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Review

Modelling pan evaporation using mean air temperature and mean pan evaporation relationship in middle south Saurashtra Region

Gundalia Manoj J.[1]* and Dholakia Mrugen B.[2]

[1]Gujarat Technological University, Chandkheda, Ahmedabad, Gujarat 382 424, India.
[2]Directorate of Technical Education, Gandhinagar, Gujarat 382 010, India.

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Evaporation and evapotranspiration are the major parameters in the hydrologic cycle and water resources research. Most precipitation is lost in the form of evaporation and evapotranspiration with the percentage varying from region to region globally. Therefore, accurate estimate of evapotranspiration is needed for numerous management activities and its application in rainfall-runoff models. The reference evapotranspiration ET_o concept has been gaining significant acceptance by scientists throughout the world since its introduction and it can also be estimated from pan evaporation E_p. E_p provides a measurement of the combined effect of temperature, humidity, wind speed and solar radiation on reference crop evapotranspiration. Hence, it is extensively used to estimate ET_o. A significant relationship exists between mean daily air temperature and observed mean daily pan evaporation in monsoon season in middle South Saurashtra region of Gujarat State (India). The objective of this study is to develop a model for prediction of Ep using mean air temperature. The four quantitative standard statistical performance evaluation measures, (R^2), (MAPE), (RMSE) and Nash-Sutcliffe efficiency coefficient (E) are employed to evaluate the model. These performance measure ratings are found well within the acceptable limits. Prediction of E_p with the help of mean air temperature will lead to minimization of the time, cost, and equipment maintenance necessary for onsite monitoring and will help researchers to use data from other sources too.

Key words: Mean air temperature, pan evaporation, reference evapotranspiration, Saurashtra region

INTRODUCTION

Pan evaporation E_p is one of the most important climatic parameters in the hydrological cycle, and is often applied to estimate terrestrial evaporation and water requirements. Annual $E_p$is an important climatic variable, and it is often used to estimate potential evaporation (Kirono et al., 2009) and reference evapotranspiration (Chen et al., 2005), as well as to forecast agricultural production (Wang et al., 2009). Evaporation can be directly measured from $E_p$and lysimeter. Many methods for estimation of evaporation losses from free water surfaces were reported and it can be divided into several categories including: empirical methods (Kohler et al., 1955), radiation (Priestley and Taylor, 1972), water budget methods (Shuttleworth, 1988; Guitjens, 1982), energy budget methods (Anderson, 1954), mass-transfer methods (Harbeck, 1962), temperature based (Thornthwaite, 1948; Blaney and Criddle, 1950), and combination methods (Penman, 1948). In the direct method of measurement, the observation from Class A Pan evaporimeter and Eddy correlation techniques were used (Linsley et al., 1982), whereas in indirect methods, the evaporation is estimated from other meteorological

*Corresponding author. E-mail: mjgundalia@yahoo.com, mrug63@rediffmail.com.

variables like temperature, wind speed, relative humidity and solar radiation (Benzaghta et al., 2010).

Monitoring evaporation is a great challenge since specific and costly equipment are required. Penman–Monteith method is widely used due to its simplicity and ease of data interpretation and has come to be known as the most precise and accurate measure of ET_o in humid areas (Irmak et al., 2002). Many scientists have attempted to establish relationship between Ep data and other weather parameters and to explain this puzzling phenomenon.

Singh et al. (1992) investigated relationship between evaporation from US Class A open pan evaporimeter and meteorological parameters at Hisar. Wind velocity, sunshine hours, mean air temperature and solar radiation were positively correlated with evaporation and relative humidity was negatively correlated with evaporation. The highest correlation value (r = 0.78) were obtained with relative humidity.

Singh et al. (1995) obtained simple correlations between different meteorological parameters and evaporation measured from US Class A open pan evaporimeter at Hisar. The highest value of correlation coefficient (0.85) was found with maximum temperature followed by wind speed (0.82). The coefficient of determinates for minimum air temperature, relative humidity and bright sunshine hours were 0.70, –0.56 and 0.15, respectively.

Khanikar and Nath (1998) established relationship between meteorological parameters and evaporation from an open pan evaporimeter at Jorhat, Assam. The coefficient of determination for maximum temperature (0.64), minimum temperature (0.65), wind speed (0.53) and soil temperature at 5 cm depth (0.68) was positively correlated.

