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Comparison of Temperature Based Reference Evapotranspiration Methods with FAO 56 Penman-Monteith Method

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ABSTRACT

In this study paper four alternative temperature based methods *viz*., romenenko, schendel, hargreaves-samani modified 2 and hargreaves model 2 are compared with standard FAO 56 PM method using 34 years daily data on temperature recorded at GKVK station. The results showed that among these, remenenko method was found to provide better estimates of FAO 56 PM with values of MAE, MAXE, SEE and RMSE of 0.71mm, 1.85 mm, 0.86 mm and 0.84 mm per day, respectively. Further, this method gave 14.22 per cent deviation from standard FAO 56 PM method which is least among all the temperature based methods for the study region.

Keywords : Reference evapotranspiration, FAO 56 penman-monteith

EVAPOTRANSPIRATION is considered to be the dominant component of the hydrologic cycle due to the fact that 60 per cent of annual precipitation falling over the land surface is returned to atmosphere as Evapotranspiration (ET). Under the semi arid or arid climatic conditions coupled with low and erratic rainfall, water is the most limiting factor for agricultural productivity and irrigation planning. Evapotranspiration is estimated as a two step process. The evaporative demand of the environment is estimated based on weather conditions and is often estimated as the evapotranspiration from a theoretical, reference grass crop (ET_0) with the crop defined as an actively growing, uniform surface of grass, completely shading the ground, and not short of water (Doorenbos and Pruitt, 1977). The ET_0 value is then adjusted to estimate the evapotranspiration of the particular crop of interest using a crop-specific crop coefficient (Allen *et al*., 1998).

Many methods have been proposed for estimating ET_0 based on weather data and range from locally developed empirical relationships to physically based energy and mass transfer models. FAO 56 Penman-Monteith (PM) method is considered worldwide as the most accurate method under various climatic conditions and declared as standard method for estimating reference evapotranspiration by FAO (Jensen *et al*., 1990; Allen *et al.*, 1998; Irmak *et al*., 2003, 2008; Hargreaves and Allen, 2003; Tabari *et al*., 2013). However, the major drawback of FAO 56 PM method is that it requires numerous weather data *viz.*, maximum and minimum air temperature, maximum and minimum relative humidity, atmospheric pressure, wind speed, wet bulb and dry bulb temperature, daily net radiation, sunshine hour, etc. which are not easily available in many meteorological stations. Keeping in view of the above, the present study was undertaken to compare different temperature based methods with standard FAO 56 PM method for estimation of reference evapotranspiration.

MATERIAL AND METHODS

The daily data on maximum and minimum temperatures were collected from the Department of Agro-meteorology, UAS, GKVK, Bengaluru for a period of 34 years from 1983 to 2016. The geographical co-ordinates of this station are $13^0$4'43''N longitude and 77^o34' 46" E latitude with 30 m altitude.

Evaporation estimation methods

Four reference evapotranspiration models *viz.*, Romanenko, Schendel, Hargreaves-Samanimodified-2 and Hargreaves model-2 were used to compare the estimates of ET_0 with the standard FAO 56 Penman-Monteith method. The details of these methods are shown in Table I. The performance of these methods were tested using the statistical tests described in Table II.

TABLE I

Details of standard and selected temperature based methods along with their references

Methods	Formulae	References
FAO 56 Penman - Monteith (Standard)	$ET_0 = \dfrac{0.408\,\Delta(R_n - G) + ¥\,\dfrac{900}{T+273}\,u_2(e_s - e_a)}{\Delta + ¥\,(1 + 0.34\,u_2)}$	Batchelor, (1984) ; Smith et al. (1991)
Romanenko	$ET_0 = 4.5\left[1 + \left(\dfrac{T_{mean}}{25}\right)^2\right]\left(1 - \dfrac{e_a}{e_s}\right)$	
Schendel	$ET_0 = 16\,\dfrac{T_{mean}}{RH_{mean}}$	Schendel (1967)
Hargreaves Samani Modified - 2 Samani (2000)	$ET_0 = 0.0023 \times R_a (T_{max} - T_{min})^{0.653} \times \left(\dfrac{T_{max} + T_{min}}{2} + 17.8\right)$	Hargreaves and Samani (1985)
Hargreaves Model - 2	$ET_0 = 0.408 \times 0.0025 \times R_a \times (T_{mean} - 16.8) \times (T_{mean} - T_{min})^{0.5}$	Allen *et al.* (1998). Droogers and Allen (2002)

