ECALTOOL: fuzzy logic based computer program to calibrate the Hargreaves equation for accurate estimation of evapotranspiration

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Abstract: A reference evapotranspiration rate (ET_0) is vital information for irrigation scheduling as well as plant growth modeling. Estimation of evapotranspiration using environmental variables is a convenient approach compare to direct measurement. Several mathematical models have been proposed for the estimation of ET_0. Among all these, the Hargreaves equation has received maximum attention of the agricultural fraternity as it needs minimum weather data. However, requirement of minimal weather data in the Hargreaves equation makes it a simple and pragmatic model for estimation of ET_0. The minimalist approach makes the equation incapable to estimate ET_0 accurately under extreme weather conditions. The calibration or adjustment of the Hargreaves equation parameter C_H and E_H for different climate conditions is well accepted approach to accomplish error free estimation from the equation. The establish calibration methods are empirical and time consuming. Further, the results obtained by these methods are valid only for the restricted area and season only. This paper presents Evapotranspiration CALibration TOOL (ECALTOOL), which is a fuzzy based universal computer program developed on the platform of NI LabVIEW to calibrate C_H and E_H. The key features of the tool are its ability to provide calibration of ET_0 for 1100 locations of 190 countries, and its user friendliness. The performance of the tool is compared and validated against the benchmark Penman-Monteith equation as well as the experimentally calibrated values for various locations with diverse climate conditions. Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) is in the range of 0.4856 – 1.1562 and 1.21%– 2.06% respectively. The calibrated values of C_H and E_H are proved to be accurate in comparison with experimentally carried out calibration. The developed tool eliminates the need of location specific experimental calibration process for the Hargreaves equation.

Keywords: evapotranspiration, fuzzy logic, Hargreaves equation, LabVIEW

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1 Introduction

A reference evapotranspiration rate (ET_0) is a very significant parameter in agriculture science. It indicates the water consumption of the plant. So, it plays an important role in irrigation scheduling as well as plant growth modeling. Due to difficulty in direct measurements of evapotranspiration, estimation of evapotranspiration with the help of the atmospheric variables is proposed by many researchers. Comparison between ET_0 measured by lysimeter and ET_0 estimated by eight different equations under humid condition is well presented (Yoder et al. 2005).

Comparison of various models of evapotranspiration rate for different locations is available in the literature (Wang et al. 2011), (Martinez & Thepadia, 2010), (Xing et al. 2008). Penman-Monteith (PM) equation is the most accurate method among all. It is adopted as a benchmark method for the estimation of evapotranspiration by Food and Agriculture Organization

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(FAO), and other organizations (Allen et al. 1998). Although FAO-56 PM is a highly accurate method but could not become practically useful for irrigation scheduling purpose as it needs as many as six atmospheric variables - solar radiation, wind speed, air temperature, humidity data, vapor pressure and soil heat flux. It is not possible that all these variables are available at weather stations.

Accurate estimation of evapotranspiration rate with limited weather data is yet an open scientific challenge. History of the development of equations for ET_0 estimation is quite comprehensive (Farahani et al. 2007). Among all other methods, the Hargreaves equation has generated the highest attention (Hargreaves & Allen, 2003). This is because it needs minimum weather data. These are maximum day temperature, T_{max}, minimum day temperature, T_{min} and extraterrestrial solar radiation, R_a. These data are normally available at most of the weather stations. The relation is shown in Equation (1) (Hargreaves & Allen, 2003).

$$ET_0 = C_H (T_{max} - T_{min})^{E_H} (T_{mean} + 17.8) R_a \qquad (1)$$

Under the nominal climate condition, values of constants C_H and E_H are proposed as 0.0023 and 0.5 respectively.

