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A COMPARISON OF SOME METHODS FOR DETERMINATION OF POTENTIAL EVAPOTRANSPIRATION FOR ROGERM BASIN, MANGESH, KURDISTAN REGION OF IRAQ

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ABSTRACT

Potential evapotranspiration is an important component of the hydrological cycle at various spatial scales that impacts the runoff quantity and the irrigation water requirements. Potential evapotranspiration is a projectile worker in the ecosystem of the operation of evapotranspiration. The aims of this is to find the most suitable method for calculating monthly potential evapotranspiration in Rogerm basin area by comparing several methods. The climatic data for the period 2012-2021 were used in the models to estimate the potential evapotranspiration. The performance index was applied by using statistical criteria including R^2, RMSE, MBE, and MAPE were used to compare the FAO-56-PM into four temperature-based methods and four radiation-based methods of PET at Mangesh Agrometeorological station. The study found that the Hargraves method is the most accurate one compared with other.

KEYWORDS: Penman-Monteith, potential evapotranspiration, radiation-based method, temperature-based method

1. INTRODUCTION

Evapotranspiration (ET) is defined as the total amount of the evaporation of water from the earth's surface and transpiration from plants to the atmosphere. Evapotranspiration is considered the second greatest important changeable after the rainfall in hydrological cycle and has a substantial role as controlling factors of the volume of runoff, soil moisture content and the requirement of irrigation water (Mohan and Arumugam, 1996). Around 64% of the mean annual precipitation which is land-based returns back to the atmosphere through the evaporation process (Ngongondo, *et al*. 2013). A considerable amount of precipitation around 50% - 80% is come back to the atmosphere as ET in the Southern part of United States, as it is an area heavily covered up by forests and has multiple topographic features (Sun *et al*., 2002; Liang *et al*., 2002). Evapotranspiration is affected by many factors such as weather (climatic) parameters which consist of air temperature, solar radiation, relative humidity and wind speed; Crop factors include the type of crop, crop roughness, height of crop, development and the stage of variety, variation in resistance to transpiration, reflection, crop rooting and the ground cover; and environmental and management factors that include salinity of soil, poor earth fertility, finite implementation of fertilizers (Choudhary, 2011). Potential evapotranspiration (PET) is the total amount of water which could be separated from the earth's surface during evapotranspiration as the total of evaporation and plant transpiration given abundant supply of the soil moisture (Amatya *et al*., 2014). The extraction of water from evapotranspiration relies only on the accessible energy. Potential evapotranspiration is the main factor of evapotranspiration process in the ecosystem of the operation of evapotranspiration. It is often used in a lot of hydrological process such as water and contaminant balance, design of reservoir, arranging the irrigation for crops, restoration of wetland hydrology and in climate change researches also in land use by applying hydrologic modeling (Kim *et al*., 2013 and Dai *et al*., 2013). Potential PET can be directly measured by the lysimeters instrument, but mainly, it is calculated by empirical or theoretical formula (Grismer *et al*., 2002). Around 50 mathematical methods or models are available to calculate the potential evapotranspiration but those calculating methods gives inaccurate values because of their different presumption and input figures needed (Rao *et al*., 2011). Some of these common potential evapotranspiration models are Thornthwaite (1948), Makkink (1957), Priestley-Taylor (1972), and others. Recently, FAO-56 PM model, which is slightly modified from the original Penman-Monteith model, represents as a standard reference for ET (Alkaeed *et al*., 2006). Generally, the common practical ways for calculating potential evapotranspiration are relied on one or more climatic changeable like temperature, solar radiation, wind speed and relative humidity. The main purpose of this research is to calculate and display the monthly potential evapotranspiration methods in Rogerm basin area, then determination of alternate method for estimating PET that can be utilized when climatological data is scarce, as well as comparing and evaluating the values from the tested formulas through statistical analysis.

