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Environmental Assessment of Future Potential Evaporation for Al-Najaf Governorate, Iraq through Evaluating Various Estimation Methods Using Statistical Downscaling Model

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Abstract: The hydrological cycle in nature is affected by climate changes, which are reflected in the water resources on the Earth (surface and underground) as evapotranspiration, thereby causing water scarcity. Increasing global temperature rates have exacerbated evaporation rates (PET). To estimate PET, scientists invented many mathematical equations, the most prominent of which is the Penman-Monteith equation. Most of the innovative methods require the provision of many parameters to be implemented; therefore, feasibly worthless for application in data mingy regions. The performance of the four PET estimation methods has been investigated depending either on temperature or radiation observed at Al-Najaf Governorate, Iraq. The accuracy and efficiency of each method have been evaluated with the outputs of the reference Penman-Monteith method. Through assessment, Hargreaves Samani temperature-based method reveals high acceptability of the estimated PET than the Jensen-Haise method and the other radiation-based methods (Penman and Makkink). The Statistical Downscaling Model/Tool (SDSM version 5.2) is applied to predict temperature values for the years 2050 and 2100. Estimated PET using Hargreaves Samani formula for 2050 and 2100 shows that Al-Najaf Governorate will encounter severe water scarcity due to the expected future increase in evaporation rates. Overall, regions classified as dry with high temperatures are compatible with methods of estimating PET values that depend on temperatures more than those that depend on radiation.

Key words: PET forecasting, PET methods' evaluation, future PET impact prediction, Al-Najaf Governorate, Iraq.

Introduction

Evaporation from the surface of rivers, oceans, water ponds and groundwater reservoirs, in addition to transpiration from the surfaces of plants all together is used to describe evapotranspiration (PET). The hydrological cycle in nature depends mainly on two important factors, namely rain and evaporation, as the latter has the ability to control river drainage, which affects the size and quantity of surface runoff, as well as soil moisture, which is greatly affected by evaporation (Lee and Cho, 2012; Morin et al., 1979). Hydrological planning for water balance depends largely on the accurate estimation of the value of evaporation. The proven effects of climate change are represented by a sharp increase in temperature, which will be reflected in changes in the pattern of precipitation and increase in evaporation rates (Brumbelow and Georgakakos, 2001; Winter et al., 2003).

Hydrologists have done a lot of work developing methods to calculate the PET value due to its importance in the hydrological cycle. These methods

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differ from one to another, as each has its own concept and perspective and has been developed to suit specific climates. Accuracy, efficiency and reliability in estimating the value of PET is the most important element in determining the appropriate computational method (Das and Mohanty 2006; Moazed et al., 2014). Nurul et al. (2012) have explored six methods used to estimate PET through applying them on Kedah, north of Malaysia and then compared the results with each other and with the reference on Penman-Monteith to evaluate all methods.

The methods that have been developed depend mainly on the geographical area and the nature of the climate to which of those areas are exposed, which leads to some failure to estimate the value of PET when applied in other climatic regions. The Penman-Monteith method is one of the methods that have the ability to estimate the value of PET in a wide variety of climatic regions. The methods currently available in research studies have high reliability because they have been applied in different regions of the world and have given results that are close to the observed values. These methods need to collect comprehensive hydrological data and information about the area to be studied. Here a complex problem arises as most meteorological stations generally measure precipitation and temperatures and rarely measure the hydrological parameters required to measure the PET value (Nurul et al., 2012; Paparrizos et al., 2014). Another challenge faced while applying PET valuation methods is future climate change. Most of the General Circulation Models (GCM) predict the amounts of precipitation and average future temperatures (in the long term) while most methods of estimating the value of PET contain a lot of hydrological parameters that must be provided in addition to the average temperature and amount of rainfall to determine the PET value. Recently, the computational Statistical Downscaling Models are being used in which it is possible to predict the parameters required to apply PET calculation methods. The PET methods are not much applicative to be used for the climatic conditions of the region, which gives unequal results for the PET value (Anderson and Smith, 1981; Droogers and Allen-Richard, 2002; Garcia et al., 2004).

