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Do changes in meteorological parameters and evapotranspiration affect declining oak forests of Iran?

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ABSTRACT: Decline of the Zagros forests of western Iran dominated by oak trees is assumed to be highly connected with changes in meteorological parameters. To examine this hypothesis, we aimed at observing the long-term trends of meteorological parameters and reference evapotranspiration (ET_0) in the Zagros region. Long-term (1961–2010) data of air temperature (T_a), relative humidity (*RH*), precipitation (P), and wind speed (*WS*) were obtained from meteorological stations located in the Zagros region. The Penman-Monteith equation was applied to calculate ET_0. The results indicated that since 2000, coinciding with the emerging oak decline, meteorological parameters and ET_0 have been changed: T_a +0.6°C, P –60 mm, *RH* –3%, *WS* +0.4 $m \cdot s^{-1}$, and ET_0 +0.25 $mm \cdot day^{-1}$. Although this research confirmed a significant relationship between oak decline and changes in meteorological parameters, full datasets recorded in different parts of the Zagros region are essential for a reasonable research to fully explain this hypothesis. Managers should think of the expected changes in meteorological parameters and evapotranspiration owing to global warming.

Keywords: air temperature; global warming; Penman-Monteith equation; precipitation; reference evapotranspiration

The effect of anthropogenic changes to the land and atmosphere on climate change is pursued as a dynamic multidisciplinary problem. Atmospheric temperature is probably the most widely used indicator of climate change at both global and regional scales. According to the fourth assessment report of IPCC (2007), global temperature has increased by 0.3 to 0.6°C since the late 19th century and by 0.2 to 0.3°C over the past forty years. Previous research suggests that climate change may have a significant impact on hydrological parameters; namely runoff, evapotranspiration (*ET*), soil moisture, rainfall interception, and groundwater (Němec, Schaake 1982; Bultot et al. 1988; Anderson et al. 2008). Some of the researchers have also investigated the trends in different types of hydrological, ecohydrological, and hydrometeorological parameters such as soil moisture, drought characteristics, groundwater, pan evaporation and reference evapotranspiration – ET_0 (Němec, Schaake 1982; Bultot et al. 1988; Tabari et al. 2011). ET_0, a major component of the hydrological cycle, is one of the most important elements for quantifying available water since it generally constitutes the largest components of the terrestrial water cycle (Tabari 2010). ET_0 considered to be critical to many applications including water resource management, irrigation scheduling, and environmental studies (Sabziparvar, Tabari 2010) is one of the main factors in the hydrological cycle and can be affected by changes in air temperature, sunshine duration, wind speed, and so on. It is well known that ET_0 is a nonlinear complex function of many parameters and changes in any parameter can change the other parameter(s) (Tabari et al. 2011). There-

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fore, any change in climatic parameters due to climate change will likely affect ET and ET_0 (Goyal 2004). Eventually, climate change will increase the dry conditions in the arid regions by increasing potential evapotranspiration, aggravating the process of desertification in conjunction with the ever-growing impact of humans and domestic animals on fragile and unstable ecosystems (Tabari et al. 2011). In drier regions, evapotranspiration may produce more frequent drought periods.

Small changes in ET may have important consequences in arid regions (Attarod et al. 2015). For example, Goyal (2004) reported that a five percent increase in air temperature could increase ET_0 by 3.6% in arid regions of Rajasthan, India, where the annual rainfall varies from 100 to 400 mm and the mean yearly air temperature is 25°C. According to Aber et al. (2001), a 3°C rise in air temperature in California resulted in an approximately 19% increase in ET_0 where average annual precipitation is 640 mm and mean yearly air temperature is 15°C. Furthermore, Martin et al. (1989) and Rosenberg et al. (1989) reported that a 3°C increase in air temperature resulted in an around 17% increase in ET_0 over a grassland in Northeastern Kansas, USA, during the summer with an air temperature range between 24 and 35°C. The effect of climate change may be exacerbated by the ever-growing impact of humans and domestic animals on the fragile and unstable ecosystems (Mahmood 1997).

