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Sensitivity of Reference Evapotranspiration to Global Warming in the Caspian Region, North of Iran

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ABSTRACT

The goal of this study was to estimate the sensitivity of reference evapotranspiration (ET_0) to changes in meteorological parameters in the Caspian region. Long-term meteorological data (1961-2008) were obtained from three synoptic meteorological stations. The region was primarily classified into three climatic zones, based on De Martonne climate classification. The Penman–Monteith equation was applied to calculate the ET_0 and the sensitivity of ET_0 was studied in terms of changes in air temperature, solar radiation, wind speed and vapor pressure within a possible range of ±20% from the normal long-term meteorological parameters. The results indicated that the Caspian region could be classified into the three climatic classes: Mediterranean, humid, and extremely humid. During the last half century, meteorological parameters and, in particular, temperature of the Caspian region has changed dramatically and the ET_0 has increased as a result of climate change. The study suggests that an increase in temperature by 20% (approximately 3.3 ºC) will result in ET_0 demand increase by 16%. Changes in vapor pressure (20%) represented the highest inverse effect on annual ET_0 throughout the Caspian region (-19% in the Mediterranean, and -30% in other climates). The Mediterranean and extremely humid climates of the Caspian region showed an increase of 2 and 5% of the total ET_0, respectively, in response to 20% change in the wind speed. It is quite essential for managers to take into consideration the expected change in evapotranspiration owing to global warming while planning for development of artificial and natural ecosystems in the Caspian region.

Keywords: Climate change, Meteorological parameters, Penman-Monteith.

INTRODUCTION

Global warming is currently one of the world's most challenging issues. The effect of anthropogenic changes to the land and atmosphere on climate change is being pursued as a dynamic multi-disciplinary problem. Increases in atmospheric greenhouse gases, *i.e.* water vapor, carbon dioxide, methane, nitrous oxide and ozone are considered the major reason for global warming (IPCC, 2013).

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 the IPCC (2013), 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. Global land-surface air temperature has increased in the Northern Hemisphere by 0.3°C per decade from 1979 to 2005 (Hansen *et al*., 2001; Smith and Reynolds, 2005; Brohan *et al*., 2006; Lugina *et al*., 2007).

Previous research suggests that climatic change may have a significant impact on hydrological parameters; namely runoff,

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evapotranspiration (*ET*) soil moisture, and ground water (Nemec and Schaake, 1982; Gleick, 1986; Bultot *et al.*, 1988). *ET* is a major component of the hydrological cycle and 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* is also critical to many applications including water resource management, irrigation scheduling, and environmental studies (Sabziparvar and Tabari, 2010). The principal factors that influence crop water requirements depend upon several climatic parameters such as rainfall, temperature, humidity, sunshine hours, and wind speed. Therefore, any change in climatic parameters due to global warming will likely affect *ET* (Goyal, 2004). Eventually, climate change will increase the dry conditions in the world's 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).

Small changes in *ET* may have important consequences in arid climates. For example, Goyal (2004) reported that a five percent increase in air temperature could increase reference *ET* by 3.6% in arid regions of Rajasthan, India, where the annual rainfall varies from 100 to 400 mm and mean yearly air temperature is 25°C. According to Anderson *et al*. (2008), a 3°C rise in the air temperature in California resulted in approximately 19% increase in reference *ET* where annual average 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 around 17% increase in reference *ET* over a grassland in Northeastern Kansas, USA, during the summer with an air temperature range between 24 and 35°C.

Global warming may increase dry conditions in the world's arid regions by increasing *ET*, thereby aggravating the processes of desertification.

To evaluate the effect of global warming on *ET*, the predictions/forecasts of the change in climatic parameters is necessary. The forecast for the overall spatial and temporal changes in climate owing to the global warming is challenging. However, recent studies provide a range of likely changes in temperature, humidity, precipitation, radiation and wind velocity. These changes will likely affect *ET*. The objective of the present study was to estimate the sensitivity of reference evapotranspiration ET_0 in the Caspian region, north of Iran, as a consequence of changes in climatic parameters due to global warming.

MATERIALS AND METHODS

Characteristics of the Study Area

The research was conducted in the Caspian region, north of Iran (Figure 1). The region is located in the north facing slopes of Alborz Mountains and south of the Caspian Sea. The average annual precipitation varies with approximately 600 mm in the east to more than 2,000 mm in the western Caspian region (Zohary, 1973).

Meteorological Data

Long-term meteorological data (1961-2008) from three meteorological stations were used to parameterize the De Martonne Aridity index [Equation (1)] (Croitoru *et al.,* 2013):

$$I_{DM} = P / (T_a+10) \quad (1)$$

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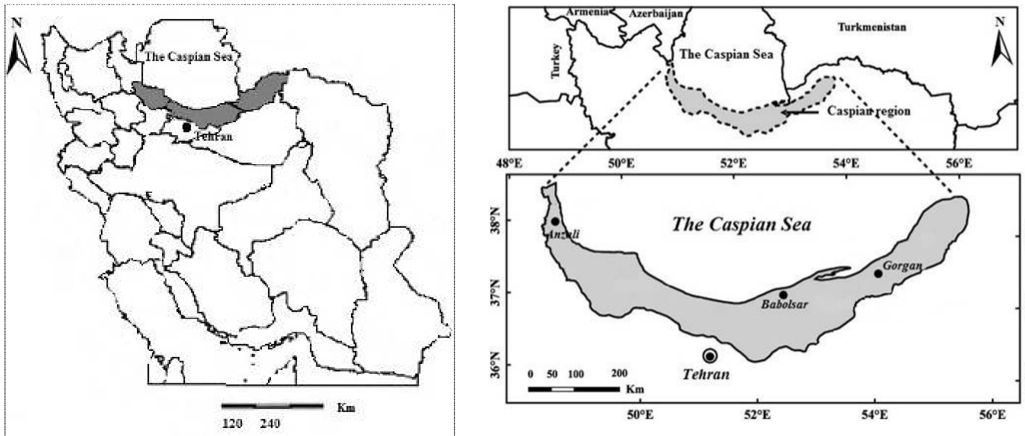

Figure 1. Location of the Caspian region, north of Iran. The names on the lower image represent the locations of synoptic meteorological stations.

