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Evaluation of Alternative Methods for Estimating Radiation Based Reference Evapotranspiration

SUCHITA P. KALEKAR AND K. N. KRISHNAMURTHY
Department of Agricultural Statistics, Applied Mathematics and Computer Science
College of Agriculture, UAS, GKVK, Bengaluru - 560 065
E-mail : kkmurthy13@gmail.com

ABSTRACT

Reference Evapotranspiration (ET_0) plays a key role in simulating hydrological effect of climate change, and a review of evapotranspiration estimation methods in hydrological models is of vital importance. FAO-56 PM model is considered as the standard method for estimation ET_0. As this, method requires large number of weather parameters which could not be easily available at meteorological stations. In addition to the use of complicated unit conversions and lengthy calculations, the reliable quality data, time consuming and difficulties in data collection present another serious limitation for this method. Keeping in view, the relevance of precise ET_0 estimation, an attempt has been made to estimate and select an alternative method on the basis of their performance with widely acclaimed FAO - 56 PM model secondary data for the study on weather parameters for 34 years (1983-2016) was obtained from AICRP on Agrometerology, UAS, GKVK, Bengaluru. The results showed that among all the nine radiation based methods, FAO-24 Radiation method performed well with high accuracy having least values MAE, MAXE, SEE and RMSE. 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 these methods are comparatively less than that of the standard FAO-56 PM model.

Keywords : Reference evapotranspiration, FAO 56 PM model, Radiation based method

A knowledge of the magnitude and variation of evaporative losses is required in water resources planning and management, design of reservoirs, assessment of irrigation efficiency of existing projects, evaluation of future drainage requirements, quantification of deep percolation losses under existing water management practices, water supply requirements of proposed irrigation projects, and preparation of river forecasts (Bates *et al*., 2008). There exist a multitude of methods, for measurement and estimation of evaporation. The availability of many equations for determining evaporation, the wide range of data types needed, and the wide range of expertise needed to use the various equations correctly, make it difficult to select the most appropriate evaporation method. Hence, the present study was conducted to identify different radiation based methods to evaluate evapotranspiration and to compare it with the Standard FAO-56 PM model for GKVK station.

MATERIAL AND METHODS

The present study was based on the secondary data on weather parameters Temperature (°C), Relative Humidity (%), Vapour Pressure (kPa), Sunshine hours (hrs/day), Wind speed (km/hr), Potential Evapotranspiration by FAO-56 (mm/day)) over a period of 34 years (1983-2016) which was collected from AICRP on Agro Meteorology, University of Agricultural Sciences, GKVK, Bengaluru.

Analytical Tools and Techniques

Evapotranspiration can be measured directly by specific equipment's or determined by micro meteo-rological methods, in carefully planned experiments of high cost and long term (Kumar *et al*., 2008). As an alternative to direct measurements, several researchers developed estimation methods by means of hydro meteorological models (Maeda *et al.,* 2011) and mathematical models (Landeras *et al*., 2008).

TABLE 1

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

Methods	Formulae	References
FAO-56 Penman-Monteith Model(Standard)	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$	Walter *et al.* 2000
Turc method	$ET_0 = 0.4 \times \left[\frac{T_{mean}}{T_{mean} + 15}\right]\left(\frac{R_s + 50}{\lambda}\right) \quad if \; RH > 50$	Turc, 1961
Stephens-Stewart method	$ET_0 = (0.0148 \times T_{mean} + 0.07)\frac{R_s}{\lambda}$	Jensen,1966, Stephens and Stewart, 1963
McGuinness–Bordne method	$ET_0 = (0.00597 \times T_{mean} - 0.0838) \times R_s$	Mc Guinness and Bordne, 1972
FAO-24 Radiation	$ET_0 = a + b\left(\frac{\Delta}{\Delta + \gamma} R_s\right)$	Doorenbos and Pruitt, 1977, Jensen *et al.* 1990
Caprio method	$ET_0 = (0.01092708 \times T_{mean} - 0.0060706) \times R_s$	Caprio, 1974
Hargreaves-Samani method	$ET_0 = 0.0135 \times \left(\frac{R_s}{\lambda}\right) \times (T_{mean} + 17.8)$	Hargreaves and Samani, 1985
Makkink method	$ET_0 = 0.61 \times 0.408 \times \left(\frac{\Delta}{\Delta + \gamma}\right) R_s - 0.12$	Makkink, 1957
Irmak method	$ET_0 = 0.149 \times R_s + 0.079 \times T_{mean} - 0.611$	Irmark *et al.* 2003
Castaneda-Rao method	$ET_0 = 0.7 \times \left(\frac{\Delta}{\Delta + \gamma}\right) \times \left(\frac{R_s}{\lambda}\right) - 0.12$	Castaneda-Rao, 2005

