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Full Length Research Paper

Elevation of spatio-temporal variation of recent and future evapotranspiration trends in arid areas of Iran (Case study: Yazd)

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The present research has been conducted aiming at simulation of the effect of climate changes on evaporation in Yazd. This research considers both the changes of the trend of the observational meteorological data in the past decades and the changes of the future decades. In evaluation of the evaporation data of the Yazd in the past decades, the statistical period of 1953 to 2009 has been considered. In the next step and in order to identify the changes of temperature of the future decades, meteorological data has been simulated based on Global Climate Models (also known as General Circulation Models, GCM). To do so, GCM model have been used based on a single scenario called P 50. Consequently, the results show that temperature rise occurs in all studied months, while these variations in annual temperature rise is accompanied with temperature rise of +0.35°C in every decade from 1953 to 2009. But after simulation of temperature changes for the future, the results indicated that the Yazd's temperature in 2100 would have an increase of 4.25°C in comparison with the average temperature of the period from 1960 to 1990. Also, in general, by simulating evapotranspiration rate, it has been found that in most months of the year, especially the warm seasons (spring and summer), evapotranspiration rate is more than the long-term mean, so that we would experience warmer springs and summers than previous decades. On the other hand, considering the fact that evapotranspiration rate would have the increase of 684.31 mm to the long-term mean by 2100, the intensification of water requirement in different areas especially agriculture may appear as a big problem and great crisis. In such a climatic condition, there would be no place for dry farming, so the main focus is mostly on irrigation, which is itself faced with serious problems because of unavailability of water resources such as lakes, rivers, etc.

Key words: Simulation, global climate models, arid region, evaporation, water requirement, Yazd.

INTRODUCTION

Shortly after the invention of the thermometer in the early 1600s, efforts began to quantify and record the weather. The first meteorological network was formed in northern Italy in 1653 (Kington, 1988; IPCC, 2007) and reports of temperature observations were published in the earliest scientific journals (Wallis and Beale, 1669; cited in IPCC, 2007).

In the 1950s, the greenhouse gases of concern remained CO_2 and H_2O, the same two identify by Tyndall a century earlier. It was not until the 1970s that other greenhouse gases – CH4, N_2O and CFCs – were widely recognized as important anthropogenic greenhouse gases (Ramanathan, 1975; Wang et al., 1976; cited in IPCC, 2007). By the 1970s, the importance of aerosol-cloud effects in reflecting sunlight was known (Twomey, 1977; IPCC, 2007), and atmospheric aerosols (suspended small particles) were being proposed as climate-forcing constituents.

Evidence indicates that increasing atmospheric concentrations of trace gases such as CO_2, CH_4, N_2O, tropospheric O_3, the CFCs and others will enhance the earth's natural greenhouse effect and lead to a global warming and consequent alterations in global climate (Norman et al., 2003).

The most likely global average surface temperature increase by the 2020s is around 1°C relative to the preindustrial period, based on all the IPCC special report on emissions scenarios SRES (Nakićenović and Swart, 2000; cited in IPCC, 2007) scenarios. By the end of the 21st century, the most likely increases are 3 to 4°C for the A2 emissions scenario and around 2°C for B1 (IPCC, 2007).

Therefore Based on the simulation of GCMS, future changes of global average temperature are expected to be between 2.8 and 4.58°C in this century (IPCC, 2001), and some regional areas would be even warmer than the global average (Giorgi and Bi, 2005; Roshan et al., 2010). So, both for policymakers and scientists, impacts of global warming on agriculture and water resources are referred to as an important issue (Gregory and Ingram, 2000; Sanchez, 2000; Fuhrer, 2003; Guo et al., 2009). Under climate warming, and CO_2 concentration increasing as well, the crop production could be affected in several ways. The environment changes including soil conditions (mainly changes of soil moisture) and air conditions could strongly affect the physiological processes such as photosynthesis, respiration and partitioning of photosynthesis production (Chartzoulakis and Psarras, 2005; Yang and Zhang, 2006; Guoe et al., 2009). Along with the mean temperature increasing, the occurring frequency of extreme temperature may increase, that may abruptly affect the crop activity (Ko¨rner et al., 2002; Wu et al., 2006).