2. METHODOLOGY

2.1. Study Area

Rogerm basin is the study area that is located in Mangesh region, Duhok city around 45 km north west of Duhok Governorate, size of the specified area is almost 179.5 km^2 between Latitude (37º 03 0́ ˊ- 36º 57 0́ˊ N) and Longitude (E 42º 57 0́ ˊ- E 43º 9 0́ˊ) (Figure1). The climate condition of the study area is hot and dry in summer and rainy cold in winter which is almost the same as the Mediterranean climate. From October to May is considered the wet periods as a heavy rainfall starts, while the other months of the year are dry periods. The Agrometeorological station of Mangesh agricultural offices is the source of meteorological information for the period from 2012 to 2021 at table (1). According to the recorded data of the meteorological station of Mangesh agricultural office, the average annual rainfall of the specified area from 2012-2021 is around 738.5 mm. In summer 30.8 Cº was the mean monthly temperature, while in winter was 5.1 Cº with an annual average of 17.8 Cº. The average monthly of minimum and maximum temperature lies in the range of 9.5 Cº - 38.5 Cº in summer and 0.8 Cº to 23.1 Cº winter, respectively. The hottest month is July and the coolest month is January. The average monthly minimum and maximum relative humidity were 26.6 % and 62.6 % with an annual average of 44.6 %. The average monthly wind speed and sunshine were 2.71ms^{-1} and 8.2 hr. respectively.

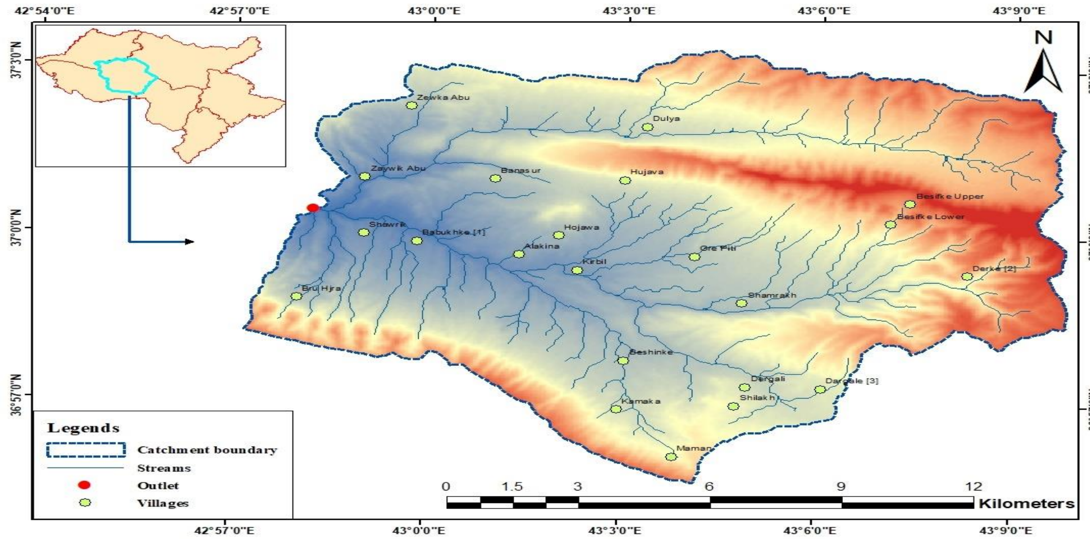

Fig. (1): Rogerm basin area /Mangesh region, Duhok city /Iraq

2.2. PET Methods

Based on their effectiveness, the nine reference evapotranspiration equations were selected in dry environment exam and assessments, as well as how a few climatic information is needed to compute methods, which makes them simple. They include four methods based on temperature as Thornthwaite, Blaney and Criddle, Kharrufa and Hargreaves and Samani, and four methods based on radiation as Makkink, Jensen-Haise, Priestley& Taylor and Hargreaves.

1. Penman Monteith Method (FAO 56-PM)

The Penman method was suggested to calculate evaporation from open water surfaces (Penman, 1948). The model was subsequently altered by Monteith so that it could also be used with surfaces that were cropped. The equation of the modified Penman-Monteith technique was expressed by (Allen, *et al*. 1998) as:

$$PET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T_{mean+273}}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \text{........1}$$

where, PET= Potential evapotranspiration [mm/day], R_n = Net radiation on a crop's surface [MJ/ m^2 day], G = Heat flux density in the soil [MJ /m^2 day] T_{mean}= Mean daily air temperature at 2 meters in altitude [°C], U_2= Wind speed at a height of two meters [m/s], e_s = the vapor pressure of saturation at the mean air temperature in °C [kPa], e_a = Average real air vapor pressure [kPa], (e_s - e_a) = Measurement of the vapor pressure deficit vapor pressure of saturation at the mean air temperature in °C [kPa], e_a = Average real air vapor pressure [kPa], (e_s - e_a) = Measurement of the vapor pressure deficit at a height of two meters [kPa], Δ = Vapor pressure slope curve [kPa°/C]. γ = Psychrometric equilibrium [kPa/°C].

