EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 14(2) 2021 40-50
DOI 10.14456/ea.2021.15
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Comparison of Some Mathematical Models to Calculate Evapotranspiration in Contrasting Regions of Iraq

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Received: June 30, 2020; Revised: August 16, 2020; Accepted: December 23, 2020

Abstract

Evaporation is one of the major components of hydrologic cycle and water balance. The data required for its accurate estimation are commonly available only at widely spaced weather stations. Evapotranspiration can be estimated using mathematical models based on atmospheric variable, which can be measured directly. However, these mathematical models differ among themselves in terms of accuracy of the results due to the different determinants of each mathematical model. In addition, the accuracy of the model varies from region to region. The current study aims to compare some mathematical models performance in selected regions in Iraq. The results showed that Penman-Monteith model was the best model for calculating Evapotranspiration in Iraq as it achieved values close to the observed values of evapoetranspiration with a high correlation and an absolute error coefficient ratio is small. In comparison, Ivanov model was the least accurate model with a smaller correlation values and higher absolute error rate values than the other methods . The data used in this study are a time series of the evapotranspiration values of agricultural stations. These data are measured by means of lysrometers.The model that uses the largest number of atmospheric variables that influence on Evapotranspiration calculation is the best.

Keywords: Evapotranspiration; Penman-Monteith; Thornthwaite; Khrrufa; Ivanov; Correlation; Mean Absolute Error.

1. Introduction

Water resources management is a critical demand for increased agricultural production in arid regions where food insecurity has become a major concern (De Zeeuw *et al.,* 2009). The water cycle is the main process in the different iteractions and for different scales of the earth system. However, Earth surface evapotranspiration (ET), as an important part of the water cycle, is the main method of water consumption in the Earth system, as it plays an important role in the global and regional climate of the lands (Wang *et al.,* 2012; Jung *et al.,* 2010). Farmland ET refers to the total water exchanged with the air by plants and the Earth's surface respectively.

ET around the world consumes about 60% of the rain and 99% of the water in the farmland system (Kite, 2000). With global climate change, evapotranspiration, is a prerequisite for understanding the interactions between soil, plants and the atmosphere (Nemani *et al.,* 2002). ET consists of evaporation and transpiration. The first is the process by which water transfers from the surface, liquid to vapor, and enters the atmosphere, and the second is the process by which water in plants passes through the stomata and spreads outward (Lulu *et al.,* 2012). As for reference evapotranspiration (ETo) represents the maximum amount of steam that can be released from a given area of the earth to the atmosphere is under the influence of the weather factors specific to that region (Ammar and Haidar, 2013). Evaporation is an component not only in the surface heat balance but also in the hydrological cycle (Jingxin *et al.,* 2013). It has the functions of regulating temperature, increasing humidity, affecting the environmental ambience, and thus affects the sustainable development of society and economy (Liu *et al.,* 2013). Farmland irrigation and ET can use and insert 60% and 80% of the net radiation during the growing season, receptively (Suyker *et al.,* 2008).

ET is a function of a number of environmental variables including temperature, precipitation, radiation, wind velocity and humidity (Lulu *et al.,* 2012; Liu *et al.,* 2013). Therefore, varying ET good indicator of climate change drivers (Chattopadhyay *et al.*1997).

In the literature, different works have used a variety of methods for estimating ET (Roderick and Farquhar, 2002). Lysimeters have been applied to determine ET of mass balance for shallow groundwater environments. However, it has been found that this method might give false readings due to air entrapment (Fayer and Hillel, 1986), as well as fluctuating by the water table (Yang *et al.,* 2000). In addition, some methodologies such as the energy budget and eddy correlation are also restricted to calculating net ET(Net evapotranspiration). Net ET occurs when the rate of evaporation exceeds the rate of condensation (Summer, 2006).

The Penman – Monteith method was found better than the Kharrufa, Samani, Hargreaves models and modified Blaney–Criddle methods to estimate the ET in Mosul city in Iraq (Al-Rijabo *et al.,* 2008). In Karbala city (Aljumaili *et al.,* 2014), the ET was estimated using the Food and Agriculture Organization (FAO) Penman - Monteith, Penman - Kimberly, Jensen - Haise and Hargreaves models; the first of those methods was more consistent with observed data than the others. Studies of Al - Sudani (2018) and Jawad (2016) adopted the Thornthwaite equation to estimate the ET in Iraq. The results were dependable for calculating ET.

