Estimation of Reference Evapotranspiration in Middle South Saurashtra Region of India Using Dominant Meteorological Variables

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Abstract: In this paper attempt is made to estimate reference evapotranspiration (ET_o) from standard meteorological observations. The FAO-56 Penman-Monteith method is the most physical, reliable and mostly used as a standard to verify other empirical methods. However, it needs a lot of different input parameters. Hence, in the present study, a model based on most dominant meteorological variables influencing ET_o is proposed to estimate ET_o in the Middle South Saurashtra region of Gujarat (India). The performance of five different alternative methods and proposed model is compared keeping the FAO-56 Penman-Monteith method as reference. The models are evaluated by using Nash-Sutcliffe efficiency coefficient (E), (R^2), (d_r), (RSR) and (MAE) statistical criterions. The results show that the developed model and Hargreaves and Samani (1985) method provide the most reliable results in estimation of (ET_o), and it can be recommended for estimating (ET_o) in the study region.

Keywords: Reference Evapotranspiration, Meteorological Variables, FAO-Penman-Monteith Method, Middle South Saurashtra Region

1. Introduction

The reference evapotranspiration (ET_o) is a function of local weather, represents the evapotranspiration (ET) from a defined vegetated surface, and serves as an evaporative index by which users can predict ET for agricultural or landscaped areas. Reference evapotranspiration ET_o is an important agro meteorological parameter for climatological and hydrological studies, as well as for irrigation planning and management. ET_o can been applied to a wide variety of research problems in the field of agro meteorology and agricultural water management. Many applications require estimating ET_o in areas where meteorological measurements are limited. Numerous ET_o equations have been developed and used by researchers which have really left the question of the best method to be used unanswered [3] and [15]. Existing ET_o equations are in range from simple empirical temperature-based equations to complex multi-layer resistance based equations. The International Commission for Irrigation and Drainage and Food and Agriculture Organization of the United Nations have

recommended using the Penman–Monteith method as the standard method for estimating ET_o, and for appraising other methods [5] and [6].

The Penman–Monteith method is ranked as the best method for estimating daily and monthly ETo in all the climates. This has been confirmed by many researches in the last decade [1], [7], [8], [9], [10], [12], [14], [20], [23], [24], [25], [27] and [28]. The FAO-56 PM is a physically based approach which requires measurements of air temperature, relative humidity, solar radiation, and wind speed. In most of the situations, stations with reliable data of these parameters are limited. Therefore FAO-56 PM method not appropriate in many such situations. Simple methods with fewer input parameters are better choice in such situation. This has created interest and has encouraged development of practical model, based on a reduced number of weather parameters for estimating ET_o.

In this study, dependency of controlling meteorological variables is compared and analyzed. Appropriate model

based on dependency of significant variables is then developed. The performances of radiation-based and temperature-based methods [13], [16], [21], [22] and [26] methods are compared and evaluated. Finally, the overall applicability of the selected methods and proposed model are examined by evaluation of ET_o predictability in the study region.

2. Study Area and Data Collection

Geographical Areas of Middle South Saurashtra region of Gujarat state (India) encompasses Junagadh district (lies between 20^0 26$^{'}$ to 21^0 24$^{'}$ North latitudes and 69^0 24$^{'}$ to 71^0 03$^{'}$ East longitudes) and Amreli district (lies between 20^0 27$^{'}$ to 22^0 15$^{'}$ North latitudes and 70^0 18$^{'}$ to 71^0 45$^{'}$ East longitudes) as shown in (Figure 1). The area is situated in semi-arid region with mean annual rainfall of 955 mm, mean maximum temperature 33.70^0C and mean minimum temperature 22.70^0C. Meteorological data of Junagadh and Amreli meteorological stations of Gujarat state (India) were used in this study. Junagadh station is located at latitude of 21^0 31$^{'}$ N, longitude of $70^0$33$^{'}$ E, and 61m msl while the Amreli station is located at latitude of 21^0 35$^{'}$ N, longitude of $71^0$12$^{'}$ E, and 130m msl. This region is characterized by a semi-arid climate, with warm and dry summers and mild winter conditions. The highest mean annual wind speed was observed 12.84 Km/h in the month of June whereas lowest mean annual wind speed was observed 3.10 Km/h in the month of November.