Limited weather data based methods shows considerable inconsistency and inaccuracy in the estimation of the ET_0 (Jianbiao et al. 2005). Particularly, the Hargreaves equation is incapable to accurately estimate the ET_0 under extreme weather conditions. It overestimates for hot and humid conditions (Subburayan et al. 2011). In case of windy location the Hargreaves equation underestimate ET_0 (Martinez-Cob & Tejero-Juste, 2004). Error in the ET_0 estimation using the Hargreaves equation under non-ideal climate condition is reported by many authors for different climate conditions (D.T.Jensen et al. 1997) and (Geroge, 1989). As presented in the chronological evolution of Hargreaves equation (Hargreaves & Allen, 2003); it is reported that the effect of humidity, cloudy condition and wind gust is indirectly considered in the Hargreaves equation. As these effects are not considered explicitly, the Hargreaves equation does not provide accurate estimates of the ET_0 in extreme weather condition. The calibration of C_H and E_H values [Equation (1)] for different climate conditions is accepted approach to accomplish error free estimation from the Hargreaves equation.

Large number of endeavors found in the literature on calibration of the Hargreaves equation. Location specific calibration of C_H and E_H are presented for different climate conditions like arid and cold (Tabari & Talaee, 2011), cold and humid (Ravazzani et al. 2012), semiarid (Mohawesh, 2011), humid (Ruiz-Canales et al. 2012) and different locations like high and low elevation (Ravazzani et al. 2012) and coastal and inland (Mendicino & Senatore, 2012).

The calibration methods published are based on lengthy experimental procedure. Each one of these is valid for confined location only. Even this calibration is only valid for the specific season of that location. The experimental calibration method is not a suitable approach. This has motivated many researchers to apply fuzzy, Neuro -fuzzy, genetic, support vector machines (SVM), adaptive Neuro-fuzzy inference system (ANFIS) and multiple linear and nonlinear regression methods for accurate estimation of ET_0 (Shiri, et al., 2012), (Hossein, et al. 2012), (Cobaner, 2011), (Gocic & Trajkovic, 2011). Above approaches involve complex mathematics, require a computation tool to make it useful, and are location specific. There is a need for user friendly, universal software program which is capable to estimate ET_0 accurately with minimum weather data. The proposed tool - ECALTOOL is a solution to this problem. The tool has required features like - ease of use and universal applicability. These make the ECALTOOL distinct from other such endeavors. ECALTOOL is a fuzzy based universal computer software to calibrate C_H and E_H. It is the acronym of Evapotranspiration CALibration TOOL. ECALTOOL is an open software tool for the researchers and professionals working in the field of agricultural science. It eliminates the need of location specific and lengthy calibration process for the Hargreaves equation. The tool is capable to obtain appropriate values of C_H and E_H of the Hargreaves equation for almost any location of the world. It is developed on National Instrument's programming software platform LabVIEW (National Instruments, 2012).

The calibration of C_H and E_H improves the accuracy of estimation of evapotranspiration using the Hargreaves equation. A Fuzzy Inference System (FIS) is developed to find out accurate C_H and E_H values. The FIS needs only few past data of humidity, wind velocity and temperature to typify the location. Typically these data are available at most of the weather stations. The block diagram is shown in Figure 1. The proposed generalized approach abolishes the need of location specific calibration methods. Development of the fuzzy ruled base discussed in the next section with more details.

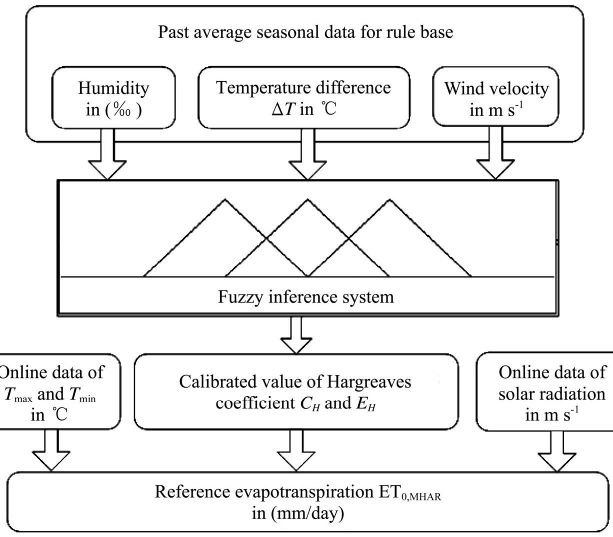

Figure 1 Block diagram representation of Fuzzy Inference System (FIS)

