Estimation of MeanReference Evapotranspiration in Basrah City, South of Iraq Using Fuzzy Logic

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ABSTRACT

Evapotranspiration (ET) is important for hydrological practices, water planning, and it plays an influential role in the design, operation and management of irrigation systems. There are a number of methods suggested to estimate reference evapotranspiration (ETo). Detailed meteorological data required for the equation of FAO-56 Penman-Monteith (P.M) method that was adopted by Food and Agriculture Organization (FAO) as a standard method in estimating reference evapotranspiration (ETo) are not often available, especially in developing countries. In this research the possibility of estimating reference evapotranspiration using fuzzy logic control in BasrahCity is studied. The four models of fuzzy logic are constructed based on the available meteorological data in BasrahCity during the period (1990-2012).Various combinations of long-term average monthly climatic data ofair temperature, relative humidity, wind speed and solar radiation are used as inputs to construct four models of fuzzy logic. Fuzzy logic models evaluated based on root mean squared error (*RMSE*) and coefficient of correlation (R^2).Depending on the values of *RMSE* and R^2, model No.4 with input parameters (T_{mean}, T_{min}, T_{max}, Rh, W_s, Rn)give the best values of estimated (ETo), it gives a *RMSE* and *R*values of 0.094 and 0.998 ,respectively. Fuzzy logic models have high efficiency in estimating the reference evapotranspiration values.

KEYWORDS:- Evapotranspiration, Fuzzy logic,Penman-Monteithmethod, Basrah.

الخلاصة

يعتبرالتبخر النتح(ET) مهم في التطبيقات الهيدرولجيه، التخطيط المائي، كذلك فإنه يلعب دورا مؤثرا في تصميم ، تشغيل و ادارهنظم الري. هناك عدد من الطرق المقترحه لتخمين التبخر النتح المرجعي (ETo). لكن اداء هذه الطرق يكون مقيد باختلاف الخصائص المناخيه من منطقه الى اخرى. ان المعلومات المناخية اللازمه لحساب (ETo) بطريقة بنمن- مونتينث(Penman-Monteith Method)والتي تم اقترحها من قبل منظمة الغذاء والزراعه العالمية FAO كطريقة قياسية لحساب (ETo) عادة لا تكون متوفره وخاصة في البلدان النامية. في هذا البحث تم دراسه امكانيه تخمين (ETo) باستخدام نظريه المنطق الضبابي (Fuzzy logic theory) في مدينه البصره بالاعتماد على بيانات الارصاد الجويهللفتره(1990-2012). استخدمت في البحث مزجات مختلفة للمعدلات الشهرية طويلة الامد لمتغيرات المناخية (الرطوبة النسبية، درجة الحرارة، سرعة الرياح و الاشعاع الشمسي) في انشاء اربعة نماذج للمنطق الضبابي.تم تقييم نماذج المنطق الضبابي (Fuzzy logic) بالاعتماد على المعاملات الاحصائية جذر معدل الخطأ التربيعي (*RMSE*)، و معامل الارتباط (R^2). بالاعتماد على قيم *RMSE* و R^2 فإن النموذج الرابع ذو المدخلات (T_{mean}, $T_{min}T_{max}$, Rh, W_s, Rn) أعطى قيم ETo الاقرب الى القيم المحسوبة بطريقة بنمن- مونتينث. كانت قيم *RMSE* وR^2للنموذج الرابعهي 0.094 و 0.998 بالترتيب. اثبتت النتائج ان هناك كفاءه عاليهفي تخمين قيم (ETo) بأستحدام نموذج المنطق الضبابي (Fuzzy logic).

الكلمات المفتاحية: التبخر النتح، المنطق الضبابي،طريقةبنمن- مونتينث، البصرة

1.INTRODUCTION

The main two processes of water loss from vegetated land surface to atmosphere, evaporation and transpiration, are refered to asevapotranspiration (ET).When liquid water is converted to water vapour (vaporization) and is removed from sources such as the wet vegetation, soil surface, pavement, water bodies, etc; thisprocess is called evaporation. Transpiration consists of the vaporization of liquid water within a plant and subsequent loss of water as vapour through leaf stomata. Both processes (evaporation and transpiration) occur simultaneously and depend on air temperature, solar radiation,wind speed and relative humidity (i.e., vapour pressure deficit).A common practice for estimating evapotranspiration (ET) from a well irrigated agricultural crop is to estimate reference evapotranspiration (ETo) from standard surface and apply an appropriate empirical crop coefficient, which accounts for difference between the standard surface ET and crop ET [Pakhale *et.al.,*2015].

(ETo) is defined as the ET rate from a uniform surface of dense, actively growing vegetation having a specified height and surface resistance (to transfer of water vapour), not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation [Allen *et .al*.,2005]. This definition leaves open the option of using more than one reference surface when measuring or computing ETo.

