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Performance evaluation of evapotranspiration estimation methods in Sultanpur, Uttar Pradesh, India

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ABSTRACT

Accurate estimation of evapotranspiration plays a vital role in judicious irrigation scheduling. Keeping this in view, a study was undertaken to compare the performance of five methods, viz. Penman method (PM), FAO Penman Monteith (FAO-PM), Priestley-Taylor (PT), FAO Radiation method (FAO-RM) and Hargreaves methods (HM) for Sultanpur District of Uttar Pradesh, India using the daily weather data acquired from automatic weather station during 2016–17. The performance evaluation of selected methods was carried out using linear regression and simple statistical analysis to suggest a substitute of FAO-PM for estimation of reference evapotranspiration using minimal climatic parameters available at regional scales. It was observed that the PM method performed the best and was in line with estimated ET_0 by FAO-PM method with coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Modified Nash-Sutcliffe Coefficient (E_{MNS}), Percent Bias (PBIAS) estimated as 0.94, 0.54, 0.40, 0.73, 3.74 for the year 2016 and 0.95, 0.44, 0.36, 0.73, 6.01 in 2017, respectively. Nonetheless, it was observed form this study that the PM method which requires four parameters, viz. daily solar radiation, maximum and minimum air temperature, and wind speed can be a substitute to FAO-PM that require more parameters for ET_0 estimation in data scarce situations.

Keywords: Irrigation scheduling, Performance evaluation, Reference evapotranspiration models, Weather parameters

Evapotranspiration is a major component of the water cycle, which accounts for 90% of the precipitation in semi-arid and arid regions (Song *et al.* 2019). However, due to non-availability of measured evapotranspiration data at many locations, the reference evapotranspiration (ET_0) is being used to estimate actual evapotranspiration, and crop water requirements (Cruz-Blanco *et al.* 2014). Reference evapotranspiration (ET_0) is one of the most important parameters for climatological, hydrological and agricultural studies (Allen *et al.* 1998). Studies indicated that the performance of different evapotranspiration estimation methods displayed spatial and temporal patterns, and most of these methods may be applicable only in areas where they were developed. Moreover, universally accepted method for estimating ET_0 is the FAO Penman-Monteith (FAO-PM) method. Considering the input data requirement for the FAO-PM method, an alternative method need to be identified that could be beneficial to some regions having limited meterological data. A plethora of studies indicated FAO-PM method to be the most accurate method under various climatic conditions (Azhar and Perera 2011, Xie and Zhu 2012, Zhao *et al.* 2014, Djaman *et al.* 2017, Song *et al.* 2019). Moreover, Pandey *et al.* (2016) compared 11 radiation based and seven temperature based methods for ET_0 estimation for the north eastern region of India. It was reported that five methods such as four radiations based and one temperature based ET_0 estimation was at par with FAO-PM method. Further, they indicated that the radiation and temperature extremes are most sensitive parameters for accurate ET_0 estimation. Keeping in view of the above, an effort was made in this study to compare five different ET_0 estimation methods using the data of Sultanpur district, UP, India, in which 59.78% of farm land is under irrigated rice-wheat cropping system.

MATERIAL AND METHODS

Sultanpur district of UP, India is located between 26^0 to $26^040'$ N latitude and $81^030'$ to $82^040'$E longitude. Total geographical area of the district is 4436 sq. km. Daily weather data was acquired from automatic weather station

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of Sultanpur District of Uttar Pradesh during 2016–17. The average annual rainfall is 1005 mm. The climate is sub-humid and it is characterized by a hot summer and a pleasant cold season, about 89% of rainfall takes place from June to September. The mean monthly maximum temperature is 32.4^{0}C and mean monthly minimum temperature is 19^{0}C. Land use/cover map (LULC) map was classified into five classes, viz. agricultural land, fallow land, water bodies, forest and settlement. Maximum land use pattern of catchment was found under agricultural land. Rice is the dominant crop of *kharif* and accounts for 34.78% of the total cropped area in the District. The degree of dominance is comparatively less in the north-western part than the south-western part of the district. The next most important cereal crop is wheat which occupies nearly 25% area of the total cropped area and well distributed all over the district. Other crops like barley and millets occupied 4% and 5% of the gross cropped area respectively. The study area having different soil texture, viz. coarse texture, fine texture, medium texture and moderately coarse texture.