Daily meteorological data, including air temperature, wind speed, relative humidity, bright sunshine hours and evaporation for period of 21 years (1992-2012) were collected from Junagadh Agro meteorological Cell and Amreli Agricultural Research Station of Junagadh Agricultural University, Junagadh. The associate parameters like solar radiation, saturation vapor pressure and vapor pressure deficit were computed with standard meteorological formula as described in FAO. Out of this data set, 11 years data (1992-2002) were used for calibration and 10 years data (2003-2012) were used for simulation.
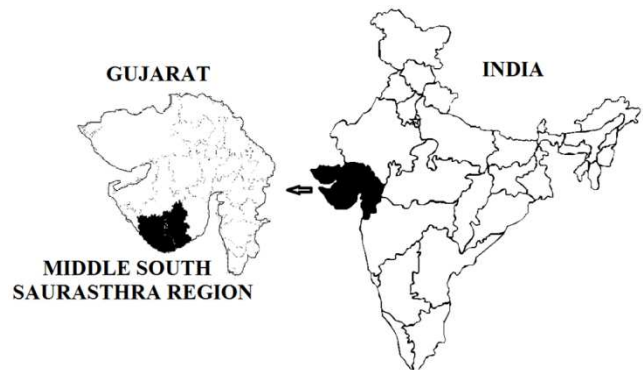

Figure 1. Middle South Saurashtra Region of Gujarat State.

Periodic insufficient rainfall pattern, limited water storage capacity of aquifer and natural water conservation are vital issues for this region. Water availability is a critical factor in this area and therefore accurate estimation of ET_o is needed for water resources management, crop water use, farm irrigation scheduling, and environmental assessment.

3. Materials and Methods

All This study is done in four steps as fallowing.
First step
Select appropriate methods by determining dependency of ET_o–PM on different meteorological variables. For better comparative evaluation, the dimensionless standardized values of each variable were computed and compared by using the transformation shown in equation 1.

$$Z_i = \frac{(X_i - \mu)}{\sigma} \qquad (1)$$

Where X is a variate, i is the ith value, μ is the mean of X and σ is the standard deviation of X.
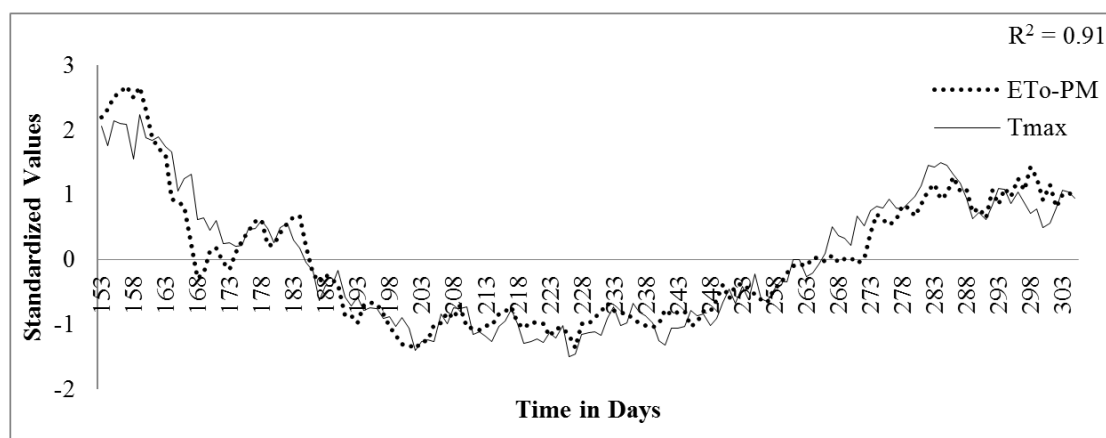