A large number of empirical methods has been developed over last five decades by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. The analysis of the performance of the various calculation methods reveals the need for formulating a standard method for the computation of ETo. The Food and Agriculture Organisation (FAO) suggestedthe use of the FAO Penman-Monteith method for estimation of ETo because it is the most adequate method[Smith *et. Al*.,1998],it is a method with strong likelihood of correctly predicting ETo in a wide range of locations and climates [Jensen *et.al*.,1990,and Allen *et.al*.,1998], however, ranking of other methods varied depending on their adoption to local calibrations and conditions. Therefore, there is a need for developing an appropriate method for estimating ETo, using fewer and simpler input data.

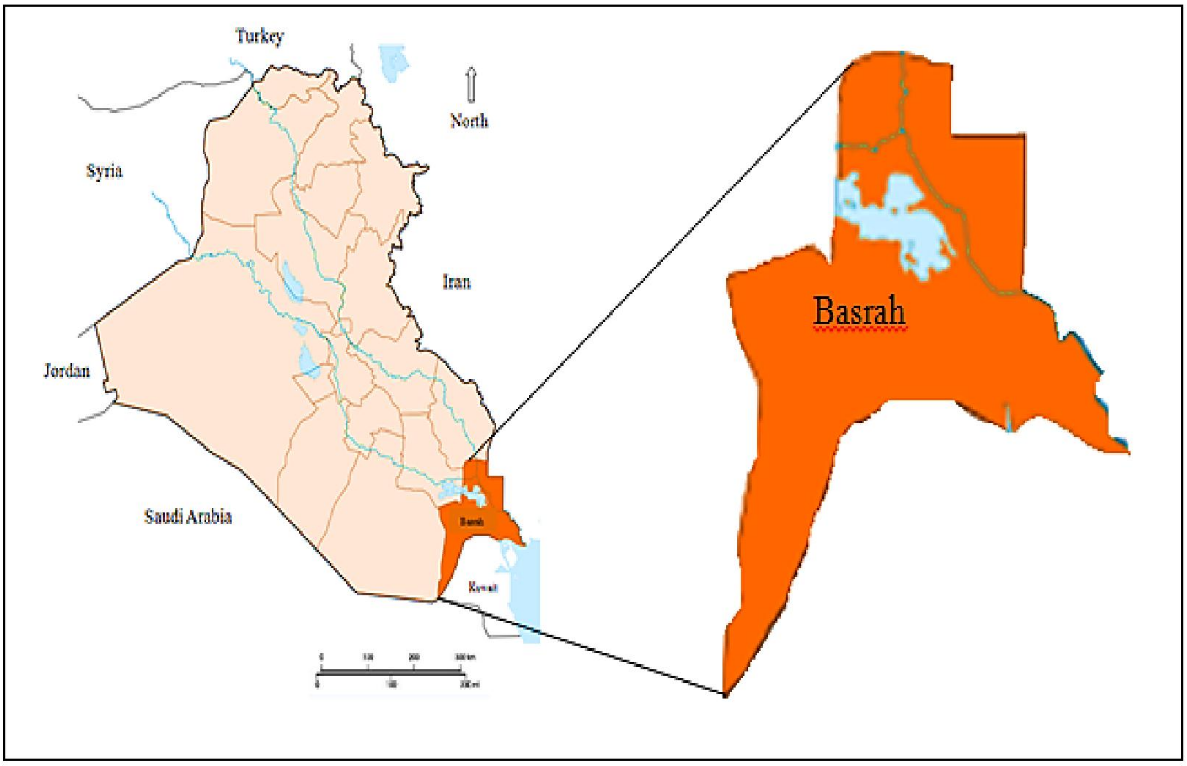
In recent years, many applications using Fuzzy logic theory were appeared, since it is an alternative and effective tool for studying complex phenomena.Fuzzy logic models can give answers to practical problems, without being time consuming. Fuzzy rule systems have been used successfully inreservoir management [Panigrahi, and Mujumdar , 2000], rainfall-runoff problems [Nayak *et.al.,*2005] and in parameters of groundwater flow [Chalkidis, *et .al.,*2006].

In the present paper, an attempt is made to apply Fuzzy Rule based (FRB) to estimatemean reference evapotranspiration based on meteorological data for BasrahCity, south of Iraq.

2. Study Area and Data Set

Basrah is the most southern governorate of Iraq and have borders with Iran, Kuwait and Saudi-Arabia as shown in Figure (1). It is located between longitude line (47°30'-48°30') and latitude-line (30°00'-30°30') and its area 19070 km^2. In the south,the governorate is made up of a vast desert plain, intersected by the Shatt AI-Arab waterway which isformed by the confluence of the Tigris and Euphrates rivers at Al-Qurnah and empties into the ArabianGulf. Around Al-Qurnah and Al-Medina a number of lakes can be found, while marshland stretches fromthe north of the governorate into the neighbouring governorates Thi-Qar and Missan. Similar to the surrounding region, the governorate of Basrah has a hot and arid climate. Thetemperatures in summer are among the highest recorded in the world. Due to the vicinity of the ArabianGulf, humidity and rainfall are however relatively high. The annual average rainfall is152mm occurs between the months October and May.

The climate information used in this study is obtained from meteorological recording station in BasrahCity for the period (1990-2012).