Effects of higher temperature, elevated CO_2 concentration and changed precipitation are complicated (Dhungana et al., 2006; Walker and Schulze, 2008). However, CO_2 fertilization will alleviate the effects of temperature and precipitation on crop yield (Brown et al., 2000; Ludwig and Asseng, 2006; Krishnan et al., 2007). Increment of atmospheric CO_2 had an obvious positive effect on photosynthetic rates, leading to enhancement of total biomass and yield of C3 crops (Dhakhwa et al., 1997; Wolf et al., 2002; de Costa et al., 2006; Ruiping Guo et al., 2009). With the physiological process's changes, the management practices could be affected through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers.Surface temperatures should rise around the world, but not uniformly in all regions. Since the capacity of the atmosphere to hold water increases exponentially with its temperature, evaporation and transpiration rates will increase.

Precipitation (PPT) will also increase as its geographic and temporal patterns change. Although there will be more precipitation overall, not all regions will receive more; some will almost certainly receive less. These expected climatic changes will undoubtedly impact both the supply of and the demand for water (Norman et al., 2003). All IPCC regions show an overall net negative impact of climate change on water resources and freshwater ecosystems (high confidence).Areas in which runoff is projected to decline are likely to face a reduction in the value of the services provided by water resources (very high confidence). The beneficial impacts of increased annual runoff in other areas will be tempered by the negative effects of increased precipitation (PPT) variability and seasonal runoff shifts on water supply, water quality, and flood risks (high confidence) (IPCC, 2007).

Also, numerous studies have been carried out on the impact of climate variability and change on crop production as a function of water balance (Mearns et al., 1992; Bacsi and Hunka´r, 1994; Semenov and Porter, 1995; Eitzinger et al., 2000; Xie et al., 2001; Alexandrov et al., 2002). The anticipated climatic changes will have considerable effects on cropping systems worldwide. Both positive and negative temperature and precipitation trends have been established with a fair degree of accuracy during recent decades (IPCC, 2001) while changes in global evaporation rates are still under discussion .Climate change impact studies on crop production are affected by uncertainties, however, which can be caused by several factors (Carter et al., 1999).To estimate changes in potential irrigation demand climatic scenarios are developed from observed trends rather than from GCM results. Particular emphasis is put on the effects of inter annual climatic variability in the scenarios.

A key question is how much irrigation water is actually necessary under present and future climatic conditions to support the Yazd agriculture. The capacity to supply irrigation water is the key to future sustained, or even extended agricultural production.

MATERIAL AND METHODS

Trend of evaporation in past and recent

The first part is related to analysis of the Yazd's evaporation trend by the use of the existing data. To evaluate Yazd's evaporation trend using the available data, the mean temperature from January 1953 to December 2009 have been used.

The trend tests are classified into two parametric and nonparametric groups. The presupposition of the parametric tests is that the data are random and outcomes of a normal distribution. Still, the presupposition of normality of the data does not exist in the nonparametric tests. Therefore, in case the normality of the data is not reliable, it is more confident to use nonparametric tests. Notwithstanding, some researchers have proved that the difference between the results of the 2 methods is not significant in regard to many of the climate components (Roshan et al., 2011).

Here, for the purpose of performing the evaporation trend test, we suppose that evaporation is a linear function of time; therefore, the changes model would be as follows:

$$Evaporation = \alpha + \beta Time \qquad (1)$$

It is evident that a positive value of β indicates the evaporation increase by time, and a negative value for β indicates the evaporation decrease by time. If β=0, the presupposition is not proved. But since the value of β is definite, an estimation of β is obtained from the following equation with 95% of reliability (Masoudian, 2005):

$$\hat{\beta} = \pm t_{0.025} \frac{S}{\hat{S}} \qquad (2)$$

If the upper and the lower limits of β, achieve by this method are both positive, the presupposition of increasing trend of evaporation is not rejected, but if the upper and he lower limits of β are both negative, the presupposition of decreasing trend of evaporation is rejected. If one of the upper or the lower limit is positive and the other one is negative, the trend presupposition is not confirmed.

