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RESEARCH PAPER

A comparison of empirical equations of Estimating Potential Evapotranspiration (PET) from climatological data in Erbil city

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ABSTRACT:

Potential evapotranspiration (PET) is an important index of hydrologic budgets at different spatial scales and it is a critical variable for understanding regional hydrological processes. The objective of this study is to find the most suitable method for estimating PET in Erbil city which was done by comparing seven commonly PET methods. Radiation based method: Pristley –Taylor(PT), Turc(TU), Makkink (MK), and temperature based method: Ivanov (IV), Penman–Monteith method (1965) , FAO Penman–Monteith method, and Thornthwaite(TW). The data were collected and used in the models to find PET for the period (1992-2015). The performance indicators were applied by using statistical parameters such as: the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), person correlation coefficient (R2), MBE Mean bias error. The monthly PET results from the models were compared with the actual evaporation. Current work shows that Makkink (MK) model is better than the other models for estimating the potential Evapotranspiration in Erbil depending on the values of statistical parameters.

KEY WORDS: potential evapotranspiration , PET ,Pristley –Taylor(PT) , Turc(TU) Makkink (MK) , Ivanov (IV) , Penman–Monteith , FAO Penman–Monteith Thornthwaite(TW)
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1.INTRODUCTION

Evapotranspiration (ET) may be defined as the process of water transfer to the atmosphere, which is consisted of the combined procedures of evaporation from the soil and water surface and transpiration from a vegetated surface; therefore it has a special importance in agricultural, hydrological, meteorological, water and soil conservation research. Evapotranspiration is an important index in Planning and designing any irrigation project in arid and semi-arid regions. Accurate estimation of Evapotranspiration would reduce the wasting of massive quantities of water (Abdullah et al., 2014).

Three terms are normally used in describing evaporation and evapotranspiration: (1) Free water evaporation (E) is used for the amount of evaporation lost from an open water surface (Peterson et al., 1995) (2) Actual evapotranspiration (AET) describes all the processes by which liquid water at or near the land surface becomes atmospheric water vapor under natural condition (Morton, 1983) (3) Potential evapotranspiration (PET) is water loss that will occur if there is no deficiency of water in the soil for use of vegetation at any time (Thornthwaite., 1 944).

The measurement of actual evapotranspiration is so difficult and impractical (Efthimiou et al., 2013; Ahmed Saud et al., 2014).The differences among PET methods are very important to be identified in order to find the most suitable method to predict the actual evapotranspiration

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(AET). Different PET methods give wide different annual values at particular locations as demonstrated in previous studies (Federer et al., 1996). Recent hydrological modeling activities and their results are not quite accurate due to their different assumption and data requirements, and these models were designed for specific climate region. However, it is very important to find a well performed model to predict potential evapotranspiration accurately. During the past 50 years, several empirical models were developed by different scientists and technicians for measuring evapotranspiration based on various climatic variables (Federer et al., 1996). However, PET methods may give different values for evapotranspiration which could not be convenient with specific region. The PET method that requires fewer parameters with high accuracy are the preferred one for regional scale studies (Fennessey and Vogel, 1990).

The effects of climate change on the terrestrial water cycle still unknown parameter in current model calculations. Climate observations of many climate stations report that temperature has increased in the last century while the change in precipitation shows regionally differentiated patterns of increase and decrease. PET methods is subject to many different parameters: atmospheric precipitation, soil water reserve, solar radiation, air and soil temperature, wind speed, depth of groundwater, type of vegetation etc (Bormann, 2011). Therefore it would be necessary to take such an essential parameters in consideration in computing the evapotranspiration which could be expressed as the equivalent amount of water evaporated per unit of time and generally expressed as water depth per unit of time (e.g. mm day-1 (Efthimiou et al., 2013).

Evaporation and transpiration (ET) happen at the same time and there is no easy way to separate them. For example, when the crop is small, the main process for losing water is evaporation, but once the crop completely developed and covered the soil, transpiration becomes the main process (Jahanbani and El-Shafie, 2011). Lu et al. (2005) found a great differences among the temperature based PET methods and radiation based PET methods. He recommended Priestley-Taylor, Turc, and Hamon methods for southeastern United States due to its accurate performing for finding PET in the region of the study.

