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Evaluation of different methods for evapotranspiration estimation using automatic weather station data*

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ABSTRACT

In the present study, six empirical models, namely, FAO-Penman-Monteith, Priestley-Taylor, Hargreaves-Temperature, Hargreaves-Radiation, Turc-Radiation and Makkink-Radiation were computed using Automatic Weather Station database. The AWS data were recorded at 3 min logging interval and 30 min averaging interval. The global short wave radiation recorded from AWS was used as input parameter for radiation based models like that of Turc, Hargreaves and Makkink and combined approach like that of FAO-Penman-Monteith and Priestley-Taylor. The empirically determined ET from all these models were validated with the pan derived ET, which was obtained from observatory records of pan evaporation and AWS records of RH and wind speed. From the overall analysis, it may be concluded that FAO-Penman-Monteith approach is most suitable for new alluvial zone of West Bengal where details database on temperature, humidity and radiation were available. However, in absence of humidity data Makkink approach may be recommended for empirical estimation of ET. On the other hand,.when only temperature is available Hargreaves-Temperature model can give reasonable estimation of reference evapotranspiration.

Key words : AWS data, empirical model, evapotranspiration, pan evaporation

A significant part of precipitation returns back to the atmosphere by evapotranspiration. Evapotranspiration can be broadly defined as the cumulative sum of water that is evaporated from surface and transpired by plants as a part of their metabolic process. The evapotranspiration rate from a reference surface that is abundantly watered is called reference evapotranspiration (ET_0) (Allen *et al.,* 1998). It is an important variable used in hydrology and agriculture. Developing formulations aimed at accurately quantifying ET_0 over a given region can aid a wide variety of users including water managers and hydrologist. There are various empirical methods to derive reference evapotranspiration of a region based on energy balance or dynamic or combined approach. However, quantitative estimation of ET_0 with existing mathematical formula produces inconsistent result in different agro climatic region. In order to select the best method for estimating ET_0 in any particular region a comparative study is required. In this paper, ET_0 is estimated through different empirical models, namely, Modified FAO Penman Monteith (FAO-PM), Priestley-Taylor (PT), Hargreaves Radiation (HR), Turc Method (TU) and Makkink Method (MK) and the end results are compared with pan derived ET through statistical analysis. Here, pan derived ET_0 values are used as the benchmark solution for comparison purpose.

MATERIALS AND METHODS

In order to select the best method for ET_0 estimation in the Gangetic Alluvial Zone on a daily basis, six empirical methods were selected. All the weather parameters, used for ET_0 estimation were recorded over two consecutive years (2007 and 2008) from the Automatic Weather Station located at the University Farm (22°58′19″ North latitude and 9.6 m. above mean sea level). Daily values of all available agrometeorological data such as air temperature, wind speed, relative humidity and solar radiation were recorded at 3 min logging interval and 30 min averaging interval. From these recorded data daily total, average, maximum and minimum values were estimated as per the model requirements. The vapour pressure parameters were derived from RH and temperature. These parameters were used for simulation of ET_0 on daily basis using the numerical models. Similarly, the daily pan evaporation data from the observatory were used for estimation of Pan Derived ET_0, which was selected as the benchmark for comparative study. For pan coefficient estimation, the RH and wind speed data from AWS were used. The statistical analysis was based on monthly averaged daily ET_0 derived through various approaches. This was done to avoid the possible day-to-day inconsistency in measurement of pan evaporation.

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Equations used for estimating ET_0

1. Hargreaves temperature model (Hargreaves *et al.*, 1985)

$HT=0.0023Rs(T+17.8)[TD]^{0.5}$

Where,

Rs=Daily extra terrestrial radiation (MJ m^{-2}), T=Daily mean temperature, TD=Daily maximum and minimum temperature difference

2. Priestley-Taylor model (Priestley and Taylor, 1972)

$$PT = \alpha\left\{\frac{\Delta}{\Delta+\gamma}\right\} * R_n$$

Where,

α=Empirical coefficient (1.56), Δ=Slope of saturation vapour pressure curve (K Pa°C), γ=Psychometric constant (KPa°C), Rn=Net radiation (MJ m^{-2})

3. Turc model (Turc, 1961)

$$TU = \beta\,\frac{T}{(T+15)} * (23.88 * Rs + 50)$$

Where,

β=Empirical coefficient (0.013), T=Daily mean temperature, Rs=Solar radiation (MJ m^{-2})

4. Hargreaves radiation model

$HR=0.0135(T+17.8)R_s$

Where,

T=Daily mean temperature, Rs=Solar radiation (MJ m^{-2})

5. FAO-PM model (Allen *et al.*, 1998)

$$ET_0 = \frac{[0.408\,\Delta(Rn-G) + \gamma\{900/(T+273)\}\,U_2 * D]}{\Delta+\gamma\,(1+0.34 * U_2)}$$

