An Approach for Estimation of Evapotranspiration by Standardizing Parsimonious Method

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Abstract Evapotranspiration (ET) is one of the important components of the hydrological cycle which is essential for sustainable water resource management and ecohydrological studies. Accurate estimation of ET is a crucial task in data-scarce regions due to limited meteorological variables. There exist a number of indirect methods among which the standard method for computing ET is FAO-56-Penman–Monteith (PM) method. However, due to paucity of flux data such as the components of net radiation, relative humidity, vapour pressure, and wind speed in many parts of the world, the use of standard benchmark method is limited. This limitation provides the widespread acceptance of the method which uses fewer variables and can give an accurate estimation of ET for water resource management. In this study, we have developed a framework to standardize the Hargreaves-based ET in the Kangsabati River basin. We utilize the weather datasets from six stations, namely Purulia, Bankura, Mohanpur, Jhargram, Kharagpur, and Midnapore to apply the ET standardization method. We have compared both the raw and corrected ET from Hargreaves with FAO-56-PM ET prior and after correction by using harmonization method. Performance evaluation of harmonization technique is done using statistical and graphical indicators for the duration of 2006–2010. It is observed that Purulia ($r = 0.83$ and $d = 0.80$) and Mohanpur ($r = 0.85$ and $d = 0.87$) stations are almost standardized appropriately on daily scale. Further, the highest r and R^2 was obtained for Mohanpur station ($r = 0.972$; $d = 0.940$), while least for Jhargram station ($r = 0.961$; $d = 0.741$) at monthly scale. Overall, this approach can be used to provide the utility in data-scarce conditions irrespective of agro-climatic conditions.

Keywords Evapotranspiration · FAO-56-PM Penman–Monteith equation · Hargreaves · Data-scarce · Harmonization

Introduction

Evapotranspiration (ET) is the most significant variable in the global hydrological cycle as it one of the significant losses which take place in the surface energy budget [16]. Accurate estimates of ET are essential for crop modelling, hydrological modelling, climate studies, and agriculture management from regional to global scales [1, 13]. Though there are several methods in the literature which are used to estimate ET, however, for data-scarce regions there is a need to provide a framework to standardize ET with the benchmark method FAO-56-PM. This will provide a basis in different climatologies to use this framework for estimation of ET with parsimonious datasets [20]. The reference ET is estimated about a standard (alfalfa) grass surface, 12 cm in average height with a fixed surface resistance of 70 s/m and albedo of 0.23 [2]. Nowadays, the standard FAO-56-PM ET estimation method is utilized in various regions [3] as the keystone for the irrigation system and various other water supply systems [21, 25]. Depending on varied data availability conditions, different ET estimation methods exist in the literature which has various accuracy levels when compared with the benchmark method.

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There are a wide variety of methods [4, 14, 22] which exists in the literature ranging from empirical approach to physically distributed approach. FAO-56-PM is the sole approach which has been widely accepted [3, 28] in various regions of the world. Undoubtedly, the ET results are quite well in different regions estimated with this method due to the existence of a large number of energy and mass transfer variables. Due to the combination of a large number of variables in the benchmark equation, it limits the usage of this method in the regions where limited weather datasets are available. The importance of ET in the water cycle and hydrological management, in addition to the expensive and sensitive measuring equipment, has led to extensive efforts for modelling the ET mechanism. Also in many regions, estimation of ET is restricted due to limited availability of shortwave and longwave radiation, which is inbuilt with albedo, atmospheric transmissivity, and emissivity which rely on different biomes. Especially, satellite-based estimates of radiation in remote areas have a coarser resolution. This necessitates the parsimonious variable ET method which can be used in remote areas, especially in developing countries like India. The least variable is the temperature method which can be obtained easily almost everywhere. So we chose the desired method, i.e. Hargreaves–Samani (HS) method to estimate the ET which uses fewer variables and widely accepted [18, 26] in comparison with existing methods in the literature. The accuracy of the HS method is quite questionable as it only relies on maximum and minimum temperature. To enhance the accuracy of the HS method, we have used the harmonizing technique to remove the biases from the HS method. The harmonization has well resulted in water and energy-limited ecosystems to remove the bias in the HS method [8]. To overcome the above-mentioned issue, this framework is presented by considering the real scenario of the developing world. A robust and simple methodology is presented to estimate standardize HS ET for management of irrigation strategies and allocation of water resources [15].