Figure(1)Basrah map

3. Penman-Monteith method

Actual evapotranspiration estimation from the field requires Lysimeter data. However, it is not always possible to estimate ETo using lysimeter, because it is time-consuming, requires large infrastructure and precise and carefully planned experiments. Therefore, empirical methodscan be used to estimate evapotranspiration from different climatic variables. FAO-56Penman-Monteithis used for estimating ETo because it closely approximates grass ETo at the location evaluated,and is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Penman-Monteith equation has generally been considered as a standard method for predicting ETo [Allen *et.al.,*1998 and Muhammad Umair , Usman , 2010]

The final form of the FAO Penman-Monteith equation is as given below:

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma\left[\frac{900}{T+273}\right]u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where, *ETo* is the reference evapotranspiration

$R_n$is net radiation at the crop surface

$G$is soil heat flux density

$T$is mean daily air temperature at 2m height.

$u_2$is wind speed at 2m height.

$e_s$is saturation vapour pressure

$e_a$actual vapour pressure .

$e_s - e_a$is saturation vapour pressure deficit .

$\Delta$is slope ofvapour pressure curve.

$\gamma$is psychometric constant .

4. Fuzzy Logic

The most common method to deal with the uncertainties was probability theory, until 1965, when Zadeh introduced the fuzzy set theory [Zadeh,1965]. Fuzzy logic is an effective tool forhandling the ambiguity and uncertainty of the real world systems. The Fuzzy Rule Based (FRB) systems or Fuzzy Inference Systems (FIS) originate from fuzzy logic and the fuzzy set theory in general. FRB systems provide an effective way to capturethe approximate nature of the real world processes, due to the rule formulation. Therelationships can be described verbally instead of using mathematical equations. Theinput and output variables are related using fuzzy IF-THEN rules, where IF relates tothe vector of fuzzy premises and THEN to the vector of the consequences, which hasthe form of a fuzzy set as well. The linguistic formulation of the rules resembles thehuman reasoning, since it is based on “IF-THEN” expressions and this is why it is fuzzyto problems where the procedures are complex and difficult to be defined mathematically.

In Boolean logic the boundaries of a set are clearly defined and it is evident whetheran object belongs to a set or not. It is described by a binary function, the characteristicfunction, taking the value 0 when an element x doesn’t belong to the set A and thevalue 1 when it does. On the contrary, in fuzzy logic, it is possible for elements tobelong partially to a set. Fuzzy sets are a generalization of the classical sets since theydon’t have clearly defined boundaries. If X is a collection of objects denotedgenerally by x, then a fuzzy set Ã in X is a set of ordered pairs:

$$\widetilde{A} = \{(x, \mu_{\widetilde{A}}(x)) |\ x \in X\} \tag{2}$$

Where $\mu_{\widetilde{A}}(x)$ is called the membership function or grade of membership of x in Ã. Thedegree to which an element belongs to a fuzzy set is shown by the membershipfunction, which takes values from the [0, 1] interval. The closer the membershipfunction $\mu_{\widetilde{A}}(x)$is to 1, the more the element x belongs to the fuzzy set Ã.

4.1 Fuzzy System Function

A fuzzy system R is defined as the collection of rules consisting of fuzzy premises$A_{i,k}$ with membership functions $\mu_{Ai,k}$and fuzzy responses $B_{i,k}$with a form of a fuzzyset also. A fuzzy rule has the following general form:

If a_1 is $A_{i,1} \otimes a_2$ is $A_{i,2}$ $\otimes$ ………. $\otimes$ a_k is $A_{i,k}$ then B_i

All rules use the same variables as fuzzy premises and the same variable as fuzzyresponse. A fuzzy rule is composed of linguistic variables connected together withlogical operators. The most usual ones are the AND, or represen⊗d by the symbol above.

In fuzzy systems the partial fulfillment of a rule is possible. The degree to which arule is true is called Degree of Fullfillment (DOF). Zero DOF value denotes nofulfillment of the rule and unitary value means that the rule is fully applicable. Thevalues within the interval [0, 1] show the degree of applicability of the rule. Since thepremise part of the rule is applicable to some degree, the same degree stands for theantecedent part too. If there is more than one fuzzy premise, then the membershipvalues should be combined, in order to obtain the DOF[Zimmermann ,2011].

Overlap between premise membership functions is necessary in order to reducethe error sensitivity. An As seen in figure 2,anoverlap exists when the domains betweenneighboring fuzzy numbers partially cover each other. This means that when a crispnumber is imported to the system, it belongs partially to more than one fuzzynumbers. Each premise fuzzy set corresponds to a different rule. When a crisp numberbelongs to an overlapping section then there are as many rules triggered as the fuzzysets belonging to the particular section. Crisp values are assigned using a training set(to train the rules) and a verification set (to test model performance).