2 ECALTOOL - Fuzzy based Tool

The main part of the tool is the Fuzzy Inference System (FIS). FIS is used to derive modified value of Hargreaves constants C_H and E_H depending upon the type of the location i.e. arid, semiarid, humid, semi humid, cold, etc. The fuzzy rules are developed on the basis of the enormous research work done on localized calibration of C_H and E_H (Patel et al. 2014). To obtain C_H value three input variables are used. These are humidity (5 levels: Dry, Moderate Humid, Medium Humid, Humid and Very Humid), temperature difference between the highest and the lowest day temperature (5 levels: Very low, Low, Medium, High and Very High) and wind velocity (4 levels: Very Low, Low, High and Very High). While two variables – humidity (5 levels: Dry, Moderate Humid, Medium Humid, Humid and Very Humid) and the temperature difference (5 levels: Very low, Low, Medium, High and Very High) are used in FIS to find out E_H. The levels of input are represented in linguistic variable like very high, high, low, very low, etc., Fuzzy rule based is developed on the basis of the influence of these variables on value of C_H and E_H. (Patel et al. 2014). Hundred (100) rules are used in FIS for C_H and Twenty five (25) rules are used in FIS for E_H. Membership functions for input and output variables are shown in Figure 2 and 3 respectively.

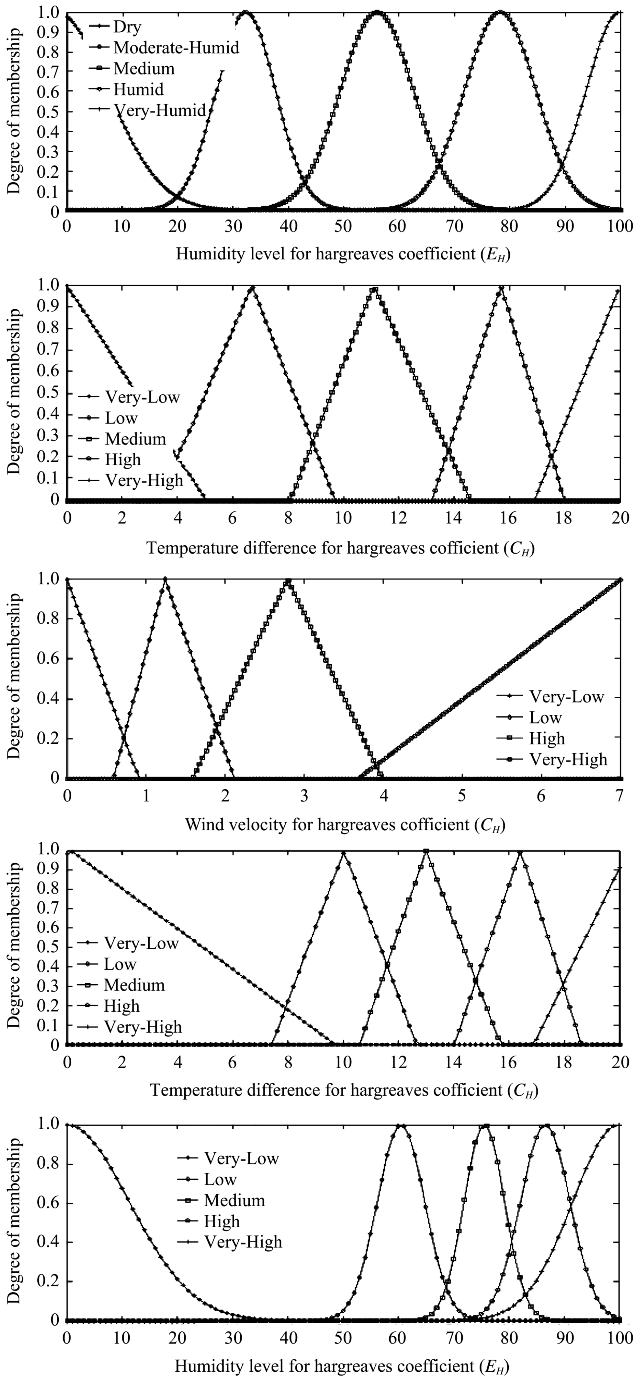

Figure 2 Membership functions of input variables–humidity, temperature difference and wind velocity

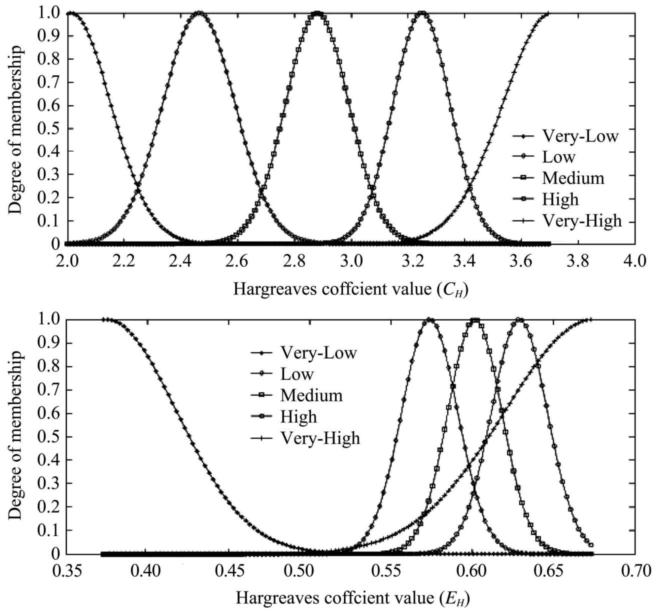

Figure 3 Membership functions of output variables C_H and E_H

The graphic panel of the tool comprises of two options as shown in Figure 4. The first option is for C_H and E_H calibration of the location available in the tool library. There are about 1100 locations of 190 countries available in the built in library. Required data of the minimum temperature, maximum temperature, humidity, solar radiation, wind velocity, and humidity of the locations are taken from CLIMWAT (Martin, 1993).