ET_0 - Reference evapotranspiration [mm/day], R_n - Net radiation at the surface [MJ/m^2/day], G- Soil heat flux density [MJ/m^2/day], T - 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}– Average temperature, R_a - Extraterrestrial radiation [MJ/m^2],

a = - 0.3,

$$b = 1.066 - 0.13X10^{-2} RH_{mean} + 0.045 u_2 - 0.02X10^{-3} RH_{mean} u_2 - 0.315X10^{-4} RH^2_{mean} - 0.11X10^{-2} u_2^2$$

$$Atmospheric \; pressure \; P = 101.3\left[\frac{293 - 0.0065z}{293}\right]^{5.26}$$

Psychometric con $\gamma = \frac{C_p P}{\lambda \mu} = 0.000665 \; P$

λ - Latent heat of vaporization, 2.45 [MJ /kg],

C_p - Specific heat at constant pressure, 1.013 10^{-3}[MJ/ kg/ °C],

μ - Ratio of molecular weight of water vapour/dry air = 0.622.

$$R_s = 0.61 \times (T_{max} - T_{min})^{0.5} \times R_a$$

Models for Adequacy Checking

TABLE 2

Statistical tests for adequacy checking

Statistical tests	Formulae
Mean Absolute Error (MAE)	$MAE = \frac{\sum_{i=n}^{n} \lvert ET_{method} - ET_{FAO-56\,PM} \rvert}{n}$
Maximum Absolute Error (MAXE)	$MAXE = MAX \lvert ET_{Method} - ET_{FAO-56\,PM} \rvert_{i=1}^{n}$
Root Mean Square Error (RMSE)	$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (ET_{Method} - ET_{FAO-56\,PM})^2}{n}}$
Standard Error of Estimation (SEE)	$SEE = \sqrt{\frac{\sum_{i=1}^{n} (ET_{Method} - ET_{FAO-56\,PM})^2}{n-1}}$
Percent Error (PE)	$PE = \left\lvert \frac{E\overline{T}_{Method} - E\overline{T}_{FAO-56\,PM}}{E\overline{T}_{FAO-56\,PM}} \right\rvert \times 100$
Ratio between standard and computed ET_0	$RATIO = \frac{E\overline{T}_{Method}}{E\overline{T}_{FAO-56\,PM}}$

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

Mean of ET_0 of standard FAO-56 PM Model $E\overline{T}_{FAO-56\,PM} = \frac{\sum_{i=1}^{n} ET_{FAO-56\,PM}}{n}$

Mean of ET_0 of other computed method $E\overline{T}_{Method} = \frac{\sum_{i=1}^{n} ET_{Method}}{n}$

Simple linear egression

$$Y_{ET_{0_{FAO-56\,PM}}} = \beta_0 + \beta_1 X_{ET_{0_{Method}}} + \varepsilon$$

$$where\ \varepsilon \sim N(0, \sigma_e^2)$$

Generalization of the methods for GKVK station

Owing to the wide ranging inconsistency in meteorological data collection procedures and standards much different evaporation equation, which has more or less the same, has been discussed by different authors were used. These empirical formulae used in this study may be reliable in the areas and over the periods for which they were developed but large error can be expected when they are extrapolated to other climatic areas without recalibrating the constants involved in the formulae. Accordingly, modification was made to the original equation by re-calibrating using the simple linear regression such that slope is nearer to one and intercept is nearer to zero. Further using these re-calibrated constant values in original equation reference evapotranspiration was calculated and PE encountered was estimated for further comparison.

