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A Fuzzy-GAs for Calculating Grass Reference Evapotranspiration

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Abstract: This study proposed a fuzzy sets model for computing ET_0 using only a few basic hydrological parameters including temperature, humidity and wind speed. Genetic algorithm technique was applied to calibrate membership function condition of fuzzy sets model. The proposed model was applied to determine the ET_0 of 5 Meteorological Stations in Thailand. The daily data of the stations were used in the study. Results showed that the fuzzy-GAs model can be used to calculate the ET_0, given only the basic hydrological parameters; temperature, humidity and wind speed. The obtained ET_0 of the proposed model closed to the ET_0 of the accepted Penman-Monteith equation. Furthermore, the results presented that the Genetic algorithm calibration provided the optimal condition of membership function.

Key words: Reference evapotranspiration, penman-monteith, fuzzy set, genetic algorithm, evaporation, crop water requirement

INTRODUCTION

Grass reference evapotranspiration (ET_0) is an important information in irrigation systems planning. ET_0 is defined as the rate of evaporation from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and with adequate water (Allen *et al*., 1998). The grass reference ET_0 is used to calculate crop water requirements by multiplying with crop coefficient (Kc) for planning irrigation systems. Generally, the ET_0 is acceptably calculated by FAO Penman-Monteith equation (Doorenbos and Pruitt, 1977; Jensen *et al*., 1990). This computation of ET_0 is based on sound theoretical reasoning and is obtained by a combination of the energy-balance and mass-transfer approach. The Penman-Monteith's equation requires necessary climatological data such as solar radiation, vapour pressure, duration of bright sunshine, temperature, relative humidity and wind velocity etc. (Irmak *et al*., 2008; Allen *et al*., 2006; Chow *et al*., 2003). Therefore, the lack of necessary climatological data is difficult to obtain the reliable ET_0. In addition, some parameters are difficult to measure and record in small meteorological station. However, these basic hydrological parameters temperature, wind speed and humidity are easily to measure and collect by small meteorology station especially in poor countries. It seem to be more benefit for poor countries, if can use only a few basic hydrological data to estimate the ET_0 by new technique.

A fuzzy set is mathematical theory for describing the interested variables from uncertain factors or variables like daily climatological data such as temperature, wind speed and humidity. The relationship between input and output variables is defined from fuzzy rule, according to human processes in thinking and decision. In addition, fuzzy rules are relatively easy to explain and understand. Recently, the fuzzy model was accepted to describe the relationship of the uncertain variables (Ross, 1995; Shrestha *et al*., 1996; Jairaj and Vedula, 2000; Panigrahi and Mujumda, 2000; Kangrang and Chaleeraktrakoon, 2007; Lu *et al*., 2007). Often, the calibration processes of the fuzzy model were performed by manual adjusting (trial and error) the membership functions and rule bases. Therefore, depending on the result of the human adjustment, it does not guarantee to yield the optimal solution.

A Genetic algorithm (GAs) is search and optimization techniques based on the principles of national selection and genetics. GAs is a robust method for searching for the optimum solution of a complex problem. It can provide the near global optimal solution. The GAs was applied to solve the optimal solution of water resource problems (Goldberg, 1989; Wardlaw and Sharif, 1999; Chang *et al*., 2003; Kangrang and Chleeraktrakoon, 2008; Hormwichian *et al*., 2009). The best part of GAs is that they can handle any type of objective function describing decision variables.

This study thus proposes the fuzzy set model for estimating the ET_0 using only a few basic hydrological

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parameters such as temperature, humidity and wind speed. The genetic algorithm technique is applied to calibrate the membership of the fuzzy model. The FAO Penman-Monteith equation was adopted to compute the ET_o for evaluating the proposed model.

MODEL FORMULATION

The fuzzy sets model and its rule-based system are applied to estimate the ET_o. The input parameters include temperature, wind speed and humidity. The output is ET_o. The steps for working are described as following.

Firstly, the input variables are transformed to the fuzzy variable through the membership function. The number and type of membership functions are constructed based on statistical data and experience of engineers, generally upon the considering problem (Saruwatari and Yomota, 1995; Jang *et al*., 1997). The fuzzy sets with triangular membership functions are used to describe all parameters due to their easy computation.