Where,

Rn=Net radiation (MJ m^{-2}), Δ=Slope of saturation vapour pressure curve (KPa°C^{-1}), G=Ground heat flux, D=Vapour pressure deficit, 900= Conversion factor, γ=Psychometric constant (KPa°C^{-1})

6. Makkink model (Makkink, 1957)

$$MK = 0.61\left[\frac{\Delta}{\Delta+\gamma}\right] * \left(\frac{R_s}{2.45}\right) - 0.12$$

Where,

Δ=Slope of saturation vapour pressure curve (KPa °C^{-1}), Rs=Solar radiation (MJ m^{-2})

7. Pan derived Et method

ETo=Kp*Epan

Where,

Kp=0.108-0.0286 μ^2+0.0422 ln(FET)+ 0.1434 ln(RHmean)-0.000631 $[\ln(FET)]^2$ ln (RHmean)

FET=Fetch length (200 mt), RHmean=Mean relative humidity, Epan=Pan evaporation (from observatory), μ^2=Wind speed, Kp= Pan coefficient

Statistical analysis

For statistical comparison, the following indices were used :

1. Root mean square error (RMSE)

$$RMSE = \left[\frac{1}{N}\sum_{n}^{i=1}(Pi - Oi)^2\right]^{0.5}$$

2. Normalized root mean square error (NRMSE)

$$NRMSE = \frac{RMSE}{Range\ of\ obs.}$$

3. Coefficient of variance of root mean square error (CVRMSE)

$$CVRMSE = \frac{RMSE}{Mean\ of\ obs.}$$

4. Mean bias error (MBE)

$$MBE = \frac{1}{N}\sum_{n}^{i=1}[Pi - Oi]$$

RESULTS AND DISCUSSION

Comparison of empirically derived reference

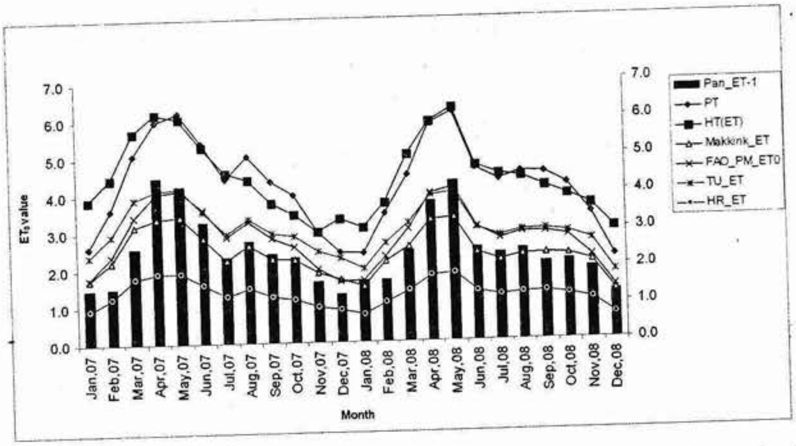

Fig 1: Comparison of numerically estimated reference evapotranspiration with pan derived method.