Figure 2. Dependency of ET_o-PM on T_{max} at Daily time-scale for Junagadh (1992-2002).
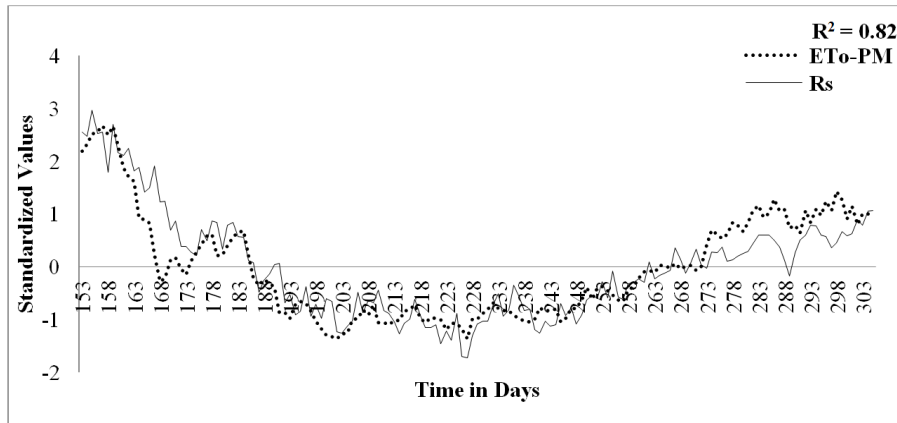
Figure 3. *Dependency of ET_o-PM on R_s at Daily time-scale for Junagadh (1992-2002).*
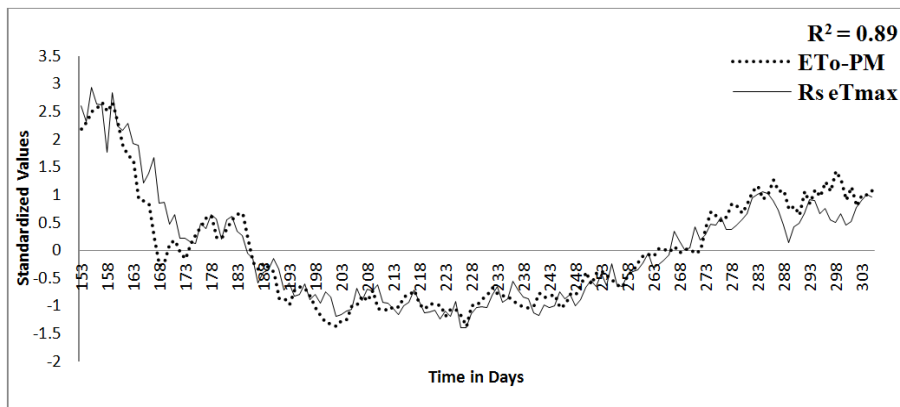

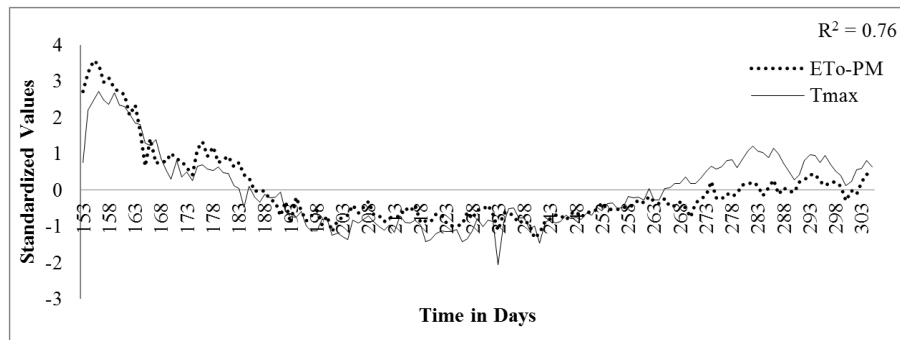**Figure 4.** *Dependency of ET_o-PM on $R_s\ e^{Tmax}$ at Daily time-scale for Junagadh (1992-2002).*