Table (1): Monthly Variables at (General Directorate of Duhok meteorological station) and Parameters Required by Each PET Method:

No.	PET methods	Derived / Estimated	Data input is mandatory
			Estimations
1	**FAO- 56-Penman Monteith**	Solar rays	Air temperature, wind speed, Relative humidity, hourly sunshine brightness
2	**Blaney–Criddle**	Temperature	Mean air temperature, day light hours
3	**Kharrufa**	Temperature	Mean daily air temperature
4	**Thornthwaite**	Temperature	Mean monthly Temperature
5	**Hargreaves & Samani**	Extraterrestrial radiation	Min. & Max. air temperature
6	**Makkink**	Solar Radiation	Mean air temperature
7	**Jensen-Haise**	Solar radiation	Mean air temperature
8	**Priestley & Taylor**	Net Radiation	Mean daily air temperature
9	**Hargreaves**	Solar radiation	Mean air temperature

2. Blaney–Criddle Method

One of the most basic temperature methods used to predict PET is Blaney-Criddle (Ahmad *et al*., 2017). The method only needs to calculate the temperature change in a specific area. The equation was written by (Blaney-Criddle, 1950) as follows:

$$PET = KP(0.46T + 8.13) \text{........2}$$

Where K is the correction factor equal to (0.0311T + 0.24), T is the average monthly temperature in (°C) and P is the average monthly percentage of daylight hours per year.

3. Kharrufa Method

Kharrufa (1985) developed the simple and flexible formula for estimating the PET values, which is represented as:

$$PET = 0.34\, PT^{1.3} \text{..........3}$$

Where: P and T are as defined before.

4. Thornwaite method

Thornthwaite (1948) found a link between PET and the average monthly temperature, as shown with the following formula:

$$ET = 16 * d\left(\frac{10T}{I}\right)^2 \text{ .... 4}$$

Where:

D is the monthly correction factor depends on the latitude, T is the average monthly air temperature (°C), and I yearly thermal index derived from the monthly thermal indices determined as follows:

$$I = \sum_{j=1}^{12} ij \text{.............5}$$

Where ij=$(Tm/5)^{1.514}$, Tm is the average temperature of the air in °C for month j; j = 1......,12; and a= 0.492+(179*10-4) I-(771*10-7)I_2+(675*10.9)I_3

The Thornthwaite approach, in general, underestimates PET in arid region while overestimating PET in humid region (Alkaeed *et al*., 2006).

5. Hargreaves and Samani (1985) method

Hargreaves–Samani (HS) created an empirical equality that can compute evapotranspiration using only temperature and radiation data when meteorological data are limited (Todorovic *et al.* 2013) as this equation:

$$PET = 0.0023(T + 17.8)(\sqrt{T_{max} - T_{min}})R_a \quad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where: T is average daily air temperature (^oC), Tmax. is maximum daily air temperature (^oC), Tmin. is minimum daily air temperature (^oC) and Ra is the extra-terrestrial radiation (MJ m^{-2} d^{-1}). In the Hargreaves and Samani method, the average air temperature is derived as the mean of Tmax and Tmin, and Ra is estimated using information about the site's location and time of year. As a result, the only parameter that must be monitored continually in order to employ this approach is air temperature (Temesgen *et al*., 2005).

6. Makkink method

According to Makkink (1957) the equation for this method as:

$$PET = 0.61\left(\frac{\Delta}{\Delta+\gamma}\right) * \left(\frac{R_S}{\lambda}\right)\ldots\ldots\ldots 7$$

Where: Δ is the slope of the temperature vapor pressure saturation curve (kPa /oC), γ is psychometric constant (kPa /oC), Rs is the total solar radiation (cal/ m^2 d); and λ is the vaporization's latent heat index (1/calg) and λ=0.0501-0.0002361*T*,where T is the average daily air temperature (^oC).

7. Jensen-Haise Method

According to Jensen and Haise (1963) the experimental formula for estimating potential evapotranspiration in dry and semiarid regions developed this equation:

$$PET = R_s(0.025T + 0.078)\ldots\ldots\ldots 8$$

Where: T Average daily temperature (°C) and R_S is worldwide solar radiation data (mm/ day).

