Assessment of Evapotranspiration Estimation Models for Irrigation Projects in Karbala, Iraq

Dr. Karim K. AlJumaili
Building and Construction Engineering Department, University of Technology/Baghdad
Dr. Mahmoud S. Al-Khafaji
Building and Construction Engineering Department, University of Technology/Baghdad
Aysar T. Al-Awadi
Building and Construction Engineering Department, University of Technology/Baghdad
Email:linoxer@Gmail.com

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ABSTRACT

The variation in climatic conditions of the regions complicates the process of estimating evapotranspiration using one equation or one way because it needs so much data. The adoption of special method for each region based on the lowest climatic parameters and the historical record can be more useful. Five evapotranspiration (ET_0) models had been analyzed statistically by comparing Penman-FAO-24 (PF) model with: Penman Monteith -FAO-56 model (PM), Penman-Kimberly model (PK), Jensen-Haise model (JH) and Hargreaves model (H). The performances of the simpler models were evaluated using bias, root mean square error and Pearson Correlation Coefficient. Also, Regression analysis for predicting (ET_0) from minimum climatic data (Hargreaves model) has been developed. The results indicated that the models which depends on more climatic data are close from each other and that is very clear in (PF), (PM) and (PK). The differences between models are due to wind function used in each model. The developed linear regression model from minimum climatic data (H) model with slope of 1.254, an interception point of -1.801 and coefficients of determination R^2 of 0.988 matched very closely to (PF**)** model values.

Keywords: evapotranspiration (ET_0) models**,** Penman Monteith**,** minimum climatic data**,** Karbala city**.**

تقييم نماذج حساب التبخر نتح لمشاريع الري في كربلاء، العراق

الخلاصة:

إن تباين الظروف المناخية في اي منطقة يعقد عملية حساب التبخر نتح باستخدام معادلة واحدة او طريقة واحدة بسبب الحاجة الى بيانات كثيرة ولذلك فان تبني طريقة خاصة لكل منطقة تعتمد على اقل عدد من المتغيرات وعلى السجل التاريخي للبيانات المناخية يكون ذو فائدة كبيرة. تم تحليل خمس

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

نماذج لحساب التبخر نتح إحصائيا وذلك بمقارنة نموذج بنمان فآو 24 بالنماذج بنمان مونيث 56 ، بنمان كامبرلي ، جانسن هايس ، و هارغريفز. اعتمد التحليل الإحصائي لكل زوج من النماذج على إيجاد الانحياز، مربع جذر الخطأ المتوسط، و معامل الارتباط لبريسون. كذلك تم تحليل الانحدار لاستخراج التبخر نتح من خلال النموذج الذي يعتمد على اقل عدد من المتغيرات المناخية (هارغريفز). أشارت النتائج لاى ان النماذج التي تعتمد على اكبر قدر من البيانات المناخية تكون متقاربة من بعضها البعض وهذا واضح في النماذج: بنمان فآو 24 وبنمان مونيث 56 وبنمان كامبرلي. أن الاختلاف بين هذهِ النماذج يعود الى دالة سرعة الرياح المستخدمة فيها النماذج. اظهر النموذج الناتج من تحليل الانحدار تطابقا كبير مع بنمان فآو 24 بميل مقداره 1,254، وتقاطع 1,801- وبمعامل حساب 0,988.

INTRODUCTION

Knowledge of reference crop evapotranspiration (ET_0) is routinely required to estimate crop water use in the planning, design and operation of irrigation and, soil and water conservation systems. Reliable estimates on evapotranspiration (ET_0) from cropped surfaces are required for efficient irrigation management. Several models, which can be categorized into temperature-based, radiation, mass transfer and combination models have therefore been developed for the estimation of evapotranspiration using weather data. These models range from the most complex energy balance equations requiring detailed climatological data (Penman-Monteith, Allen, 1989) to simpler equations requiring limited data (Blaney-Criddle, 1950, Hargreaves-Samani, 1982, 1985).

The combination models are assumed to be the most reliable because these models are based on physical principles and because they consider all the climatic factors, which affect reference evapotranspiration. Although temperature based methods are useful when data on other meteorological parameters are unavailable, the estimates produced are generally less reliable than those, which take other climatic factors into account-based models, [1].