Shrivastava et al. (2001) developed a statistical relationship between pan evaporation and the meteorological parameters recorded at Jabalpur. The method of regression was adopted as suggested by Mendenhall and Sincich. From the analysis, it was revealed that the morning relative humidity and the maximum temperature have a significant influence on the rate of evaporation. The highest correlation value was obtained with morning relative humidity (R2 = 0.95) followed by the maximum temperature (R2 = 0.94).

Snyder et al. (2005) presented sine-wave approach to estimate ET_o from E_p data according to fetch distances by eliminating the need for relative humidity and wind speed data. Jhajharia et al. (2009) examined the influence of different meteorological parameters on E_p at Agartala and using the linear and exponential methods concluded that the wind speed and mean temperature have positive and significant influence on E_p. Chu et al. (2010) used wind tunnel experiments to investigate the wind effects on the evaporation rate of the Class A evaporation pan and found that the evaporation rate increased as the wind speed increased; It was also discovered that the wind could blow water over the edges of the pan when wind speed exceeded 6.0 m/s. Xiaomang et al. (2011) concluded that increasing air temperature dominated the change in E_p, which offset the effect of wind speed and led to the increase in E_p. Yuhe and Guangsheng (2011) discovered strongest correlation between annual relative humidity and E_p in the Liaohe Delta in the period 1961 to 2005. Xing-Jie et al. (2012) evaluated the linear trends in annual and seasonal E_p and detected significant increasing trends in mean temperature at annual and seasonal time scales, except for summer and the E_p paradox in the lower Yellow River Basin. Fekih et al. (2013) evaluated energy budget equation and the computational fluid dynamics methods for estimation of rate of evaporation from dams in wet, arid and semi-arid areas in Algeria.

Necessity of the study

Quantitative estimation of ET is of great significance in water resource planning, estimation of crop water requirements for irrigation, agricultural production forecasting, in understanding the hydrologic cycle and rainfall-runoff modelling. Unfortunately weather stations are scarce and do not always have the instrumentation to measure relevant variables for its calculation. Therefore standard method PM is not appropriate in many such situations. Saurashtra, a water scarcity-prone area of Gujarat State has only limited number of weather stations facilitated with U.S. Weather Bureau evaporation pans to measure evaporation. It is impractical to place evaporation pans at every point and also highly unlikely to have it in inaccessible areas where accurate instruments cannot be established or maintained. A practical means of estimating the amount of pan evaporation where no pans are available is of considerable significance to the hydrologists, agriculturists, and meteorologists. On the other hand, air temperature is relatively easy to measure and available at most of the weather stations. Therefore, a model is developed with the motivation to bridge between research findings, especially prediction of E_p by air temperature.

METHODOLOGY

Study area and data collection

Geographical areas of middle south Saurashtra region of Gujarat State, India (Figure 1) encompasses Junagadh district (lies between 20.44° to 21.40° North latitude and 69.4° to 71.05° East longitude) and Amreli district (lies between 20.45° to 22.25° North latitude and 70.30° to 71.75° East longitude). The area is situated in semi-arid region with mean annual rainfall of 955 mm, mean maximum temperature 33.70°C and mean minimum temperature 22.70°C.

Mean temperature and mean E_p data are collected from Agro Meteorological Cell, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat,

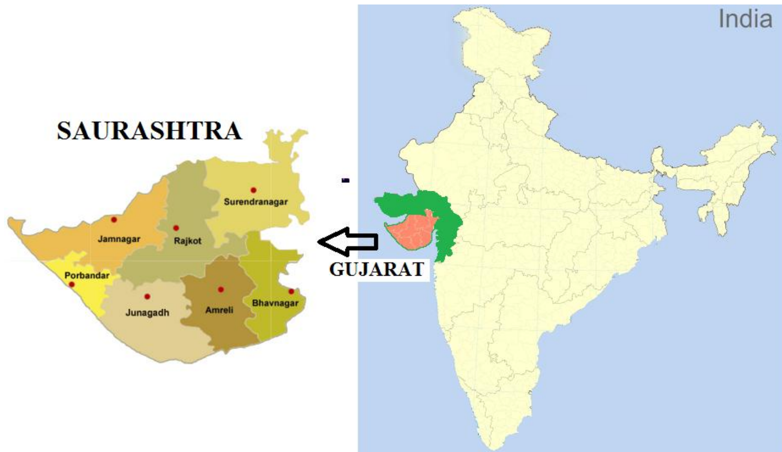

Figure 1. Saurashtra Region of Gujarat State.

