Mathematical model for estimating evaporation from a farm pond in a semi-arid region

P. N. Dalavi[1]; P.A.Gawande[2] and A.N.Mankar[3]

[1]Post Graduate Student, Department of Irrigation and Drainage Engineering, Dr. PDKV, Akola, Maharashtra.
[2]Assistant Professor, Department of Agricultural Engineering, Dr. PDKV, Akola, Maharashtra.

[3]Assistant Professor, Department of Agricultural Engineering, Dr. PDKV, Akola, Maharashtra.

ABSTRACT :

The present study used three existing models to estimate the rate of evaporation from pan and farm pond. Statistical analysis was performed to screen the models. The root mean square error (RMSE), percent deviation, coefficient of determination (R^2), and scatter plot analysis reveal that for pan and pond evaporation Dalton model predict the evaporation rate close to the actual observed evaporation. Models were developed for predicting pan and pond evaporation on multiple linear regression, and energy balance method. For pan evaporation, model developed by energy balance method gave results with highest coefficient of determination ($R^2 = 0.9473$), lowest root mean square error (1.1403 $mmday^{-1}$) with closer association between estimated and observed evaporation. For pond evaporation the model developed by stepwise multiple linear regression analysis gave results with highest coefficient of determination ($R^2 = 0.9638$), lowest root mean square error (0.7377 $mmday^{-1}$) with closer association between estimated and observed evaporation.

INTODUCTION

Information on evaporation is also required for planning of irrigation scheduling, irrigation system design, for calculating water requirement of crops and in planning, for conservation of water in agriculture. Of all the components of hydrologic cycle, evaporation is perhaps the most difficult to estimate owing to complex interaction between the components of land-plant-atmosphere system. Measurement of evaporation with accuracy is difficult task because of variations in size and shape of pans, their exposure, the growth of algae in water, incorrect water level, weed growth nearby, splashing of water in or out of the pan during rainfall, the protection against use of water by birds and animals and specific methods of measuring the loss of water from the pans. Information on evaporation is also required for planning of irrigation scheduling, irrigation system design, for calculating water requirement of crops and in planning, for conservation of water in agriculture. Of all the components of hydrologic cycle, evaporation is perhaps the most difficult to estimate owing to complex interaction between the components of land-plant-atmosphere system. Measurement of evaporation with accuracy is difficult task because of variations in size and shape of pans, their exposure, the growth of algae in water, incorrect water level, weed growth nearby, splashing of water in or out of the pan during rainfall, the protection against use of water by birds and animals and specific methods of measuring the loss of water from the pans. This study was useful to farmers, agencies involved in planning irrigation scheduling and utilization of water resources.

MATERIAL AND METHODS

The study was conducted at All India Co-ordinated Research Project for Dryland Agriculture, Dr. PDKV Akola. . The average precipitation is 750 mm.The mean annual maximum and minimum temperature are 38.28^{0}C and 22.22^{0}C in summer and 31.31^{0}Cnd 14.75^{0}C in winter respectively.

The performance of different existing and developed evaporation models were evaluated using the statistical parameters namely, root mean square error (RMSE), percent deviation, and index of agreement. The associated parameters such as (1) Energy term, (2) Daily net radiation at earth surface, (3) Drying power of the air, (4) Vapour pressure deficit, (5) Mean weekly relative humidity at noon and (6) Function of wind speed were computed using standard formulae as described in FAO-56.

Evaporation may be computed by the aerodynamic method when energy supply is not limiting and by the energy balance method when vapour transport is not limiting. In this study, it is considered that vapour transport is not limiting and the rate of evaporation may be computed from energy balance based model expressed as:

$$E_{en} = a + b * \left(\frac{\Delta}{\Delta+\gamma}\right) \times R_n \qquad (1)$$

Where,

E_{en} = Open water surface evaporation, (mmday^{-1})

a = value of intercept

b = slope of line

Δ = Slope of the saturation vapor pressure curve, mbar

R_n = Net radiation, (MJm^{-2}day^{-1})

γ = Psychrometric coefficient, (kPa°C^{-1})

3.5 Evaluation of different evaporation models

Most popular three models for estimating evaporation were selected to analyze and evaluate. The evaporation was estimated by using these models. The comparison was based on daily evaporation rates.

Following existing evaporation models were evaluated in this study for Akola station.