Figure 5. *Dependency of ETo-PM on T_{max} at Daily time-scale for Amreli (1992-2002).*
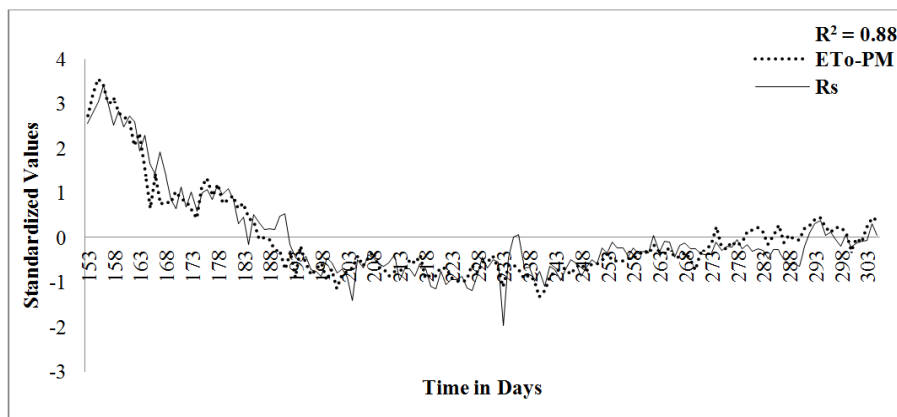

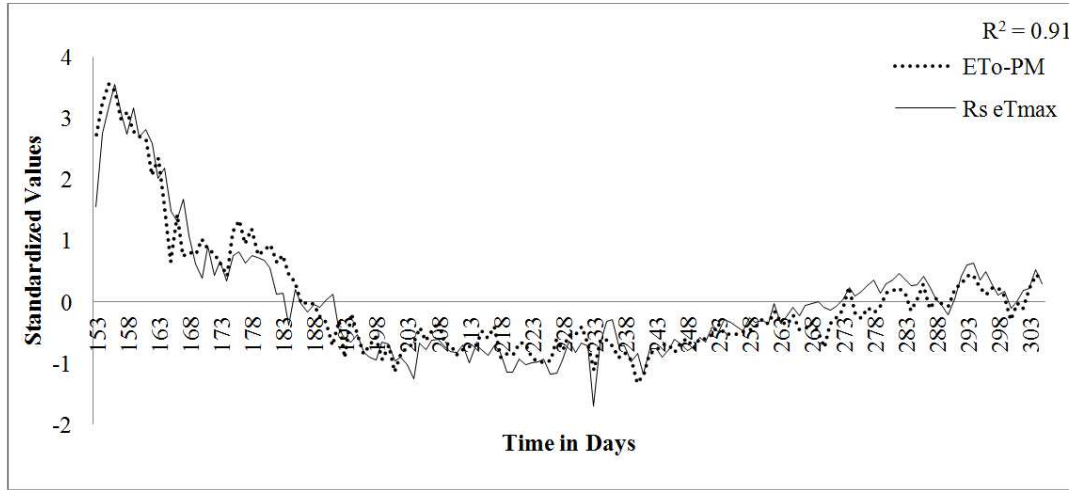**Figure 6.** *Dependency of ET_o-PM on R_s at Daily time-scale for Amreli (1992-2002).*

Figure 7. Dependency of ET_o-PM on $R_s e^{Tmax}$ at Daily time-scale for Amreli (1992-2002).