Secondly, the fuzzy rule bases are created using daily historical data and fuzzy operator. For the historical data of will be presented in the next section. These fuzzy operators including AND and OR are applied to combine the input variables.

Thirdly, the input membership functions and the rule bases are applied to obtain the output membership functions. This step is done by the implication method which obtaining a fuzzy set of output when given a single number of each inputs. Then the output membership functions of each rule are jointed to one output fuzzy set.

Finally, a fuzzy set of output is converted into a single crisp value using the centroid method.

The calculated ET_o from Penman-Monteith equation are used to evaluate the obtained ET_o of the fuzzy model. This formula is described as:

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

where, ET_o is the grass reference evapotranspiration (mm day^{-1}), γ is psychrometric constant (kPa°C^{-1}), Δ is slope vapour pressure curve (kPa°C^{-1}), R_n is net radiation (MJ m^{-2} day^{-1}), G is soil heat flux (MJ m^{-2} day^{-1}), T is mean daily temperature (°C), U_2 is mean wind speed measurement at 2 m. height (m sec^{-1}) and e_a-e_d is vapour pressure deficit (kPa).

The adequacy of the fuzzy model is evaluated by considering the coefficient of determination (R^2) which defined, based on the estimated ET_o as:

$$R^2 = \frac{\left(\sum Em_i Ea_i - n\overline{Em_i}\,\overline{Ea_i}\right)^2}{\left(\sum Em_i^2 - n\overline{Em_i}^2\right)\left(\sum Ea_i^2 - n\overline{Ea_i}^2\right)} \quad (2)$$

where, Em_i is the estimated grass reference evapotranspiration using the Fuzzy model of day i, Ea_i is the calculated grass reference evapotranspiration using the Penman-Monteith equation of day I, $\overline{Em_i}$ and $\overline{Ea_i}$ are, respectively the average of above mentions and n is the number of daily data. The fuzzy model is calibrated by adjusting the membership functions and rule bases using the genetic algorithms technique, these performances will be stopped when the results obtained the highest coefficient of determination (closed to 1.0).

The calibration processes using the genetic algorithm were described as follows. The genetic algorithm requires encoding schemes that transform the decision variables into chromosome. The decision variables were the typical membership function of each type. Figure 1 and Eq. 3 show the typical membership function of triangular type. They present that the decision variables of each membership function for 1 group are a, b and c. These variables were transferred into the chromosome for searching in the process of genetic algorithm:

$$\mu_r(a,b,c) = \begin{cases} 0, & r \le a \\ \frac{r-a}{b-a}, & a \le r \le b; \\ \frac{c-r}{c-b}, & b \le r \le c; \\ 0, & c \le r \end{cases} \quad (3)$$

where, μ_r is membership function of value r for input or output variable (i.e., temperature, humidity and wind speed), μ is membership value of the variable, r is the value of input or output variable.

Then, the genetic operations (reproduction, crossover and mutation) were performed. These genetic operations generated new sets of chromosomes. The objective function of the search was to maximize the coefficient of determination (R^2). This study used population size = 80, crossover probability = 0.9, mutation

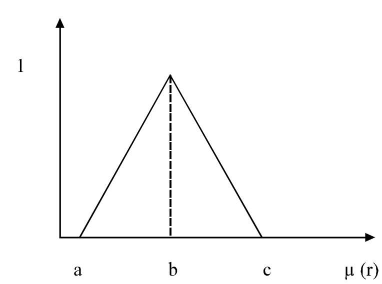

Fig. 1: Typical membership functions of triangular type

probability = 0.01 (Goldberg, 1989). The search will be stopped when obtained the highest coefficient of determination, hence the optimal value of a, b and c was met.

This study considered the numbers of membership function of each parameter from 2 to 4 groups based on the distribution of historical data.

