**Environmental Resources Research**
Vol. 9, No. 1, 2021

GUASNR

# Comparison of evapotranspiration results under climate change RCP scenarios

**M.R. Goodarzi[1*], K. Janati[2], A. Fatehifar[3]**
[1] Associate Professor, Faculty of Civil Engineering, Yazd University, Iran
[2]B.Sc. student of Civil Engineering, Faculty of Civil Engineering, Yazd University, Iran
[3]Ph.D. student of Water Resource Management, Faculty of Civil Engineering, Yazd University, Iran

***Received: January 2020 ; Accepted: July 2020***

## Abstract
Evapotranspiration after rainfall is the main component of the hydrological cycle that quantifies the amount of water lost. Since climate change directly affects the temperature and rainfall parameters, and the evapotranspiration rate is directly related to the air temperature, it is expected to have significant changes in the future. Therefore, in this research, the possible impacts of climate change on evapotranspiration changes under two RCP2.6 and RCP8.5 climate scenarios are investigated using statistical downscaling model (SDSM) and CanESM2 atmospheric general circulation model output for the future period 2030-2059. Reference evapotranspiration rate was compared with Hargreaves-Samani and Thornthwaite methods in monthly and annual periods for the base and future periods. The results showed a mean increase of annual maximum and minimum temperatures in both scenarios from 0.06 to 0.26 °C compared to the base period. The highest increase was in May by 2.61 °C under the RCP8.5 emission scenario. Overall, the trend of evapotranspiration has been increasing throughout the years. The evapotranspiration in the Hargreaves-Samani method in the RCP8.5 scenario had the highest mean change of 0.08 mm or 2.79%. Although annual changes were not perceptible, as evapotranspiration in the basin reaches its maximum in July, the changes increased by 0.45 mm/day in RCP8.5 scenario. The results of monthly survey can be used in surface and underground water resources management and watershed projects estimating the water needs of plants plus appropriate timing of useful irrigation.

***Keywords*****:** Evapotranspiration, Hargreaves–Samani, Thornthwaite, RCP, CanESM2.

## Introduction
As an important component in the water cycle, evapotranspiration in plants is one of the major factors in the loss of water flow in water resources (Liljedahl et al., 2011). Therefore, this factor is essential in determining the available water in any area. Although many attempts have been made to study the evaporation rate over the past 60 years (Liu et al., 2008; Chen et al., 2012), but this factor has not yet been accurately discovered.

Future climate change information provided by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), shows that global mean temperatures will continue for the rest of the 21st century, and the range of these changes for 2081 to 2100 will be the same as the incremental rate of 0.3 to 4.8 °C for 1986 to 2005 (under four RCP scenarios) (Stocker, 2014). One of the factors that may improve utilization management and increase water use efficiency is accurate estimation of evapotranspiration, which means the amount of water transferred from the earth's surface to the atmosphere by evaporation from the open water surface, soil surface, plant surface and in general every moist surface. Evapotranspiration after rainfall is a major component of the hydrological cycle and plays a significant role in the global climate through the hydrological cycle (Liu et al., 2014).

Therefore, a thorough and comprehensive analysis of evapotranspiration in response to future changes requires identifying and understanding the future of the water cycle and water resources management. Changes in evapotranspiration in response to climate change have been widely reported at regional and continental levels. Evaporative

[*]Corresponding author; goodarzimr@yazd.ac.ir

changes are clearly different in response to climate change depending on different geographic locations (Shi et al., 2013). In high altitudes such as the Tibetan Plateau, wind and solar radiation contribute to the reduction of evaporation (Yang et al., 2014).

According to the report by Jung et al. (2010), global evapotranspiration has experienced a growing trend dependent on the annual temperature change from 1982 to 1997, but this trend after the El Niña accident disappeared in 1998, which was accompanied by a decrease in soil moisture. Wang et al. (2013) predicted an increase in reference evapotranspiration in the Tibetan Plateau of China for future decades. Tao et al. (2015) investigated the impact of climate change on reference evapotranspiration in the Xiang Jiang River basin of China under RCP scenarios and applied SDSM exponential downscaling model. They concluded that in future periods, reference evapotranspiration is very much likely to increase under all scenarios, and the rate of increase will vary depending on the region and scenario type. They also found that the highest incremental rate would be observed under the RCP8.5 scenario. Guo et al. (2014) investigated the impacts of climate change on the ecohydrology of the Jiushu River Basin in China using the HadCM3 model and SDSM downscaling under the two scenarios A2 and B2 for the period 2010 to 2099. Their results showed that daily minimum and maximum temperatures and the expected evapotranspiration in the next 90 years would undergo incremental trend. Zhang et al. (2015) showed that evapotranspiration increased dramatically in 29% of the global land areas between 1982 and 2013, largely due to global warming associated with increased air pressure.

In domestic research, we can also cite Dastourani et al. (2010), who investigated the evapotranspiration status of Yazd station using Hargreaves-Samani and Thornthwaite methods with HadCM3 model under the uncertainty of A2 and B2 emission scenarios for 2010 to 2039. The results showed that the evapotranspiration rate in the Thornthwaite method would increase by 0.4 mm/day in the future. Ghahraman et al. (2015) studied the impact of climate change on potential evapotranspiration with Penman-Monteith Equation in Mashhad plain during 2021-2070 under RCP scenarios using a dynamic model for exponential downscaling. They concluded that the potential evapotranspiration in the future period compared to the base period would decrease in warm months and increase in the colder months. Nikbakht Shahbazi (2019) studied the changes in rainfall, evapotranspiration and agricultural products in Khuzestan Province affected by climate change with CanESM2 model for the next 60 years at 20 year intervals. The SDSM model was used for data downscaling. The results showed that the mean temperature in all selected stations increased to 4 °C in all scenarios and this increase for RCP8.5 scenario was more than that of the RCP4.5 scenario. Mean rainfall declined during 2060-2090 periods. The evapotranspiration of the Hargreaves-Samani method was compared with FAO-Penman Monteith method and the results were acceptable. Evapotranspiration will also increase in future periods. Heydari Tashekabud and Khoshkhoo (2019) predicted future changes of reference evapotranspiration at seasonal and annual scales in western Iran based on CanESM2 model and RCP 8.5 and 2.6 emission scenarios using SDSM downscaling model. The FAO-Penman-Monteith method was used to estimate the reference evapotranspiration. The overall results of this research showed higher incremental reference evapotranspiration rate of the future periods compared to the base period was at all seasonal and annual scales and in the whole region under RCP8.5 scenario and 2071-2100. Comparison of reference evapotranspiration rate changes between different seasonal and annual scales also showed that the incremental rate of reference evapotranspiration increase in western Iran was much more dramatic than the other time scales.