RESULTS AND DISCUSSION

Analysis of evapotranspiration trend of Yazd in a period from 1953 to 2009

At this stage, first the variation trend of temperature components for Yazd station has been studied and analyzed. The results indicate temperature rise trend in all months of the year. The temperature rise in autumn for the months of January, February and March is r=0.14, r=0.10 and r=0.07, respectively. However this temperature trend is increasing for the months of winter; it does not show an acceptable significant level (Figure 1). In the months of spring, the trend of temperature rise shows a significant level for April (r = 0.36), May (r=0.26) and January (r=0.42), respectively (Figure 2). Also this trend has been done for the months of summer, in which the months of July (r =0.31), August (r= 0.34) and finally September (r=0.39) have shown a reliable significant level (Figure 3).

In the study done for recognizing temperature variation trend in autumn, we have had the maximum significant level of temperature rise in this season as compared with other seasons of the year in which October (r=0.46), November (r=0.47) and December (r=0.39) have shown the highest significant level (Figure 4). Generally, the annual temperature variation with (r =0.59) indicates temperature rise with the rate of 0.3°C in every decade from 1935 to 2009.

However, in the study conducted for recognizing the trends of evapotranspiration component, we could mention the following results:

Based on the statistical period from 1953 to 2009, the minimum mean evapotranspiration in January has been 5.92 mm in average, the evapotranspiration rate of this month has had a decrease of -0.02 mm in every decade. The statistical values related to evapotranspiration trend are as follows (p=0.585; r = -0.08). In the second month of winter, February, the monthly long-term mean evapotranspiration has been calculated to be 12.68 mm, which is increased by about +0.10 mm. in every decade. (p=0.532; r=-0.09) (Table 1). For March in which the long-term mean evapotranspiration is 31.67 mm. The evapotranspiration has an increase of +0.37 mm. In every decade (p=0.410; r=-0.12). In the calculation done for the months of spring, the long-term mean evapotranspiration in April, May and January are respectively 69.55, 117.09, and 176.56 mm, respectively that the increase of this component in every decade is respectively as follows: 1.09 (April), 3.19 (May), and 3.96 mm. (January). The statistical values for variation of the trend of this component were calculated and the following values are obtained: April (p=0.05; r = 0.26), May (p= 0.063; r = 0.07) and January (p= 0.000; r = 0.51) (Table 1).

The highest monthly mean evapotranspiration is seen in summer. This mean has been calculated for July (202.8 mm), August (177.71 mm) and September (129.29 mm), respectively.

Moreover, the highest evapotranspiration increase in every decade has been allocated to July with the rate of 6.03, 4.52 for August and finally 3.38 mm for September. The statistical values of trend variation has been (p=0.001; r=0.51) for July, (p=0.003; r = 0.040) for August and (p=0.002; r = 0.41) for September.

In autumn, known as the first cold season of the year, the monthly mean evapotranspiration is again decreased, as compared with the warm seasons of the year that are spring and summer, so that the long-term mean extracted for October is (69.50), November is (26.68) and December is (9.26). The increase of evapotranspiration has been calculated for every decade, so that it is +3.37 mm for Oct. (p=0.004; r = 0.39), +0.53 mm for November (p=0.028; r = 0.30) and +0.44 mm for December (p=0.065; r = 0.25).

Simulation of temperature and evapotranspiration value using proposed models of GCM for the future decades

Considering the significance of recognizing the effect of global warming on evapotranspiration variations in future decades, here we apply INMCM-30 model to simulate temperature rate in 2025, 2050, 2075 and 2100 decades. First in this part, the values of temperature rise in Yazd station has been forecasted for different months of the future decades, and the results indicate temperature rise with the rate of 4.53°C as compared with the long-term mean (1960 to 1990) until the year 2100. In this regard, the highest mean temperature rise is simulated by the year 2100 with 3.6°C in September and 1.8°C in February (Figures 5 and 6).

In the study conducted for monthly evapotranspiration values, it has been specified that, in most months we see the increase of evapotranspiration value except for the months of January (R^2=0.15; r=-0.39), February (R^2=0.94; r=-0.97), and December (R^2=0.56; r =- 0.75). The highest mean is related to July from the year 2025 to 2100, which is about 284 mm, while the lowest value is simulated for January with the rate of 0.65 mm. Therefore, the statistical values related to increasing trend of evapotranspiration for different months are as follows: March (R^2=0.84; r=0.92), April (R^2=0.90; r=0.95), May (R^2=0.99; r=0.99), June (R^2=0.98; r=0.99), July (R^2=0.99; r=0.99), August (R^2=0.99; r=0.99), September (R^2=0.96; r=0.98), October (R^2=0.97; r=0.98) , November (R^2=0.89; r =0.94).

