



## Application of Evapotranspiration Model for Al-Ramadi Irrigation Project, Al-Anbar, Iraq

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### PAPER INFO

#### Paper history

Received: 05/08/2023

Revised: 22 /09/2023

Accepted: 13/10/2023

#### Keywords:

Reference evapotranspiration

(ET<sub>0</sub>) models

Penman-Monteith

Minimum climatic data

Penman-Kimberly (PK)

Penman-FAO-24 (PF)



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### ABSTRACT

Since evapotranspiration typically makes up the largest portion of the terrestrial water cycle, it is one of the most crucial factors in determining how much water is available. Penman-FAO-24 (PF), Penman-Monteith-FAO-56 (PM), Penman-Kimberly (PK), and Jensen-Haise (JH) are the four models that are frequently used to compute monthly reference crop evapotranspiration (ET<sub>0</sub>) values for the Ramadi irrigation project (fourth stage). These models were evaluated in this study. The considered statistical indicators were the root mean square error (RMSE), mean absolute error (MAE), relative error (RE), correlation coefficient (R<sup>2</sup>), and mean bias error (MBE). The evapotranspiration for Al-Ramadi city was estimated using the models. It was also calculated based on the available climate data that the PF model yielded the lowest MBE = 0.02945, highest RMSE = 29.369, and highest R = 0.9641 values among the four models, confirming its excellence. The JH model, which achieved the highest values of MBE = 0.00978 and RSME = 58.509, was the least accurate of the models. The study's conclusions are useful to farmers, decision-makers, and local water organizations in assessing irrigation water requirements, planning, and effective use of water resources

## 1. Introduction

In some countries, including Iraq, where evapotranspiration cannot be measured directly, it can be calculated indirectly by utilizing some models that depend on climate data directly. In this research, four models were used: Penman-FAO-24 (PF), Penman-Monteith -FAO-56 (PM), Penman-Kimberly (PK), and Jensen-Haise (JH) (Jensen & Haise, 1963). Evapotranspiration is the main component of the hydrological cycle because 65% of the rainfall each year returns to the atmosphere in the form of evapotranspiration (Summit et al., 2003). The word "evapotranspiration" (ET) refers to all activities that cause water to evaporate from the surface of the soil and to be lost by plants through transpiration. There is no simple method to distinguish between evaporation and transpiration since they happen concurrently (Almhab, 2009). Reference evapotranspiration must be calculated in

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order to calculate crop water usage, which is crucial for the efficient planning and execution of policies on irrigation projects. To estimate  $ET_0$  in varied climatic and geographic settings, numerous empirical models have been created over time for calculating  $ET_0$ . In accordance with this, empirical models are classified into three different categories: models that take into account temperature, radiation, and a combination of these factors (Shiri et al., 2019). According to the study by the Ministry of Water Resources (MOWR), the evapotranspiration rate was from 1300 to 2200 mm/year for all regions of Iraq. Whereas, evapotranspiration was measured for the city of Ramadi at a rate of 1727 mm/year (Ministry, 2014). The reference evapotranspiration was calculated for Anbar Governorate in the city of Ramadi by the Penman-Monteith equation. The rate of evapotranspiration was 1745 mm/year (Najm, 2020). Evapotranspiration was calculated for the Tal-Aswad region located within Al-Anbar governorate, depending on the Blaney-Criddle, Penman method, and water balance. Utilizing the water budget for 1982, the evapotranspiration results for the research area were determined to be 2150 mm/year annually (hydrological study of the Tal Aswad region within Anbar province, 2001). Evapotranspiration was also studied for Al-Hussainiya irrigation project in Karbala Governorate. Five models were verified; the Penman model was applied to be more reliable when compared with the Penman-FAO-24 (PF) model, while the model of Hargreaves & Samani (1985) did not provide reliable results with the Penman-FAO-24 (PF) model (Al-Awadi, 2013). Reference evapotranspiration must be established in order to design and carry out irrigation project strategies effectively, which is extremely important for calculating crops using water. The objectives of this study were to evaluate the four models (PF, PM, PK, and JH) presented and compare them with the actual evaporation employing statistical equations. These were represented by the lowest MBE value, the highest RMSE value, and the highest R value. We determine the optimal evaporation-transpiration reference model for the city of Ramadi by utilizing these statistical indicators.