Unlike previous studies, a robust and simplified framework is proposed in this study to standardize parsimonious ET method using the benchmark FAO-56-PM method. This proposed approach is conducted through ET analysis in Kangsabati River basin, which lies in the tropical monsoon climatology of Eastern India. The main objective of this research work is to critically evaluate the performance of Hargreaves-based ET estimates against the standard FAO-56-PM method. Further, it is aimed to standardize these parsimonious methods at daily and monthly timescales at six different locations. This study is first of its kind in energy-limited ecosystems which can be of great significance in weather-limited regions.

Materials and Methods

Study Site

The harmonization technique is performed in Kangsabati River basin which lies in the eastern part of India, a tropical monsoon region with 1400 m of annual rainfall. Among which the majority of the rainfall occurs from June to October. The basin lies in the state of West Bengal with 86°00′ E and 87°40′ E longitude and 22°20′ N and 24°40′ N latitude. The altitude of this region ranges from 19 to 656 m having steeper slopes at Purulia and Bankura and gentler slopes at rest of the stations. Due to the orographic influence of rainfall at steeper slopes, high evapotranspiration rates, and low water holding capacity in Purulia that comes under the drought-prone region [19]. At the same time, due to high average annual rainfall and hardpan geology, the basin is prone to flood as well. The changes in the extremes of temperature and precipitation will further worsen the situation in the basin. There are six rainfall stations, namely Jhargram, Mohanpur, Kharagpur, Midnapore, Purulia, and Bankura as shown in Fig. 1. Among these gauging sites, the first five lies within the basin, while Bankura comes under the Kangsabati command area. Daily maximum and minimum air temperatures data were collected for the period 2006–2010. Due to the limited availability of meteorological data for ET estimations from the nodal agency, these six stations are only used during this study period. Further, the detailed description for each rain gauge station is given in Table 1. It was used to calculate the Hargreaves and FAO-56-PM ET and could be used for harmonization.

ET Estimation Using the FAO-56 Penman–Monteith Equation

The FAO-56-PM equation used for estimating the reference evapotranspiration is given as Eq. 1.

$$ET = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T_{mean}+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

where R_n is the net solar radiation flux density at the reference grass surface (MJ/m^2/day); G is the soil heat flux density (MJ/m^2/day); T_{mean} is average daily air temperature (°C); Δ is the slope of saturation vapour pressure–temperature curve (kPa/°C); e_s is the saturation vapour pressure (kPa); e_a is the actual vapour pressure (kPa); u_2 is the average daily wind speed at 2.0 m height from the surface (m/s); and γ is the psychrometric constant (kPa/°C).

Fig. 1 Index map of the Kangsabati River basin showing all the six rain gauge stations
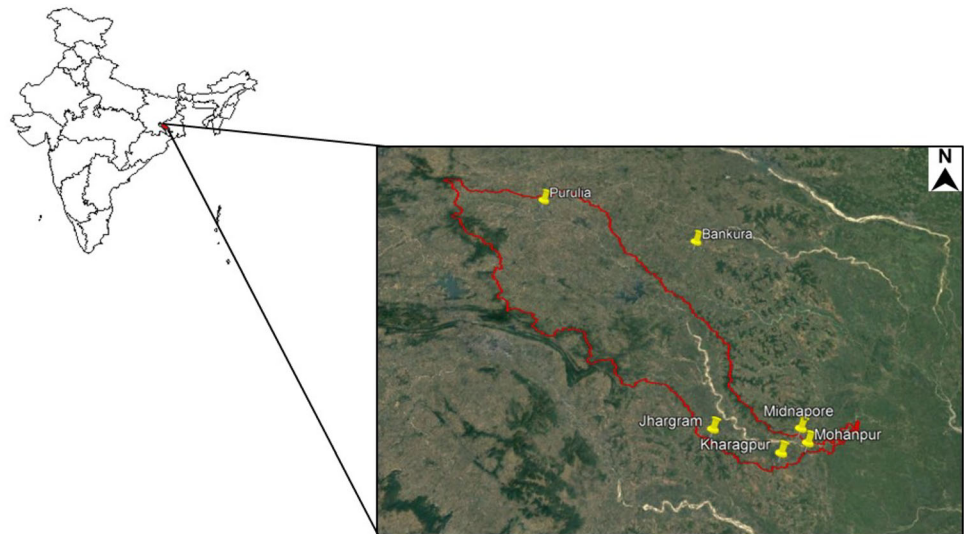
Table 1 Weather station information as used in this study

Weather station	Latitude	Longitude	Elevation (m)	Land use class	Available weather data during 2006–2010
Purulia	23.33° N	86.36° E	254	Paddy	Daily maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, solar radiation
Bankura	23.25° N	87.06° E	78	Paddy	
Mohanpur	22.37° N	87.33° E	29	Paddy	
Jhargram	22.43° N	86.99° E	81	Paddy	
Kharagpur	22.34° N	87.23° E	68	Paddy	
Midnapore	22.42° N	87.31° E	–	–	