Previous studies did not focus on the performing of PET methods across our region (Kurdistan region). Therefore, the main objective of this study is to compare and evaluate the performance of seven empirical methods Pristley –Taylor (PT), Turc (TU), Makkink (MK), Ivanov (IV), Penman–Monteith method (1965), FAO Penman–Monteith method, and Thornthwaite (TW) in estimating monthly potential evapotranspiration (PET) compared to the monthly actual evapotranspiration in Erbil Governorate.

1. STUDY AREA

The study area current research is Erbil city which is considered as one of the oldest living city in the world, Erbil is also the capital of the federal Kurdistan region which is about 350km^2 north of Baghdad (see figure 1) . It is located 360 km away from Baghdad and it is considered as the fourth city in Iraq in terms of size after Baghdad, Basra, and Mosul.

Fig (1): Erbil Governorate

The climate of Erbil is semi-arid continental. Summer season (June-September) is hot and dry, while winter is cold and wet with a short spring and autumn seasons. Rainfall is limited to the period between October – February with an average of 543 mm. The geographical location of the study area lies between latitude 36.195 ° N, longitude 44.039°E and altitude 420 m (Zohary, 1950).The highest point is the Peak of Hasarost Mountain in Erbil Governorate which is about 3607 m above mean sea level. According to Koppen classification, the climate of Kurdistan region is classified as arid and semi-arid climate (steppe - BSh and Mediterranean – Csa).

2. DATA COLLECTED

Five meteorological parameters are recorded in climate station in Erbil Governorate and used in this research to estimate potential evapotranspiration by using different models. In order to estimate the potential evapotranspiration, several parameters are used: monthly average temperature, maximum temperature, minimum temperature, solar radiation and relative humidity for the period 1992-2015. The station elevation is about 470 m with latitude 36.12 N° and longitude 44.04 E° fig 2. (kareem et al.,2017,rashed et al.,2017).

Fig (2): Climate station in Erbil Governorate

3. METHODS FOR ESTIMATING THE POTENTIALEVAPORANSPIRATION

There are many scientific models used in previous studies to estimate the Potential Evapotranspiration, each model used different meteorological parameters. In current research we chose seven models that were not used before to estimate PET in Erbil city.

3.1 Thornthwaite Method (1948) (TW):-

The mathematical formula of Thornthwaite method is based on a hypothesis that potential evapotranspiration (PET) is determined by one meteorological parameter which is temperature. However, it does not explicitly reflect the dependency on air humidity and windiness (Kijne 1974, Henderson 2012, Ibrahim et al. 2012, Anderson et al. 2011a). The formula of the model:

$$PET = 1.6 \times L_d \times \left(\frac{10\,T}{I}\right)^{a} \dots (1)$$

La - Monthly correction constant function of latitude.

$$I = \sum_{j=1}^{12} i_j \dots (2)$$

$$i_j = \left(\frac{T_j}{5}\right)^{1.514} \quad \dots (3)$$

$$a = (6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 0.49239) \dots (4)$$

Where PET is the potential evapotranspiration (mm/month), I is the annual heat index and can be calculated by using equation (2), T denotes average monthly temperature C°, i_j is the monthly heat index and can be estimated from using equation (3) and a is a constant and can be calculated by equation (4).

3.2 Makkink method (MK):

This model was developed by Makkink in 1957. Makkink method used incoming short-wave radiation Rs and temperature instead of using net radiation, Rn, and temperature (Bakhtiari, 2011). Daily evapotranspiration is calculated as:

$$PET = 0.61 \times \left(\frac{\Delta}{\Delta + \gamma}\right) \times \left(\frac{R_s}{58.5}\right) - 0.12 \dots (5)$$

In equation (5), PET is the daily evapotranspiration (mm /day), and Rs is solar radiation ($MJm^{-2}day^{-1}$); Δ is the slope of the saturation vapor pressure temperature curve (kPa℃$^{-1}$) given by:

$$\Delta = 0.2 \times (0.00738\,T + 0.8072)^7 - 0.000116 \dots (6)$$

And γ is the psychometric constant modified by the ratio of canopy resistance to atmospheric resistance (kPa℃$^{-1}$).