ILLUSTRATIVE APPLICATION

These daily climatological data such as solar radiation, vapour pressure, duration of bright sunshine, temperature, relative humidity and wind velocity etc., of five locations were used in the study. The meteorological stations were Nakhon Sawan, Chiang Rai, Chiang Mai, Phitsanulok and Phetchabun (in the Central and Northern regions of Thailand). These data were used to compute the Et_0 by the Penman-Monteith equation, only temperature, relative humidity and wind velocity were used in the proposed model.

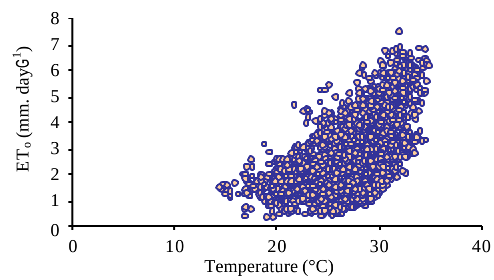

Fig. 2: Temperature and ET_0 of Penman-Monteith

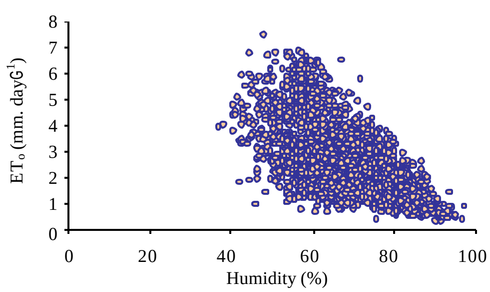

Fig. 3: Humidity and ET_0 of Penman-Monteith

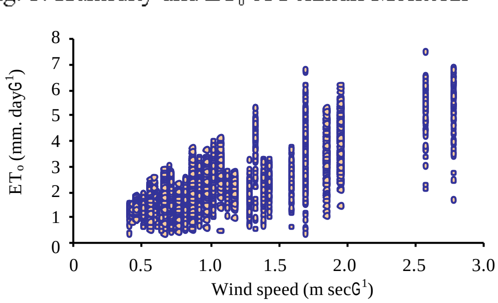

Fig. 4: Wind speed and ET_0 of Penman-Monteith

Figure 2 shows relationship between ET_0 of Penman-Monteith equation and temperature for five locations during 1993-1995. Figure 3 shows relationship between ET_0 of Penman-Monteith equation and humidity. Figure 4 shows relationship between ET_0 of Penman-Monteith equation and wind speed. They indicate that the temperature during 15-35°C affects to the ET_0 and high temperature influences to high ET_0. While the humidity about 50-60% persuades to high ET_0. For the wind speed values are varying during 0.5-2.5 m sec^{-1} and high wind speed affects to high ET_0. These data are used to set the initial membership function and rule base of fuzzy model.

Table 1 shows an example of fuzzy rule bases using AND and OR operators such as If the medium temperature AND the low humidity AND high wind speed THEN the ET_0 is high, If the medium temperature AND the low humidity AND low wind speed THEN the ET_0 is low. There are eighteen rule bases. These rule bases were used to construct the relationship between input and output parameters.

RESULTS AND DISCUSSION

Table 2 presents the coefficient of determination of several membership functions using the GAs calibration which the number of temperature group of 2 and the number of other parameters are 2, 3 and 4. It indicated that the range of R^2 is 0.803 for 2-2-3-2 to 0.932 for 2-4-3-4. Table 3 presents the coefficient of determination of several membership functions using the GAs calibration which the number of temperature group of

Table 1: Example of fuzzy rule bases for estimating ET_0

No.	IF Temperature	AND Humidity	AND Wind speed	THEN ET_0
1	Low	Low	Low	Low
2	Low	Low	Medium	Medium
3	Low	Low	High	Medium
4	Low	Medium	Low	Low
5	Low	Medium	Medium	Low
6	Low	Medium	High	Medium
7	Low	High	Low	Low
8	Low	High	Medium	Low
9	Low	High	High	Low
10	Medium	Low	Low	Low
11	Medium	Low	Medium	Medium
12	Medium	Low	High	High
13	Medium	Medium	Low	Low
14	Medium	Medium	Medium	Medium
15	Medium	Medium	High	High
16	Medium	High	Low	Low
17	Medium	High	Medium	Low
18	Medium	High	High	Medium