Increasing decline of oak trees and in particular of *Quercus petraea* (von Mattuschka) Lieblein has been observed in European countries (Freer-Smith, Read 1995; Führer 1998; Thomas, Büttner 1998). Similarly, decline of the Zagros forests in the west of Iran with an area of 5 million ha dominated by oak (*Quercus brantii* var. *persica*) trees has been occurring since 2000. Forest managers in Iran believe that no single reason is responsible for the decline of oak forests. In other words, diseases and pests are not the sole motive for the death of this seriously vulnerable ecosystem located in a semiarid climate. The impacts of changes in meteorological parameters on decline of Zagros forests are likely to be unevenly distributed not only across different bioclimatic zones but also among different climate types of each zone.

Research showed that several biotic and abiotic factors have been considered in oak decline stud-

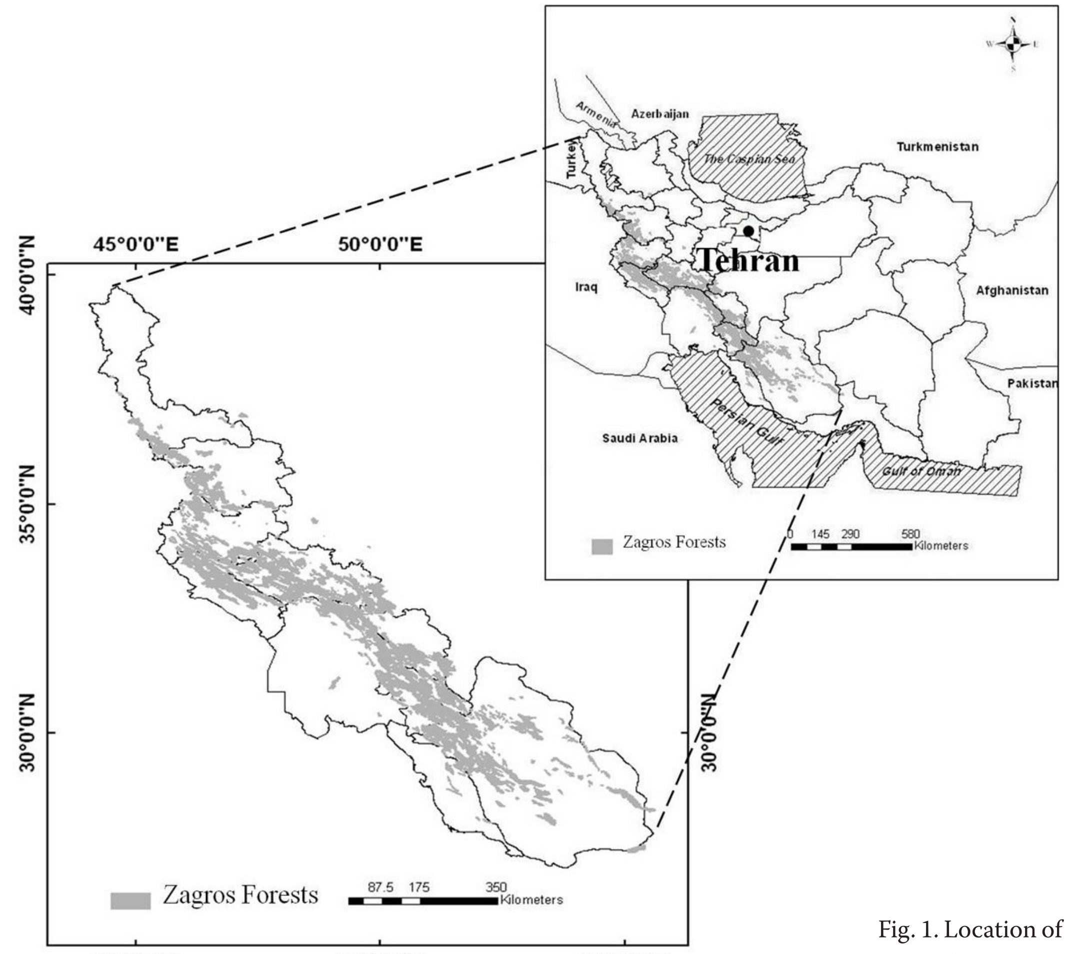

Fig. 1. Location of the Zagros region, west of Iran

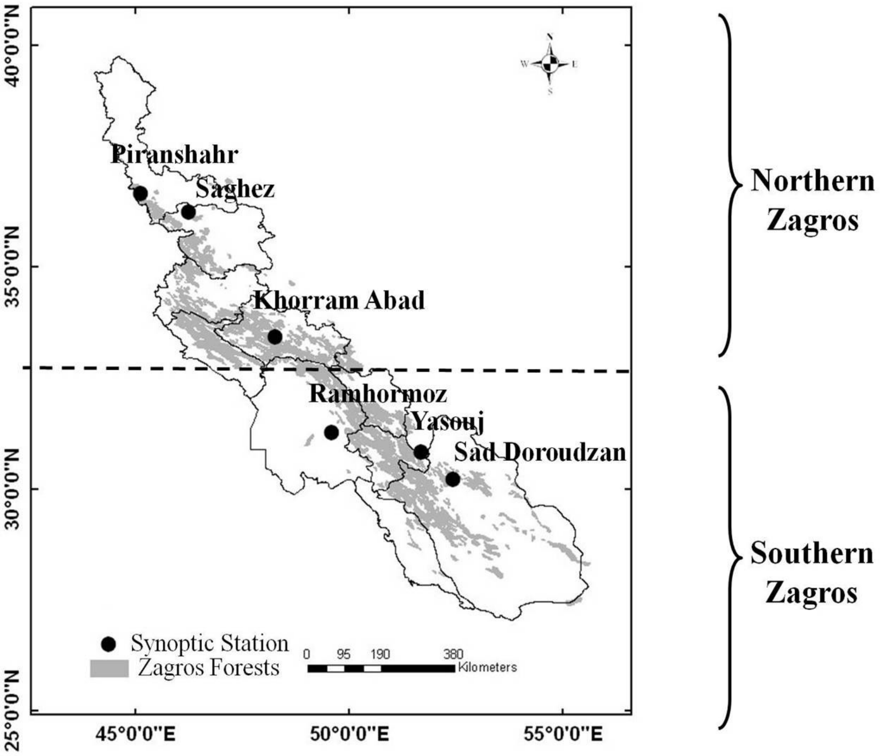

Fig. 2. Positions of the selected synoptic weather stations in the Zagros region, west of Iran

ies, such as extreme weather conditions, drought, storms, heat, insect fluctuations, or human-induced influences such as climate change, air pollution, and fires. These factors may modify the functioning of the whole forest ecosystem and may lead to tree decline events (Misik et al. 2013).