ET Estimation Using the Hargreaves Temperature Equation

As sunshine data are not available for most of the regions across the globe, an alternative approach based upon the geographical locations and minimum and maximum air temperatures is better options. The Hargreaves temperature equation is one of the most straightforward and most accurate comparisons used to estimate (ET) in the mm/day [10, 27] which is expressed as Eq. 2 given by [9].

$$ET = 0.0023R_a[0.5(T_{max} + T_{min}) + 17.8]\sqrt{T_{max} - T_{min}} \tag{2}$$

where R_a is extraterrestrial radiation (mm/day), (1 MJ/m^2/day is 0.408 mm/day) and T_{max} and T_{min} are maximum and minimum temperature.

Harmonization of ET Estimates

Harmonization is basically termed as the adjustment of variabilities and inconsistencies within various methods and measurements. It is basically used to minimize the different types of errors, namely systematic and non-systematic errors between two more different sources of datasets without hampering the internal compatibility of the new composite dataset [6, 11]. FAO-56-PM method requires several meteorological variables for the computation of the ET, and hence, in data paucity conditions we could not use it. To overcome this problem, there are several methods to estimate ET out of which the parsimonious method like Hargreaves model was taken and compared with the FAO-56-PM equation. In this way, Hargreaves model overestimated throughout the whole period of study as it considers only the effect of radiation, whereas in the former method a large number of weather variables are contemplated.

In this study, the ET values at daily and monthly scale using the HS method were harmonized with the benchmark FAO-56-PM method for the period of 5 years (2006–2010) in order to give corrected HS ET for the six different stations in the given study area. Figure 2 shows the detailed description of all the steps followed in the bias correction HS ET provided in the flowchart. The harmonization of HS ET against the FAO-56-PM ET is done by estimating the

Fig. 2 Flowchart illustrating the steps followed in the harmonization of ET
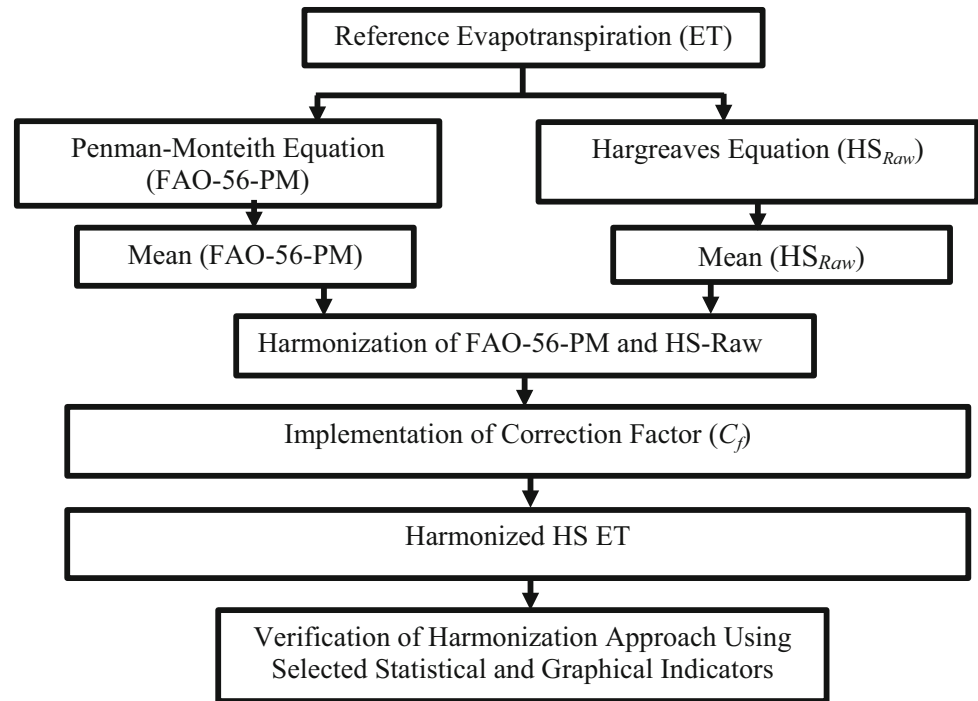
correction factor (C_f) as shown in Fig. 2. First of all, the mean of FAO-56-PM data and raw HS ET (HS_{Raw}) were estimated for each station during the entire study period. Thereafter, C_f is estimated for every station in order to obtain the harmonized HS ET as given in Eq. 3 for entire time step ($i = 1$ to n) during study period.