Table 2: Membership function numbers and R^2 (the number of Temperature group = 2)

No. of membership function				
Temperature	Humidity	Win speed	ET_0	R^2
2	2	2	2	0.882
2	2	2	3	0.890
2	2	2	4	0.855
2	2	3	2	0.803
2	2	3	3	0.863
2	2	3	4	0.871
2	2	4	2	0.858
2	2	4	3	0.839
2	2	4	4	0.835
2	3	2	2	0.869
2	3	2	3	0.872
2	3	2	4	0.853
2	3	3	2	0.896
2	3	3	3	0.812
2	3	3	4	0.878
2	3	4	2	0.912
2	3	4	3	0.855
2	3	4	4	0.891
2	4	2	2	0.888
2	4	2	3	0.845
2	4	2	4	0.855
2	4	3	2	0.902
2	4	3	3	0.873
2	4	3	4	0.932
2	4	4	2	0.848
2	4	4	3	0.851
2	4	4	4	0.877

Table 3: Membership function numbers and R^2 (the number of Temperature group = 3)

No. of membership function				
Temperature	Humidity	Win speed	ET_0	R^2
3	2	2	2	0.826
3	2	2	3	0.853
3	2	2	4	0.851
3	2	3	2	0.832
3	2	3	3	0.889
3	2	3	4	0.886
3	2	4	2	0.855
3	2	4	3	0.823
3	2	4	4	0.837
3	3	2	2	0.866
3	3	2	3	0.895
3	3	2	4	0.846
3	3	3	2	0.945
3	3	3	3	0.992*
3	3	3	4	0.969
3	3	4	2	0.863
3	3	4	3	0.955
3	3	4	4	0.916
3	4	2	2	0.886
3	4	2	3	0.945
3	4	2	4	0.955
3	4	3	2	0.926
3	4	3	3	0.873
3	4	3	4	0.974
3	4	4	2	0.885
3	4	4	3	0.857
3	4	4	4	0.895

*The optimal value of the search using GA

3 and the number of other parameters are 2, 3 and 4. They present that the lowest of R^2 is 0.826 for 3-2-2-2 and the highest of R^2 is 0.992 for 3-3-3-3 according the previous study (Kangrang and Chaleeraktrakoon, 2007). Table 4 presents the coefficient of determination of several membership functions using the GAs calibration which the number of temperature group of 4. It indicated that the range of R^2 is 0.832 to 0.976. These results found that the optimal number and shape of membership functions give the highest coefficient of determination. Hence, this condition is accepted to calculate the ET_0 according to the concept of Goldberg (1989). However, this accepted model is necessary to validate with other data for evaluating the performance of the model.

Table 4: Membership function numbers and R^2 (the number of Temperature group = 4)

No. of membership function				
Temperature	Humidity	Win speed	ET_0	R^2
4	2	2	2	0.888
4	2	2	3	0.832
4	2	2	4	0.857
4	2	3	2	0.845
4	2	3	3	0.869
4	2	3	4	0.942
4	2	4	2	0.955
4	2	4	3	0.839
4	2	4	4	0.834
4	3	2	2	0.899
4	3	2	3	0.900
4	3	2	4	0.853
4	3	3	2	0.896
4	3	3	3	0.963
4	3	3	4	0.978
4	3	4	2	0.912
4	3	4	3	0.967
4	3	4	4	0.976
4	4	2	2	0.976
4	4	2	3	0.966
4	4	2	4	0.936
4	4	3	2	0.902
4	4	3	3	0.873
4	4	3	4	0.942
4	4	4	2	0.848
4	4	4	3	0.855
4	4	4	4	0.879

The accepted model was further validated using climatological data which were not considered (2002) in calibrating process. These data of five stations were used to calculate the ET_0 by the Penman-Monteith equation and the proposed model. Figure 5 shows the calculation of ET_0 computed by Penman-Monteith equation compared against the daily ET_0 calculations using the fuzzy-GAs model of Nakhon Sawan, Chiang Rai, Chiang Mai, Phitsanulok and Phetchabun respectively. They indicate that calculations by two methods are linear with each another, with R^2 higher than 0.9117. Figure 6 presents the calculation of 120-day Et_0 computed by the Penman-Monteith equation and the fuzzy-GAs model. It indicates that the ET_0 of both method are similar with the standard error of the estimate (SEE) 0.154 mm day^{-1}. In summary, the proposed fuzzy-GAs model can use to