Recent studies show that climate factor plays an important role in determining the spatial patterns of water flows over large areas (Yuan et al.,2012; Yang et al., 2015).

Overall, studies on the impact of climate change on evapotranspiration in different regions have had a different nature and intensity and have shown effects on water and soil resources in different ways. Therefore, it is necessary to examine these impacts in different regions, especially based on new RCP scenarios. As such, the purpose of this research was to investigate the impact of climate change on evapotranspiration using Hargreaves-Samani and Thornthwaite methods in Azarshahr basin using CanESM2 atmospheric general circulation model under two RCP2.6 and RCP8.5 emission scenarios in 2030-2059.

**Materials and Methods**

Azarshahr watershed is one of the sub-basins of the Aji Chay basin in northwestern Iran. The studied area is located in East Azerbaijan Province. The only weather station in this basin is Azarshahr temperature recording station. This station is located at 57' 45° longitude and 47' 37° latitude. The average annual temperature in the basin is about 13.22 ° C, and the average annual rainfall is 266.21 mm. In the present research, daily data of minimum and maximum temperatures of 1990-2005 and climatic data from CanESM2 model under two scenarios RCP2.6 and RCP8.5 from 2030 to 2059 were used for simulation of evapotranspiration. Finally, using the available data, we attempted examining the evapotranspiration of the base and future periods and comparing them. Figure 1 shows location of Azarshahr chay basin.

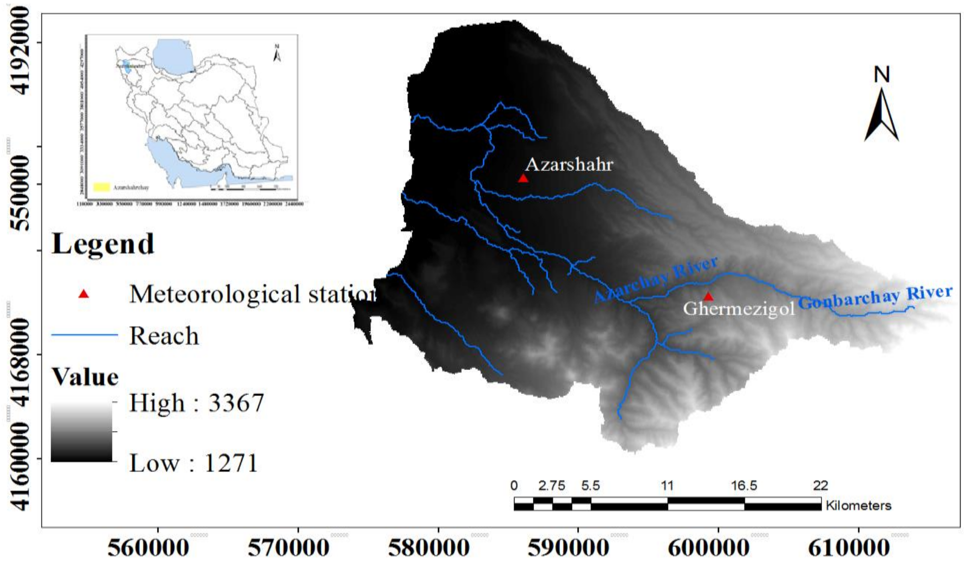


**Figure 1.** The location of the case study

***CanESM2 Model and Emission Scenarios***

The Fifth Report of the Intergovernmental Panel on Climate Change (IPCC) in 2014 addressed the socio-economic aspects of the climate change and its role in sustainable development, risk management and its overall framework for greenhouse gas reduction and climate change adaptation approaches. In this research, CanESM2 model was used from among the series of the CMIP5 models.

The CanESM2 atmospheric general circulation model is provided by the Canadian Centre for Climate Modelling and Analysis (CCCMA). This model has a surface grid with dimensions of about 2.81° longitude and latitude. The data extracted from the above database included time series of standardized daily values of historical and NCEP reanalysis data for 1966-2005 as well as data on climate change conditions of the future decades over 2006-2100 under different Representative Concentration Pathways (RCP) (Pervez & Henebry, 2014). The database contains 26 large-scale daily climate variables. Currently, the CanESM2 model is the only model with daily data applicable to the SDSM model.

The Fifth Report on Climate Change is written on the basis of radiative forcing. Radiation forcing is the difference between the radiation energy received from the sun and the energy returned to the atmosphere by the earth. New RCP emission scenarios are known as agents of different concentrations paths of greenhouse gases, which are divided into four categories based on different technology, socio-economic status, future policies that may lead to different emission levels of greenhouse gases and climate change in each condition. In the present research, the optimistic and pessimistic scenarios have been used. CO2 concentrations by 2100 in the RCP2.6 and RCP8.5 scenarios are estimated to be 490 and 1370 PPM (IPCC, 2014).

### *SDSM Downscaling*

The outputs of general circulation models need to be downscaled using statistical and dynamic methods. The SDSM model was developed by Wilby and Dawson (2013) to evaluate the local impacts of the climate change. This model with a hybrid stochastic and correlation method at its core was designed to explain local (predicted) climate variability at a station for the most influential large-scale (predictor) variables. In order to calibrate and evaluate the model, large-scale daily variables in the observed period (NCEP variables) as independent and daily maximum and minimum observed temperatures as dependent variables were entered into the model separately, and then the results obtained from the observed values were compared and the model's performance was evaluated. In summary, SDSM modeling steps included: 1) data quality control, 2) selection of the best predictor variables, 3) model calibration, 4) meteorological model generation, 5) statistical analysis, 6) graphical output, and 7) climatic scenario generation (Wilby & Dawson, 2013).

To evaluate the reliability of the simulated information, two statistical indices were used including coefficient of determination (R2) according to Equation 1 and Nash-Sutcliffe efficiency coefficient (NSE) of Equation 2.