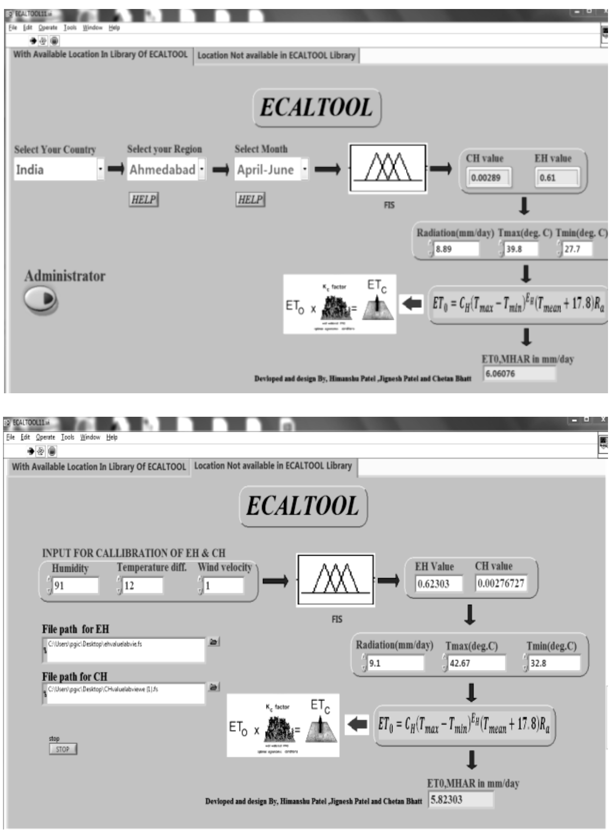

Figure 4 GUI panel view of ECALTOOL

The user only needs to select the country, the region and the months to get calibrated value of C_H and E_H. It also provides the value of reference evapotranspiration (ET_0) with this calibrated value of C_H and E_H using the Hargreaves equation. If the location is not available in the library, then the user needs to select the second option: "Location not available in ECALTOOL library". The user needs to provide humidity in %, maximum and minimum temperature difference of the day in °C and Wind velocity in m/Sec data (Only single value) of the particular location.

3 Discussion

To validate the proposed tool, experimental calibration work for diverse climate conditions like arid and cold (Bam- Iran), cold and humid (Pallanza-Italy), semi arid (Amman airport-Jordan) and humid (Madrid-Spain) are considered. An experimental calibration of C_H and E_H are accomplished for different locations by various researchers as shown in Table 1.

Table 1 Comparison of ECALTOOL and experimental based calibration of C_H and E_H

Author and year	Location	Empirical calibration by author		Calibrated using ECALTOOL	
		C_H	E_H	C_H	E_H
Tabari and Talaee (2011)	Bam (Iran)	0.0035	0.5*	0.00337	0.5697
Ravazz-ani et al. (2012)	Pallanza (Italy)	0.0023*	0.424	0.00257	0.5615
O.E. Moha-wesh (2011)	Amman airport (Jordan)	0.0030	0.4	0.00294	0.5591
A. Ruiz-Canales et al. (2010)	Madrid (Spain)	0.00256	0.5*	0.00263	0.5631

Note: * Not considered for the calibration by the author..

A comparison of C_H and E_H values suggested on the basis of experimental work with the values achieve using ECALTOOL is presented. The result confirms the proper functionality of the tool. In addition to this, ET_0 estimation using experimentally calibrated values of C_H and E_H and ECALTOOL based values for different locations are compared. The comparison is shown in Figure 5. In this comparison, ET_0 estimation by FAO-Penman-Monteith (PM) is taken as benchmark values. ET_0 estimation by Modified Hargreaves (MHAR) with experimental calibration and ECALTOOL based calibration is compared with PM based estimated value of ET_0. The locations and values for C_H and E_H are taken as shown in Table 1. The result shows better accuracy with ECALTOOL based calibration. Error estimation is also carried out for the given comparison. Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) for both the estimation of ET_0 in comparison with Penman-Monteith (PM) is carried out and presented in Table 2. The range of MAE is 0.4856 – 1.1562 and MAPE is 1.21% – 2.06%.