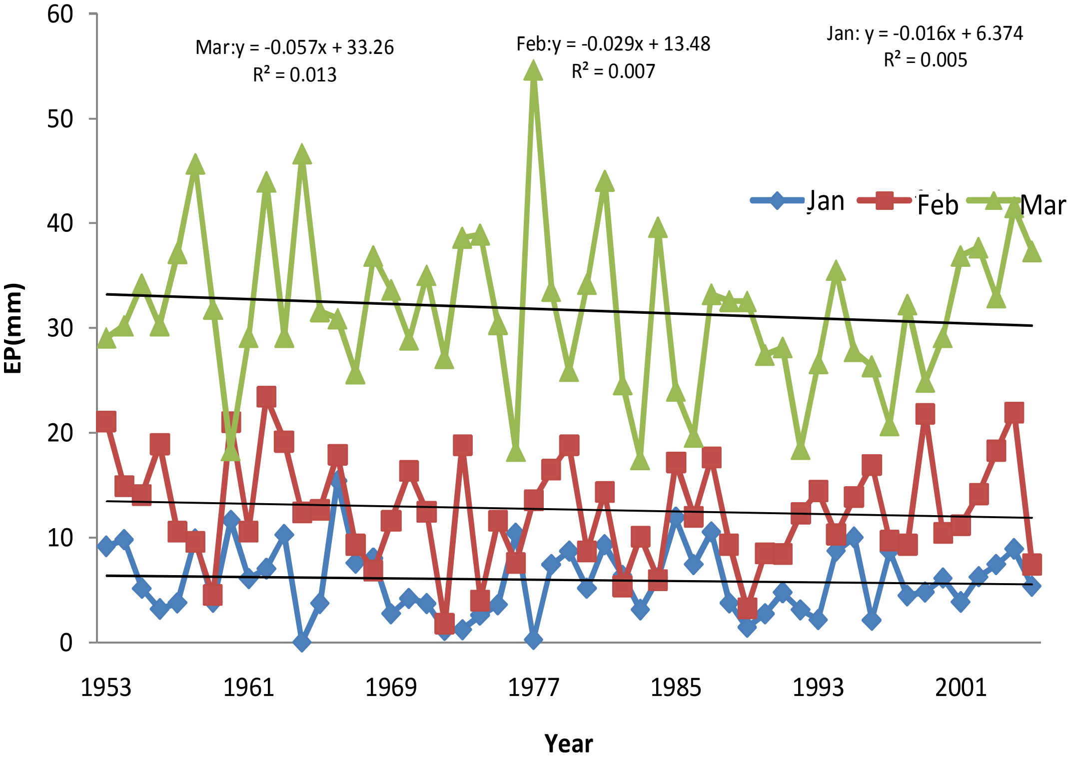

Figure 1. Long-term trend (1953-2009) recognition of evapotranspiration in the months of winter.