Analyzed and compared the dependency of controlling meteorological variables like air temperature, vapor pressure and relative humidity on ET_o for the study area. Maximum air temperature (T_{max}), radiation (R_s) and the product ($R_s e^{Tmax}$) were found to be the most significant factors influencing ET_o–PM when tested by dependence analysis for calibration period (1992-2002) in the study area. The dependency of ET_o–PM on (T_{max}), (R_s) and ($R_s e^{Tmax}$) at daily time-scales was presented with R^2 values in (Figure 2 to 7). Direct linear relationship of the product ($R_s e^{Tmax}$) with ET_o–PM has been found in dependency assessment for the study area and this relationship can be proposed and expressed as:

$$ET_o = a(R_s e^{Tmax}) \qquad (2)$$

Where, a is calibration constant
Estimate ET_o using above proposed equation 2.
Second step
The daily ET_o was calculated by FAO Penman Monteith method [4] based on equation 3.

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T_m + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \qquad (3)$$

where R_n is the net radiation at the crop surface (MJ m^{-2} d^{-1}), G is the soil heat flux density (MJ m^{-2} d^{-1}), T_m is the mean daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kP$_a$), e_a is the actual vapor pressure (KP$_a$), e_s–e_a is the saturation vapor pressure deficit (VPD) (KP$_a$), Δ is the slope vapor pressure curve (KP$_a$ °C^{-1}) and γ is the psychrometric constant (KP$_a$ °C^{-1}). The ET_o values estimated using the standard FAO–56 PM method ranged between a minimum 3.30 mm d^{-1} in July to a maximum 14.70 mm d^{-1} in June.
Third step
As we observed that (T_{max}) and (R_s) were significant factors influencing ET_o–PM in dependency assessment, hence, the temperature and radiation based methods for ET_o estimation can comparatively perform better. Compute ET_o based on meteorology parameters by five different temperature- radiation based methods:

Turc (1961)

$$\left. \begin{array}{l} ET_o = a \, \frac{T_m (R_s + 50)}{T_m + 15} \text{ if RH} > 50\% \\ ET_o = a \, \frac{T_m (R_s + 50)}{T_m + 15} \left(1 + \frac{50 - RH}{70} \right) \\ \qquad \text{if RH} < 50\% \end{array} \right\} \qquad (4)$$

Where R_s is solar radiation (MJ m^{-2} d^{-1}) and RH is relative humidity in %
Jensen and Haise (1963)

$$ET_o = C_T (T_m - T_x) R_s \qquad (5)$$

Where C_T ans T_x are constants expressed as

$$C_T = \frac{1}{\left[\left(45 - \frac{h}{137} \right) + \left(\frac{365}{e^0 (T_{max}) - e^0 (T_{min})} \right) \right]}$$

$$T_x = -2.5 - 0.14 (e^0 (T_{max}) - e^0 (T_{min})) \frac{h}{500}$$

Where h is the altitude of location in meter and $e^0(T)$ saturation vapour pressure at the air temperature T (KP$_a$)
Hargreaves and Samani (1985)

$$ET_o = a((T_{max} - T_{min})^c (T_m + b) R_a \qquad (6)$$

Where Ra is total extra-terrestrial solar radiation (MJ m^{-2} d^{-1})
Priestley and Taylor (1972)

$$ET_o = a \, \frac{\Delta}{\Delta + \gamma} \, \frac{(R_n - G)}{\lambda} \qquad (7)$$

Where λ is the latent heat of vaporization (MJ Kg^{-1})
Makkink (1957)

$$ET_o = a \, \frac{\Delta}{\Delta + \gamma} \, \frac{(R_s - G)}{2.45} - b \qquad (8)$$

Where a, b and c are calibration constants. The original parameters values of all the above selected methods are presented in (Table 1).

Table 1. Selected Methods with their Original Parameters Values (Parameters are Dimensionless).