Ministry of Water Resources in Iraq (MoWR) and Soyuzgiprovodkhoz Institute, 1982, [2], investigated the water resources availability in Iraq. The study included a long term development for different strategic sectors, like land and water availability, agriculture production, natural condition, river flow control and water use, water resources and land conservation. One of the most important investigations was the reference evapotranspiration and crop water requirements for different zones in Iraq. The study suggested evapotranspiration ranges for each zone which was between 1300 to more than 2200 mm/year. MoWR and Engineering Consulting Bureau at University of Technology; 1990**,** [3], presented a long term development for Hussainyah River irrigation Project in the province of Karbala. The development included water balance study, land and water availability, agriculture production, proposed crops rotation and its requirements. The study found that the average reference ET_0 and maximum discharge were 2244 mm/year and 52.32 m^3/sec, respectively at the main canal head to meet the requirements of the year 2000. Five climatological models were used for estimating the reference crop evapotranspiration on a daily basis. Some of these models are based on combination based (aerodynamic and bulk surface resistance), and others are empirical methods based primarily on solar radiation, temperature and relative humidity. The five models that were used to estimate the potential evapotranspiration were listed in Table (1). The varying climatic conditions of the regions makes finding an equation or one way to calculate the evapotranspiration of a complex process and need so much data. The adoption of special method for each region based on the lowest climatic parameters depending on the historical record can be more useful.

The objective of this paper is to analyze the potential evapotranspiration by different models and develop empirical model from minimum climatic data.

Materials and Methods

This section describes requirements, equations, and procedures for estimating and assessment of reference evapotranspiration (ET_0) on a daily time step**.** The study area (Karbala city) extends between latitudes N 32° 36' to 32° 48' and longitudes E 43° 55' to 44° 17 '. It contains two big irrigation projects which are Al- Hussainiyah and Bani Hassan irrigation projects.

Climatic Parameters

The main climatic parameters that affect crop water requirements include: air temperature, humidity, prevailing wind speed, sun shine duration, free-water surface evaporation, and rainfall. Some of the techniques available to calculate crop water requirements depend upon all the above mentioned data, and some of them require only part of the data. Data from Karbala weather station have been gathered for the main climatic parameters which include mean maximum monthly air temperature, mean minimum monthly air temperature, mean average monthly air temperature, mean sun shine duration, wind speed, mean monthly evaporation, mean relative humidity and rainfall, [4]. summary of this data was listed in Table (2). The SPSS 17 software was used to estimate the missing data using linear interpolation method.

Reference Crop $(\mathbf{ET_0})$ Estimation Models

Penman-FAO-24 Model (PF) originally proposed an equation for estimating the evaporation from free-water surface and then applied empirical coefficients to convert an estimated evaporation to a reference evapotranspiration from vegetated surfaces. Penman assumed that the heat flux into and out of the soil is small enough to be conveniently ignored. By combination method, the reference evapotranspiration rate from a short green crop completely shading the ground is expressed in generalized form as follows**, [1]**:

$$\lambda\, ET_o = \frac{\Delta}{\Delta+\gamma}\left(R_n - G\right) + \frac{\Delta}{\Delta+\gamma} 6.43(1 + 0.53\, U_2)(e_{s-}e_a) \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (1)$$

where, ET_o is the reference crop evapotranspiration (mm d^{-1}), (R_n is the net radiation at the crop surface (MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), U_2 is the wind speed measured at 2 m height (m s^{-1}), (e_s- e_a) is the vapour pressure deficit (kPa), i.e., the difference between saturation vapor pressure, (e_s) and the actual vapor pressure, (e_a). The symbol γ denotes the psychrometric constant (kPa/ $^{\circ}C$), Δ the slope of the vapour pressure versus temperature curve (kPa/ $^{\circ}C$) and λ is the latent heat of vaporization (MJ kg^{-1}). The Penman Monteith -FAO-56 model (PM) as described by, [1and 5] is stated as:

$$ET_o = \frac{0.408\left(R_n - G\right) + \gamma \frac{900\, U_2}{T+273}(e_{s-}e_a)}{\Delta + \gamma(1+0.34\, U_2)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots \qquad (2)$$

where T is the average air temperature ($^{\circ}C$).

Wright (1982) presented variable wind function coefficients for reference evapotranspiration. The resulting equations were later simplified and known as Kimberly- Penman model (PK). The model is given as follows, [1 and 6]:

$$\lambda\, ET_o = \frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\Delta}{\Delta+\gamma} 6.43\, W_f\,(e_s - e_a) \quad \ldots\ldots\ldots\ldots \quad (3)$$

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

$$W_f = a_w + b_w U_2 \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$a_w = 0.3 + 0.58\exp[-(\frac{J-170}{45})^2] \quad \ldots\ldots\ldots\ldots \quad (5)$$

$$b_w = 0.32 + 0.54\exp[(\frac{J-228}{67})^2] \quad \ldots\ldots\ldots\ldots \quad (6)$$