Where G - Soil heat flux density [MJ/m^2/day],T - Air temperature [°C], T_{max} - Maximum air temperature [°C], T_{min} - Minimum air temperature [°C], u_2 - Wind speed at 2 m height [m/s],

e_s - Saturation vapour pressure [kPa], e_a - actual vapour pressure [kPa], Ä - Slope of vapour pressure curve [kPa/ °C],ã - Psychometric constant [kPa /°C], T_{mean} - Mean air temperature [°C], RH_{mean} - Mean relative humidity[kPa],Ra – Extraterrestrial Radiation [MJ/m^2].

TABLE II

Statistical tests for comparison of methods

Statistical tests	Formulae
Mean Absolute Error (MAE)	$MAXE = MAX\ \left\|ET_{Method} - ET_{FAO-56\,PM}\right\|_{i=1}^{n}$
Maximum Absolute Error (MAXE)	$RMSE = \sqrt{\dfrac{\sum_{i=1}^{n}(ET_{Method} - ET_{FAO-56\,PM})^2}{n}}$
Root Mean Square Error (RMSE)	$SEE = \sqrt{\dfrac{\sum_{i=1}^{n}(ET_{Method} - ET_{FAO-56\,PM})^2}{n-1}}$
Standard Error of Estimation (SEE)	$PE = \left\|\dfrac{E\overline{T}_{Method} - E\overline{T}_{FAO-56\,PM}}{E\overline{T}_{FAO-56\,PM}}\right\| \times 100$
Percent Error (PE)	$PE = \left\|\dfrac{E\overline{T}_{Method} - E\overline{T}_{FAO-56\,PM}}{E\overline{T}_{FAO-56\,PM}}\right\| \times 100$

Where ET_{Method} - Computed method, $ET_{FAO\text{-}56\,PM}$ - Standard method and n = No. of observations

Results and Discussion

Monthly average ET_0 values were estimated using 4 temperature based methods in order to compare these estimates with a standard FAO-56 PM model. The results are presented in Table III.

Romanenko method

The reference evapotranspiration (ET_0) estimated by Romanenko method for different months ranged from 3.63 mm/day to 6.61 mm/day with an overall average of 4.60 mm/day. It was observed that ET_0 values increased from January to April and steadily decreased from May to December. This shows that evaporation was high during summer and gradually decreased during monsoon season. Further, the estimates of ET_0 by this method were found very close to the Standard FAO-56 PM model.

Schendel method

The mean reference evapotranspiration estimated by Schendel method was found to be slightly higher than that of FAO-56 PM model with an overall average of 5.76 mm/day. Further, the pattern of variation of ET_0 during different months was similar to standard FAO-56 PM model.

Hargreaves Model-2 method

According to Hargreaves model-2, the average reference evapotranspiration (ET_0) estimates were found to be very low when compared to standard FAO-56 PM model. Further, ET_0 values ranged from 1.57 mm/day to 2.54 mm/day with an overall average of 2.10 mm/day.

Hargreaves-Samani Modified-2 method

The estimates of reference evapotranspiration (ET_0) by Hargreaves-Samani modified-2 method for different months were found to be very high when compared to standard FAO-56 PM model. The values ranged between 5.28 mm/day to 8.70 mm/day with an overall average of 6.69 mm/day.