Methods	Original Parameter Values		
	a	b	c
Turc (Equation (4))	0.0133	-	-
Jensen and Haise(Equation (5))	-	-	-
Hargreaves and Samani (Equation (6))	0.0023	17.80	0.50
Priestley and Taylor (Equation (7))	1.26	-	-
Makkink (Equation (8))	0.61	0.12	-

Fourth step

Compare the ET_o estimated by proposed developed expression (Equation 2) and five temperature-radiation based methods with standard FAO-PM method.

4. Statistical Criterions

Geographical ET_o–PM method was selected as a benchmark method for comparison as it is a globally accepted model, used under a variety of climatic regimes and reference conditions. Daily ET_o values estimated from each empirical equation were compared with daily ET_o values calculated using ET_o–PM method. This paper places special emphasis on monsoon season comparison because it is the most significant period for hydrological studies. The performance of selected methods and proposed model against ET_o–PM values were evaluated using five quantitative standard statistical performance evaluation measures, Nash-Sutcliffe efficiency coefficient (E), coefficient of determination (R^2), refined Willmott's index (d_r) [29], root mean square of errors-observations standard deviation ratio (RSR) and mean absolute error (MAE). R^2 describes the degree of collinearity while E reflects the overall fit between simulated and measured data. In general, model simulation can be judged as ''satisfactory'' if (R^2 and E) > 0.50 and (RSR) < 0.70. The d_r is applied to quantify the degree to which values of ET_o–PM are captured by the selected methods. The range of d_r is from -1.0 to 1.0. A d_r of 1.0 indicates perfect agreement between model and observation, and a d_r of -1.0 indicates either lack of agreement between the model and observation or

insufficient variation in observations to adequately test the model. Mean absolute error (MAE) measure provides an estimate of model error in the units of the variable [18]. The MAE provides a more robust measure of average model error, since it is not influenced by extreme outliers. A higher MAE value indicates poor model performance and vice versa. MAE=0 indicates a perfect fit. MAE is the most natural and unambiguous measure of average error magnitude.

5. Results and Discussion

Dependency analysis indicates that ET_o–PM was significantly influenced by (T_{max}) and (R_s) parameters, and the product ($R_s e^{Tmax}$) has direct relationship with ET_o–PM. In this study, model is proposed to estimate ET_o based on this relationship. Performance of the proposed model was compared with existing five different temperature-radiation based models. Calibration and validation were performed using data set from the year of 1992 to 2002 and from the year 2003 to 2012 respectively for both Junagadh and Amreli stations of the study area.

The selected methods may be reliable in the areas and over the periods for which they were developed, but large errors can be expected when they are generalized to other climatic areas without recalibrating their parameters. Accordingly, parameters of selected models were optimized to improve their performance for the study area. Optimized values of the parameters of models for both the stations are presented in (Table 2).

Table 2. Selected Methods and Proposed Model with their Optimized Parameters Values for Junagadh and Amreli Stations (Parameters are Dimensionless).

Methods	Junagadh			Amreli		
	a	b	c	a	b	c
Turc (Equation (4))	0.1636	-	-	0.1582	-	-
Jensen and Haise (Equation (5))	-	-	-	-	-	-
Hargreaves and Samani (Equation (6))	0.0006	0.0000	1.1172	0.0009	0.0000	0.8274
Priestley and Taylor (Equation (7))	2.0312	-	-	1.8459	-	-
Makkink (Equation (8))	3.0444	3.6908		2.5114	2.6655	-
Proposed Model (Equation (2))	0.0799	-	-	0.0666	-	-

Table 3. Performance of selected Methods and Proposed Model in Validation Period (2003-2012) for Junagadh.