Desert (arid) and semi-arid areas suffer from excessive thermal stresses imposed on them. Accuracy and efficiency in estimating the value of evaporation depend on the applied method, which should be compatible with the climatic and spatial changes of the candidate area in order to predict the best future of climate accidents like evaporation, temperatures or precipitation. The geographical location and the nature of the climate to which the area is exposed and the observed data are the ones that precisely control the results of the applied mathematical equation (Hosseinzadeh et al., 2014; Lee et al., 2004; Muniandy et al., 2016). Therefore, the researcher is required to use the observed and sometimes experimental parameters in the evaporation equations to obtain future values (Ali et al., 2000).

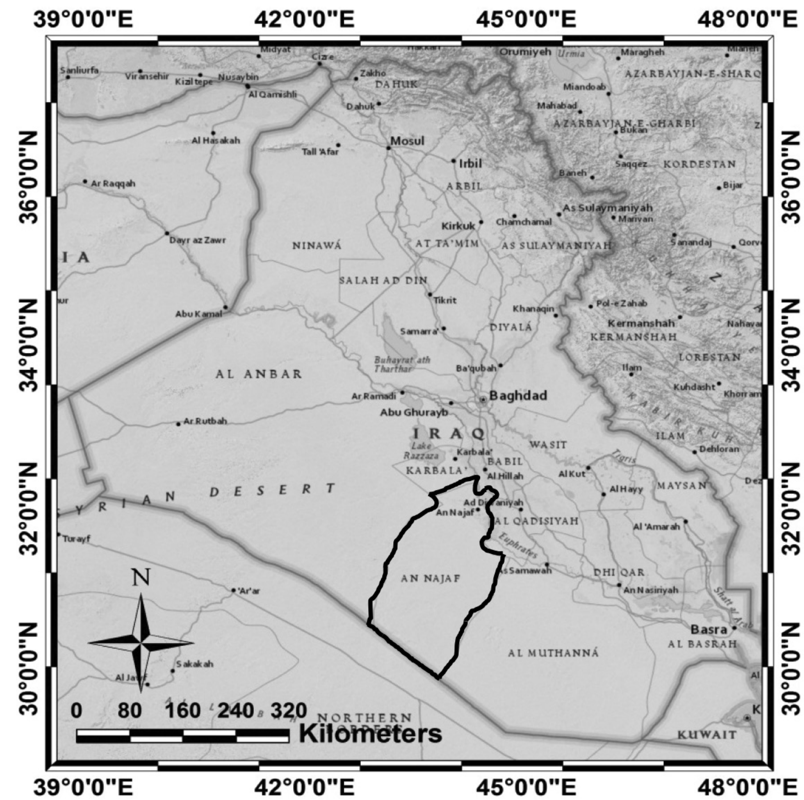
The present study aims at exploring the performance of four widely spread methods that are worldwide used hydro-geologically in estimating PET: Penman, Makkink, Jensen–Haise and Hargreaves Samani methods for estimating the PET value of Al-Najaf Governorate, Iraq. This study will accurately assess the value of PET for better and efficient management of the water resources available in this city. The Penman-Monteith method will be used as a reference due to its most reasonable and reliable method for estimating the value of PET as it fully and comprehensively takes into account hydro-meteorological climatological changes (Djaman et al., 2015; Gocic and Trajkovic, 2010; Song et al., 2019).

