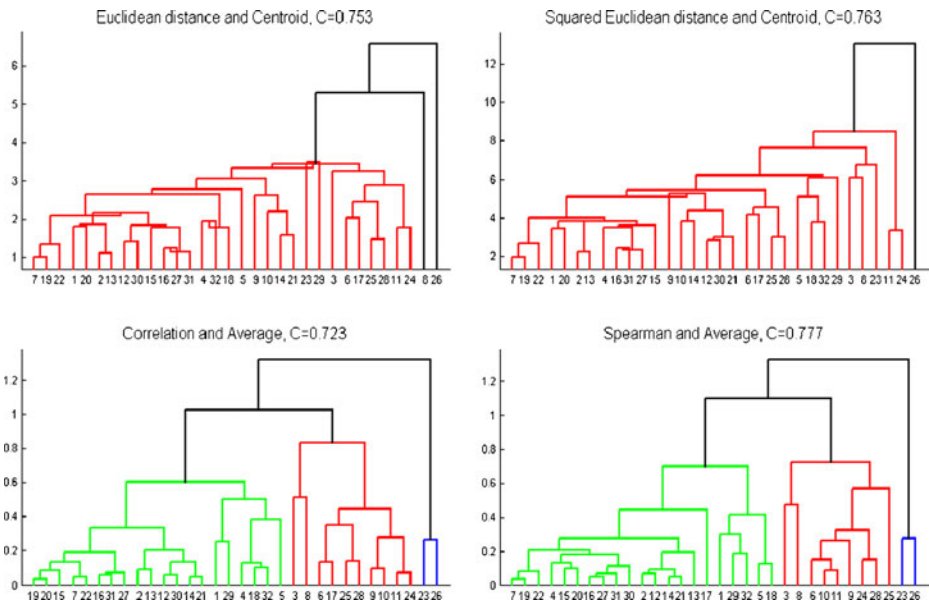
Fig. 9 Dendrograms showing the hierarchical clustering results of 32 normalized and filtered annual ET0 time series in synoptic stations based on Euclidean distance, Squared Euclidean distance, Correlation and Spearman methods
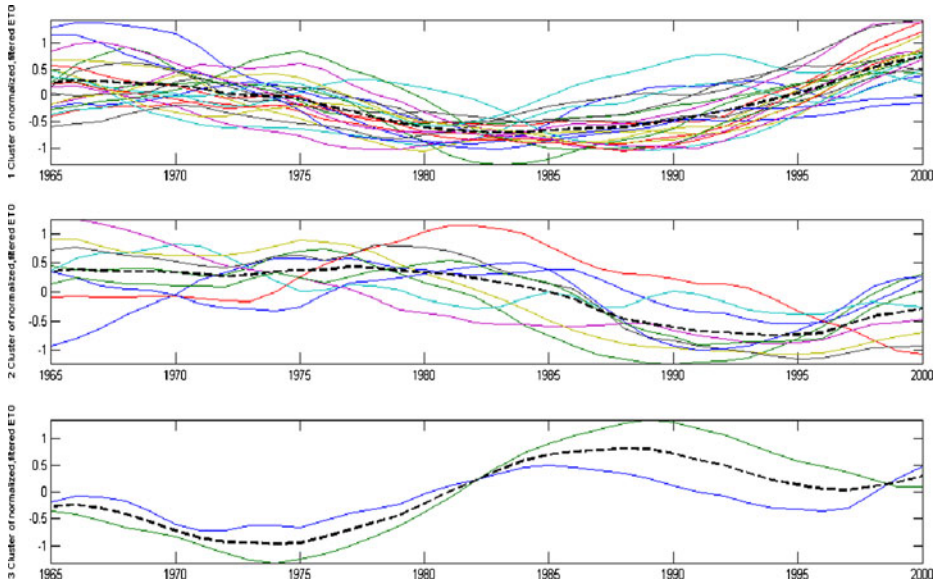
Fig. 10 Three clusters of normalized and filtered ET$_0$ in relation to annually time scale based on combination of Spearman and average methods
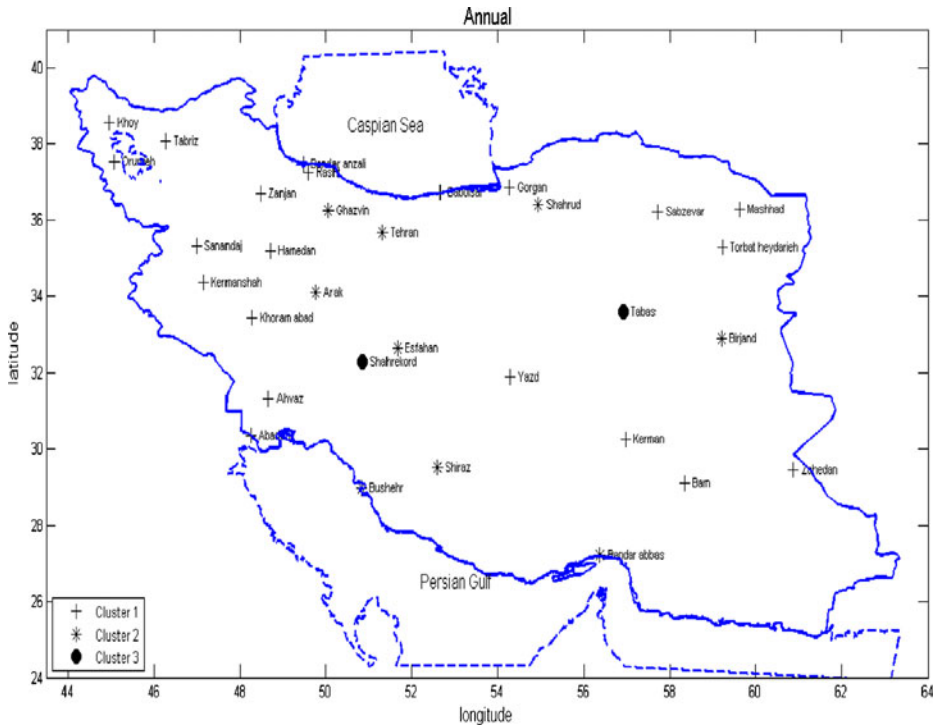
Fig. 11 spatial distribution of three clusters in normalized and filtered annual ET0 time series and based on combination of Spearman and average methods