Where J is the number of the days in the year between 1 (1 January) and 365 or 366 (31 December), a_w and b_w are the wind function coefficients**.** It is necessary to adjust the wind speed at the height 2 m for equation (1) to (3). The following can be used to accomplish this correction, [5 and 7]:

$$\frac{U_2}{U_1} = (\frac{Z_2}{Z_1})^{0.2} \quad \ldots\ldots\ldots\ldots \quad (7)$$

$$\frac{U_2}{U_1} = (\frac{Z_2}{Z_1})^{0.14} \quad \ldots\ldots\ldots\ldots \quad (8)$$

$$\frac{U_2}{U_1} = \frac{\log 6.6}{\log Z_1} \quad \ldots\ldots\ldots\ldots \quad (9)$$

$$U_2 = U_z(\frac{4.87}{\ln(67.8\,z - 5.42)}) \quad \ldots\ldots\ldots\ldots \quad (10)$$

where,

U_1 is the wind speed measured at height Z_1 above ground surface, m/s, U_2 is the wind speed measured at height 2 m above ground surface, m/s, Z_1 or Z is the height aboveground surface m, and Z_2 is the 2 m height above ground surface. The Jensen-Haise (1963) model (JH) for calculating grass reference evapotranspiration was stated as follows**,** [1 and 8]:

$$\lambda\, ET_o = C_T\,(T_{mean} - T_X)R_S \quad \ldots\ldots\ldots\ldots \quad (11)$$

where, ET_o is reference evapotranspiration (mm d^{-1}), λ is the latent heat of vaporization (MJ kg^{-1}), R_S is solar radiation (MJ m^{-2} d^{-1}) and, T_{mean} is the average air temperature (°C), while C_T and T_X are station constants obtained as follows:

$$C_T = [(38 - \frac{z}{138.5})7.3(\frac{5.3}{e_{smax} - e_{smin}})]^{-1} \quad \ldots\ldots\ldots\ldots \quad (12)$$

$$T_X = -2.5 - 1.4(e_{smax} - e_{smin}) - \frac{z}{550} \quad \ldots\ldots\ldots\ldots \quad (13)$$

where, z is altitude of the location (m); $e_{s\,max}$ and $e_{s\,min}$ are saturation vapour pressures (kPa) at the average monthly maximum air temperature and monthly minimum temperature (^{0}C).

Hargreaves and Semani (1985) proposed several improvements for the Hargreaves (1968) model (H) for estimating grass-related reference evapotranspiration The developed model is as follows, [1, 5 and 8]:

$$\lambda ET_o=0.0023(T_{mean}+17.8))(T_{max}-T_{min})^{0.5}R_a \quad \ldots\ldots\ldots \quad (14)$$

where, ET_0 is reference crop evapotranspiration (mm d^{-1}), R_a is extraterrestrial radiation and (MJ m^{-2} d^{-1}), T_{mean} , T_{max} and T_{min} are respectively the average, maximum and minimum temperatures($^\circ C$).

Accuracy Assessment and Models Evaluation

The ET_o predictions of each of the four simpler models, **[**(PM), (PK), (JH) and (H)**]** were compared with the corresponding outputs of (PF) model. The performances of the simpler models were evaluated using bias, root mean square error (RSME) and Pearson Correlation Coefficient, Eqs (15) to (17). The linear regression equation developed for the purpose of estimating (PF) predictions from (H) model (minimum climatic parameters) was also evaluated on the basis of the coefficients of determination **(**R^2) and standard errors of regression by Microsoft Excel 2007. The bias of each of the simpler models can be obtained with the expression:

$$MBE=\frac{1}{N}\sum_{I=1}^{N}[E(PY)-E(PX)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

where, MBE is the bias (mm d^{-1}) , E(PX) and E(PY*)* are respectively the corresponding ET_o predictions of the simpler model and (PY) model, (mm d^{-1}), while N is the number of paired comparisons. MBE could reflect the estimation error. The root mean square difference can be estimated from:

$$RSME=[\frac{1}{N}\sum_{I=1}^{N}[E(PY)-E(PX)]^2]^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

where RMSD is root mean square difference (mm d^{-1}), which reflects the estimated sensitivity and extreme effect of samples, smaller value means more accuracy. The magnitude of Correlation Coefficient, Cor $[E(PY), E(PX)]$ or R can be estimated from:

$$R=\frac{\sum[E(PY)-E(PY^{-})][E(PX)-E(PX^{-})]}{\sqrt{\sum[E(PX)-E(PX^{-})]^2\sum[E(PY)-E(PY^{-})]^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

where, $E(PY^{-})$ and $E(PX^{-})$ are the mean value of the E(PY) model and corresponding ET_o predictions of the simpler model. The closer Cor [E(PY), (EPX)] is to 1 or -1, the stronger relationship between E(PX) and E(PY), [9 and 10].