Where, I_{DM} is De Martonne Aridity index, P is the total annual precipitation (mm), and T_a is the mean annual air temperature (°C). The De Martonne index was used to classify the climate for the region surrounding each station (Table 1)

Sensitivity of ET_0 to climate change was studied in relation to changes in air temperature, net solar radiation, wind speed and vapor pressure. The range of future meteorological variables was based upon literature review and as used by other researchers. Accordingly, air temperature, net solar radiation, wind speed, and vapor pressure were selected for analysis in a range of variation between +20% to -20% (Goyal, 2004).

Change in precipitation was not considered in this study since it is indirectly related to changes in the other meteorological parameters.

Evapotranspiration Model

We used the Penman-Monteith combination equation to calculate daily ET_0. The FAO Penman-Monteith combination equation is a reliable method for determining reference ET worldwide (Inman-Bamber and McGlinchey, 2003). According to the FAO Penman-Monteith combination equation, ET_0 can be expressed through the following equation (2):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(900/(T_a + 273))u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2)$$

Table 1. Characteristics of the synoptic meteorological stations located in the Caspian region, north of Iran.

Station	Lat (North)	Long (East)	Elevation asl (m)	I_{DM}	Climate classification[a]	Range of meteorological data
Gorgan	36° 51′	54° 16′	13	21	Mediterranean	1961-2008
Babolsar	36° 43′	52° 39′	-21	33	Humid	1961-2008
Anzali	37° 28′	49° 28′	-26	67	Extremely humid	1961-2008

[a] Climate classification is according to the De Martonne Aridity index (I_{DM}) after Croitoru et al. (2013).

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Where, ET_0 (mm day^{-1}) is the reference ET; R_n (MJ m^{-2} day^{-1}) is the net radiation at the crop surface; G (MJ m^{-2} day^{-1}) is the soil heat flux density; T_a (°C) is the mean daily air temperature at a height of 2 m; u_2 (m s^{-1}) is the wind speed at a height of 2 m; e_s (kPa) is saturation vapor pressure; e_a (kPa) is actual vapor pressure; e_s-e_a (kPa) is vapor pressure deficit (VPD); Δ (kPa °C^{-1}) is the slope of vapor pressure curve at the daily mean air temperature; and γ (kPa °C^{-1}) is the psychrometric constant calculated as 0.665×10^{-3} P; in which P (kPa) is the atmospheric pressure.

To calculate daily ET_0, daily mean air temperature, humidity, wind speed at 2 m height, and sunshine hours were employed. Sensitivity of ET_0 was estimated by changing one meteorological parameter between the ranges of ±20% and keeping the remaining three parameters constant. The sensitivity of ET_0 was considered both in the growing (April-September) and non-growing (October-March) seasons.

RESULTS

Long Term Trends of Meteorological Parameters and ET_0

Figure 2 shows monthly mean precipitation and air temperature recorded by meteorological stations located in the Caspian region, from east (Gorgan) to west (Anzali), during 48 years (1961-2008). The long-term trends of the meteorological parameters and ET_0 recorded in the three synoptic meteorological stations throughout the Caspian region can be seen in Figures 3 and 4. The mean values of meteorological parameters within the growing and non-growing seasons are shown in Table 2.

Table 3 shows the changes in meteorological parameters, ET_0 and De Martonne Aridity index in the Caspian region in the recent years (fifteen years) data (1994-2008).

Mean annual air temperature and wind speed increased at all stations during the past 48 years (Figures 3 and 4). Air temperature has increased in all stations during the two past decades (Table 3). The maximum increase in the air temperature (1ºC) was recorded in the central part of the Caspian region, Babolsar station (Table 3). Furthermore, wind speeds increased in all stations, with the highest increase occurring in Gorgan station (1.6 m s^{-1}). Relative humidity marginally increased in Gorgan (+4.9%), but

Table 2. Long term (1961-2008) average and standard errors (±SE) of meteorological parameters as well as reference evapotranspiration in the Caspian region of northern Iran.

Meteorological Station	Season[a]	Mean annual air temperature (° C)	Mean annual precipitation (mm)	Mean annual relative humidity (%)	Wind speed (m s^{-1})	Reference evapotranspiration (mm day^{-1})
Gorgan	G	23.9 ± 0.10	207 ± 9.21	70 ± 0.71	3.4 ± 0.20	4.4 ± 0.11
	N - G	11.7 ± 0.14	375 ± 12.03	73 ± 0.74	2.5 ± 0.17	1.6 ± 0.04
	A	17.8 ± 0.10	582 ± 16.35	70 ± 0.69	3.0 ± 0.18	3.0 ± 0.07
Babolsar	G	22.6 ± 0.10	354 ± 16.14	80 ± 0.28	4.1 ± 0.13	3.8 ± 0.05
	N - G	11.6 ± 0.13	550 ± 18.82	85 ± 0.30	3.5 ± 0.12	1.5 ± 0.01
	A	17.2 ± 0.10	906 ± 22.67	83 ± 0.27	3.8 ± 0.12	2.6 ± 0.03
Anzali	G	21.7 ± 0.09	777 ± 31.75	82 ± 0.44	4.4 ± 0.12	4.5 ± 0.13
	N - G	10.8 ± 0.14	984 ± 34.28	87 ± 0.37	4.7 ± 0.12	1.6 ± 0.60
	A	16.3 ± 0.09	1763 ± 48.30	84 ± 0.38	4.5 ± 0.12	3.1 ± 0.08

[a] G: Growing season (April-September); N-G: Non-Growing season (October-March), A: Annual.

