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Analysis of Evapotranspiration Models for Estimating reference Evapotranspiration in Sub-tropic region

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ABSTRACT
This study aimed to assess the Performance of the different evapotranspiration models. The objective was to determine the most accurate model for estimating reference evapotranspiration (ET0).Performance Evaluation of all the ET_0models, on the limited weather data basis is prerequisite for selecting an alternative approach in accordance with available weather data such as maximum air temperature, minimum air temperature, mean relative humidity, solar radiation and wind speed. Therefore, standard recommended,FAO-56 Penman Monteith (FAO56-PM) model locally calibrated FAO-56 P-M model, Hargreaves-Samani (H-S) model, Jensen- Haise (J-H) model, Rohwerand Travert ET_0basedmodel,were used to estimate monthly reference evapotranspiration (ET_0) at Gwalior (Madhya Pradesh), India. Further, the performance of all these ET_0methods were evaluated, by error analysis between observed ET_0 value using FAO-56 PM model and ET_0 values estimated using all other ET_0models. The result showed that the Hargreaves- Samani, Rohwer and Trabert model systematically, underestimated ET_0 in all months .Jensen-Haise (J-H) model was found lower value of RMEA, MAE and MAPE(1.056),(0.852), (19.299). Travert model, with highest value of R^2(0.980) RMEA(4.326) , MAE(4.183) and MAPE (80.596)and H-S model with lower value of R^2 (0.820). J-H model best performed on the basis of RMSE. Based on overall results it was concluded that the ET_0based model provides average monthly accurate estimate of reference evapotranspiration compared to other models.
Key words: *Reference evapotranspiration, Sub-tropic, Madhya Pradesh*

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INTRODUCTION

Reference evapotranspiration is play significant role in irrigation scheduling, water resource management, and hydrology, water balance models. The of Food and Agricultural, Organization of the United Nations[10] [4] proposed a methodology for computing, crop coefficient (*K*c) and crop evapotranspiration (ET_c). These coefficients [2] depend on several factors including stage of crop growth, canopy height density and crop type. To irrigation schedule properly, an accurate and standard method by several authors [3], [8] and [1] to estimate ET_0 to predict, crop water requirements was stated. A great number of different models were developed [5] to estimate ET_0 for use in environments that lack direct ET_0 measurements. A major problem in ET_0 estimation, using these models is the requirement for meteorological, weather data that may not be easily available. This restriction at times prohibits use of more accurate models, and necessitates, the use of models that have less demanding data requirements.

An international scientific community (ISC) has accepted the FAO56, Penman-Monteith (FAO56PM) modeless, the most precise one for its good results when compared with other models in various, regions of the entire world [5], [9] and [10]. Estimation of reference evapotranspiration ($ET_{0)}$ by globally accepted FAO-56 Penman Monteith [2] requires, the all metrological parameters like maximum and minimum temperature, wind speed, relative humidity and solar radiation,. However, for many locations, as is the case Madhya Pradesh, such meteorological variables are often incomplete and/ or not available. The proposed methodology uses temperature data for estimating the other climate parameter required by the standardized FAO-56, Penman Monteith. The procedure has been applied around the world for estimating ET0 from limited weather data billability the studies using the FAO missing data estimation procedure done in north china environment [6], [8] and [7]. The procedure has been, reported with good alternative for

searching the evapotranspiration estimation that fits the weather datasets availability. However, to the knowledge of the authors, it is found that no research has been yet, using such methodology for estimation ET_0 in Madhya Pradesh sub-tropic region where full weather data availability is very poor.
Therefore, the present study explores applicability of such procedure in the wide agro-climatic, zone of Madhya Pradesh. In Madhya Pradesh irrigation, planning is done on annual basis, hence the average monthly weather data, for eleven years for the period of 2004 to 2014 was used to model performance evaluation of the methodology in the sub-tropic climatic condition of Madhya Pradesh.

MATERIAL AND METHODS

This chapter encompasses description of study area, collection and analysis of metrological data and comparison of reference evapotranspiration, by using four deferent models with against FAO-56 model.

(A) General description of study area and data collection

The study was carried out for Northern part of the Madhya Pradesh namely Ashok Nagar district which are situated between 24°34'N latitude and 77°43'E longitude and 499 m above m.s.l. The metrological data were collected from Global Weather Data site. The weather data set includes daily maximum temperature, minimum temperature, mean relative humidity, wind speed and solar radiation for periods of 11 years period (2004-2014). The area has lies in sub-tropic condition in girdh region of Madhya Pradesh with three district season vlz. Summer (march- June), monsoon(July – October) and Winter (November-February).

(B) Evapotranspiration estimation models.

Four evapotranspiration models:, Trabert [11], Hargreaves-Samani [12], Jensen-Haise Rosenberg [13], Rohwar [13] were used to estimate ET_0. The model selection was based on the complexity or simplicity of the models, and the quality and quantity of the weather data (Table 2). These four models were used to compute ET_0using daily weather data (Table 2). The four models have advantages and disadvantages in terms of input data requirements and quality of results. A primary goal of this study was to identify the model that most closely approximates FAO56PM while considering the input data required.

