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MODELING EVAPORATION FROM FARM POND IN SEMI-ARID REGION

Pradip Dalavi*[1], A. N. Mankar[2] and S. B. Wadatkar[3]

Department of Irrigation and Drainage Engineering, Dr. Panjabrao Deshmukh, Krishi Vidyapeeth, Akola, India.

Abstract

The present study was undertaken with major objective to develop a mathematical model for estimating evaporation from a farm pond in a semi-arid region. The study was conducted to develop and evaluate different evaporation estimation models considering importance and difficulty in measurement of evaporation. Models were developed for predicting pond evaporation on multiple linear regression, and energy balance method. For pond evaporation the model developed by stepwise multiple linear regression analysis gave results with highest coefficient of determination ($R^2 = 0.967$), lowest root mean square error (0.737 mm day^{-1}) with closer association between estimated and observed evaporation. The present study used three existing models to estimate the rate of evaporation from 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.

Key words : Evaporation, modeling, farm pond, semi-arid region, energy balance method, statistical analysis.

Introduction

Farm pond in rainfed agriculture ensure against drought, while increasing cropping intensity and sustaining crop productivity (Panda *et al*., 2012). Estimation of evaporative losses is of paramount importance for the monitoring, survey and management of water resources, at a farm scale as well as at a regional or catchment's scale (Morton, 1990; Bruton *et al*., 2000; Stanhill, 2002). In the case of agricultural water reservoirs for irrigation (AWRIs), evaporation losses can represent a significant fraction of the total water stored during the irrigation season (Hudson, 1987; Mugabe *et al*., 2003) and could be a serious constraint for irrigation water-availability under arid and semi-arid conditions. Valuation of techniques for increasing AWRI storage efficiency, such as shading structures (Martinez Alvarez *et al*., 2006), requires an accurate estimation of the amount of evaporated water.

Therefore, it is of primary interest to estimate AWRIs evaporation rate, either from measurements or from formulae and models (Lenters *et al*., 2005). This method is commonly used to derive the evaporation over water surfaces, E, for hydrological applications (Linsley *et al*., 1992), or the reference crop evapotranspiration, ET for agricultural and irrigation purposes (Doorenbos and Pruitt, 1977; Allen *et al*., 1998; Lopez-Urrea *et al*., 2006). For both types of application, an empirical pan coefficient, Kp, defined as the ratio of E (or ET) to Ep is used to supply an estimate of either E or ET. Accurate estimation of evaporation is required for efficient irrigation management. Evaporation from a water body is associated with many complex interactions having the parameters of a hydrological system. Therefore, it is very difficult to estimate evaporation, compared with the other outflow components of an on farm reservoir (OFR). To overcome the inconvenience of directly measuring the evaporation, many mathematical models have been developed for various regions across the globe. Numerous equations, classified as temperature-based, radiation-based, pan evaporation-based and combination-type, have been developed for estimating evaporation. However, calibration and validation of these models need to be performed by using carried out using the local soil, water, and climatic data before applying them in other regions. (Panda *et al*., 2012).

The main objective of this study is to mathematical model for estimating evaporation based on available

****Author for correspondence :*** E-mail: pradipdalavi@gmail.com

meteorological data under semi-arid conditions. Using Penman combination Model, Priestley-Taylor model, Dalton model evaporation was estimated. Their values were compared with the observed pond evaporation. This study will be useful to farmers, agencies involved in planning irrigation scheduling and utilization of water resources. It is necessary to develop the appropriate evaporation models under the prevailing climatological conditions to estimate evaporation directly from climatic data. Considering the above aspects study has been conducted with following objectives (i) To estimate evaporation from the farm pond using different evaporation models, (ii) To compare different evaporation models with real time pond evaporation and (iii) To develop a mathematical model for estimating evaporation from a farm pond in a semi-arid region.

Materials and Methods

Description of experimental site

The farm pond located in semi-arid agro-climatic zone. The form pond is constructed at All India Co-ordinated Research Project for Dryland Agriculture, Dr. Panjabrao Deshmukh, Krishi Vidyapeeth, Akola, India. The average annual rainfall of this region is 750 mm. In this region the mean annual maximum and minimum temperature are 38.28˚C and 22.22˚C in summer and 31.31˚C and 14.75˚C in winter, respectively.