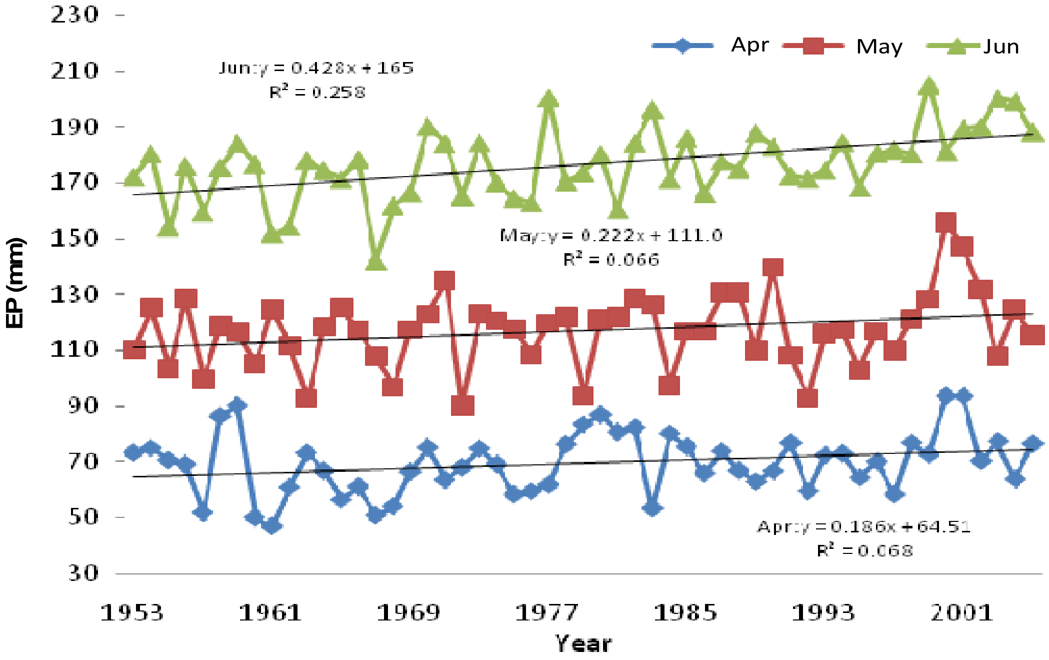

Figure 2. Long-term trend (1953-2009) recognition of evapotranspiration in the months of spring.

Conclusion

Analyzing monthly temperature mean data from the years 1953 to 2009, it has been specified that we have temperature rise in most months. In general, annual temperature variations (r=0.59) indicate temperature rise

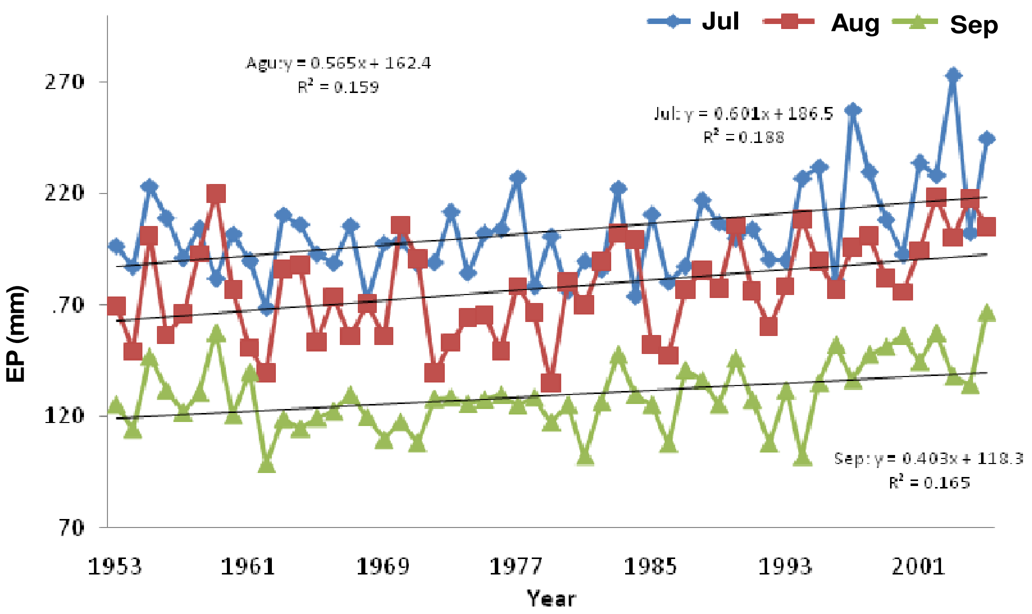

Figure 3. Long-term trend (1953-2009) recognition of evapotranspiration in the months of summer.