$$C_f = \sum_{i=1}^{n} \frac{1}{n} \{ \text{Mean}(\text{FAO56PM}) - \text{Mean}(\text{HS}_{Raw}) \} \quad (3)$$

Once the C_f is obtained, the HS ET is estimated for all the stations by using Eq. 4.

$$HS_{hm} = \sum_{i=1}^{n} \frac{1}{n} \{ HS_{Raw} + C_f) \} \quad (4)$$

Further, the results were plotted, and these ET estimation methods were evaluated with each other by using graphical methods such as scatter plots and bar graphs and statistical performance indicators such as r, R^2, and d as explained in the next subsections. The entire analysis is carried out on both daily and monthly scales (from 2006 to 2010).

Performance Evaluation Indicators

The comparison of simulated model values with the observed values determines how well a model fits the study area. The graphical representation of the results could be easily interpreted if calibration is done for only one watershed at one stream gauge location. Continuous time series plot of the recorded and simulated series and a

scattergram of recorded data plotted against simulated flows were therefore used in this study for model calibration and validation.

Pearson correlation coefficient (r) The division of the covariance of the two variables obtained the Pearson product-moment correlation coefficient by the products of the standard deviations. If there are n observations and n model simulated values, then the correlation coefficient measure is estimated as given by Eq. 5.

$$r = \frac{\sum_{i=1}^{n} [(O_i - \bar{O})(P_i - \bar{P})]}{\sqrt{\left[\left(\sum_{i=1}^{n} (O_i - \bar{O})^2 \right) \left(\sum_{i=1}^{n} (P_i - \bar{P})^2 \right) \right]}} \quad (5)$$

where $\bar{P}$ and $\bar{O}$ are observed and simulated mean value.

It ranges between -1 to $+1$ such that correlation of $+1$ shows a correctly increasing linear relationship and -1 shows a perfectly decreasing linear relationship, and the values in between indicate the degree of linear relationship between modelled and observational data.

Index of agreement To evaluate each ET estimation method, index of agreement (d) is used. [24] gives the index of the agreement as given by Eq. 6.

$$d = 1 - \frac{\left\{ \sum_{i=1}^{N} (P_i - \bar{O}_i) \right\}^2}{\sum_{i=1}^{N} \{ (P_i - \bar{O}) + (O_i - \bar{O}) \}^2} \quad (6)$$

where P_i is ET estimates by the existing model; O_i is ET estimates by the benchmark FAO-56-PM model; $\bar{O}$ is mean ET value calculated using the FAO-56-PM model; and N is number of observations. A value of d is 1 indicates perfect

agreement, and a value d is 0 indicates poor agreement. A model is accepted if $r \geq 0.5$ and $d \geq 0.5$, else rejected.

The coefficient of determination (R^2) It is the square of the Pearson's correlation coefficient (r) and describes the proportion of the total variance in the observed data that can be explained by the model. It is expressed as in Eq. 7.

$$R^2 = \frac{\left[\sum_i^n \left(Y_i^{sim} - Y_{sim}^{mean}\right)\left(Y_i^{obs} - Y^{mean}\right)\right]^2}{\sum_i^n \left(Y_i^{sim} - Y_{sim}^{mean}\right)^2 \sum_i^n \left(Y_i^{obs} - Y^{mean}\right)^2} \tag{7}$$

The values of R^2 range from 0 to 1, with higher values indicating better agreement between observed and simulated values.

Results

First, the raw HS ET for six stations, namely Mohanpur, Bankura, Purulia, Kharagpur, Midnapore, and Jhargram, was evaluated using the Hargreaves method and then compared with FAO-56-PM method (Fig. 3) without using a correction factor. It showed that all of the stations showed systematic overestimation of HS ET with respect to FAO-56-PM ET. It was further verified by the statistical indicators that Jhargram showed the highest bias ($r = 0.61$ and $d = 0.69$) in HS ET estimation (Table 2). These stations showed correlation coefficient ranging between 0.61 and 0.80 and index of agreement varying in between 0.69 and 0.81 without the correction factor applied.

Thereafter, Hargreaves model was refined using a correction factor, which gave a better correlation as compared to the relationship without considering the correction factor (Fig. 4). The estimates of r and d values show that after incorporating the correction factor in Hargreaves model, the performance has been improved for all six stations (Table 2). As it is evident from Table 2, the stations, namely Bankura, Midnapore, and Mohanpur, have shown outstanding improvement in the ET estimation after the application of correction factor. While on the other hand, Jhargram does not show good agreement after use. Once the correction factor was used, these values surged from 0.69 to 0.85 (r) and 0.71 to 0.87 (d). Among the six stations, the scatter plot of Purulia and Midnapore was highly correlated with FAO-56-PM ET and HS ET, while Jhargram showed the least correlation among the two ET estimations.