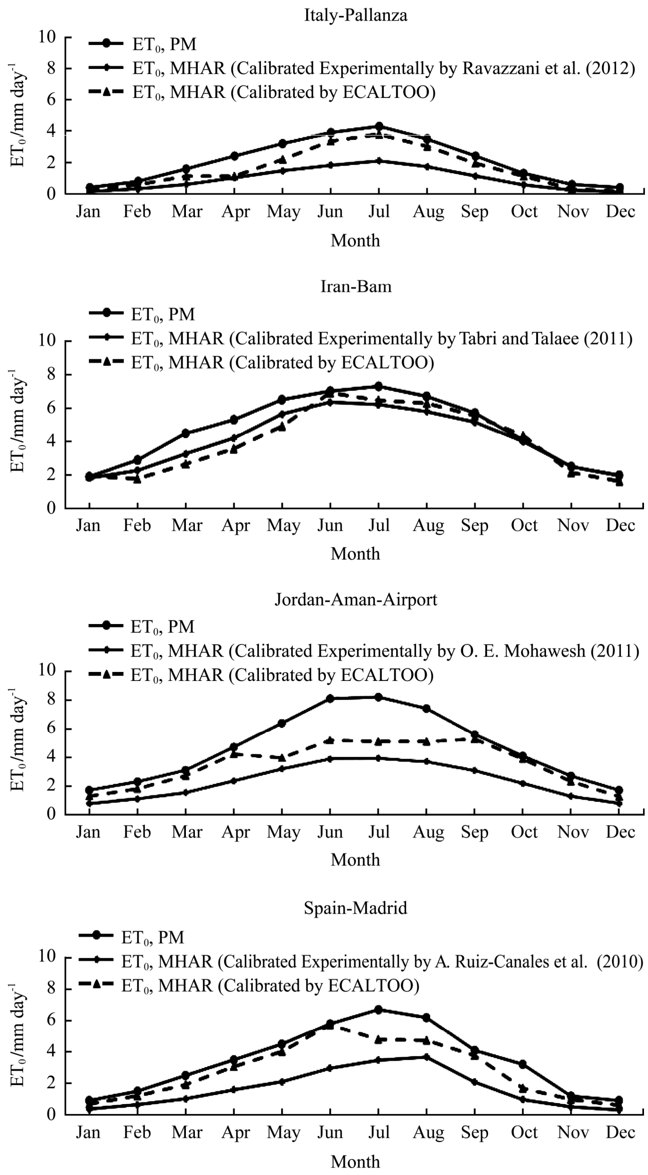

Figure 5 ET_0 estimates by the Penman-Monteith (PM) and Modified Hargreaves (MHAR) with experimental and ECALTOOL based calibration

The error estimation of the proposed ECALTOOL confirms its accuracy over the experimental method for the Hargreaves equation calibration. Apart from the accuracy, ECALTOOL is very easy to use. This tool proved to be universal and accurate for the Hargreaves equation calibration. It will surely very useful tool for the agriculture science fraternity. ECALTOOL helps to make the Hargreaves equation more pertinent and effective.

Table 2 Mean Absolute Error and Mean Absolute Percentage Error calculation in comparison with Penman-Monteith (PM)

Location	A	B	C in %	D in %
Bam (Iran)	0.6026	0.6814	1.07	1.21
Pallanza (Italy)	1.1284	0.4856	4.55	1.96
Amman Airport (Jordan)	2.35	1.1562	4.2	2.06
Madrid (Spain)	1.7742	0.6566	4.33	1.6

Note: A. MAE for calibration experimentally by author; B. MAE for calibration using ECALTOOL; C. MAPE for calibration experimentally by author; D. MAPE for calibration using ECALTOOL.

4 Conclusion

Fuzzy based computer program- ECALTOOL, for the calibration of C_H and E_H of the Hargreaves equation is developed and validated. The tool has a very rich library of about 1100 locations of 190 countries. The users just required selecting the country, location and season to arrive at accurate values of C_H and E_H. The performance of the tool has been compared with published calibrated values for varied climatic conditions. It is proved to be accurate than the experimentally calibrated values of C_H and E_H. It is also possible to get the values of C_H and E_H for the location which is not available in the library of the tool. In the true sense the ECALTOOL is a universal tool for the calibration of the Hargreaves equation. The tool can be easily downloaded at the *https://sites.google.com/a/ nirmauni.ac. in/ecal/home* or at the download section of *www. krishisense.org*. Correctness and consistency of the tool is checked with ET_0 calculated using PM equation. The result reveals considerable improvement in the accuracy of ET_0 estimation by the Hargreaves equation. The proposed calibration tool provides a successful solution of ever persisted problem of inaccuracy of the Hargreaves equation in extreme climate and the requirement of the location specific calibration of C_H and E_H. It also takes care of wide variation in the climate condition of the specific location during a year. The features like ease of operation, free to use and universal coverage will surely make the ECALTOOL a very useful computer application to the agricultural fraternity.

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