The study of potential evapotranspiration in future periods due to climate change in west of Iran

Ahmad Rajabi and Zahra Babakhani
Department of Water Engineering, College of Agriculture, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

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Abstract

Purpose – This study aims to present the climate change effect on potential evapotranspiration (ETP) in future periods.

Design/methodology/approach – Daily minimum and maximum temperature, solar radiation and precipitation weather parameters have been downscaled by global circulation model (GCM) and Lars-WG outputs. Weather data have been estimated according to the Had-CM3 GCM and by A1B, A2 and B1 scenarios in three periods: 2011-2030, 2045-2046 and 2080-2099. To select the more suitable method for ETP estimation, the Hargreaves-Samani (H-S) method and the Priestly–Taylor (P-T) method have been compared with the Penman-Monteith (P-M) method. Regarding the fact that the H-S method has been in better accordance with the P-M method, ETP in future periods has been estimated by this method for different scenarios.

Findings – In all five stations, in all three scenarios and in all three periods, ETP will increase. The highest ETP increase will occur in the A1B scenario and then in the A1 scenario. The lowest increase will occur in the B1 scenario. In the 2020 decade, the highest ETP increase in three scenarios will occur in Khorramabad and then Hamedan. Kermanshah, Sanandaj and Ilam stations come at third to fifth place, respectively, with a close increase in amount. In the 2050 decade, ETP increase percentages in all scenarios are close to each other in all the five stations. In the 2080 decade, ETP increase percentages in all scenarios will be close to each other in four stations, namely, Kermanshah, Sanandaj, Khorramabad and Hamedan, and Ilam station will have a higher increase compared with the other four stations.

Originality/value – Meanwhile, the highest ETP increase will occur in hot months of the year, which are significant with regard to irrigation and water resources.

Keywords Climate change, HadCM3, Lars-WG, Potential evapotranspiration, Statistical downscaling

Paper type Case study

1. Introduction

Global warming owing to an increase in greenhouse gases leads to climate change all around the earth. Climate change has found a great significance during recent years. Initial studies by intergovernmental panel on climate change (IPCC) indicated changes in different

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climate parameters, such as temperature, precipitation, snow coverage and sea levels, owing to climate change (IPCC, Climate Change, 2014). The hydrologic cycle has also been affected by this phenomenon (Peng *et al.*, 2013). It is important to study the climate change effect on hydrologic cycle parameters, such as runoff, evapotranspiration (ETP), surface storage and soil moisture, to evaluate conditions of water resources, flood damage amount and hydrologic balance (Xu *et al.*, 2013).

Considering the following factors, population growth, humans' need for food and water resources changes due to climate change, it seems so significant to evaluate the climate change effects on ETP. ETP is needed both in agricultural water requirement planning and hydrologic conceptual models (Allen *et al.*, 1998).

In climate change studies, global circulation models (GCMs) and regional climate models are widely used (IPCC, Climate Change, 2007). GCMs simulate annual or seasonal means of large-scale climate properties. As a matter of fact, their spatial and temporal accuracy do not agree with required hydrologic models' accuracy. By using downscaling methods, we can change GCM outputs in to the data with the scales of a given basin. GCM downscaling statistical methods can predict climate change scenarios in an area better than other methods (Wilby and Dawson, 2013).The present study uses the Lars-WG downscaling model. Lars-WG is a stochastic weather generator which is used to simulate climate data in a given station at present and future conditions affected by climate change. Its data is in the form of daily time series for a set of climate variables, such as precipitation, minimum and maximum temperature and sunshine (Semenov and Barrow, 2007). In the new version of this model, a complete development has been established to provide a powerful model to produce artificial climate data in an extensive climate area. This model has been compared with other stochastic generations with extensive application which use the Markov chain. In the areas with climate variation, it has been specified that if the results are not better than other models, they are at least as good as them (Semenov and Barrow, 2007).

Using the Lars-WG stochastic weather generator, climate change scenarios with high accuracy have been presented to be used in agriculture and hydrology fields (Semenov, 2007). The results have been used to analyse present and future extreme climate events and to study climate change effects on wheat in England. Using the data of 20 stations in different parts of the world with different climates, the ability of the Lars-WG weather generator model to simulate extreme weather events has been studied (Semenov, 2008).

Tiegang *et al.* (2016) studied reference evapotranspiration (ETO) changes in the southwest of China. Results showed that there was a slight downward trend of ETO from 1960 to 2010 and spatially increasing trend from northeast to southeast in an annual time scale. Katerji *et al.* (2016) made a comparison between Allen and Katerji and Perrier formulas for calculating daily ETO. These two formulas have been compared for both the observed period and the future period (2070-2100). Liu *et al.* (2017) investigated the spatiotemporal patterns of evapotranspiration (ET) and primary driving meteorological variables based on a historical and RCP 8.5 scenario daily data set from 40 weather stations over the 3H Plain using linear regression, spline interpolation method, a partial derivative analysis and multivariate regression. Temperature-based methods may be particularly prone to error when extrapolated into the future to assess effects of greenhouse gas-driven warming on potential evapotranspiration (PET). Such biases are derived from the fact that increasing temperature by increasing solar radiation would likely cause a greater increase in PET than would increasing temperature by increasing greenhouse gases, because radiation provides the energy driving ETP (King *et al.*, 2015).