The variation in monthly mean reference evapotranspiration (ET_0) by temperature based methods are shown in Fig. 1. It was observed that among these methods, Schendel and Hargreaves-Samani modified-2 methods overestimated ET_0 while Hargreaves-2 model was underestimated when compared to standard FAO-56 PM model. Further, Romanenko method was found to be very close to the standard FAO-56 PM model. The pattern of variation in all these models were similar. That is, the evaporation increases from January and

TABLE III

Monthly average reference evapotranspiration ET_0 (mm/day) estimates based on temperature

Month	Romanenko	Schendel	Hargreaves Samani Modified - 2	Hargreaves Modified - 2	Standard FAO - 56 PM
Jan	4.01	5.12	6.02	1.75	3.42
Feb	5.10	6.14	7.32	2.10	4.10
March	6.42	7.33	8.58	2.46	4.90
April	6.61	7.52	8.70	2.54	5.20
May	5.96	6.95	8.30	2.45	5.16
June	4.58	5.70	6.75	2.06	4.6
July	3.95	5.23	6.21	1.92	4.16
Aug	3.69	5.04	5.99	1.87	4.00
Sept	3.83	5.15	6.08	1.88	3.87
Oct	3.75	5.06	5.75	1.77	3.55
Nov	3.72	4.85	5.32	1.61	3.18
Dec	3.63	4.73	5.28	1.57	3.07
Average	4.60	5.76	6.69	2.10	4.10

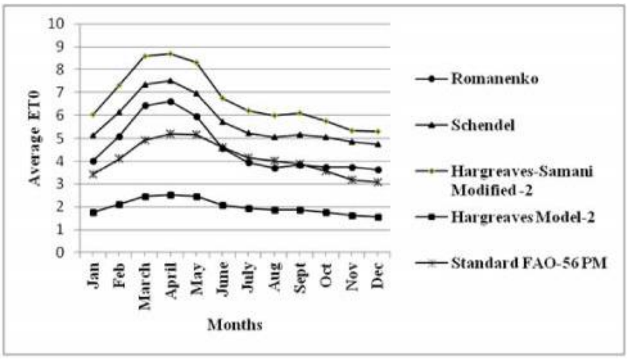

Fig.1: Variation in monthly average Reference Evapotranspiration (ET_0) calculated by temperature based methods for the period 1983-2016.

reaches peak level during April and then decreases from May to December.

Comparison of different evapotranspiration methods with a Standard FAO-56 PM model by using Adequacy tests

The estimates of reference evapotranspiration (ET_0) were compared by using statistical adequacy tests such as Mean Absolute Error (MAE), Maximum Absolute Error (MAXE), Root Mean Square Error (RMSE), Standard Error of Estimation (SEE), Per cent error (PE) and Ratio between standard value and computed value for temperature based methods (Table IV).

From Table IV it was observed that all the ET_0 estimates of temperature based methods were overestimated except Hargreaves model-2 when compared to the standard FAO-56 PM model. The values of MAE (2.59 mm/day), MAXE (3.68 mm/day), SEE (7.51 mm/day) and RMSE (2.63 mm/day) were found to be highest for Hargreaves-Samani modified-2 method while Romanenko method estimated with low values of MAE (0.71 mm/day), MAXE (1.85 mm/day), SEE (0.86 mm/day) and RMSE (0.84 mm/day). Thus, Romanenko method can be considered to be best among all the temperature based methods. Further, the percentage error of these methods ranged from 14.22 per cent for Romanenko to 63.55 per cent for Hargreaves-Samani modified-2 method with an overall average of 42.32 per cent. Though, Hargreaves model-2 and Hargreaves-Samani-modified-2 had good linear relationship with FAO-56 PM model with R^2 values of 0.72 and 0.66, the estimation was greatly biased as indicated by high value of RMSE (2.13 mm/day) and (2.63 mm/day) respectively.