Figure 5 shows the results of harmonization of Hargreaves-based ET with respect to the standard FAO-PM method at monthly scale for all the six stations. It showed that the ET estimates provided by the corrected Hargreaves method show substantial improvement over those provided by the raw Hargreaves estimation. Similarly, like daily estimation, in the monthly ET corrections, stations like

Purulia, Mohanpur, Kharagpur, and Midnapore showed comparatively better bias corrections on Hargreaves method as compared to Jhargram and Bankura. In all the stations, the highest biasness was visible in the month March, April–May, and June with the ET ranging from 700 to 1300 mm/month. While on the other hand, the winter months had reduced differences between the FAO-PM ET and Hargreaves ET at all the stations (300–500 mm/month). It was easily inferred from the statistical analysis over the monthly bias correction at each station separately as given in Table 3. In addition to mean and standard deviation values of FAO-PM and Hargreaves-corrected ET, the values of r, R^2, and d were reduced and improve significantly at both daily and monthly time scales (Table 2). The highest r and R^2 was obtained for Mohanpur station ($r = 0.972$; $R^2 = 0.944$), while least for Jhargram station ($r = 0.961$; $R^2 = 0.922$). Second, the maximum d was obtained at Mohanpur station (0.944) and least d was observed at Bankura station (0.822) for bias-corrected Hargreaves ET. Altogether, this results show that the harmonization or standardization of the less data-intensive ET method like Hargreaves method improves the performance of the original ET methods significantly; hence, the harmonized ET methods are far more accurate in ET estimation.

Discussion

In this study, we have compared and harmonized the parsimonious ET estimation method with FAO-56-PM method in Eastern India. We applied Hargreaves method which showed large differences in their applicability if used without harmonization at all the six stations (Fig. 3). The temperature-based method improved the estimates of ET performance by using harmonized ET estimates than the non-harmonized estimates across all the six stations in the study area. This is well corroborated with the findings of previous studies in other parts of the world [4, 7, 17]. Among all the stations, Purulia and Midnapore showed the best performance followed by the other stations. This method is established in a tropical monsoon climatology, which are mostly suitable for regions with abundant rainfall like our study area [7, 17]. This is probably one of the reasons this method can be used to estimate ET in the tropical climate.