In different research works, the climate change effect on ETP has been evaluated. The climate change effect on hydrologic cycle parameters such as reference ETP was studied in the Guishui River Basin in China (Guo *et al.*, 2014). Reference ETP change in the Haihe River Basin in China owing to climate change was evaluated in the observed period and in the future period (Xu *et al.*, 2013).

During the recent years, many researchers tried to calibrate the Hargreaves model (Gavilan *et al.*, 2006; Tabari and Talaee, 2011; Berti *et al.*, 2014; Shiri *et al.*, 2014, 2015; Marti *et al.*, 2015; Cobaner *et al.*, 2016; Xu *et al.*, 2016; Feng *et al.*, 2017).

The results obtained from most of the mentioned studies indicated that ETP has an increasing trend owing to climate change. This leads to an increase in water requirements of plants and presents worry regarding water resource management.

The main objective of the present study is to provide answers to the following questions:

Q1. Which of the mentioned formulas can simulate the amounts of ETP in the western part of Iran?

Q2. If the more proper ET formula is applied in climate change scenarios for future, what results can be observed?

Changes in ETP in regards to meteorological parameters and agricultural production practice should be given greater attention. It receives more significance when we consider the hydrological process and water management in the coming decades regarding climate change. It is in order to avoid problems such as the overexploitation of groundwater resources.

2. Materials and methods

2.1 Data

The area which is studied includes five provinces in the west of Iran, which is surrounded by mountains and has a semi-arid weather (Figure 1). The required data have been received from the Iran meteorological organization. Regarding the fact that circulation scenarios have been calculated based on period weather parameters since 1960, the stations which possess sufficient data in this period are Kermanshah, Hamedan, Khorramabad, Sanandaj and Ilam synoptic stations. Therefore, the data of these stations have been used to continue the present study (Table I).

2.2 Lars-WG stochastic weather generator

Lars-WG model has been established according to the weather generator series, which has been analysed by Racsko *et al.* (1991). In Lars-WG version 5, minimum and maximum

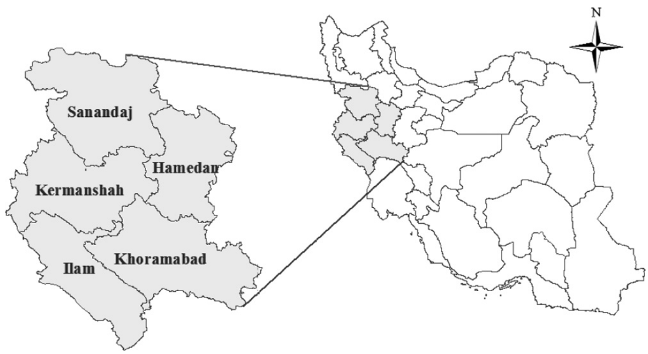

Figure 1.
Location of the stations used in Iran

temperatures for dry and wet days are estimated for each month by a semi-empirical distribution which is calculated by auto-correlation and a monthly cross-correlation coefficient. Applying these changes leads to a significant improvement in the extreme temperature simulation (Semenov and Stratonovitch, 2010).

2.3 Climate change scenarios

For more climate-predicting models, there are different circulation scenarios, including B1, A1B and A1. In the B1 scenario, the assumption is based on an endurable world, rapid change in economic constructions, human rights equality development and a care for protecting our environment. With this assumption, greenhouse gas circulation can be controlled and a pollutant controlling programme for factories and industries will be carried out. In the A1B scenario, the assumption is based on a wealthy world with a rapid economic growth (3 per cent per year), population growth decrease (27 per cent per year), rapid new and effective technology, cultural and economic convergence and a fundamental decrease in regional differences. In the A2 scenario, the assumption is based on the existence of a separate world. Different cultural identities in different parts of the world lead to more differences in the world and a decrease in international cooperation. Local customs and growth increase are emphasized, and there is less emphasis on economic issues (1/65 per cent per year) (IPCC, Climate Change, 2001; IPCC, Climate Change, 2007). In the present study, the Had-CM3 GCM has been used.