In this study, monthly time series of observation and estimated data are compiled and tested by the Pearson Index (R^2) and the Mean Absolute Error (MAE). We used four methods over the four agriculture stations to investigate the best one to characterize the ET in Iraq.

2. Methodology

2.1 Study area

The monthly data of the climatic parameters from the Iraqi Meteorological Organization are used in to estimate the values of ET by the four methods (FAO Penman - Monteith, Thornthwaite, Khrrufa, and Ivanov), also the monthly real values of ET are provided through the same source. The chosen study area is represented by four meteorological stations distributed over four Iraqi governorates; Mosul, Baghdad, Anbar and Basrah as shown in (Figure 1), and located in different regions in terms of longitude and latitude, as shown in (Table 1). These governorates have the advantage that they differ in terms of geographical characteristics. In addition, the variation in the values of atmospheric elements that affect the value of evaporation, as well as these governorates have the advantage that they include all climatic patterns for all governorates of Iraq.

Table 1. The geographical and weather characterization of some climatic parameter for the study stations

Stations	Altitude (m)	Longtude (°E)	Longtude (°N)	Avg. temperature (C)	Wind velocity (m/sec)	Monthly total solar rad. (Mj/m²)	Relative humidity (%)
Baghdad	31	44.23	33.32	23.37	1.62	18.6	42.8
Mosul	223	43.16	36.33	21.95	1.2	17.3	48.98
Al-Anbar	30	43.97	32.55	23.38	1.67	18.68	38.6
Basrah	2	47.45	30.93	13.13	3.78	25.87	38.3

Figure 1. Iraq map, Baghdad, Mosul, Anbar and Basrah weather stations locations.

2.2 Methods

In this study, four mathematical models FAO Penman - Monteith, Thornthwaite, Khrrufa, and Ivanov methods are used to estimate the values of the Evapotranspiration. Where data for the region is entered into the four mathematical models followed by a comparison of the evaporation values of the Evapotranspiration that were estimated for each model with values Evapotranspiration observation. The data of the observed values used in this study were obtained from the Agricultural Meteorological Network at the Iraqi Ministry of Agriculture. Regional data were analyzed using Pearson correlation statistics with error checking the mean absolute error (MAE). This process was applied to all four chosen agricultural areas.

Because the calculation of Evapotranspiration using Evapotranspiration measurement devices is not accurate in addition to neglecting transpiration from the plant (Ammar and Haidar, 2013), so Khrrufa, Thornthwaite, Hargreaves and Ivaov have found mathematical equations by which the transpiration evaporation can be estimated, and many equations have appeared in the calculation of transpiration evaporation on temperature, soil heat, wind velocity, vapor pressure-and sun shine duration, some of which relied on temperature and humidity like (Ivanov) and others depend on the temperatures and rates of solar brightness (Kinjo, 2009), such as the modified lamb. These equations were adopted in estimating the evaporation values of latent transpiration in Iraq due to their ease of application and the availability of climatic data required in the model.

2.2.1 FAO Penman-Monteith method

Its mathematical formula
(Biesdore et al., 2017)

$$ET_o = \frac{\left[0.408\nabla(Rn - G) + r\left\{\left(\frac{900}{T273}\right)U2(es - ea)\right\}\right]}{\Delta + r(1 + 0.34U2)} \quad (1)$$

Where:
ET_0: reference evapotranspiration (mm day^{-1}).
G: soil heat flux (MJ/m^2 day).
Rn: net radiation (MJ/m^2 day)
Δ: slope of the saturation vapor pressure-temperature curve (Pa/ °C).
r : humidity constant.
T: temperature (C)
U2: wind velocity on hight 2meter (m/sec)
e_s :saturated water vapor pressure (kPa).
e_a : Actual water vapor pressure (kPa).