3.3 Turc Method (TU):-

Turc model is modified in 1961 which considers only air humidity under dry conditions, (Bormann, 2011).The equation to estimate PET is given by two formulas:

$$PET = 0.013 \times \left(\frac{T}{T+15}\right) \times (R_S + 50) \times \left(1 + \frac{50-RH}{70}\right) \dots (7) \quad \text{when (RH>50)}$$

$$PET = 0.013 \times \left(\frac{T}{T+15}\right) \times (R_S + 50) \dots (8)$$

when (RH<50)

Where, PET is the daily PET (mm/day); T is the daily mean air temperature (°C); Rs is the daily solar radiation (cal/cm^2/d) and where cal/cm^2/d equals (100/4.1868) MJ/m2/day; and RH is the daily mean relative humidity (percent) (Lu et al., 2005).

In equations (7) and (8), two different formulas are presented for areas with relative humidity of lower and higher than fifty percent this model depend on the relativity humidity and solar radiation.

3.4 Priestley–Taylor method (PT):-

Priestley–Taylor equation is modified in 1972. Evapotranspiration is expressed as modified Priestley–Taylor model in irrigated maize. (Priestley and Taylor, 1972):

$$PET = \alpha \times \left(\frac{\Delta}{\Delta + \gamma}\right) \times (R_n - G)/\lambda \ldots (9)$$

PET is the daily potential evapotranspiration (mm/day); λ is the latent heat of vaporization (MJ/kg), λ =2.501-0.002361T; T is the daily mean air temperature in (°C); α is the calibration constant (α = 1.26) for wet or humid conditions; Δ is the slope of the saturation vapor pressure temperature curve (kPa/°C) given in equation:

Δ = 0.200 (0.00738 T + 0.8072)7 - 0.000116

3.5 Ivanov method (IV):-

Ivanov had been able to develop an equation estimates the potential evapotranspiration using temperature and relative humidity as an equation parameters.

$$PET = 0.0018 \times (T + 25)^2 \times (100 - RH) \ldots (10)$$

Where PET is the monthly Potential Evapotranspiration mm / month , RH and T stand for monthly relative humidity, and monthly average temperature (°C), respectively (Shakeel et al., 2017).

3.6 Penman –Monteith equation:-

Penman equation is modified by Monteith (1965) to represent the evapotranspiration from vegetation surface by including parameters such as: atmospheric conductance and canopy conductance. The formula is expressed for daily values as:

$$PET = \frac{\Delta(R_n - G) + \rho_a c_p \dfrac{(e_s - e_a)}{r_a}}{\lambda(\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right))} \ldots (11)$$

Where PET is monthly evapotranspiration (mm/month), Rn is the net radiation (MJ/m2 .month), G is the soil heat flux neglected, es saturation vapour pressure (kPa). ea actual vapour pressure (kPa), ρa is the mean air density at constant pressure ,cp is the specific heat of air (1.013*10^{-3}MJk/g °C) , Δ represents the slope of the saturation vapour pressure temperature relationship(kPa/°C), γ is the psyschrometric constant (kPa/°C), λ latent heat of vaporization (2.45 MJ/ kg), rs and ra are the surface and aerodynamic resistance (sm^{-1},sm^{-1}) γ is found by using this equation:-

$$\gamma = 0.665 \times 10^{-3} P \ldots (12)$$

Where P is the atmospheric pressure (kPa):-

$$P = 101.3 \times \left(\frac{293 - 0.0065 \times z}{293}\right)^{5.26} \ldots (13)$$

And z is elevation above sea level (m).

3.7 FAO-56 Penman –Monteith equation

Fao penman equation was derived from three equations: Penman-Monteith equation, Aerodynamic resistance (ra), and surface resistance (rs). The equation depends on meteorological parameters such as solar radiation (sunshine), air temperature, humidity and wind speed. The measurements should be made on a condition that the instrument height should at 2 m above the surface.

The general form of Fao – 56 Penman equations to estimate the evapotranspiration is in the form (Allen et al., 1998):

$$\mathrm{PET} = \frac{0.408\,\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma \frac{\mathrm{C_n}}{\mathrm{T_a} + 273} \mathrm{U}_{2\,(\mathrm{e_s} - \mathrm{e_a})}}{\Delta + \gamma(1 + 0.34\ \mathrm{U_2}\ )} .. (14)$$

Where:

ET is evapotranspiration [mm day-1], Rn net radiation at the crop surface [MJ m-2 day-1] , G soil heat flux density [MJ m-2 day-1] , T mean daily air temperature at 2 m height [°C] , u2 wind speed at 2 m height [m s-1] , es saturation vapour pressure [kPa] , ea actual vapour pressure [kPa] , es - ea saturation vapour pressure deficit [kPa] , Δ Slope vapour pressure curve [kPa °C-1] , γ Psychrometric constant [kPa °C-1] and Cn- numerator constant.