## 2. Materials and Methods

### 2.1. Study area

The study area is located between latitudes  $33^{\circ}26'84''$  and  $33^{\circ}22'15.46''$  N and  $43^{\circ}35'36.63''$  and  $43^{\circ}57'59.50''$  E, positioned 53 meters above sea level. Al-Ramadi City is considered the capital of Al-Anbar Governorate and has a strategic location 108 kilometers west of Baghdad (Al Dulaimy, 2018). The irrigation project was divided into four phases, distributed over the area of Al-Ramadi city. In this study, the fourth phase (Al-Jazeera) of the project was evaluated, which represents the largest phase in terms of area, with an estimated area of about 45,000 dunums, which starts from Al-Bu'itha to Tarabsha as shown in figure (1).

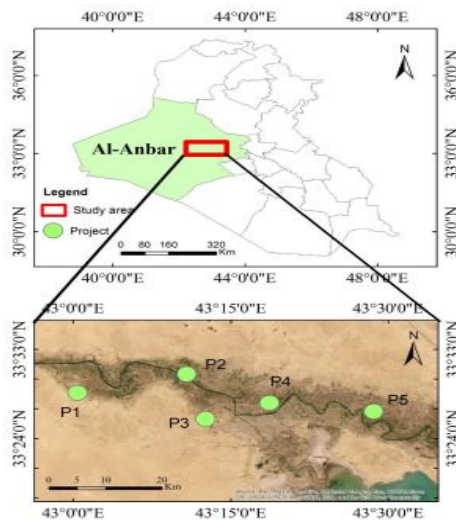


Fig. 1 Study area map, using ArcGIS Version 8.0

## 2.2. Climatic Factors

The main climatic factors influencing water needs for crops are air temperature, prevailing winds, humidity, length of sunshine, free water surface evaporation, and precipitation. Information was gathered from Al-Ramadi meteorological station. The primary climatic variables are monthly minimum and maximum air temperature, monthly average air temperature, monthly average sunlight hours, monthly average wind speed, average monthly evaporation, monthly mean relative humidity, and monthly mean precipitation. Table (1) indicates the average climatic parameters.

**Table 1 – Summary of the average climatic conditions for the study region from 1990 to 2020.**

Climate Variable Month	Mean air temp. (°C)	Mean rainfall (mm)	Mean effective rainfall (mm)	Mean max air temp. (°C)	Mean min air temp. (°C)	Mean monthly evaporation (mm)	Mean relative humidity (%)	Mean sunshine duration (hr/day)	Mean wind speed at 2 meters (m/sec) of height
Jan.	8.6	24.3	23.4	15.7	4.1	68.9	70.7	6.1	1.4
Feb.	11.1	17.1	16.6	18.7	5.8	99.8	59.4	7.5	1.5
Mar.	15.5	16	15.8	23.8	10	180	49.8	8	1.8
Apr.	21.2	15.4	15	30.1	15.5	258.7	41.4	8.6	0.9
May	27.1	3	3	36.7	20.5	364.4	31.4	9.5	1.7
June	31.5	0	0	41.6	23.8	479.6	25.1	11.6	1.9
July	34.1	0	0	44.3	26	525	24.5	11.6	1.9
Aug.	32.7	0	0	43.7	25.2	475.4	26.6	11.2	1.6
Sept.	30.1	0.1	0.1	40.1	21.1	354.4	32.1	10.3	1.6
Oct.	24	4.1	4.1	33.5	16.5	232.9	42	8.5	1.8
Nov.	16.3	13.3	13	23.8	9.8	114.6	58	7.2	1.2
Dec.	10.3	16.6	16.2	17.5	5.5	75.4	69.5	6.1	1.6

\* Ramadi Meteorological Station, 48 m above sea level, located at 33.27333 N and 43.01667 E.

