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Comparative evaluation of different reference evapotranspiration models

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Abstract: The study was carried out to select best alternative method for the estimation of reference evapotranspiration (ET_0). Accurate estimation of potential evapotranspiration is a necessary step in water resource management. Recently, the FAO-56 version of Penman-Monteith equation has been established as a standard for calculating reference evapotranspiration (ET_0) which requires measurement of a number of meteorological parameters namely, air temperature, relative humidity, solar radiation, and wind speed which may not be available in most of the meteorological stations. Still there are different approaches (requiring less data) which estimate ET_0 closely to Penman-Monteith (P-M) method for different climatological conditions. The present study is based on analysis of long term of 13 years (2000 to 2012) climatic data to calculate monthly reference evapotranspiration for Capsicum production (September–March) and also to compare the performance of evapotranspiration equations for Jhalawar district of Rajasthan with the standard FAO-56 Penman-Monteith method on the basis of the least root mean square error (RMSE) analysis. Hargreaves method and Pan evaporation ($E\text{-}_{Pan}$) method overestimated the values of ETo when compared with FAO-56 Penman-Monteith method. On the basis of lowest value of RMSE, Pan evaporation method is found best alternative method to FAO-56 Penman-Monteith method in the study area.

Keywords: CROPWAT, Hargreaves and Pan evaporation, Reference evapotranspiration, RMSE analysis

INTRODUCTION

Allen *et al.* (1994) defined reference evapotranspiration (ET_0) as “the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23 closely resembling the evapotranspiration from an extensive surface of green grass of uniform height actively growing completely shading the ground and with adequate water. The combination of two processes i.e. evaporation and transpiration is called Evapotranspiration. Evaporation is the process where by liquid water is converted to water vapour and removed from evaporative surface. Transpiration consists of the vaporization of liquid water contained in plant tissues and vapour removal to the atmosphere. Evaporation and transpiration occur simultaneously and there is no way to distinguish between the two processes. The most common and important factors affecting evaporation are solar radiation, temperature, relative humidity, vapour pressure deficit, atmospheric pressure, and wind (Kumar *et al.*, 2013). Evapotranspiration not only plays a major role in global water balance but also significantly influence the global energy balance (Nikam *et al.*, 2014). Evapotranspiration is one of the most important and complicated phases of the hydrological cycle. Hence, quantification of evapotranspiration is necessary for water resources management, irrigation scheduling and environmental assessment, design of reservoirs, irrigation systems, water balance and simulations studies Jensen *et al.* (1990). Several methods have been developed to assess ET_0 based on temperature, radiation and their combination. Performance evaluation of all the approaches is prerequisite for selecting an alternative approach in accordance with available data. Solar radiation provides the energy required for the phase change of water and often limits the evapotranspiration (ET) process where water is readily available. A number of ET equation methods have been developed based on energy balance (Turc, 1961; Priestley and Taylor, 1972; Doorenbos and Pruitt, 1977). Jensen *et al.* (1990) found that radiation methods considerably underestimated evapotranspiration for rates greater than 4 mm/day. George *et al.* (2002) have developed decision support system for estimating reference evapotranspiration using temperature, radiation and combination methods. Specific devices and accurate measurements of various physical parameters of the soil water balance in lysimeters are required to measure actual evapotranspiration. These methods are often expensive and require accuracy for measurements. Direct methods are inappropriate for routine measurements. It is important to evaluate the ET_0 estimated by indirect methods. Due to simplicity

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in indirect methods, weather parameters are used for estimation of ET_0 (Meshram *et al.*, 2011). In search of the best ET_0 model for global application, many researchers (Allen *et al.*, 1998; Villa Nova *et al.*, 2007) have compared different reference evapotranspiration models. Sikka *et al.* (2001); Kar and Martha (2006) and Meshram *et al.* (2010) have provided the detail reviews on the comparison of different models and concluded The Penman-Monteith model is the most appropriate for determining ET_0.

Owing to its superiority tested worldwide the “physically based” combination approach of FAO-56 version of Penman–Monteith (FAO-PM) equation has been accepted as a standard for calculating reference evapotranspiration. Superior accuracy of FAO-56 Penman–Monteith methods is also verified in Indian conditions by Kashyap and Panda (2001). Viswanadh *et al.* (2004) developed a computer program in Microsoft Visual C^{++} which is generalized to calculate reference evapotranspiration (RET) using FAO-56 PM method. This program is based on the FAO-56 Penman–Monteith equation as given by FAO irrigation and Drainage Paper No.56 (Allen *et al.* 1988). Giridhar *et al.* (2004) compared ET_0 values estimated through various ET_0 equations with FAO-56 PM method for different irrigation project locations in Andhra Pradesh. Lakshman and Gicy (2006) studied the performance of various ET_0 equations and concluded that there is growing evidence to show that the more physically based FAO-56 Penman–Monteith (PM) combination method yields consistently more accurate ET_0 estimates across a wide range of climates. Rahimikhoob *et al.* (2012) evaluated the performance and characteristic behaviour of four equations for estimating reference evapotranspiration (ET_0) at eight meteorological sites in a subtropical climate and concluded that good performance from the modified Hargreaves (equation (0.53 mm d^{-1} of RMSE) must be emphasized, given the simplicity of that method, which only requires maximum and minimum air temperature data.