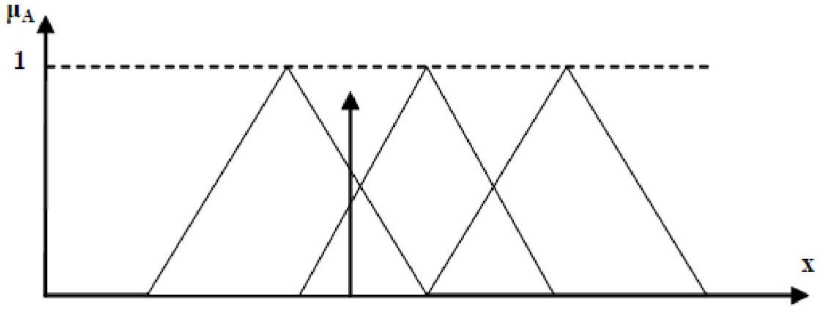


Figure (2) Fuzzy numbers with overlap

It is obvious that in this case every rule has a different DOF and leads to adifferent response for the same inputs. All fuzzy responses are being aggregated to afuzzy set which results from all the fuzzy premises and takes into account also theDOFs.

The fuzzy logic toolbox (MATLAB) is a library of function implementing a framework for creating, editing. This toolbox was used to develop the fuzzy logic model for modeling the reference evapotranspiration in this study.

5. Methodology

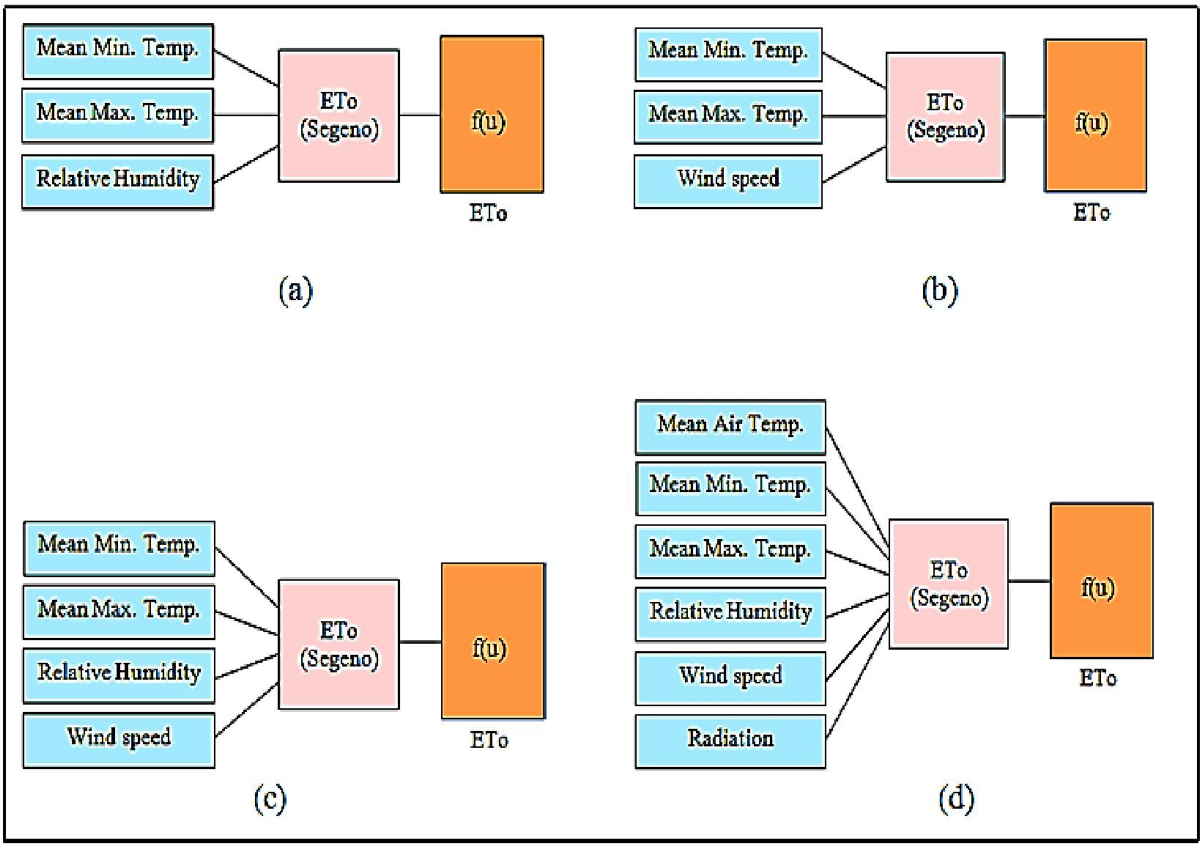
In this study, the climate data obtained by meteorological station in BasrahCity for the period (1990 to 2012) used to calculate EToFAO-56 Penman-Monteith equation.

Four models constructed by usingFuzzylogic to estimate the reference evapotranspiration (ETo) in BasrahCity.The climate data is classified into two types, training and testing period, the period from 1990 to 2004 is taken as training set, in this period the rules of fuzzy logic were constructed. The second set, is treated as testing set from period 2005 to 2012. Table (1) shows the input variables for each model. The output variable is ETo for each model. Figure (3) shows the proposed fuzzy logic system for each model.