8. Priestley–Taylor method

The original Penman (1948) equation has been condensed into the Priestley-Taylor model. According to Priestly and Taylor (1972), the net radiation is the primary variable that influences the rate of evapotranspiration as the huge land area gets more saturated.

$$PET = 1.26\frac{\Delta}{\Delta+\gamma}(R_n - G)\frac{1}{\lambda} \quad \ldots\ldots\ldots 9$$

Where:

Rn is the crop surface's net radiation. (MJ / m^2 day); Δ; λ G and γ is defined before.

9. Hargreaves Method.

This method for calculating PET uses the following approach (Hargreaves, 1975):

$$PET = 0.0135(T + 17.8)\left(\frac{R_s}{\lambda}\right)\ldots\ldots 10$$

Where T, R_s and λ are as defined before.

3.3. Statistical Analysis

The FAO-56 PET model was statistically with linear regression compared with the all-other models in Rogerm basin. Based on coefficient of Determination (R^2), Root Mean Square Error (RMSE), Mean bias error (MBI) and Mean absolute Percentage Error (MAPE) as those equations:

$$R^2 = \frac{\sum_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{[\sum_{i=1}^{n}(O_i-\bar{O})^2][\sum_{i=1}^{n}(P_i-\bar{P})^2]}}\ldots\ldots 11$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i-p_i)^2}{\bar{O}}}\ldots\ldots\ldots 12$$

$$MBI = \sum_{i=1}^{n}\frac{(P_i-O_i)}{n} \quad \ldots\ldots\ldots 13$$

$$MAPE = \left(\frac{1}{n} * \sum\frac{(O_i-P_i)}{O_i}\right)\ldots\ldots 14$$

Where:

Oi =PET as estimated by Penman-Monteith method

Pi= ET as determined by the in question empirical relationship.

i= the signal data point

$\bar{O}$ = the average of Penman-Monteith method data and $\bar{P}$ the average empirical method data

N= number of observations

3. RESULT AND DISCUSSION

The meteorological data from 2012 to 2021 at the Agrometeorological station of Mangesh Agricultural offices were collected and used for analyzing and estimating the potential evapotranspiration using various methods. PET values at Rogerm basin were estimated monthly by temperature based-methods (Thornthwaite, Hargreaves and Samani, Kharrufa, Blaney and Criddle) and solar radiation-based (Makkink, Jensen-Haise, Priestley–Taylor and Hargreaves) in addition to FAO-56-Penman Monteith method. PET values gained from the empirical equations were compared with those gained by FAO-56- Penman Monteith model on a monthly.

In Table (2) explained that the normal values of monthly PET at agrometeorological Mangesh station in by different methods. The PET values for all methods were maximum during July and August Except by Priestley–Taylor method was maximum during Jun and July was 335.05 and 331.25 respectively. While were minimum during December and January.

Table (2): Show the monthly PET of all methods.

Month	Monthly PET (mm)								
	FAO- 56- Penman Monteith	Blaney–Criddle	Kharrufa	Thornwaite	Hargraves-Samani	Makkink	Jensen-Haise	Priestley–Taylor	Hargreaves
Jan.	83.77	19.75	13.19	4.19	25.17	96.89	23.74	75.94	87.99
Feb	95.26	31.11	25.68	9.19	38.50	109.88	35.06	164.71	114.06
Mar	120.98	43.73	42.63	21.09	57.92	117.52	49.26	224.62	126.48
Apr	156.86	85.91	92.83	48.84	93.03	147.34	77.65	279.13	126.55
May	227.20	134.58	150.73	98.21	130.43	166.81	105.77	296.13	199.60
Jun	289.42	267.71	298.80	171.73	167.17	224.34	160.54	335.05	286.68
Jul	305.23	327.74	360.88	222.23	179.55	242.30	186.57	331.25	310.38
Aug	297.37	303.08	333.86	206.45	161.44	240.56	185.05	318.14	320.72
Sep	197.85	225.87	252.35	138.71	118.02	227.10	160.80	280.95	230.96
Oct	172.66	116.10	129.75	70.40	71.58	178.70	109.38	201.48	190.05
Nov	100.56	52.01	53.79	25.40	39.14	135.66	63.52	111.83	149.27
Dec	94.09	25.49	21.35	8.50	25.45	105.58	34.66	43.55	109.85