The study was undertaken to compare five widely used reference evapotranspiration (ET_0) models, viz. Penman Method (PM), FAO Penman Monteith (FAO-PM), Priestley Taylor (PT), FAO Radiation method (FAO-RM) and Hargreaves methods (HM) for Sultanpur District using the daily weather data acquired from automatic weather station during 2016 and 2017. The Mean monthly maximum temperature for year 2016 values ranged from 21.60^{o}C in January to 39.66^{o}C in May with coefficient of variation of 18.31%. Similarly, the mean monthly minimum temperature year 2017 values ranged from 8.2^{o}C in December to 26.62^{o}C in August with coefficient of variation of 38.48%. Thus, January recorded coldest month while May recorded the highest value of mean monthly temperature indicating the warmest month of a year. The mean monthly average relative humidity values were 83.46%. The maximum wind velocity was observed to be during April, which was 5.45 km/h and a minimum of 1.66 km/h during November. The data of daily solar radiation, daily rainfall, maximum and minimum air temperature and average daily relative humidity were used in the analysis.

Penman method (PM): The Penman method (Doorenbos *et al.* 1977) is a modification of the initial Penman formula and require four input parameters for estimation of ET_0 (Pandey *et al*. 2016).

FAO- Penman Monteith method (FAO-PM): The reference ET_0 values on daily basis were estimated using FAO-PM method, which is a hypothetical *alfalfa* grass reference and radiation based model that require nine input parameters for estimation, which is detailed in Allen *et al.* (1998). This method is used as the standard method for comparison with other methods (Pandey *et al*. 2016).

Priestley Taylor method (PT): Priestley and Taylor (1972) developed a radiation based model to calculate ET_0 using net radiation and soil heat flux. The Priestley-Taylor method is the modifications and simplifications of the Penman formula (Doorenbos *et al.* 1977) and requires seven input parameters for estimation of ET_0 (Pandey *et al*. 2016).

FAO Radiation method (FAO-RM): Radiation method uses radiation based approach to estimate ET0 and it requires only two input parameters (Doorenbos *et al.* 1977, Pandey *et al*. 2016).

Hargreaves method (HM): The Hargreaves method (Hargreaves and Samani 1985, Hargreaves and Allen 2003) is the temperature based estimation of daily ET_0. This method requires four input parameters for ET_0 estimation (Pandey *et al*. 2016).

Performance evaluation of ET_0 estimation methods: Result of each reference evapotranspiration model was compared with FAO-PM method. Different statistical indicators were assessed *i.e.* The coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Modified of Nash-Sutcliffe Coefficient (E_{MNS}), Percent Bias (PBIAS), for the model's evaluation using equations 1 to 5.

$$\text{RMSE} = \frac{\sum_{i=1}^{n}\left|Y_i^{obs} - Y_i^{sim}\right|}{Y_i^{obs}\left(n-1\right)} \tag{1}$$

$$\text{MAE} = \frac{\left(Y_i^{obs} - Y_i^{sim}\right)}{N} \tag{2}$$

The coefficient of determination (R^2)

It represents the proportion of the total in the observed data that can be explained by the model and calculated using the equation;

$$R^2 = \left\{\frac{\sum_{i=1}^{N}\left(Y_i^{obs} - Y_{mean}^{obs}\right)\left(Y_i^{sim} - Y_{mean}^{sim}\right)}{\left[\left[\sum_{i=1}^{N}\left(Y_i^{obs} - Y_{mean}^{obs}\right)\right]0.5\left[\sum_{i=1}^{N}\left(Y_i^{sim} - Y_{mean}^{sim}\right)2\right]0.5\right]}\right\}^2 \tag{3}$$

Percent Bias (PBIAS) is calculated by using following equation;

$$\text{PBIAS} = \left(\frac{\sum_{i=1}^{N}\left(Y_i^{obs} - Y_i^{sim}\right)\times 100}{\sum_{i=1}^{N}Y_i^{obs}}\right) \tag{4}$$

where, PBIAS is the deviation of data being evaluated, expressed as %

Modified Nash-Sutcliffe Coefficient (E_{NS}) is calculated using the equation:

$$E_j = 1 - \frac{\sum_{i=1}^{n}\left|Y_i^{obs} - Y_i^{sim}\right|^i}{\sum_{i=1}^{n}\left|Y_i^{obs} - Y_{mean}^{obs}\right|^i}\, with j \in N \tag{5}$$

where, Y_i^{obs} is the ith observed data, Y_{mean}^{obs} is mean of observed data, Y_i^{sim} is the ith simulated value, Y^{sim}_{mean} is the mean model simulated value and N is the total number of events.