Modifications to ET_0 equations for GKVK Station, Bengaluru Urban District

The empirical formula, for ET_0 as used in this study, may be reliable in the areas and over the periods for which they were developed. But, large errors can be expected when they are extrapolated to other climatic areas without re-calibrating the parameters involved in the formulae. Accordingly, an attempt has been made to modify these constant values to the original equations to improve the results. These modifications were done keeping the climatic condition of the study region (GKVK station, Bengaluru Urban District). A Comparison of the original equations with the re-calibrated values of parameters along with the improved mean estimates and per cent error (PE) of reference evapotranspiration (ET_0) are presented in Table V.

TABLE IV

Statistical performance of temperature based methods versus FAO-56 PM model for estimating ET_0 values for the period 1983-2016

Temperature based methods	Mean of Standard	Mean of other method	MAE	MAXE	SEE	RMSE	PE	R^2	Intercept	Slope	Ratio
Romanenko	4.10	4.60	0.71	1.85	0.86	0.84	14.22	0.62	1.79	0.5	1.12
Schendel	4.10	5.73	1.63	2.74	3.15	1.69	40.51	0.66	0.56	0.62	1.41
Hargreaves Samani Modified 2	4.10	6.69	2.59	3.68	7.51	2.63	63.55	0.66	0.58	0.53	1.64
Hargreaves Model -2	4.10	2.00	2.10	2.71	4.87	2.13	51.07	0.72	-0.05	2.07	0.49

TABLE V

Comparison of parameters before and after calibration for temperature based methods

Temperature based methods	Generalized equation forms	Original parameter values	Parameter vales after re-calibration	Mean of Standard method	Mean before re-calibrathio	Mean after re-calibrathio	PE before re-calibrathio	PE after re-calibra-thio
Romanenko	$ET_0 = a\left[1+\left(\frac{T_{mean}}{b}\right)^2\right]\left(1-\frac{e_a}{e_s}\right)$	a = 4.5	a= 4.2	4.10	4.60	4.29	14.22%	4.63%
Schendel	$ET_0 = a\frac{T_{mean}}{RH_{mean}}$	a =16	a=13	4.10	5.73	4.66	40.5%	13.65%
Hargreaves Samani Modified - 2	$ET_0 = a\times R_a(T_{\max}-T_{\min})^b \times(T_{mean}+c)$	a = 0.0023 b = 0.653 c = 17.8	a = 0.0023 b = 0.5 c = 17.8	4.10	6.69	4.61	63.50%	12.44%
Hargreaves Model 2	$ET_0 = a\times b\times R_a\times(T_{mean}-c) \times(T_{mean}-T_{\min})^d$	a = 4.08d = 0.5 b = 0.0025 c = 16.8	a= 4.08 b = 0.0045 c = 16.9 d = 0.5	4.10	2.10	3.99	-51.07%	-2.68%

In Table V, the parameter values of 4.5, 16, 0.653 and 0.0025 used in Romanenko, Schendel, Hargreaves-Samani modified-2, and Hargreaves model-2 methods were re-calibrated and new values obtained were 4.2, 13, 0.5 and 4.08 thus, improving the average ET_0 of 4.29 mm/day (from 4.6 mm/day), mm, 4.66 mm/day (from 5.73 mm/day), 4.61 mm/day (from 6.69 mm/day) and 3.99 mm/day (2.0 mm/day) respectively. Further, the values of PE has drastically reduced after re-calibration in all the four methods.

From the present study, it was concluded that among all the four temperature based methods, the estimated values of Hargreaves-Samani modified -2, and Schendel were overestimated except Hargreaves model-2 when compared to the standard FAO-56 PM model. Further, Romanenko method resulted in estimates of ET_0 values which are in close agreement with standard FAO-56 PM model. Hence, this method can be recommended for use as an alternative to calculate reference evapotranspiration for GKVK station, Bengaluru Urban District with proper calibration. Besides this, the weather parameters required for use in this method is comparatively less than that of the standard FAO-56 PM model. Non-the-less, the findings of this study would assist stakeholders in selection of alternative methods where ever climatic data is scarce for the regions in order to estimate ET_0 for judicious planning of irrigation and water requirement and thus for enhancing the productivity of crops in the region.

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