The mean monthly potential evapotranspiration values were estimated by different models (methods) are given in Fig (2). Generally, the values of PET ranged between 0-350 mm/day. The peak values are shown in July and August months because of the temperature is high through this period, while the least values of PET are found in December and January months. The monthly pattern of potential evapotranspiration produced by different methods is not similar. PET estimated by Kharrufa method in July was slightly higher than that computed by other methods, while Hargreaves and Samani and Jensen-Haise method showed almost similar PET for all months with the value of 167.17 and 160.54 (Fig. 2).

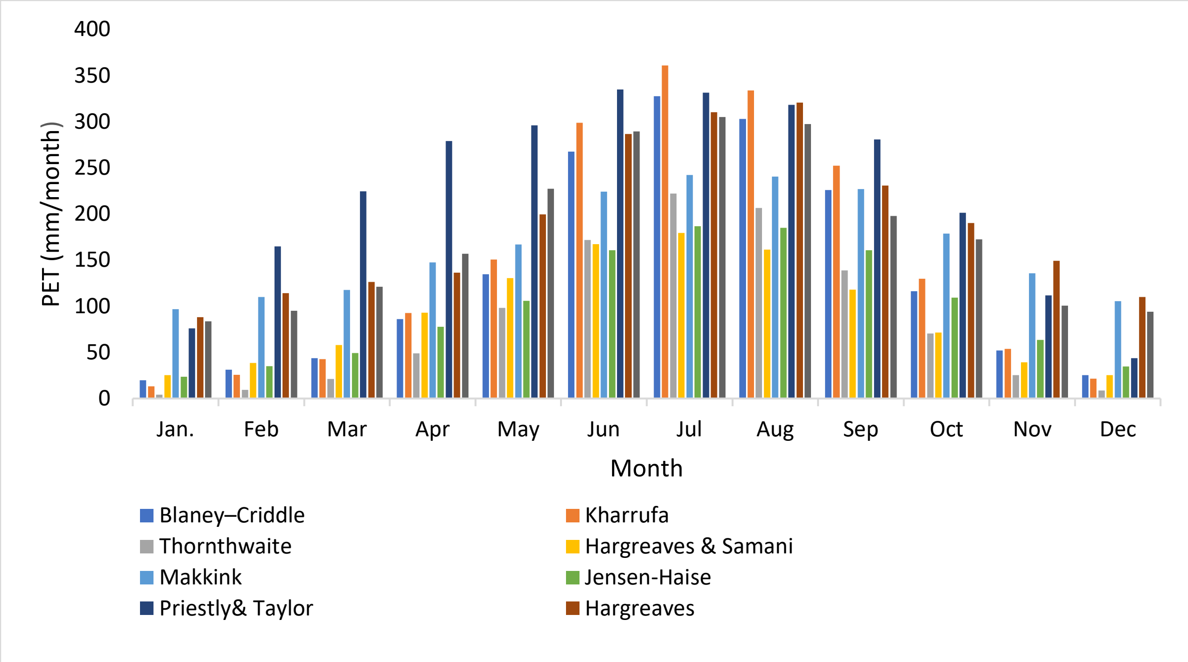

Fig. (2): Applying various methods for prediction PET in Rogerm basin from 2012 to 2021.

The values of monthly PET calculated by each method are explained in Table (3). The lowest mean value of PET was calculated by Thornwaite (85.41 mm) and the highest mean value of PET was estimated by Priestley–Taylor (221.91 mm). The coefficient of variation (C.V.) of temperature-based methods was much higher than the radiation-based methods. while, the lowest coefficient of variation (C.V.) was (32.00) which was found by using the Makkink method and the highest (C.V.) was (90.34) in Thornthwaite method. The maximum value of PET is showed by Kharrufa method is about (360.88) and the minimum value of PET is found by Thornthwaite method is (4.19). Hassan *et al*. (2013) showed that the Hargreaves method is the most accurate one compared with other considered method because the mean, minimum, maximum, standard deviation, and coefficient of variation for this method have values nearby to their conforming values of FAO-56 PM method at (Table 3).

Table (3): Descriptive Statistics for all PET Methods.