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i-\bar{O}).(S_i-\bar{O})]^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2 . \sum_{i=1}^{n}(S_i-\bar{S})^2} \qquad \text{Equation (1)}$$

$$NSE = 1-\frac{\sum_{i=1}^{n}(S_i-O_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \qquad \text{Equation (2)}$$

Where, $\bar{O}$, $\bar{S}$, Oi and Si are the mean observed data, the simulated mean data, the observed data of each month over the whole period, and the simulated data of each month over the whole period.

### *Evapotranspiration Calculation*

We used Hargreaves-Samani and Thornthwaite methods due to their simplicity of application, basic data requirements, and compatibility with the climate of Iran (Alizadeh et al. 2012) to calculate reference evapotranspiration in past and future periods. Reference evapotranspiration, which shows the evapotranspiration rate of the reference plants (short grass) can provide a good estimate of the regional evapotranspiration rate in the base and future periods. Potential evapotranspiration is obtained from the maximum evapotranspiration in a given climate (if there is no water restriction) from a vegetation such as grass. Many climat classifications are based on potential evapotranspiration values rather than actual evapotranspiration (Alizadeh, 2004).

### *Hargreaves-Samani Method*

In the Hargreaves-Samani method, the reference evapotranspiration value is calculated using Equation 3 (Alizadehm 2004):

$$ET_0 = 0.0023.R_a.\left(\frac{T}{+17.8}\right).TD^{0.5} \qquad \text{Equation (3)}$$

In this equation, $ET_0$, TD, T are the reference evapotranspiration (mm/day), maximum and minimum temperature difference (in °C) and mean temperature in a given period (in °C) respectively calculated by averaging the maximum and minimum temperatures. $R_a$ is the number of extraterrestrial radiation (in millimeters of water) taken from the available tables

(Alizadeh, 2004) given the latitude of the station and the desired month.

**Table 1.** Extraterrestrial radiation values (Ra) in mm/day for the studied area

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra | 4.57 | 6.87 | 9.87 | 13.19 | 15.6 | 16.7 | 16.18 | 14.26 | 11.19 | 7.99 | 5.27 | 4.01 |

***Thornthwaite Method***

This method was first developed for the east US and uses only the monthly mean temperature to determine the potential evapotranspiration. In Thornthwaite method, the potential evapotranspiration is calculated by Equation 4 (Alizadeh, 2004):

$$PET = 16\left(\frac{10T_m}{I}\right)^a * N_m \quad \text{Equation (4)}$$

In this equation, PET and Tm are the potential evapotranspiration in millimeters and mean monthly temperature (in °C) respectively calculated by averaging the maximum and minimum temperatures. I is the annual thermal index calculated from Equation (5):

$$I = \sum_{i=1}^{12} i_m \quad \text{Equation (5)}$$

Im is the monthly heat index calculated from Equation (6):

$$i_m = \left(\frac{T_m}{5}\right)^{1.51} \quad \text{Equation (6)}$$

The coefficient a is also obtained from Equation (7):

$$a = (6.75 \times 10^{-7})I^3 - (7.71 \times 10^{-5})I^2 + (1.792 \times 10^{-2})I -$$

Nm is the correction coefficient of illumination hours for different months of the year, taken from the tables in the field according to the latitude of the station and the desired month (Alizadeh, 2004).

**Table 2.** Correction coefficient of illumination hours for different months of the year for the studied area

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_m$ | 0.79 | 0.8 | 1.02 | 1.13 | 1.29 | 1.03 | 1.32 | 1.22 | 1.04 | 0.94 | 0.78 | 0.74 |

Equation 4 presents the potential evapotranspiration in mm/month. To calculate the evapotranspiration of the reference plant (grass) in mm/day, it is sufficient to divide the number of each month by the number of days in that month.

## Results and Discussion

### *SDSM Model Validation*

In the present research, first, using the Large-scale observed parameters of the NCEP and SDSM model and the predictors of the required climatic parameters were selected. For this purpose, among the 26 large-scale NCEP parameters, the final large-scale parameters were selected for the most highly correlated climatic variables. Table (3) shows the results of the model's high performance.

**Table 3.** Calibration results and evaluation of the CanESM2 general circulation model in the SDSM model

| Station | Parameter | Calibration Period | | | Evaluation Period | | |
|---|---|---|---|---|---|---|---|
| | | Period Year | NSE | $R^2$ | Period Year | NSE | $R^2$ |
| Azarshahr | Maximum Temperature | 1990-2000 | 0.999 | 0.999 | 2001-2005 | 0.981 | 0.989 |
| | Minimum Temperature | 1990-2000 | 0.999 | 0.999 | 2001-2005 | 0.980 | 0.988 |

***Trend of Minimum Temperature Changes***

The trend of minimum temperature changes in the base period (1990-2005), and future period (2030-2059) under RCP2.6 and RCP8.5 scenarios and comparison of their changes at Azarshahr station were plotted the results of which are shown in Figure 2.

The results of the comparison of the monthly mean temperature in the base period with the equivalent value in the future period in Fig. 2a show the minimum temperature in the future period under the RCP2.6 scenario would increase compared to the base period in all months except January, September, October and November. Comparing the RCP8.5 scenario with the base period showed the same increase in all months except September, October and November. The highest increase of the minimum temperature was in May occurring under all emission scenarios. As is evident in Figure 2 there was a further increase in RCP8.5 compared to other scenarios.

An overview of the trend of future temperature changes (under both RCP8.5 and RCP2.6 scenarios) in Fig. 2b, c, d shows an incremental trend over all the periods. According to Fig. 1b, the minimum temperature undergoes an upward trend and during this period an increase of about 1.64 °C is detected. Fig. 2c shows that minimum temperature under the RCP2.6 scenario has an upward trend and shows an increase of about 0.11°C over the base and the selected period. As can be seen from Fig. 2d, the minimum temperature under the RCP8.5 scenario shows a rising trend with an increase of 0.23 °C compared to the base period and an increase of about 0.14 °C during the selected period. Therefore, the rate of change in RCP8.5 is predicted to be higher than RCP2.6.