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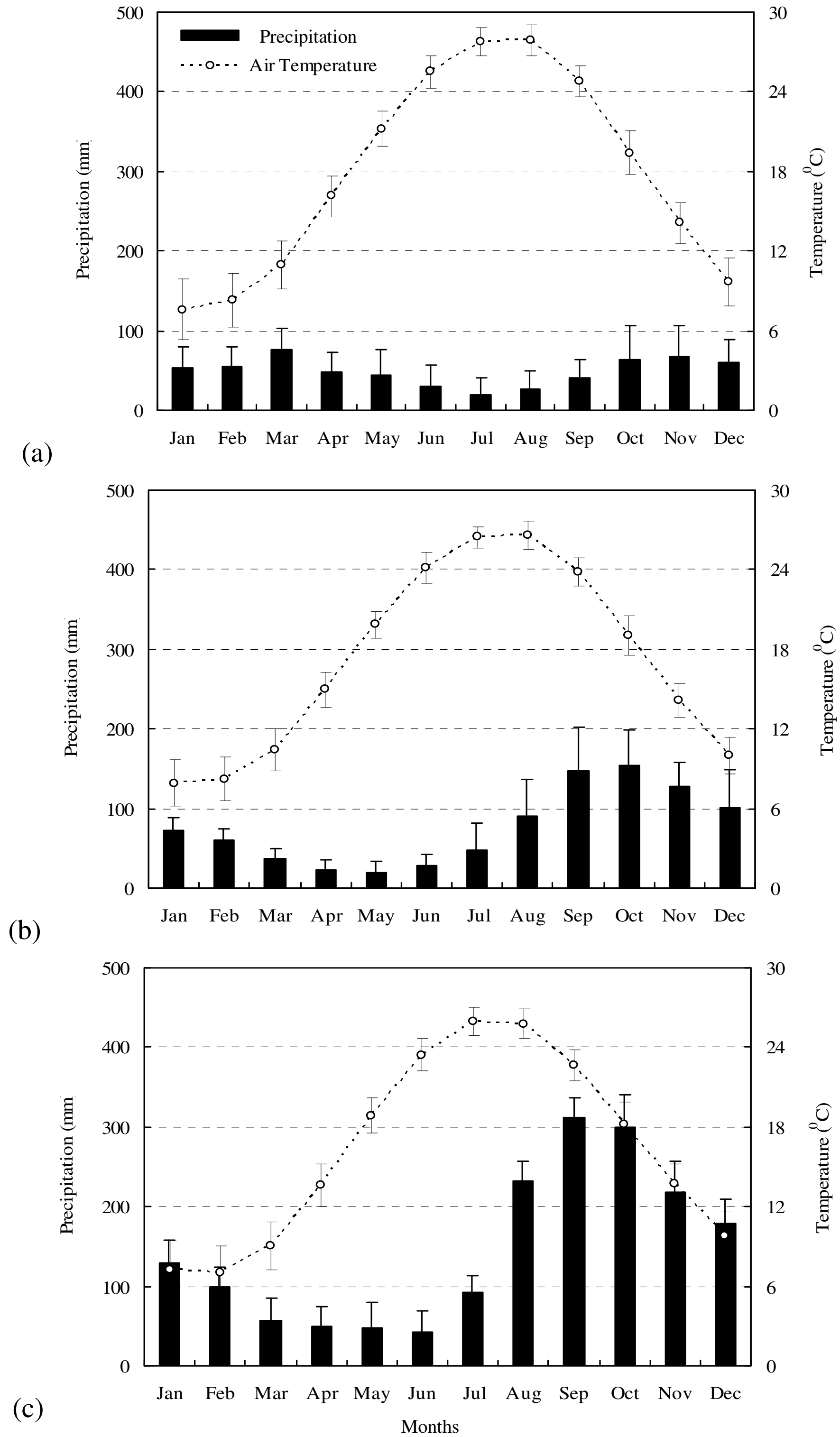

Figure 2. Monthly mean precipitation and air temperature recorded during 48 years (1961-2008) by the Synoptic Meteorological Stations located in the Caspian region [(a) Gorgan; (b) Babolsar, and (c) Anzali]. Error bars show the standard deviation (SD) of monthly precipitation and temperature during the recorded periods.

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Table 3. Changes in meteorological parameters, reference evapotranspiration and De Martonne Aridity index in the Caspian region, northern Iran, in the recent years (fifteen years) data (1994-2008).