Methods	E	R^2	dr	RSR (mm)	MAE (mm)
Turc (1961)	0.21	0.67	0.54	0.89	2.08
Jensen and Haise (1963)	-2.30	0.90	0.01	1.81	4.47
Hargreaves and Samani (1985)	0.85	0.86	0.84	0.38	0.73
Priestley and Taylor (1972)	0.34	0.38	0.58	0.81	1.90
Makkink (1957)	0.38	0.38	0.62	0.78	1.74
Proposed Model	0.89	0.93	0.84	0.33	0.73

Table 4. Performance of selected Methods and Proposed Model in Validation Period (2003-2012) for Amreli.

Methods	E	R^2	d_r	RSR (mm)	MAE (mm)
Turc (1961)	0.28	0.75	0.55	0.85	1.42
Jensen and Haise (1963)	-2.71	0.86	-0.21	1.92	4.01
Hargreaves and Samani (1985)	0.84	0.91	0.81	0.40	0.59
Priestley and Taylor (1972)	0.54	0.63	0.63	0.67	1.17
Makkink (1957)	0.59	0.63	0.67	0.64	1.04
Proposed Model	0.91	0.94	0.85	0.30	0.46

The results of the statistical analysis of all the models versus FAO ET_o-PM values in validation period (2003-2012) for Junagadh and Amreli stations are presented in (Table 3) and (Table 4) respectively. According to E, R^2, and RSR criteria, except Turc and Jensen and Haise models, all other models give satisfactory results for Amreli station while for Junagadh station, Hargreaves and Samani and proposed model offer results within acceptable limits. d_r and MAE criterias showed that Hargreaves and Samani and proposed model afforded reasonable results for Junagadh as well as for Amreli stations. The proposed model produced the highest E, R^2 and d_r values 0.89, 0.93 and 0.84 respectively, and the lowest RSR and MAE values 0.33 mm and 0.73 mm respectively for Junagadh station. The Hargreaves and Samani method also produced E, R^2, d_r, RSR and MAE values within permissible limits 0.85, 0.86, 0.84, 0.38 and 0.73 respectively for Junagadh station. The proposed model attained the highest E, R^2 and d_r values 0.91, 0.94 and 0.85

respectively, and the lowest RSR and MAE values 0.30 mm and 0.46 mm respectively followed by the Hargreaves and Samani method with E, R^2, d_r, RSR and MAE values 0.84, 0.91, 0.81, 0.40 mm and 0.59 mm respectively for Amreli station.

The Turc and Jensen methods had relatively poor performance for the study area. This might be due to there are no calibration parameters in the Jensen and Haise equation and the Turc equation has only one calibration parameter and it depends on meteorological variable RH, which was not significantly influenced on ET_o in the study area. The proposed model with two calibration parameters and Hargreaves and Samani method with three recalibrated parameters produced the most reliable relationship with the standard FAO ET_o-PM for daily time step. Performance of Hargreaves and Samani method and proposed model for daily time step in validation for Junagadh and Amreli are presented in (Figure 8) and (Figure 9) respectively.
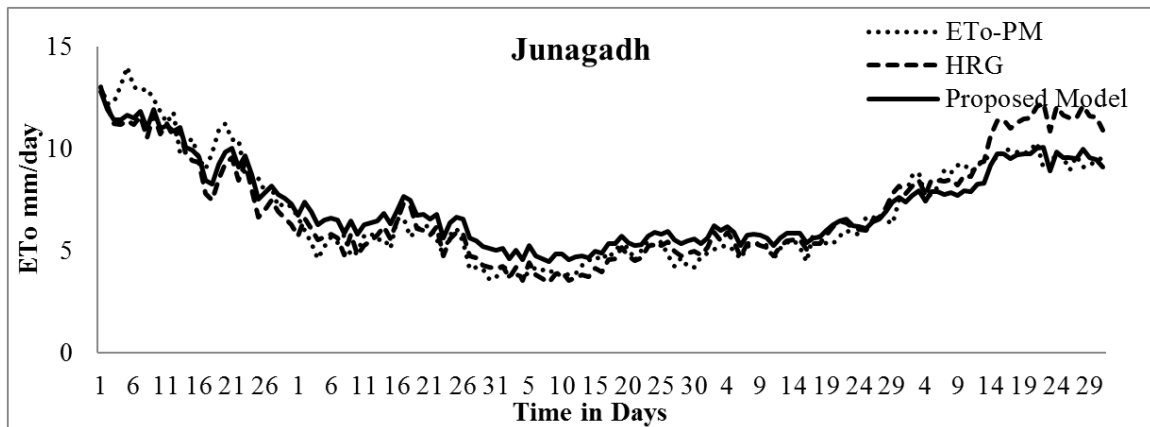