Al-Najaf Governorate Study Area

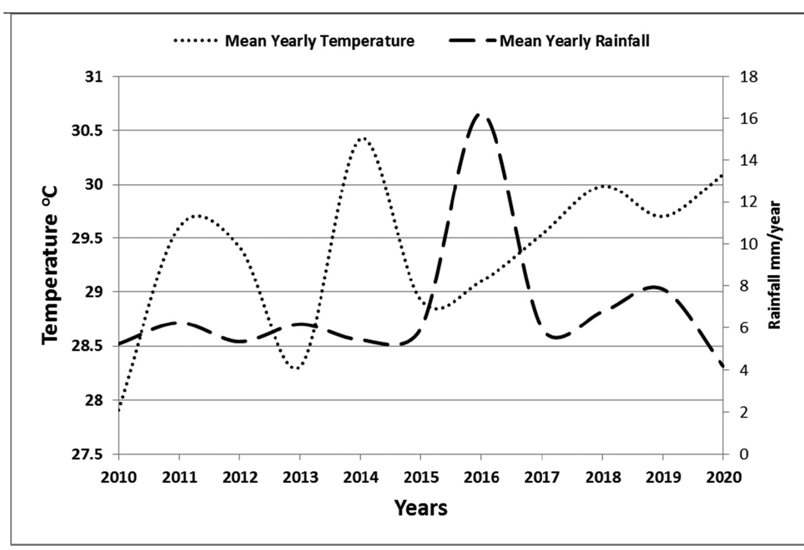
The province of Al-Najaf astronomically lies between latitude (29°-32°) North and longitude (42°-44°) East, and it has this astronomical position by 2.25 latitude, which means that it is located within the sub-tropical latitudes that are located within the global heat flux regions. It is located in the southwestern part of Iraq, and its shape takes a northeast-southwest extension close to the extension. Its short side constitutes the southern border with the Kingdom of Saudi Arabia, and it is bordered on the north by the governorates of Babel and Karbala, and on the east by the governorates of Qadisiyah and Muthanna and Anbar province in the west, as it can be seen in Figure 1a. The area of the Al-Najaf governorate is 28824 km^2 and thus constitutes (6,6%) of the total area of the country (Kareem, 2018).

The rates of conservative temperatures vary monthly and seasonally due to the variation in the rates of solar radiation reaching the surface of the governorate, as well as the influence of other factors such as depressions. The average annual temperature in the governorate is 30.5 ^oC, as temperatures start to rise gradually from March (27.7 ^oC) and continue to increase to reach 39.2 ^oC in June when the sun is vertical over the course of Cancer. The highest average temperature is recorded in the governorate in July and August

(46-50 ^{o}C). Winter temperatures (November – February) range between 10 and 20 ^{o}C. Al-Najaf receives small, variable and fluctuating amounts of rain monthly, seasonally and annually, as the average annual total rainfall is approximately 97.1 mm. The rains fall during the short winter months, starting in October (1.7 mm) and then around 9.9 mm and 19.9 mm in November and December, respectively, while it reaches its highest amount in January (20.1 mm). In recent few decades, due to the high rates of temperatures recorded as well as the activity of hot dry winds in the summer months, the rains have begun to subside. The values of evaporation in Al-Najaf are seen to increase dramatically, reaching an annual total of approximately 3655.57 mm (MOWR, 2015) (See Figure 1b).



(a)



(b)

Figure 1: (a) The study area (Al-Najaf Governorate) and (b) yearly temperature and rainfall observed values 2010-2020 (as adopted by MOTRANS, 2018).

Description of SDSM

As a result of climate change on a global and regional scale, a future temperature projection process will be required in order to predict possible changes in the PET value. To perform the projection, the Statistical Downscaling Model/Tool (SDSM version 5.2) is used in order to reduce the effect of the GCM output at the regional level of the study area and to highlight the temperature that the study area is exposed to over the mid and end of the twenty-first century. This tool is a hybrid tool that has the ability to predict the influences and changes that the climate is exposed to at the local or regional level using the multiple regression techniques by linking the atmospheric variables with the climate variables of the local or regional area under study. Reducing the size of the model requires the provision of two types of data: predict and predictor. The temperature daily data recorded at the station located in the Western Desert of Al-Najaf Governorate (2010-2020) will be implemented as a predict, while the atmospheric variables will be considered as predictors.

Materials and Methods

PET Eminent Estimation Methods

Four of the most famous and accurate methods are applied to estimate the PET value for Al-Najaf Governorate.