3.8 Statistical Parameters

The Root mean square error (RMSE) is the square root of the mean square error (MSE). The mean square error is defined as the expected value of the square of the difference between the estimator and the parameter. It is the sum of variance and squared Bias. By using this relation (Moeletsi et al., 213)

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{n}}\sum(\mathrm{ET_{Obs.}} - \mathrm{ET_{model}})}$$

Where (n) is the number of observations (month of the year) .

The mean bias error (MBE) is the difference between the mean of the predicted and observed concentrations. It indicates the degree to which the observed concentrations are 'over' or 'under' predicted by the mode (Moeletsi et al., 213).

$$\mathrm{MBE} = \frac{\sum_{\mathrm{i}=1}^{12}(\mathrm{ET_{Obs.}} - \mathrm{ET_{model}})}{12}$$

The mean absolute error (MAE) is a measure of difference between two continuous variables.

$$\mathrm{MAE} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\left|\frac{\mathrm{ET_{Obs.}} - \mathrm{ET_{model}}}{\mathrm{ET_{Obs.}}}\right| \times 100\ \%$$

4. **METHODS**

Seven PET models were used in our study in order to compare their results with actual measured data in Erbil government which in turn could help to find out the most suitable method in our region.

Seven commonly PET methods were used, radiation based method: Pristley –Taylor(PT), Turc(TU), Makkink (MK), and temperature based method: Ivanov (IV), Penman–Monteith method (1965) , FAO Penman–Monteith method, and Thornthwaite (TW). The output data of these methods have been compared with the real data of pan evaporation. To evaluate the performance of these method and find out the suitability of them for simulate the potential evapotranspiration, we have made the following assumption:

1. Since our region have very limited green land area and mostly appears during winter, and crop is small which in turn lead to consider the main process for losing water is evaporation, therefore we have neglected the transpiration term from the crops compared to the evaporation term.

2. The second assumption is that the potential evapotranspiration from selected models should exceed measured evaporation.

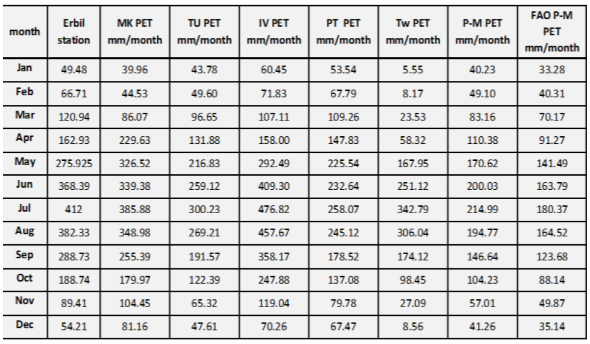
3.The relationship between potential evapotranspiration and measured evaporation should be linear. Statistical analysis methods were applied for each PET method by using the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Correlation coefficient (R2), and Mean bias error (MBE) to find the nature of the relationship between measured data and simulated data of each PET method.

5. RESULTS

The performance of PET empirical methods were evaluated and compared to the measured climate data for study models. Several models were used to determine the evapotranspiration in Erbil city. Table (1) shows the potential evapotranspiration values from the models of the study for each month of the year.

The maximum potential evapotranspiration values were 385,300, 476, 258, 342, 214, and 180, in July for Makking, Turc, Ivanov, Priestley- Taylor, Thornthwait, Penman-Monteith and Fao Penman-Monteith methods respectively. In contrast, the minimum values were 39, 43, 60, 53, 5,40, and 33 occurred in January for Makking, Turc, Ivanov, Priestley- Taylor, Thornthwait, Penman-Monteith and Fao Penman-Monteith methods respectively.