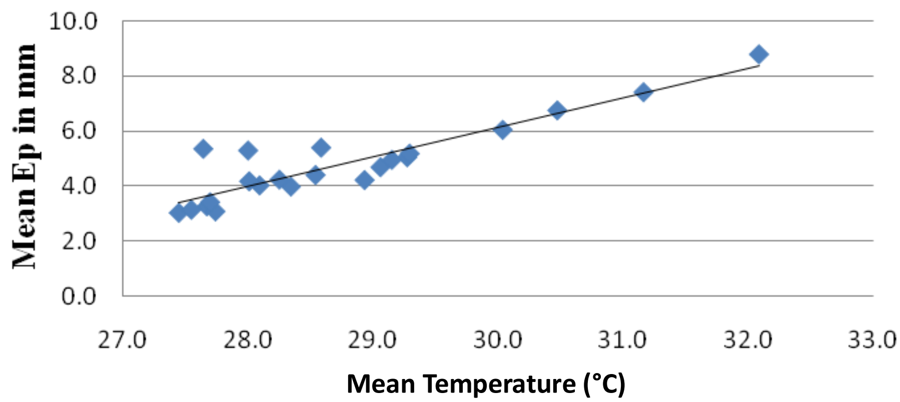

Figure 2. Scatter plot of weekly mean temperature V_s. Mean E_p during monsoon season in Junagadh district.

India.

Model development

Jhajharia et al. (2009) found in his study, wind speed and the mean temperature have positive and significant influence on E_p. Scatter plots of mean weekly temperature v_s, mean weekly E_p for monsoon season and scatter plots of mean weekly wind speed v_s, mean weekly E_p for monsoon season of Junagadh district are shown in Figures 2 and 3 respectively. These scatter plots are offered better relationship between E_p and temperature than between E_p and wind speed during monsoon season in middle south Saurashtra region. A significant relationship has been found between mean daily air temperatures and observed mean daily E_p during monsoon season in Junagadh district of Gujarat State, India through data analysis. Equation 1 is developed based on the relationship between mean E_p and mean air temperature for monsoon season.

$$E_p = \frac{\frac{E_{pm}}{T_m}(T_d - a)}{\text{Cos}\, b} \quad (\text{Where, } b \neq \frac{\pi}{2}) \qquad (1)$$

Where, E_p is the daily pan evaporation in mm, E_{pm} is the mean daily evaporation, T_m is the mean daily air temperature in °C, T_d is the daily air temperature in °C and 'a' and 'b' are the calibration coefficients. The developed model is calibrated for daily air temperature and daily E_p data using dataset of period 1984 to 1991 and validated using dataset of period 1995 to 2000 for Junagadh district. Model is also tested on weekly time scale for Junagadh and Amrelii districts.

Goodness of fit

In this study, coefficient of determination (R^2) is used as standard regression to describe the degree of collinearity between simulated and measured data. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001; Van Liew et al., 2003).

Two standard error measures: mean absolute percentage error (MAPE) and root of mean of square of errors (RMSE) are employed to quantify the deviation in the units of the data. A scale to judge the accuracy of the model based on the MAPE measure, developed by

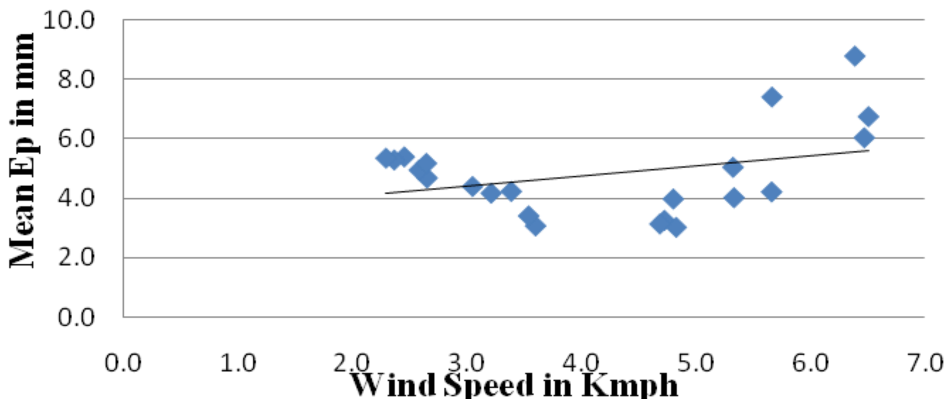

Figure 3. Scatter plot of weekly mean wind speed V_s weekly mean E_p during monsoon season in Junagadh district.