Methods	Mean	Min.	Max.	St. deviation	Coefficient of Variation
FAO- 56-Penman Monteith	178.44	83.77	305.23	80.70	45.23
Blaney–Criddle	136.09	19.75	327.74	110.04	80.86
Kharrufa	147.99	13.19	360.88	124.51	84.14
Thornwaite	85.41	4.19	222.23	77.16	90.34
Hargreaves-Samani	92.28	25.17	179.55	55.09	59.70
Makkink	166.06	96.89	242.30	53.13	32.00
Jensen-Haise	99.33	23.74	186.57	58.39	58.78
Priestley–Taylor	221.91	43.55	335.01	98.01	41.00
Hargreaves	188.55	87.99	320.48	78.43	44.16

In Table (4) statistical criteria including R^2, RMSE, MAPE and MBE at Rogerm basin in Mangesh agrometeorological station.

The FAO-56-PM was evaluated by comparing four temperature-based methods and four radiation-based PET methods. For all of the approaches, the R^2 were high; more than 0.9 in all methods except Priestley–Taylor method had the lowest value 0. 78.

The average values of the RMSE ranged between 0.12 and 0.83 in Hargreaves and Hargreaves-Samani respectively. Those indicated that the Hargraves was very close to PET value assessed at FAO-56-PM model.

According to the statistical performance MPE was under the 30 percentage in three radiation-based method as Hargreaves, Makkink and Priestley–Taylor On the other hand, the MPE values of Jensen-Haise and all temperature-based method as Hargreaves-Samani, Blaney–Criddle, Kharrufa and Thornwaite methods were above 30 percentage at Rogerm basin, showing a considerable divergence pertaining to the PET values calculated by the FAO-56 PM method. The MBE values estimated constant underestimation in Makkink method with value -33.36 mm/month, while overestimated in Priestley–Taylor methods with the value 43.48 mm/month. Although the value of Hargreaves-Samani model's coefficient of determination had a higher value than those of the others, a different statistical test revealed that the Hargraves model had the best overall performance of all statistical tests (Mohawesh, 2011) Table (3 and 4).

Figures 3 and 4 provide scatter plots representing the R^2 values for the monthly PET models in FAO-56-PM to all other models by simple linear regression. The R^2 gives a good performance in all temperature-based methods as the higher value of was 0.97, 0.95 and 0.93, however radiation- based methods 0.94, 0.90, 0.89 and 0.78 respectively.

.**Table (4):** Monthly Statistical performance PET models.

Methods	R^2	RMSE	MAPE	MBE
Blaney–Criddle	0.93	0.23	38.21	11.90
Kharrufa	0.93	0.40	42.13	-20.86
Thornwaite	0.95	0.35	47.50	6.87
Hargreaves-Samani	0.97	0.83	34.98	6.15
Makkink	0.87	0.40	15.66	-33.36
Jensen-Haise	0.90	0.21	35.83	-4.51
Priestley–Taylor	0.78	0.36	22.50	43.48
Hargreaves	0.94	0.12	13.69	-10.11