Results and Discussion

Evaluation of reference evapotranspiration (ET_0) by different methods

Monthly average reference evapotranspiration (ET_0) values were computed for nine different radiation methods in order to know the closeness of these estimates with FAO-56 PM model as per the studies reported by the Tomar (2015) and Pandey *et al.* (2016) as given in Table 3. Among these methods, majority of them either overestimated or underestimated ET_0 values when compared to standard FAO-56 PM model. McGuinness-Bordne and Turc methods over estimated the ET_0 values while, Makkink, Caprio, Irmak, Hargreaves-Samani and Castaneda-Rao methods had underestimated the ET_0 values for the entire study period. Further, FAO-24 Radiation method gave ET_0 values nearer to standard FAO-56 PM model. Fig. 1 shows the variation in monthly average Reference Evapotranspiration (ET_0) calculated by radiation based methods

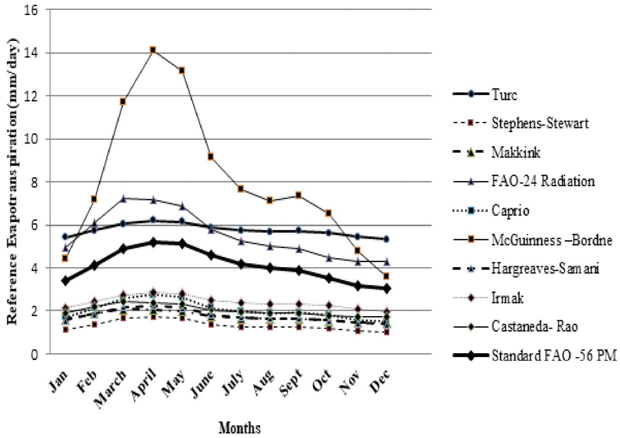

Fig.1: Variation of monthly average Reference Evapotranspiration (ET_0) calculated by radiation based methods during the period 1983-2016.

Table 3

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

Month	Turc	Stephens -Stewart	Makkink	FAO-24 Radiation	Caprio	McGuinness - Bordne	Hargreaves - Samani	Irmak	Castaneda - Rao	Standard FAO -56 PM
Jan	5.43	1.13	1.63	4.98	1.71	4.39	1.56	2.12	1.89	3.42
Feb	5.74	1.38	1.89	6.11	2.12	7.15	1.86	2.43	2.18	4.10
March	6.06	1.66	2.10	7.20	2.59	11.72	2.18	2.75	2.42	4.90
April	6.21	1.75	2.08	7.15	2.75	14.09	2.25	2.88	2.40	5.20
May	6.15	1.68	2.02	6.90	2.63	13.16	2.17	2.82	2.33	5.16
June	5.86	1.38	1.76	5.78	2.14	9.12	1.82	2.49	2.04	4.6
July	5.74	1.28	1.67	5.28	1.97	7.67	1.70	2.37	1.94	4.16
Aug	5.69	1.24	1.64	5.01	1.90	7.12	1.65	2.31	1.90	4.00
Sept	5.71	1.25	1.64	4.91	1.92	7.37	1.66	2.33	1.90	3.87
Oct	5.63	1.17	1.55	4.50	1.79	6.54	1.57	2.24	1.80	3.55
Nov	5.45	1.05	1.46	4.27	1.60	4.76	1.43	2.08	1.70	3.18
Dec	5.33	1.01	1.46	4.32	1.52	3.60	1.39	1.99	1.70	3.07
Average	5.75	1.33	1.74	5.54	2.05	8.06	1.77	2.02	2.20	4.10

Further, the pattern of variation in estimates for different months was uniformly stable for all the under estimated methods whereas McGuiness-Bordne, Turc and FAO-24 Radiation methods showed similar pattern of increase from January to April and a decline from May to December when compared to standard FAO-56 PM model.