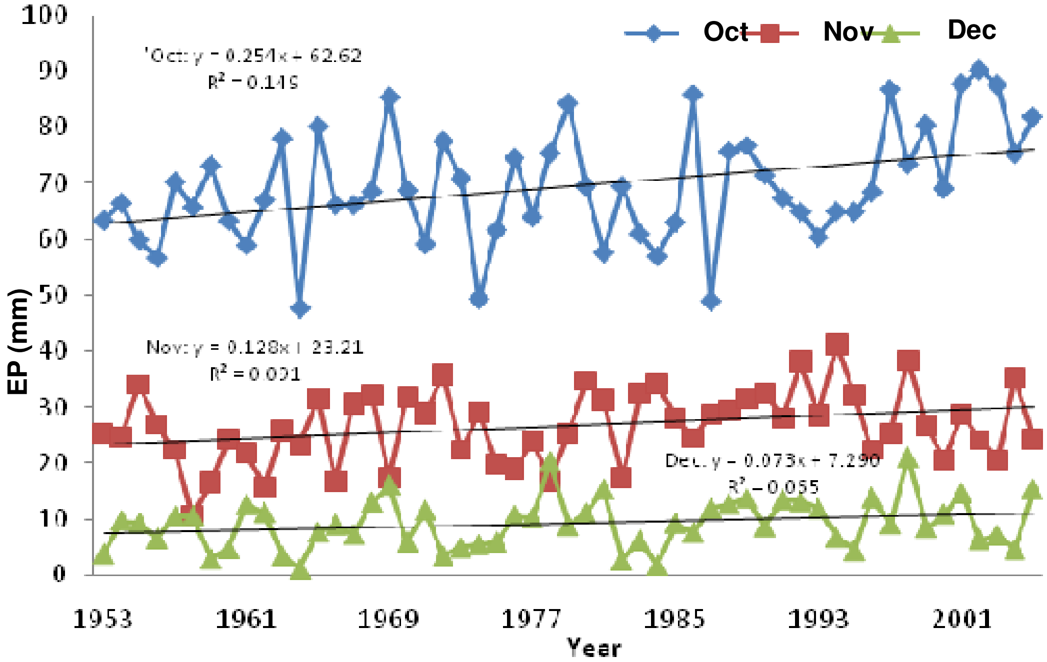

Figure 4. Long-term Trend (1953-2009) Recognition of Evapotranspiration in the Months of Autumn.

with the rate of 0.35°C in every decade from the year 1935 to 2009. Although, evapotranspiration rise is seen in almost all months, the decrease of evapotranspiration occurred in January with the rate of -0.02 mm in every decade and the highest evapotranspiration is seen in July with the increasing rate of 6.03 mm in every decade. Analyzing variations in annual evapotranspiration trend, it has been found that there is an increase of evapotranspiration with the rate of 26.95 mm from 1950 to 2009, and the statistical values of these variations are as follows: (p=0.000 ; R^2 =0.38). Simulating the effect of global warming on temperature variations, it has been specified that the temperature of Yazd station would be increased to 4.53 mm by the year 2100, while the highest

Table 1. Statistical values related to long-term trend of evapotranspiration variations in Yazd station.

Months evaporation	Slop EP(mm/decade)	SE	R^2	P
Jan	-0.02	3.4	0.01	0.585
Feb	0.10	5.25	0.01	0.532
Mar	0.37	7.74	0.01	0.410
Apr	1.09	10.76	0.07	0.059
May	3.17	13.06	0.07	0.063
Jun	3.96	11.31	0.26	0.000
Jul	6.03	19.49	0.19	0.001
Aug	4.52	20.2	0.16	0.003
Sep	3.38	14.31	0.17	0.002
Oct	3.37	9.48	0.15	0.004
Nov	0.53	3.31	0.09	0.028
Dec	0.44	4.31	0.06	0.065

SE: standard error; R^2: linear regression; P: significance value.