	Gorgan	Babolsar	Anzali
Mean air temperature (1961- 1993) (ºC)	17.7	16.8	16.1
Mean air temperature (1994- 2008) (ºC)	18.1	17.8	16.7
Air temperature changes (ºC)	0.4	1	0.6
Air temperature changes (%)	2.2	6	3.5
Mean relative humidity (1961- 1993) (%)	68.5	83.2	84.7
Mean relative humidity (1994- 2008) (%)	73.4	80.9	83.7
Relative humidity changes (%)	4.9	-2.3	-1
Relative humidity changes (%)	7.2	-2.8	-1.2
Mean wind speed (1961- 1993) (m s^{-1})	2.5	3.4	4.2
Mean wind speed (1994- 2008) (m s^{-1})	4.1	4.6	5.1
Wind speed changes (m s^{-1})	1.6	1.2	0.9
Wind speed changes (%)	64.1	35.7	21.1
Mean precipitation (1961- 1993) (mm)	608.5	891.6	1792.9
Mean precipitation (1994- 2008) (mm)	524.5	938.3	1696.4
Precipitation changes (mm)	-84	46.6	-96.5
Precipitation changes (%)	-13.8	5.2	-5.4
Reference evapotranspiration (1961- 1993) (mm day^{-1})	2.7	2.5	3
Reference evapotranspiration (1994- 2008) (mm day^{-1})	3.3	2.8	3.3
Reference evapotranspiration changes (mm day^{-1})	0.6	0.3	0.3
Reference evapotranspiration changes (%)	22	12.4	9.7
De Martonne Aridity index (1961-1993)	21.9	33.2	68.5
De Martonne Aridity index (1994-2008)	18.7	33.7	63.5

decreased in Babolsar and Anzali (-2.3 and 1%, respectively) during the past fifteen years.

Due to changes in meteorological parameters, ET_0 demonstrated increasing trends throughout the Caspian region (Figure 4). The greatest increase was observed in Gorgan station (22%) (Table 3). Our results indicated that De Martonne Aridity index has decreased in eastern and western parts of the Caspian region, however, rose slightly in the center of the Caspian region (Babolsar).

Sensitivity of Reference Evapotranspiration

Table 4 represents the future possible changes in the seasonal and annual ET_0 in response to expected changes in meteorological parameters due to global warming. The relative changes in seasonal and annual ET_0 owing to the relative changes in meteorological parameters are presented in Figure 5 (a-e).

The long-term average annual ET_0 (1961-2008) for the three stations in the Caspian region was 960 mm (Table 3). The minimum ET_0 values were observed in Anzali, very humid climate, (902 mm) and the maximum values happened in Gorgan (1126 mm). Seventy percent of the annual ET_0 occurred in the growing season, and July had the highest mean monthly ET_0; approximately 15% of the total annual ET_0 was in July.

In response to the change in net radiation (± 20%), ET_0 varied approximately ±12% in all stations. The change in net radiation had more effect on ET_0 during the non-growing season (approximately ±15%) than the growing season (approximately ±12%).

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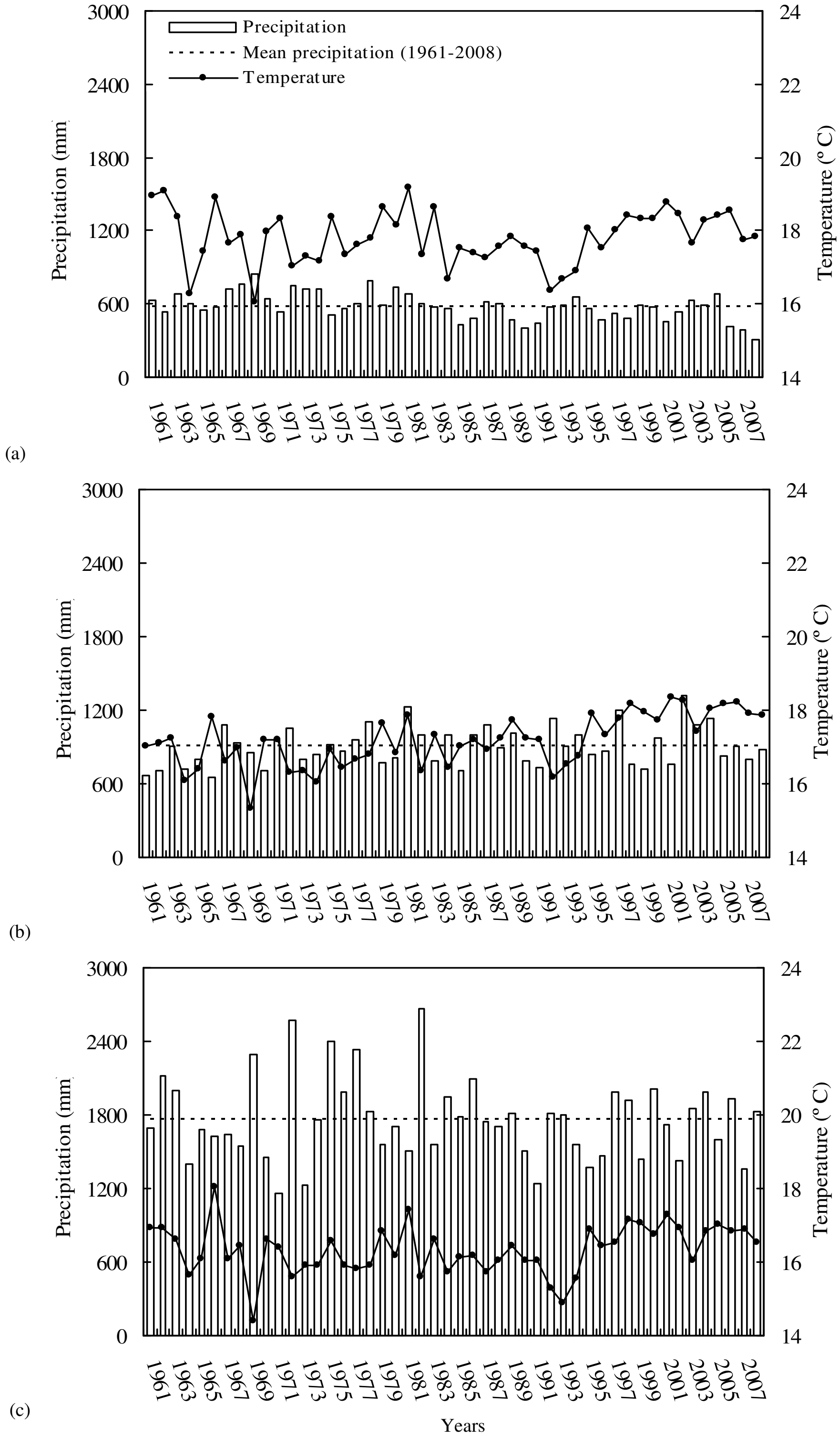

Figure 3. Long-term (1961–2008) trends of mean annual precipitation and air temperature in the Caspian region of northern Iran [(a) Gorgan; (b) Babolsar, and (c) Anzali].

