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BRIEF RESEARCH ARTICLE

Selection of the Best Method of ET_o Estimation Other Than Penman–Monteith and Their Application for the Humid Subtropical Region

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Abstract Evapotranspiration (ET) is one of the largest components of hydrological cycle, and its accurate quantification is needed in water allocation, irrigation management, and to protect surface and ground water quantity and quality. So there is a need of improved techniques for accurate quantification of ET to enhance efficient use of water resources and sustainability of agro-ecosystem productive. A number of methods have been developed till now for ET_o estimation, but most of them are only applicable in areas where they have been developed. Till now, only the Penman method has been accepted worldwide which is acceptable in almost all climatic conditions, but the only major drawback of this method is the large number of data requirement. Therefore, in this study, we have used four reference ET_o estimation methods which include two radiation methods (Turc and Priestley–Taylor), one temperature (Hargreaves), and one combined method (Penman method) of ET_o estimation. The weekly average meteorological data for the period 1975–2005 were used here to estimate ET_o. This study has attempted to select reliable reference ET estimation method other than Penman where less input variables are required. Here, Penman-derived ET_o has been selected as the standard for evaluating the performance of other methods of ET_o estimation. This study has further attempted to demonstrate some of the significant applications of estimated ET_o. The execution of all radiation- and temperature-based methods shows that outcome of Turc-derived ET_o is comparable with Penman-derived ET_o, and thus this can be used for ET_o estimation for this region other than Penman method.

Keywords Reference evapotranspiration · Hargreaves radiation method · Turc method · Priestley–Taylor method · Penman–Monteith method

Introduction

Evapotranspiration (ET) is a major component of the hydrological cycle [2] which can account for more than 90 % of the precipitation in semi-arid and arid regions [17]. Accurate estimation of ET is required to better understand hydro-meteorological behavior across a range of systems and scales such as local, regional, and global. Knowledge of this variable provides insights and understanding into the complex processes, mechanisms, and mutual interactions between the land and atmosphere in terms of mass and heat transfers. Over the land surface, ET accounts for approximately 60 % of the total precipitation that is returned to the atmosphere [4]. Estimation of ET is required in many fields such as water resources management, irrigation management, and hydrological studies. In multi-source schemes, the total ET from the land surface is generally partitioned into evaporation from the soil, transpiration from the canopy, and evaporation from the intercepted water in the canopy. Located in south-central Asia, India has great economic dependence on agriculture, and thus studies relating to potential changes in ET in India are very important.

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However, there are very few studies in literature related to ET in India [4]. Knowledge of the accurate amount of ET for a given location is an essential component in the design, development, and monitoring of hydrological, agricultural, and environmental systems [9]. It varies regionally and seasonally according to ambient environment conditions, such as climatic condition, land cover, land use, soil moisture, available radiation, etc. Because of this variability, and its importance for integrating water resource modeling, dynamic crop weather modeling, drought monitoring, a thorough understanding of ET process and knowledge about spatial ET are needed [11]. A number of methods are available for ET estimation which varies in their complexity from simple radiation-based methods to the combination method and data requirement [9, 10], but very few of them have emphasized on the comparative method of ET estimations for any particular region. Hence, the Penman method was selected as the standard for evaluating the performance of other radiation- and temperature-based methods of ET estimation, as FAO-PM method has been accepted by the scientific community as the most precise one for its good results when compared with other equations in different regions worldwide [3, 8, 15].

Reference ET_o has been estimated in this study using radiation- and temperature-based methods as well as through Penman method for comparison. Thus, these comparisons have led to find out the best method of ET_o estimation with less number of input variables required other than the Penman method and to study water balance component from the estimated ET_o.

Materials and Methods

Study Area and Data Used

Area selected for the present study is Ranchi city, located in the eastern part of India between the range of latitude 23°21′0″ and longitude 85°19′48″. Temperature ranges from 20 to 42 °C in summer, while in winter it varies between 0 and 25 °C with humid subtropical climate. The required input variables from different methods of ET estimation were temperature (maximum and minimum), sunshine duration, humidity, wind speed, and other parameters such as vapor pressure deficit, mean temperature, and slope of the vapor pressure curve which has been derived from these parameters. All the essential meteorological inputs used were according to the standardized week days and year-wise for the period 1975–2005, the averages of which were computed accordingly for our convenience of reference ET estimation from different methods.

Expression of Mathematical Methods

Temperature-Based Methods

Hargreaves Method This is the most accepted and reliable temperature-based method of reference ET estimation and has been given equal importance just after Penman–Monteith method. This method is often used to compute ET_o through temperature data for daily/weekly or longer period for use in regional planning, reservoir operation studies where other climatic data are not available. The equation can be written as follows:

$$HR = 0.0135\,(\mathrm{T} + 17.8).$$

Radiation-Based Methods

Priestley–Taylor method The Priestley–Taylor equation [14] is useful for the daily reference ET estimation for the area where the weather inputs for the aerodynamic term (relative humidity wind speed) are unavailable:

$$PT = \alpha \frac{\Delta}{\Delta + T} \times \mathrm{Rn}.$$

Here, the aerodynamic term of Penman–Monteith equation is replaced by a dimensionless empirical multiplier (α: Priestley–Taylor coefficient), and an implementation of α from Steiner et al. [16] is given, depending on the value of the vapor pressure deficit for each day:

$$ET_o = \frac{1}{\alpha \cdot s} \cdot \frac{\mathrm{Rn} - G}{S + \gamma} \cdot \alpha,$$

where α is the empirical coefficient (1.56), Δ the slope of the vapor pressure curve (KPa °C), γ the Psychometric constant, and Rn is the net radiation (MJ/m^2) [5].