1. Penman combination model
2. Priestley-Taylor model
3. Dalton model

These criteria are estimated as follows:

The Root Mean Square Error

It is a frequently used measure of the difference between values predicted by a model and the values actually observed values. The RMSE of a model prediction is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(E_{model} - E_{obs})^2}{n}} \tag{2}$$

Where,

E_{model} = Modeled values

E_{obs} = Observed values

n = Number of observations

Percent Deviation

It is the percent error of the selected models in predicting evaporation rate and it is determined by using:

$$Percent\ deviation = \sum_{i=1}^{n} \frac{E_{model} - E_{obs}}{E_{obs}} \times 100 \tag{3}$$

Where, E_{model} = Modeled values

E_{obs} = Observed values

The index of agreement (D)

Willmott (1981) proposed the index of agreement (D) and it represents the ratio of the mean square error and the potential error. D provides information about the goodness of fit of model. The range of D is between zero (no correlation) and one (perfect fit).

$$D = 1 - \left[\frac{\sum_{i=1}^{n}(E_{model} - E_{obs})^2}{\sum_{i=1}^{n}(|E_{model} - \overline{E_{obs}}| + |E_{obs} - \overline{E_{obs}}|)^2}\right] \tag{4}$$

Where,

E_{model} = Modeled values

E_{obs} = Observed values

$\overline{E_{obs}}$ = Mean of observed values.

RESULTS AND DISCUSSION

In this study, three most commonly used evaporation estimation models viz., (1) Penman combination model (2) Priestly-Taylor model and (3) Dalton model were selected for evaluating their suitability under the semi-arid climatic conditions of Akola.

These three evaporation models have been screened through testing their accuracy in predicting the evaporation rate from open water surface. Evaluation of selected models was carried out by finding pond factor for each of these models. Values of pond factor for each of these models were determined by linear regression analysis between model evaporation value and observed pond evaporation (E_{po}). Estimated evaporation rate were compared with observed evaporation rate. The performances of models were evaluated using the statistical parameters namely, highest coefficient of determination, lower standard error, minimum percent deviation, and highest index of agreement.

Penman combination model

Using Penman combination model with pond factor 1.23 the daily pond evaporation was estimated for Akola. The results are evaluated for its suitability to Akola region. Daily estimation and observed pond evaporation were compared and presented in Fig.1 and Fig. 2.

Fig.1 shows the variation between daily observed and estimated pond evaporation during period 21 November 2013 to 15 March 2014. It is evident from Fig. 1 that pond evaporation was slightly underestimated for most of the days during study period. However, overestimation of evaporation rate was observed during 27 Feb. 2013 to 15 Mar. 2014.

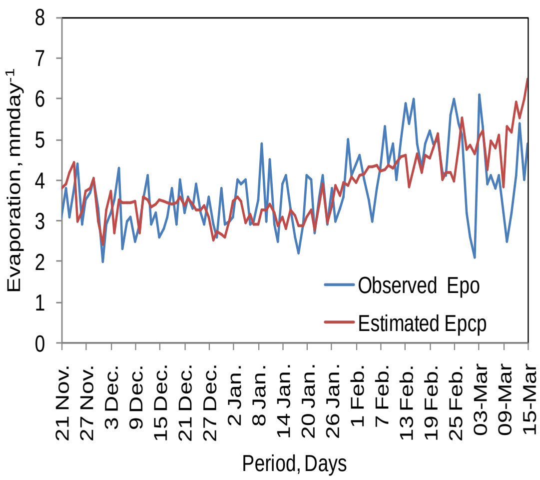

Fig. 1.Variation of daily observed (Epo) and estimated pond evaporation by Penman model

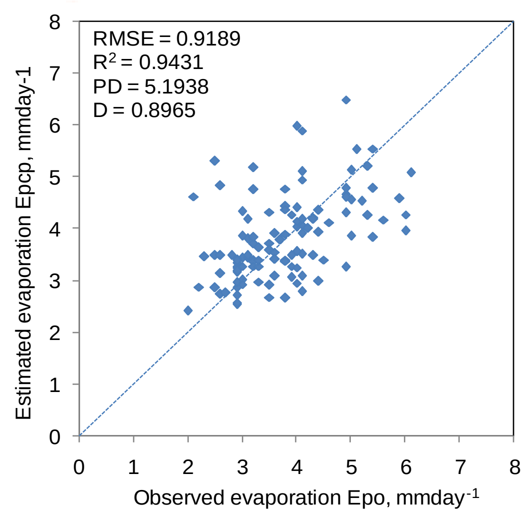

Fig. 2.Daily distribution of observed (Epo) and estimated pond evaporation (Epcp) around 1:1 line

Priestley–Taylor model

Priestley–Taylor with pond factor 1.04 was evaluated for pond evaporation of Akola for the period 21 November 2013 to 15 March 2014. Variation and distribution of observed and estimated daily pond evaporation for Akola is represented in Fig. 3 and Fig. 4.

Fig. 3 indicates the underestimation of evaporation rate by Priestley–Taylor model. It is seen that slightly overestimation was observed during last days of study period.

Fig. 4 shows fair distribution of data points around 1:1 line. Regression analysis between the evaporation rates predicted by the Priestly-Taylor model and the corresponding observed values shows that the model values have strong R^2 values (0.9412). The model error, as evidenced through the RMSE, is lower (0.9337mmday^{-1}). The percent deviation of error, (4.8746 %) reveals the suitability of model with pond factor 1.04 for evaporation studies. In addition, index of agreement of modeled values, D (0.8812) is on higher side. Therefore, the Priestley–Taylor model is suitable for evaporation studies in climatic conditions of Akola.