RESULTS AND DISCUSSION

The mean monthly reference evapotranspiration estimated for the year 2016 using different models indicated that the highest mean monthly ET_0 was estimated to be 223.72 mm for the month of April by HM model and the least value (33.82 mm) was estimated by FAO-RM for the month of November. However in the year 2017 (Table 1), the highest estimated mean monthly ET_0 was 214.65 mm in month of May by HM model and least value was estimated by FAO-RM which was 40.53 mm in month of January for year 2017. Moreover, the coefficients of variation of the evaluated models ranged from 34.11% (HM Model) to 51.97% FAO-RM Model. The result showed that the average of mean monthly ET_0 estimated by FAO PM (benchmark) model was 108.02 mm, but that of the Priestley-Taylor was 104.03 mm indicating underestimation, whereas PM, HM and FAO-RM model yielded 112.08 mm, 139.91 mm, and 111.79 mm, respectively indicating over estimation compared to PM Monteith Model. It was observed (Fig 1) that none of the models gave identical results but the PM model estimation was very close to the FAO-PM model. It was also observed that the estimation by Hargreaves model was lower by 23.94%, as compared to PM method, which was the highest variation as compared to all tested models, whereas the PM model underestimated (-6.01%) followed by PT model (-1.89%). The mean monthly reference evapotranspiration for the year 2017 (Table 1) indicate that the coefficients of variation of estimated models ranged from 32.54% (Hargreaves model) to 45.87% (FAO-RM model). Results showed that the average of mean monthly ET_0 estimated by FAO PM model was 110.47 mm. It was observed that the Priestley Taylor model underestimated (+3.69%) as compared to the FAO-PM model (Fig 2). However, other evaluated models overestimated ET_0 as estimated by the benchmark model. Moreover, the overestimation percentage of HM model was the highest (-29.53%), indicating its poor performance amongst all tested models.

Evaluation of daily reference evapotranspiration using different models for the year 2016 and 2017: Daily reference evapotranspiration value pertaining to FAO-PM model versus PM, PT, HM, FAO-RM methods for year 2016 showed that none of the models gave identical results but the PM model estimation was very close to the FAO-PM model. It was observed that PM and HM were the most and the least appropriate models, respectively. The coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Modified Nash-Sutcliffe Coefficient (E_{MNS}), Percent Bias (PBIAS) during 2016 were 0.94, .54, 0.40, 0.73, 3.74, respectively for the PM model (Table 2). The PM model performed better than other models. FAO-RM and PT were ranked as the second and third best models respectively (Djaman *et al.* 2017). The coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Modified Nash-Sutcliffe Coefficient (E_{MNS}), Percent Bias (PBIAS) were 0.95,0.44, 0.36, 0.73, 6.01 during 2017, respectively for PM model. The PM model showed better performance than other models. FAO-RM and PT were placed as the second and third best models respectively. Gupta *et al.* (2010) also found similar result pertaining to performance of different methods (Table 2**).**

Table 1 Estimated mean monthly reference evapotranspiration using different models (2017)

Month	FAO PM	PM	P&T	HM	FAO-RM
January	46.75	53.95	43.34	78.63	40.53
February	69.34	76.63	64.65	103.28	74.33
March	122.79	131.08	112.18	161.53	146.75
April	174.26	171.54	157.75	201.44	193.99
May	193.44	187.96	175.23	214.65	213.24
June	166.52	168.65	168.43	183.79	177.35
July	115.80	120.05	133.51	128.45	110.02
August	109.27	115.10	129.37	129.36	102.42
September	115.73	125.30	137.52	126.85	119.08
October	100.24	115.90	115.36	129.01	115.41
November	62.40	77.86	63.79	101.33	75.53
December	49.07	61.26	49.63	84.66	58.63
SD	48.84	43.90	46.58	44.55	54.55
SEM	14.10	12.67	13.45	12.86	15.75
CV(%)	44.21	37.49	41.38	32.54	45.87
Average	110.47	117.11	112.57	136.91	118.94

Ranking of ET_0 estimation methods: A Ranking of ET0 estimation method is based on the accuracy of ET_0