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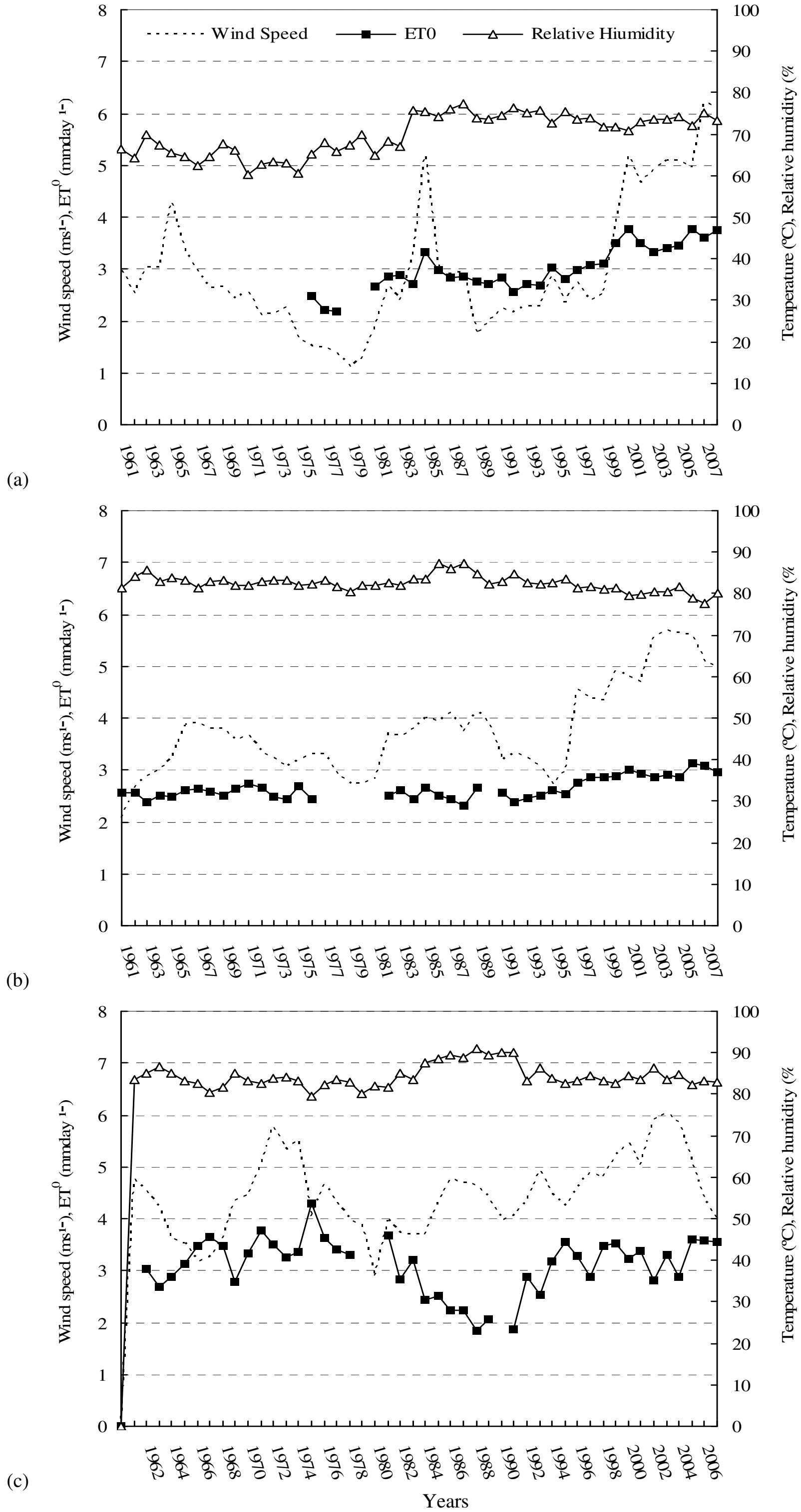

Figure 4. Long-term (1961–2008) trends of mean annual wind speed, relative humidity, and reference evapotranspiration in the Caspian region of northern Iran [(a) Gorgan; (b) Babolsar, and (c) Anzali].

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Table 4. Estimated total reference evapotranspiration (*ET_0*) in response to expected changes in each meteorological parameter (in isolation) due to global warming change [(a) Gorgan; (b) Babolsar, and (c) Anzali].

