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Full Length Research Paper

Evaluation of Reference Evapotranspiration Estimation for Arid Sites with Only Temperature Records

Abdulaziz Alharbi[1] and Ahmad Alzoheiry[1,2]

[1]Plant Production and Protection Department, Agricultural College, Qassim University, KSA.
[2]Department of Agricultural Eng. & Natural Resources, College of Agriculture, Damanhour University, Egypt.

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To estimate the actual evapotranspiration for any plant, it is necessary to calculate reference evapotranspiration (ET_o), because it gives an indication of the plant water requirement to complete its life cycle. Reference evapotranspiration was calculated using 4 models and compared with FAO-56Penman-Monteith (PM) depending on weather data collected from an in-situ meteorological station at Buariydah, Qassim region, Saudi Arabia. Predictions of the four models were compared with the PM prediction by using the Mean Absolute error and correlation analysis. From the four equations used, the Jensen Haise equation gave the closest prediction to PM prediction and it was the most consistent equation in the predictions throughout the year. The Baney-Criddle equation also gave prediction close to the PM prediction but the error in its predictions was greater in summer than in winter. Both Hargreaves and Samani and Thornthwait equations overestimated the values of ET_o when compared with PM prediction.

Keywords: Evapotranspiration, weather, Temperature Records.

INTRODUCTION

Management of irrigation water is one of the main issues faced by farmers all over the world, and this has become more important in arid areas were water scarcity is dominant. Water amount, ground water management, fuel, fertilizers need and future planning of the agricultural production process all depend on the predictions of irrigation requirement, which depend mainly on the type of plant and predicted reference evapotranspiration (ET_o).

Evapotranspiration is used to explain the amount of plant transpiration and soil evaporation, and it indicates the amount of water required by the plant to complete its life cycle. Evapotranspiration depends on many weather factors (solar radiation, air temperature and humidity, and wind speed) and some crop factors such as type and growth stage. ET_o is required to estimate the actual evapotranspiration of any plant and is defined as evapotranspiration from a wide surface of green grass actively growing uniformly in height and completely covering the ground, with no water shortage (Allen et al., 1998). Different methods have been proposed to estimate ET_o, and are classified as temperature-based (Baney-Criddle, 1950; Hargreaves and Samani, 1985), radiation-based (Jensen and Haise, 1963) and a combination of both (Penman, 1948). The Penman equation has physical basis, modified by Monteith (1965), and is called the Penman-Monteith equation. This method has been recommended by many researchers (Jensen et al., 1990; Yoder et al., 2005; Mcmahon et al., 2012) in humid environment. Er-

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*Corresponding Author's Email: aabanialharby@hotmail.com

Raki et al. (2010) reported that the radiation-based methods may perform poorly under arid and semi-arid conditions, and the values of the radiation-based methods were too high when compared with the Penman-Monteith equation (Xu and Singh, 2002). Tukimat et al. (2012) reported that radiation based methods yielded better performance when compared with temperature methods in the north of peninsular Malaysia, and the radiation based methods produced similar evapotranspiration values to the Penman-Monteith equation. However, in Hungary, temperature methods such as Shuttleworth-Wallace, Blaney-Criddle and Makkink models were found to be closest to the Penman-Monteith method (Racz et al., 2013). In the semiarid region (Northeast of Iran), Hargreaves-Sammani showed the smallest difference in comparison with the Penman-Monteith method, but the Blaney-Criddle equation value presented during the cold months is more than that of all other methods, and recorded the worst results (Sheikh and Mohammadi, 2013). With the use of radiation methods such as Jensen-Haise and Thornthwait equations, there was a significant difference as compared to the Penman-Monteith method, and Thornthwait equation was preferred to the Penman-Monteith method (Zarei et al., 2015). The value of temperature based methods such as Blaney-Criddle equation was lower (about 27%) as compared to the value obtained using the Penman-Monteith method (Alharbi et al., 2016). In general, during the warmest months of the year, all the empirical methods had less value as compared to the Penman-Monteith method in a semiarid region (Sheikh and Mohammadi, 2013).

Burnash (1995) reported that reliability and accuracy of the methods are the major concerns in estimating ET_o. Unfortunately, many methods require extensive data, while most meteorological stations measure temperature and rainfall. Fernandes et al. (2012) demonstrated the need for evaluating different evapotranspiration methods to support users and farmers exposed to different levels of data availability. They tested 6 different equations for estimating ET_o and found that radiation methods such as Hargreaves were the closest to FAO Penman-Monteith 56 method in predictions. This work aimed to evaluate the accuracy of some ET_o estimations for arid areas with only temperature data available.

MATERIALS AND METHODS

Weather data

In this study, weather conditions including wind speed, solar radiation, air temperature, relative humidity and rainfall were obtained from an in-situ meteorological station at Buariydah, Qassim region, Saudi Arabia (26° 30` 63 N̏ latitude, 43° 51` 52`E longitude and 720 m altitude). ET_o was calculated using 4 models and compared with FAO-56Penman-Monteith (PM); these models include:

Penman-Monteith-FAO-56 model (PM):

The FAO Penman-Monteith Method (PM) has a strong theoretical basis for calculating ET_o and can be written as:

$$ET_{\circ} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 034u_2)} \tag{1}$$

Where, ET_o is the reference evapotranspiration (mm day^{-1}); R_n is the net radiation ($MJm^{-2}day^{-1}$); G is the soil heat flux density ($MJm^{-2}day^{-1}$); is the slope vapor pressure (kPa°C^{-1}); T_a is the mean daily air temperature at 2 m height (°C); u_2 is the wind speed at 2 m height (ms^{-1}); is the psychometric constant (kPa°C^{-1}); e_s is the saturation vapor pressure (kPa); and e_a is the actual vapor pressure (kPa).