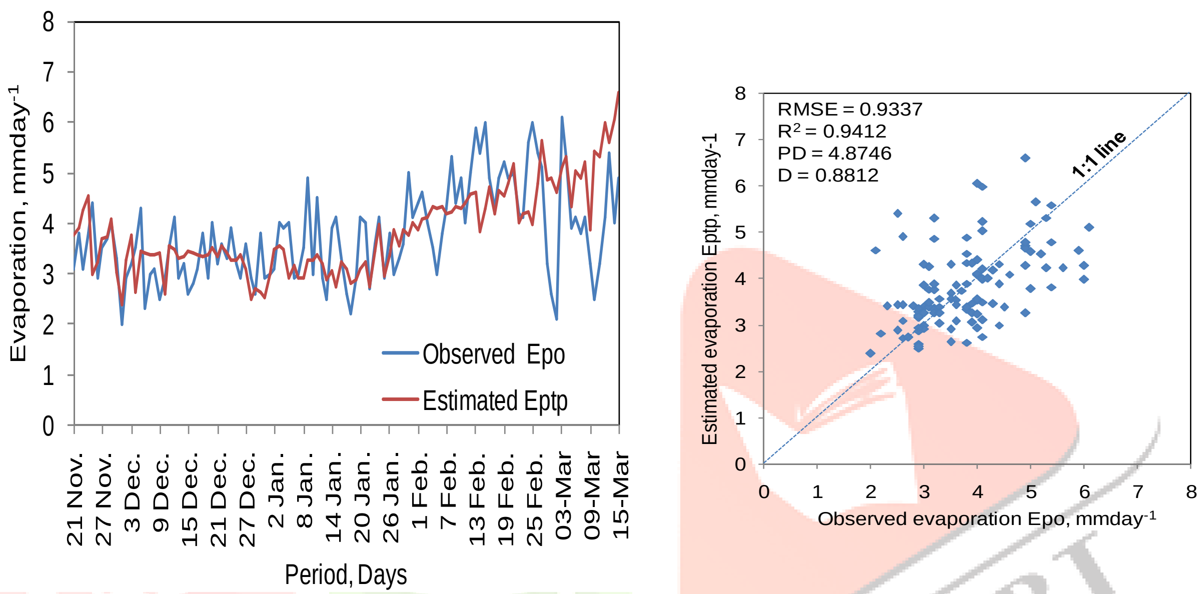

Fig. 4 **Daily distribution of observed (Epo) and estimated pond evaporation(Eptp) around 1:1 line**

The results of stepwise multiple linear regression analysis for estimation of weekly pan evaporation at Akola arepresented in Table 1. It shows the seven possible models obtained for Akola by stepwise regression analysis. It is seen from Table 1 that the highest coefficient of determination (R^2 = 0.9638) was obtained in seventh model. The model included three parameters T_x, BSH, and WS. Model error, as expressed through RMSE is found to be minimum (0.7377mmday^{-1}) in seventh model as compared to others. It is, therefore the best statistically developed model for prediction of pond evaporation under climatic condition of Akola and it is expressed as:

$$E_{mrp} = 0.0830T_x + 0.1199BSH + 0.3127WS \qquad (5)$$

(R^2 = 0.9638)

Where,

E_{mrp}= Pond evaporation predicted from multiple linear regression model.

Equation 5 was used for predicting daily pond evaporation at Akola during the period 21 November 2013 to 15 March 2014 .

Table 1: Multiple linear regression analysis of daily pond evaporation with meteorological parameters

Sr. No.	Parameter	Coefficient	RMSE ($mmday^{-1}$)	R^2	PD	D
1	T_X	0.1263	0.8667	0.9504	5.6948	0.8903
2	BSH	0.5456	1.3581	0.8784	-5.5708	0.7864
3	WS	1.4625	2.1902	0.6837	-9.7413	0.5123
4	T_X	0.1095	0.3531	0.9524	5.4815	0.9226
	BSH	0.0800				
5	T_X	0.1105	0.7863	0.9595	4.7032	0.9644
	WS	0.2741				
6	BSH	0.4102	1.012	0.9329	-2.9908	0.8744
	WS	0.5831				
7	T_X	0.0830	0.7377	0.9638	4.1636	0.9963
	BSH	0.1199				
	WS	0.3127				

Conclusion:

The coefficient of determination was found to be maximum (R^2 = 0.9638) with minimum RMSE (0.7377 mmday-1) of the model indicates the model's predictability, as far as the climate of the study region is concerned.

The developed model may be used with high degree of accuracy for Akola. The developed model based on multiple linear regression for predicting daily pond evaporation was compared with energy balance based model, penman combination model, Priestley–Taylormodel, Dalton model and tested for its suitability and found simple, easy to use with good degree of accuracy and suitable for semi-arid region of Akola.

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