2.2.2 Thornthwaite method (Saud et al., 2014)

$$ET_o = 16 * \left(10\frac{T}{I}\right)^a * \mu\frac{N}{360} \quad (2)$$

Where:
E: is monthly potential evapotranspiration (mm/month)
T: monthly mean temperature (C)
I: the empirical annual heat index, the sum of 12 monthly index values i. The value of i for each month is derived from mean monthly temperatures according to the formula:
ij = 0.09*(Tj)1.5, where subscript j indicates the specific month under investigation,
μ: the number of days in the month
N: the mean number of daylight hours in a particular month
a: an empirically derived exponent which is a function of I, and is given by the formula:
a = 0.016*I + 0.5.

2.2.3 Khrrufa Equation (Chen et al., 2005)

$$ET_o = 0.34pT^{1.3} \quad (3)$$

T is mean temperature (C), *p* is sunrise hours (sun shine duration)

2.2.4 Ivanov method (Cunha et al., 2017)

$$ET_o = 0.0018 * (25 - T) * (100 - RH) \quad (4)$$

T is mean monthly temperature (C), RH is Relative Humidity

For the purpose of knowing the efficacy of the mathmatical models and evaluate the performance of these models in ET Calculation. The comparison is made between the estimated and measured evapotranspiration using the Class A pan method values. Class A evaporation ponds are widely used for estimating the ETo reference evaporation-transpiration of green grass reference plant (Snyder, 1992)

Several performance criteria were used including Pearson type coefficient of determination index (R^2) and Mean Absolute Error (MAE), these criteria are defined as:

(a) Pearson type coefficient of determination index, R^2 (Mondal and Mondal, 2017)

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (5)$$

Where: R^2 is Pearson type coefficient of determination index
yi : observation values, $\bar{y}$: average of values, n: number of values, $\hat{y}$: estimated values of (ET) The value of (ET) represents the estimated values of evapotranspiration, which can be estimated using the mathematical models that were adopted in this study.

(b) Mean Absolute Error (MAE): measures the average magnitude of the errors in a set of predictions, without considering their direction. It's the average over the test sample of the absolute differences between prediction and actual observation. and its mathematical formula (Wang and Lu, 2018)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{\hat{y} - y_i}{y_i}\right| \quad (6)$$

y_i and $\hat{y}$: , are the observation and estimated values respectively

Mean Absolute Error (MAE) represents the mean deviation between two values, its optimal value is zero. These statistics are between the estimated values and the observed real values. It is worth noting that each M.A.E measures errors as it gives an indication of the difference between the real values and the estimated values. This has been used to test the accuracy of many mathematical models.

The MAE, R^2 values are important criteria in assessing the efficiency of the method used to estimate evapotranspiration values.

3. Results

The evaluations of the four methods are emphasized through the comparison between the observed and estimated evapotranspiration time series. Pearson type coefficient of determination index (R^2) and Mean Absolute Error (MAE) tests are used to determine the best model also.

3.1 Comparison between observation and estimation evapotranspiration data for Baghdad.

Time series were used for the observed and estimated evapotranspiration data to find out the nature of the similarities or differences between them (Fig. 2a-c). The time series estimated by Penman-Monteithand and Thornthwaite methods (Fig 2a,b) have better consequence with the observed data than the other two methods (Fig. 2c,d). The Pearson correlation index and Mean Absolute Error between the observed data and estimated values from the four methods are emphasized. For Baghdad station, the estimated values by Penman-Monteith (Table 2) method correlated strongly (0.92) with the observation data, the value of R^2 is significant and the MAE has very small value (0.20), these values refer to confirm with the similarity of the values calculation and observation time series. The Thornthwaite method is also significant for estimate the evapotranspiration for Baghdad station but less than the Penman-Monteithmethod, the MAE is (0.43). The R^2 value is (0.88) less than the other three method but the Thornthwaite method has less error than Khrrufa and Ivanov (Table 2). Khrrufa and Ivanov method have higher values of MAE than Penman-Monteithand and Thornthwaite that that mean these two methods not good to estimate the evapotranspiration in in Baghdad.