Table 1. A scale of judgment of forecast accuracy (Lewis, 1982).

MAPE	Judgment of Forecast Accuracy
Less than 10%	Highly Accurate
11 to 20%	Good Forecast
21 to 50%	Reasonable Forecast
51% or more	Inaccurate Forecast

Lewis (1982).

The smaller the MAPE value, the better the fit of the model. Using MAPE, and applying Lewis's scale, provides some framework as shown in Table 1 to judge the model.

RMSE is one of the commonly used error index statistics (Chu and Shirmohammadi, 2004; Singh et al., 2004; Vasquez-Amábile and Engel, 2005; Gupta et al., 2009).

The higher the RMSE, the poorer the performance of the model, and vice versa. RMSE = 0 indicates a perfect fit. In addition to (R^2), MAPE and RMSE, accuracy of the developed model is also evaluated by dimensionless statistic, Nash-Sutcliffe criterion (E) (Nash and Sutcliffe, 1970), (E) indicates how well the plot of observed versus simulated data fits the 1:1 line.

Values of (E) between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values less than 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

Parameter estimation

In this study, objective function of minimising sum of squares errors between observed and computed E_p (Equation 2) is selected to optimise the values of model parameters 'a' and 'b'.

$$E_{min} = Min \sum_{i=1}^{n} \left| Epo - Epc \right|^2 \qquad (2)$$

Where E_{po} is the observed E_p; E_{pc} is calculated E_p and n is the number of observations. The optimum values of model parameters are computed using Microsoft Excel spread sheet Microsoft Excel built-in optimisation tool Solver (Front Line 2010).

RESULTS AND DISCUSSION

The graphical results of the developed model in calibration and validation for daily time scale are shown in Figures 4 and 5 respectively. The MAPE, RMSE, E and R^2 values of Junagadh station for daily time in calibration and validation are produced 15.79, 0.84 mm, 0.87, 0.75 and 14.17, 0.99 mm, 0.69, 0.71 respectively. The statistical results are presented in Table 2.

The model is also evaluated on weekly time step for Junagadh as well as for Amreli district and presented in plots shown in Figures 6, 7, 8 and 9. The MAPE and RMSE values of Junagadh station are estimated in calibration and validation 10.71, 0.66 mm, 10.49 and 0.62 mm respectively. The E and R^2 values of Junagadh station are estimated in calibration and validation 0.8, 0.81, 0.8 and 0.82 respectively. The MAPE and RMSE values of Amreli station are estimated in calibration and validation 10.3, 0.71 mm, 8.1 and 0.72 mm respectively. The E and R^2 values of Amreli station are estimated in calibration and validation 0.83, 0.71, 0.83 and 0.76 respectively.

In all applications, the initial value of parameter 'a' and 'b' is taken equal to 1. The values of 'a' and 'b' on daily time scale for Junagadh station are found to be 24.0697 and 1.4013 respectively. On weekly time scale, the values of 'a' and 'b' are estimated for Junagadh and Amreli stations 24.3975, 1.4197 and 21.8337, 1.3148 respectively. The values of 'a' and 'b' on daily scale are found to be 1.34 and 1.40% lower than that of the corresponding values on weekly time scale for Junagadh station. While the values of 'a' and 'b' on weekly scale for Amreli station are found to be 10.51 and 7.39% lower than that of the corresponding values for Junagadh station. Model evaluation results and optimized calibrated values of parameters for weekly time scale are presented in Table 3.