## 2.3. Reference Crop ( $ET_0$ ) Models

Penman (1948) initially offered an equation to calculate evaporation from free-water surfaces. He then converted the calculated evaporation into evapotranspiration from surfaces covered with plants using empirical factors. Penman believed that the soil's heat flux was sufficiently negligible to be conveniently ignored. Using the combination approach, the average rate of evapotranspiration from a short crop of green that completely shadows the ground is generally provided in the following form (Doorenbos & Pruitt, 1977):

$$\lambda ET_0 = \frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\Delta}{\Delta + \gamma} 6.63(1 + 0.53U_2)(e_s - e_a) \quad (1)$$

where,

- $ET_0$  is the reference crop evapotranspiration ( $\text{mmd}^{-1}$ ).
- $R_n$  is the net radiation ( $\text{MJ m}^{-2} \text{d}^{-1}$ )
- $G$  is the soil heat flux ( $\text{MJ m}^{-2} \text{d}^{-1}$ )
- $U_2$  is the wind speed measured at 2 m height ( $\text{md}^{-1}$ )
- $(e_s - e_a)$  the vapour pressure deficit (kPa), Saturation vapour pressure,  $e_s$  and actually present vapour pressure  $e_a$
- The psychrometric constant (kPa/ °C) is represented by the symbol  $\gamma$ .

- $\lambda$  is the latent heat of vaporization ( $\text{MJ kg}^{-1}$ ), and  $\Delta$  is the slope of the vapour pressure vs temperature curve ( $\text{kPa/}^\circ\text{C}$ ).

$$e_s = \left[ \frac{e^o(T_{Max}) + e^o(T_{Min})}{2} \right] \quad (2)$$

$$e^o(T) = 0.6108 \exp \left[ \frac{17.27 T}{T+237.3} \right] \quad (3)$$

$$e_a = \frac{RH_{mean}}{100} \left[ \frac{e^o(T_{Max}) + e^o(T_{Min})}{2} \right] \quad (4)$$

Due to its superior performance when compared to other models in a number of global locations, the Penman-Monteith (FAO-56 PM) model was adopted (Adeboye et al., 2009):

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900 U_2}{T+273} (e_s - e_a)}{\Delta + \gamma(1+0.34 U_2)} \quad (5)$$

T is the standard air temperature in degrees Celsius.

Penman-Kimberly's (PK) reference evapotranspiration was given variable wind function coefficients by Wright (1982) as follows:

$$\lambda * ET_0 = \frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\Delta}{\Delta + \gamma} 6.43 W_f (e_s - e_a) \quad (6)$$

where,  $W_f$  is the wind function and can be computed according to the following:

$$W_f = a_w + b_w U_2 \quad (7)$$

$$a_w = 0.3 + 0.58 \exp \left[ -\left( \frac{J-170}{45} \right)^2 \right] \quad (8)$$

$$b_w = 0.320.54 \exp \left[ -\left( \frac{J-228}{67} \right)^2 \right] \quad (9)$$

where J is the number of days in the year.

The Jensen-Haise (1963) model (JH) was used to calculate the evapotranspiration of grass (Jensen & Haise, 1963); (Jensen et al., 1970):

$$\lambda * ET_0 = C_T (T_{mean} - T_x) R_s \quad (10)$$

while  $C_T$  and  $T_x$  are station constants obtained as follows:

$$C_T = \left[ \left( 38 - \frac{z}{138.5} \right) 7.3 \left( \frac{5.3}{e_{smax} - e_{smin}} \right) \right]^{-1} \quad (11)$$

where z is the altitude of the location (m).

## 2.4. Statistical Models

Standard performance assessment criteria for statistics were used to assess the effectiveness of the evapotranspiration models used in this study. The statistical indicators considered were the root mean square error (RMSE), mean absolute error (MAE), relative error (RE), correlation coefficient ( $R^2$ ), and mean bias error (MBE) (Allawi, et al. 2018). The three criteria were calculated utilizing the following equations:

$$MAE = \frac{1}{N} \sum_{t=1}^N |(F_t) - (A_t)| \quad (12)$$

$$RSME = \left[ \frac{1}{N} \sum_{t=1}^N [(F_t) - (A_t)]^2 \right]^{0.5} \quad (13)$$