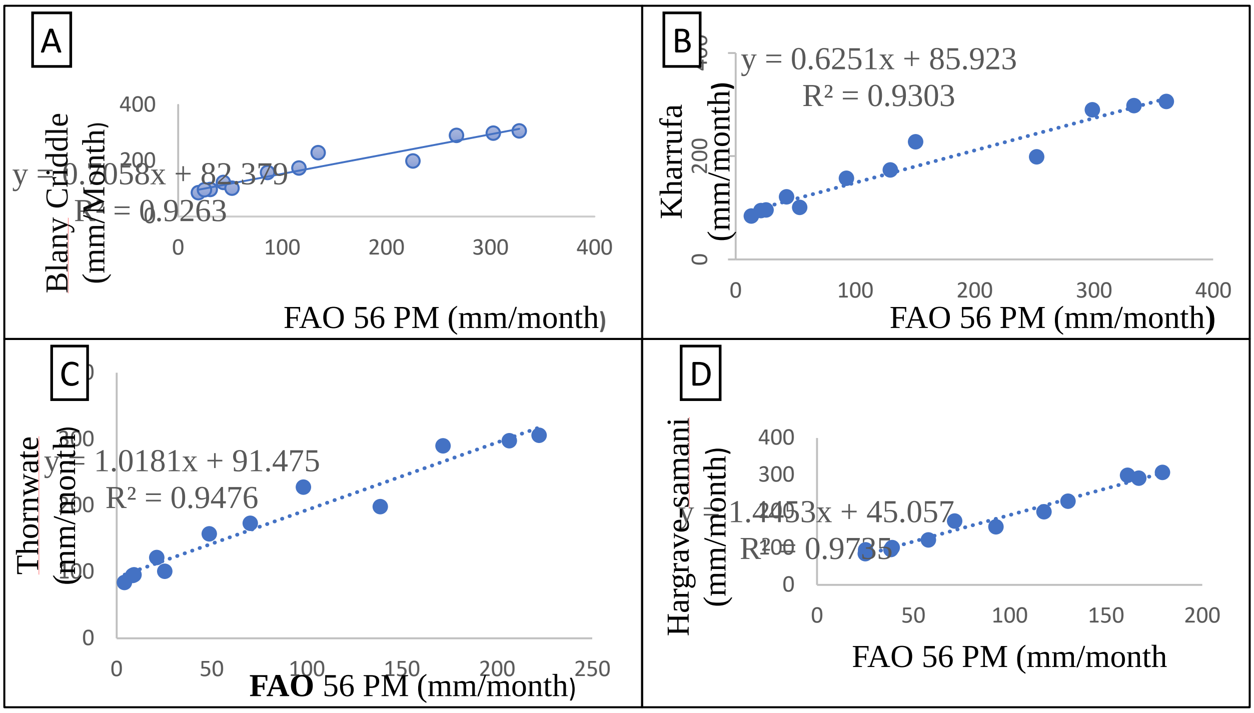

Fig. (3): scatter plots of FAO 56 – PM compared with temperature-based model as (A) Blaney-Criddle (B) Kharrufa (C) Thornwaite and (D) Hargraves and Samani method

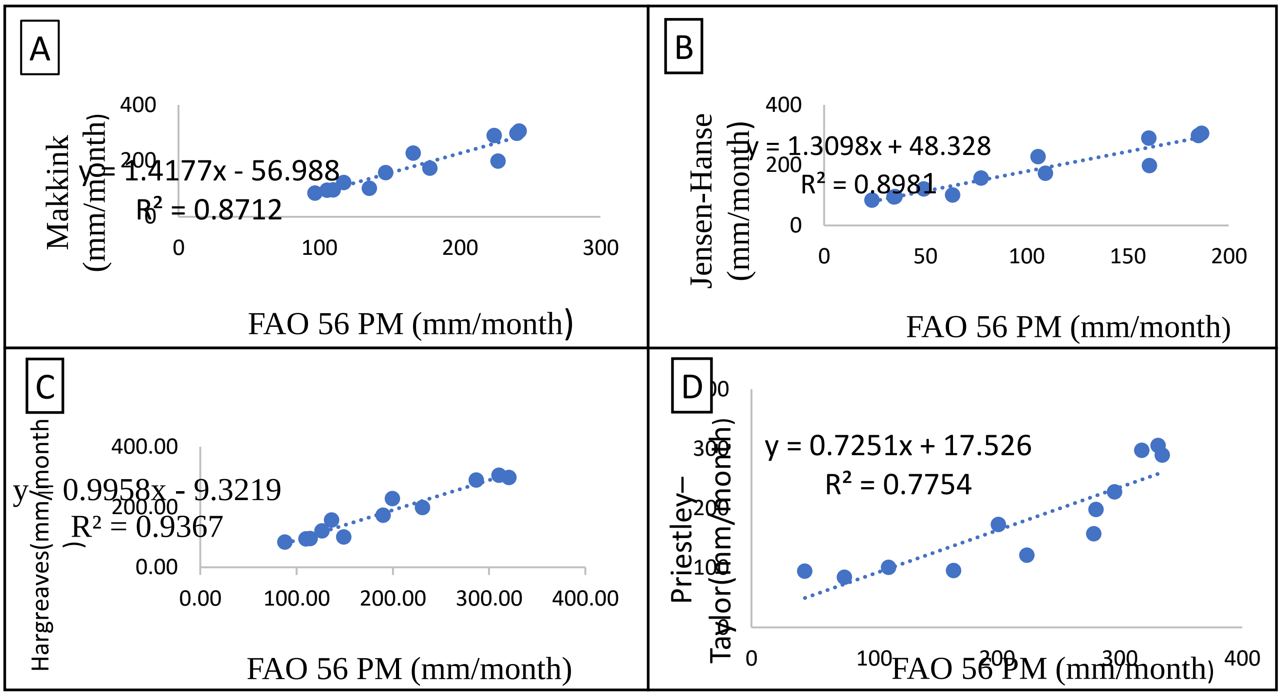

Fig. (4) scatter plots of FAO 56 – PM compared with radiation-based model as (A) Makkink (B) Jensen-Haise (C) Priestley–Taylor and (D) Hargrave method