2.4 Potential evapotranspiration

There are different methods for estimating daily ETP. The most reliable and common method is the Penman–Monteith (P-M) method. In this method, parameters such as the relative moisture, wind speed and sunshine hours are needed, besides minimum and maximum daily temperature. In this study, regarding the fact that the data cannot be downscaled by Lars-WG, estimation of ETP in future periods is carried out by using methods which make it possible to calculate ETP with present variables. Among different methods, two were selected and used, namely, the Hargreaves-Samani (H-S) method and the Priestly-Taylor (P-T) method. The reason is that these methods possess an almost high accuracy and also need less meteorological data, compare with other methods (Samani, 2000). According to this fact, the P-M method is considered as the reference method. The accuracy of the two methods is evaluated by the P-M method. To compare the results, the values of the root mean square error (RMSE), mean absolute error (MAE) and mean bias error (MBE) statistical indices are used.

The description of the details of ETP methods is available in previous work (Allen *et al.*, 1998; Priestley and Taylor, 1972; Samani, 2000).

Table I.
Properties of the desired synoptic stations

Station	Latitude (°N)	Longitude (°E)	Altitude (m a.s.l.)
Hamedan	35° 12′	48° 43′	1,679.7
Khorramabad	33° 26′	48° 17′	1,147.8
Kermanshah	34° 21′	47° 09′	1,318.6
Sanandaj	35° 20′	47° 00′	1,373.4
Ilam	33° 38′	46° 26′	1,337.0

3. Results and discussion

Monthly ETP in the present statistical period available in the mentioned five synoptic stations was calculated by using REF-ET software. Table II presents monthly ETP mean of different methods. Table III demonstrates the difference percentage between monthly ETP by the two methods H-S and P-T with the P-M method (as the reference method) in different stations in the observed period.

As shown, the ETP difference percentage calculated by the H-S method with the P-M method is less than the P-T method.

To make sure about selecting the more suitable method for calculating ETP in future periods, RMSE, MAE and MBE evaluating indices have been used. The results are presented in Table IV in short.

It can be observed that in all stations, the above evaluating indices indicate that ETP amounts of the H-S method are closer to ETP amounts of the P-M method as the reference method in all months. Therefore, this method is used in future periods.

3.1 Generating climate change scenario in future

Daily precipitation, minimum and maximum temperatures and solar radiation data of the mentioned stations have been provided in the observed period by the required format of Lars-WG model, and the model input files have been established according to this. Then, downscaled data of each weather parameter have been simulated for three 20-year periods:

(1) first period (2020 decade): 2011-2030;

(2) second period (2050 decade): 2045-2065; and

(3) third period (2080 decade): 2080-2090.

In the present study, the effects of different scenarios, A1B, A2 and B1, of the GCM model are studied. The GCM which has been used is the Had-CM3 model.

Considering the results of applying the Lars-WG model, the following points are worthy of mention:

- Minimum and maximum temperatures increase considerably in future periods.
- In future periods, minimum and maximum temperature increase peak will be in warm months of the year (July and August) and February.
- The highest solar radiation increase will be in warm months of the year (July and August) and also February.

3.2 ETP estimation in future

After calculating the minimum and maximum temperatures and solar radiation weather parameters in future periods by different scenarios, ETP is estimated by the H-S method. Figures 2 to 6 present daily ETP changes in future periods compared with the observed period in the mentioned stations. As it is obvious, in all five stations, ETP changes in future periods will be almost similar. In all three scenarios and in all three periods, ETP will increase. The 2080 decade will have the highest increase and the 2020 decade will have the lowest increase in ETP. The highest increase in ETP will be in the A1B scenario and then in the A1 scenario, and the lowest increase will be in the B1 scenario. This fact is in accordance with the assumptions of the scenarios. The lowest ETP increase will be in December and January. The highest increase will be in May, July and August. During this period, there will be a lower increase in June.

Table II.
Calculated ETP mean by different methods in the observed period (mm/day)