The objectives of the present study to select best alternative method for the estimation of daily and monthly reference evapotranspiration (ET_0) for Jhalawar district (Rajasthan), India. Therefore, two most popular approaches Hargreaves and Pan evaporation based on very less number of meteorological data, were used to estimate daily and monthly reference evapotranspiration (ET_0) compare the performance of these equations with FAO-56 Penman–Monteith method.

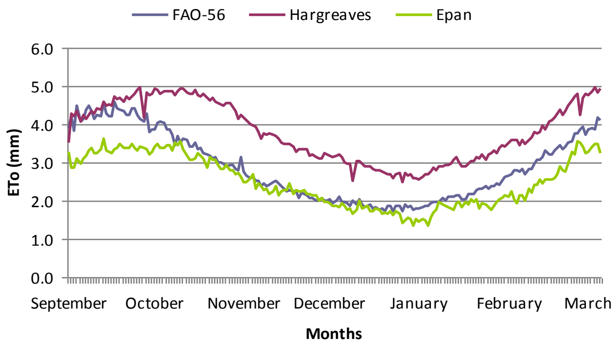

Fig 1. *Estimated reference evapotranspiration, ET_0 (mm) by different methods.*

MATERIALS AND METHODS

Study area: Jhalawar district is located at 23°45’ to 24°52’ N-Latitude and 75°27’ to 76°56’ E-Longitude in south eastern Rajasthan. Agro-climatically, the district falls in Zone V, known as Humid South Eastern Plain. The rainfall is mostly concentrated in four monsoon months of June to September besides some regeneration in the winter months. On the basis of available rainfall data, the average annual rainfall in the study area is 910 mm (Singh, 2016). Maximum temperature range in the summer is 43-48 °C and minimum 1.0–2.6 °C during winter. The district is having conspicuous physiographic variations comprising undulating or flat terrain. About 78.5 percent population of the district is rural whose main occupation is agriculture (Anonymous, 2011).

Meteorological parameters viz., maximum temperature, minimum temperature, minimum relative humidity, maximum relative humidity, wind speed, sun shine duration were collected from CSWCRTI, Kota and analysed for capsicum (*Capsicum annuum* L.*var. grossum*), popularly known as sweet pepper, capsicum and shimla mirch (September-March) for a period of 2000 to 2012. In the present study, the same method was chosen as the standard method against which performance evaluation of the other methods was carried out. The average monthly ET_0 were calculated on the basis of meteorological data. The ET_0 values estimated from Hargreaves methods and Pan evaporation method were compared with the standard method i.e., FAO-56 PM on the basis of the least root mean square error (RMSE) analysis. RMSE provides a good measure of how closely the datasets match (Ventura *et al.*, 1999).

Table 1. Average monthly meteorological data during crop growing period during (2000-2012) for the study area.

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/hr)	Sun Hours	Ep
September	23.8	33.5	70	2.1	7.9	4.4
October	17.9	34.7	54.68	1.1	9.4	4.3
November	12.71	30.45	58	0.94	8.3	3.2
December	8.69	25.36	64.74	1	7.6	2.4
January	6.54	23.09	64.43	1.4	7.9	2.3
February	9.59	26.84	59.2	1.9	9.1	3.2
March	13.2	31.2	49.1	2.8	9.7	3.8

Table 2. Average monthly reference evapotranspiration (ET_0) in mm estimated by different methods (2000-2012).

Months	P-M	Hargreaves	E_{pan}
September	128.23	130.42	130.81
October	110.31	147.38	133.3
November	73.8	111.98	95.3
December	59.03	93.79	74.6
January	63.51	89.82	72.22
February	83.12	106.6	88.92
March	137.19	168.38	170.1

Table 3. Monthly root mean square error (RMSE) over Penman-Monteith method (2000-2012).

Parameter	Methods	
	Hargreaves	E_{pan}
RMSE (mm/Month)	29.908	18.641

The RMSE was calculated by using the equation (1)

$$RMSE = \sqrt{\frac{1}{n}\sum (ETo_1 - ETo_2)^2} \quad (1)$$

Where,

n = Number of observations

ETo_1 = Estimated ETo, by P-M method

ETo_2 = Estimated ETo, by one of two methods

FAO-56 penman-monteith equation: The definition of ET_0 by Allen *et al.* (1994) was the basis for FAO Penman–Monteith method in the estimation of Reference Evapotranspiration. The FAO-56 PM is a physically based approach that requires measurements of a number of meteorological parameters. Biswas *et al.*, (2014) computed actual crop evapotranspiration (ET_0) by multiplying the reference evapotranspiration (ET_0) with crop coefficient (K_c) for different growth stages of the crop. The monthly reference evapotranspiration (ET_0) was estimated by using the 'CROPWAT 8.0' Model based on FAO Penman-Monteith (Allen *et al.*, 1998) method from the available data of temperature, relative humidity, wind speed at 2 m height and sunshine hours.