Table (1): potential evapotranspiration



month	Erbil station	MK PET mm/month	TU PET mm/month	IV PET mm/month	PT PET mm/month	Tw PET mm/month	P-M PET mm/month	FAO P-M PET mm/month
Jan	49.48	39.96	43.78	60.45	53.54	5.55	40.23	33.28
Feb	66.71	44.53	49.60	71.83	67.79	8.17	49.10	40.31
Mar	120.94	86.07	96.65	107.11	109.26	23.53	83.16	70.17
Apr	162.93	229.63	131.88	158.00	147.83	58.32	110.38	91.27
May	275.925	326.52	216.83	292.49	225.54	167.95	170.62	141.49
Jun	368.39	339.38	259.12	409.30	232.64	251.12	200.03	163.79
Jul	412	385.88	300.23	476.82	258.07	342.79	214.99	180.37
Aug	382.33	348.98	269.21	457.67	245.12	306.04	194.77	164.52
Sep	288.73	255.39	191.57	358.17	178.52	174.12	146.64	123.68
Oct	188.74	179.97	122.39	247.88	137.08	98.45	104.23	88.14
Nov	89.41	104.45	65.32	119.04	79.78	27.09	57.01	49.87
Dec	54.21	81.16	47.61	70.26	67.47	8.56	41.26	35.14

From table 1 it is clear that maximum evapotranspiration occurs during July for all study models while the minimum evapotranspiration occurs in January. The table revealed that Ivanov method has the highest value of evapotranspiration. The Pearson correlation coefficients were computed for calculated values of evapotranspiration and real measured evapotranspiration of each method of Erbil station (measured value Vs simulated value).The Pearson correlation coefficient values (R2) (table 2) were around (0.93, 0.98, 0.98, 0.96, 0.96, 0.98, and 0.98) for each of Mikkinc, Turc, and Ivanov, pristley, Thornthwait, penman, and Fao - penman method respectively. Table (2) shows Statistical parameters such as: Root Mean Square (RMSE), Mean bias error (MBE), Mean Absolute Error (MAE) for each model. The highest value of Root Mean Square, Mean bias error, Mean Absolute Error, Pearson correlation coefficients where 10.3, 2.9, 4.3, and 0.98 for Fao P-M model while the minimum value where 1.7, 0.5, 0.12, and 0.93 respectively for Mikking model.

Table (2): Statistical parameters

statistical parameters	MK	TU	IV	PT I	TW	P-M	FAO P-M
RMSE	**1.7**	**7.4**	**5.5**	**7.4**	**9.1**	**9.3**	**10.3**
MBE	**0.5**	**2.1**	**1.6**	**2.1**	**2.6**	**2.7**	**2.9**
MAE	**0.12**	**2.2**	**1.2**	**2.2**	**3.34**	**3.54**	**4.3**
R^2	**0.93**	**0.98**	**0.98**	**0.96**	**0.96**	**0.98**	**0.98**

It is obvious from fig 2 that monthly potential evapotranspiration from Makkink method is the closest one to the real evapotranspiration from Erbil station. Fig 3 clearly indicates that the Makkink method is identical to the real data of evapotranspiration from Erbil station for the periodic time (1992-2015) where the coefficient (R) is around 0.96.

Figure 4 represents the yearly evapotranspiration values from all study models, the results of the graph is consist with the measured value and support that Makking model is the best one for Erbil city. Figure 5 shows the monthly mean values of PET for the period 1992 to 2015. Both cases reveal that makkink model is very close to the measured PET.

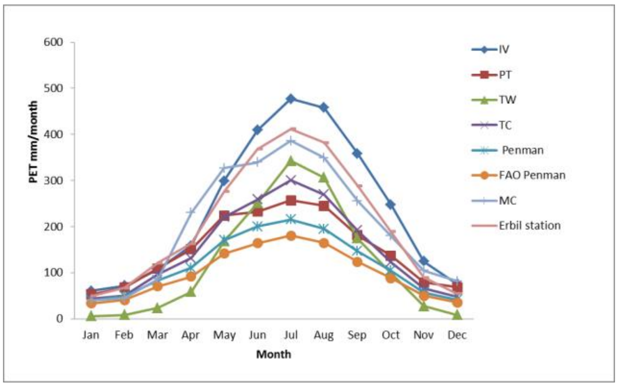


Fig 5. Monthly estimation of Potential Evapotranspiration models with month (1992-2015)

Figure 6 shows the mean annual values of evapotranspiration for each model. Frome both yearly and monthly values, Ivanove model show the highest value, while Fao model shows the minimum value. It is quite obvious from the graphs that Makking model is very close to the real value.