Penman Method

The Penman (1948) equation is a powerful equation that takes into account the physical phenomenon of evaporation. To apply this equation, it needs to provide the climatic parameters represented by relative humidity, wind speed and solar radiation in addition to temperature.

$$PET = \left(\frac{\Delta}{\Delta+\gamma}\right) * R_W + \left(\frac{\Delta}{\Delta+\gamma}\right) * V_{at} \quad (1)$$

$$R_W = R_S * (1-r) - R_L \quad (2)$$

$$R_L = 0.95 * [8.64 * 10^7 / (\rho * \lambda)] * \beta * 9273.16 + t)^4 * 90.53 + 0.065 * (da-1)^{1/2}) * (0.1 + 0.9 * (m/M)) \quad (3)$$

$$V_{at} = 0.3 * (1 + 0.5 * V) * (ds - da) \quad (4)$$

where R_s is the value of short-wave radiation reflected from the body of water; R_L is the value of long-wave radiation reflected from the body of water; r represents a coefficient related to the cover of vegetation, ρ is water density (kg/m^3), λ is the latent vapour heat (MJ/kg), β is the constant of Bolzman's equals (5.7*10-8 kW/(m^2*grad^4)), and m/M is the percentage of actual to possible sunshine hours for bright sunshine.

Makkink Method

Through the use of radiation (mainly) and temperature data in Makkink (1957) formula, it can estimate the PET value from below:

$$PET = 0.61 \frac{\Delta}{\Delta+\gamma} \frac{rn}{\lambda} - 0.12 \quad (5)$$

Jensen–Haise Method

Jensen-Haise (1963) equation is one of the developed and modern equations used to calculate the evaporation value of weeds that depend on irrigation. This equation includes a few parameters and depends on some experimental constants to avoid difficulty in the application as it depends on the principle of energy balance.

$$PET = [0.014\,(1.8 * t + 32) - 0.5] \frac{Rs}{\lambda} \quad (6)$$

Penman-Monteith Formula (Reference Method)

Monteith (1965) has combined the parameter of aerodynamic vapour with the parameter of resistance related to the bulk surface, which reflects a strong theoretical expression as demonstrated:

$$PET = \frac{0.408\Delta(rn-g) + \gamma \frac{900}{\sqrt{t+273}} V_2 (ds-da)}{\Delta + \gamma(1+0.34V_2)} \quad (7)$$

where PET is the evapotranspiration estimated value (mm/month); Δ is the curve of vapour slope (kPa/°C); rn is the cross radiation reflected by the surface of crops (1/MJm^2 month); g is heat flux density of the soil (1/MJm^2 month); t is the temperature of air (°C); V is the speed of wind (m/s); ds is the pressure of saturated vapour (kPa); da is the pressure of actual vapour (kPa); γ is the constant of psychrometric (kPa/ °C).

Hargreaves-Samani Method

The Hargreaves and Samani (1985) formula, is needed to provide the information of temperature and relative humidity to estimate the value of PET, as expressed below:

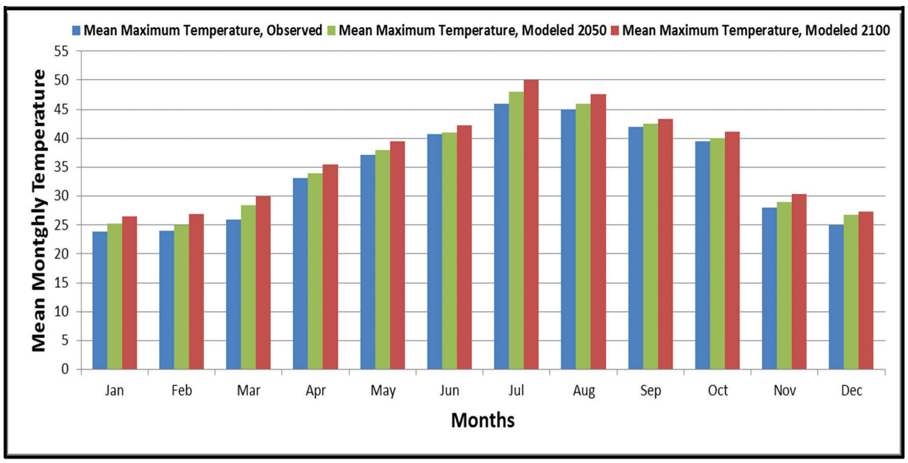
$$PET = 0.00551\ (Tx - Tn)^{0.5}(Tm + 17.8)*rn \quad (8)$$

where Tx, Tn and Tm are the data of maximum, minimum, and mean temperature (°C), respectively.

