RESEARCH ARTICLE

ESTIMATION OF REFERENCE EVAPOTRANSPIRATION USING FUZZY LOGIC WITH GRID PARTITION MODEL

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Abstract: The study was conducted to evaluate performance of fuzzy logic (FL) models to estimate reference evapotranspiration (ET_0) for semi-arid region of Haryana state and results were compared against standard FAO Penman-Monteith method. 10 years data (2009-2018) consisted of maximum temperature, minimum temperature, relative humidity; wind speed and sun shine hours was acquired from the Meteorological observatory at CCS HAU Hisar. FL with grid partition and eight membership functions, two optimization methods and two output types were evaluated to reach at the best performance. The models output were evaluated using four different statistical parameters viz. root mean square error (RMSE), correlation coefficient (R) and model efficiency (ME). Performance for FL with grid partition was found best with hybrid optimization, linear type output and triangular membership function with RMSE, R, R2 and ME values of 0.314, 0.984, 0.969 and 0.967 respectively Study outcome recommends FL with grid partition as a handy tool in quick and accurate prediction of reference evapotranspiration.

Keywords: Evapotranspiration, Penman-Monteith, Fuzzy logic, Training method, Grid partition

INTRODUCTION

Evapotranspiration is one of the most important components of the hydrological cycle, and its prediction is an important task in agriculture and water resource management, especially in semiarid and arid regions. Over the time, FAO Penman-Monteith method (Allen *et al*., 1998) which has been accepted as standard method for reference evapotranspiration (ET_0) and is widely used to calibrate, validate and evaluate other methods for estimation of evapotranspiration. However, the calculations of FAO Penman-Monteith procedure are very tedious and time consuming, therefore restricts its use limited to only researchers. Since the physical processes associated with evaporation are highly nonlinear (Kisi, 2007), reliable predictive models must be able to address the nonlinearities associated with the evapotranspiration and its related input datasets.

Fuzzy logic is an effective tool for handling the ambiguity and uncertainty of the real world systems and requires fewer inputs. Fuzzy rule based systems provide an effective way to capture the approximate nature of the real world processes, due to the rule formation. Fuzzy rule systems have been used successfully in reservoir management (Panigrahi & Mujumdar, 2000), rainfall-runoff problems (Nayak *et al*., 2005) and in parameters of groundwater flow (Moutsopoulos *et al*., 2005; Chalkidis *et al*., 2006). Considering the limited irrigation facility, uneven and ill-distributed rainfall and possibility of draught in the semi-arid region of Haryana, accurate estimation of evapotranspiration is highly desirable. In view of these study on estimation of reference evapotranspiration using fuzzy logic models for semi-arid region of Haryana was conducted so that a very flexible but accurate method for evapotranspiration estimation so that a handy tool could be made available to the developmental agencies involved in planning and utilization of water resources in the region

REVIEW OF LITERATURE

Singh *et al*. (2013) predicted evapotranspiration using fuzzy logic based algorithm with weather data set for Nagini watershed, located in Tehri Garhwal district (Uttarakhand), India. The evapotranspiration predicted by fuzzy logic rule based algorithm was found to be comparable with the evapotranspiration estimation by FAO Penman-Monteith method. The developed model was validated by testing its performance using correlation coefficient (R = 0.92) and root mean square error (RMSE = 0.51). Mamak *et al*. (2017) estimated the daily evapotranspiration using an empirical method and fuzzy logic model in St. Johns FL, USA region. They used climatic variable which effects evapotranspiration as directly or indirectly such as minimum and maximum temperature, solar radiation, wind speed and relative humidity. In this study author predicted evapotranspiration by using fuzzy logic model and results were compared with FAO Penman-Monteith methods. 1158 data were trained and 358 data were used in testing the fuzzy logic model. Coefficients of determination for daily observed evapotranspiration were found as 0.909 for fuzzy logic model. Maroufpoor *et al*. (2018) in their study used three artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS) and gene expression programming (GEP), to estimate evaporation losses The ANFIS model (with RMSE = 1.64% and R^2 = 0.94) performed better than ANN model

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(with RMSE = 2.56% and R^2 = 0.87). Laaboudi & Slama (2020) estimated daily reference evapotranspiration in arid region of Algeria, using Fuzzy Inference System (FIS) results obtained by the best FIS model were 0.98, 0.27, 0.36 and 5.52 respectively for R, MAE, RMSE and MARE. The findings of the present research would help managers, engineers, and decision makers to sustainability manage natural water resources in warm-arid regions.