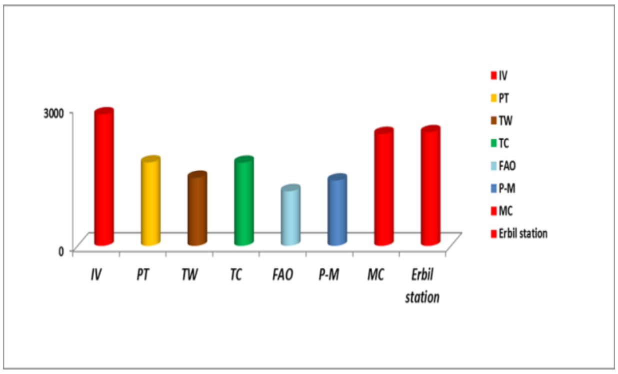


Fig 6. Yearly estimation of Potential Evapotranspiration Models (1992-2015)

6. CONCLUSION

Seven empirical methods for calculating potential evapotranspiration in Erbil governorate were evaluated by using climatological data from Erbil station. Makkink method was proven to be more desirable for estimating potential evapotranspiration (PET) in Erbil city. A less reliable result can be expected from thornthwaite (TW). All the other five empirical methods gave much less acceptable estimates for potential evapotranspiration (PET) in the region of the study. The methods of the study show a maximum potential evapotranspiration (PET) in July while the minimum value was in January.