ETP methods	January	February	March	April	May	June	July	August	September	October	November	December	ANN
Kern													
P-M	1.1	1.7	2.7	3.8	5.1	7.0	7.5	7.1	5.5	3.4	1.8	1.1	4.0
H-S	1.1	1.6	2.6	3.9	5.4	7.4	8.0	7.3	5.5	3.4	1.9	1.2	4.1
P-T	0.8	1.3	2.2	3.2	4.2	5.3	5.3	4.7	3.4	2.1	1.2	0.8	2.9
Ham													
P-M	0.8	1.3	2.4	3.7	4.8	6.7	7.5	7.0	5.1	3.1	1.6	1.0	3.8
H-S	0.8	1.2	2.3	3.7	4.8	6.8	7.3	6.7	5.1	3.1	1.6	0.9	3.7
P-T	0.7	1.1	1.9	3.0	3.9	5.0	5.0	4.4	3.2	1.9	1.0	0.6	2.7
Sanan													
P-M	0.9	1.3	2.4	3.7	4.8	6.4	6.9	6.3	4.9	3.0	1.5	1.0	3.6
H-S	0.9	1.4	2.4	3.8	5.2	7.0	7.6	6.9	5.3	3.2	1.7	1.1	3.9
P-T	0.7	1.2	2.1	3.2	4.1	5.2	5.2	4.5	3.4	2.0	1.1	0.7	2.8
Khora													
P-M	1.1	1.7	2.6	3.5	4.7	6.0	6.2	5.9	4.8	3.2	1.8	1.2	3.6
H-S	1.3	1.9	2.9	4.2	5.8	7.6	8.1	7.4	5.9	3.7	2.1	1.4	4.4
P-T	0.9	1.4	2.2	3.1	4.0	4.8	4.8	4.4	3.3	2.1	1.3	0.9	2.8
Ilam													
P-M	1.2	1.7	2.7	3.9	5.6	7.2	7.5	7.0	5.5	3.5	1.9	1.2	4.1
H-S	1.1	1.5	2.3	3.6	4.9	6.1	6.5	6.0	4.6	3.0	1.7	1.2	3.5
P-T	1.0	1.5	2.3	3.5	4.4	5.3	5.4	4.7	3.5	2.2	1.3	0.9	3.0

ETP methods	January	February	March	April	May	June	July	August	September	October	November	December
Kerm												
HS	−0.6	−5.9	−4.3	1.9	6.1	5.0	6.4	2.4	0.7	−0.6	5.8	4.5
PT	−23	−21	−20	−16	−17	−24	−29	−34	−37	−39	−35	−31
Ham												
HS	−7.0	−7.0	−6.3	−1.7	0.2	1.0	−3.0	−4.8	−0.6	−2.3	0.5	−3.6
PT	−19	−13	−19	−21	−19	−25	−33	−37	−36	−38	−36	−32
Sana												
HS	6.4	2.8	0.9	3.0	8.4	10.0	8.7	10.0	9.3	5.9	13.7	9.7
PT	−15	−10	−13	−13	−13	−18	−24	−27	−30	−33	−29	−28
Khor												
HS	17.5	10.0	10.2	19.0	22.2	27.7	29.7	27.0	21.1	16.3	20.3	17.7
PT	−17	−16	−15	−11	−15	−19	−22	−25	−31	−33	−28	−25
Ilam												
HS	−5.2	−13	−13	−9.9	−12	−14	−13	−14	−15	−14	−8.0	0.9
PT	−18	−14	−12	−12	−21	−26	−28	−32	−35	−36	−32	−26

Table III.
ETP Difference percentage by H-S and P-T methods with P-M method in the observed period

Table IV. Evaluating indices ETP estimation methods (mm/day)

Indices	January	February	March	April	May	June	July	August	September	October	November	December	ANN
Kermanshah													
RMSE													
HS	0.2	0.2	0.4	0.4	0.8	1.0	1.2	0.9	0.8	0.5	0.3	0.2	0.6
PT	0.3	0.4	0.6	0.8	1.0	1.9	2.4	2.5	2.2	1.5	0.7	0.4	1.2
MAE													
HS	10	10	11	7.6	10.5	8.5	9.9	8.9	11	10	11	11	10
PT	29	26	25	20	22.3	35	45	53	62	65	54	45	40
MBE													
HS	0.0	0.1	0.1	0.0	−0.4	0.0	0.0	−0.2	0.0	0.0	−0.1	0.0	−0.1
PT	0.3	0.4	0.6	0.6	0.8	1.7	2.3	2.4	2.1	1.4	0.6	0.4	1.1
Hamedan													
RMSE													
HS	0.2	0.2	0.4	0.4	0.9	1.3	1.5	1.3	1.0	0.5	0.3	0.2	0.7
PT	0.3	0.3	0.6	0.9	1.2	1.9	2.7	2.8	2.0	1.3	0.7	0.4	1.3
MAE													
HS	20	18	14	9.3	14.5	13	15	15	14	10	15	16	14
PT	26	20	26	28	27.2	38	54	64	63	66	57	48	43
MBE													
HS	0.1	0.1	0.1	0.1	−0.2	0.0	0.2	0.3	0.0	0.1	0.0	0.0	0.1
PT	0.2	0.2	0.5	0.8	0.8	1.7	2.5	2.6	1.9	1.2	0.6	0.3	1.1
Sanandaj													
RMSE													
HS	0.2	0.2	0.3	0.4	0.8	1.1	1.4	1.2	0.9	0.5	0.3	0.2	0.6
PT	0.2	0.2	0.5	0.7	0.9	1.4	1.9	1.9	1.6	1.1	0.5	0.4	0.9
MAE													
HS	12	10	10	8.7	11.4	11	13	13	12	12	15	14	12
PT	19	16	17	18	19.1	26	35	41	46	51	40	40	31
MBE													
HS	0.0	0.0	0.0	0.0	−0.5	0.0	0.0	−0.6	0.0	0.0	−0.2	0.0	−0.3
PT	0.1	0.1	0.3	0.5	0.6	1.2	1.8	1.7	1.5	1.0	0.4	0.3	0.8

(*continued*)

Table IV.