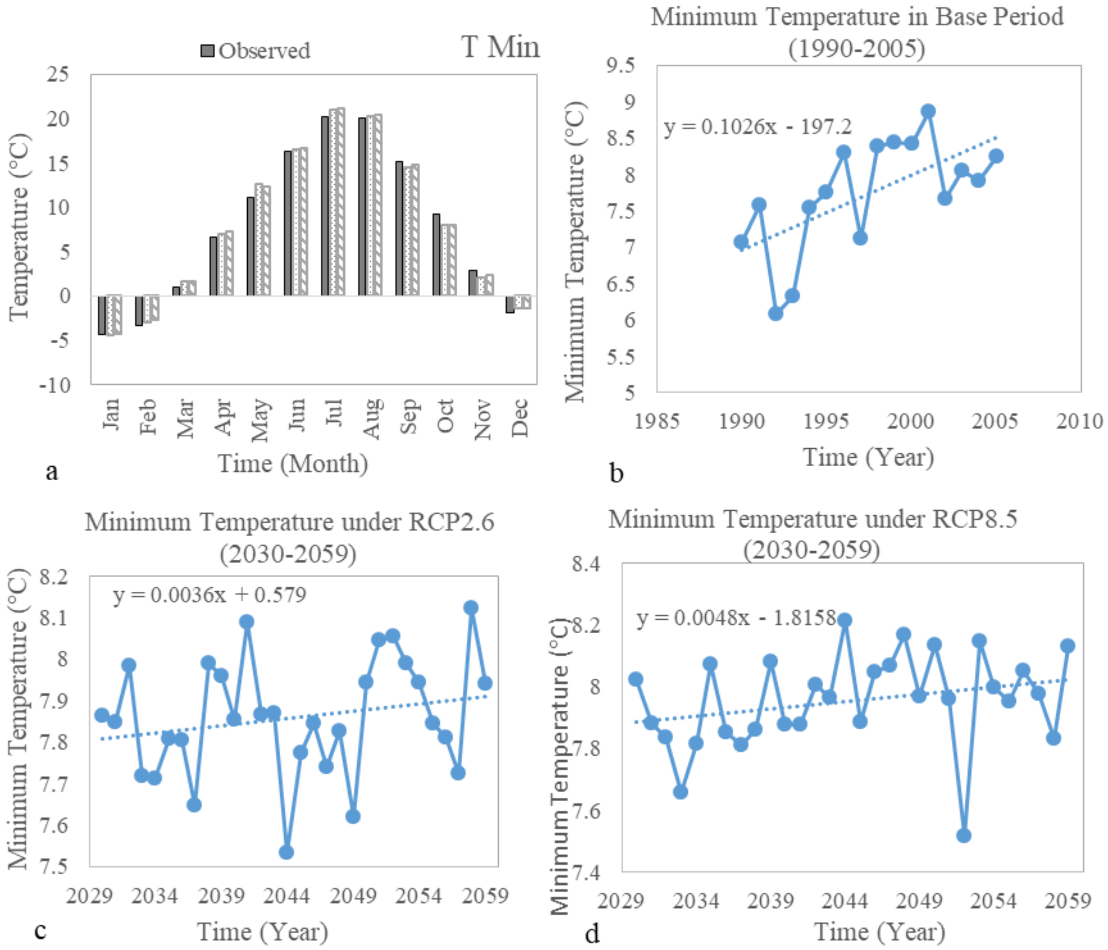


**Figure 2.** a) Comparison of monthly mean long-term minimum temperature in the observed and future periods, trends of annual minimum temperature changes in b) Base and c) Future under RCP2.6 scenario, d) Future under RCP8.5 scenario

***Trend of Maximum Temperature Changes***

The trend of maximum temperature changes in the base period (1990–2005), future period (2059–2030) under RCP2.6, and RCP8.5 scenarios and a comparison of their changes at the Azarshahr station is plotted in Figure 3.

Comparison of the monthly mean maximum temperature in Figure 3a shows that the maximum temperature in the future period would increase under the RCP2.6 scenario compared to the base period in all months except August, September, October, November and December. For the RCP8.5 scenario, the same increase will happen in all months except August, September, October, November and December. Also, during the 2030-2059, the highest temperature increase at maximum temperature was in May with 2.61 °C under the RCP8.5 emission scenario and the temperature reached its maximum in July.

Changes in the maximum base temperature trend as seen in Figure 3b show an upward trend over the 16 years showing an increase of about 2.07 °C. Figure 3c shows that the trend of maximum temperature changes under the RCP2.6 scenario has an upward trend with an increase of about 0.07 °C compared to the base period and 0.09 °C during the selected period. Figure 3d shows that the maximum temperature under the RCP8.5 scenario has an upward trend with an increase of about 0.26 °C compared to the base period and an increase of 0.36 °C compared to the selected period.