Not surprisingly, forest degradation, frequent droughts, suspended particles and dusts originated from neighbouring countries coupled with changes in meteorological parameters in recent years are assumed to deteriorate the ability of the ecosystem to combat environmental stresses. Oak trees react to the stress of prolonged drought and defoliation by converting starch stored in the roots to sugar to support continued metabolism (Clatterbuck, Kauffman 2006). Once these stored reserves are depleted, trees are not able to maintain the status quo and begin to decline (Clatterbuck, Kauffman 2006). To our knowledge, no studies have used meteorological variables to detect and monitor the oak decline in Iran.

Variations in meteorological parameters and consequently ET_0 belong among the prevalent hypotheses in decline of the Zagros forests. Therefore, to examine this assumption, our objectives were: (*i*) to observe the long-term trends of meteorological parameters and ET_0, (*ii*) to reveal the relationships between changes in meteorological parameters and oak decline in the Zagros forests.

MATERIAL AND METHODS

Study area. The research was conducted in the Zagros region, west of Iran (Fig. 1). The average annual precipitation varies approximately from 250 to 800 mm and the mean annual air temperature ranges from 9 to 25°C (Fathizadeh et al. 2013).

Meteorological data. Detection of climatic changes requires the use of a large number of long, high-quality series of observed meteorological variables. To achieve this, long-term meteorological data (1961–2010) from six synoptic meteorological stations (Fig. 2) were used to parameterize the De Martonne aridity index (I_{DM}) (Croitoru et al. 2013).

I_{DM} was used to classify the climate for the region surrounding each station (Table 1).