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), Percent error (PE) and Ratio between standard value for radiation based methods (Table 4). Further, the relationship between radiation based methods with standard FAO-56 PM model were fitted using linear regression analysis as shown in Fig. 2, respectively. The radiation based methods considered here were mostly underestimated ET_0 values with very low ratios as seen in Table 3. However, they showed very good linear relationship with the standard FAO-56 PM model with relatively high R^2 values ranging from 0.64 to 0.76. But, the analysis of regression methodology does not consider the errors of ET_0 due to combination of errors of variable that nurture the equation. Considering the errors associated with ET_0, standard FAO-24 PM model performed good with consistently low value of MAE, SEE, and RMSE. Further, the per cent error was observed to be 35.10 per cent with good linear relationship of 0.75, having a slope of 0.63 and an intercept of 0.37. Among all the radiation based methods, McGunniess-Bordne performed the worst with the highest PE of 89.21 per cent as this method was suitable for the sub-humid regions. The other radiation methods such as Turc and Makkink which has performed very well in other regions (Zarei *et al*., 2015) has performed poorly to this station may be due to indirect measurement of solar radiation among weather parameters. All the methods resulted in larger difference between SEE and RMSE which indicates that error variance of these methods are not same. Whereas, all the radiation based methods have nearly same value of MAE and RMSE which shows that the errors are of equal magnitude. The evaluated solar

TABLE 4

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

Radiation based methods	Mean of Standard method	Mean of other methods	MAE	MAXE	SEE	RMSE	PE	R^2	Intercept	Slope	Ratio
Turc	4.10	5.75	1.65	2.49	3.15	1.70	43.30	0.75	-10.40	2.52	1.43
Stephens-Stewart	4.10	1.33	2.77	3.39	8.29	2.79	67.56	0.74	0.36	2.81	0.24
McGuineess-Bordne	4.10	8.06	3.98	6.01	23.72	4.09	89.21	0.73	2.45	0.20	1.89
FAO-24 Radiation	4.10	5.54	1.44	2.23	2.47	1.48	35.10	0.75	0.57	0.63	1.35
Caprio	4.10	2.05	2.05	2.64	4.58	2.08	50.03	0.74	0.58	1.72	0.50
Hargreaves - Samani method	4.10	1.77	2.33	2.94	5.94	2.36	56.66	0.72	-0.08	2.36	0.43
Makkink	4.10	1.74	2.36	2.99	6.15	2.39	57.08	0.63	-0.74	2.77	0.43
Irmark	4.10	2.40	1.69	2.30	3.31	1.74	40.83	0.76	-1.79	2.45	0.59
Castaneda-Rao	4.10	2.02	2.08	2.72	4.87	2.12	50.32	0.64	-0.79	2.42	0.50