(a)

Meteorological parameters	Seasons[a]	Change in total evapotranspiration (mm) in relation to a percent change in each meteorological parameter								
		-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
Net radiation	G	736	758	779	801	823	845	867	889	911
	N - G	265	275	284	294	303	313	322.6	332	342
	A	1001	1033	1063	1095	1126	1158	1189.6	1221	1253
Wind speed	G	786	796	805	814	823	832	840	848	856
	N - G	292	295	298	301	303	306	3088	311	314
	A	1078	1091	1103	1115	1126	1138	3928	1159	1170
Temperature	G	729	750	772	797	823	852	883	916	952
	N - G	286	290	294	298	303	308	314	319	325
	A	1015	1040	1066	1095	1126	1160	1197	1235	1277
Vapor pressure	G	976	938	900	862	823	785	746	707	669
	N - G	358	345	331	317	303	290	276	262	248
	A	1334	1283	1231	1179	1126	1075	1022	969	917

(b)

Meteorological parameters	Seasons[a]	Change in total evapotranspiration (mm) in relation to a percent change in each meteorological parameter								
		-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
Net radiation	G	617	639	661	683	705	727	749	771	793
	N - G	228	237	247	256	265	274	284	293	302
	A	845	876	908	939	970	1001	1033	1064	1095
Wind speed	G	688	692	697	701	705	709	713	716	720
	N - G	260	262	263	264	265	266	267	268	269
	A	948	954	960	965	970	975	980	984	989
Temperature	G	647	660	674	689	705	722	741	762	784
	N - G	254	257	259	262	265	268	272	275	279
	A	901	917	933	951	970	990	1013	1037	1063
Vapor pressure	G	885	840	795	750	705	660	614	569	523
	N - G	345	325	305	285	265	245	225	205	184
	A	1230	1165	1100	1035	970	905	839	774	707

(c)

Meteorological parameters	Seasons[a]	Change in total evapotranspiration (mm) in relation to a percent change in each meteorological parameter								
		-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
Net radiation	G	577	598	619	640	661	682	703	724	745
	N - G	209	217	225	233	241	249	257	265	273
	A	786	815	844	873	902	931	960	989	1018
Wind speed	G	648	652	655	658	661	664	667	670	672
	N - G	237	238	239	240	241	242	243	244	245
	A	885	890	894	898	902	906	910	914	917
Temperature	G	609	621	633	646	661	677	694	712	731
	N - G	230	233	235	238	241	244	248	251	255
	A	839	854	868	884	902	921	942	963	986
Vapor pressure	G	848	802	755	708	661	614	567	519	472
	N - G	337	313	289	265	241	217	193	169	145
	A	118 5	111 5	104 4	973	902	831	760	688	617

[a] G, N-G, and A refer to the Growing season (April-September); Non-Growing season (October-March), and Annual estimates, respectively.

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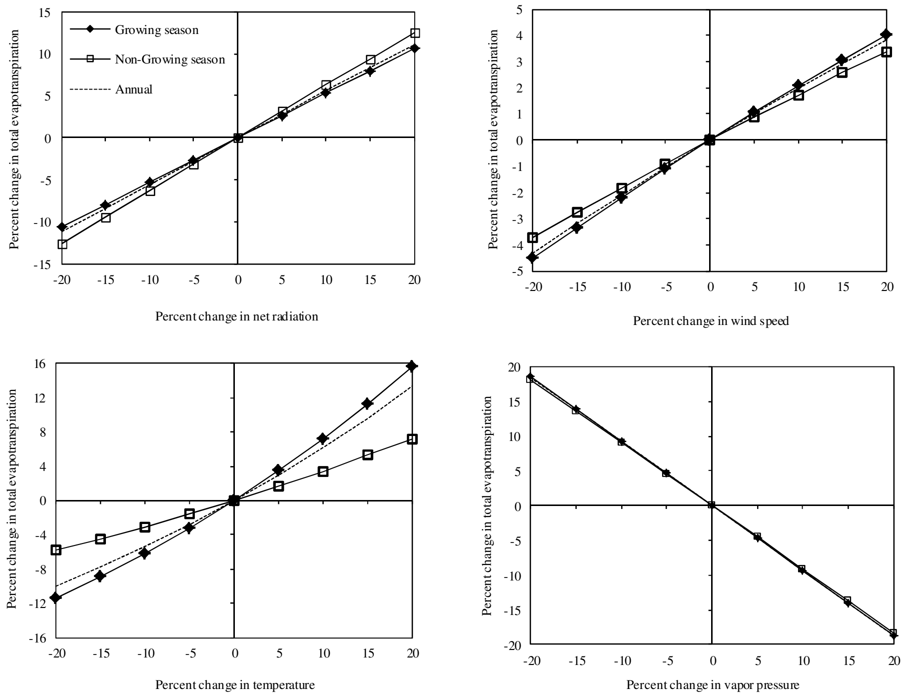
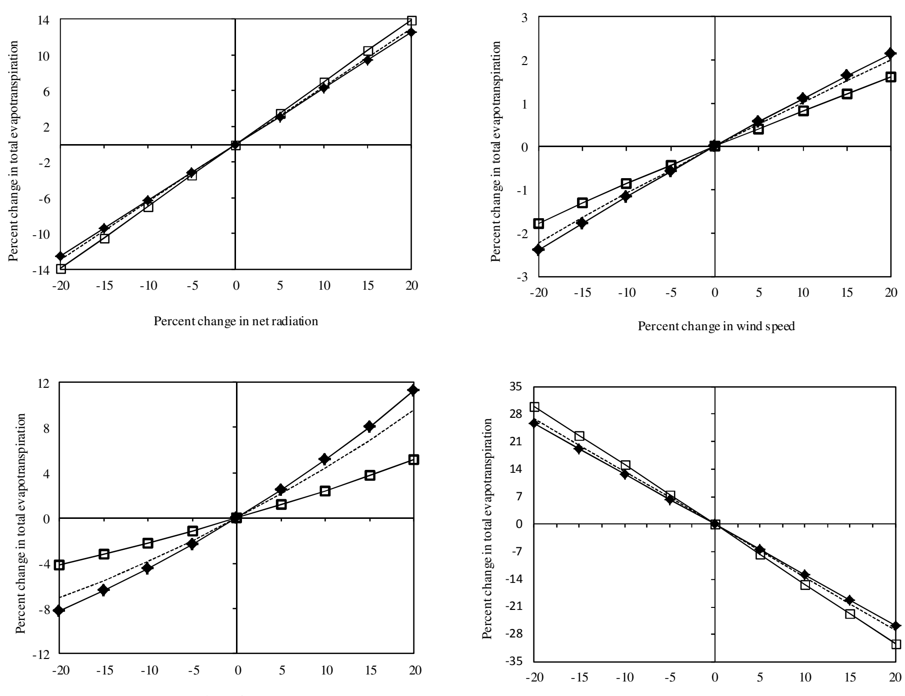


