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Comparison of Different Evapotranspiration Estimation Techniques for Mohanpur, Nadia District, West Bengal

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ABSTRACT

The accurate estimation of reference evapotranspiration (ET_o) plays a pivotal role in water resources planning and management studies. The present study was attempted to estimate the reference evapotranspiration (ET_o) using three temperature based methods namely, Blaney-Criddle method, Thornthwaite method and Hargreaves-Samani model and three radiation based methods namely, Turc method, Priestly-Taylor model, and FAO - 24 Radiation Model for Mohanpur area, Nadia district, West Bengal. ET estimates of the above mentioned methods were then compared with FAO Penman - Monteith (FAO-56 PM) method, which was considered as the standard method of ET_o estimation, to check the capabilities of different models to predict ET_o for the study area. The present analysis was carried out using 10-years daily weather data of Mohanpur weather station. The results of the study revealed that, the ET_o values at Mohanpur, Nadia district, West Bengal, India were in the range of 3.5 mm/day to 5.0 mm/day. A rank was assigned to different methods based on the comparative analysis of different ET_o estimation methods with FAO-56 PM method and it could be inferred that Turc method as the closest method and Thornthwaite method as the least-matched method to FAO 56 Penman-Monteith for the study area.

Keywords: Reference evapotranspiration, Mohanpur, FAO-56 Penman-Monteith method, water resources

I INTRODUCTION

Evapotranspiration (ET) contributes a major portion towards the hydrologic cycle of any watershed. It is a complex and non-linear process since it depends upon various interdependent factors such as radiation, temperature, wind speed, relative humidity etc. and it's precise estimation plays a vital role in various water resource planning and management studies, for example, irrigation scheduling, crop production, water budgeting etc. Evapotranspiration mainly constitutes of two parts, one is evaporations, i.e., loss of water from any wet surface or water body and transpiration which is the loss of water from plant body to the atmosphere. Evapotranspiration can be classified as potential evapotranspiration (PET) and actual evapotranspiration (AET) based upon the availability of water, canopy cover, soil type etc. Another term commonly used to theoretically define ET is reference evapotranspiration (ET_o). Reference evapotranspiration can be defined as theoretical evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground, and not short of water [1]. Numerous research works were carried out in developing various empirical and semi-empirical models for accurate estimation of this vital hydrologic cycle parameter using various climatological data. Some of these models depend on a variety of weather parameters whereas, some models give good results with less climatological data. The different ET_o estimation methods can be grouped under different categories according to their data requirement namely temperature based methods, radiation based methods, combination methods etc, and their names suggest the type of data requirements by the methods. However, not only data requirement varies from method to method, but also the performance and accuracy of different methods vary with different climatic conditions and with the availability of data [2]. One of the methods that are widely used to estimate reference evapotranspiration is the Penman-Monteith method [3] and it has proved to be the most accurate method of estimating evapotranspiration. But the requirements of large input parameters have limited the use of this method. To overcome this situation, comparative assessment of several ET_o estimation methods with FAO-Penman-56 method were carried out by various researchers in order to select the most dependable ET_o estimation method with sparse data for a particular location. Several

researchers ([4]; [5]; [6];[7]**)** have compared various evapotranspiration estimation methods in order to find out the best ET_o estimation model in various parts of the country as well as the world. Alkaeed et al., [8] compared six reference evapotranspiration method considering FAO-56 Penman method as the standard method and found Thronthwaite method as the most appropriate method for ET_o estimation for the study area. Chavan et al., [9] conducted a comparative analysis of four ET_o estimation methods with FAO-Penman method for southern hot and humid region of *Konkan* platue in Maharashtra state and found Blaney-Criddle is the most reliable and accurate methods for estimation of ET_o for the study region. Nikam et al., [10] has also performed a comparetive assessment study to select the most appropriate method for estimating reference evapotranspiration for Pantnagar (Uttarakhand), India on a monthly as well as on a seasonal basis.
With this context, the present paper aims to compare the performance of seven broadly used ET_o estimation methods, namely Hargreaves Samani Method, Thornthwaite Method, Blaney-Criddle Method, Priestley-Taylor Method, FAO - 24 Radiation Model, Turc Method and FAO-56 Penman-Monteith method to suggest the most appropriate method of reference ET estimation for Mohanpur area. The estimated ET_o values by different methods were compared with the ET_o values estimated by FAO-56 Penman-Monteith method which was considered as the standard method of reference ET estimation and the most reliable ET estimation method for the study area was suggested.