terrestrial water bodies will increase. In the contrary, terrestrial observations over the past 50 years showed the reverse (Roderick and Farquhar 2002). In the case of previous studies in Iran, some researchers (for example Dinpashoh et al. 2011 and Kousari and Ahani 2012) have pointed out both increasing and decreasing trends, however, the significant positive ones have been more considerable than decreasing types. It should be mentioned that the number of surveyed stations and data length period were different in the current study and previous ones and therefore, some differences have been found. However, deeper review in regard to decreasing or increasing trend by exploring in presented time series and their clustering is essential.

Presented time series particularly 10 year normalized moving average ones exhibited the rising of ET_0 after about 1980 in the first cluster (Fig. 10). Second cluster showed decreasing trend until 1990 and then it indicated new slight rise after 1995. In the third cluster, two stations displayed an increasing trend after 1975. As it can be seen, although all clusters have shown an increasing trend in the last years, the first and second clusters which cover the main proportion of stations have exhibited a decreasing trend in the main parts of the surveyed time. This feature is more striking for the second cluster. Therefore, detection of more negative significant trends by non-parametric MK statistics can be anticipated. Anyway, the results reveal that in recent years (in most cases after 1980 and 1995 toward 2000) ET_0 has shown increasing trends in most parts of the country.

Based on the results of this study, it is rather difficult to say that climatic changes and global warming have affected the ET_0 trend. On one hand, the decreasing and increasing trends of ET_0 values in many surveyed time series showed considerable fitness between the observed global warming occurrence in the world (Florides and Christodoulides 2009) and in Iran (Kousari and Ahani 2012) especially in the case of rising the temperature after around 1980 as well as increasing trend of ET_0 after this year which is pointed out in this study. From the other hand, some studies have shown that wind is the most important parameter on the ET_0 trends in Iran (Dinpashoh et al. 2011; Kousari and Ahani 2012; Tabari et al. 2012). Based on these studies, the relative humidity and sunshine duration are other important parameters which effect on ET_0 trends in Iran. Therefore, another assumption can focus on the interactions among the climatic parameters (Fan and Thomas 2013) e.g. wind, sunshine and temperature and their effects on the ET_0 trends. Future studies shall investigate this assumption.