Figure 8. Performance of Hargreaves method and proposed model at daily time step in validation period (2003-2012) for Junagadh.
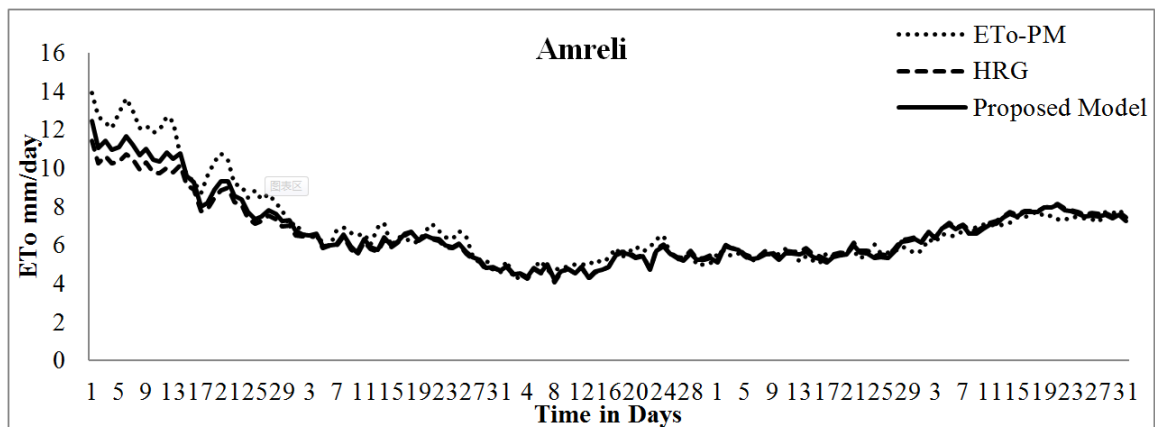

Figure 9. Performance of Hargreaves method and proposed model at daily time steps in validation period (2003-2012) for Amreli.

6. Conclusions

In this study dependency analysis of ET_o–PM on different meteorological variables was made for the Middle South Saurashtra region of Gujarat state (India). A model based on significant meteorological variables influencing ET_o is proposed to estimate daily ET_o in the study area. Estimated ET_o values by using five selected methods (viz. Turc, Jensen and Hasie, Hargreaves and Samani, Priestley and Taylor and Makkink methods) and proposed model are compared to the ET_o values calculated by the standard FAO ET_o-PM method for monsoon season. The results show that proposed model with single calibration parameter performed outstandingly best for all statistical tests and for both the stations. The performance of the Hargreaves and Samani method with recalibrated parameters has also been found to be reliable in the study area.

Therefore, a practical point of view, proposed model can be considered suitable to serve as a tool to estimate ET_o in the study area for monsoon season. Several authors have pointed out that a disadvantage of Penman's formula is the need for climate data which are not always available [2], [11], [17], and [19]. The Proposed model having fewer input parameters may be an attractive alternative to the more complicated FAO ET_o-PM method and could be recommended for ET_o computation under these prevailing conditions for the study area. This finding can help to overcome the shortage of data and will lead to minimize the time, cost, and equipment maintenance necessary for onsite monitoring. The methodology presented in this paper could be applied to the other regions for requisite regional calibrations.

Acknowledgement

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