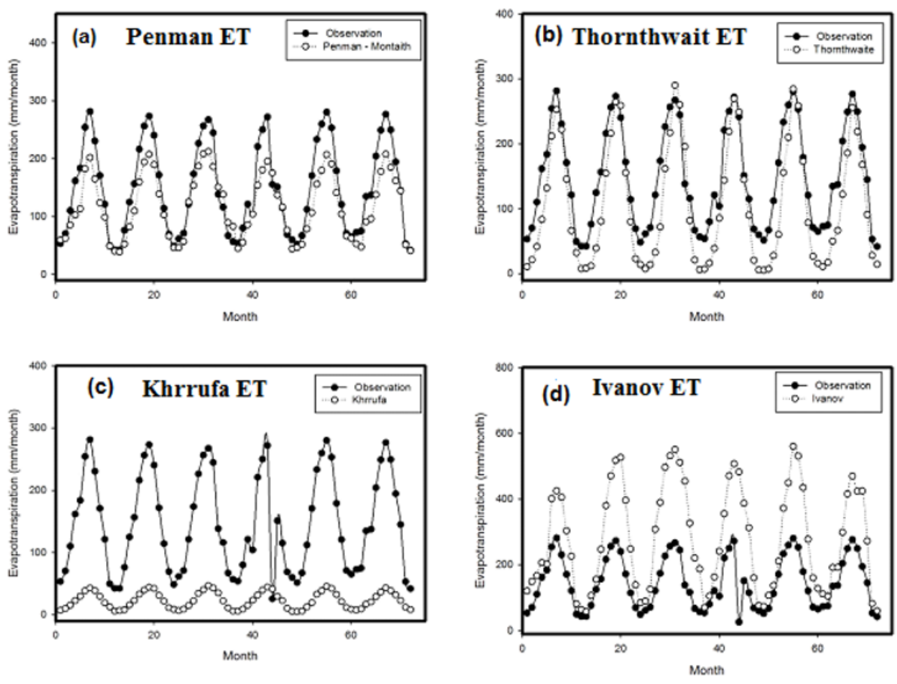

Figure 2. Observation and estimation of evapotranspiration in Baghdad station by (a) Penman, (b)Thornthwaite, (c) Khrrufa and (d) Ivanov methods

Table 2. Pearson index (R^2) and Mean Absolute Error (MAE) for the Penman, Thornthwaite , Khrrufa and Ivanov methods in Baghdad

Station	Method	R^2	MAE
Baghdad	FAO Penman-Monteith	0.92	0.20
	Thornthwaite	0.88	0.43
	Khrrufa	0.91	0.84
	Ivanov	0.87	1.09

3.2 Comparison between observation and estimation evapotranspiration data for Mosul.

To evaluate the evapotranspiration values which estimated from the four methods and compare it with the observed values, the time series for estimated and observed data are configured (Fig. 3a-c), Pearson index and Mean Absolute Error are used also. Time series computed through Penman-Monteithand and Thornthwaite methods (Fig. 3a,b) have similar behavior more than the other two methods to estimate the evapotranspiration (Fig.3c,d). For Mosul station, the estimated values by Penman-Monteith (Table 3) method correlated strongly (0.99) with the observation data, the value of R^2 is significant and the MAE has very small value (0.26), these values are confirm with the similarity of two time series. The Thornthwaite method is also significant for estimate the evapotranspiration for Mosul station but less than the Penman-Monteith method, the MAE is (0.43). The R^2 value is (0.93) less than the other three methods but the Thornthwaite method has less error than Khrrufa and Ivanov (Table 3).Khrrufa and Ivanov method have higher values of MAE than Penman - Monteithand and Thornthwaite that reversed the efficiency of the Penman - Monteithand and Thornthwaite methods to represent the evapotranspiration in Mosul.