Turc Radiation is a simple radiation-based method for reference ET estimation:

$$TU = \beta\left[\left(\frac{T}{T+5}\right)\right] \times (23.88 \times Rs + 50),$$

where β is the empirical coefficient (0.00135), T the daily mean temperature, and Rs is the solar radiation (MJ/m^2) [7].

Combination Method

FAO56-Penman–Monteith: The Penman [13] and Penman–Monteith [12] equations incorporate energy balance and aerodynamic water vapor mass transfer principal and are therefore known as combination equation. According to the FAO [1], the Penman–Monteith method for ET_o can be expressed as follows: [6]

Table 1 Statistical analysis of ET_o estimated by different methods

ET_o estimation methods	Mean	SD	Sum	Minimum	Median	Maximum
Penman–Monteith	5	2	243	3	4	8
Hargreaves	8	3	420	5	8	14
Priestley–Taylor	16	4	829	4	16	25
Turc radiation	3	1	157	2	3	5

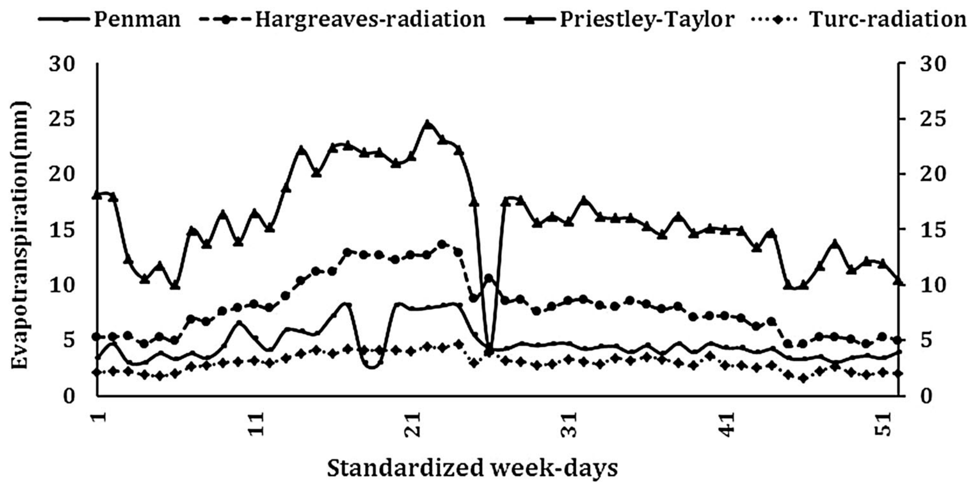

Fig. 1 Comparison graph of ET_o estimated by different methods

$$ET = 0.408\Delta(\mathrm{Rn} - G) + \gamma\frac{900}{T + 273}u2\frac{(e_s - e_a)}{\Delta + \gamma}(1 + 0.34u2),$$

where ET_o is the daily reference crop ET, mm day^{-1}; *Rn* the net radiation flux density, MJ m^{-2} day^{-1}; *G* the heat flux density into the soil, MJ m^{-2} day^{-1}; *T* the mean daily air temperature which is very small and can be neglected, °C; γ the psychometric constant, kPa $°C^{-1}$; *u* the wind speed measured at 2 m height, m s^{-1}; e_s the saturation vapor pressure, kPa; e_a the actual vapor pressure, kPa; 100RHes ×=RH, relative humidity, %; and Δ is the slope of saturation vapor pressure curve, kPa $°C^{-1}$. The Penman–Monteith equation provides a standard to which ET in different periods of the year or in other regions can be computed and to which the ET from other crops can be related.

Results and Discussion

Execution of all radiation- and temperature-based methods of ET_o estimation and its comparison with Penman-derived ET_o shows overestimated value of ET_o through Priestley–Taylor and Hargreaves, while Turc-derived ET_o is comparable with Penman-derived ET_o. Various literature studies indicate that Hargreaves method has also been given equal importance just after Penman. However, this study showed that Turc method also gives better results for this region. This result fulfills our objective very well as this method requires less inputs and we got a comparable result as good as Penman-derived ET_o. These are further supported by statistical analyses which have been shown in Table 1. The results of this study led us to conclude that temperature and radiation are the main parameters which effect ET_o for this area as these two variables are directly correlated with ET_o processes. This has also been similarly inferred by Allen et al. [1]. Almost similar findings are reported by Jhajharia et al. [9, 10] for humid climate where they got that for similar climatic condition by Priestley–Taylor-derived ET_o is giving comparable result like Penman. The comparison graph of radiation, temperature, and combination methods has been shown in Fig. 1 and their statistical analyses results in Table 1.