As it was mentioned before, two cluster maps are presented in this study. One shows the clusters in regard to annual ET_0 and another one indicates the three clusters of the normalized and filtered annual ET_0 time series. The two maps obviously are different. But, the clustered map based on normalized and filtered annual ET_0 time series is in accordance with another map which shows spatial distribution of increasing, decreasing and non-significant trends of ET_0 in annually time scale (Fig. 5). For example, the stations with identical trends (e.g. decreasing trends) based on MK test or Sen's slope estimator, have been classified in one cluster. In most cases comparing the annual Z value and cluster maps indicated the same patterns clearly. In Fig. 5, two neighbor stations Ghazvin and Zanjan showed significant decreasing and increasing trends, respectively. They were classified in the same cluster (cluster 3) when the initial ET_0 values were applied (Fig. 8). When the normalized and filtered time series were considered (Fig. 11), it is obvious that they have been classified in different clusters. Therefore, it can be said that in order to facilitate trend analysis besides the application of other statistical test such as MK or Sen's slope estimator, using normalized and filtered values appears more effective than initial data especially when the original data have considerable fluctuations or the surveyed time series have remarkable differences in average or ranges. When the data is normalized during time series analysis, it comes to

specific range and filtering masks the fluctuations. In these conditions exploring in data for investigation of trend analysis is easier than using initial data that was also used in this study. In regard to clustering of original of data, in most cases the data with near averages and ranges will bring together in the same cluster. It can be said that using original data is more useful for regionalization of the surveyed parameter or climate zone delineation while, for trend analysis application of normalized and filtered values has more advantages. Of course for regionalization, multivariate data are more considerable than univariate inputs. As stated Farmer et al. (2010), hierarchical cluster analysis has been used for a range of applications, including ecological analyses (Mckenna 2003; Nemec and Brinkhurst 1988), hydrological regionalization (Rao and Srinivas 2006; Poff 1996), and climate zone delineation (Gong and Richman 1995; Unal et al. 2003). Cluster analysis in its most general form is a method for identifying patterns within multivariate data (Sneath and Sokal 1973; Kaufman and Rousseeuw 1990), and more specifically, it involves recursively grouping similar objects based on multivariate attributes into groups.

Also, about the application of non-parametric statistical tests in this study it should be mentioned that according to Duhan and Pandey (2012) there are various parametric and non-parametric tests which were used for identifying trends in hydro-meteorological time series. However, recently nonparametric tests have been mostly used for non-normally distributed and censored data, including missing values, which are frequently encountered in hydrological time series. In this study the presented time series of initial annual ET_0 show a lot of fluctuations. In these cases, MK analysis produces the results which are not biased by this variability. While, using the simple linear regression would be useless in these conditions. Therefore in case of Iran, linear regression results are difficult to interpret and should be used with caution.

Since ET_0 is an important and key parameter in determining crop water demand and scheduling irrigation, the upward trend of ET_0 in recent years is an important concern which should be investigated more. As stated by Tabari and Aghajanloo (2012) in recent years, the development of irrigated agriculture to support population growth have raised the demand for water and created a condition of water stress (Alizadeh and Keshavarz 2005). This situation is beyond a water shortage or crisis and aggregates the serious scientific, technical, ecological, economic and social issues surrounding water for now and the years to come (Ghazi 2002). Furthermore, in arid and semi-arid regions such as Iran, dam construction is a common way to provide irrigation water in times of dry seasons and droughts. Since the major water resource consumers in Iran are agricultural activities and in most cases more than 80 % of the water behind dam reservoirs is allocated to agricultural aims, any increase in ET_0 will end up in an increase in crop water demand which can impose considerable costs on economy.

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