The most commonly used method in fuzzy inference isMamdani and Sugeno. Sugeno method is chosen, due to its suitability to optimization, adaptive techniques, and mathematical analysis.

Table (1) Input variables of fuzzy system

Model No.	Input variables
M1	Mean min. temperature (T_{min}), Mean max. temperature (T_{max}) and relative humidity (Rh)
M2	Mean min. temperature (T_{min}), Mean max. temperature (T_{max}) and wind speed (W_s)
M3	Mean min. temperature (T_{min}), Mean max. temperature (T_{max}), relative humidity (Rh) and wind speed (W_s)
M4	Mean air temperature (T_{mean}), Mean min. temperature (T_{min}), Mean max. temperature (T_{max}), relative humidity (Rh), wind speed (W_s) and solar radiation(Rn)



Figure(3) Fuzzy inference system for computing ETo, (a) Model 1, (b) Model 2, (c) Model 3, and (d) Model 4

Different input contributions including various monthly mean climatic data, which are: air temperature, relative humidity, wind speed and solar radiation are used in fuzzy logic models to estimate ETo.

The available data 22 years (1990-2012) were separated into two parts as training and testing data sets. The training set includes 168 records which represent 64% of the total data. In order to make more reliable comparisons, the models are evaluated by the testing data set which is not used during the training phase. The testing set consists of 96 records which represent 36% of the total data. In order to investigate the effect of monthly mean climatic data on ETo, each input variable, (air temperature, relative humidity, wind speed or solar radiation), is used to estimate ETo, one by one, and the degree of effect of each variable on ETo is evaluated through calculating statistical parameters, root mean square error RMSE (Eq.3) and coefficient of correlation R^2 (Eq.4).

Optimum membership functions are found by trial and error, the triangular linear membership functions for input and output set respectively are found to be optimal as shown in figure (4). The estimation results of fuzzy logic models by RMSE and R^2 are given in table (2). Fuzzy rule table is generated after setting the membership function. Part of these numerous for model 2 is shown in Figure 5.