For instance, [4, 5] suggested Hargreaves with satisfactory performance in the USA, whereas it performed the best among all other methods in Iran for different climatic conditions [18]. The reason for the variation in the results by using similar approach may be due to the different climatic conditions and geographical environments [4, 17, 18, 23]. Though in our study we have most of the
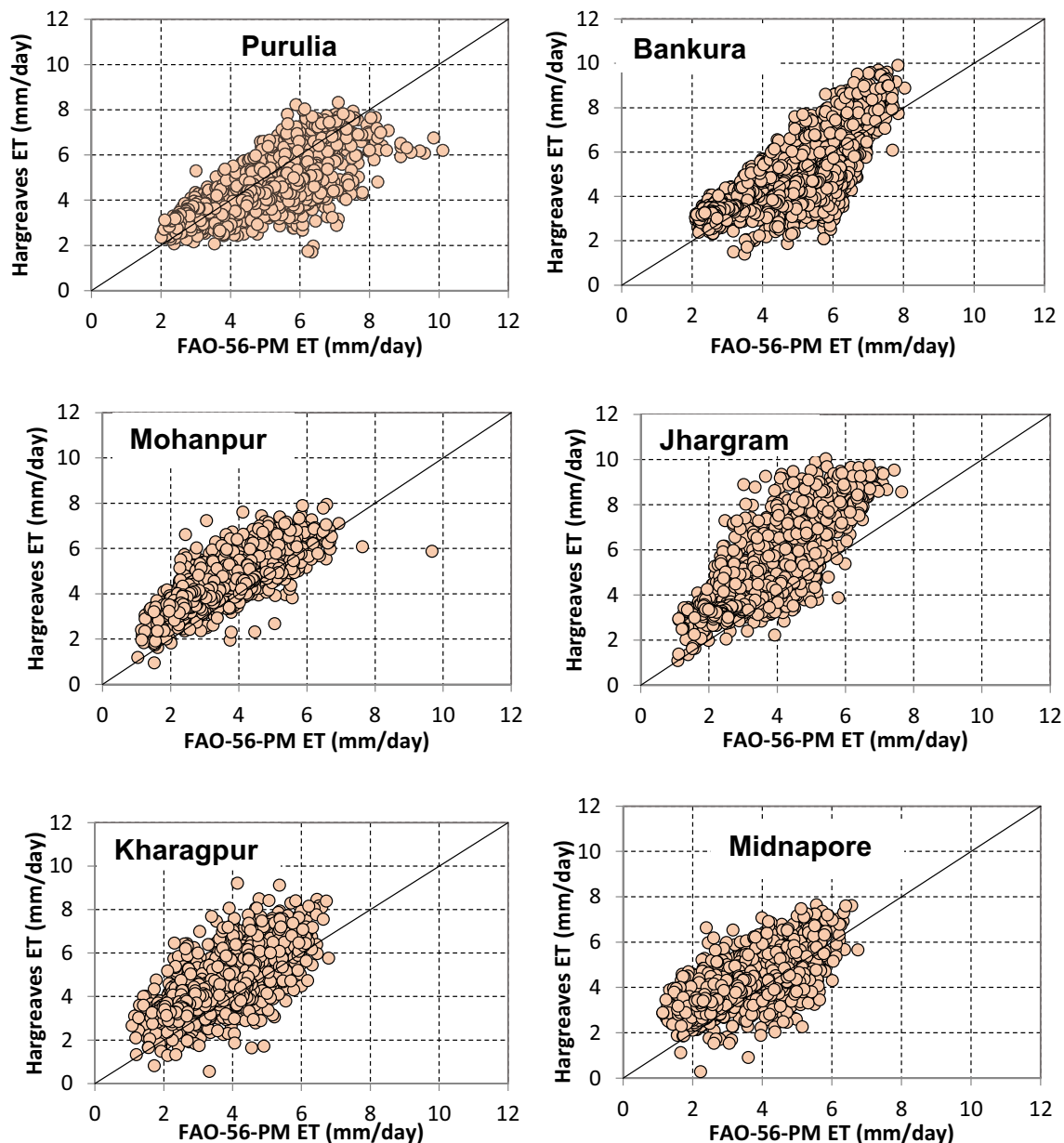
Fig. 3 Scatter plots of ET estimates for six different locations without bias correction by using FAO-56 PM and Hargreaves method at daily scale (2006–2010)

stations at downstream of the Kangsabati River basin, however, our results are appropriate with the other studies at different time scales. Moreover, in the present study, HS ET estimation has been tested for its applicability in tropical climate condition. The HS method included extraterrestrial solar radiation in the input parameters, while other temperature-based methods do not have this parameter, which is the reason that only HS is used to estimate ET in the study region. The three statistical indicators showed various simulation effects. On a seasonal scale, r showed HS method match FAO-56-PM method better than at daily. Overall, HS ET method is

recommended as the simple and practical method [4, 12, 23] when the available meteorological datasets are not easily accessible in the world.

Conclusions

ET is one of the major crucial and complicated parameter which is affected by different interacting factors like minimum and maximum temperature, relative humidity, solar radiation, and type and development of the crop. The lysimeter or water balance methods of ET estimation take

Table 2 Performance evaluation for the comparison of Hargreaves model with FAO-56 PM equation for all six stations during 2006–2010 with and without applying a correction factor on daily scale