Results and Discussion

Results of the studied five models, [(PF), (PM), (PK), (JH) and (H)] using the climatic data, Table (2), were as listed in Table (3). These results show that the maximum annual (ET_o) was obtained by (PF) model and it was 2209 (mm), while the minimum annual was obtained by the (H) model and it was 1778 (mm). The (H) model was under estimated, because the wind function effect was negligible. Figure (1) shows the comparison for the results obtained using the models. For statistical analysis it was assumed that the best models were those of the lowest RSME, MBE and the highest (R) with respect to (PF) model result. The models were ranked according to the results of statistical analysis as listed in Table (4). The results indicated that the (PM, (PK) and (JH) models were close to (PF) model, while (H) model was far from (PF) model**.** So, the results of (H) model are considered poor for predicting (ET_o), but it has a good correlation coefficient (R= 0.994) with respect to (PF) model, therefore the regression analysis was conducted to examine the relationship and produce linear regression for predicting (ET_o) (PF) model from (H) model which needs minimum data (temperature only). The end linear regression equation together with the coefficients of determination **(**R^2) are shown in Figure (2). Hargreaves regression matched very closely to (PF) model with slope of 1.254, an interception point of -1.801 and coefficients of determination R^2 of 0.988.

CONCLUSIONS

The estimates ET_o that obtained using five commonly ET_o estimation models indicated that (PM) model produces the most reliable estimates compared to (PF), while (H) model did not show a close agreement with (PF). The results indicated that the models which depended on more climatic data are close from each other, and that is very clear in (PF), (PM) and (PK). The differences between these models were due to the wind function used in each model.

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Table (1) ET_o estimation models.

ID	Classification	Models	Reference crop
1	Combination based	Penman -FAO-24 model (PF)	Grass
2	Combination based	Penman Monteith -FAO-56 model (PM)	Grass
3	Combination based	Penman-Kimberly model (PK)	Grass
4	Radiation based	Jensen -Haise model (JH)	Grass
5	Radiation based	Hargreaves model (H)	Grass

Table (2) Summary of the average climatic parameters.

Climatic parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean air temp., ^{0}C (1992-2005)	10.8	13.4	17.9	24	30.1	34.4	36.6	36.4	31.4	26	17.6	12.7
Mean rainfall, mm (1975-2005)	19.6	14.88	17.45	13.9	5.1	0.1	0	0	0.4	4.7	11.48	19.3
Effective rainfall factor	0.65	0.65	0.75	0.75	0.8	0.7	0	0	0	0.7	0.7	0.65
Mean effective rainfall, mm (1975-2005)	12.74	9.7	13.1	10.43	4.1	0.07	0	0	0	3.3	8	12.5
Mean max air temp, ^{0}C (1992-2005)	16	19.2	24.3	30.8	37.3	42	44	44.5	39.3	32.7	23.5	18
Mean min air temp, ^{0}C (1992-2005)	5.6	7.5	11.4	17.2	22.8	26.8	28.9	28.2	23.5	19	11.6	7.4
Mean monthly evaporation, mm (1992-2006)	58.43	92.3	168.7	241.74	333.7	410.12	445	397	300.84	203.52	98.5	57.8
Mean relative humidity, % (1980-2009)	72.86	60.7	52	43	33	28	29	31	35	45	62	73
Mean sun shine duration, hr/day (1977-2005)	6.1	7.5	8	8.6	9.5	11.63	11.6	11.2	10.3	8.5	7.21	6.1

Mean wind speed at 2 m height, m/sec (1976-2006)	1.62	1.93	2.24	2.39	2.47	3	3.25	2.7	1.9	1.6	1.42	1.5

ID	Models	JAN	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	(PF)	62	83	135	185	251	312	337	303	220	155	87	79	2209
2	(PM)	54	73	124	171	234	300	329	293	210	136	81	67	2072
3	(PK)	43	60	100	150	217	310	372	326	210	133	70	62	2053
4	(JH)	31	45	87	150	242	330	363	344	231	133	54	31	2041
5	(H)	52	68	112	159	217	240	257	245	180	124	72	52	1778

Table (3) Estimated ET_O in mm/month using five models.

Table (4). Statistical analysis for models with respect to (PF) model.