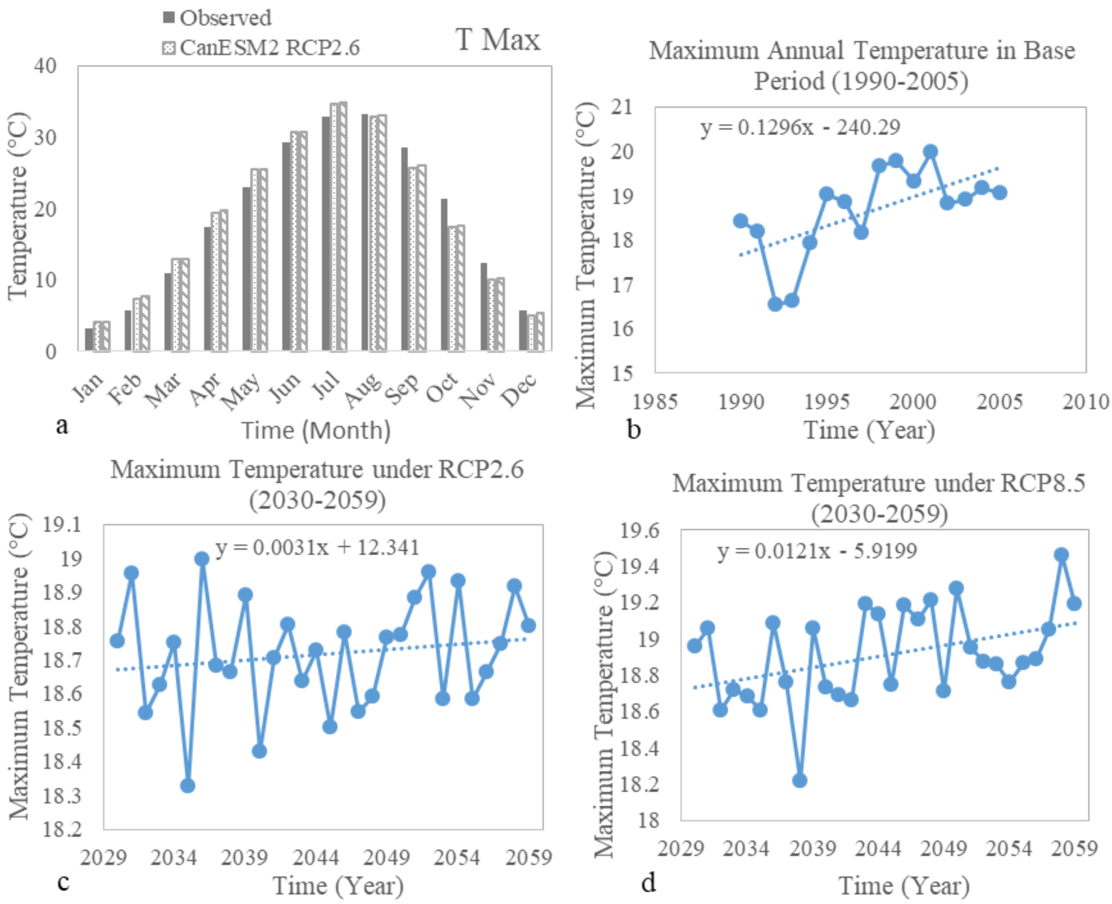


**Figure 3.** a) Comparison of monthly mean long-term maximum temperature in observed and future period, trends of annual maximum temperature changes in b) Base, c) Future under RCP2.6 scenario, and d) Future under RCP8.5 scenario.

Overall, the air temperature has been increasing in the past, which suggests the necessity of studying the evapotranspiration phenomenon which has been less well-known in this area.

The future air temperature will also increase in the warm seasons of the year while it will decrease in the cold seasons of the year (the final months of the year). In other words, warmer summers and colder winters are predicted compared to the past.

Also, by comparing the base and future temperatures, it can be concluded that the temperature fluctuations will be higher in the future. Table 4 shows the monthly long-term mean of the minimum and maximum temperatures in the base period (1990-2005) and the future period (2030-2059) under the two RCP8.5 and RCP2.6 scenarios.

As can be seen, the mean of the minimum and maximum temperatures of the future period has generally increased compared to the past period. It is also understood that the RCP8.5 scenario predicts a higher temperature than the RCP2.6 scenario for the future period.

**Table 4.** Mean monthly long-term minimum and maximum temperatures in the base and future periods

| Period | Minimum Temperature (°C) | Maximum Temperature (°C) |
|---|---|---|
| Base (1990-2005) | 7.73 | 18.65 |
| Future (RCP2.6) 2030-2059 | 7.86 | 18.72 |
| Future (RCP8.5) 2030-2059 | 7.96 | 18.91 |

***Evaluation of trend of changes in evapotranspiration***

Increasing temperature has a significant impact on the evapotranspiration of a region, which is further investigated by Hargreaves-Samani and Thornthwaite methods.

***1) Hargreaves-Samani Method***

Figure 4 shows the reference evapotranspiration rates using the Hargreaves-Samani method in the base period (1190-2205) and future period (2030–2059) under two RCP2.6 and RCP8.5 scenarios.

According to Figure 4a in the RCP2.6 scenario, the reference evapotranspiration rate increased with the Hargreaves-Samani method over all months except August, September, October, November and December. In the RCP8.5 scenario, evapotranspiration rates increased over all months except August, September, October, November and December. These results are also in line with the results of the previous discussion as the final months of the year become colder thus evapotranspiration would decrease in the final months of the year.

As can be seen in Figure 4b, the reference evapotranspiration is increasing in the base period which is consistent with the results of the previous section on increasing temperature (with increase in temperature, so does the evapotranspiration). Reference evapotranspiration in the base period increased by approximately 0.18 mm/day.

Figure 4c shows the reference evapotranspiration increase in the future period under the RCP2.6 scenario, which is consistent with the results of the previous section on temperature increase under the same scenario. This increase is approximately 0.02 mm/day. The highest and lowest rates of reference evapotranspiration in the future period under the RCP2.6 scenario based on Hargreaves-Samani is approximately 2.97 mm/day in 2054 and 2.85 mm/day in 2040.