The FAO-56 Penman Monteith model is given by:

According to Allen [1], recommended form of FAO56-PM model consisting of aerodynamic and surface resistance terms is:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T_{av}+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \ldots (1)$$

where ET_0 is reference evapotranspiration (mm d^{-1}), R_n is net radiation at crop surface (MJ m^{-2} d^{-1}), G is soil heat flux density (MJ m^{-2} d^{-1}), T_{av} is mean daily air temperature (°C), U_2 is wind speed at 2 m height (m s^{-1}), e_a is actual vapour pressure (kPa), e_s is saturation vapour pressure (kPa), e_s-e_a is vapour pressure deficit (kPa), Δ is slope of vapour pressure curve (kPa°C^{-1}), and γ is psychrometric constant (kPa°C^{-1}).

Hargreaves-Samani [12]

This method is one of the simplest methods to compute daily grass reference evapotranspiration as it requires measurements of maximum and minimum temperatures only, with extra-terrestrial radiation calculated as a function of latitude and day of year :

$$ET_0 = 0.408 \times 0.0030 \times R_a \times (T_{av} + 20.0) \times (T_{max} - T_{min})^{0.4} \ldots (2)$$

ET_0 is reference evapotranspiration (mm d^{-1}), T_{av} is mean temperature (°C), T_{max} is maximum temperature (°C), T_{min} is minimum temperature (°C), R_a is water equivalent of extra-terrestrial radiation (mmd^{-1}), and 0.408 is constant to convert MJ m^{-2} d^{-1} into mm d^{-}

Jensen-Haise Rosenberg [13]

$$ET_0 = 0.0102 \times R_s \times (T_{av} + 3.2) \ldots (3)$$

Where, ET_0 is reference evapotranspiration (mm d^{-1}), R_s is solar radiation (MJ m^{-2} d^{-1}), and T_{av} is mean temperature (°C).

Trabert [11]

$$ET_0 = 0.3075 \times \sqrt{U_2} \times (e_s - e_a) \ldots.(4)$$

Rohwar [14]

$$ET_0 = 0.44 \times (1 + 0.27 \times U_2) \times (e_s - e_a) \ldots.(5)$$

ET_0 is reference evapotranspiration (mm d^{-1}), U_2 is wind speed (m s^{-1}), $e_a$and e_s are actual and saturation vapour pressure, respectively. The values of e_a and e_s are in hPa in equations 9.8 (except Rohwer methods, where it is in mm Hg), U_2 is in m s^{-1} in all equations.

Table 1: Weather data

	FAO56-PM	Trabert	J-H	Rohwar	H-S
Maximum temperature (°C)	✓	✓	✓	✓	✓
Minimum temperature (°C)	✓	✓	✓	✓	✓
Humidity (%)	✓	✓		✓	
Wind speed (m/s)	✓	✓		✓	
Solar radiation (MJ/m2/day)	✓		✓		

Statistical Criteria for Performance Evaluation of Models

Coefficient of determination (R^2)

It assesses the performance of different methods as it directly measures the ability of method to reproduce observed values. It also indicates "goodness of fit" of statistical model in the form of a line or curve. It is also defined as ratio of explained variance to total variance and is a measure of linear covariance between two variables. The mathematical expression of R^2 is expressed as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad \ldots (6)$$

When value of R^2 was greater than or equal to 0.90, it is considered very satisfactory, whereas, for its value lying between 0.80-0.90, results are considered fairly good, and when it ranges in between 0.60 and 0.80, it is considered unsatisfactory.

Root mean square error (RMSE)

It is a criteria used to compare various empirical methods and indicate "goodness of fit" of estimates. It also represents standard deviation of difference between "observed" and "predicted" values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \qquad \ldots (7)$$

RMSE ranges from zero to infinity and its lower values are preferable.

Mean Absolute Error

$$MAE = \frac{\sum_{i=1}^{n}|P_i - O_i|}{n} \qquad \ldots (8)$$

Where,

P_i = ET_0 for i^{th} observation by different models (predicted)

O_i = ET_0 for i^{th} observation by P-M method (measured)

N = Number of observations.

Mean Absolute Percentage Error

It is the percentage of fraction of difference between "predicted" and "observed" values to that of the observed values, and is expressed as:

$$MAPE = \left|\frac{\bar{P} - \bar{O}}{\bar{O}}\right| \times 100\% \ldots (9)$$

Its lower values are considered better.

RESULTS AND DISCUSSION

This study was carried out to calculate the ET_0 values on a monthly basis for each method using the meteorological data in Ashok Nagar district of Madhya Pradesh State by using value of ET_0obtained with FAO56 P-M model and different ET_0 based models to assess evaluation of different model for calculating the difference of ET_0 values.This variation increases or decreases between the methods depending on the type of method used and the weather parameters included in the method.