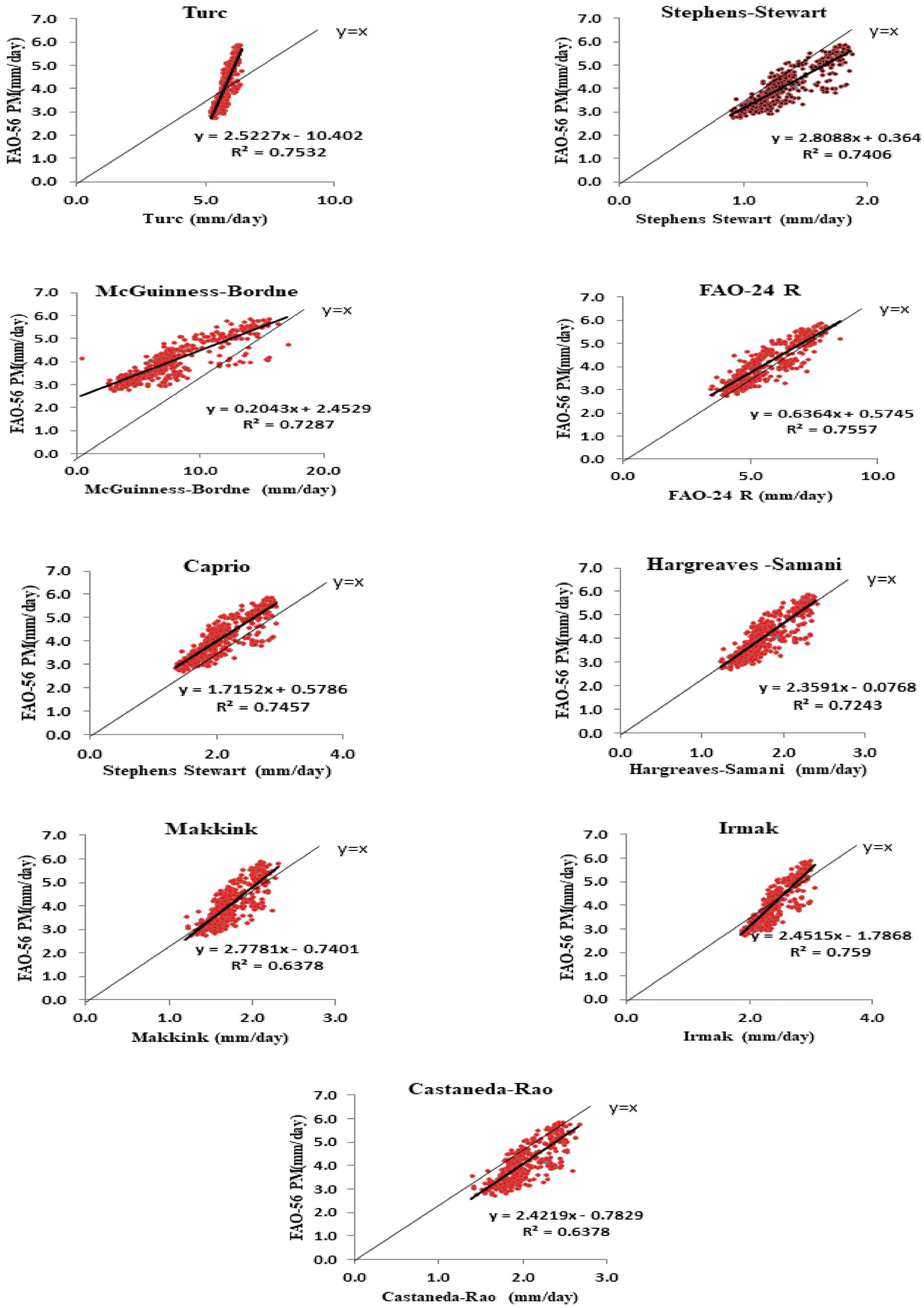

Fig.2: Relationship between estimates of ET_0 by radiation based methods with standard FAO-56 PM model.

TABLE 5

Comparison of parameters before and after calibration for Radiation based methods (Contd..)