II MATERIALS AND METHODS

2.1 Study area description

The study site is located at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal at latitude $23^0 30$N, longitude 89^0E and at an elevation of 9.75m above the mean sea level (MSL). It has humid climate with an average rainfall of 1400 mm, approximately 75% of which occurs during the month of June to September due to onset of southwest monsoon. The mean temperature, relative humidity and bright sunshine hours of the study area vary from 8 ^{0}C to 40^0 C, 30 to 95% and 6.94 to 6.97, respectively.

2.2 Data collection

Daily data of maximum temperature, minimum temperature, wind speed, sunshine hour, maximum RH(%), minimum RH(%) for 10 years period (1st January 2006-31st December 2015) for the study site were collected from "Department of Agricultural Meteorology and Physics", Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal.

2.3 Description of ET estimation methods

In the present study, daily ET_o values were estimated using seven different ET_o estimation methods. Three temperature based methods namely, Blaney-Criddle method, Thornthwaite method and Hargreaves-Samani model were considered in the present study. Blaney-Criddle method requires monthly temperature data which can be estimated from daily temperature data. It also requires monthly percentage of annual day light hours which can be calculated from the latitude of the place. The other two temperature based methods, i.e., Thornthwaite method and Hargreaves-Samani model also require information on temperature and location of that particular place. The three radiation based methods considered in the present study are Turc method, Priestly-Taylor model, and FAO-24 Radiation Model. Evapotranspiration was also estimated using FAO-56 Penman-Monteith method. This method is based on sound physical principles considering both the mass transfer and energy transfer approaches of evapotranspiration estimation. In the present study, ET_o calculated by FAO-56 Penman-Monteith method were taken as standard reference evapotranspiration value for the location for various comparative analysis and selection of most suitable method of ET_o estimation for the study area. The methods used in the present study are briefly described in the following sections.

2.4Temperature based methods

a) Blaney-Criddle Model

Blaney-Criddle [11] (1950) formula is purely empirical formula based on data from arid western United States. This formula assumes that the potential evapotranspiration (PET) is related to hours of sunshine and temperature, which are taken as measures of solar radiation at an area. The reference evapotranspiration in a crop-growing season is given by

$$ET_0 = (0.46t + 8.13)P$$

Where, ET_0= reference evapotranspiration (cm); P= monthly % of annual day-time hours, depends on the latitude of the place; t = daily average temperature (^{0}C).

b) Thornthwaite Model

Thornthwaite [12] (1948) correlated mean monthly temperature with ET as determined by east-central United States water balance studies. The Thornthwaite equation is:

$$ET_0 = 1.6L_a\left(\frac{10\overline{T}}{I_t}\right)^a$$

Where, ET_0 in cm ; L_a= adjustment of no. of day light hours and days in the month ; $\overline{T}$ is the meanmonthly air temperature in ^{0}c , I_t total 12 monthly values of heat index and can be estimated by the following equation

$$I_t = \sum_1^{12} i$$

Where, $i = \left(\frac{\overline{T}}{5}\right)^{1.514}$; $a = 6.75 * 10^{-7} I_t^{\,3} - 7.71 * 10^{-5} I_t^2 + 1.792 * 10^{-2} I_t + 0.49239$

c) Hargreaves - Samani model

Hargreaves and Samani [13] (1985) proposed an equation for estimating grass-related reference ET. Since solar radiation data are not frequently available, this method estimates ET_0 from extraterrestrial radiation and mean monthly maximum and minimum temperatures as follows:

$$ET_0 = 0.0023\, R_A \sqrt{TD}\,(T_{mean} + 17.8)$$

Where, *TD* is the difference between mean daily maximum and minimum temperatures (°C); and R_A is the extraterrestrial solar radiation (MJ m^2 d^1).