Evapotranspiration model. We used the Penman-Monteith combination equation to calculate daily ET_0 (Allen et al. 1998). The Penman-Monteith combination equation is a reliable method for determining ET_0 worldwide.

RESULTS

Trends of meteorological parameters and ET_0

The mean values of meteorological parameters within the growing and dormant seasons are shown

Table 1. Characteristics of the synoptic meteorological stations located in the Zagros region, west of Iran (1961–2010). Climate classification according to the De Martonne aridity index – I_{DM} (Tabari et al. 2011)

Station	Latitude	Longitude	Elevation (m a.s.l.)	I_{DM}	Climate classification	Range of observation
Piranshahr	36°42'N	45°09'E	1,455	29	humid	1986–2009
Saghez	36°15'N	46°16'E	1,523	23	mediterranean	1961–2009
Khorram Abad	33°26'N	48°17'E	1,148	18	semiarid	1961–2010
Ramhormoz	31°16'N	49°36'E	150	8	arid	1987–2010
Yasuj	30°50'N	51°41'E	1,831	33	humid	1987–2009
Sad Doroudzan	30°13'N	52°26'E	1,620	17	semiarid	1988–2010

in Table 2. Our data suggested that mean annual air temperature and precipitation at the selected stations are 16.7°C and 545.8 mm, respectively. Mean annual relative humidity, wind speed, and ET_0 were 45%, 2.0 m·s^{-1}, and 4.2 mm·day^{-1}, respectively. The maximum daily ET_0 was calculated in Ramhormoz (6.1 mm) and the highest yearly precipitation was recorded in Yasuj.

Table 3 shows the ET_0, relative humidity, and wind speed trends in terms of Kendall's Tau statistic within the long-term period (1961–2010). Two and one out of the six stations exhibited statistically significant positive and negative trends ($P < 0.05$) for the annual air temperature time series, respectively. Positive and negative trends were similarly pronounced for air temperature during this period.

In the last two rows, two numbers, in each cell, denote the number of trends with positive or negative sign, and the number of statistically significant trends at a 5% level.

Fig. 3 shows the yearly ET_0, relative humidity, and wind speed time series of selected stations in the period 1961–2010. The magnitude of the trend in annual ET_0 at Ramhormoz station located in the central Zagros region revealed the highest positive trend line slope with a value of 0.4 mm per decade. Similarly, for wind speed, the highest positive trend line slope was observed at Sad Doroudzan station with a value of 0.3 m·s^{-1} per decade.

Table 4 shows the quantitative values of meteorological parameters and ET_0 changed in recent years (2000–2010) in comparison with the previous peri-

Table 2. Long-term (1961–2010) annual average and standard deviation (± standard deviation) of meteorological parameters as well as reference evapotranspiration in the Zagros region of western Iran