Radiation based methods	Generalized equation forms	Original parameter values	Parameter values after re-calibration	Mean of Standard method	Mean of other methods	Mean of other re-calibration methods	PE before re-calibration	PE afterre-calibration
Turc	$ET_0 = a \times \left[\frac{T_{mean}}{T_{mean}+b}\right]\left(\frac{R_s+50}{\lambda}\right)$ $if\ RH > 50$	a = 0.4 b = 15	a = 0.3 b = 15	4.10	5.75	4.31	43.30	5.12
Stephen-Stewart	$ET_0 = (aT_{mean} + 0.07)\frac{R_s}{\lambda}$	a = 0.0148	a = 0.05	4.10	1.33	4.34	- 67.56	5.85
McGuinness-Bordne	$ET_0 = (aT_{mean} - b) \times R_s$	a = 0.00597 b = 0.0838	a = 0.0045 b = 0.062	4.10	8.06	7.61	89.21	85
FAO-24 R	$ET_0 = a + b\left(\frac{\Delta}{\Delta+\gamma}R_s\right)$	a = - 0.3	a = - 0.9	4.10	5.54	4.85	35.10	18.29
Caprio	$ET_0 = (a \times T_{mean} - a) \times R_s$	a = 0.01092708 b = 0.0060706	a = 0.022 b = 0.0060706	4.10	2.05	4.08	-50.03	-0.48
Hargreaves Samani	$ET_0 = a \times \left(\frac{R_s}{\lambda}\right) \times (T_{mean} + 17.8)$	a = 0.0135 b = 17.8	a = 0.0279 b = 17.8	4.1	1.77	3.65	-50.66	-10.73
Makkink	$ET_0 = a \times b \times \left(\frac{\Delta}{\Delta+\gamma}\right)R_s - 0.12$	a = 0.61 b = 0.408 c = -0.12	a = 1.27 b = 0.408 c = -0.12	4.1	1.74	3.75	-57.08	-8.5
Irmark	$ET_0 = a\,R_s + b \times T_{mean} - c$	a = 0.149 b = 0.079 c = 0.611	a = 0.3 b = 0.079	4.1	2.40	3.56	-40.83	-13.7
Castaneda-Rao	$ET_0 = 0.7 \times \left(\frac{\Delta}{\Delta+\gamma}\right) \times \left(\frac{R_s}{\lambda}\right) - 0.12$	a = 0.7 b = -0.12	a = 1.25 b = -0.12	4.1	2.02	3.69	50.32	-10

radiation methods for estimating ET_0 can be ranked based on their performance as FAO-24 Radiation, Turc, Irmark, Caprio, Castaneda-Rao, Hargreaves-Samani and Makkink, Stephens-Stewart method had performed very poorly.

Modifications to ET_0 equations for 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 PE of reference evapotranspiration (ET_0) are presented in Table 5. 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).

In Table 5, it was observed after re-calibration that the parameter values of 4.5,16, 0.653 and 0.0025 used in Romanenkos, 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 (2.00 mm/day), respectively. Further, it was observed that the parameter values of 0.4, 0.0148, -0.3 and 0.01092708 used in Turc, Stephen-Stewart, FAO-24 and Caprio methods were re-calibrated to 0.3, 0.055, -0.9, and 0.022 thus, increasing the ET_0 value of 4.31 mm/day (from 5.75 mm/day), 4.34 mm/day (from 1.33 mm/day), 4.85 mm/day (from 5.54 mm/day) and 4.08 mm/day (from 2.05 mm/day), respectively. Further, McGuinness-Bordne does not show any improvement in the estimation of ET_0. Similarly, it was also observed that constant values of 0.0135, 0.61, 0.149 and 0.7 used in Hargreaves Samani, Makkink, Irmak and Castaneda-Rao were changed to 0.0279, 1.27, 0.3 and 1.25 thus, improving the ET_0 values of 3.65 mm/day (from 1.77 mm/day), 3.75 mm/day (from 1.74 mm/day), 3.56 mm/day (2.40 mm/day), 3.69 mm/day (2.02 mm/day).

From the present study, it can be concluded that among all nine radiation based methods, the estimated values of Turc and McGuinness-Bordne were over estimated while all other methods were found to be under estimated. Thus, FAO-24R based on radiation 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 the proper calibration. Besides this, the weather parameters required for use in these methods are 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.

References

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P., 2008, Climate change and water. Technical paper of the intergovernmental panel on climate change. IPCC Secretariat: Geneva, Switzerland.