MATERIALS AND METHODS

For development of the fuzzy logic model and its performance evaluation, 10 years data (2009-2018) is acquired from the Meteorological observatory at CCS HAU Hisar consisting of maximum temperature (T_{max}), minimum temperature (T_{min}), relative humidity (RH); wind speed (WS) and sunshine hours (SH) from the observatory were collected and arranged for analysis. A substantial part of data should be used for model development and improvement process (Sarangi *et al.*, 2005), accordingly, out of total 3652 days data, 85 per cent data is utilized for model training (1-3104 days) and remaining 15 per cent for testing phase (3105-3652 days).

FAO Penman-Monteith ET_0

Reference evapotranspiration (ET_0) was calculated using the reference FAO Penman-Monteith equation (Allen *et al*. 1998). This method was derived from the original Penman–Monteith equation and the equations of the aerodynamic and surface resistance in form of following equation:

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T_a + 273}\,u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

where,

ET_0 = Reference evapotranspiration [mm day^{-1}]
R_n = Net radiation [MJ m^{-2} day^{-1}]
G = Soil heat flux density [MJ m^{-2} day^{-1}]
T_a = Average daily air temperature at 2 m height [°C]
u_2 = Wind speed at 2 m height [m s^{-1}]
e_s = Saturation vapour pressure [kPa]
e_a = Actual vapour pressure [kPa]
e_s - e_a = Saturation vapour pressure deficit [kPa]
Δ = Slope of the vapour pressure curve [kPa °C^{-1}]
Γ = Psychrometric constant [kPa °C^{-1}]

The monthly average values of FAO PM calculated ET_0 varied from 1.64 mm/day in January to 7.92 mm/day in June for the period 2009-2018. The standard deviation in monthly average of reference evapotranspiration varied from 0.23 mm/day in December to 0.60 mm/day in March.

Fuzzy-logic structure

Fuzzy logic operates on mathematical entities that are fuzzy sets, which obey rules, structures and axioms similar to those of classical logic. Belonging to a subset, in fuzzy logic, is associated with a degree of membership. The set of deduction rules to be applied to a given system to achieve results through the use of fuzzy logic is the fuzzy inference process. Fuzzy inference is divided into three main phases: fuzzification, inference and defuzzification.

The fuzzification is the process by which the input variables are converted to fuzzy measures of their belonging to certain classes (such as, for example, Very Low, Low, Medium, High, Very High). This conversion from deterministic greatness to fuzzy greatness is done through membership functions.

A membership function is a function that associates a value, usually numeric, to the degree of membership. By convention, the degree of membership assumes values ranging from zero, when the element does not belong to the subset, to one, when it belongs entirely to the subset. Fuzzy inference is the mapping process, starting from an input space and going to an output space. In order to obtain an output, the fuzzy rules needs to be assigned which integrate fuzzy sets through a series of antecedents and consequents.

The Grid Partition is the most commonly used fuzzy partitioning methods in practice. The grid partition produces an input variable partition where each rule has a zero coefficient on its output. In this method, the input data space is divided into rectangular subspace using an axis-paralleled partition and each input is partitioned into identically shaped membership functions. Various fuzzy logic models tried for this study were constituted with two optimization (Hybrid or Back propagation), two output type (linear or constant) and eight membership functions (trimf, trapmf, gbellmf, gaussmf, gauss2mf, pimf, dsigmf and psigmf).

Model performance criteria

Three different statistical parameters viz. Root Mean Square Error (RMSE), Correlation Coefficient (R) and Model Efficiency (ME) were used for testing the performance of FL for their capabilities in estimation of reference evapotranspiration based on climatic data.

RESULTS AND DISCUSSION

Performance of FL with grid partition for estimation of reference evapotranspiration has been presented in Table 1.