Observation data

The meteorological data used to estimate the evaporation was acquired from the Agricultural Meteorological Observatory of Dr. Panjabrao Deshmukh, Krishi Vidyapeeth, Akola, India. Meteorological data includes maximum and minimum temperature, relative humidity, wind speed, bright sunshine hours and evaporation from Class A pan, for the period 21 November, 2013 to 15 March, 2014. Also, daily pond evaporation data recorded for the same period.

Different evaporation models

Penman combination model

Penman (1948) presented the equation for the estimation of evaporation from open water surface. The Penman equation (Penman, 1948) can be written as follows :

$$E = \left(\frac{\Delta}{\Delta + y}\right) \times Rn + \left(\frac{\Delta}{\Delta + y}\right) \times E_a \tag{1}$$

Where,

E = Open water-evaporation (mm day^{-1})

Δ = Slope of the saturation vapor pressure curve, ($kPa°C^{-1}$)

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

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

E_a = Drying power of the air, ($mmday^{-1}$)

$= 0.35(e_s - e_a)(1.0+U_2/160)$

U_2 = Wind speed at 2m above ground surface (ms^{-1})

e_s = Saturation vapor pressure, (kPa)

e_a = Actual vapor pressure, (kPa)

Priestley–Taylor model

Priestley and Taylor (1972) proposed a simplified version of Penman's combination equation for use when surface areas are generally wet, which is a condition for evaporation.

Therefore, it is possible to write Priestley and Taylor equation (Priestley and Taylor, 1972) as :

$$E = \beta\left(\frac{\Delta}{\Delta + y} \times \frac{R_n}{\lambda}\right) \tag{2}$$

Where,

E = Open water-evaporation, ($mmday^{-1}$)

β = Priestley- Taylor coefficient

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

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

Δ = Slope of the saturation vapor pressure curve ($kPa°C^{-1}$)

Dalton model

Dalton enunciated the fundamental principle of evaporation from a free surface. Dalton's model is expressed as follows (Thilahun, 2003).

$$E = f(u)(e_s - e_a) \tag{3}$$

Where,

f(u) = Function of wind speed

$= 0.26(1+0.54U_2)$

U_2 = Wind speed at 2m above ground surface (ms^{-1})

Developed mathematical models

Model based on energy balance

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 (Mandavia *et al*., 1948) expressed as :

$$E_{en} = a + b \times \left(\frac{\Delta}{\Delta + y} \right) \times R_n \qquad (4)$$

Where,

E_{en} = Open water surface evaporation (mm day^{-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})

Model based on multiple linear regressions

The multiple linear regression model was developed on the basis of combinations of different meteorological parameters. Here, the pond evaporation was considered as dependent variable while different meteorological parameters were independent variable. Thus, the multiple linear regression models is in the form:

$$E_{p0} = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + ... + b_z x_z \qquad (5)$$

Where,

E_{po} = evaporation rate of farm pond (mm day^{-1})

a = intercept on Y-axis

b_1 to b_z = respective partial regression coefficients and

x_1 to x_z = respective meteorological parameters.

The data was analyzed by statistical package designed for data analysis on computer.

Pan Evaporation

The evaporation rate from the pan estimated by using equation :

$$E_{ws} = E_{pan} \times K_{pan} \qquad (6)$$

Where,

K_{pan} = Pan coefficient

E_{pan} = Pan evaporation rate, (mmday^{-1})

E_{ws} = Evaporation from the water surface (mmday^{-1})

Statistical analysis

The performance of different existing and developed evaporation models were evaluated using the statistical parameters namely, Root Mean Square Error (RMSE), Percent Deviation and The Index of Agreement. The following equations were used for the computation of the aforementioned parameters:

1. 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:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(E_{model} - E_{obs} \right)^2}{n}} \qquad (7)$$

2. Percent Deviation

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

$$Percent\ deviation = \sum_{i=1}^{n} \frac{E_{model} - E_{obs}}{E_{obs}} \times 100 \qquad (8)$$

3. 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).

$$D = 1 - \left[\frac{\sum_{i=1}^{n} \left(E_{model} - E_{obs} \right)^2}{\sum_{i=1}^{n} \left(\left| E_{model} - \overline{E_{obs}} \right| + \left| E_{obs} - \overline{E_{obs}} \right| \right)^2} \right] \qquad (9)$$

Where,

E_{model} = Modeled values

E_{obs} = Observed values

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

Results and Discussion

Evaluation of evaporation estimation models for Farm pond

Five 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 comparing estimated evaporation rate with observed evaporation rate. Performance of all evaporation models in terms of statistical parameters presented in table 1.