Relationship between rainfall and ET_o found from the selected datasets indicates that rainfall value exceeded ET_o value in monsoon season which shows that Ranchi has good potential of ground water recharge and soil moisture storage which leads to better crop growth of the study area. This is one of the significant applications of ET_o in the field of agricultural and hydrological study. Besides this, there are various other applications of ET_o for optimization of irrigation water requirements, understanding the drought pattern of a region as well as different components of water balance. ET versus Rainfall graph prepared for this region has been shown in Fig. 2. And delineated water balance

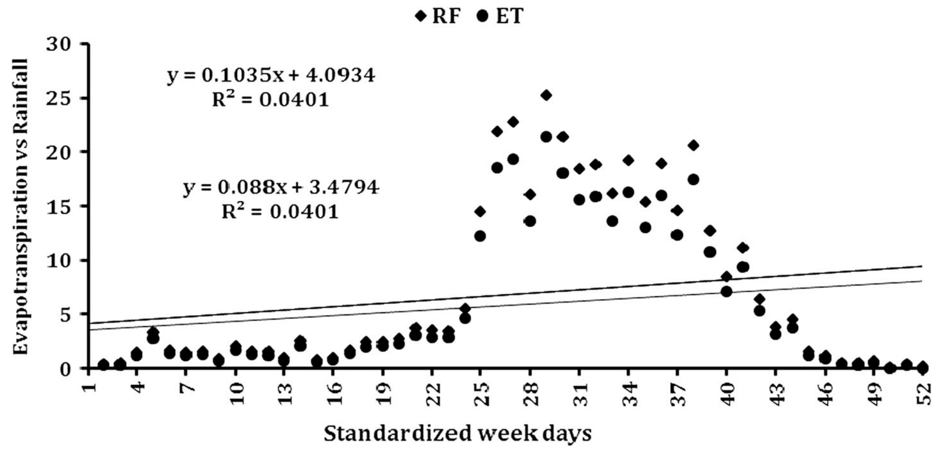

Fig. 2 ET_o versus Rainfall graph

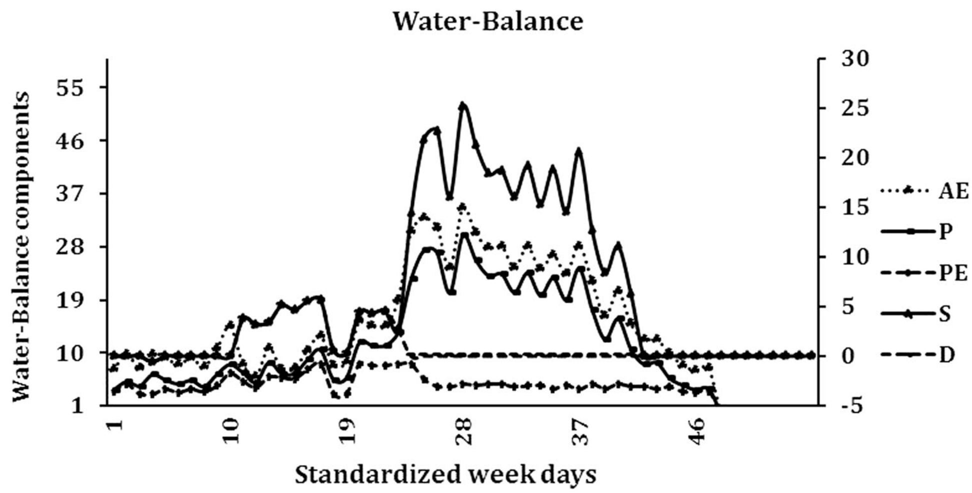

Fig. 3 Water balance graph. Where *AE* actual evapotranspiration and *PE* potential evapotranspiration *S* water surplus, *D* water deficient and *P* precipitation

graph has been shown in Fig. 3, indicating the good condition of water resource availability of the region.

Conclusions

This study has helped us in selecting appropriate methods of ET_o estimation other than Penman where less input variables are needed. Among the evaluated simple radiation-based methods, Turc-derived ET_o was good followed by Hargreaves and Priestley–Taylor. Thus, through the execution of all the methods, we can say that Turc was superior to the other two methods based on the comparison of evaluating parameters and can also be used for ET_o computation of this climatic condition other than Penman. Here, we have also tried to see some of the applications of ET_o with the help of Penman-derived ET_o for water budget, and got very good result for ground water recharge particularly in monsoon season which is a good indication for crop planning of the study area.

As a significant finding, this study has led to understand the fact that other than Penman method, we could also rely on Turc method requiring less input variables for ET_o estimation of this area. ET_o has further importance as an indicator of good potential of ground water recharge and soil moisture storage capacity of this area particularly in monsoon which is significant for agriculture. Thus, this study has the potential to allow understanding the agricultural and hydrological conditions of the study area, whose proper management can be very beneficial.

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