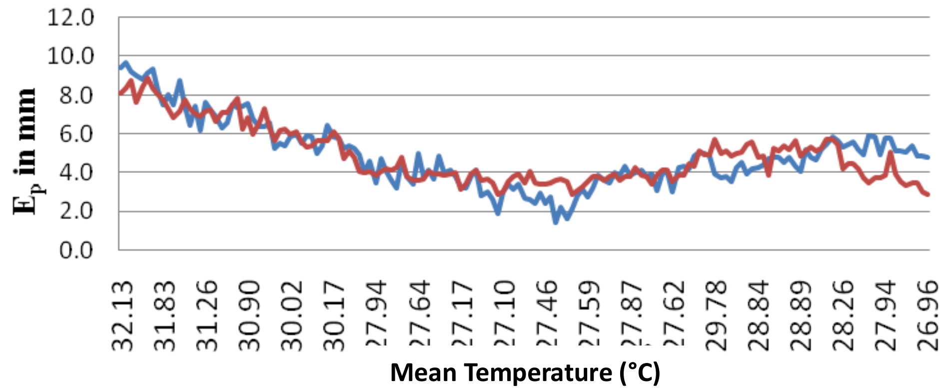

Figure 4. Relationship between mean daily T and mean daily E_p during monsoon season in Junagadh for calibration period 1984 to 1991.

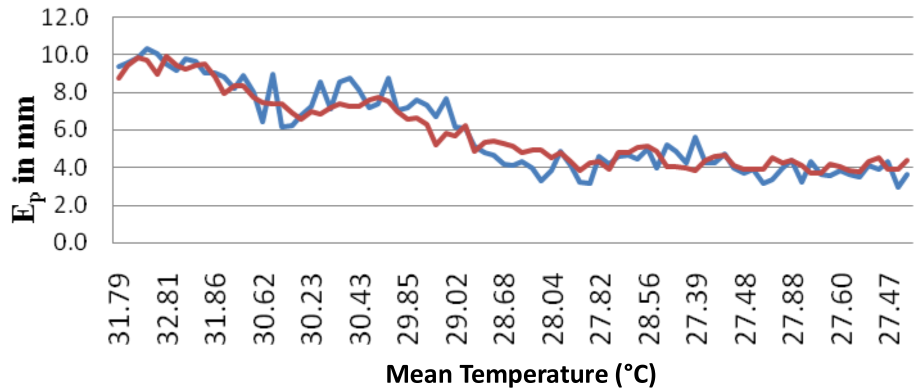

Figure 5. Relationship between mean daily T and mean daily E_p during monsoon season in Junagadh for validation period 1995 to 2000.

Table 2. Results of model on daily time scale for Junagadh Station.

Calibrated model parameters	a = 24.0697, b = 1.4013		
	Calibration (1984 to 1991)	**Validation (1995 to 2000)**	**% difference**
MAPE	15.79	14.17	-10.26
RMSE	0.84	0.99	17.86
E	0.87	0.69	-20.69
R^2	0.75	0.71	-5.33

Conclusions

The minimum values of MAPE and RMSE and values close to 1.0 of (R^2) and (E) show the performance of the model clearly. The results in this study indicated that, the model is found to be more accurate for Junagadh station with RMSE and (E) values 0.66 mm and 0.80 in calibration and 0.62 mm and 0.81 in validation respectively on weekly time scale. Moreover, percentage difference in calibration and validation results of model evolution parameters for Junagadh station was found to be less than that of Amreli station. According to the model evaluation guidelines, the developed model satisfactorily simulated E_p.

The poor performance of model on daily time scale might be because of comparatively higher scatter pattern observed in daily data than that of weekly data.
Moreover, averaging over daily data to weekly time scale will not reduce the trend but will reduce the effect of natural variability and thus more detection probability and lead to more robust prediction.