2.5 Radiation based methods

a) Turc model

Turc (1961) [14] proposed the following equations for estimating evapotranspiration for two humidity conditions:

$$ET_0 = 0.013\frac{T_{mean}}{T_{mean}+15}(R_S^{'} + 50)\frac{1}{\lambda}$$

For RH_{mean}>50%

$$ET_0 = 0.013\frac{T_{mean}}{T_{mean}+15}(R_S^{'} + 50)\frac{1}{\lambda}\left(1 + \frac{50-RH_{mean}}{70}\right)$$

For $RH_{mean} \leq 50\%$

Where, $R_S^{'}$ is the solar radiation in cal/cm^2/day; $R_S^{'} = \frac{R_S}{0.041869}$ Where, R_s is the solar radiation in MJ/m^2/day; RH_{mean}(%) and λ is the latent heat of vaporization MJ/kg;

b) FAO - 24 Radiation Model

Doorenbos and Pruitt [15] (1977) proposed a radiation based approach of estimating evapotranspiration which is known as FAO - 24 Radiation model. The development of this model is based on an earliar evapotranspiration estimtion method develpoed by Makkink [16].

$$ET_0 = a + b\left[\frac{\Delta}{\Delta+\gamma}R_s\right]\frac{1}{\lambda}$$

Where, a= -0.3; b is an adjustment factor

$$b = 1.066 - 0.13 * 10^{-2} - 2RH_{mean} + 0.045u_d - 0.2 * 10^{-3}RH_{mean} - 0.315 * 10^{-4}RH_{mean}^2 - 0.11 * 10^{-2}u_d^2$$

.

Where, RH_{mean} is the mean relative humidity (%); u_d is the day time wind speed(m/s); R_S is the solar radiation.

c) Priestly and Taylor model

Priestly and Taylor [17] (1972) suggested an evapotranspiration estimation model for wet surface area which is the key condition for potential evapotranspiration. The equation can be expressed as:

$$ET_0 = \frac{1}{\lambda}\alpha\frac{\Delta}{\Delta+\gamma}(R_n - G)$$

Where, Δ is slope of saturation vapor pressure-temperature curve (kPa/ºC), it can be calculated if T_{mean} values are known using Teten's expression as:

$$\Delta = \frac{4098\ e^{0}_{mean}}{(T_{mean} + 237.3)^2}$$

Where, e^{o}_{mean} is saturation vapor pressure at mean temperature (kPa); γ is Psychometric constant (kPa/ºC); R_n is Net Radiation (MJ/m^2/day); α is short wave reflectance or albedo and its value is taken as 0.25; G is heat flux density to the ground (MJ/m^2/day).

2.6 Combination of temperature and radiation based method

a) FAO-56 Penman-Monteith method:

FAO-56 Penman-Monteith method is considered as a sole standard method for the computation of ET_0 from meteorological data. This model contains energy balance term, aerodynamic term, and surface resistance. It is expressed as [1]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \frac{900}{T+273}\gamma(e_s - e_a)u_2}{\Delta + \gamma(1 + 0.34u_2)}$$

where, ET_0 = reference evapotranspiration (mm/day); R_n= net radiation at the crop surface (MJ/m^2/day); G = soil heat flux density (MJ/m^2/day); T = mean daily air temperature at 2 meter height (^{0}c); u_2 = wind speed at 2 meter height (m/sec); e_s= saturation vapour pressure (kPa); e_a= actual vapour pressure (kPa); Δ = slope of vapour pressure curve (kPa/^{0}c); γ = psychometric constant (kPa/^{0}c).

2.7 Statistical Evaluation

In order to select the most appropriate method of ET_o estimation for the study area the performances of the different ET_o estimation techniques were evaluated by comparing the output values of the different methods with that of the FAO-56 PM estimated reference ET using standard error of estimates (SEE). The following equation was used to estimate SEE.

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{n-1}}$$

Further, the performances of the six models were compared with the standard method (FAO-56 PM) using coefficient of correlation (R^2). The method which had provided the lowest SEE and the highest coefficient of correlation (R^2) was selected as the best method. The various methods were also ranked based on the SEE values.

III RESULTS AND DISCUSSIONS

The mean daily ET_0 values for different months estimated by the seven reference evapotranspiration estimation methods as discussed in the section above for the study area are given in Table 1. The data is represented graphically in Figure 1.