From table 1, it is found that Dalton model can be effectively used for prediction of the evaporation at Akola.

Table 1 : Performance of all evaporation models in terms of statistical parameters.

S. no.	Evaporation model	Root Mean Square Error (RMSE) (mm/day)	R^2	Percent Deviation (%)	Index of agreement
1.	Penman combination model	0.919	0.943	5.194	0.897
2.	Priestley-Taylor model	0.934	0.941	4.875	0.881
3.	Dalton model	0.862	0.953	5.448	0.915

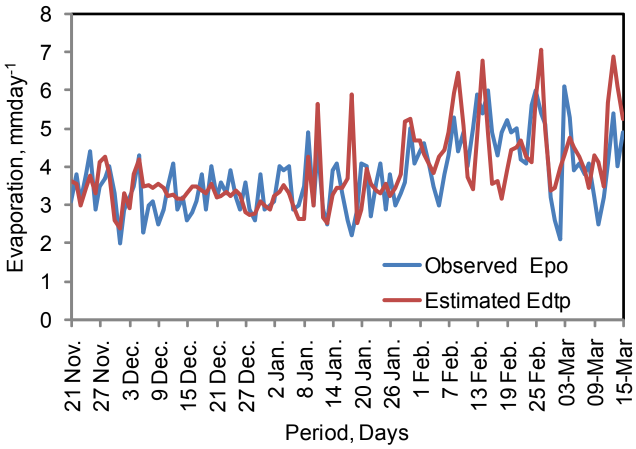

Fig. 1 : Variation of daily observed (Epo) and estimated pond evaporation by Dalton model (Edtp).

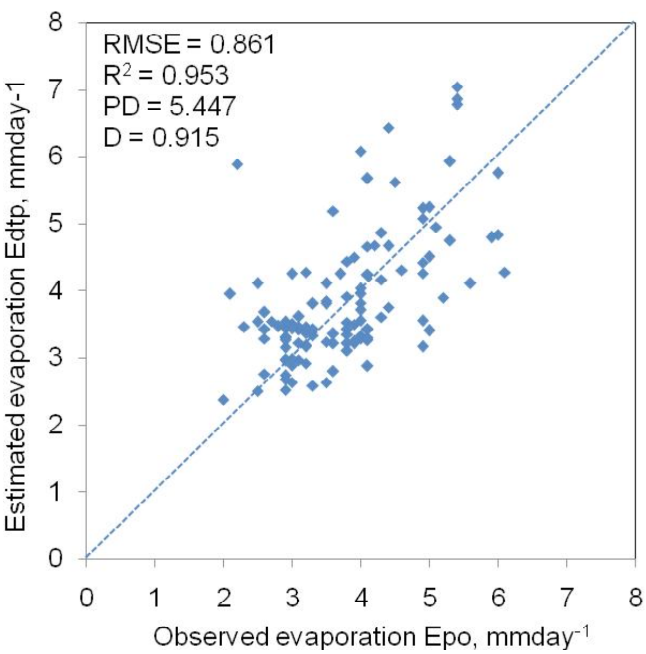

Fig. 2 : Daily distribution of observed (Epo) and estimated pond evaporation (Edtp) by Dalton model around 1:1 line.

Variation of daily estimated pond evaporation by Dalton model were compared with observed pond evaporation for Akola and presented in fig. 1.

Also, nearness of the correlation line with 1:1 line tested correlation and presented in fig. 2.

Evaluation of developed mathematical models

Two mathematical models were developed for estimation of evaporation from farm pond. These two evaporation models have been screened through testing their accuracy in predicting the evaporation rate from open water surface. Evaluation of developed models was carried out by comparing estimated evaporation rate with observed evaporation rate. Performance of all evaporation models in terms of statistical parameters presented in table 2.