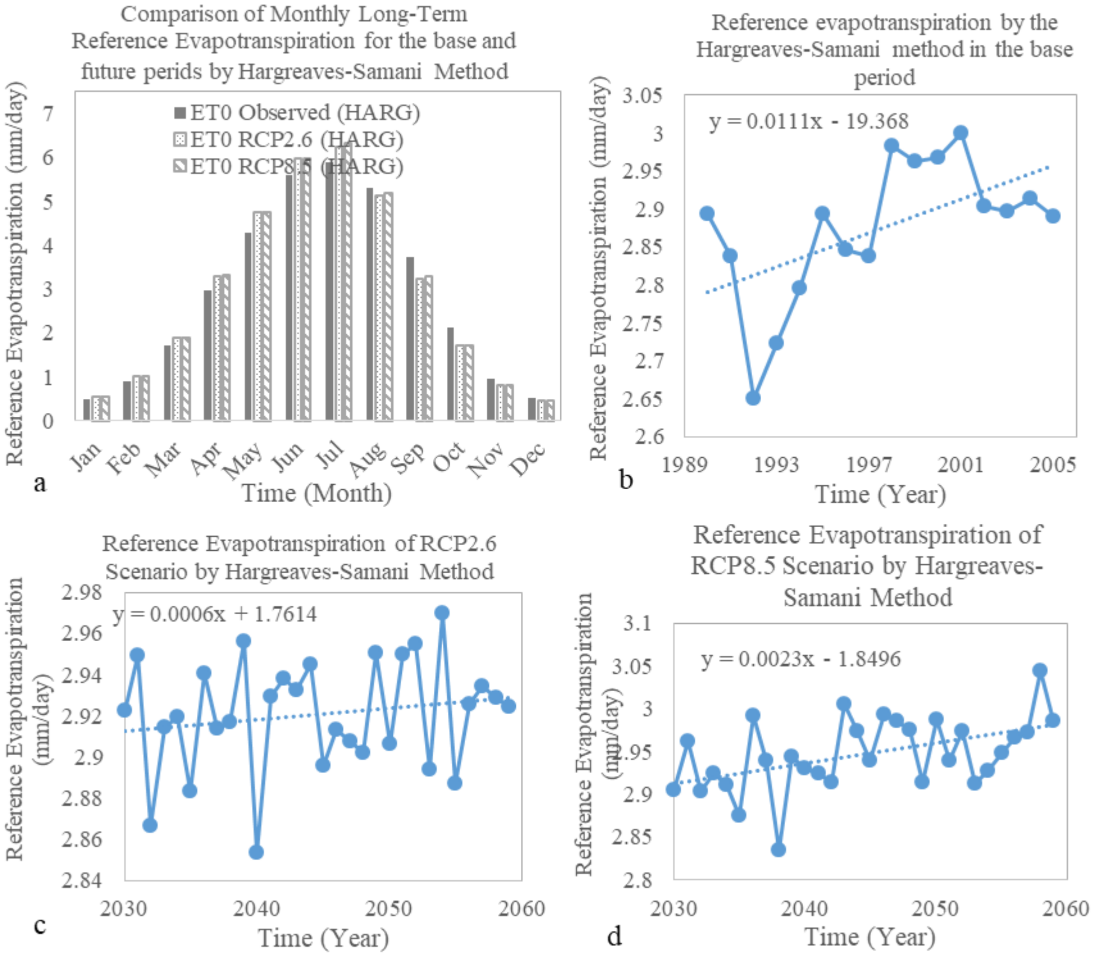


**Figure 4.** Comparison of mean monthly reference evapotranspiration in the observed and future period, trends of annual reference evapotranspiration temperature changes in b) Base, c) Future under RCP2.6 scenario, d) Future under RCP8.5 scenario with Hargreaves-Samani method

In Figure 4d, the reference evapotranspiration rate increases with the Hargreaves-Samani method in the future period under the RCP8.5 scenario, which is consistent with the results of the previous section on temperature increase under the same scenario. This increase is approximately 0.07 mm/day.

The highest reference evapotranspiration in the future period under the RCP8.5 scenario, according to the Hargreaves-Samani method in 2058, is approximately 3.04 mm/day, and the lowest in 2038 is approximately 2.83 mm/day.

### *2) Thornthwaite Method*

The results of monthly comparisons and trends of evapotranspiration changes in the base period (1990-2005) and future period (2030-2059) under the two RCP2.6 and RCP8.5 scenarios are obtained by the Thornthwaite method in Figure 5.

Monthly mean comparison of evapotranspiration changes under the RCP2.6 scenario with the Thornthwaite method increased in all months except August, September, October, November and December and increased under the RCP8.5 scenario in all months except for August, September, October, November and December compared to the past. These results are in line with the results of the previous section on the temperature reduction in the cold months of the year in future under the same scenario (Figure 5a).

Figure 5b shows that the evapotranspiration in the Thornthwaite method during the base period has increased. This result is also consistent with the results of the previous section on temperature increase. This increase in the base period is approximately 0.21 mm/day.

Figure 5c shows an increase in evapotranspiration in the future period under the RCP2.6 scenario by approximately 0.003 mm/day and the highest evapotranspiration in 2051 by approximately 2.295 mm/day. The lowest increase is seen in 2038 by approximately 2.231 mm/day.

It can be seen from Figure 5d that the evapotranspiration rate in the future period under the RCP8.5 scenario is increased by approximately 0.05 mm/day, which is consistent with the results of the previous section on future temperature increase under the same scenario.

Also, the highest evapotranspiration in this scenario is approximately 2.34 mm/day in 2058 and the lowest is approximately 2.22 mm/day in 2038.

Table 5 presents the mean evapotranspiration in the base and future periods with the two Hargreaves-Samani and Thornthwaite methods.

It can be seen from Table 5 that the overall RCP8.5 scenario predicts higher evapotranspiration than the RCP2.6 scenario in future as it is also the case with temperature. In both cases the amount of evapotranspiration in the future is greater than in the past, though not as significant. Figure 6 shows an overview of monthly long-term evapotranspiration under the RCP8.5 and the RCP2.6 scenarios.

According to Fig. 6, it can be said that in all months of the year (except August) the evapotranspiration obtained by the Hargreaves-Samani method is higher than that obtained by the Thornthwaite method. Also, in all months of the year (except May), the RCP8.5 scenario predicts more evapotranspiration than RCP2.6 scenario.

As observed in the previous sections, the evapotranspiration rate at the final months of the year in the future is lower than in that seen in the past. Also, the evapotranspiration rate under RCP8.5 scenario was higher than RCP2.6 scenario. The cause of this can be explained by the Hargreaves-Samani formula and the TD parameter (maximum and minimum temperature difference) which have a direct relationship with the reference evapotranspiration rate. According to Figs. 2d and 3d, the slope of the minimum and maximum temperature increase under RCP8.5 scenario is more than the slope of maximum and minimum temperature (Figs. 2c and 3c) under RCP2.6 scenario, which increases the maximum and minimum temperature difference (TD) under the same scenario (RCP8.5). The same reason explains why the reference evapotranspiration is higher under the RCP8.5 scenario than the RCP2.6 scenario.