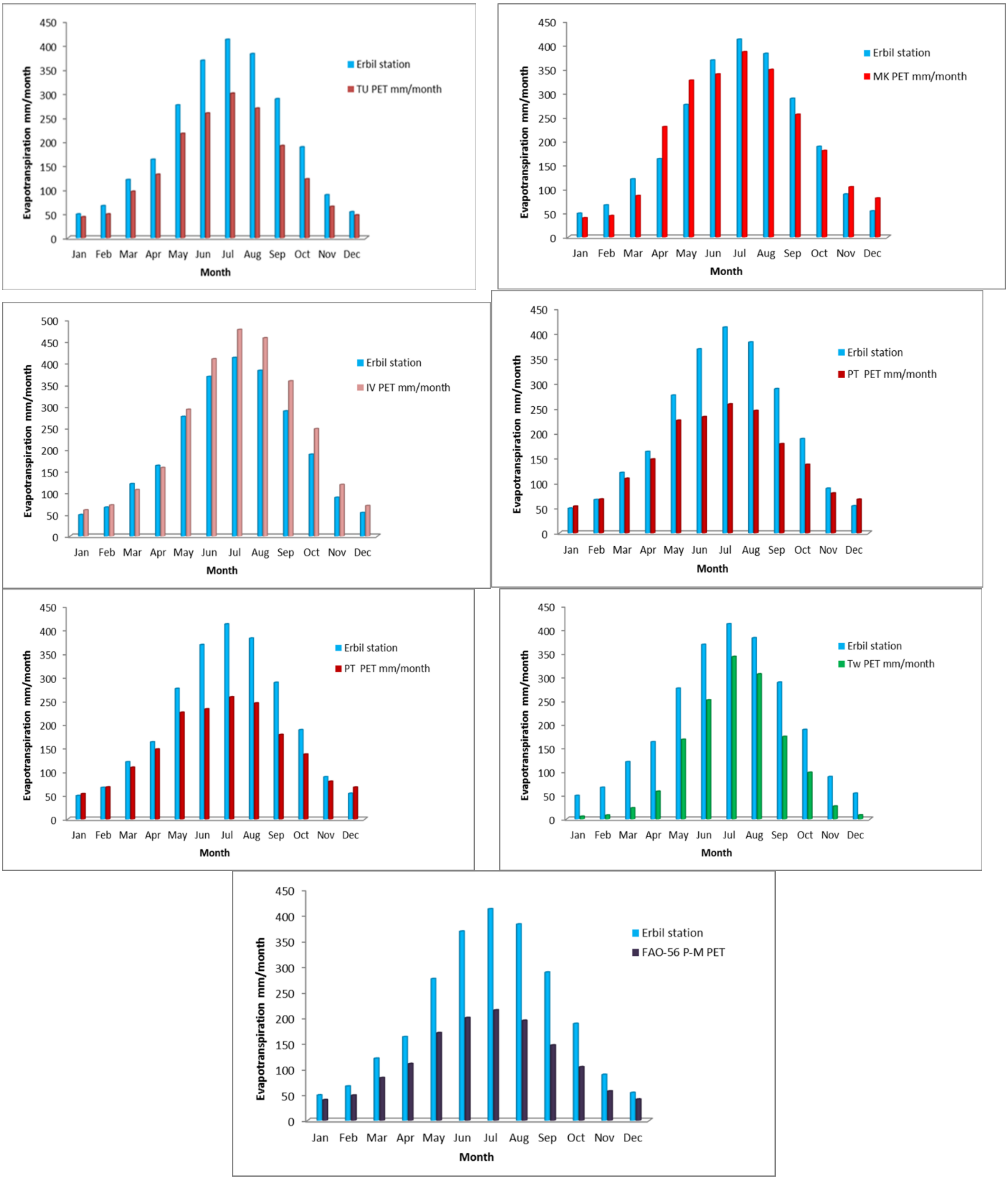


Fig 2. Average monthly Potential Evapotranspiration by seven models with measured PET in Erbil station (1992-2015)

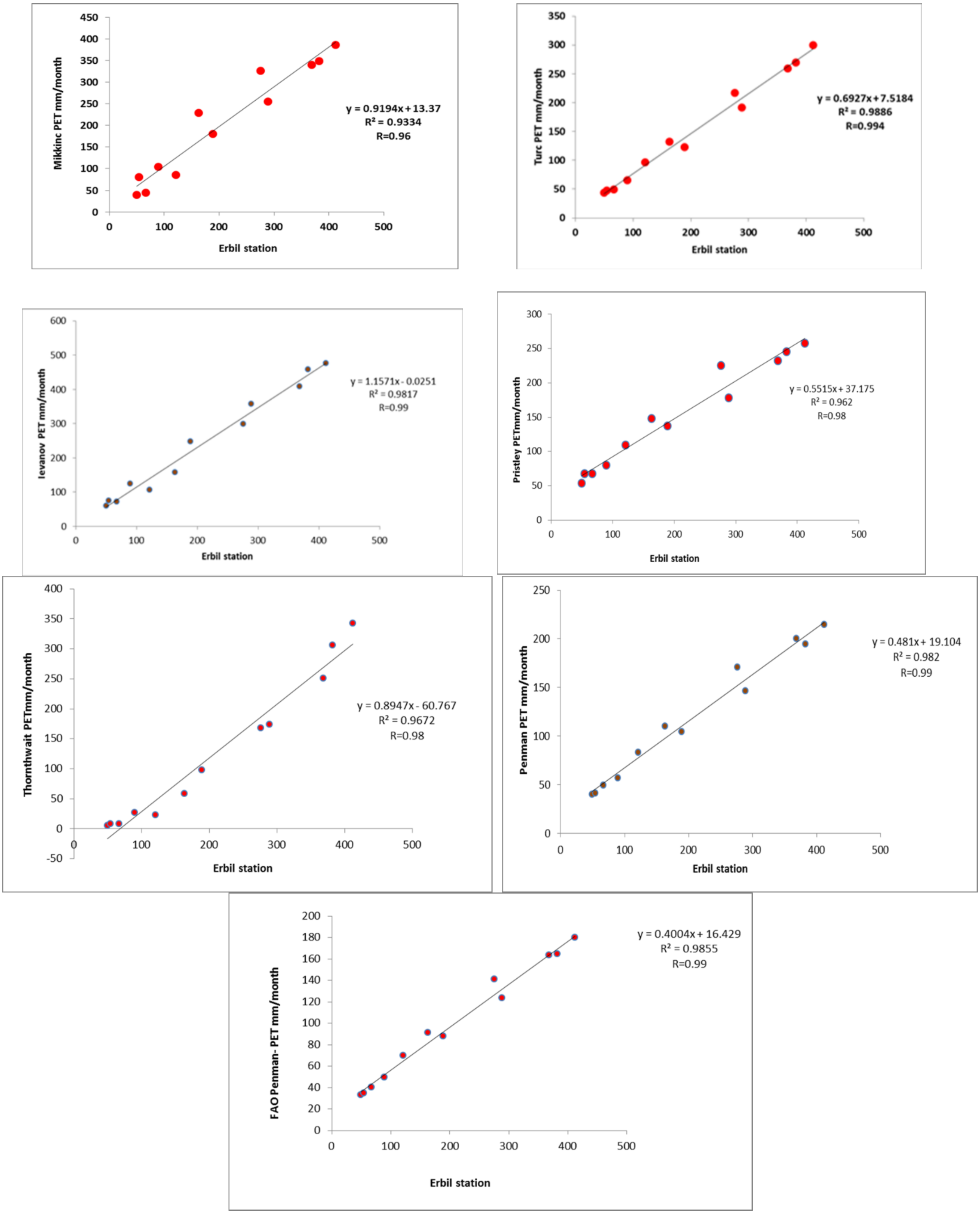


Fig3. Monthly estimation of Potential Evapotranspiration by seven models with Observer PET in Erbil station (1992-2015)

