

Modeling daily reference evapotranspiration in middle south Saurashtra region of India for monsoon season using most dominant meteorological variables and the FAO-56 Penman-Monteith method

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(Received 11 December 2014, Accepted 16 September 2015)

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सार – मानक मौसम वैज्ञानिक प्रक्षेपों से निर्दिष्ट वाष्पोत्सर्जन (ET_0) का आकलन करने के लिए बहुत सी पद्धतियाँ उपलब्ध हैं। FAO-56 पेनमेन-मौन्टिथ पद्धति को सर्वाधिक भौतिक और विश्वसनीय पद्धति माना जाता है और अन्य आनुभाषिक पद्धतियों को सन्चापित करने के लिए इसे प्रायः उपयोग किया जाता है तथापि इसमें विभिन्न इनपुट प्राचलों की आवश्यकता होती है। अतः इस अध्ययन के गुजरात (भारत) के मध्य दक्षिणी सौराष्ट्र क्षेत्र में ET_0 का आकलन करने के लिए ET_0 को प्रभावित करने वाले सर्वाधिक प्रभावी मौसम वैज्ञानिक परिवर्तितों पर आधारित मॉडल प्रस्तावित किया गया है। पाँच विभिन्न वैकल्पिक पद्धतियों और प्रस्तावित मॉडल के निष्पादन की मानक FAO-56 पेनमेन-मौन्टिथ से तुलना की गई।

चयनित पद्धतियों और प्रस्तावित मॉडलों के निष्पादन का मूल्यांकन करने के लिए पाँच मात्रात्मक मानक सांख्यिकीय निष्पादन मूल्यांकन उपाय-नैश-सुशलिफे दक्षता गुणांक (E), निर्धारण का गुणांक (R^2), परिष्कृत विलमॉट इंडेक्स (d_r), त्रुटियों प्रक्षेपों का माध्य मूल मानक विचलन अनुपात (RSR) तथा माध्य निरपेक्ष त्रुटि (MAE) का उपयोग किया जा रहा है। परिणाम दर्शाते हैं कि पुनः अंशांकित प्राचलों सहित विकसित मॉडल तथा हार्ग्रीव्स और समानी (1985) पद्धति वाष्पोत्सर्जन (ET_0) के आकलन के सबसे विश्वसनीय परिणाम उपलब्ध कराती है और अध्ययन के क्षेत्र में आकलन के लिए इसकी सिफारिश की जा सकती है।

ABSTRACT. Many methods are available to estimate reference evapotranspiration (ET_0) from standard meteorological observations. The FAO-56 Penman-Monteith method is considered to be the most physical and reliable method and is often 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_0 is proposed to estimate ET_0 in the Middle South Saurashtra region of Gujarat (India). The performance of five different alternative methods and proposed model is compared with the standard FAO-56 Penman-Monteith method.

The five quantitative standard statistical performance evaluation measures, Nash-Sutcliffe efficiency coefficient (E), coefficient of determination (R^2), refined Willmott's index (d_r), root mean square of errors-observations standard deviation ratio (RSR) and mean absolute error (MAE) are employed in evaluating the performance of the selected methods and proposed model. The results show that the developed model and Hargreaves and Samani (1985) method with recalibrated parameters provide the most reliable results in estimation of (ET_0) and it can be recommended for estimating (ET_0) in the study region.

Key words – Reference evapotranspiration, Meteorological variables, FAO-Penman-Monteith method, Middle South Saurashtra region.

1. Introduction

The reference evapotranspiration (ET_0) 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. ET_0 is an important agro meteorological parameter for climatological and hydrological studies, as well as for irrigation planning and management. It can be applied to a wide variety of research problems in the field of agro meteorology and agricultural water management. Many applications require

estimating ET_0 in areas where meteorological measurements are limited. Numerous ET_0 equations have been developed and used by researchers which have really left the question of the best method to be used unanswered (Allen, 2000; Itenfisu *et al.*, 2000). Existing ET_0 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 the Penman-Monteith method as the standard method for estimating ET_0 and for appraising other methods [Allen *et al.* 1994 (a&b)].

The Penman-Monteith method is ranked as the best method for estimating daily and monthly ET_0 in all the climates. This has been confirmed by many researches in the last decade (Abdelhadi *et al.*, 2000; Berengena and Gavilan, 2005; Beyazgul *et al.*, 2000; Delghani Sanij *et al.*, 2004; Gavilan *et al.*, 2006; Hargreaves and Allen, 2003; Hussein, 1999; Lopez-Urrea *et al.*, 2006; Todorovic, 1999; Trajkovic, 2005; Trajkovic and Kolakovic, 2009; Tyagi *et al.*, 2003; Ventura *et al.*, 1999). 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 is not practical 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_0 .