(a)



(b)

Figure 5. Sensitivity of reference evapotranspiration (ET_0) demand in response to expected change in each meteorological parameter (in isolation) due to global warming [(a) Gorgan; (b) Babolsar, and (c) Anzali].

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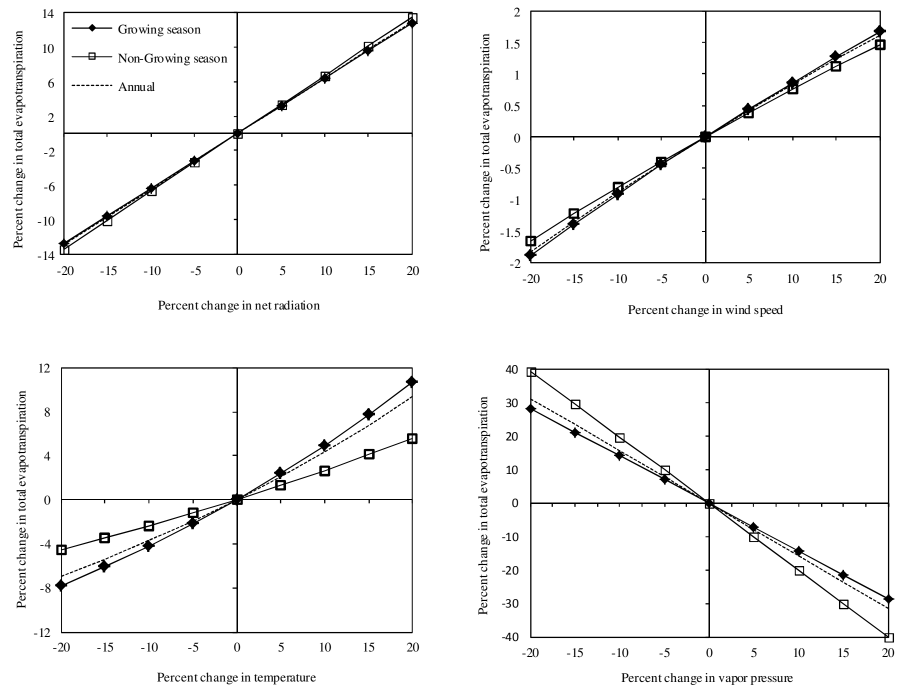

Continued of Figure 5. (c)

Our results showed that ET_0 was very sensitive to the change in actual vapor pressure in the Caspian region. Changes in actual vapor pressure (±20%) represented the highest effect on annual ET_0 throughout the Caspian region (±19% in Gorgan compared to ±30% in other stations). ET_0 increased with the decreases in actual vapor pressure. The behavior of ET_0 in response to the change in vapor pressure, however, was different from the eastern to the western Caspian region. The sensitivity of ET_0 to the change in actual vapor pressure (20%) during the non-growing season in western region near Anzali (±40%) was higher than those of other more eastern stations (Gorgan: ±18%, Babolsar: ±30%).

At all of the stations, changes in wind speed had the least effect on ET_0. The maximum and minimum sensitivity to ET_0 in response to changes in the wind speed (±20%) were observed in Gorgan (±5%) and Anzali (±2%), respectively.

In response to the change in air temperature, the eastern Caspian region, with the Mediterranean climate (Gorgan), showed the highest sensitivity of ET_0, *i.e.* ±16% changes in ET_0 against ±20% change in the air temperature. ET_0 was more sensitive to increasing air temperature relative to decreasing air temperatures.

DISCUSSION

Throughout the Caspian region, we observed increasing trends in ET_0. Tabari *et al.* (2011) considered the annual, seasonal, and monthly trends in the ET_0 at 20 meteorological stations in the western half of Iran and showed that the magnitude of significant positive trends in annual ET_0 varied from +11.28 to +2.30 mm per year. Changes in ET_0 can have a profound effect on agriculture, forests, and water resources in the Caspian region and this may put a pressure on existing water resources.

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Understanding the impact of climate change on ET_0 rates is essential for water resources planning. For example, increases in ET_0 may increase the water requirements of the agricultural crops. Since crop water requirements depend upon several climatic parameters including rainfall, radiation, temperature, humidity, sunshine hours, and wind speed, any change in climatic parameters attributed to climate change will also affect ET_0 (Moratiel *et al.*, 2010).

Meteorological parameters have changed in the Caspian region in the past half century. In this region, 70% of the annual ET_0 typically occurs within the growing season, from April to September, and around 15% of the total annual ET_0 happens in July. Since the greatest water need for crops occurs in July, any changes in the monthly *ET* rate can affect the distribution and/or sizing of the irrigation system (Moratiel *et al.*, 2010).