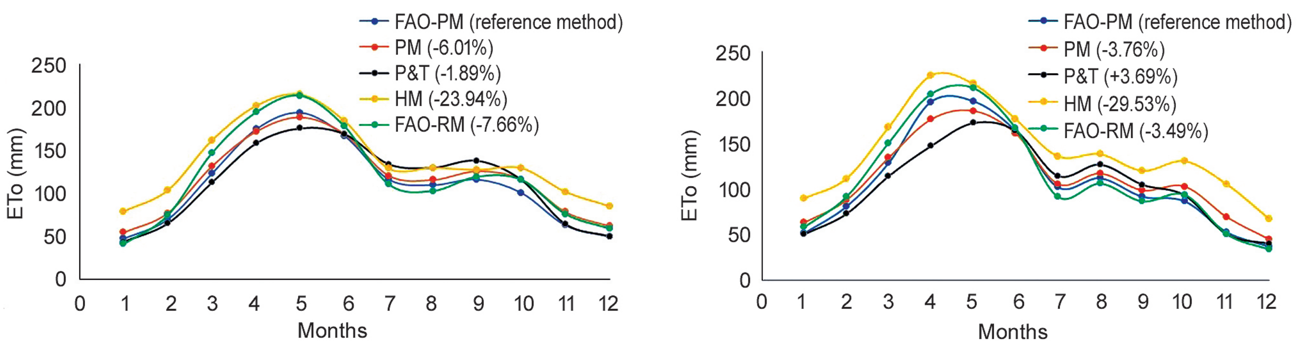

Fig 1 Trends of monthly ET_0 values (mm) estimated using four empirical models compared with FAO-PM model during 2016 (A) and 2017 (B).

Table 2 Prediction error statistics and prioritized ranking of Penman model, Priestely-Taylor, Hargreaves, Radiation models compared with the FAO-PM model for years 2016 and 2017

Year	Method	R^2	RMSE	MAE	PBISAS	E_{MNS}	Prioritized Rank
2016	PM	0.94	0.54	0.40	3.74	0.73	1
	PT	0.84	0.76	0.53	3.70	0.65	3
	HM	0.83	1.28	1.14	29.48	0.24	4
	FAO-RM	0.95	0.67	0.51	12.48	0.67	2
2017	PM	0.95	0.44	0.36	6.01	0.73	1
	PT	0.86	0.62	0.48	1.89	0.65	3
	HM	0.79	1.15	1.08	23.94	0.27	4
	FAO-RM	0.92	0.60	0.46	7.66	0.67	2

prediction as compared to the FAO-PM method. Among different attempted methods, the FAO-PM method (Allen *et al.*, 1998) was considered as the method for comparison because of its consideration as standard method to estimate ET_0 under diverse climatic conditions. Ranking of different ET_0 estimation methods for years 2016 and 2017 of Sultanpur district (Uttar Pradesh, India) was carried out with respect to the estimated value by FAO-PM model on the basis of their prediction error statistics [*viz.*coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Modified Nash-Sutcliffe Coefficient (E_{MNS}), Percent Bias (PBIAS)].The result of such comparison is presented in Table 2. It can be observed from (Table 2) that the ranks are in line with the ranks as reported by Gotardo *et al*. (2016). Moreover, the deviation of results as compared to FAO-PM can be attributable to the fact that the FAO-PM uses additional weather parameters, viz. daily solar radiation, maximum and minimum air temperature, wind speed, average daily relative humidity besides leaf area effect on canopy resistance and influence of vegetation height on the surface roughness parameter. Thus, inclusion of these parameters significantly improved the accuracy of FAO-PM method for estimating ET_0 under a wide range of climatic variations and locations. The PM method resulted in the highest coefficient of determination (R^2), lower Root Mean Square Error (RMSE), Mean Absolute Error (MAE) as compared to other methods, hence it was ranked as the number one for the study area. Performance of HM and PT methods were not in line with the FAO-PM as compared to other methods, which may be due to consideration of only temperature and radiation based parameters. The performance of temperature based methods is not as good as compared to other methods. This is because the temperature based models do not take into account the solar radiation and wind speed data besides exclusion of the aerodynamic component in estimation of ET_0. Similarly, the radiation methods do not take into account the wind speed and relative humidity in the evapotranspiration estimation process resulting in poor ET_0 estimation.

Performance of four different evapotranspiration estimation models, viz. PM, FAO-RM, PT, HM were compared with the standard FAO-PM model using daily weather data acquired from automatic weather station during 2016 and 2017 for the Sultanpur District, Uttar Pradesh, India. The results indicated that the Penman model and Hargreaves model were the best and the least appropriate methods for estimating daily ET_0 in both years, respectively as compared to the FAO-PM model. The prime hindrance in adopting FAO-PM model pertains to requirement of nine weather parameters as model input to estimate ET_0, out of which the solar radiation and wind speed data is not recorded by all meteorological observatories in India. In such situation for estimation of ET_0 in data scarce regions, models with minimal input parameters which are generally recorded in observatories of India are required for estimation of ET_0. Therefore, this study can assist users in estimation of ET_0 based on availability of weather data besides its estimation accuracy leading to judicious application of irrigation water for enhancement of water productivity at regional scales.

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