$$R^2 = \left[ \frac{\sum_{t=1}^n [(A_t) - (\bar{A}_t)] [(F_t) - (\bar{F}_t)]}{\sqrt{\sum_{t=1}^n ((A_t) - (\bar{A}_t))^2 \sum_{t=1}^n ((F_t) - (\bar{F}_t))^2}} \right] \quad (14)$$

$$RE = \frac{F_t - A_t}{A_t} * 100\% \quad (15)$$

$$MBE = \frac{1}{N} \sum_{t=1}^N \left[ \frac{(F_t) - (A_t)}{A_t} \right] \quad (16)$$

where ( $F_t$ ) the predicted data, ( $A_t$ ) is the actual data,  $\bar{F}_t$  is the average predicted data series,  $\bar{A}_t$  is the average actual data series and N is the number of data.

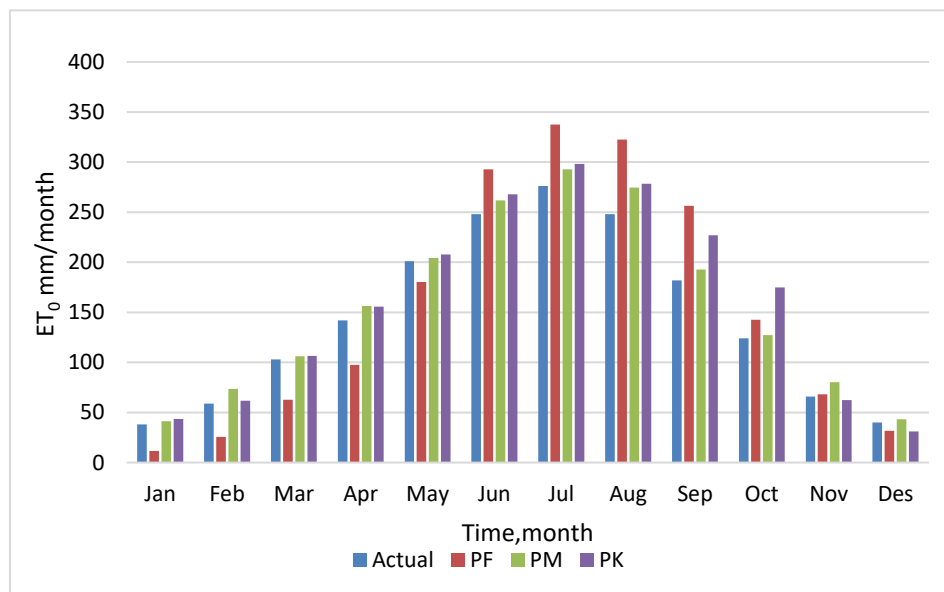
## 3. Results and Discussion

The actual evapotranspiration in Al-Ramadi city is measured at a rate of 1727 mm/year (Minstry, 2014). Evapotranspiration was estimated by four models depending on climatic factors for 12 months; Table (2) and Figure (1) indicate these results. The results showed that the (PF) model gets an annual rate of evapotranspiration equal to 1828 mm/year, while the (PM) model gets an annual rate of 1854 mm/year, as well as the (Pk) model getting an annual rate of evapotranspiration equal to 1914 mm/year, and the (JH) model gets an annual rate of 1929 mm/year, as shown in Table (2). Evaluation by statistics assumes that the best model is the one that gets the lowest value of MBE, RSME, and RE and the highest value of  $R^2$ . For MBE, the lowest value was obtained by the PM model (8.478), the value of RSME by the PF model (29.36), and for RE by the PF model (05.890), and the highest value of R was obtained by the PF model also (0.9756), as shown in Table 3. The FAO-56 method is considered a benchmark and has been widely used by scientists in multiple climates (Tahsin, 2020). There has been a significant link between the  $ET_0$  values acquired using the FAO-56 technique and direct measurements, even in different climatic conditions. The FAO-56's intended outcome is the Monteith technique. Method of Penman-Monteith: artificial intelligence powered by data and various combinations of meteorological factors are used as inputs in this method to precisely estimate  $ET_0$  (Kumar et al., 2008), (Eslamian et al., 2012), (Mohawesh, 2013), (Citakoglu et al., 2014), (Alves et al., 2017), (Apaydin et al., 2020). Figure (2) shows the linear regression equation with determination equations ( $R^2$ ). The regression of the PF model matches the actual evapotranspiration with an estimated slope of (1.368), an intercept point at (-44.561), and determination coefficients  $R^2$  of (0.988) shown in Figure (2). Figure (3) shows the linear regression equation with determination equations ( $R^2$ ), The regression of the PM model matches the actual evapotranspiration with an estimated slope of (1.0466), an intercept point at (+3.917), and determination coefficients R of (0.9951). Figure (4) shows the linear regression equation with determination equations ( $R^2$ ), The regression of the (PK) model matches the actual evapotranspiration with an estimated slope of (1.1164), an intercept point at (-1.1164), and determination coefficients  $R^2$  of (0.9736). Figure (5) shows the linear regression equation with determination equations ( $R^2$ ). The regression of the JH model