Station	Season	T_a (°C)	P (mm)	RH (%)	WS (m·s^{-1})	ET_0 (mm·day^{-1})
Piranshahr (1986–2009)	G	19.7 ± 1.2	146 ± 68.2	40 ± 5.4	2.4 ± 0.5	5.1 ± 0.5
	N-G	4.7 ± 1.5	512 ± 154.4	63 ± 4.6	3.0 ± 0.5	2.0 ± 0.2
	A	12.4 ± 1.1	658 ± 178.4	51 ± 4.3	2.7 ± 0.5	3.9 ± 0.4
Saghez (1961–2009)	G	18.8 ± 1.2	141 ± 66.8	40 ± 5.6	2.5 ± 0.6	5.0 ± 0.5
	N-G	3.7 ± 1.8	339 ± 108.7	64 ± 4.2	2.3 ± 0.4	1.9 ± 0.2
	A	11.3 ± 1.2	480 ± 135.8	52 ± 3.8	2.4 ± 0.5	3.7 ± 0.3
Khorram Abad (1961–2010)	G	24.7 ± 1.1	99 ± 69.1	33 ± 4.7	2.0 ± 0.6	5.8 ± 0.8
	N-G	10.3 ± 1.2	396 ± 120.9	59 ± 4.8	1.8 ± 0.5	2.2 ± 0.2
	A	17.2 ± 1.1	504 ± 122.9	46 ± 4.2	1.9 ± 0.5	4.1 ± 0.4
Ramhormoz (1987–2010)	G	34.2 ± 1.0	22 ± 20.6	22 ± 2.3	2.4 ± 0.5	9.5 ± 1.2
	N-G	18.7 ± 1.0	296 ± 95.4	52 ± 4.4	1.6 ± 0.3	2.8 ± 0.3
	A	26.5 ± 1.1	307 ± 1,008	37 ± 2.2	2.0 ± 0.4	6.1 ± 0.8
Yasuj (1987–2009)	G	22.0 ± 0.6	88 ± 59.9	31 ± 8.4	1.6 ± 0.5	4.4 ± 0.8
	N-G	8.4 ± 0.7	752 ± 195.4	87 ± 6.2	1.3 ± 0.4	2.9 ± 0.1
	A	15.2 ± 0.6	841 ± 211.5	44 ± 7.0	1.4 ± 0.5	3.6 ± 0.2
Sad Doroudzan (1988–2010)	G	24.7 ± 0.6	48 ± 38.5	31 ± 3.8	2.3 ± 0.6	6.2 ± 0.6
	N-G	10.8 ± 0.7	437 ± 124.1	50 ± 4.2	1.9 ± 0.5	2.4 ± 0.2
	A	17.7 ± 0.6	485 ± 135.1	40 ± 3.7	2.1 ± 0.5	4.3 ± 0.4

G – growing season (April-September), N-G – dormant season (October-March), A – annual, T_a – air temperature, P – precipitation, RH – relative humidity, WS – wind speed, ET_0 – reference evapotranspiration

Table 3. Trend tests, Kendall's Tau, obtained by the Mann-Kendall method for the meteorological parameters as well as reference evapotranspiration in the Zagros region of western Iran in the period 1961–2010

Station	T_a	P	*RH*	*WS*	ET_0
Piranshahr (1986–2009)	0.6**	–0.1	–0.2	0.0	0.1
Saghez (1961–2009)	–0.2	–0.1	0.2	0.1	–0.2*
Khorram Abad (1961–2010)	–0.3**	–0.1	0.1	0.0	0.8
Ramhormoz (1987–2010)	0.4**	–0.2	–0.4**	0.1	0.2
Yasuj (1987–2009)	0.0	0.4	0.0	0.0	0.1
Sad Doroudzan (1988–2010)	0.2	–0.4*	–0.4*	0.2	0.3
+ trend number	4 (2)	1 (0)	3 (0)	6 (0)	5 (0)
– trend number	2 (1)	5 (1)	3 (2)	0 (0)	1 (1)

T_a – air temperature, **statistically significant trends at the 99% confidence level, P – precipitation, *statistically significant trends at the 95% confidence level, *RH* – relative humidity, *WS* – wind speed, ET_0 – reference evapotranspiration

od (1961–1999). Exclusive of Saghez – air temperature increased by approximately 4% at all stations as an average. The highest change in wind speed was observed in Yasuj, approximately 0.4 m·s^{-1} from 2000 to 2010. Except Yasuj station, showing a very slight change in annual precipitation, at other stations a notable decrease was observed. Our data proposed that reference evapotranspiration