Id	Models	MBE	RMSE	R
1	(PM)	11.42	11.97	0.999
2	(PK)	13	24.86	0.989
3	(JH)	14	32.52	0.993
4	(H)	35.92	41.98	0.994

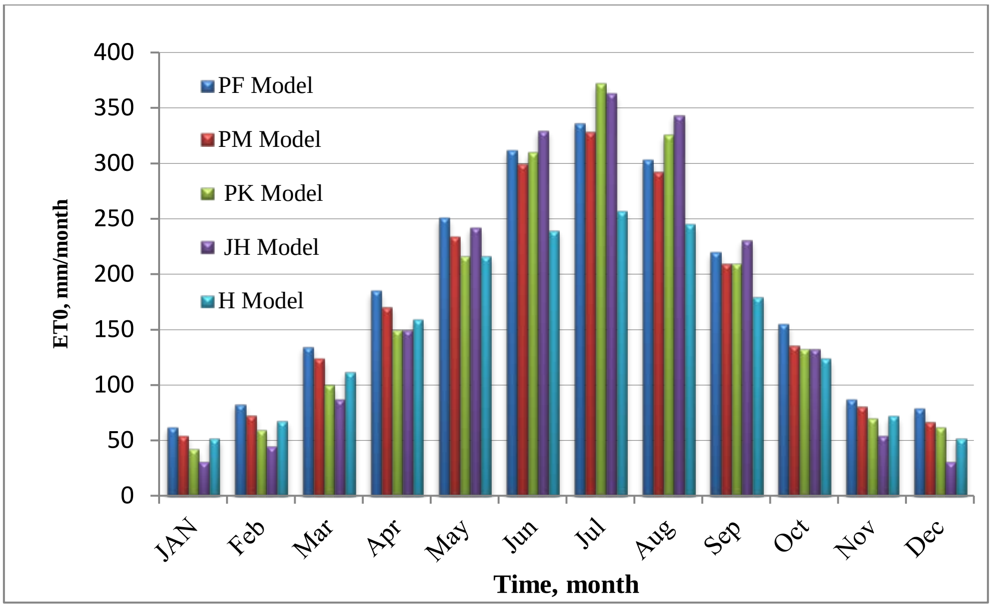

Figure (1) Comparison of estimated ET_O using the five models.

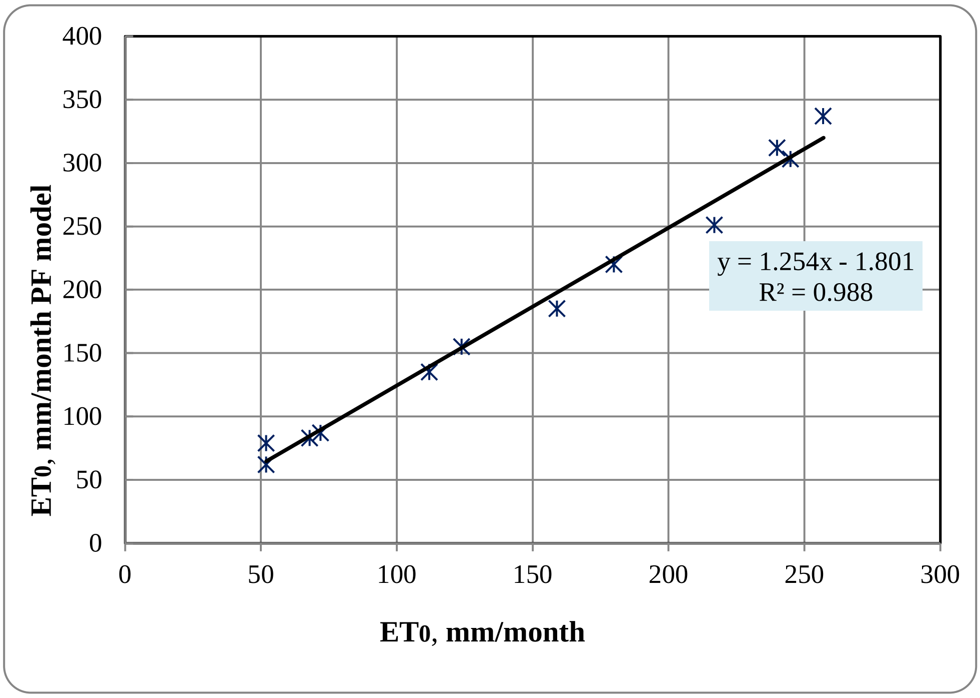

Figure (2) Regression analysis for predicting ET_o from minimum climatic data by using Hargreaves model.