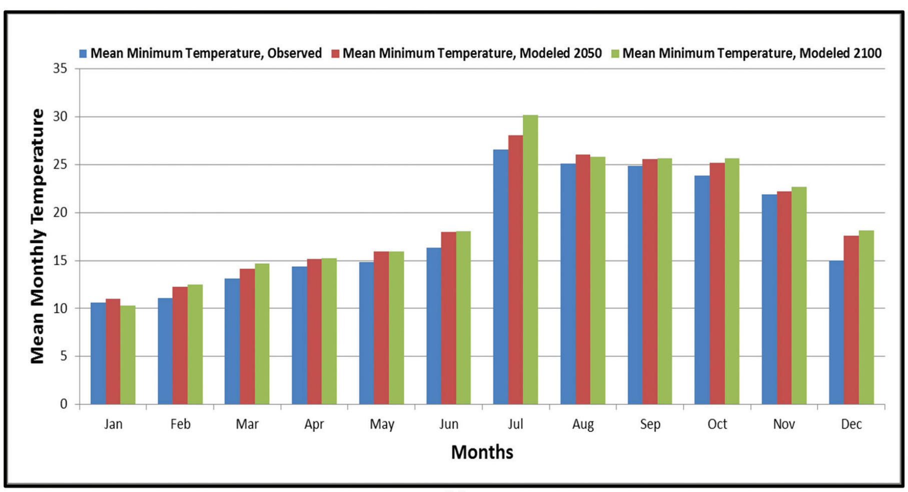
Results and Discussions

Predicted Temperatures at 2050 and 2100 in the Study Area

The temperature daily data collected for the study area will be simulated using the SDSM program to predict the changes that will occur to it for the period from 2021 to 2100. Overall, temperature values follow the normal distribution as it begins low in the winter and rises gradually in the spring until it reaches its peak in the summer and then begins to decline in the autumn. Figure 2 shows the results of the temperature projection, as it can be seen that the maximum (Figure 2a) and minimum (Figure 2b) temperatures will averagely increase by 1.6 °C and 0.8 °C, respectively, in the study area by 2050. The results shown in Figure 2 clearly indicate that the maximum temperature will rise constantly and its value will range from 32-47 °C for the period between May and July, during which the winds are classified as northwesterly, while their value will gradually and continuously decrease for the period from August to February. Similarly, for 2100, the trend of temperature will follow the same pattern for 2050. Clearly, it can be noticed that the results of reducing the size of the study area that the maximum temperature will increase dramatically by 2° (in 2050) to reach its value of 48.7 °C by the middle of the current century, as the average temperature will continue to rise by 1.3 °C (in 2100) at the end of this century, which creates great hydrothermal pressure on the sources of water which will lead to increase in evaporation rates. The minimum temperature values will also increase gradually in 2050 and 2100, but it is noticed from Figure 2a, b that its



(a)



(b)

Figure 2: Observed and predicted modelled temperatures for Al-Najaf Governorate: (a) predicted mean monthly maximum and (b) predicted mean monthly minimum.

value will expose to a dramatic increase in July and August which are considered the warmest months, as the temperature will increase by 7 ºC (2050) and 9 ºC (2100) in July and by 3 ºC (2050) and 4 ºC (2100) in August.

PET Methods Implementation for Al-Najaf Governorate

To evaluate the accuracy and reliability of the five methods that are applied in the study area to estimate the PET value, the results obtained will be compared with those estimated using the Penman-Monteith method. Where the evaluation process is based on the results of two parameters, which are (1) the Standard Error of The Estimate (SEE), which gives the amount of error between the calculated and observed values and (2) the Correlation Coefficient (CC), which explains the extent and manner of the correlation applied between the PET estimates measured for each method. The SEE should be as little as possible to indicate good performance. The CC value ranges between 1 and -1 as when its value is closer to 1, this indicates good correspondence between the simulated and observed data.