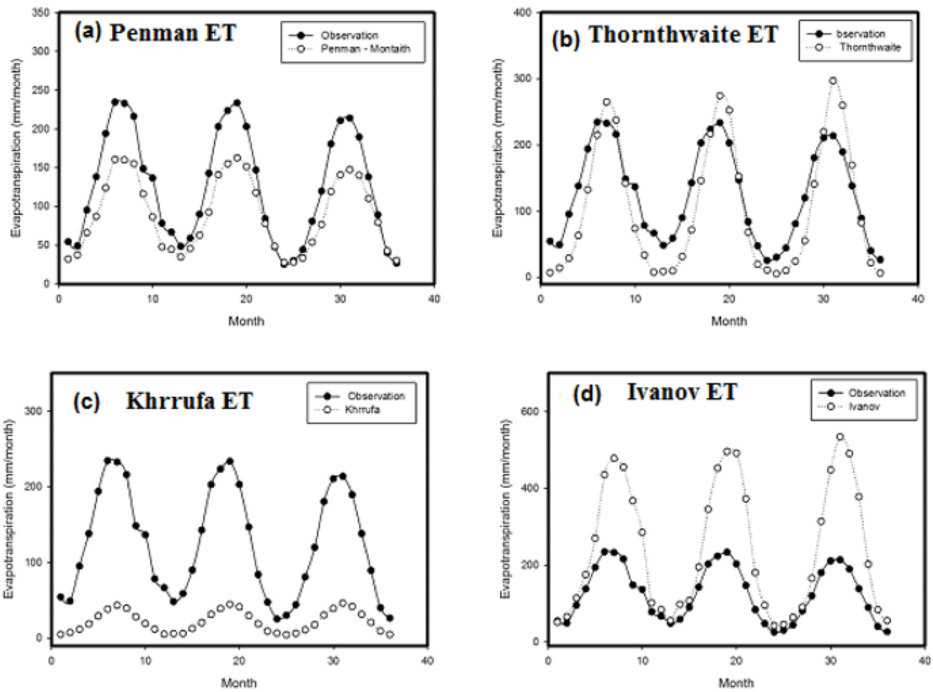

Figure 3. observation and estimation of evapotranspiration in Mosul station by (a) Penman, (b)Thornthwaite, (c) Khrrufa and (d) Ivanov methods

Table 3. Pearson index (R^2) and Mean Absolute Error (MAE) for the Penman, Thornthwaite, Khrrufa and Ivanov in Mosul

Station	Method	R^2	MAE
Mosul	FAO Penman-Monteith	0.99	0.26
	Thornthwaite	0.93	0.43
	Khrrufa	0.96	0.83
	Ivanov	0.94	0.80

3.3 Comparison between observation and estimation evapotranspiration data for Al-Anbar.

Time series were used for the observed and estimated evapotranspiration data to find out the nature of the similarities or differences between them (Fig. 4a-c)) . The time series estimated by Penman-Monteithand and Thornthwaite methods (Fig. 4a,b) have better representation for evapotranspiration than Khrrufa and Ivanov methods (Fig.4c,d). The Pearson index and Mean Absolute Error between the observed data and estimated values from the four methods are used to test the best method that could present the real data evapotranspiration. For Al-Anbar station, the estimated values by Penman-Monteith(Table 4) method correlated strongly (0.98) with the observation data, the value of R^2 is good and the MAE has very small value (0.25), these values confirm the similarity between the calculated and observed time series. The Thornthwaite method is also good for estimate the evapotranspiration for Al-Anbar station but less than the Penman-Monteith_method, the MAE is (0.40). The R^2 value is (0.94) less than the other three methods but the Thornthwaite method has less error than Khrrufa and Ivanov(Table 4). Khrrufa and Ivanov method have higher values of MAE than Penman-Monteith and Thornthwaite. Therefore, Penman-Monteith and Thornthwaite methods are the best in estimating the values of evapotranspiration in Al-Anbar.