Table 1: Mean daily ET_0 values estimated using seven ET_0 estimation methods

Month	Temeparature based method			Radiation based method			Combination method
	Blaney-Criddle	Thornthwaite	Hargreaves-Samani	Priestly-Taylor	FAO-24 Radiation	Turc	FAO-PM
Jan	3.72	0.88	4.43	4.3	4.22	3.95	3.7
Feb	5.3	1.87	4.93	5.03	5.15	4.55	4.39
Mar	5.53	4.1	5.51	5.64	5.6	4.87	5.07
Apr	6.32	6.73	5.52	6.07	5.6	5.01	5.68
May	5.65	7.32	5.18	5.72	5.21	4.71	5.3
Jun	3.94	7.53	4.63	5.72	3.82	3.94	4.27
Jul	3.04	6.73	4.25	4.33	3.2	3.63	3.78
Aug	3.26	6.3	4.08	4.51	3.46	3.79	3.87
Sep	3.94	5.86	4.33	4.9	3.78	4.11	4.14
Oct	4.67	4.46	4.62	5.43	4.69	4.62	4.53

Nov	4.89	2.49	4.9	5.38	4.98	4.75	4.53
Dec	3.64	1.12	4.6	4.52	4.3	4.16	3.84

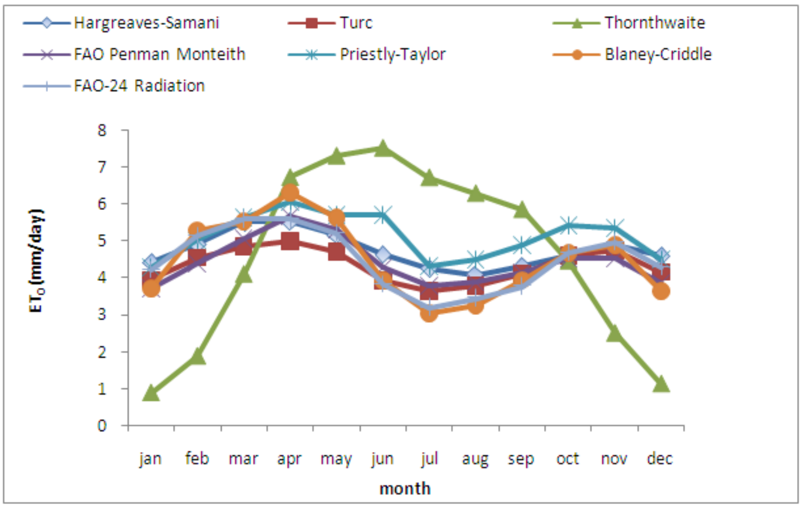

Figure. 1 Comparison of ET_o estimates of different methods with FAO-PM method

In general, the ET_o values at Mohanpur, Nadia district, West Bengal, India are in the range of 3.5 mm/day to 5.0 mm/day. The peak values are found in March to May as the temperature is high during this period. On the other hand, the least ET_o values are observed in the months of November-December. The monthly pattern produced by different methods is not similar. The Thornthwaite method showed a different pattern than the other methods as Thornthwaite method is totally a temperature based method. Blaney-Criddle method, Turc method and FAO-24 Radiation method showed almost similar ET_o values. The overall mean ET_0 estimated by Priestly-Taylor Method was slightly higher (5.13 mm/day) than that computed by other methods. It is apparent from Fig. 1 that monthly ET_o values estimated by all the methods (except Thornthwaite method) show almost same trend throughout the year, i.e., ET_o values decreases during the months of June, July, August and September, which comprise the peak monsoon months with high relative humidity, low wind speed and lower temperature. ET_o values also show a decreasing trend during winter months (of November, December and January) (but more than monsoon months) with low temperature causing low evaporation rates as shown in Fig. 1. Fig. 1 also reveals that Thornthwaite method overestimate the ET_o values during the high temperature months as this method is solely depends on temperature.

3.1Comparison of six ET_0 estimation methods with FAO-Penman Monteith method

The accuracy and reliability of the six different ET_o estimation methods were assessed by comparing the outputs of the different models with that of the reference ET estimates by FAO-Penman method using SEE and regression analysis. The estimated values of SEE and R^2 are presented in Table 2. The graphical representations of regression relationship of the ET_o estimates by six different methods with the ET_o estimates by FAO-56 PM method are presented in Figure. 2 a-f. From the Table 2 it is clear that among the temperature based methods Thornthwaite method gives lowest R^2 value and highest error values, whereas, Blaney-Criddle and Hargreaves-Samani merthod gave the coefficient of correlation as well as the error values in the close range. On the other hand, among the radiation based methods, Turc method gives less SEE and Priestly-Taylor method gives highest R^2 value. Less the standard error more closest the value with respect to the standard value (here ET_o calculated by FAO-Penman-Monteith equation), so based on standard error estimation Turc method was found most close to FAO 56-Penman-Monteith method in Mohanpur, and Thornthwaite method performed poor as compared to FAO-Penman-Monteith method.

