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A User Friendly Tool for Performance Evaluation of Different Reference Evapotranspiration Methods

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***Abstract*—**Evapotranspiration (ET) is a major component of the hydrologic cycle and its accurate estimation is essential for hydrological studies. In past, various estimation methods have been developed for different climatological data, and the accuracy of these methods varies with climatic conditions. Reference crop evapotranspiration (ET_0) is a key variable in procedures established for estimating evapotranspiration rates of agricultural crops. Values of ET_0 are used with crop coefficients for many aspects of irrigation and water resources planning and management. Numerous methods are used for estimating ET_0. As per internationally accepted procedures outlined in the United Nations Food and Agriculture Organization's Irrigation and Drainage Paper No. 56(FAO-56), use of Penman-Monteith equation is recommended for computing ET_0 from ground based climatological observations. In the present study, seven methods have been selected for performance evaluation. User friendly software has been developed using programming language visual basic. The visual basic has ability to create graphical environment using less coding. For given data availability the developed software estimates reference evapotranspiration for any given area and period for which data is available. The accuracy of the software has been checked by the examples given in FAO-56.The developed software is a user friendly tool for estimating ET_0 under different data availability and climatic conditions.

***Keywords*—**Crop coefficient, Crop evapotranspiration, Field moisture, Irrigation Scheduling.

I. Introduction

REFERENCE Evaporation (ET_0) is defined as the "The rate at which water, if readily available, would be removed from soil and plant surfaces of a specific crop, arbitrarily called the reference crop". Estimates of evapotranspiration (ET) flux occurring from cropped land surfaces are essential in studies relating to hydrology, climate, and agricultural water management. ET is a complex phenomenon because it depends on several climatological factors, such as temperature, humidity, wind speed, radiation, and type and growth stage of the crop. ET can be either directly measured using lysimeter or water balance approaches, or estimated indirectly using climatological data [4], [5]. However, it is not always possible to measure ET using a lysimeter because it is a time-consuming method and needs precise and carefully planned experiments. The procedure for computation of Reference Evapotranspiration (ET_0) is to record climatological data like altitude, longitude, latitude, wind speed, air temperature, radiation, air humidity etc. and thereafter to put them into equations under consideration i.e., FAO-56 Penman-Monteith equation (PM), FAO-24 Radiation, FAO-24 corrected Penman (c=10), Priestley-Tailor equation etc.

The PM method has been proposed as the best estimator of ET_0 [1]. The PM method is considered to be more "physically based" since it incorporates the effects of physiological and aerodynamic characteristics of the reference surface. Several worldwide studies have proved the superiority of the PM method across a wide range of climatic conditions [9], [10], [11]. Accordingly, the recent version of the FAO methodology for estimation of crop water requirements [1] recommends the sole use of the PM method for ET_0 estimation in all climates.

Several studies [2], [9] showed that the Penman method is superior; when the required data are available and reliable, to all other commonly used methods (Jensen-Haise, Turc, Makkink, Priestley-Taylor, Hargreaves-Samani, Thornthwaite, and FAO pan evaporation) for estimating reference crop ET under varying locations and climatic conditions. Reference [15] further modified the Penman method by incorporating a stomatal resistance term specific to the type of crop in addition to the existing aerodynamic term, and formulated the Penman-Monteith evapotranspiration model.

The performance of different ET_0 estimation methods varies with climatic conditions and availability of data, and the data requirements vary from method to method. Furthermore, ET_0 estimations depend upon the quality of the meteorological data.

One of the purposes of this study is to evaluate the performance of six methods (FAO-24 Penman, FAO-24 Radiation, FAO-24 Blaney-Criddle, Priestley-Taylor, Turc, and FAO-56 Hargreaves) relative to the FAO-56 Penman-Monteith at Hamirpur (HP), India and to identify the alternative climatic based method that yield results closest to the PM method due to a common lack of more complete climatic data.

So for this, we, first of all, have gone through the literature review, and then enlisted the different hydro-meteorological parameters and ET_0 methods. Then we started work to develop software using programming language Visual Basic.