Indices	January	February	March	April	May	June	July	August	September	October	November	December	ANN
Khorramabad													
RMSE													
HS	0.3	0.4	0.5	0.9	1.4	2.3	2.6	2.2	1.5	0.9	0.5	0.4	1.2
PT	0.3	0.4	0.6	0.7	1.0	1.5	1.7	1.8	1.8	1.2	0.7	0.5	1.0
MAE													
HS	18	17	15	18	20.3	25	25	23	22	20	20	22	20
PT	25	22	22	18	23.2	27	31	37	49	51	42	36	32
MBE													
HS	0.0	0.0	−0.3	−1	−1.1	−2	−2	−1.6	−1	0.0	−0.4	0.0	−0.8
PT	0.2	0.3	0.4	0.3	0.6	1.1	1.3	1.4	1.4	1.0	0.5	0.3	0.7
Ilam													
RMSE													
HS	0.2	0.3	0.5	0.6	1.0	1.3	1.4	1.3	1.1	0.7	0.3	0.2	0.7
PT	0.3	0.3	0.5	0.6	1.3	2.0	2.3	2.4	2.0	1.4	0.7	0.4	1.2
MAE													
HS	10	16	17	14	16.7	19	19	19	19	21	15	10	16
PT	24	18	16	15	29.2	38	43	52	57	56	48	36	36
MBE													
HS	0.1	0.2	0.4	0.4	0.7	1.0	1.0	1.0	0.8	0.5	0.1	0.0	0.5
PT	0.2	0.2	0.3	0.5	1.1	1.8	2.0	2.2	1.9	1.2	0.6	0.3	1.0

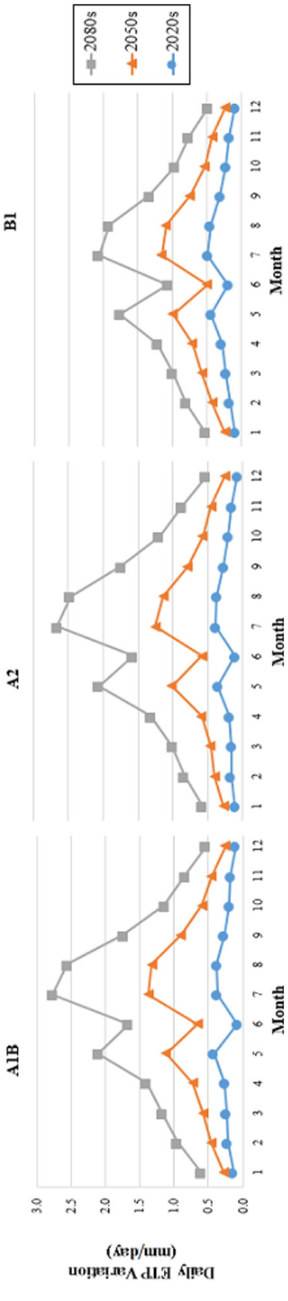

Figure 2.
Daily ETP changes compared with the observed period in Kermanshah station