Table 1. Performance of FL with grid partition

Membership function type	Hybrid						Back propagation					
	Linear			Constant			Linear			Constant		
	RMSE	R	ME	RMSE	R	ME	RMSE	R	ME	RMSE	R	ME
trimf	**0.325**	**0.987**	**0.974**	0.327	0.987	0.974	0.328	0.987	0.974	0.331	0.987	0.973
trapmg	0.362	0.984	0.968	0.750	0.939	0.855	0.388	0.982	0.963	0.755	0.943	0.857
gbellmf	0.338	0.986	0.972	0.482	0.974	0.942	0.357	0.985	0.969	0.485	0.975	0.945
gaussmf	0.335	0.986	0.972	0.384	0.983	0.964	0.355	0.985	0.970	0.386	0.983	0.963
gauss2mf	0.451	0.976	0.952	0.690	0.949	0.879	0.535	0.967	0.935	0.695	0.951	0.884
pimf	0.403	0.980	0.961	0.882	0.916	0.803	0.587	0.958	0.916	0.886	0.924	0.808
dsigmf	0.423	0.979	0.958	0.799	0.938	0.848	0.466	0.974	0.947	0.679	0.950	0.885
psigmf	0.598	0.956	0.905	0.827	0.928	0.829	0.672	0.950	0.902	0.799	0.938	0.848

Performance for FL with grid partition was found best with hybrid optimization, linear type output and triangular membership function having RMSE, R and ME values of 0.325, 0.987 and 0.974 respectively while worst performance was found with back propagation optimization, constant type output and pi membership function having RMSE, R and ME values of 0.886, 0.924 and 0.808 respectively. The regression plot of best FL with grid partition has been presented in Fig 1. The predicted verses measured evapotranspiration values are scattered close to the 45^0 line, indicating the good performance of the model.

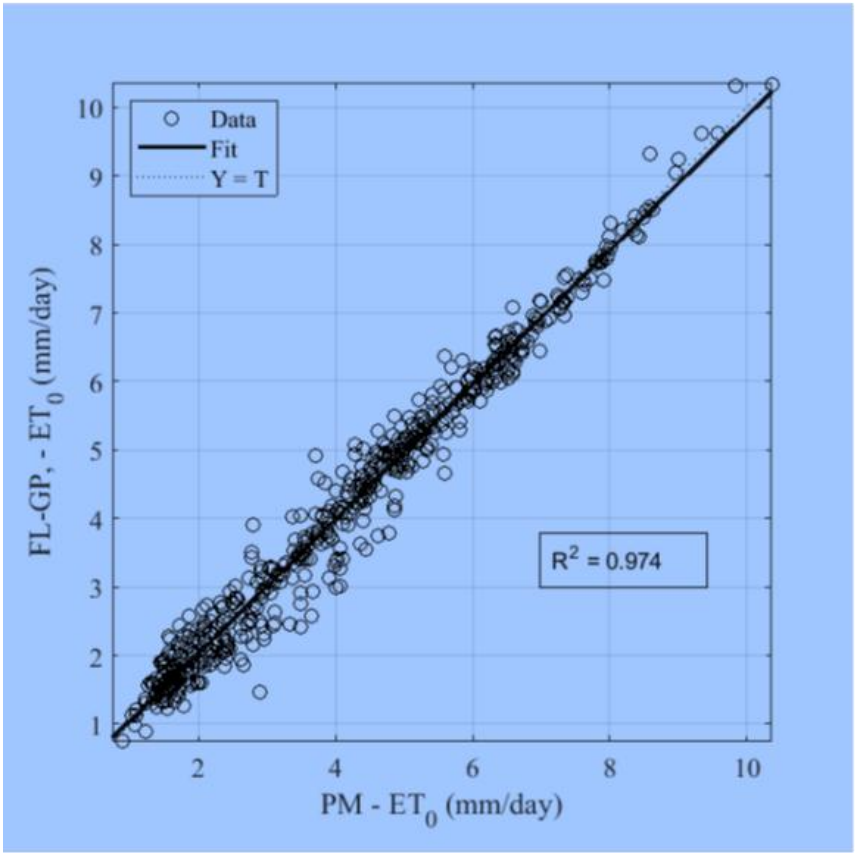

Fig. 1: Scatter plot of FL- GP predicted and PM calculated ET_0

Error plot of FL estimation

Error plot of best FL (grid partition with hybrid optimization, liner output type and triangular membership function) is presented in Fig. 2. The absolute error varied from 0.009 mm/day to 1.3944 mm/day, with mean value of 0.2520 mm/ day and standard deviation of 0.2230 mm/day.