Caprio, J. M., 1974, The solar thermal unit concept in problems related to plant development and potential evapotranspiration. Phenology and seasonality methods in ecological studies, **8**, H. Lieth, ed. Springer, New York, 353-364.

Castaneda, L. and Prasad Rao, 2005, Comparison of methods for estimating reference evapotranspiration in southern California. *The Electronic Journal of the Int. Assoc. for Environ. Hydrology,* **13** : 65-73.

Doorenbos, J. and Pruitt, W., 1977, Crop water requirements irrigation and drainage paper 24, Food and Agriculture Organization of the United Nations, Rome, 144.

Hargreaves, G. H. and Samani, Z. A., 1985, Reference crop evapotranspiration from temperature. *Appld. Engg. in Agric.*, **1** (2) : 96-99.

IRMAK, S., IRMAK, A., ALLEN, R. G. AND JONES, J. W., 2003, Solar and net radiation-based equations to estimate reference evapotranspiration in humid climates. *Journal of Irrig. Drain. Eng.,* **129** (5) : 336-347.

JENSEN, M. E., 1966, Empirical methods of estimating or predicting evapotranspiration using radiation. evapotranspiration and its role in water resources management, American Society of Agricultural Engineers. Chicago, **64** : 49 - 53.

JENSEN, M. E., BURMAN, R. D. AND ALLEN, R. G., 1990, Evapotranspiration and irrigation water requirements. In: ASCE Manual No. 70. *Am. Soc. Civil Engr*., New York, NY.

KUMAR, S. A., LO, P. H. AND CHEN, S. M., 2008, Electrochemical selective determination of ascorbic acid at redox active polymer modified electrode derived from direct blue 71. *Biosensors and Bioelectronics*, **24** (4) : 518-523.

LANDERAS, G., ORTIZ-BARRETO, A., LOPEZ, J. J. AND SINGH, R., 2008, Comparison of artificial neural network models and empirical and semi-empirical equations for daily reference evapotranspiration estimation in the Basque country (Northern Spain). *Agricultural Water Management*, Amsterdam, **95** : 298-306

MAEDA, E. E., WIBERG, D. A. AND PELLIKKA, P. K. E., 2011, Estimating reference evapotranspiration using remote sensing with limited ground data availability in Kenya, App. Geography, Amsterdam, **31** (1) : 251-258.

MAKKINK, G. F., 1957, Testing the penman formula by means of lysimeters. *Journal of Inst. Water Eng.,* **11**: 277-288.

MCGUINNESS, J. L. AND BORDNE, E. F., 1972, A comparison of lysimeter derived potential evapotranspiration with computed values, Technical Bulletin 1452, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, DC.

PANDEY, K. P., DABRAL, P. P. AND PANDEY, P., 2016, Evaluation of reference evapotranspiration methods for the North-eastern region of India. *Int. Soil and Water Conservation Res.*, **4** : 52-63

STEPHENS, J. C. AND STEWART, E. H., 1963, A comparison of procedures for computing evaporation and evapotranspiration. *Int. Assoc. Science Hydrol***.,** **62** : 123 - 133.

TOMAR, ARVIND, SINGH, 2015, Comparative performance of reference evapotranspiration equations at Sub-Humid Tarai Region of Uttarakhand, India. *Int. Journal of Agric. Res.*, **10** (2) : 65-73.

TURC, L., 1961, Water requirements assessment of irrigation, potential evapotranspiration: simplified and updated climatic formul. *Ann. Agronom*., **12** : 13-49.

WALTER, I. A., ALLEN, R. G., ELLIOTT, R., JENSEN, M. E., ITENFISU, D., MECHAM, B. AND SPOFFORD, T., 2000, ASCE's standardized reference evapotranspiration equation. In Watershed management and operations management, 1-11.

ZAREI, A. R., ZARE, S. AND PARAMEHAR, A. H., 2015, Comparison of several methods to estimate reference evapotranspiration. *West African Journal of Applied Ecology*, **25** (2) : 17-25.

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