4. CONCLUSION

Appling different climatic information from Mangesh Agrometeorological station, four temperature-based methods and four radiation-based methods used a tool for evaluating potential evapotranspiration in Rogerm basin. Hargraves method in radiation-based method has been shown to be more preferable for calculating potential evapotranspiration in Rogerm basin. Jensen-Haise output should be less trustworthy. In the study region the PET were all substantially less acceptable for the other six empirical methods. According to the study's methodology, the value of PET was greatest in July and smallest in January.

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بەراوردكرنا دنافبەرا هندەك شێوازان دا بو دیاركرنا پێش بینیا هەلم و هەلمژین ێ ل ئاڤرێژا روگەرم دا ل مانگیّشكێ, هەرێما كوردستانا عیراقێ

پوختە

دهێتە زانین كو پێش بینیا هەلم وهەلمژینێ ئێك ژ پێكهاتێن گرنگە د زڤروكا ئاڤێدا, ل سەر ئاستێن جهێن جیاواز كو كارتێكرنێ لسەر چەنداتیا ئاڤ رابونێ و پێدڤیێن ئاڤا ئاڤداندنێ دكەت. هەلمبونە ئێك ژ پروژا یە د كاركرنا ژینگەهێ دا بو پێش بینیكرنا هەلمژینێ . ئارمانجێن ڤێ ڤەكولینێ بو دیاركرنا باشترین شێواز بو پێش بینی كرنا بهەلم و هەلمژینێ یا هەیڤانە ل ناڤ ئاڤریژا روگەرم ب ریكا بەراوردكرنا چەند شێوازەكا. داتایێن گەش و هەوای بو ماوێ 2012-2022 ل ڤێ مودێلێ دا هاتینە بكارئینان. و پیڤەر ێن ئامارێ یێن هاتینە بكارئینانR2 ، NRMSE، PEو MBE و شێوازێ FAO-56-PM هاتینە بەراوردكرن دگەل چوار شێوازێن پالپشتێ ددنە پلا گەرماتێ و چوار شێوازێن پالپشتێ ددنە تیشكا روژێ ل ویسگەها گەشناسیا مانگیّشكێ دا . د دەرئەنجامان دا دیاربو كو شێوازَێ پالپشتێ ددەتە تیروشكا روژێ Hargrave ئێك ژ باشترین شێوازایە بەرواردی دگەل شێوازێن دی.

مقارنة بين بعض الطرق لتقدير تبخر- نتح الممكن لحوض روكرم، مانكيش، إقليم كردستان العراق

الاخلاصة

تبخر النتح الممكن من المكونات المهمة فى الدورة الهدرولوجية على مستويات مكانية مختلفة و التي تؤثر على كمية الجريان و كذلك على متطلبات الرى. تبخر نتح الممكن عامل موَثرفي نظام البيئي لعملية تبخرو النتح. الغرض من هذة الدراسة هو ايجاد افضل طريقة لحساب تبخر نتح الممكن الشهري في حوض روكرم بالمقارنة بين طرق المختلفة. معلومات مناخية لفترة ما بين 2012-2021 تم استخدامها في هذة الطريقة لتقدير تبخر نتح الممكن مقياس الاَداء طبق باستخدام معاير احصائية منها R2، NRMSE، PE وMBE و التي استغدمت لمقارنة FAO-56-PM في اربعة طرق المعتمدة على درجة الحرارة و اربعة طرق المعتمدة على الاشعاع لتبخر نتح الممكن في محطة انواء الجوية فى مانكيش. الدراسة بينت ان الطريقة المعتمدة على الاشعاع (طريقة Hargraves) هي الاكثر دقة مقارنة مع طرق الاخرىَ.