matches the actual evapotranspiration with an estimated slope of (1.1904), an intercept point at (-10.508), and determination coefficients R of (0.9746).

**Table 2 – Expected  $ET_0$  in mm/month for the duration (1990–2020) utilizing 4 models.**

Model \ Month	Actual	PF	PM	PK	JH
January	38	11.41	41.43	43.4	46.6
February	59	25.62	73.46	61.86	51.6
March	103	62.58	106	106.5	83.59
April	142	97.47	156.3	155.7	156.2
May	201	18.1	204.2	207.6	260
June	248	292.8	261.7	267.8	288.2
July	276	337.6	292.9	298.1	320.4
August	248	322.3	274.6	278.2	266.9
September	182	256.39	192.86	227.03	193.2
October	124	142.51	127.39	174.74	156.01
November	66	68.04	80.14	62.24	60.55
December	40	31.66	43.27	31.1	46.15
<b>Total</b>	<b>1727</b>	<b>1828</b>	<b>1854</b>	<b>1914</b>	<b>1929</b>



**Fig. 2 A comparison between estimated evapotranspiration ( $ET_0$ ) from the four models and actual evapotranspiration.**

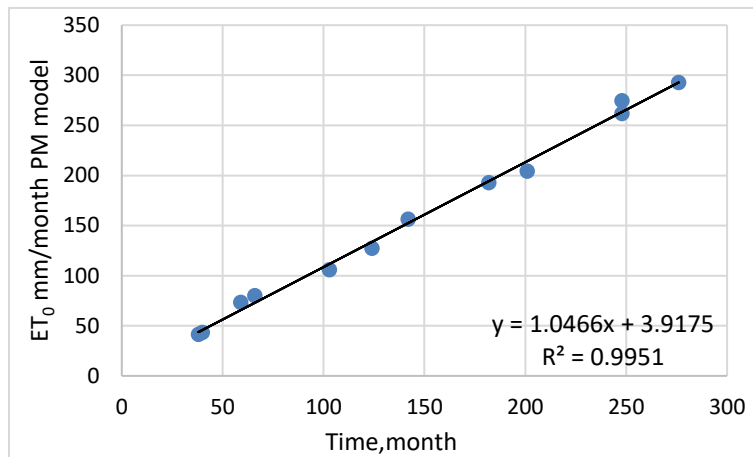


Fig. 3 Regression analysis for predicting  $ET_0$

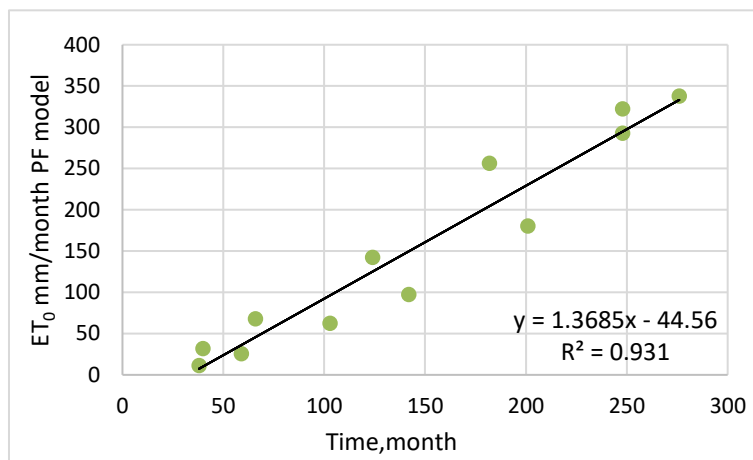


Fig. 4 Regression analysis for predicting  $ET_0$

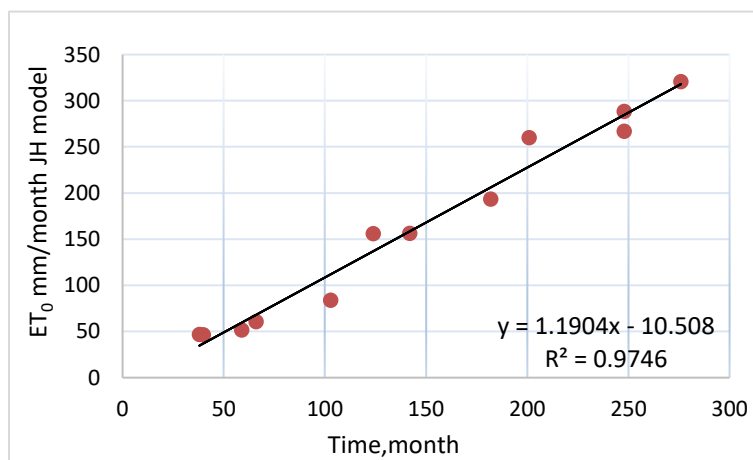


Fig. 5 Regression analysis for predicting  $ET_0$

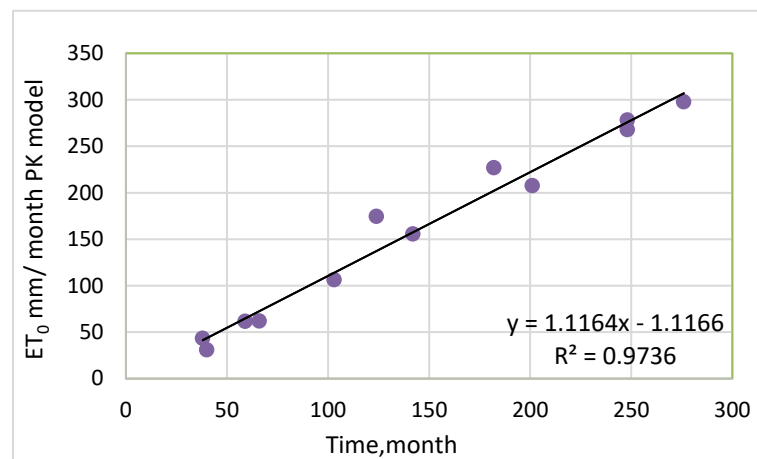


Fig. 6 Regression analysis for predicting  $ET_0$

Table 3 – Statistical analysis for models

Models	MAE	RMSE	R <sup>2</sup>	MBE	RE
PF	8.478	29.369	0.9756	0.00935	5.89091
PM	10.618	36.781	0.9318	0.00615	7.37771
PK	15.63	54.143	0.9736	0.00955	10.8602
JH	16.89	58.509	0.9746	0.00978	11.7361

## 4. CONCLUSIONS

This paper evaluated four models (PF, PM, PK, and JH) in  $ET_0$  estimation of the climate of Al-Ramadi city within Anbar Governorate. The  $ET_0$  values were extracted by comparing the four models to the corresponding actual  $ET_0$  values. For statistical analysis, it was considered that the models with the lowest RSME, MBE, and greatest (R) values were the most effective. The PF model showed that it is the most efficient among the four models, obtaining the lowest value of MBE = 0.02945, RMSE = 29.369, and the highest value of R = 0.9641. The JH model was the least accurate among the models because it obtained the highest values of MBE = 0.00978 and RSME = 58.509. Simple reference evapotranspiration equations are often used to obtain the best estimates possible. In order to estimate irrigation water requirements, plan ahead, and make optimal use of resources, policymakers, farmers, and local water groups benefit greatly from the research's findings.

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