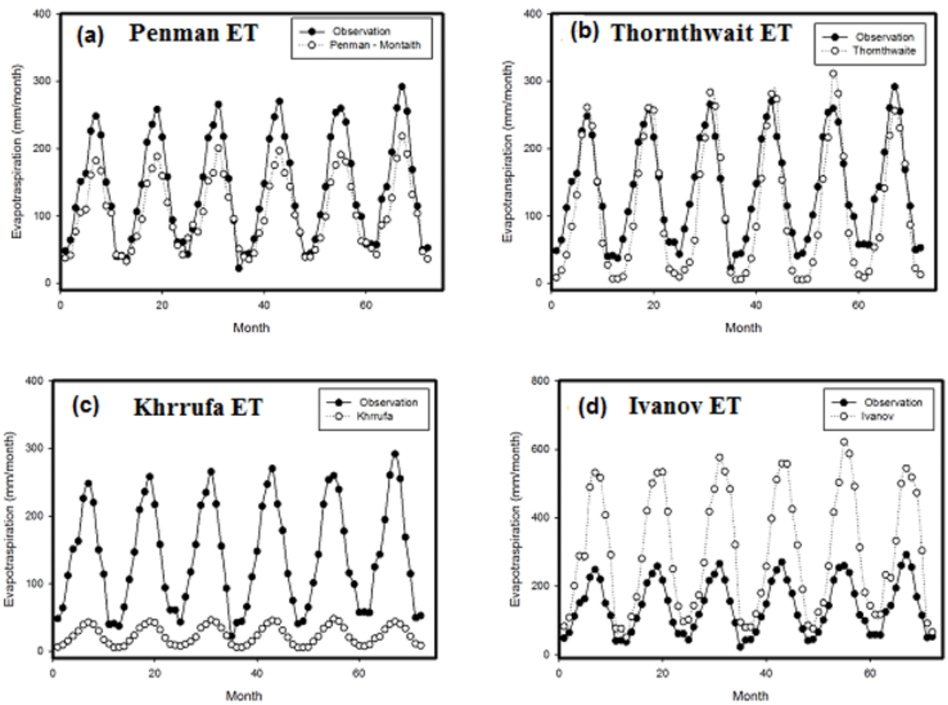

Figure 4. observation and estimation of evapotranspiration in Al-Anbar station by (a) Penman, (b)Thornthwaite, (c) Khrrufa and (d) Ivanov methods

Table 4. Pearson index (R2) and Mean Absolute Error (MAE) for the Penman, Thornthwaite, Khrrufa and Ivanov methods in Al-Anbar

Station	Method	R^2	MAE
Al-Anbar	FAO Penman-Monteith	0.98	0.25
	Thornthwaite	0.94	0.40
	Khrrufa	0.97	0.83
	Ivanov	0.95	1.11

3.4 Comparison between observation and estimation evapotranspiration data for Basrah

Time series were used for the observed and estimated evapotranspiration data to find out the nature of the similarities or differences between them (Fig. 5a-c). The time series estimated by Penman-Monteith and Thornthwaite methods (Fig.5a,b) have better consequence with the observed data than the other two methods (Fig.5c,d). The Pearson index and Mean Absolute Error between the observed data and estimated values from the four methods are used to test the best method that could present the real data evapotranspiration. For Basrah station, the estimated values by Penman-Monteith (Table 5) method correlated strongly (0.94) with the observation data, the value of R^2 is good, the MAE has very small value (0.21). This indicates the convergence of the estimated with the observed values. The Thornthwaite method is also good for estimate the evapotranspiration but less than thePenman-Monteith method, the MAE is (0.47). The R^2 value is (0.95) (Table 4). Khrrufa and Ivanov methods have higher values of MAE than Penman-Monteithand and Thornthwaite that mean these two methods not good to estimate the evapotranspiration in Basrah station.