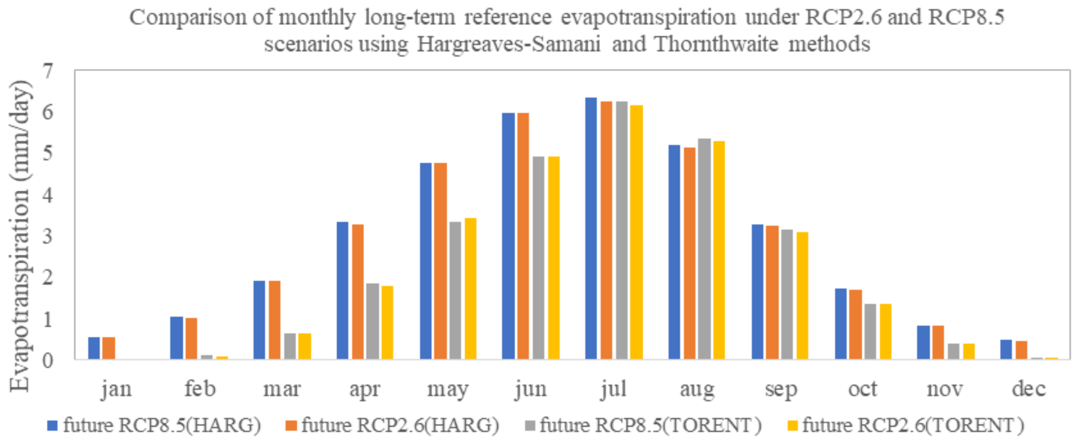


**Figure 6.** Comparison of monthly long-term reference evapotranspiration under RCP2.6 and RCP8.5 scenarios using Hargreaves-Samani and Thornthwaite methods

**Table 5.** Mean daily evapotranspiration of the base and future periods

| (*mm/day) | (Hargreaves-Samani) | | (Thornthwaite) | |
|---|---|---|---|---|
| Mean daily evapotranspiration of the base future periods (1990-2005) | 2.87 | Change% | 2.24 | Change% |
| Mean evapotranspiration Under RCP2.6 Scenario (2030-2059) | 2.92 | + 1.75 | 2.26 | + 0.9 |
| Mean evapotranspiration Under RCP8.5 Scenario (2030-2059) | 2.95 | + 2.79 | 2.28 | +1.76 |

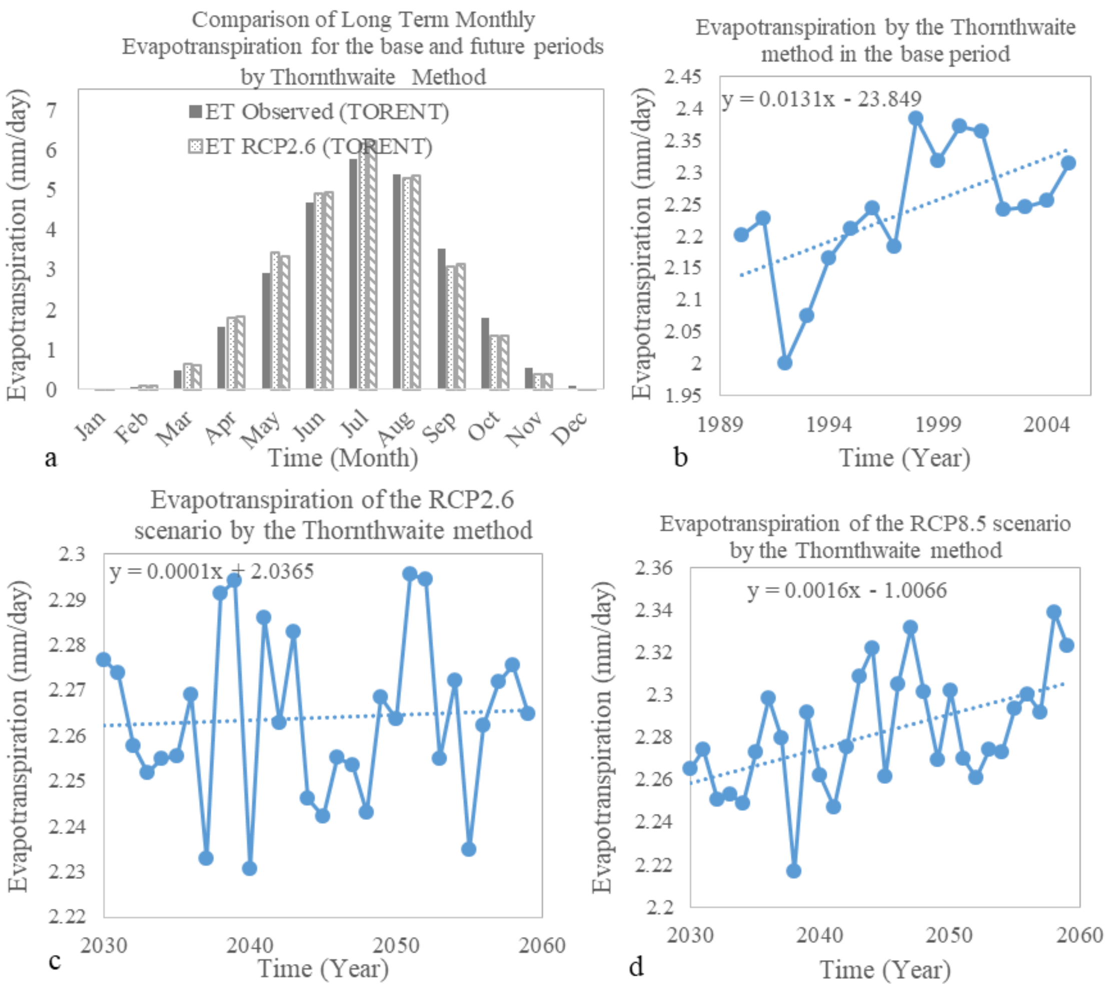


**Figure 5.** Comparison of mean monthly evapotranspiration in the observed and future periods, trends of annual evapotranspiration temperature changes in b) Base, c) Future under RCP2.6 scenario, d) Future under RCP8.5 scenario with Thornthwaite method