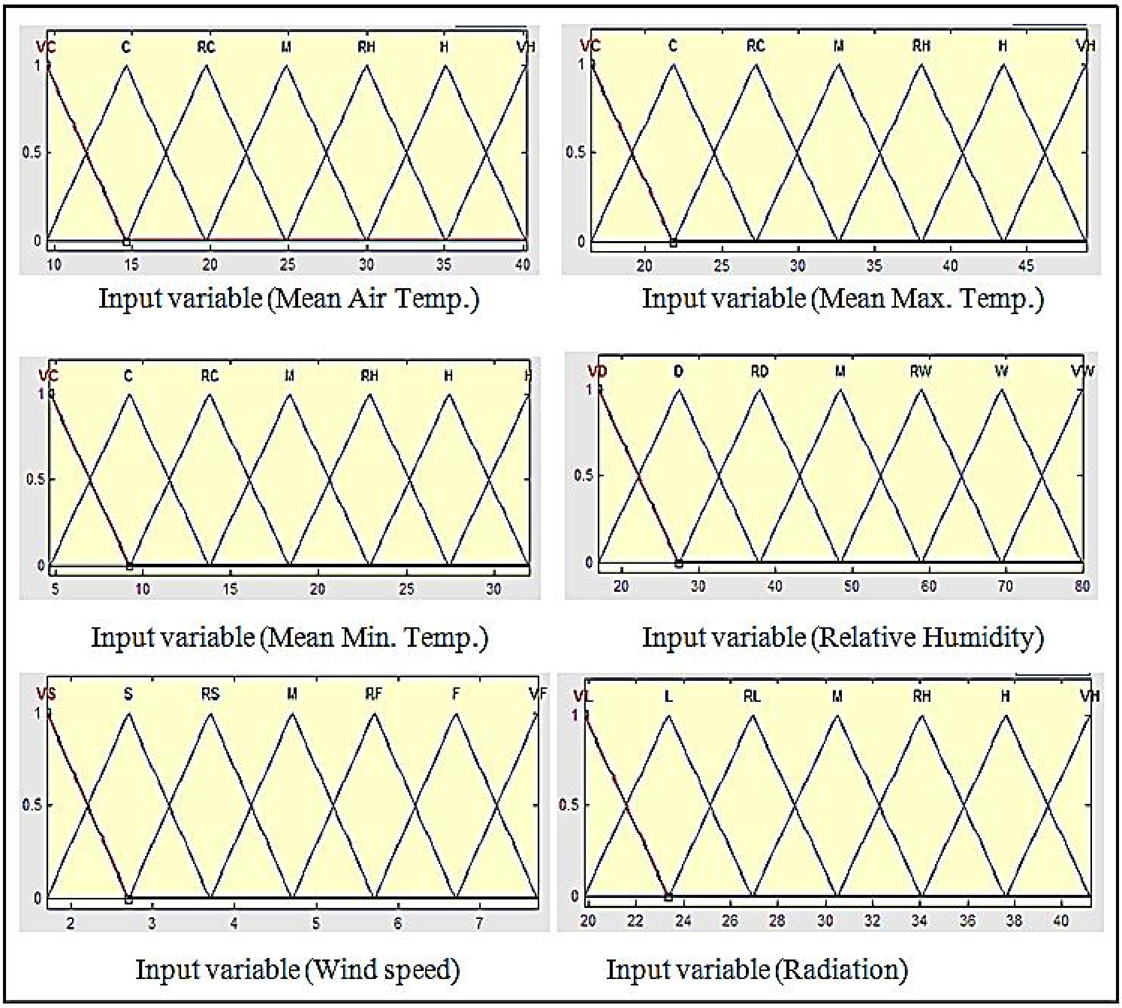


Figure (4) Membership degree of input variables

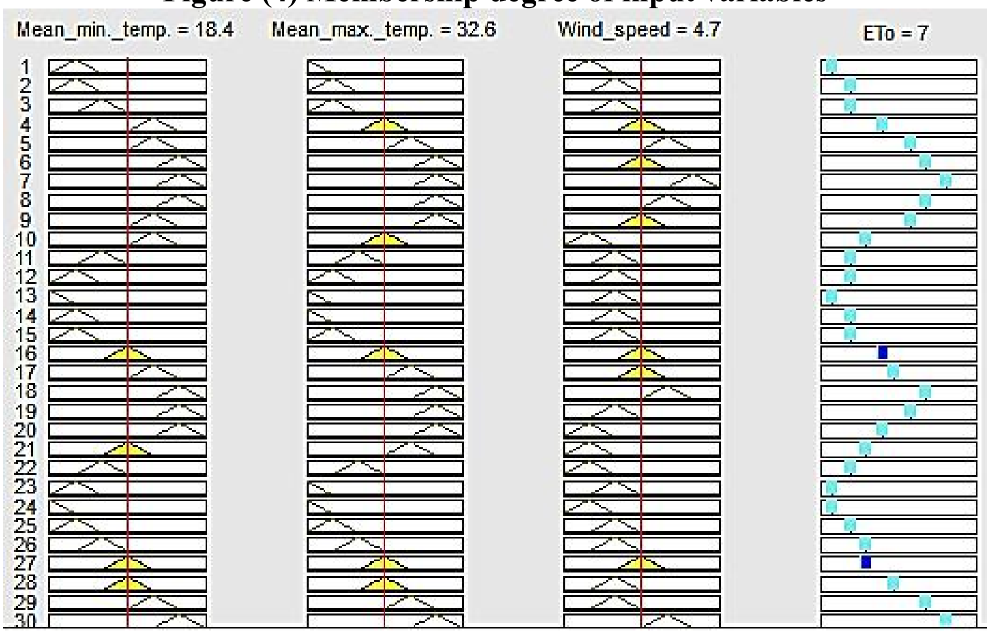


Figure (5) Part of the fuzzy rule table for model 2

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{i=n}\left(Q_m - Q_s\right)^2} \qquad \text{……….} \ (3)$$

$$R = \frac{\sum_{i=1}^{i=n}\left(Q_m - \bar{Q}_m\right)\left(Q_s - \bar{Q}_s\right)}{\sqrt{\sum_{i=1}^{i=n}\left(Q_m - \bar{Q}_m\right)^2 \sum_{i=1}^{i=n}\left(Q_s - \bar{Q}_s\right)^2}} \text{ ………. (4)}$$

Where:

Q_m : Measured value (from Penman-Monteith equation).

Q_s : Simulated value (from fuzzy logic).

$\bar{Q}_m$: Average of measured values.

$\bar{Q}_s$: Average of simulated values.

n : The number of observations.

6. Results and Discussion

Four models are used for estimating reference evapotranspiration (ET_o). The four models are adopted by using fuzzy logic techniques. These models are described as follow:

Model No. 1:-
ETo=f (T_{min}, T_{max}, Rh)

Model No. 2:-
ETo=f (T_{min}, T_{max}, W_s)

Model No. 3:-
ETo=f $(T_{min}, T_{max}, Rh, W_s)$

Model No. 4:-
ETo=f $(T_{mean}, T_{min}, T_{max}, Rh, W_s, Rn)$

Based on that the measuring of temperature, relative humidity, wind speed and radiation are very easy, those variables are adopted as an input for estimating the *ETo* using the fuzzy logic models. Figures 6 to 9 present the details of the estimated and calculated Evapotranspiration by Penman-Monteith equation as standardfor the period (2005 to 2012). As shown in these Figures, the convergence between the two curves can be seen except Figure 6. It can be noted in Figure 6, the curve of estimated values is under the calculated values by penman-Monteith equation at the peak, which refers to under estimating. This may be belonged to the use of relative humidity in calculating ETo which has a reverse relationship withETo.

Table (2) shows the values of *RMSE* and R^2 for the four models.It is evident that the statistical parameters values are accebtable which indicates reasonableof fuzzy logic model to estimate ETo.

It is obvious from R^2 and RMSE that model no. 4 is closer to the observed ETo values than those of the other models.