There was a variation in ET_0 sensitivity in response to changes in meteorological parameters in the Caspian region, so that the highest effect on annual ET_0 was attributed to the change in actual vapor pressure during the non-growing season. Saturation vapor pressure increases exponentially with increasing temperature. If all other factors remain unchanged, warming causes drier air and hence higher ET_0.

Historically, wind speed in the Caspian region is 3-4 m s^{-1}, and a 20% change in wind speed has only a minimal effect on annual ET_0. During the growing season, the typically hot and dry wind results in more ET_0 relative to the cold wind during the non-growing season.

Some past research reports state that evapotranspiration over grasslands increased by 17% while air temperature increased up to 3°C (Martin *et al.,* 1989, Rosenberg *et al.,* 1989). However, the present study revealed that in response to the increasing air temperature of approximately 3°C, ET_0 varied around ±16% in the Caspian region. In eastern Caspian region, ET_0 was the most sensitive to a change in the air temperature because of the climate in Gorgan being drier and warmer than other stations. Since the mean air temperature in the non-growing season throughout the Caspian region was low, a percent change in air temperature had a lower effect on ET_0 during the non-growing season as compared to the growing season.

Forest ET_0 is generally larger 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 and Kanae 2006; Matsumoto *et al*., 2008). The temperate deciduous and broad-leaved forests of Iran are located in the Caspian region. These natural commercial forests cover an area of around 2 million hectares in a narrow strip over 800 km long and 20-70 km wide. Changes in ET_0 will certainly affect the natural forest ecosystems in the Caspian region. The composition of the species, eco-physiological characteristics of the trees as well as the spatial distribution of the tree species may be threatened by climate change in the Caspian region.

The results are also informative for the forest managers in the Caspian region. Determining the forest ecosystems most sensitive to the global climate change may be one of the available solutions in this regard. Climate change is often evaluated as one of the serious risks that threaten the sustainable development in various aspects of environmental, human health, food security, economic activities, natural resources and the underlying structures (Jafari, 2008).

Increased concentration of greenhouse gases is expected to alter the radiation balance of atmosphere, causing increases in temperature and changes in precipitation patterns and other climatic variables such as ET_0. Any change in ET_0 will be likely to have a deep effect on agriculture and water resources planning as well as on forest ecosystems. This study provides a preliminarily idea about the likely changes in evapotranspiration demand of the humid

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region of Iran by considering a wide spectrum of possible scenarios. Although the results shown in this study are estimates, they may be useful in future for planning, designing, and operating irrigation systems and crop planning.

Increases in temperature, wind speed, and solar radiations and decreases in vapor pressure will likely cause an increase in evapotranspiration in this region of Iran. The long-term changes in evapotranspiration demand may have profound implications for this humid zone of Iran. Due to the increase in evapotranspiration, the agricultural activity will suffer. The Caspian region receives good amounts of precipitation and evapotranspiration rate is relatively low as compared to the other parts of Iran. The long-term meteorological data analysis of this region showed the increasing trend of evapotranspiration due to global warming.

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تعیین میزان حساسیت تبخیر و تعرق مرجع نسبت به گرمایش جهانی در ناحیه خزری

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چکیده

تحقیق حاضر با هدف بررسی میزان حساسیت تبخیر تعرق مرجع(ET_0) نسبت به تغییرات پارامترهای اقلیمی در ناحیه خزری صورت گرفت. بدین منظور در ابتدا با استفاده از داده‌های هواشناسی طولانی مدت (۲۰۰۸– ۱۹۶۱) سه ایستگاه هواشناسی همدیدی و به کمک شاخص خشکی دومارتن، سه منطقه‌ی اقلیمی مجزا در ناحیه خزری مشخص شد. معادله ترکیبی پنمن مانتیث برای محاسبه ET_0 مورد استفاده و حساسیت آن در هر منطقه نسبت به تغییرات دما، تابش خورشید، سرعت باد و فشار بخار در دامنه‌ی ۲۰± درصد از داده‌های نرمال، مورد مطالعه قرار گرفت. نتایج حاصل از این پژوهش، ناحیه خزری را از شرق به غرب به سه منطقه اقلیمی مدیترانه‌ای، مرطوب و خیلی مرطوب تقسیم بندی کرد. کلیه پارامترهای اقلیمی و همچنین ET_0 در طول نیم قرن گذشته تغییرات چشمگیری داشته‌اند، بالاخص پارامتر دمای هوا که در نیم قرن گذشته در تمامی ایستگاه‌های مورد مطالعه روند افزایشی داشته است. تغییرات ۲۰ درصدی دمای هوا (تقریبا ۳/۳ درجه سانتی‌گراد) به‌طور متوسط تغییرات ۱۶ درصدی ET_0

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را سبب خواهد شد. همچنین نتایج حاکی از آن است که تغییرات پارامتر فشار بخار (۲۰± درصد) بیشترین تاثیر را بر ET_0 داشته است (۱۹ درصد کاهش در اقلیم مدیترانه‌ای و۳۰ درصد کاهش در دو اقلیم مرطوب و خیلی مرطوب). پارامتری که تغییرات آن کمترین تأثیر را بر ET_0 در ناحیه خزری نشان داد، سرعت باد بود بطوری که افزایش ۲۰ درصدی آن منجر به افزایش ۲ و ۵ درصدی ET_0به ترتیب در اقلیم‌های مدیترانه‌ای و خیلی مرطوب گردید. در برنامه‌ریزی‌هایی که درجهت توسعه اکوسیستم‌های طبیعی و مصنوعی در ناحیه خزری صورت می‌گیرد، باید تغییرات احتمالی تبخیر تعرق در نتیجه گرم شدن جهانی در نظر گرفته شود.

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