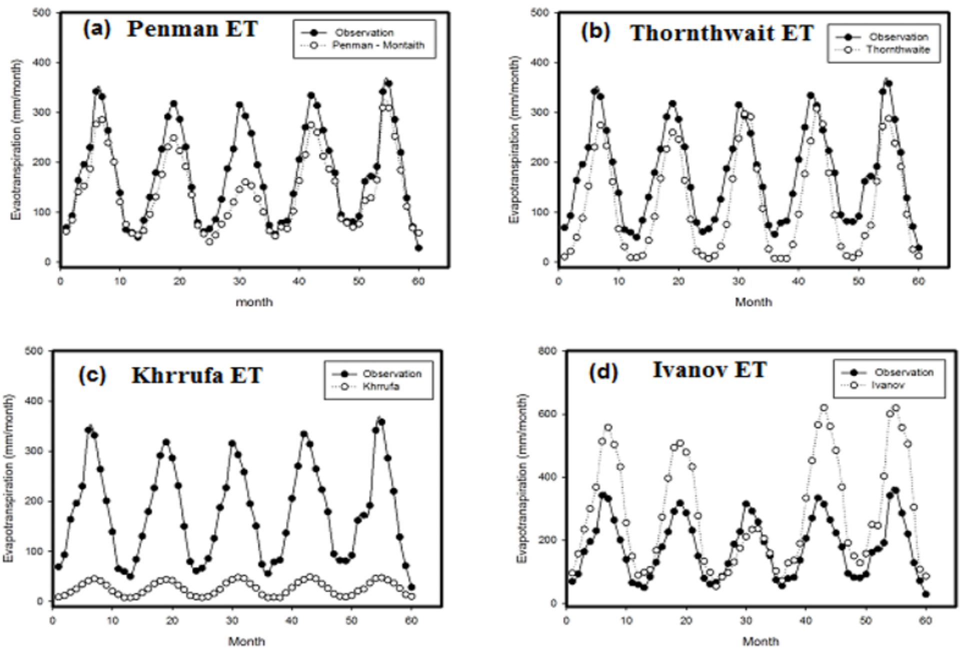

Figure 5. observation and estimation of evapotranspiration in Basrah station by (a) Penman, (b)Thornthwaite, (c) Khrrufa and (d) Ivanov methods

Table 5. Pearson index (R^2) and Mean Absolute Error (MAE)for the Penman, Thornthwaite, Khrrufa and Ivanov methods in Basrah

Station	Method	R^2	MAE
Basrah	FAO Penman-Monteith	0.94	0.21
	Thornthwaite	0.95	0.47
	Khrrufa	0.96	0.85
	Ivanov	0.87	0.65

4. Conclusion

This study has contributed to evaluate the best method can use to estimate the evapotranspiration in Iraq. The main results of this study are presented as follows:

(1) The best method to estimate the evapotranspiration in Iraq is Penman-Monteith achieved values close to the observed values with high correlation and less ratio of the absolute error than the other models. In addition, the model related to the largest numbers of variables that influence the ET, either directly or indirectly.

(2) The Ivanov model is the least accurate model for the results because it achieved results with little correlation with the high absolute error ratio compared to other models in the region in which it was applied.

(3) The values of MAE test is more significant than R^2 in evaluating the evapotranspiration through the mathematical methods.

By relying on the four mathematical models and through data for the elements included in these models for the selected agricultural regions. It was found that there is a correlation between the real evapotranspiration values and the estimated values using mathematical models as shown in the figures 2 to 5.

The study noted that the values of these indicators are not equal, and this is due to the variation in climatic conditions and the geological characteristics of these areas, which affect the accuracy of the models

As these figures show that the relationship between the estimated values and the real values is not the same in relation to the mathematical model of the four chosen areas when calculating the evaporation values, the reference is succeeded, because mathematical models in general have determinants as they achieve acceptable values when applied in regions and achieve less accurate results in regions others in some cases, their results are not realistic in other regions due to the limitations of each model. The mathematical model that achieves acceptable results in one region does not have to achieve the same precision if it is applied in other regions. There is also a variation in accuracy for different mathematical models, if they are applied in the same area. That is, for each region it can be a mathematical model that achieves acceptable results more than the rest of the models where its determinants fit with the conditions of that region and it can be adopted in estimating the value of evaporation, we refer the reference to that region. But if the mathematical model achieves acceptable values in more than one region, then this means that the model is more comprehensive and its determinants fit all conditions of those areas.

From the values in Table 2 to 5, it appears that the FAO Penman-Monteith method is the best method to estimate the ET for all the four stations, this results is similar the finding of (Al-Rijabo *et al.,* 2008; Aljumaili *et al.,* 2014). The Thornthwaite model is a good method to estimate the ET in Iraq, this results is similar to the study of (Al-Sudani, 2018; Jawad, 2016). The main finding of this study is that the best model can be used to estimate the ET is the method that have the largest number of essential variables that influence the ET, directly or indirectly, as these elements act as indicators of estimated values, which is FAO Penman-Monteith model in our study.

Acknowledgments

The authors are grateful to the Iraqi meteorological organization for providing the data.

Conflicts of Interest

The authors declare no conflict of interest.

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