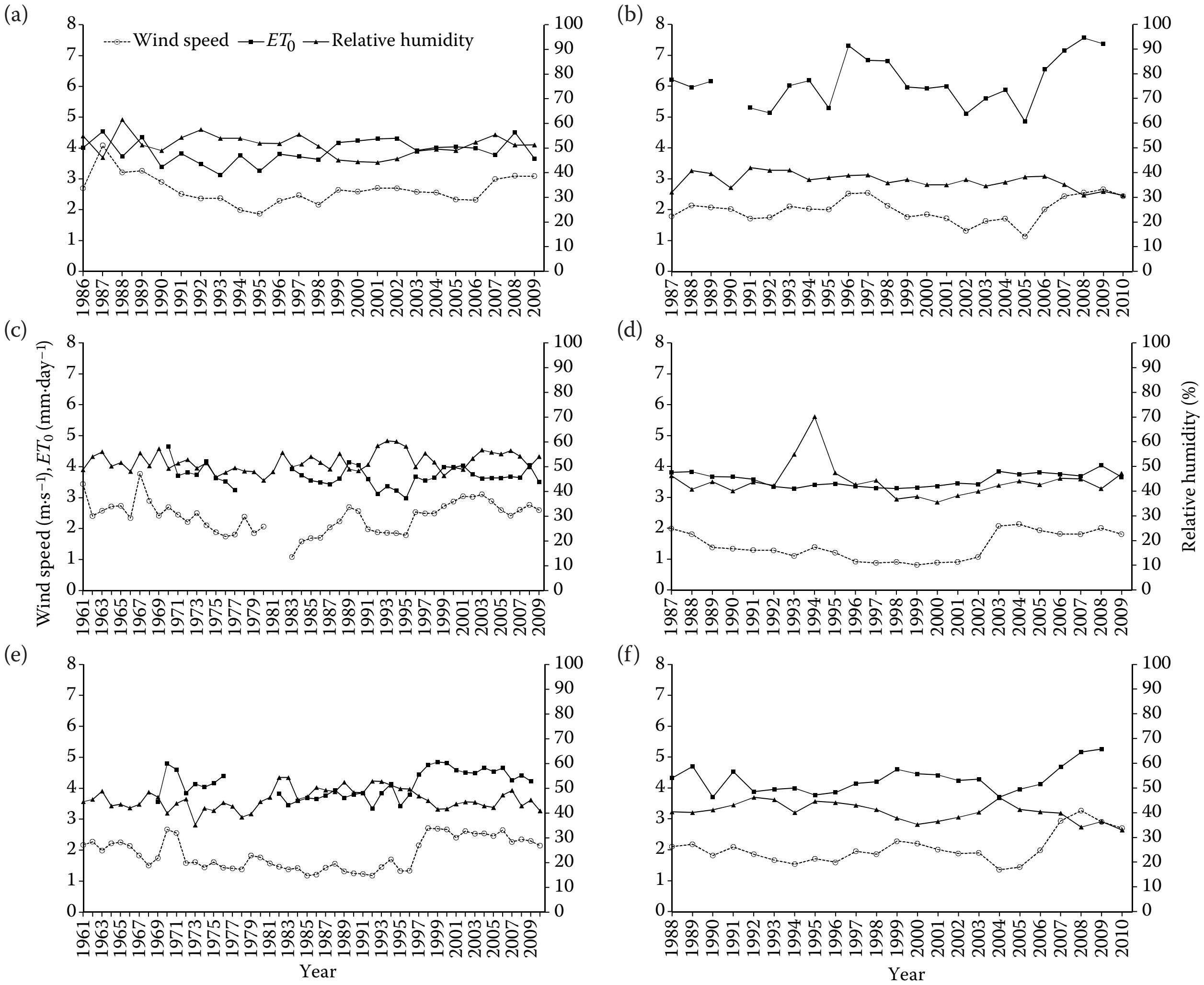

Fig. 3. Long-term (1961–2010) trends of mean annual wind speed, relative humidity, and reference evapotranspiration (ET_0) in the Zagros region of western Iran: Piranshahr (a), Ramhormoz (b), Saghez (c), Yasuj (d), Khorram Abad (e), Sad Doroudzan (f)

Table 4. Changes in meteorological parameters, reference evapotranspiration (ET_0) and De Martonne aridity index (I_{DM}) in the Zagros region, west of Iran, in recent years (2000–2010)