## Conclusions

In the present research, for estimating the base period evapotranspiration changes (1990–2005) as a result of likely climate change, the CanESM2 atmospheric general circulation model was used. This was employed according to the latest Intergovernmental Panel on Climate Change (AR5) report of RCP2.6 and RCP8.5 emission scenarios for predicting the greenhouse gas concentration in the atmosphere and the SDSM statistical model for exponential downscaling of large-scale general circulation data for simulation in the 2030-2059 period using the two methods of Hargreaves-Samani and Thornthwaite. Model efficiency was evaluated with two statistical indices of $R^2$ and NSE coefficients. The $R^2$ and NSE coefficients for the temperature calibration and evaluation of Azarshahr station were 0.99 and 0.98 respectively. Trends of minimum and maximum temperature changes were shown to be increasing. Findings indicate an increase in minimum and maximum temperatures, especially in April to July, and the highest increase was related to RCP8.5 by 0.26 °C. The trend of evapotranspiration changes was also incremental and this increase with the Hargreaves-Samani method at the base period compared to its prediction period using two scenarios RCP2.6 and RCP8.5 was 0.18, 0.02 and 0.07 mm/day respectively. These values for the Thornthwaite method were 0.21, 0.003 and 0.05 mm/day. Also in all months of the year except August the evapotranspiration obtained by the Hargreaves-Samani method was higher than that obtained by the Thornthwaite method. Also, in all months of the year except May, the RCP8.5 scenario resulted in more evapotranspiration than the RCP2.6 scenario.

The highest percentage of annual change in evapotranspiration using Hargreaves-Samani method was f 2.79% (0.08 mm/day) in the RCP8.5 scenario. Also in July, the evapotranspiration in the basin reached its maximum and it was increased by 0.45 mm/day in the RCP8.5 scenario. Although the detected amount was negligible given the small size of the basin and the availability of information for only one station and the likely change in climate, the same small amount can be extremely important. Additionally, the modeled changes were more severe in some years and months than the others. The results of monthly survey can be used in surface and underground water resources management, and watershed projects for estimating water needs of plants and better timing of useful irrigation practices.

**References**

Alizadeh, A., Kamali, Gh., and Mosavi Bayagi, M. 2012. Meteorology. Ferdowsi University of Mashhad Press, 398pp. (In Persian)

Alizadeh, A. 2004. Water, soil and plant relationship (4th edition). Imam Reza Press, 470pp. (In Persian)

Chen, X., Li, B., Li, Q., Li, J., and Abdulla, S. 2012. Spatio-temporal pattern and changes of evapotranspiration in arid central Asia and Xinjiang of China. Journal of Arid Land, 4, 105-112.

Dastourani, M.T., Pourmohammadi, S.A., Masah Bavani, A.R., and Rahimian, M.H. 2010. Evapotranspiration status of Yazd station under uncertainty of existing greenhouse gas emission scenarios and models. Journal of Watershed Management Research, 1(2), 1-12. (In Persian)

Ghahraman, N., Babaian, A., and Tabatabai, M.R. 2016. Evaluation the post processed outputs of dynamic models in estimation potential evapotranspiration changes under RCP scenarios (Case study: Mashhad plain). Journal of the Earth and Space Physics, 42(3), 687-696. (In Persian)

Guo, B., Zhang, J., Gong, H., and Cheng, X. 2014. Future climate change impacts on the ecohydrology of Guishui River Basin China. Ecohydrology & Hydrobiology, 14(1), 55-67.

Heydari Tashekabud, Sh., and Khoshkhoo, Y. 2019. Projection and prediction of the annual and seasonal future reference evapotranspiration time scales in the West of Iran under RCP emission scenarios. Researches in Geographical Sciences, 19(53), 157-176. (In Persian)

IPCC, 2014. Summary for policymakers, In: Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA p. 1-32.

Jung, M., Reichstein, M., Ciais, P., Seneviratne, S.I., Sheffield, J., Goulden, M.L., Bonan, G., Cescatti, A., Chen, J.Q., and De Jeu, R. 2010. Recent decline in the global land evapotranspiration trend due to limited moisture supply. Nature, 467, 951–954.

Liljedahl, A., Hinzman, L., Harazono, Y., Zona, D., Tweedie, C., Hollister, R.D., Engstrom, R., and Oechel, W. 2011. Nonlinear controls on evapotranspiration in arctic coastal wetlands. Biogeosciences, 8(11), 3375-3389.

Liu, H., Zhang, R., and Li, Y. 2014. Sensitivity analysis of reference evapotranspiration (ETo) to climate change in Beijing China. Journal of Desalination and Water Treatment, 52(13-15), 2799-2804.

Liu, B., Ma, Z., Feng, J., and Wei, R. 2008. The relationship between pan evaporation and actual evapotranspiration in Xinjiang since 1960. Acta Geographica Sinica, 63(11), 1131-1139.

Nikbakht Shahbazi, A. 2019. Investigation of Crop Evapotranspiration and Precipitation changes under Climate Change RCPs Scenarios in Khouzestan province. Journal of Water and Soil Conservation, 25(6), 123-139. (In Persian)

Pervez, M.S., and Henebry, G.M. 2014. Projections of the Ganges – Brahmaputra rainfall - downscaled from GCM predictors. Journal of Hydrology, 517(1), 120–134.

Shi, X., Mao, J., Thornton, P.E., and Huang, M. 2013. Spatiotemporal patterns of evapotranspiration in response to multiple environmental factors simulated by the community land model. Environmental Research Letters, 8(2), 024012.

Stocker, T. 2014. Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK.

Wilby, R.L., and Dawson, C.W. 2013. The Statistical DownScaling Model: insights from one decade of application. International Journal of Climatology, 33(7), 1707-1719.

Yang, K., Wu, H., Qin, J., Lin, C., Tang, W., and Chen, Y. 2014. Recent climate changes over the tibetan plateau and their impacts on energy and water cycle: A review. Glob. Planet. Chang, 112, 79-91.

Yang, Q., Tian, H., Li, X., Tao, B., Ren, W., Chen, G., Lu, C., Yang, J., Pan, S., and Banger, K. 2015. Spatiotemporal patterns of evapotranspiration along the north american east coast as influenced by multiple environmental changes. Ecohydrology, 8(4), 714-725.

Yuan, X., Bai, J., Li, L., Kurban, A., and De Maeyer, P. 2017. The dominant role of climate change in determining changes in evapotranspiration in Xinjiang China from 2001 to 2012. PLoS ONE, 12(8), e0183071.

Zhang, K., Kimball, J.S., Nemani, R.R., Running, S.W., Hong, Y., Gourley, J.J., and Yu, Z. 2015. Vegetation greening and climate change promote multidecadal increases of global land evapotranspiration. Scientific Reports, 5, 15956.