Figure 3 states the average yearly results of PET values over the period 2010-2020 for Penman, Makkink, Jensen-Haise, Penman-Monteith and Hargreaves-Samani, formulas, respectively. The figure shows the results of each applied formula that has been used to estimate PET. It can be noticed that the average yearly PET value that has the closest results to the reference method (Penman-Monteith) is resulting from the Hargreaves-Samani Method. While the furthest methods are highlighted by Makkink, Penman and Jensen-Haise. It can be noticed that the methods that depended on radiation in estimating the PET value (Penman (1948) and Makkink (1957)) gave very large values for SEE (as shown in Table 1) in contrast to those that relied on the temperature in evaluating PET (Jensen-Haise and Hargreaves-Samani Methods). Despite the Jensen-Haise method having mainly relied on temperature value, still it is forecasted to the PET value, which is significantly very high. Jensen-Haise method depends on humidity, as when the humidity has a value, the forecasting of this method will be to some extent correct, but the study area is classified as an arid area and this was the cause for estimating high values of PET through this method. Table 1 shows that the CC value for the Hargreaves-Samani method is closer to 1, indicating a high degree of agreement PET with the Pnman-Monteith method. While the results of the four methods used in the study area depend on radiation, the Jensen-Haise method is very far from the reference method. In conclusion, the methods used to measure the PET value based on temperature have great accuracy in estimating PET than those depending on radiation when compared to the results of the Penman-Monteith method, which means that the temperature-based methods have the ability to reconstruct the actual PET pattern with high accuracy and efficiency compared to those that adopt on the radiation. Accordingly, it can adopt this method in calculating the value of evaporation for the governorate of Al-Najaf.

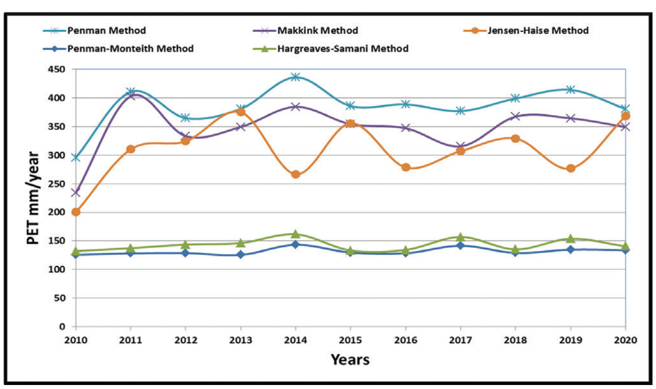


Figure 3: Average yearly PET values resulted from applying various calculation formulas.

Table 1: The SEE and CC evaluation parameters

Formula	*SEE*	*CC*
Penman	64.703	0.258
Makkink	57.874	0.282
Jensen-Haise	41.453	0.383
Penman-Monteith	----	----
Hargreaves-Samani	0.513	0.932

Forecasting the Future PET in Al-Najaf Governorate

Figure 4 is plotted to investigate the predicted PET value using Penman-Monteith and Hargreaves-Samani methods for the years 2050 and 2100. Methods that are depended and affected mainly by radiation will be neglected from the application because they do not show a perceived activity of temperature (Penman and Makkink) in addition to the Jensen-Haise temperature-based method. For the purpose of estimating the future PET value, the values of future temperature resulting from the SDSM tool will be entered, where all other elements present in the PET calculation equations will be fixed because those parameters are not affected by radiation. In general, the results for the two methods applied to the study area showed an increase in the PET value for 2050 and 2100. The expected future increase in the PET value came as a result of an increase in the values of future temperatures, as it is natural that when the temperature increases, this leads to an increase in the