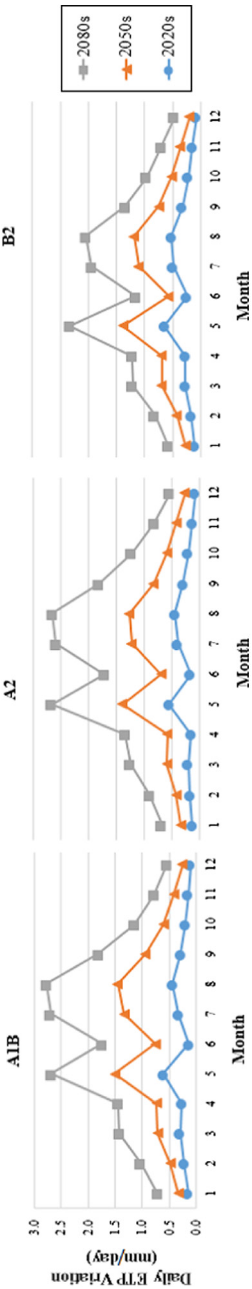

Figure 3.
Daily ETP changes compared with the observed period in Hamedan station

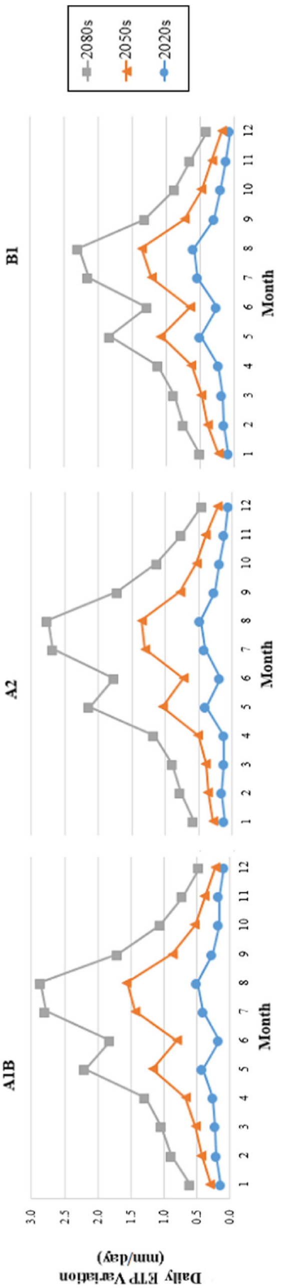

Figure 4.
Daily ETP changes compared with the observed period in Sanandaj station

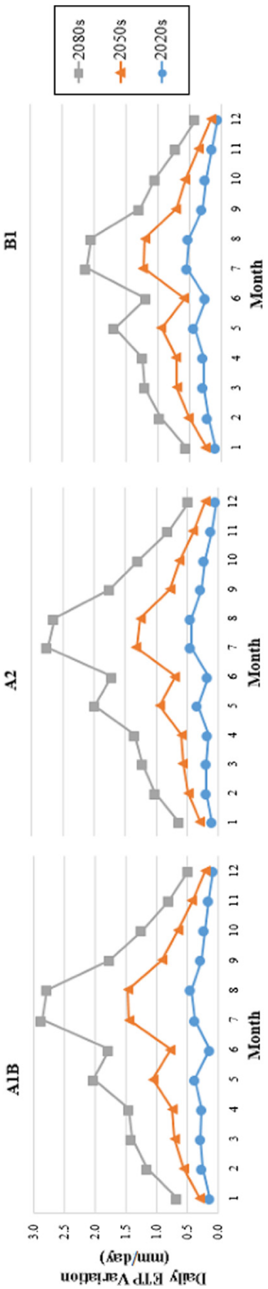

Figure 5.
Daily ETP changes compared with the observed period in Khorramabad station

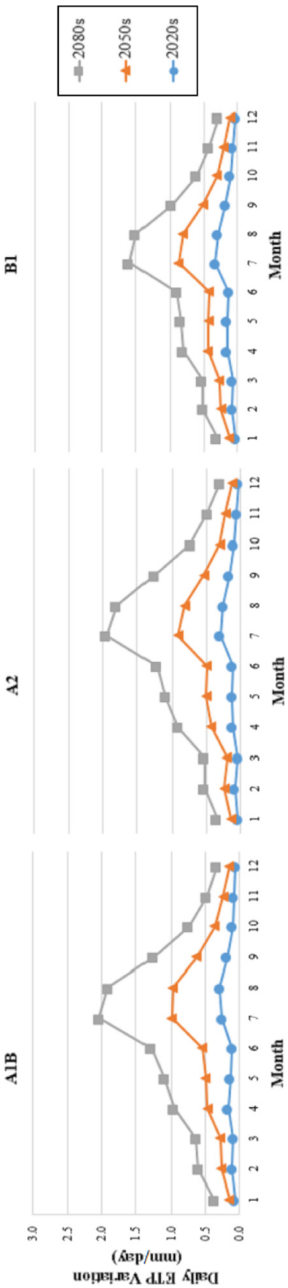

Figure 6.
Daily ETP changes compared with the observed period in Ilam station

In 2020s, the highest ETP increase percentage in all three scenarios occurs in the Khorramabad station and then in the Hamedan station; Kermanshah, Sanandaj and Ilam stations come third to fifth, respectively. In 2050s, ETP increase percentage in the scenarios will be close to each other in all five stations in the B1 scenario. It will be about 8.5 per cent in B1, 10.5 per cent in A2 and about 13 per cent in A1B scenario. In the 2080 decade, also, ETP increase percentage will be close to each other in all scenarios in four stations, Kermanshah, Sanandaj, Hamedan and Khorramabad. It will be about 11.5 per cent in B1, about 15.5 per cent in A2 and about 16.5 per cent in A1B scenario. Meanwhile, Ilam station will have a higher increase compared with the other four stations.

3.3 Uncertainty

Most of the uncertainty in climate change studies in hydrology and water resources is owing to GCM projection and regional changes (Berthelot *et al.*, 2005). Anyway, uncertainty is a challenge in hydrologic and weather parameters' prediction accuracy. Besides, a main part of uncertainty is caused by GCMs, circulations scenarios and hydrologic models (Wilby *et al.*, 2006). In A2, B1 and A1B scenarios, which have been used in the present study, there is a considerable uncertainty. The assumptions used in the scenarios may not occur in future.