The value of average monthly ET_0 to comparison between observed and calculated values for four ET_0models are presented in Fig. 1. It was observed that the ET_0 increase during the months February, March, April, May, June, and October. The ET_0 decrease during the months January, July, August, September, November and December. The variation of average monthly ET_0 values over the period of all the models.

Fig. 1 showed that the value of reference evapotranspiration (ET0) for Rohwer, Trabert and H-S model were underestimated from FAO-56 Penman Monteith (PM) model for all month. and Jensen-Haise (J-S) model was overestimated from FAO-56 PM model in month of April, May, July, August, September, October, November by 21.97%, 12.00%, 22.97%, 55.00%, 48.50%, 22.99 %and 4.50% respectively and underestimated in remaining month.

The value of statistical indices for performance evaluation of ET_0 values of FAO56-Penman-Monteith Model and other ET0 models on monthly basis are shown in Table 1 in term of R2, RMSE, MAE, MAPE and

CE. **Table 2** shows that the higher coefficient of determination were found for Trabert model with value 0.982 followed by Rohwar (0.981)J-H (0.896)as compared with other models while lower values of coefficient of determination were found for H-S model with value 0.823. It indicates that there is good correlation and determination of Trabert model with penman-monteith model followed by Rohwar model than other models. The lower values of RMSE, MAPE and MAE were found for J-H model as values 1.056, 19.299and 0.852 performed well followed by H-S and Rohwer models as compared to other models and higher values were found for Trabert model with value 4.023, 80.590 and 3.909. It indicates that J-H model showed better performance on the basis of RMSE, MAE, MAPE followed by H-S, Rohwer model and Trabert model was more accurate on the basis of R^2 followed by Rohwer, J-H than compared to other models.

The result revealed that Trabert and Jensen- Haise(J-H) model were more accurate model on the basis of correlation and arrear analysis based for estimating ET0 values.

Table 1: The value of statistical indices for performance evaluation of ET_0 values of FAO56-Penman-Monteith Model and other ET0 models on monthly basis.

Performance evaluation of ET0 value of Radiation, Mass-Transfer and Temperature-based ET_0 Models based with P-M Methods				
Methods	Criteria			
	R2	RMSE	MAE	MAPE
H-S	0.823	1.845	1.364	22.807
J-H	0.835	1.056	0.852	19.299
Rohwar	0.979	3.408	3.356	70.642
Trabert	0.98	4.023	3.909	80.596

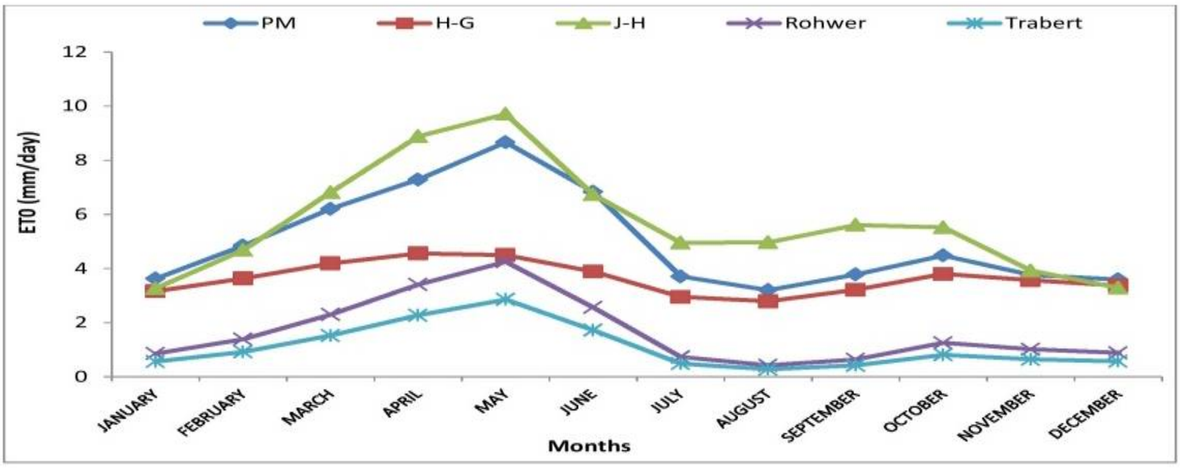

Fig. 1: Showed that the value of reference evapotranspiration (ET0) for Rohwer, Trabert and H-S model were underestimated from FAO-56 Penman Monteith (PM) model for all month

CONCUSION

Five methods for the estimation of ET0 were evaluated under a sub-tropic climate, by using over 11 years of meteorological data for Ashok Nagar District of Madhya Pradesh. The results indicated that Jensen-Haise (J-H) model provided the best results under sub-tropic conditions. However, it was found that the ET_0 estimated by the various ET_0methods was closely correlated with the ET_0observed by FAO-56 Penman Monteith model. In addition, the J-H model gave the estimates closest to the values observed in comparison to the other ET_0 models. Therefore, from these results, it is concluded that the Jensen – Haise model can be recommended for computing ET_0 for Ashok Nagar district in gird region of Madhya Pradesh.

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