The monsoon period is the most important period for hydrological studies and evaluation of rainfall-runoff models predominantly in semi-arid and arid regions. Therefore, in this study affords special emphasis on monsoon season. The dependency of controlling meteorological variables is compared and analyzed for the study region. Appropriate model based on dependency of significant variables is then developed. The performances of radiation-based and temperature-based methods (Hargreaves Samani, 1985; Jensen and Haise, 1963; Makkink, 1957; Priestley and Taylor, 1972; Turc, 1961) are compared and evaluated. Finally, the overall applicability of the selected methods and proposed model are examined by evaluation of ET_0 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 $20^{\circ} 26'$ to $21^{\circ} 24'$ North latitudes and

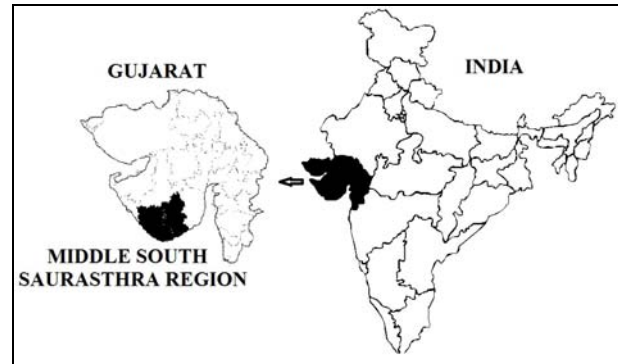


Fig. 1. Middle south Saurashtra region of Gujarat State (India)

$69^{\circ} 24'$ to $71^{\circ} 03'$ East longitudes) and Amreli district (lies between $20^{\circ} 27'$ to $22^{\circ} 15'$ North latitudes and $70^{\circ} 18'$ to $71^{\circ} 45'$ East longitudes) as show in Fig. 1. The area is situated in semi-arid region with mean annual rainfall of 955 mm, mean maximum temperature $33.70^{\circ}C$ and mean minimum temperature $22.70^{\circ}C$. Meteorological data of Junagadh and Amreli weather stations of Gujarat state (India) were used in this study. Junagadh station is located at latitude of $21^{\circ} 31' N$, longitude of $70^{\circ} 33' E$, and 61 m msl while the Amreli station is located at latitude of $21^{\circ} 35' N$, longitude of $71^{\circ} 12' E$, and 130 m 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 formulae 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.

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. Evapotranspiration is the second largest component after precipitation in the terrestrial water budget and also significantly influenced on the water balance of a watershed, and therefore accurate estimation of ET_0 is needed for water resources management, crop water use, farm irrigation scheduling, and environmental assessment.

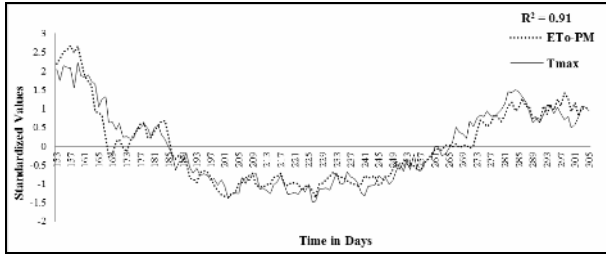


Fig. 2. Dependency of ET_0 - PM on T_{max} at daily time-scale for Junagadh (1992-2002)

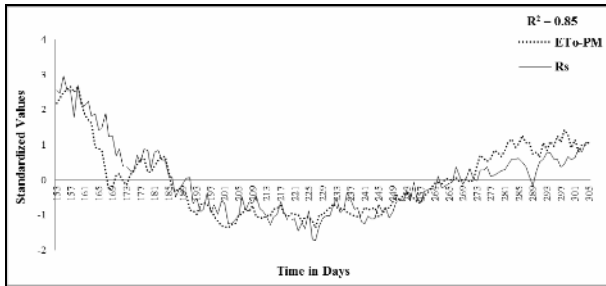


Fig. 3. Dependency of ET_0 - PM on R_s at daily time-scale for Junagadh (1992-2002)