	Piranshahr (1986–2009)	Saghez (1961–2009)	Khorram Abad (1961–2010)	Ramhormoz (1987–2010)	Yasuj (1987–2009)	Sad Doroudzan (1988–2010)
Mean T_a (1961–1999) (°C)	11.8	11.3	17.1	26.1	15.1	17.5
Mean T_a (2000–2010) (°C)	13.1	11.1	17.3	27	15.3	18
T_a changes (°C)	+1.3	–0.2	+0.2	+0.9	+0.2	+0.4
T_a changes (%)	+11.3	–2.2	+1.1	+3.4	+1.1	+2.6
Mean P (1961–1999) (mm)	670.9	498.7	515.7	343.4	838.6	509.2
Mean P (2000–2010) (mm)	639.8	407.0	458.4	285.7	844.4	455.0
P changes (mm)	–31.0	–91.7	–57.3	–57.7	+5.8	–54.2
P changes (%)	–4.6	–18.4	–11.1	–16.8	+0.7	–10.7
Mean *RH* (1961–1999) (%)	52.7	51.6	46.1	38.2	45.5	42.3
Mean *RH* (2000–2010) (%)	49.2	53.4	44.1	34.9	42.2	38.3
RH changes	–3.5	+1.8	–2	–3.3	–3.3	–4
RH changes (%)	–6.7	+3.4	–4.4	–8.6	–7.3	–9.4
Mean *WS* (1961–1999) (m·s^{-1})	2.6	2.3	1.7	2.0	1.3	1.9
Mean *WS* (2000–2010) (m·s^{-1})	2.7	2.8	2.5	1.9	1.6	2.2
WS changes (m·s^{-1})	+0.1	+0.5	+0.7	–0.1	+0.3	+0.3
WS changes (%)	+2.5	+22.7	+42.5	–4.6	+30.9	+18.4
ET_0 (1961–1999) (mm·day^{-1})	3.8	3.7	4.0	6.1	4.5	4.1
ET_0 (2000–2010) (mm·day^{-1})	4.1	3.8	4.5	6.2	3.7	4.4
ET_0 changes (mm·day^{-1})	+0.3	+0.1	+0.5	+0.1	+0.2	+0.3
ET_0 changes (%)	+8.0	+2.4	+13.5	+1.6	+5.5	+0.7
I_{DM} (1961–1999)	30.8	23.4	19	9.5	33.4	18.5
I_{DM} (2000–2010)	27.6	19.3	16.8	7.7	33.4	16.3

T_a – air temperature, P – precipitation, *RH* – relative humidity, *WS* – wind speed

increased by around 5% at selected stations. The results demonstrated that the De Martonne aridity index decreased at all stations.

Total precipitation

Background meteorological data recorded from 1961 to 2010 showed that average annual precipitation at the selected stations was 546 mm that occurred on 63 events, i.e. average 8.7 mm per event (Table 5).

However, during the previous decade (2000–2010), the yearly precipitation and the total number of events decreased to 515 mm and 60, respectively. Therefore, the amount of precipitation per event increased up to 9.3 mm. As well, in comparison with the period of 1961–2000, the recent decade has received less precipitation with the lower number of events. We separated the precipitation into five storm classes: very small (0–2.5 mm), small (2.5–7.5 mm), middle (7.5–15 mm), large (15–30 mm), and very large (> 30 mm). Three out of the six stations, Piranshahr, Ramhormoz, and

Table 5. Changes in total precipitation in the Zagros region, west of Iran, in the three periods

Station	Yearly precipitation (mm) + events			Mean daily precipitation (mm)		
	1961–2010	1961–2000	2000–2010	1961–2010	1961–2000	2000–2010
Piranshahr (1986–2009)	658 + 81	671 + 82	640 + 79	8.2	8	8.4
Saghez (1961–2009)	480 + 78	499 + 77	407 + 82	6.1	6.2	5.8
Khorram Abad (1961–2010)	504 + 70	516 + 73	458 + 60	7.2	6.9	8.4
Ramhormoz (1987–2010)	307 + 40	343 + 42	286 + 37	7.6	7.3	8.2
Yasuj (1987–2009)	841 + 63	839 + 68	844 + 57	13.4	12.4	14.8
Sad Doroudzan (1988–2010)	485 + 46	509 + 50	455 + 42	9.5	8.8	10.5
Mean	546 + 63	563 + 65	515 + 60	8.7	8.3	9.3

Saghez demonstrated that the number of events with 0.1–2.5 mm has significantly increased in the recent decade.