Table 2: Statistical analysis between ET_0 estimates by Penman-Monteith method and other models under study.

Statistical Parameters	Temperature Based Methods			Radiation Based Methods		
	Thornthwaite	Hargreaves-Samani	Blaney-Criddle	Turc	FAO-24 Radiation	Priestly-Taylor
SEE	2.34	0.45	0.51	0.33	0.47	0.79
R^2(linear)	0.12	0.82	0.88	0.77	0.69	0.81

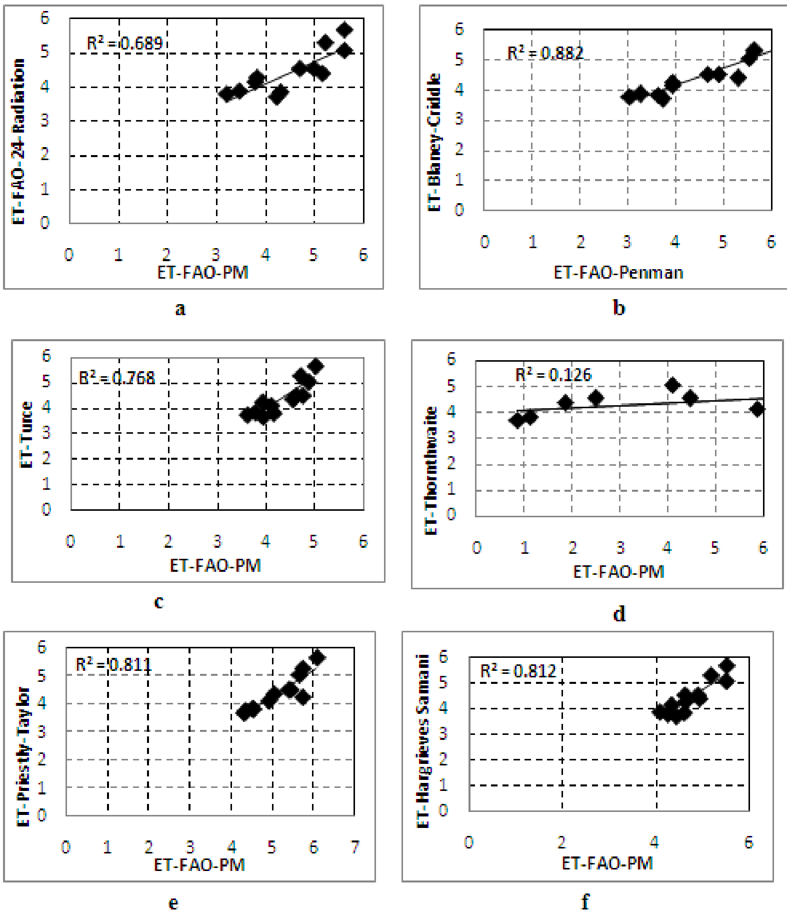

Figure 2 (a) to (f) Regression relationship between FAO-Penman Monteith method and different ET estimation methods considered in the study.

IV CONCLUSIONS

An attempt was made to identify the most suitable method for estimation of evapotranspiration for Mohanpur area, Nadia district using six well known reference evapotranspiration (ET_o) estimation methods by comparing the ET_o estimates by FAO-56 method, which was considered as the standard method in absence of reliable field data. The results of the study reveals that, the ET_o values for Mohanpur, Nadia district, West Bengal, India are in the range of 3.5 mm/day to 5.0 mm/day. The mean daily ET_o values estimated by all the methods (except Thornthwaite method) showed almost same trend throughout the year, i.e., a decreasing trend during the months of June, July, August and September, which comprised the peak monsoon months with high relative humidity, low wind speed and lower temperature. ET_o values also showed a decreasing trend during winter months (of November, December and January) (but more than monsoon months) with low temperature causing low evaporation rates. The peak values are found in March-May as the temperature is high during this period. Blaney-Criddle method, Turc method and FAO - 24 Radiation method showed almost equal ET_o for all months. The overall mean ET_o estimated by Pristly-Taylor Method was slightly higher (5.13mm/day) than that computed by other methods. A ranking of different methods based on SEE revealed Turc method as the closer method to FAO 56 Penman-Monteith method in Mohanpur, and Thornthwaite method performed poor as compared to FAO-Penman-Monteith method.

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