The mean air temperature is observed to be a

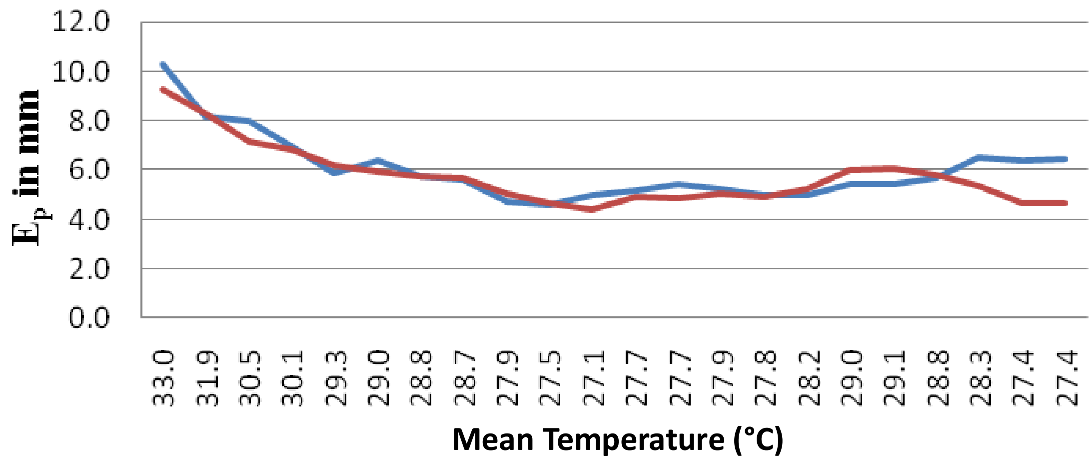

Figure 6. Relationship between mean weekly T and mean weekly E_p during monsoon season in Junagadh for calibration period 1984 to 1991.

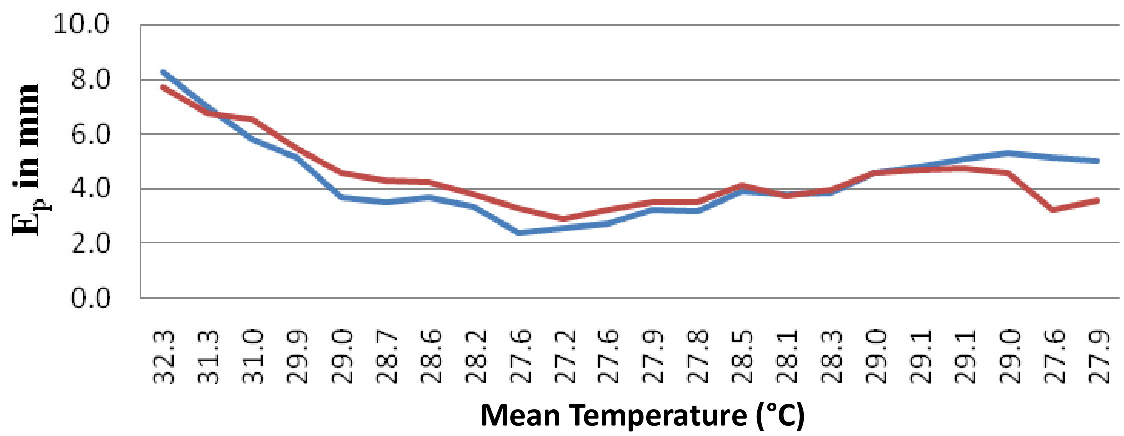

Figure 7. Relationship between mean weekly T and mean weekly E_p during monsoon season in Junagadh for Validation period 1995 to 2011.