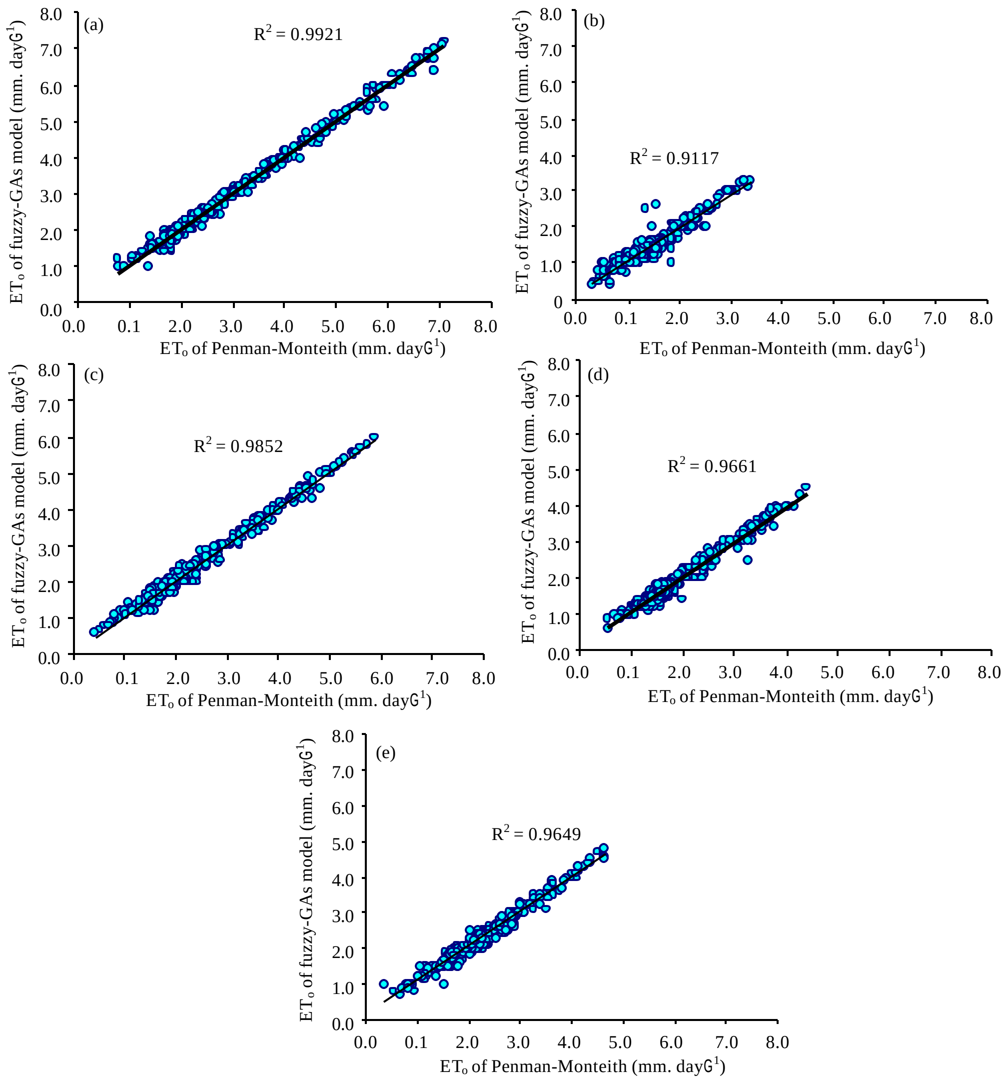

Fig. 5: Calculation of ET_o computed by Penman-Monteith equation compared against the daily ET_o calculations using the fuzzy-GAs model