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II. Literature Review

A. Reference Evapotranspiration (ET_0)

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_0. The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ET_0 values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface [1].

Numerous methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. ET_0 is supposed a represent an upper limit to the climate control evapotranspiration rate under certain restricted plant and soil conditions given the complexity of the evaporation phenomena and its dependence on the host of interacting parameters of the soil-plant-atmosphere continuum, several definitions of ET_0 are available in literature [8], while listing out various versions of available ET_0 definitions ,pointed out that each of them defines a digiting parameter representing the evaporation rate when certain conditions are imposed on the evaporating surface. Usually ET_0 has been defined as a quantity that varies with meteorological variables; however, several models of varying complexity have been developed for its estimation [3], [7], [20].

Each of these models uses a specific input data to yield estimates of the maximum evapotranspiration rate from the crop surface under conditions of unlimited moistures availability, hence also referred as potential evapotranspiration (PET).The reference crop is defined to be green grass, actively growing (8 to 15cm tall) completely setting the ground surface and not short of water. ET_0 estimation based upon climatological data varies from empirical relation to complex methods such as the penman combination method [16] based upon physical processes. These different methods of ET_0 estimation method can be grouped into combination theory types [12], [13] and empirical formulations based on radiation (Turc, Priestley Taylor, and FAO-24 radiation), temperature (Thorntwaite, Blaney-Criddle, FAO-24 Blaney- Criddle, Hargreaves).

The performance of different ET_0 estimation methods varies with climatic conditions and availability of data and the data requirement vary from method to method. Furthermore, ET_0 estimation depends upon the quality of metrological data. Therefore, it is very difficult to decide upon an appropriate ET_0 estimation method among the different available methods for particular stations given the available data [14], [17], and [18]. During the last 50 years, a large no. of empirical methods have been developed and used to estimate ET_0, using various ET_0 estimation methods under diverse climatic conditions. Numerous studies have reveals a widely varying performance of the different equations and acknowledged that penman and all other methods require local calibration [6]. Numerous researchers have analyzed the performance of the various methods for different locations [1], [15], [19], [21]. Although the result of such analysis could have been influenced by site measurement conditions or bias in weather data collection, it became evident that the proposed methods do not behave the same way in different locations around the world. Deviations from computed to observed values were often found to exceed ranges indicates by FAO. According to FAO of the United Nations, the Penman method gives more consistent ET_0 estimates and has sown to perform better than other methods when compared with lysimeter data [21]. Metrological data required to use the PM equation are vast and are not always readily available.

B. Crop Coefficient (K_c)

The K_c value, which is the ratio of crop evapotranspiration (ET_c) and ET_0, represent crop specific water use and is required for accurate estimation of irrigation requirements. Reference [7] suggested that K_c need to be derived empirically for each crop based on lysimeter data and local climatic conditions. Crop coefficient values for a no. of crops grown under different climatic conditions were suggested by [7]. These values are commonly used in places where local Data are not available. However, they emphasized the strong need for local calibration of crop coefficient under given climatic conditions. Reference [23] also represented crop coefficient for a few crops. Since, localized K_c values are not always available in many parts of India and due to lack of locally determined crop water used data, the values of K_c are as suggested by FAO of the united nations [1], [6] are being widely used to estimate crop water requirement. A comprehensive list of stage specific crop coefficient is provided is provided by [1]. These crop coefficients have been calibrated for a typical agro-climate, and hence a detailed procedure has been outlined to modify the crop coefficients for a particular study area/agro-climate [22]. The crop coefficient provided by FAO, have been calibrated, under highly controlled conditions, hence their modified can very well represents the local crop water requirement [1].

III. Methodology

A. Enlisting the ET_0 Equations

ET_0 is a complex phenomenon because it depends on several climatological factors, such as temperature, humidity, wind speed, radiation and type and growth stage of crop. The different methods of ET_0 estimation can be grouped into combination theory types (FAO-56 Penman -Monteith, FAO-24 Penman (c=1), 1982-Kimberly-Penman, FAO-24 corrected Penman) and empirical formulations based on radiation (Priestly-Taylor and FAO-24 radiation), temperature

(Thornthwaite, FAO Blaney-Criddle, Hargreaves). The performance of different ET_0 estimation methods varies with climatic conditions and availability of data, and the data requirements vary from method to method. Furthermore, ET_0 are also based upon different supporting equations, which are used to compute different parameters involved in the equations.