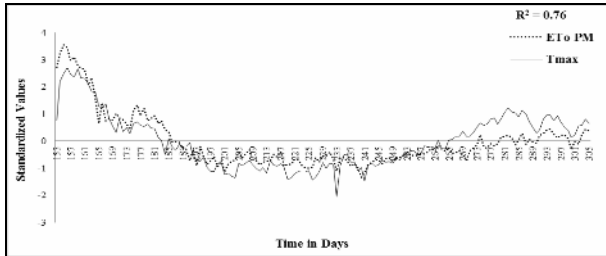


Fig. 4. Dependency of ET_0 - PM on R_s at daily time-scale for Amreli (1992-2002)

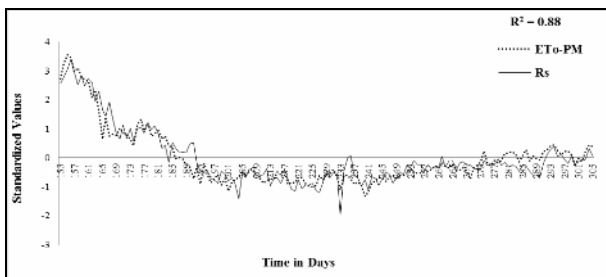


Fig. 5. Dependency of ET_0 - PM on R_s at daily time-scale for Amreli (1992-2002)

3. Materials and methods

This study is done in four steps as follows:

3.1. First step

Select appropriate methods by determining dependency of ET_0 - 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.

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

where, X is a variate, i is the i^{th} value, μ is the mean of X and σ is the standard deviation of X .

Analyzed and compared the dependency of controlling meteorological variables like air temperature, vapor pressure and relative humidity on ET_0 for the study area. Maximum air temperature (T_{max}), radiation (R_s) and the product ($R_s e^{oT_{max}}$) were found to be the most significant factors influencing ET_0 - PM when tested by dependence analysis for calibration period (1992-2002) in the study area. The dependency of ET_0 - PM on (T_{max}), (R_s) and ($R_s e^{oT_{max}}$) at daily time-scales was presented with R^2 values in Figs. 2-5. Direct linear relationship of the product ($R_s e^{oT_{max}}$) with ET_0 - PM has been found in dependency assessment for the study area and this relationship can be proposed and expressed as:

$$ET_0 = a(R_s e^{oT_{max}}) \quad (2)$$

where, T_{max} is the maximum temperature in $^{\circ}\text{C}$, 'a' is the calibration constant, R_s Solar radiation [$\text{MJ m}^{-2} \text{day}^{-1}$] and $e^{oT_{max}}$ is saturation vapour pressure at daily maximum temperature in [KP_a]. ET_0 is in mm.

3.2. Second step

The daily ET_0 was calculated by FAO Penman Monteith method (Allen *et al.*, 1998) based on equation 3.

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T_m + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (3)$$

where, R_n is the net radiation at the crop surface ($\text{MJ m}^{-2} \text{d}^{-1}$), G is the soil heat flux density ($\text{MJ m}^{-2} \text{d}^{-1}$), T_m is the mean daily air temperature at 2 m height ($^{\circ}\text{C}$), 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 ($\text{KP}_a \text{ } ^{\circ}\text{C}^{-1}$) and γ is the psychrometric constant ($\text{KP}_a \text{ } ^{\circ}\text{C}^{-1}$). The ET_0 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.

3.3. Third step

As we observed that (T_{\max}) and (R_s) were significant factors influencing ET_o - PM in dependency assessment, hence, we assume that the temperature and radiation based methods for ET_o estimation can comparatively perform better. Thus we Computed ET_o based on meteorology parameters by five different temperature- radiation based methods:

Turc (1961)

$$ET_o = a \frac{T_m (R_s + 50)}{T_m + 15} \quad \text{if RH} > 50\%$$

$$ET_o = a \frac{T_m (R_s + 50)}{T_m + 15} \left(1 + \frac{50 - RH}{70} \right) \quad \text{if RH} < 50\% \quad (4)$$

where, R_s is solar radiation ($MJ \ m^{-2} \ d^{-1}$) and RH is relative humidity in %.

Jensen and Haise (1963)

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

where, C_T and T_x are constants expressed as:

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

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

where, h is the altitude of location in meter and $e^0(T)$ saturation vapour pressure at the air temperature T (KPa).

Hargreaves and Samani (1985)

$$ET_o = a \left[(T_{\max} - T_{\min})^c (T_m + b) \right] R_s \quad (6)$$

where, R_a is total extra-terrestrial solar radiation ($MJ \ m^{-2} \ d^{-1}$).