Stations	Without correction factor		With the correction factor	
	r	d	r	d
Purulia	0.73	0.72	0.83	0.80
Bankura	0.66	0.71	0.76	0.77
Mohanpur	0.80	0.81	0.85	0.87
Jhargram	0.61	0.69	0.69	0.71
Kharagpur	0.72	0.73	0.80	0.83
Midnapore	0.69	0.76	0.73	0.84
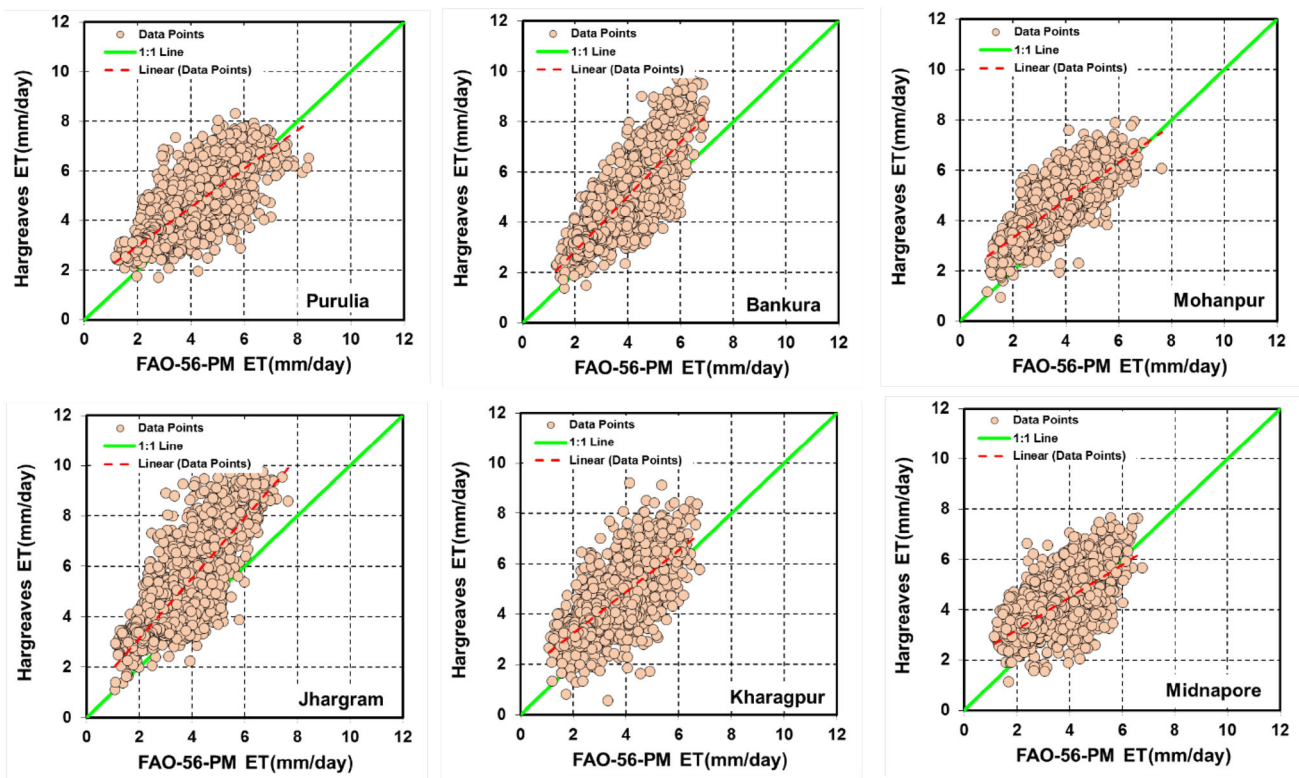
Fig. 4 Scatter plots of ET estimates for six different locations with bias correction by using FAO-56 PM and Hargreaves method at daily scale (2006–2010)

enormous time as well as lead to errors at many stages. However, there are few indirect methods available for the ET estimation used by many researchers [1] depending upon its accessibility at particular locations. Apart from the variability of different datasets requirement in terms of methodology, the respective method's performance also plays crucial role with climatic condition. Therefore, accurate estimation of evapotranspiration is a challenging task. To overcome this problem, a methodology for evaluating ET was performed in this study to test the accuracy of limited data-based ET estimates. Hargreaves ET was standardized by using a correction factor, and