DISCUSSION

Our observations showed that long-term trends (1961–2010) of air temperature, precipitation, relative humidity and reference evapotranspiration were significant at 3, 1, 2, and 1 selected stations, respectively. The historical (1961–1999) mean values of the meteorological parameters of air temperature (16.5°C), relative humidity (46%), wind speed (2.4 $\text{m}\cdot\text{s}^{-1}$), precipitation (563 mm) and reference evapotranspiration (4.4 $\text{mm}\cdot\text{day}^{-1}$) were observed at the six selected stations located throughout the Zagros region. However, during the previous decade from 2000 to 2010, since oak decline gradually started appearing, the mean annual air temperature increased by 0.6°C. Within this period, precipitation, relative humidity, wind speed, and reference evapotranspiration changed additionally by around −60 mm, −3%, +0.4 $\text{m}\cdot\text{s}^{-1}$, and +0.25 $\text{mm}\cdot\text{day}^{-1}$. Exceptions were also observed; for example, mean yearly precipitation increased up very slightly from 838.6 to 844.4 mm in Yasuj.

It indicates that all of the meteorological parameters were affected by the global warming phenomenon in the Zagros region as occurred in many regions. A review of literature also shows that precipitation has declined in the tropics and subtropics since 1970 – e.g. Southern Africa, the Sahel region of Africa, southern Asia, the Mediterranean, and the USA Southwest are getting drier. Even areas that remain relatively wet can experience long dry conditions between extreme precipitation events. ET_0, which is a nonlinear complex function of many parameters, increased up at all stations, and averaged 0.25 $\text{mm}\cdot\text{day}^{-1}$. Forest ET_0 is generally higher than those of other vegetation types such as grassland (Zhang et al. 2001; Matsumoto et al. 2008). Forests cover about 30% of the total global land area, but ET_0 from forests accounts for 45% of the total ET_0 from the global land surface (Oki, Kanae 2006; Matsumoto et al. 2008). Changes in ET_0 will certainly affect the natural forest ecosystems in the Zagros region. The composition of the species, ecophysiological characteristics of the trees as well as the spatial distribution of the tree species may be threatened by changes in meteorological parameters. Climate change is predicted to affect forests by altering both forest processes (Aber et al. 2001) and biodiversity (Hansen, Dale 2001; Hansen et al. 2001), and changes the forest location, composition, and productivity (Hansen et al. 2001).

Within the growing season the typically hot and dry wind results in higher ET_0 from the surface relative to the cold wind during the dormant season. Changes in ET_0 can have a thoughtful effect on agriculture, forests, and water resources in the Zagros region and this may put a pressure on existing water resources.

During the previous decade, both the amount of precipitation and the number of precipitation events decreased. Moreover, the number of precipitation events lower than 2.5 mm increased at three out of the six stations. If this trend persists to the future, regarding the amount of canopy water storage capacity of oak trees in the Zagros forests which is 1 mm for the growing season and 0.6 mm during the dormant season (Fathizadeh et al. 2013), it is reasonable that these forests will experience a reduction in the available water because of the increased evaporative loss.

This study examined the hypothesis of possible effects of changes in meteorological parameters on oak decline in the Zagros forests. Our data showed that during the previous decade some parameters were changed drastically, for example wind speed 23% and precipitation 12%, however, the others fairly altered, e.g. air temperature 4.6%, relative humidity 7.3%. Combined changes in meteorological parameters increased the reference evapotranspiration to 5.3%. I_{DM} also decreased to 20.2 showing the Zagros region is getting drier and warmer. Oak decline in the Zagros forests is a multidisciplinary and complicated phenomenon depending on many factors. Removing the susceptible and stressful environmental factors is considered to be the most important solution to the rehabilitation of this generous ecosystem. Great attention is now focused on climate change and its impacts on forest ecosystems (Walther et al. 2002; IPCC 2013; Sadeghi et al. 2014), because forests are highly vulnerable to climate change and significant forest dieback can occur.

Variations in meteorological parameters belong among the prevalent hypotheses in the decline of the Zagros forests. This introductory research on long-term trends of meteorological parameters and reference evapotranspiration in the Zagros regions of western Iran confirmed a significant relationship between oak decline and changes in meteorological parameters. For example, yearly air temperature increased by approximately 0.5°C and annual precipitation has been reduced by 50 mm in the Zagros region since 2000, coinciding with the emerging oak decline. To fully explain this assumption, however, more meteorological data should be analysed.

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