From table 2, it is found that developed model based on multiple linear regression can be effectively used for estimation of evaporation from farm pond. Fig. 3 shows the variation between observed and estimated pond evaporation. It is seen that estimated pond evaporation closely association with the observed values except some days during the period, where pond evaporation was slightly underestimated. The evaporation rates predicted by the multiple linear regression model are very close to the observed values, as evidenced from the high coefficient of determination (R^2 = 0.967). The lower RMSE (0.737mm day^{-1}) of the model error indicates the model's predictability, as far as the climate of the study region is concerned. Fig. 4 shows fair distribution of data points around 16:1 line. Furthermore, the percent deviation of 4.164% reveals that the modeled values are within an acceptable range. In addition, an index of agreement of modeled values, D (0.993) is on higher side. Hence, the model is a reliable model for estimating evaporation under climatic conditions of Akola.

Table 2 : Performance of developed evaporation models in terms of statistical parameters.

S. no.	Evaporation model	Root Mean Square Error (RMSE) (mm/day)	R^2	Percent Deviation (%)	Index of agreement (D)
1.	Energy balance model	0.885	0.949	5.461	0.901
2.	Multiple linear regression model	0.737	0.967	4.164	0.993

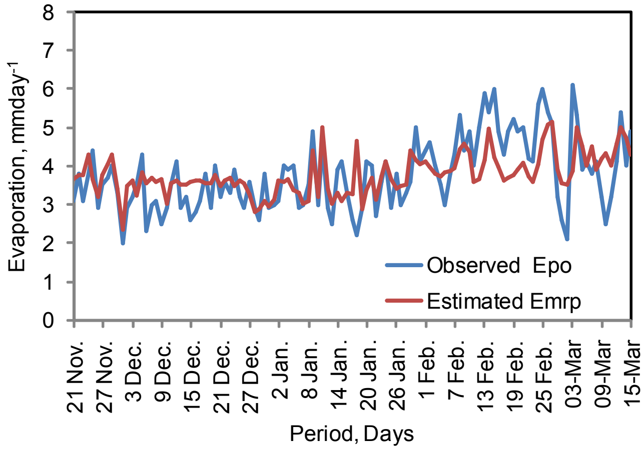

Fig. 3 : Variation of daily observed (Epo) and estimated pond evaporation by multiple linear regression model (Emrp).

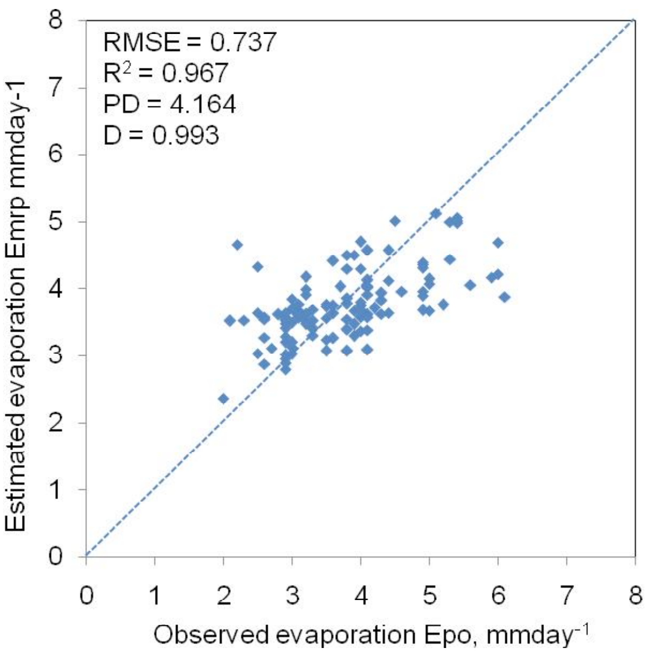

Fig. 4 : Daily distribution of observed (Epo) and estimated pan evaporation (Emrp) around 1:1 line.