On the basis of uncertainty analysis results, the contributions of different climatic variables to ET changes at different months and stations can be revealed. In general, solar radiation and daily minimum and maximum temperature are the three major contributors to PET changes in the future periods. However, causes of future PET changes are varied at different stations and months.

The next stage is the uncertainty in predicting methods, analysing climate scenarios and spatial and temporal data accuracy. This uncertainty can affect analysis evaluation accuracy directly. But the consistent trend of climate change predictions and circulation scenarios indicates that the effect of this uncertainty in the prediction results and analysis is not significant (Guo *et al.*, 2014).

The way of selecting the base period is an important factor of uncertainty and will affect the results of analysis. Therefore, the next stage of the present study is the absolute study of uncertainty.

4. Conclusion

It is obvious that in warm months of the year, ETP, which is so important in agriculture, has a higher increase compared to the cold months of the year. This causes worry about providing required water to agricultural products, while there is a decrease in precipitation owing to the climate change. In the present study, ETP has been estimated in the observed period in three future periods by three climate change scenarios, A1B, A2 and B1, by applying the Lars-WG downscaling model and by making use of the H-S equation. Regarding the length of the statistical period of the stations in the west of Iran and the parameters needed by the downscaling model, five stations have been selected for this purpose, namely, Kermanshah, Hamedan, Khorramabad, Sanandaj and Ilam. The results of the study for future periods increase considerably. In future periods, minimum and maximum temperature increase peak will be in warm months of the year (July and August) and in February. ETP increase is sensible in all stations and scenarios, especially in the irrigation season (warm months of the year), in which the highest increase amount can be seen. The results indicate that improved plans and policies in the B1 scenario are effective in the third period and lead to less ETP increase in this period compared with the other two scenarios.

References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998), "Crop evapotranspiration: guidelines for computing crop water requirements", *FAO Irrigation and Drainage Paper No. 56*, FAO, Rome, p. 301.

Berthelot, M., Friedlingstein, P., Ciais, P., Dufresne, J.L. and Monfray, P. (2005), "How uncertainties in future climate change predictions translate into future terrestrial carbon fluxes", *Global Change Biology*, Vol. 11 No. 6, pp. 959-970.

Berti, A., Tardivo, G., Chiaudani, A., Rech, F. and Borin, M. (2014), "Assessing reference evapotranspiration by the Hargreaves method in North-Eastern Italy", *Agricultural Water Management*, Vol. 140, pp. 20-25.

Cobaner, M., Citakoglu, H. and Haktanir, T. (2016), "Modifying Hargreaves-Samani equation with meteorological variables for estimation of reference evapotranspiration in turkey", *Hydrology Research*, available at: http://dx.doi.org/10.2166/nh.2016.217

Feng, Y., Jia, Y., Cui, N.B., Zhao, L., Li, C. and Gong, D.Z. (2017), "Calibration of Hargreaves model for reference evapotranspiration estimation in Sichuan Basin of southwest China", *Agricultural Water Management*, Vol. 181, pp. 1-9.

Gavilan, P., Lorite, I.J., Tornero, S. and Berengena, J. (2006), "Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment", *Agricultural Water Management*, Vol. 81 No. 3, pp. 257-281.

Guo, B., Zhang, J., Gong, H. and Cheng, X. (2014), "Future climate change impacts on the ecohydrology of Guishui river Basin, China", *Ecohydrol Hydrobiol*, Vol. 14 No. 1, pp. 55-67.

IPCC, Climate Change (2001), "The science of climate change", Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, MA.

IPCC, Climate Change (2007), *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, WMO.

IPCC, Climate Change (2014), "Impacts, adaptation, and vulnerability", *IPCC Working Group II Contribution to AR5*, IPCC, Geneva.

Katerji, N., Rana, G. and Ferrara, R.M. (2016), "Actual evapotranspiration for a reference crop within measured and future changing climate periods in the Mediterranean region", *Theoretical and Applied Climatology*, doi: 10.1007/s00704-016-1826-6.

King, D.A., Bachelet, D.M., Symstad, A.J., Ferschweiler, K. and Hobbins, M. (2015), "Estimation of potential evapotranspiration from extraterrestrial radiation, air temperature and humidity to assess future climate change effects on the vegetation of the northern Great Plains, USA", *Ecological Modelling*, Vol. 297, pp. 86-97.

Liu, Q., Yan, C. and Ju, H. (2017), "Impact of climate change on potential evapotranspiration under a historical and future climate scenario in the Huang-Huai-Hai Plain, China", *Theoretical and Applied Climatology*, doi: 10.1007/s00704-017-2060-6.