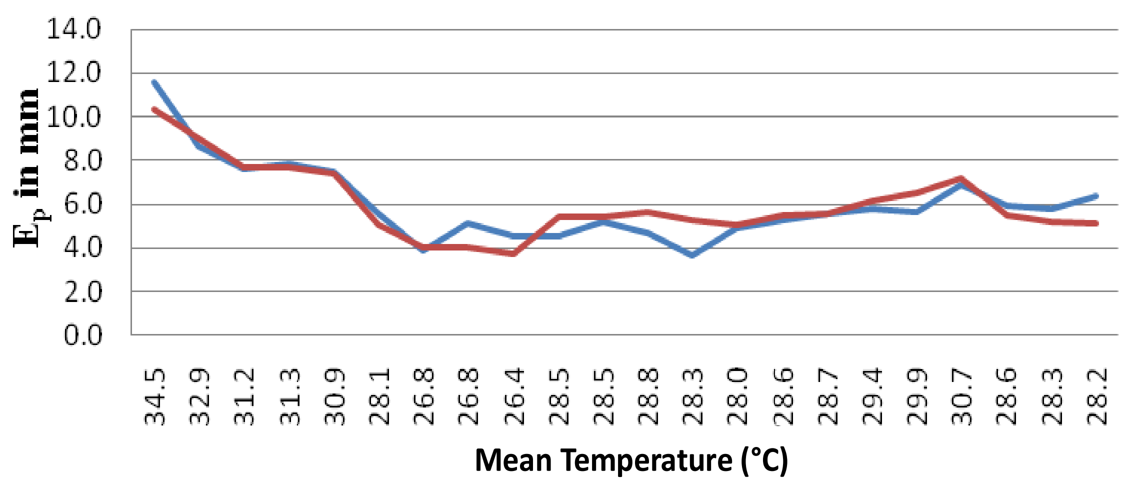

Figure 8. Relationship between mean weekly T and mean weekly E_p during monsoon season in Amreli for calibration period 1992 to 1998.

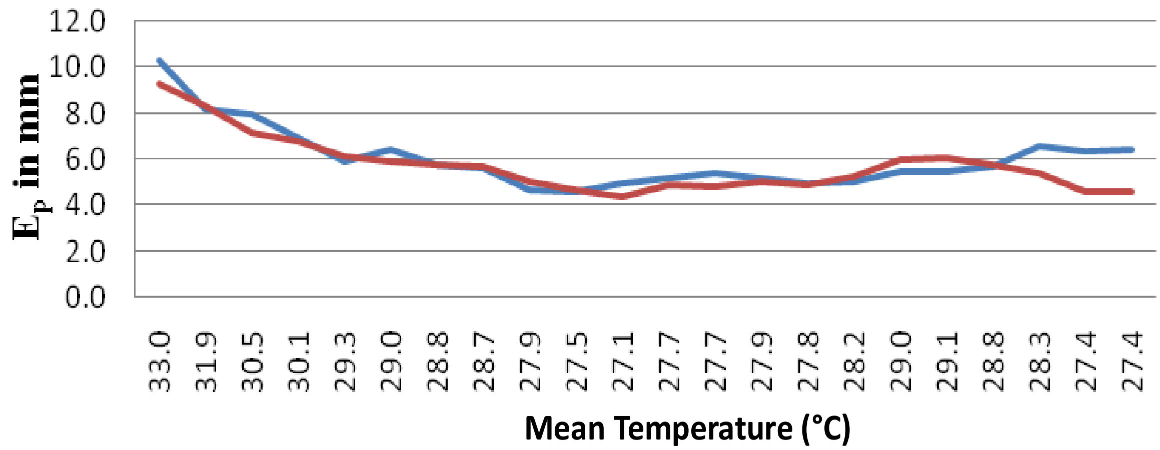

Figure 9. Relationship between mean weekly T and mean weekly E_p during monsoon season in Amreli for validation period 1999 to 2005.

Table 3. Results of model on weekly time scale for Junagadh and Amreli stations.

Junagadh Station			
Calibrated model parameters	**a = 24.3975, b = 1.4197**		
	Calibration (1984 to 1991)	**Validation (1995 to 2011)**	**% difference**
MAPE	10.71	10.49	-2.05
RMSE	0.66	0.62	-6.06
E	0.80	0.81	1.25
R^2	0.80	0.82	2.50

Amreli Station			
Calibrated model parameters	**a = 21.8337, b = 1.3148**		
	Calibration (1984 to 1991)	**Validation (1995 to 2000)**	**% difference**
MAPE	10.30	8.10	-21.36
RMSE	0.71	0.72	1.41
E	0.83	0.71	-14.46
R^2	0.83	0.76	-8.43

significant parameter for the estimation of pan evaporation in middle south Saurashtra region and explicit relationship between mean air temperature and E_p is found during monsoon period. An attempt is made in this study to develop model based on this relationship to predict pan evaporation. The model predictions are comparable with the observations. It is noticed that the variation between observed and estimated E_p increases as the rainfall decreases. Performance of the model is found better during June to September months than in October month. The poor performance of the model might be because of little rainfall in the October month. In the middle south Saurashtra region, only 6 to 8% of total mean annual rainfall occurs in October month.

The model has simplicity advantage as it can estimate evaporation from only one climatological parameter of air temperature. From a practical point of view, this model can be considered suitable to serve as a tool to estimate evaporation when input meteorological variables are insufficient. The developed model can successfully be used in prediction of E_p and will lead to minimization of the time, cost, and equipment maintenance necessary for onsite monitoring. It will also help researchers use data from other sources.

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