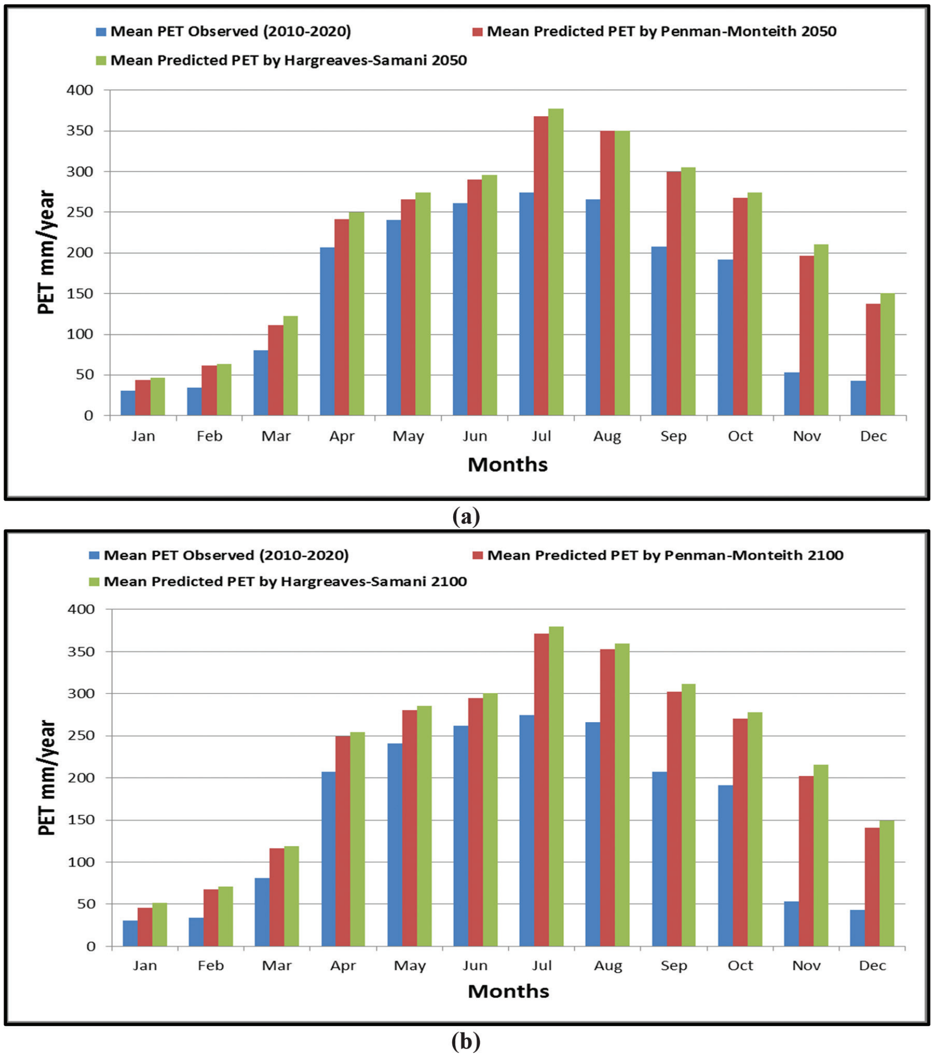


Figure 4: Values of PET observed (2010-2020) and predicted: (a) 2050 and (b) 2100.

rates of evaporation from the water sources located on the surface of the earth and from the surfaces of plants. It can be noted that the Hargreaves-Samani method predicted an evaporation value ranging from 18 to 110 mm/year in 2050 (see Figure 4a) and from 25 to 120 mm/year in 2100 (see Figure 4b) as this value gives an increase in the PET value by 0.56% annually in 2050 and 80% annually in 2100 as an average when compared to the measured PET value for the study area at present.

Conclusion

The current research deals with the study of four methods [Penman and Makkink-(radiation-dependent methods)] and [Jensen-Haise and Hargreaves-Samani-(temperature-based methods)] to estimate the value of PET for Al-Najaf Governorate, Iraq and compare their results with the reliable method, Penman-Monteith. The Hargreaves-Samani temperature-dependent method shows the best performance, lowest errors and highest correlation coefficient among the four methods that were applied to the study area. The results obtained from the study show that the PET value for the study area ranges averagely from 120 mm/year to 135 mm/year. In general, it is found that the radiation-dependent methods for estimating the PET value give overestimated results than those that depend on temperature by comparing the results of the four methods with the results of the internationally approved Penman-Monteith method. SDSM tool is used to predict the future temperatures values resulting from the impact of future climate change. Since there is only one method that can be applied to the study area, the Hargearves-Samani method, it will therefore be applied to predict future PET values and compare its results with that obtained using the Penman-Monteith method to investigate its efficiency. This study will provide unambiguously important information for stakeholders and water and hydrology researchers in addition to providing the appropriate method for estimating the PET of Al-Najaf Governorate, Iraq.

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