As results of stepwise multiple linear regression analysis the best statistical model with minimum parameter for estimation of daily pond evaporation under climatic condition of Akola is developed. It is expressed as :

$$E_{mrp} = 0.083T_x + 0.120BSH + 0.313WS \qquad (10)$$

$(R^2 = 0.967)$

Summary and Conclusion

From study, it is concluded that developed multiple linear regression model and Dalton models were found suitable for estimating pond evaporation in semi-arid region, Akola. However, considering the simplicity in using and calculating daily pond evaporation, the developed empirical model is found to be simple and easy to use for predicting daily pond evaporation with better degree of accuracy for semi-arid region, Akola region.

The model has been developed based on multiple linear regressions for Akola for predicting daily pond evaporation and it is expressed as:

$$E_{mrp} = 0.083T_x + 0.120BSH + 0.313WS$$

$(R^2 = 0.967)$

The developed model may be simple, easy to use with good degree of accuracy and suitable for semi-arid region of Akola.

References

Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). Crop evapotranspiration. *Guidelines for computing crop water requirements*. Irrigation and Drainage Paper 56, FAO, Rome, pp. 300.

Bruton, J. M., G. Hoogenboom and R. W. McClendon (2000). A compararison of automatically and manually collected pan evaporation data. *Trans. ASAE*, **43** : 1097–1101.

Doorenbos, J. and W. O. Pruitt (1977). Guidelines for predicting crop water requirements. *Irrigation and Drainage Paper* **24**. FAO, Rome, 179 pp.

Hudson, N. W. (1987). *Soil and water conservation in semiarid regions*. FAO Land and Water Conservation Service, Rome, pp. 256.

Lenters, J. D., T. K. Kratz and C. J. Bowser (2005). Effects of climate variability on lake evaporation: Results from a long-term energy budget study of Sparkling Lake, northern Wisconsin (USA). *J. Hydrol.*, **308** : 168–195.

Linsley, R. K., M. A. Kohler and J. L. H. Paulhus (1992). *Hydrology for Engineers*, 3rd ed. McGraw-Hill, New York, 508 pp.

Lo´pez-Urrea, R., F. Martý´n de Santa Olalla, C. Fabeiro and A. Moratalla (2006). Testing evapotranspiration equations using lysimeter observations in a semiarid climate. *Agr. Water Manage.*, **85** : 15–26.

Mandavia, B. R., S. S. Deshmukh and M. M. Deshmukh (2005). Evaluated different developed and existing pan evaporation estimation model. *B.Tech. (Agril. Engg.) Thesis* (unpublished), Dr. P.D.K.V., Akola: 25-63.

Martý´nez Alvarez, V., A. Baille, J. M. Molina Martý´nez and M. M. Gonza´ lez-Real (2006). Efficiency of shading materials in reducing evaporation from free water surfaces. *Agr. Water Manage.*, **84** : 229–239.

Morton, F. I. (1990). Studies in evaporation and their lessons for the environmental sciences. *Can. Water Resour. J.*, **15** : 261–285.

Mugabe, F. T., M. G. Hodnett and A. Senzanje (2003). Opportunities for increasing productive water use from dam water : a case study from semi-arid Zimbabwe. *Agr. Water Manage*., **62** : 149–163.

Panda, S. N., B. S. Sahoo and P. Patil (2012). Evaporation Studies of Canopy-Covered On-Farm Reservoir. *J. Irrig. Drain. Eng*., **138(7)** : 300-312.

Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. In *Proceedings of the Royal Society of London A : Mathematical, Physical and Engineering Sciences*, **193** : 120-145.

Priestley, C. H. B. and R. J. Taylor (1972). On the assessment of surface heat ûux and evaporation using large scale parameters. *Mon. Weather Rev*., **100 (2)** : 81–92.

Stanhill, G. (2002). Is tha Class A evaporation pan still the most practical and accurate meteorological method for determining irrigation water requirements? *Agr. For. Meteorol.*, **112** : 233–236.

Thilahun, H. (2003). Modeling of evaporation over Ethiopia. *Ph.D. Thesis* (unpublished), Dept. of Soil and Water Engineering, C.T.A.E. Maharana Pratap University of Agriculture and Technology, Udaipur: 1-298.

Willmott, C. J. (1981). On the validation of models. *Phys. Geogr*., **2** : 184-194.