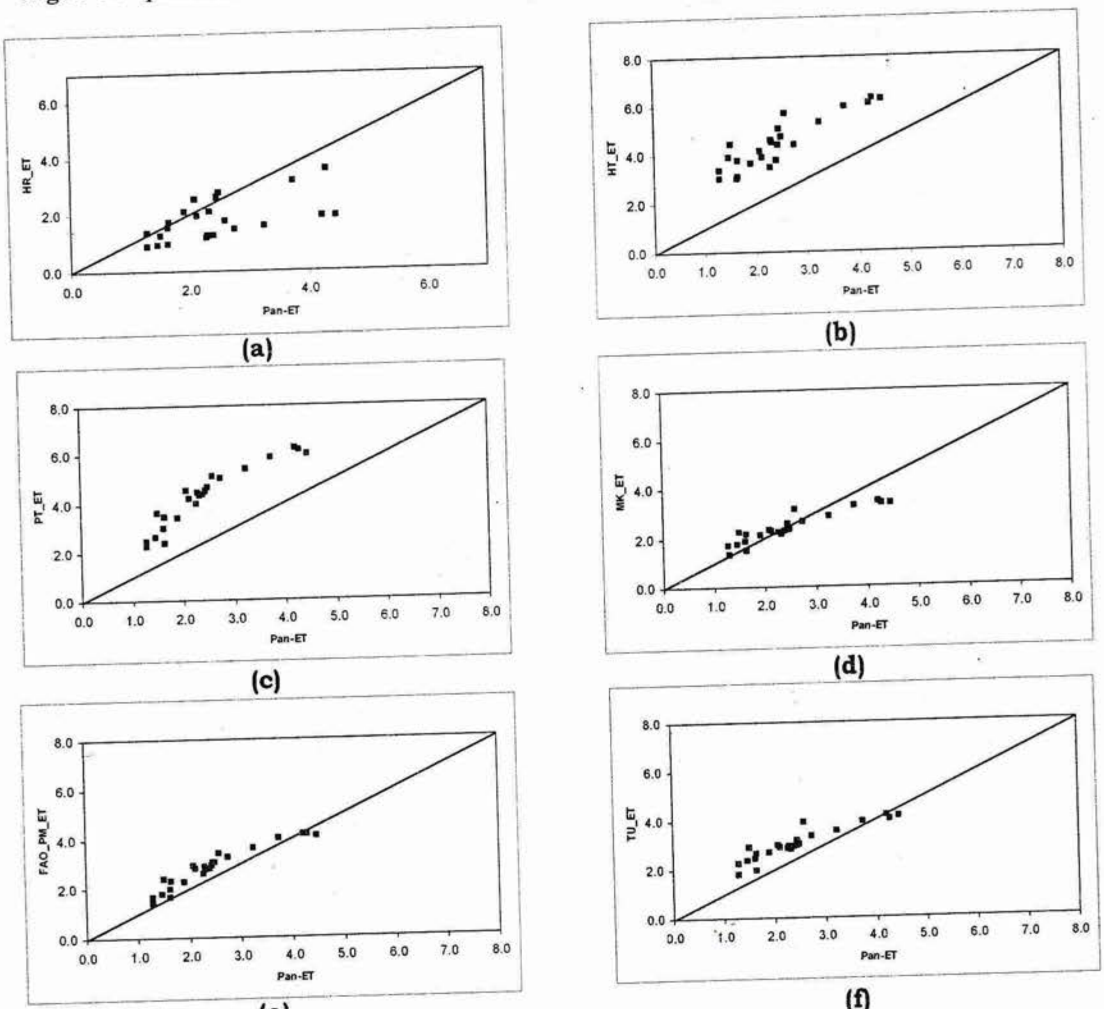

Fig. 2: Comparison of different empirically derived reference evapotranspiration with pan derived evapotranspiration (1:1 graph). (a) Comparison of HR with pan derived ET_0, (b)Comparison of HT with pan derived ET_0,(c) Comparison of PT with pan derived ET_0, (d)Comparison of MK with pan derived ET_0, (e) Comparison of FAO-PM with pan derived ET_0 and (f) Comparison of TU with pan derived ET_0.

evapotranspiration through each model was made with that derived from pan evaporation The relationships between monthly ET_0 estimates for each method against pan derived ET_0 are shown in Fig 1. From the comparative study, it was found that the ET_0 estimated from all these models was highly correlated with the pan derived ET_0 ('r' varied from 0.892 to 0.946).

Hargreaves radiation (HR) model

In HR model, solar radiation and temperature were used as input parameters. This model gave underestimation during most of the period for this region (Fig. 2a) as indicated by negative mean biased error. However, the RMSE values are comparatively lower than that of HT model.

Hargreaves temperature (HT) method

The HT method that used temperature as a single input variable is a simple energy balance based model. This model gave overestimation in both the years of observation (Fig. 2b). This was reflected in high positive value of mean bias error. The RMSE was also quite high.

Priestley-taylor (PT) model

In PT model vapor pressure parameters and radiation were used as input parameters. This method produced overestimation throughout the experimental period and more deviation was found at the middle levels of ET_0 values (Fig. 2c). The systematic overestimation produced by this model was indicated by good correlation coefficient, but high RMSE and MBE (positive) values.

Turc (TU) model

The input parameters used in TU model were temperature and solar radiation. This method gave overestimation particularly at lower range of ET_0 values and slight under estimation at higher levels (Fig. 2f). The RMSE and MBE were comparatively less than that of Hargreaves (Temperature) and Priestley-Taylor model.

Modified FAO-Penman Monteith (FAO-PM) model

The parameters used in this model were radiation parameters, vapour pressure parameters and ground heat flux. This model produced very small overestimation from lower to middle range and slight underestimation at the higher range of ET_0 values (Fig. 2e). This was indicated in the statistical analysis by low RMSE (0.682) and MBE (0.744) values.

Makkink (MK) model

In MK model vapor pressure parameters and solar radiation were used as input. This model gave very small underestimation at higher range (Fig. 2d). The mean biased error was negative (-0.113). But the lowest RMSE value (0.637) indicates its suitability in the present situation. The correlation coefficient with pan derived ET_0 was also reasonably good (0.921).

CONCLUSION

In the present study, Makkink's method and FAO-Penman-Montieth methods were found to be the most suitable in the Gangetic alluvial region of West Bengal. The ET_0 derived from Hargreaves (Radiation) and Priestley-Taylor model were highly correlated with the pan derived ET_0. However, the Priestley-Taylor and Hargreves (Temperature) model gave gross overestimation. The performance of Turc method was reasonably good as compared to Priestley-Taylor model.

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