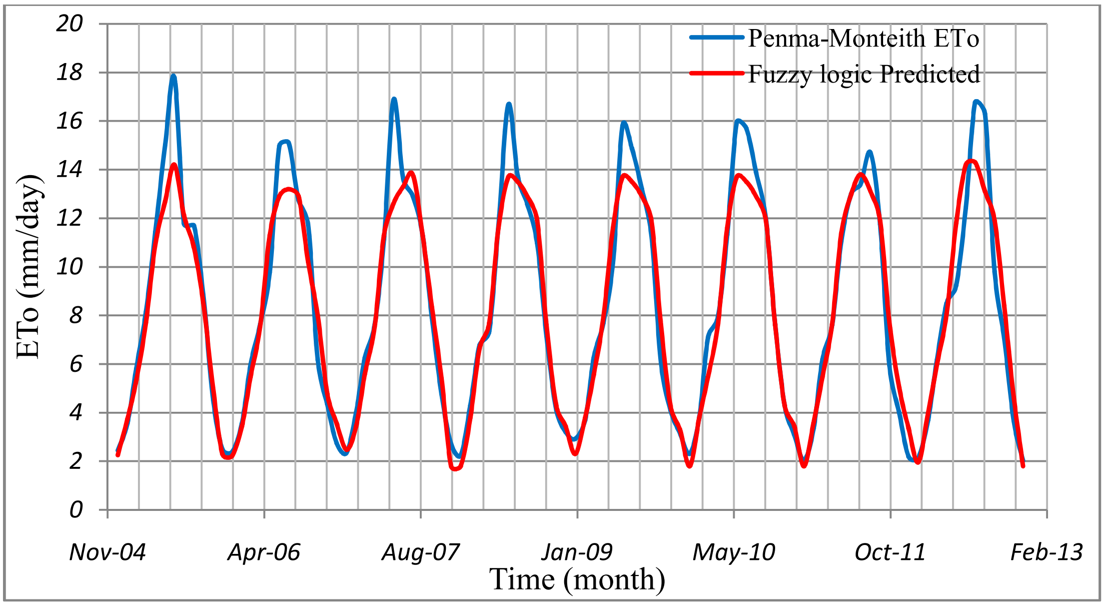


Figure (6) Comparison between standard and predicted ETo, model (1)

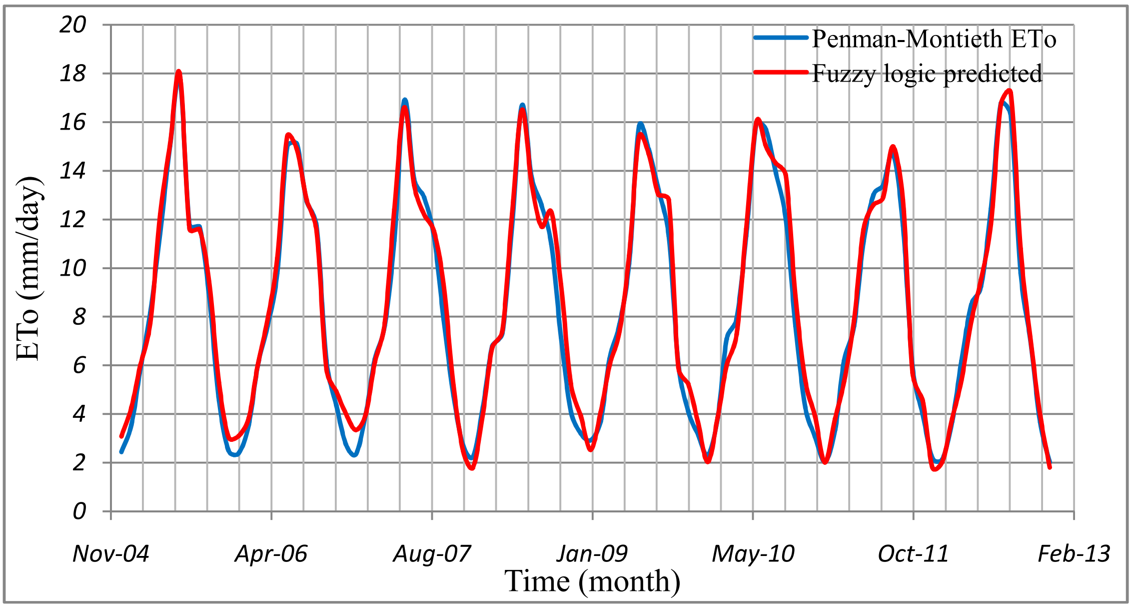


Figure (7)Comparison between standard and predicted ETo, model (2)