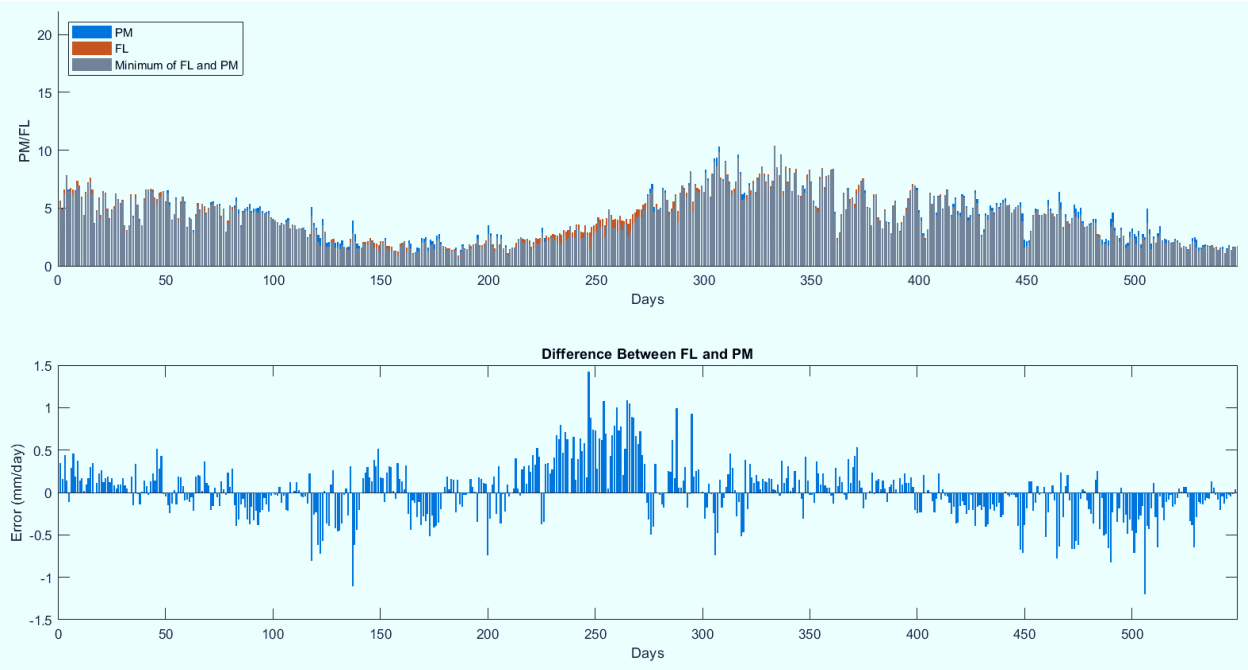

Fig. 2: Error plot of FL- GP predicted and PM calculated ET_0

CONCLUSIONS

Among the 8 different kind of membership functions, triangular membership function exhibited highest performance while pi membership function shoed lowest performance for estimation of reference evapotranspiration. Variation of triangular membership function was also found lowest among both optimization method (hybrid and back propagation) and output type (linear and constant) whereas the pi membership function results exhibited maximum variation with respect to optimization method and output type. For all kind of membership functions, hybrid optimization method produced better results (lower RMSE) than the back propagation optimization. Similarly among both kind of optimization, the linear type output exhibited better performance (lower RMSE) than the constant type output. Overall fuzzy logic models with grid partition executed very good performance in estimation of the reference evapotranspiration in semi-arid climate of Haryana and can be recommended as a handy tool in quick and accurate prediction of reference evapotranspiration.

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