Priestley and Taylor (1972)

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

where, λ is the latent heat of vaporization ($MJ \ kg^{-1}$).

Makkink (1957)

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

where, a , b and c are calibration constants.

3.4. 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. 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) (Willmott *et al.*, 2012), 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 (Legates and McCabe, 1999). 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

TABLE 1

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 2

Performance of selected methods and proposed model in validation period (2003-2012) for Junagadh

Methods	E	R^2	d_r	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 3

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 product ($R_s e^{0.7T_{max}}$) has direct relationship with ET_0 - PM. In this study, ET_0 was modeled 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

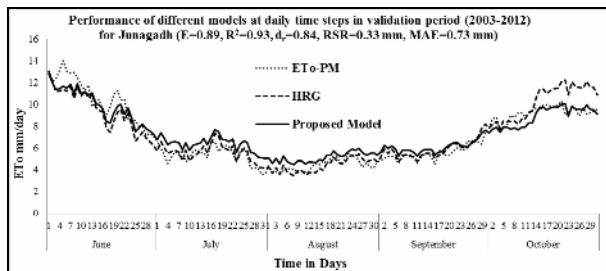


Fig. 6. Performance of Hargreaves method and proposed model at daily time steps in validation period (2003-2012) for Junagadh

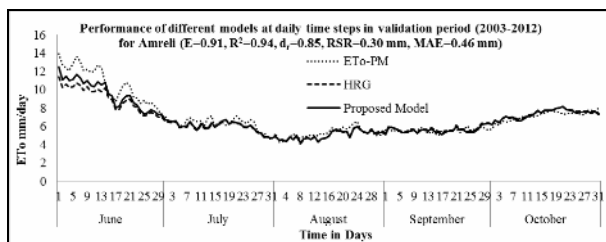


Fig. 7. Performance of Hargreaves method and proposed model at daily time steps in validation period (2003-2012) for Amreli

and from the year 2003 to 2012 respectively for both Junagadh and Amreli stations of the study area. Optimized values of the parameters of models for both the stations are presented in Table 1.

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.

The results of the statistical analysis of all the models versus FAO ET_0 - PM values in validation period (2003-2012) for Junagadh and Amreli stations are presented in Tables 2&3 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. According to d_r and MAE criteria, Hargreaves and Samani and proposed model afforded reasonable results for Junagadh as well as 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 showed relatively poor performance for the study area. This might be due to non availability of calibration parameters in the Jensen and Haise equation, while the Turc equation has only one calibration parameter and it depends on meteorological variable RH, which was not significantly influencing ET_0 in the study area. The results showed decreasing trend of ET_0 in wet months (July-September), which is mainly caused by decreasing mean temperature. The proposed model slightly overestimated ET_0 for Junagadh and slightly underestimate ET_0 for Amreli, which is due to higher value of optimized calibrated parameter 'a' (0.0799) for Junagadh than Amreli (0.0666). 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_0 - PM at daily time step. Performance of Hargreaves and Samani method and proposed model at daily time step in validation for Junagadh and Amreli stations are presented in Figs. 6&7 respectively.

6. Conclusions

In this study dependency analysis of ET_0 - PM on different meteorological variables was made for the Middle South Saurashtra region of Gujarat state (India). A model based on most dominant meteorological variables influencing ET_0 is proposed to estimate daily ET_0 in the study area. Estimated ET_0 values by using five selected methods (*viz.*, Turc, Jensen and Haise, Hargreaves and Samani, Priestley and Taylor and Makkink methods) and proposed model are compared to the ET_0 values calculated by the standard FAO ET_0 - PM method for monsoon period. The results of all statistical tests show that proposed model with single calibration parameter performed much better on the dataset of both the stations. The performance of the Hargreaves and Samani method with recalibrated parameters has also been found to be reliable for use in the study area.

Therefore, from a practical point of view, the proposed model can be considered suitable to serve as a tool to estimate ET_0 in the study area for monsoon season. Several authors have pointed out that a major disadvantage of Penman's formula is the need for a lot of climate parameters which are often not available

(Abdulai *et al.*, 1990; Hargreaves, 1983; Keskin and Terzi, 2006; Linacre, 1993). The Proposed model having fewer input parameters that are easily available, may therefore 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 other regions also with requisite regional calibrations.

Acknowledgement

The authors are grateful to Junagadh Agro meteorological Cell and Amreli Agricultural Research Station of Junagadh Agricultural University, Junagadh (Gujarat), for providing all necessary meteorological data.

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