Marti, P., Zarzo, M., Vanderlinden, K. and Girona, J. (2015), "Parametric expressions for the adjusted Hargreaves coefficient in Eastern Spain", *Journal of Hydrology*, Vol. 529, pp. 1713-1724.

Peng, H., Jia, Y.W., Qiu, Y.Q. and Niu, C.W. (2013), "Assessing climate change impacts on the ecohydrology of the Jinghe river Basin in the Loess Plateau, China", *Hydrological Sciences Journal*, Vol. 58 No. 3, pp. 651-670.

Priestley, C.H.B. and Taylor, R.J. (1972), "On the assessment of surface heat flux and evapotranspiration using large scale parameters", *Monthly Weather Review*, Vol. 100 No. 2, pp. 81-92.

Racsko, P., Szeidl, L. and Semenov, M. (1991), "A serial approach to local stochastic weather models", *Ecological Modelling*, Vol. 57 Nos 1/2, pp. 27-41.

Samani, Z. (2000), "Estimating solar radiation and evapotranspiration using minimum climatological data", *Journal of Irrigation and Drainage Engineering*, Vol. 126 No. 4, pp. 265-267.

Semenov, M.A. (2007), "Development of high-resolution UKCIP02-based climate change scenarios in the UK", *Agricultural and Forest Meteorology*, Vol. 144 Nos 1/2, pp. 127-138.

Semenov, M.A. (2008), "Simulation of extreme weather events by a stochastic weather generator", *Climate Research*, Vol. 35, pp. 203-212.

Semenov, M.A. and Barrow, E.M. (2007), LARS-WG A Stochastic Weather Generator for Use in Climate Impact Studies, User Manual.

Semenov, M.A. and Stratonovitch, P. (2010), "The use of multi-model ensembles from global climate models for impact assessments of climate change", *Climate Research*, Vol. 41, pp. 1-14.

Shiri, J., Nazemi, A.H., Sadraddini, A.A., Landeras, G., Kisi, O., Fard, A.F. and Marti, P. (2014), "Comparison of heuristic and empirical approaches for estimating reference evapotranspiration from limited inputs in Iran", *Computers and Electronics in Agriculture*, Vol. 108, pp. 230-241.

Shiri, J., Sadraddini, A.A., Nazemi, A.H., Marti, P., Fard, A.F., Kisi, O. and Landeras, G. (2015), "Independent testing for assessing the calibration of the Hargreaves-Samani equation: new heuristic alternatives for Iran", *Computers and Electronics in Agriculture*, Vol. 117, pp. 70-80.

Tabari, H. and Talaee, P.H. (2011), "Local calibration of the Hargreaves and Priestley Taylor equations for estimating reference evapotranspiration in arid and cold climates of Iran based on the Penman-Monteith model", *Journal of Hydrology Engineering*, Vol. 16 No. 10, pp. 837-845.

Tiegang, L., Longguo, L., Jianbin, L., Chao, L. and Wenhua, Z. (2016), "Reference evapotranspiration change and its sensitivity to climate variables in Southwest China", *Theoretical and Applied Climatology*, Vol. 125 Nos 3/4, pp. 499-508.

Wilby, R.L. and Dawson, C.W. (2013), "The statistical DownScaling model: insights from one decade of application", *International Journal of Climatology*, Vol. 33 No. 7, pp. 1707-1719.

Wilby, R.L., Whitehead, P.G., Wade, A.J., Butterfield, D., Davis, R.J. and Watts, G. (2006), "Integrated modelling of climate change impacts on water resources and quality in a lowland catchment: river Kennet", *Journal of Hydrology*, Vol. 330 Nos 1/2, pp. 204-220.

Xu, J.Z., Wang, J.M. and Wei, Q. (2016), "Symbolic regression equations for calculating daily reference evapotranspiration with the same input to Hargreaves-Samani in arid China", *Water Resources Management*, Vol. 30 No. 6, pp. 2055-2073.

Xu, Y.P., Zhang, X.J., Ran, Q.H. and Tian, Y. (2013), "Impact of climate change on hydrology of upper reaches of Qiantang river", *Journal of Hydrology*, Vol. 483, pp. 51-60.

Further reading

Koczot, K.M., Markstrom, S.L. and Hay, L.E. (2011), "Effects of baseline conditions on the simulated hydrologic response to projected climate change", *Earth Interactions*, Vol. 15 No. 27, pp. 1-23.

Xing, W., Wang, W., Shao, Q., Peng, S., Yu, Z., Yong, B. and Taylor, J. (2014), "Changes of reference evapotranspiration in the Haihe River Basin: present observations and future projection from climatic variables through multi-model ensemble", *Global and Planetary Change*, Vol. 115, pp. 1-15.

Corresponding author
Ahmad Rajabi can be contacted at: ahmadrjb@yahoo.com