TABLE I
DIFFERENT ET_0 ESTIMATION METHODS AND THEIR GOVERNING EQUATIONS

Method	Equations used	Reference	Supporting Equations
FAO-56 Penman-Monteith	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	[1]	$\Delta, R_n, G, \gamma, u_2, e_s, e_a$
FAO-24 Penman	$ET_0 = c\left[\frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\gamma}{\Delta+\gamma} 2.7W_f (e_a - e_d)\right]$	[7]	γ, W_f, Δ, R_n, G, e_s, e_a
FAO-24 Radiation	$ET_r = b_R\left[\frac{\Delta'}{\Delta'+\gamma'} R'_s\right] - 0.3$	[7]	$\Delta', e_s', e_a', R_a, C$
FAO-24 Blaney-Criddle	$ET_0 = a + b\left[p\left(0.46\overline{T} + 8.13\right)\right]$	[7]	a, b
Priestley-Taylor	$ET_0 = \alpha \frac{\Delta}{\Delta+\gamma}(R_n - G)$	[20]	$\alpha, \Delta, \gamma, R_n, G$
Turc	$ET_t = 0.31\left[\frac{\overline{T}}{\overline{T}+15}\left(R'_s + 2.09\right)\left(1 + \frac{50 - RH_{mean}}{70}\right)\right]$ for RH<50 $ET_t = 0.31\left[\frac{\overline{T}}{\overline{T}+15}\right]\left(R_s' + 2.09\right)$ for RH > 50	[20]	R_s
FAO-56 Hargreaves	$ET_h = 0.0023(\overline{T} + 17.8)(T_{max} - T_{min})^{0.5} * R_a$	[1]	R_a

TABLE II
METEOROLOGICAL AND CLIMATOLOGICAL PARAMETERS

Method	Site Parameters	Climatic Parameters
FAO-56 Penman-Monteith	z, z_w, φ	T_{max}, T_{min}, RH_{max}, RH_{min}, u_z, n
FAO-24 Penman	z, z_w, φ	T_{max}, T_{min}, RH_{max}, RH_{min}, n u_z, u_r
FAO-24 Radiation	z_w, φ	T_{max}, T_{min}, RH_{min}, n, u_z, u_r
FAO-24 Blaney-Criddle	z, z_w, φ	T_{max}, T_{min}, n, RH_{max}, RH_{min}, n, u_z, u_r
Priestley-Taylor	z, φ	T_{max}, T_{min}, n,
Turc	φ	T_{max}, T_{min}, n, RH_{max}, RH_{min}
FAO-56 Hargreaves	φ	T_{max}, T_{min}, n,

B. Enlisting the Climatological Parameters

Hydro-meteorological parameters which will be used in the ET_0 equations have been enlisted. The PM method requires more parameters in comparison to others methods.

C. Formulation of the Tool

Using VB, software is developed which basically calculates the ET_0 using the seven methods. Software has two main calculation features. Manual calculation option is set if, data is not available in prepared excel sheet or for daily type calculation of ET_0. Whereas the automatic calculation option is set if data available in standard format of MS-Excel sheets. By clicking manual command option, the next window is opened in which manual calculation is done and the output i.e. ET_0 is stored in the Excel sheet which exits in the directory C:/Program files/ Reference Evapotranspiration data book.xls. By clicking automatic calculation option, the next window is opened in which data is taken automatically from the prepared Excel sheet which is stored at the following directory and having a specific arrangement of columns C:/Program files/ Reference Evapotranspiration data book.xls.