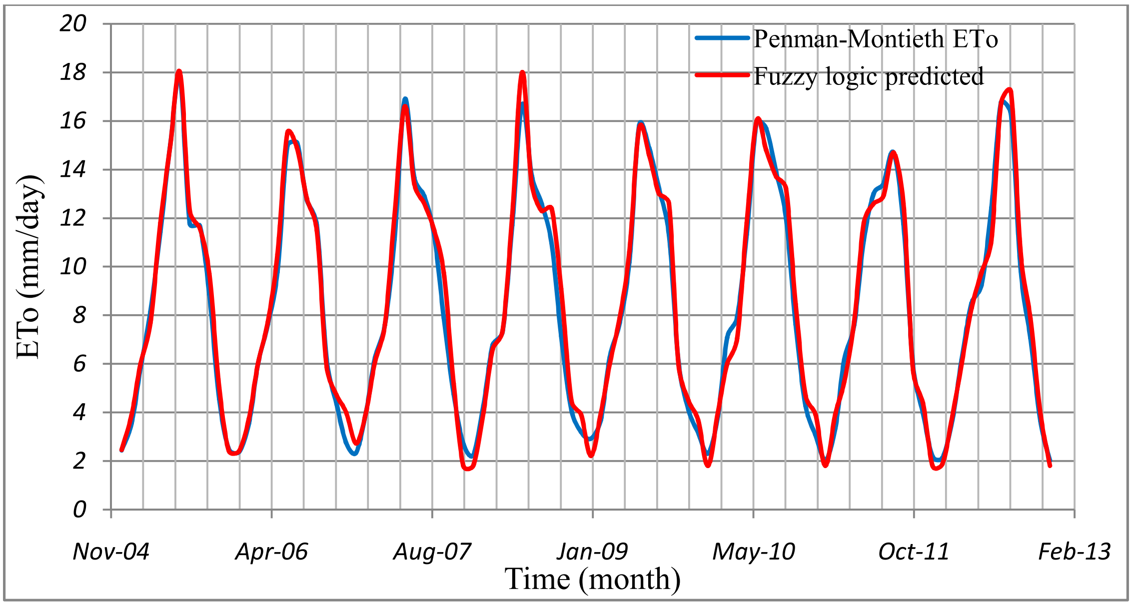


Figure (8) Comparison between standard and predicted ETo, model (3)

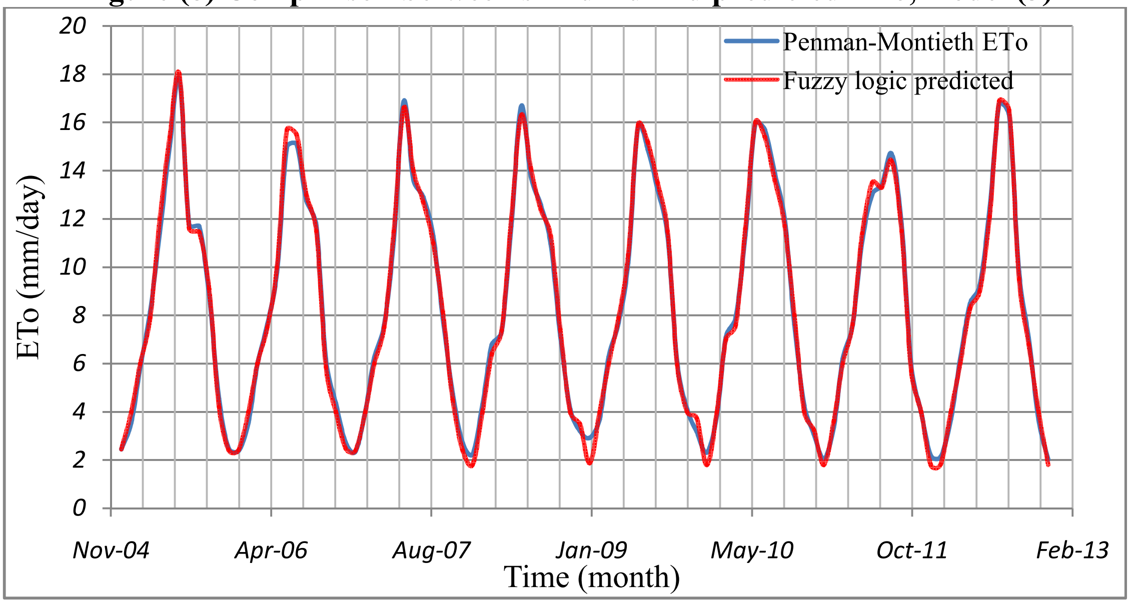


Figure (9) Comparison between standard and predicted ETo, model (4)

Model Number	Statistical parameters	
	RMSE	R^2
M1	1.44	0.94
M2	0.44	0.98
M3	0.38	0.98
M4	0.09	0.98

Table (2) Statistical parameters

7- Conclusion

In this research ,the ability of fuzzy logic theory used for reference evapotranspiration estimation was investigated in BasrahCity. Six variables (mean air temperature, max. temperature, min. temperature, relative humidity, wind speed, and radiation) are used as input data for estimating the ETo. The results of the predictability of fuzzy logic are compared with those of Penman-Monteith method for the four models to validate the model performance based on the statistical parameters (*RMSE* and R^2). The *RMSE* and $R^2$for models No. 2, No.3 and No.4 ranged between 0.44 and 0.094 and between 0.99 and 0.998, respectively. These values indicate the ability of fuzzy logic model to estimate the ETo. Based on that, the best estimation of ETo using fuzzy logic machine learning method can be used for prediction in the future.

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