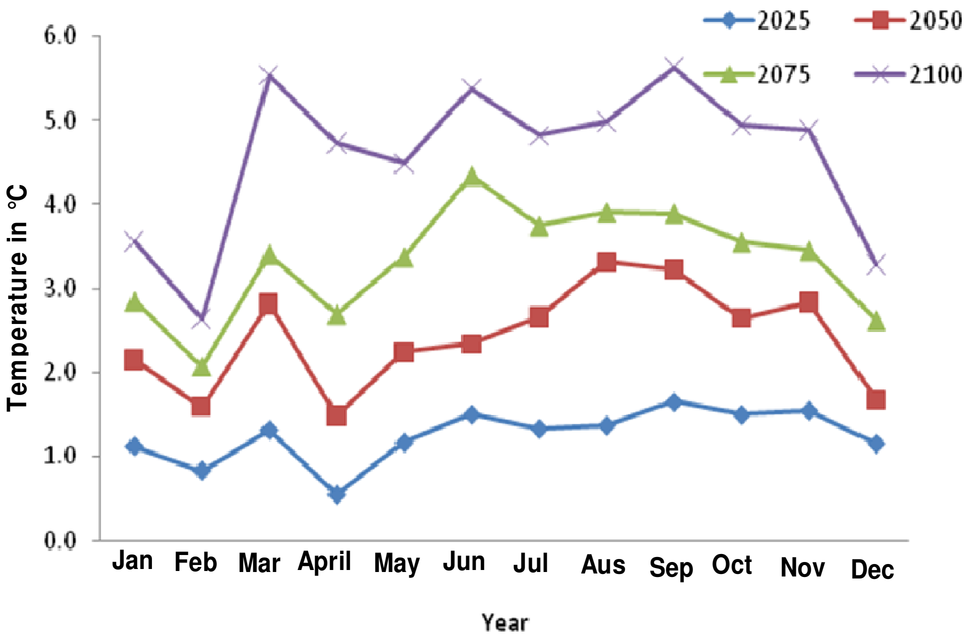

Figure 5. Simulation of monthly temperature rise for Yazd station by the Year 21.

temperature rise for the future decade is seen in September with the mean of 3.6°C (Figure 6).

The simulated data of monthly evapotranspiration indicates decreasing trend for the months of January, February, and December. This evapotranspiration decrease has shown an acceptable significant level (R^2=0.94; r = -0.97) for February as compared with January and December. In other months, in which we have evapotranspiration rise, it is in an acceptable and reliable level. In general, evapotranspiration mean has shown an increasing rate of (115.64 mm) in 2025, (268.11 mm) in 2050, (425.83 mm) in 2075, and (684.31 mm) in 2100, as compared with the long-term mean (999.98 mm) from 1990 to 1960.

Therefore, since most precipitation of Yazd station occurs in cold periods of the year, especially in winter, it is expected that warm periods of the year (spring and summer) cause the decrease of water resources due to temperature rise and consequently maximum evapotranspiration rise and we would experience warmer and dryer summers and springs as compared with previous decades. On the other hand, it could be observed that the

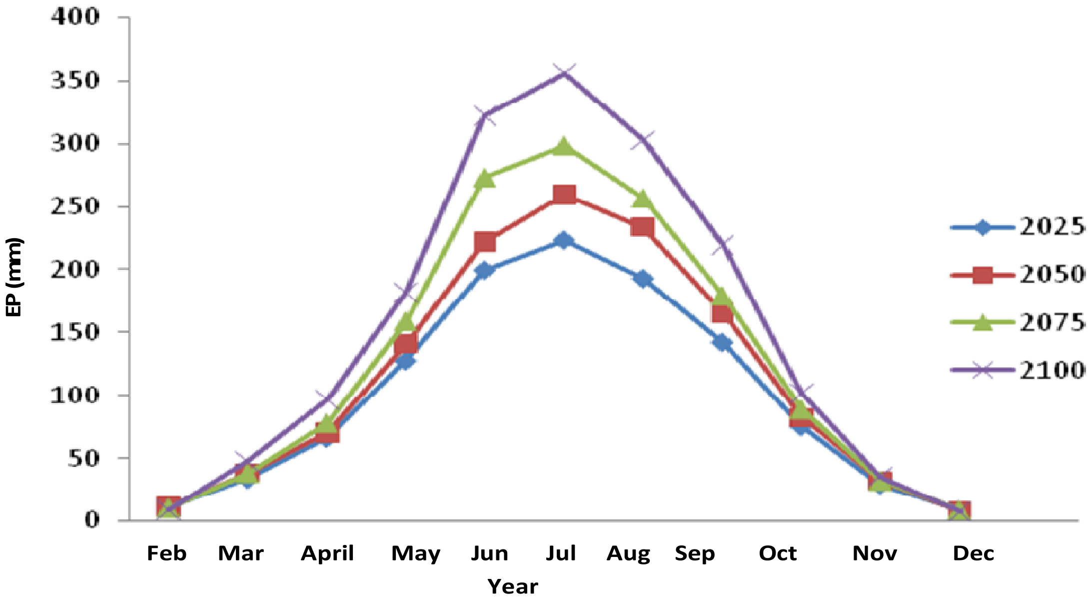

Figure 6. Simulation of monthly evapotranspiration rise for Yazd station by the year 2100.

decrease of evapotranspiration will occur in cold periods of the year, and if this evapo-transpiration decrease comes with the increase of precipitation, it is expected that the cold periods of the year be more humid than previous decades. However, in general, annual evapotranspiration rise is introduced as a serious problem in the crisis of water resources, agricultural activities, etc for Yazd region in the future decade, so that the major part of cultivation is changed from dry-farming to irrigation.

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