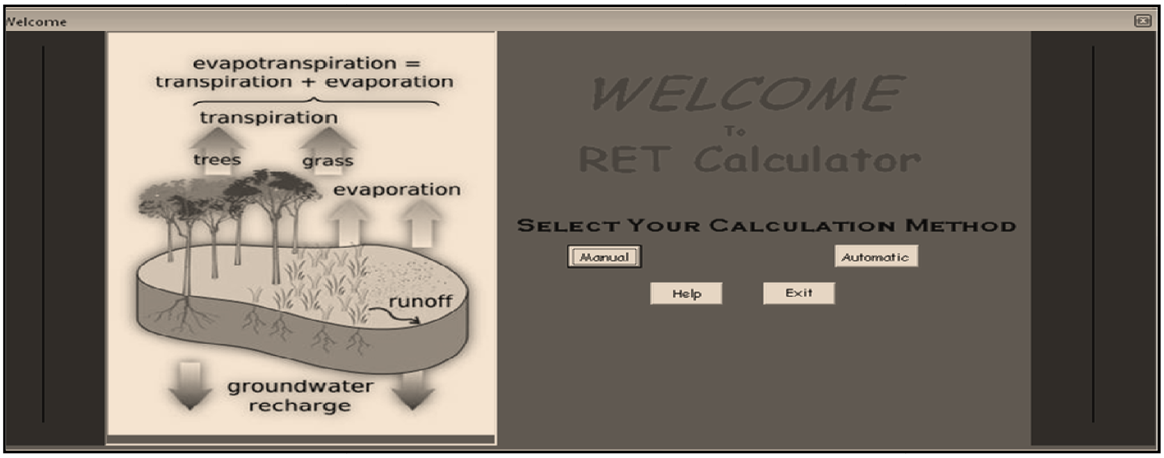

Fig. 1 Welcome window of the Tool developed

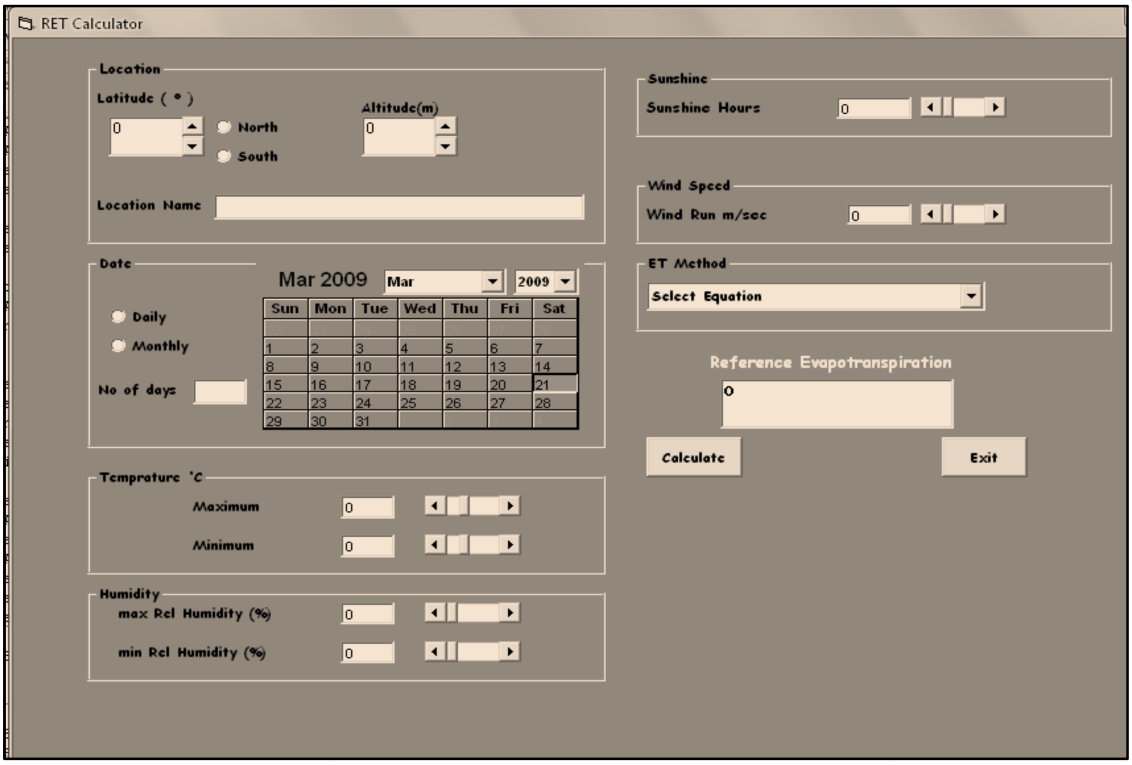

Fig. 2 Manual calculation window of the Tool developed

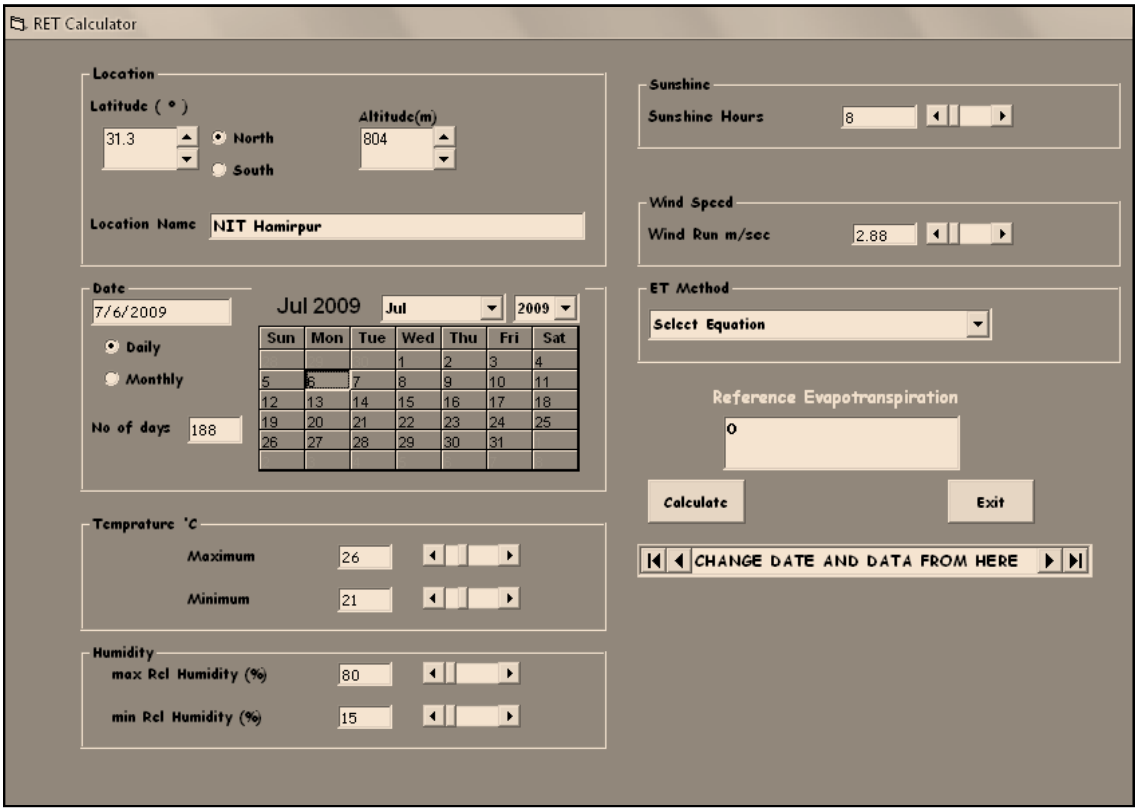

Fig. 3 Automatic calculation window of the Tool developed

IV. Results and Discussion

A. Adequacy of the Tool

Adequacy of the tool developed for the performance evaluation of different evapotranspiration methods was checked by the examples given in United Nations Food and Agriculture Organization's Irrigation and Drainage Paper No. 56 (FAO-56) and put their values in the software. Manual calculation option was selected to calculate ET_0.

V. Summary and Conclusions

A tool consisting of database in MS-Excel format and having graphical user interface was developed for estimating ET_0 using the best applicable ET_0 method, given the available data and climate. The tool, which runs under windows environment, is user friendly. The graphical user interface is mouse driven with two popup windows and, pulls down menus, and button controls. The tool consists of seven commonly used and accepted ET_0 estimation methods.

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