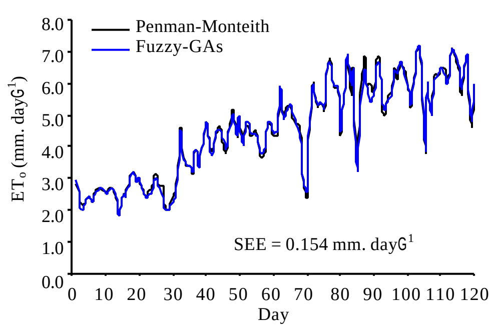

Fig. 6: Calculation of 120-day ET_o computed by the Penman-Monteith equation and the fuzzy-GAs model

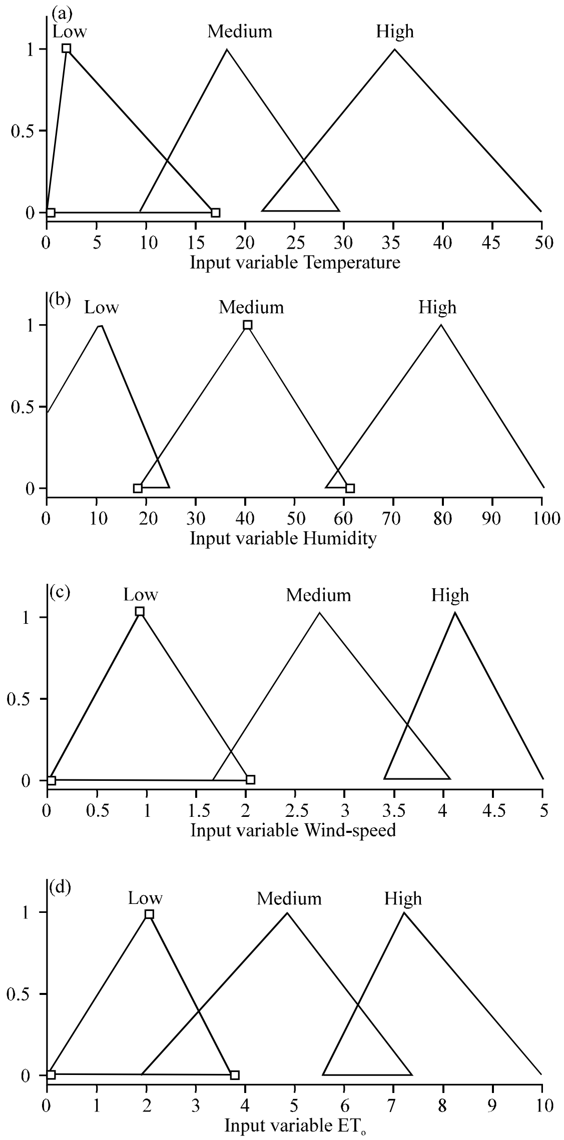

Fig. 7: The optimal Triangular membership functions of the input and output variables for the number 3-3-3-3

calculate the ET_0 that closed to the ET_0 of Penman-Monteith equation (Irmak *et al*., 2008; Allen *et al*., 2006; Chow *et al*., 2003).

Figure 7 shows the optimal Triangular membership functions of the input and output variables for the number 3-3-3-3 using GAs technique. It indicates that triangular membership function is suitable to apply in this study.

CONCLUSIONS

This study applied a fuzzy model for estimating the ET_0. Genetic algorithm technique was used to calibrate membership function condition of fuzzy sets model. The applied model using only a few basic hydrological parameters including temperature, humidity and wind speed. The model was applied to determine the ET_0 of five Meteorological Stations (in the Central and the Northern region of Thailand). The daily data (1993-1995 and 2002) of the Stations were used in the study. Results showed that the fuzzy-GAs model can be used to estimate the ET_0, given only the basic hydrological parameters; temperature, humidity and wind speed. The obtained ET_0 of the proposed model is close to the ET_0 of the Penman-Monteith equation. Furthermore, the results presented that the Genetic algorithm calibration provided the optimal condition of membership function. In summary, a few basic hydrological data can provide the ET_0 in some area which insufficient climatological data.

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