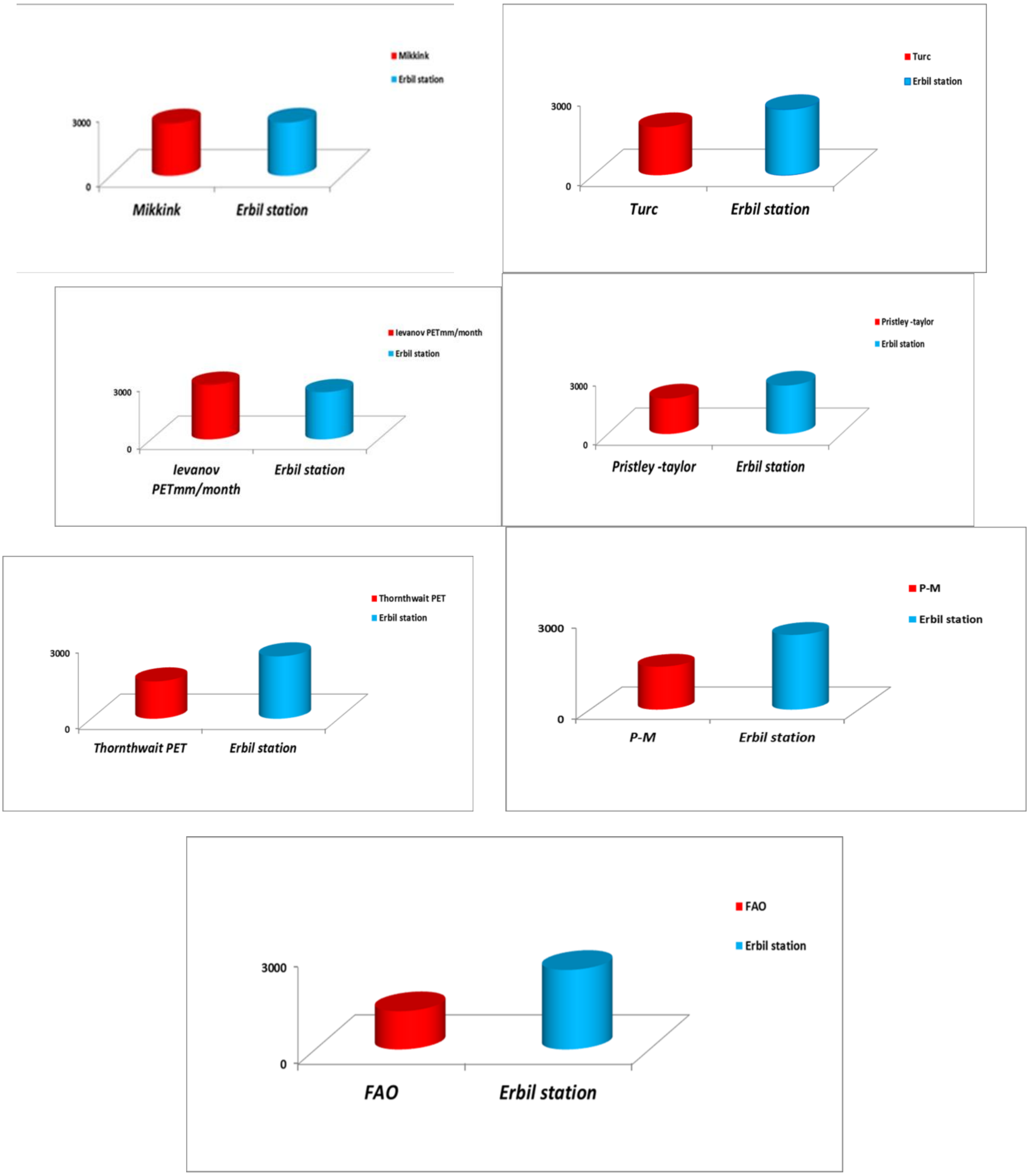


Fig4. Yearly estimation of Potential Evapotranspiration by using seven models with Observer PET in Erbil station (1992-2015)

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