The FAO Penman–Monteith method to estimate reference crop evapotranspiration is as follows

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

Where,

ET_0 = reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [MJ m^{-2} day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}], T mean 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].

Hargreaves method: The Hargreaves method (Hargreaves and Samani, 1985) of computing daily reference evapotranspiration is another empirical approach that was used in cases where the availability of weather data is limited. The method was developed in Davis, California from a lysimeter study on Alta fescue grass. This is an empirical estimation method that uses the average daily air temperature, T (°C), in combination with the extraterrestrial radiation, Ra (MJ/m2/day) as an indicator of the incoming global radiation. Hargreaves equation can be written as:

$$ET_o = 0.0135\, R_s (T_a + 17.8) \quad (3)$$

Where,

R_s = Global solar radiation (mm/day)

T_a = daily average temperature ^{0}C

$$R_s = k_r R_a (T_{max} - T_{min})^{0.5} \quad (4)$$

Where,

R_a = extraterrestrial radiation (mm/day)

k_r = empirical coefficient depending on station location

Hargreaves (1994) recommended using K_r = 0.162 for "interior" regions and K_r = 0.19 for coastal regions.

$$Ra = \frac{24*60}{\Pi} Gsc * dr[\omega s \, Sin(\phi) Sin(\delta) + Cos(\phi) Cos(\delta) Sin(\omega s)] \quad (5)$$

Where, Ra-extraterrestrial radiation [MJm-2day-1], Gsc-solar constant = 0.0820 MJm-2min-1, dr-inverse relative distance Earth-Sun, ωs -sunset hour angle [rad], ϕ- latitude [rad], δ- solar declination [rad]. The latitude, ϕ, expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere.

$$dr = 1 + 0.033 Cos\left[\frac{2\pi}{365} J\right] \quad (6)$$

$$\delta = 0.409 Sin\left[\frac{2\pi}{365} J - 1.39\right] \quad (7)$$

$$\omega s = arcCos[-\tan\phi * \tan\delta] \quad (8)$$

Pan evaporation method: The Standard US Weather Bureau Class A pan was used to measure evaporation data in the field. Evaporation pans have higher rates of evaporation than a large free water surface, and a factor is usually recommended for converting the observed evaporation rate to those of large water surface areas. This factor is called pan coefficient. Reference evapo-transpiration was calculated by multiplying pan evaporation data (E_{pan}) to pan coefficient (K_p).

$$ET_o = K_p E_{pan} \quad (9)$$

Where, ETo = Reference crop evapo-transpiration (mm/month)

K_p = Pan coefficient

E_{pan} = pan evaporation (mm/month)

RESULTS AND DISCUSSION

P-M method was accepted as the most appropriate method for estimation of ET_0 and compared with other two methods. Monthly ET_0 were calculated on the basis of meteorological data for growing period (September to March) of Capsicum using the FAO-56 Penman–Monteith, Hargreaves Method and Pan evaporation method (Table 2 and Fig. 1). It is reveled from Fig. 1 that ET_0 values estimated by Hargreaves Method are the highest followed by Pan evaporation and P-M methods. Hargreaves method was found to be the most suitable method for the Manipur region with least biasness and minimum error by Naorem and Devi (2014). Giridhar *et al.* (2004) estimated reference evapotranspiration values from Hargreaves method, Turc method, FAO-24 Radiation method and resulted in positive percentage of deviation as 26.68 %, 10.63 % and 42.69 % respectively when compared with FAO -56 Penman-Monteith method. Turc (1961) equation gave 10.63 % deviation from FAO-56 PM method and the deviation is found to be least among all the radiation methods for Andhra Pradesh, India. Lima *et al.*, (2013) estimated Reference evapotranspiration by non-calibrated Hargreaves-Samani method (ET_0HS) which was overestimated in all months (RMSE = 1.43 mm/day) in sub-humid region of Brazil.

The monthly values of RMSE were calculated to compare other two methods with P-M method and presented in Table 3. It was observed from Tables 3 that Pan evaporation method gave the RMSE values (18.641 mm/month) closest to the P-M method followed by Hargreaves (29.908 mm/month). Hargreaves overestimated due to high difference in temperatures ($T_{max} – T_{min}$) values. Hence, Pan evaporation method is recommended for the estimation of ET_0 in the absence of data required for estimation of ET_0 by P-M method for Jhalawar district of Rajasthan.

Conclusion

As the FAO-56 version of Penman-Monteith equation has been established as a standard for calculating reference evapotranspiration (ET_0) which requires measurements of a number of meteorological parameters. This study reveals that Pan evaporation approach showed lowest values of RMSE (18.641 mm/month) for both daily and monthly ET_0 values as compare to Hargreaves Samani equation. It is concluded from the comparison that Pan evaporation approach is the best alternative to P-M method to estimate ET_0 values in the Jhalawar district of Rajasthan.

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