comparatively better results were obtained for all the six stations. It is observed that Purulia ($r = 0.83$ and $d = 0.80$) and Mohanpur ($r = 0.85$ and $d = 0.87$) stations are almost standardized appropriately on daily scale; however, Jhargram station showed least improvement in terms of r (0.69) and d (0.71) on daily scale. Also, the monthly scaled bias correction showed Mohanpur as best station in terms of application of Hargreaves-corrected ET, although it was least improved at Jhargram station. Monthly HS ET was in better agreement with the FAO-56-PM that justifies the applicability of this approach towards water resource management and reservoir operations. Altogether it is an
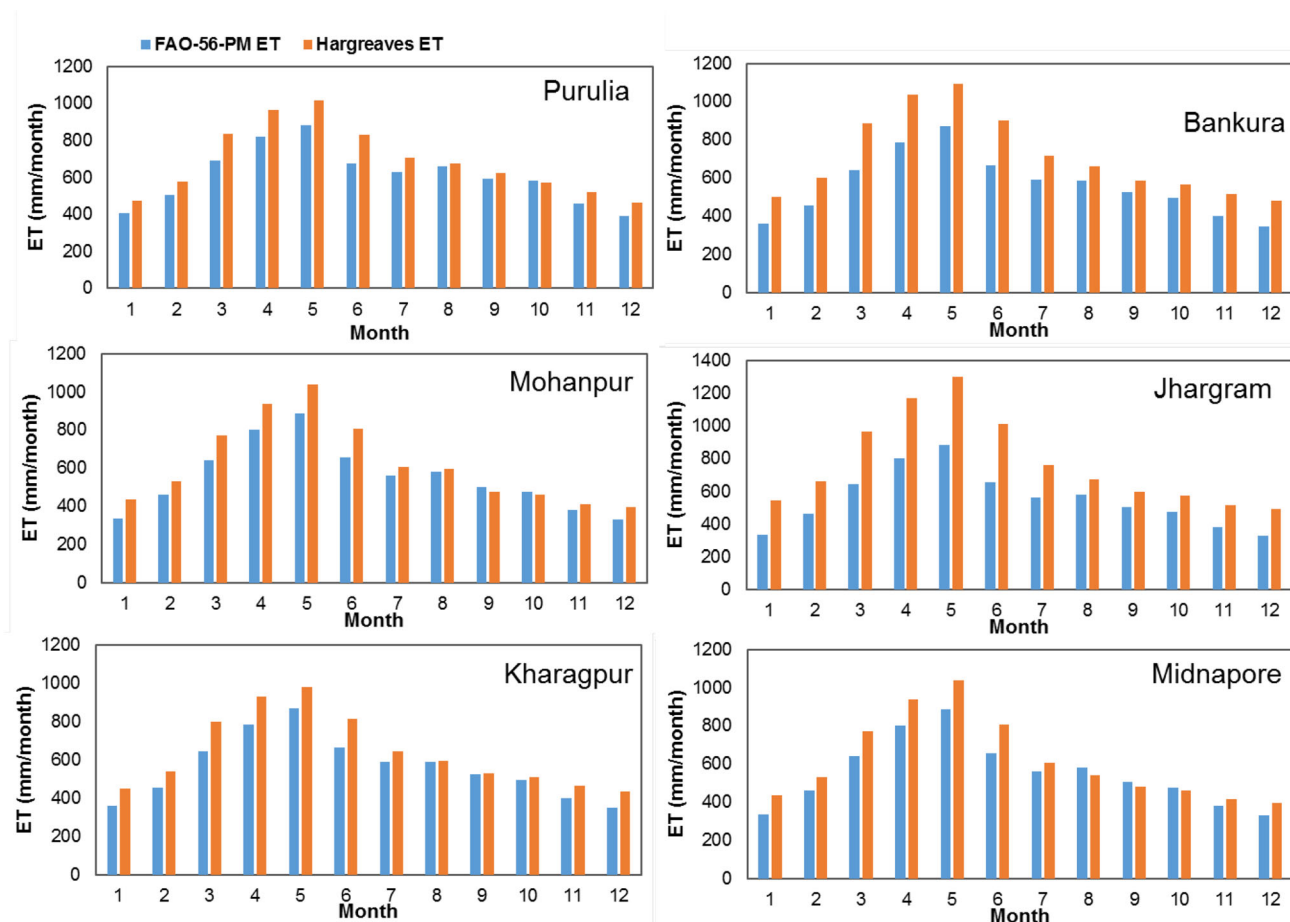
Fig. 5 Bar graphs of ET estimates for six different locations with bias correction by using FAO-56 PM and Hargreaves method at monthly scale (2006–2010)

Table 3 Performance evaluation for the comparison of Hargreaves model with FAO-56 PM equation for all six stations during 2006–2010 with and without applying a correction factor on monthly scale

Stations	ET	Mean (mm)	SD (mm)	r	R²	d
Purulia	FAO-56-PM	606.300	153.096	–	–	–
	Hargreaves	687.470	186.308	0.969	0.939	0.917
Bankura	FAO-56-PM	560.944	163.737	–	–	–
	Hargreaves	712.454	214.145	0.967	0.935	0.822
Mohanpur	FAO-56-PM	551.817	175.338	–	–	–
	Hargreaves	622.925	216.530	0.972	0.944	0.940
Jhargram	FAO-56-PM	551.817	175.338	–	–	–
	Hargreaves	772.407	272.281	0.961	0.922	0.741
Kharagpur	FAO-56-PM	560.944	163.737	–	–	–
	Hargreaves	641.209	192.730	0.967	0.935	0.925
Midnapore	FAO-56-PM	551.817	175.338	–	–	–
	Hargreaves	617.925	217.825	0.962	0.925	0.939

efficient methodology for the water resources management perspective and irrigation scheduling for the crops. Apart from that at catchment scale where there is limited data

available for ET calculation accuracy of harmonized-based ET estimation is very useful to estimate the losses.

Compliance with Ethical Standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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