Blaney-Criddel model (BC):

The Blaney-Criddel model (BC) is one of the simplest methods which depends on temperature data only, for calculating ET_o and can be expressed as:

$$ET_{\circ} = kp(0.46T_a + 8.13) \tag{2}$$

Where, p is the percentage of total daytime hours for period out of the total daytime hours of the year; and k is the monthly consumptive use coefficient, depending on location, season and plant type.

Hargreaves-Samani model (HS):

The Hargreaves (1975) equation was modified by Hargreaves and Samani (1985) and used for the estimation of ET_o and the proposed equation was:

$$ET_{\circ} = aR_aTD^{1/2}(T_a + 17.8) \tag{3}$$

Where, a is a parameter equal to 0.0023; R_a is the extra-terrestrial radiation ($MJm^{-2}day^{-1}$); T is the average daily temperature (°C); and D is the main maximum and minimum daily temperature (°C).

Jensen-Heise model (JH):

The Jensen-Heise model is based on energy balance and was reported by James et al. (1988) as:

$$ET_{\circ} = C_T(T - T_x)K_TR_aTD^{0.5} \tag{4}$$

Where, C_T, T_x and K_T are standard coefficients.

Thornthwait model (TH):

Thornthwait (1948) model depends on the relationship between evapotranspiration and mean air temperature, and the Thornthweit formula is as follows:

$$ET_{\circ} = 16N_m\frac{(10T_m)}{1}a \qquad (5)$$

Where, N_m is correction coefficient for light hours in each day; T_m is average of monthly temperature (°C); and a is the coefficient depending on the annual temperature index.

The maximum absolute error for calibration and evaluation is defined as:

$$MAE = max(|O_i - E_i|)_{i=1}^{N} \qquad (6)$$

Where, O is ET_o from PM and E is the ET_o from another method.

RESULTS

The ET_o values of a typical year were plotted for each of the chosen equations together with the values of ET_o predicted using the PM equation and the monthly average of prediction using the PMA equation. The BC equation seems to underestimate the values of ET_o when compared with the PM equation. The underestimation was higher during spring and summer than in the other seasons of the year. The JH equation predictions were closer to the value predicted using the PM equation during summer and spring but the prediction seemed to underestimate ET_o in the winter season (Figure 1). Overall, the JH equation still under predicted the values of ET_o when compared with the PM equation for all the seasons of the year.

Figure 2 shows the ET_o values of a typical year predicted using the HS (ET_oHS) and TH equations. Both equations over-estimated the ET_o values throughout the year but the TH equation had higher error as compared to all the evaluated equations, especially in the summer season (Figure 2).

The mean absolute error of each equation prediction as compared to the PM equation predictions is shown in Table 1. The minimum MEA is related to the prediction derived from the JH and BC equations, while the values of MAE for both HS and TH predictions increased sharply. The performances of the equations were not constant throughout the year when MAE was calculated for each season alone; the BC equation was the closest to the PM equation in winter with a MAE of 0.903, while the highest error in the prediction was related to the HS equation with MAE value of 5.74. The value of the MOE was higher in summer and spring for all the equations except JH. The maximum error in prediction was during summer for the TH equation with a value of 115.9.

The overall MAE shows that both HS and TH equations overestimated the ET_o values considerably and using them would result in an inaccurate estimation of the ET_o. The errors of both BC and JH were significantly less as compared to the other two equations, with MAE values of 1.68 and 1.62, respectively. Although, the MAE of both equations are not significantly different from each other, the results indicate that, the JH equation was more successful in predicting ET_o throughout the year, where the values of MAE of the seasons ranged from a minimum of 1.6 in spring to a maximum of 1.74 in winter. For BC, the values of MAE increased in summer and spring to 2.58 and 2.15, respectively. Both equations showed a tendency to underestimate the ET_o values as compared to the PM equation but JH maintained a trend of underestimation all over the year, while BC estimation errors were significantly higher in summer and spring than in winter and autumn.

Correlation analysis

An analysis of the correlation between the values of ET_o predicted using the evaluated and PM equations showed similar trends with the MAE analysis. The slope of the correlation line predicted between the values of PM and TH was 15.46, indicating a tendency to overestimate the values of ET_o. The same trend was noticed for the slope of the correlation line between the values of HS and PM with a slope value of 2.44. The correlation with two other equation values resulted in a line with a slope indicating underestimation with a slope value of 0.58 and 0.94 for BC and JH equations, respectively. The predicted correlation lines are shown in Figures 3 and 4. The correlation analysis confirms the more accurate predictions of JH equation compared to all other tested equations and the slope of 0.94 was the closest to one, in all the slopes of the valuated equations.

DISCUSSION

The results of the current study suggest that, although the BC equation is a very simple equation and it can give a preliminary estimate of the reference evapotranspiration, it does not perform equally throughout the year, and because of its nature of averaging over a monthly period, it misses the peak and day-to-day fluctuation in the reference evapotranspiration which may be suitable for long term planning of water amount and irrigation needs, but it is not suitable for daily irrigation management and predictions.

The JH equation has the advantage of averaging over a period of time without some of its disadvantages. By averaging over a period of five days, the equation is less sensitive to sudden temperature changes as compared to the TH equation, but it responds better to changes in weather conditions compared to the BC equation.

Fernandes et al. (2012) obtained a different result when they evaluated the predictions of six equations as compared to PM predictions. They found that predicted values of the equations such as HS were closer to the values predicted by the PM equation as compared to the JH equations, which was due to the presence of terms accounting for interaction between solar radiation and air moisture in the HS equation. In this study, the results of the JH equation were closer to the prediction of PM which is

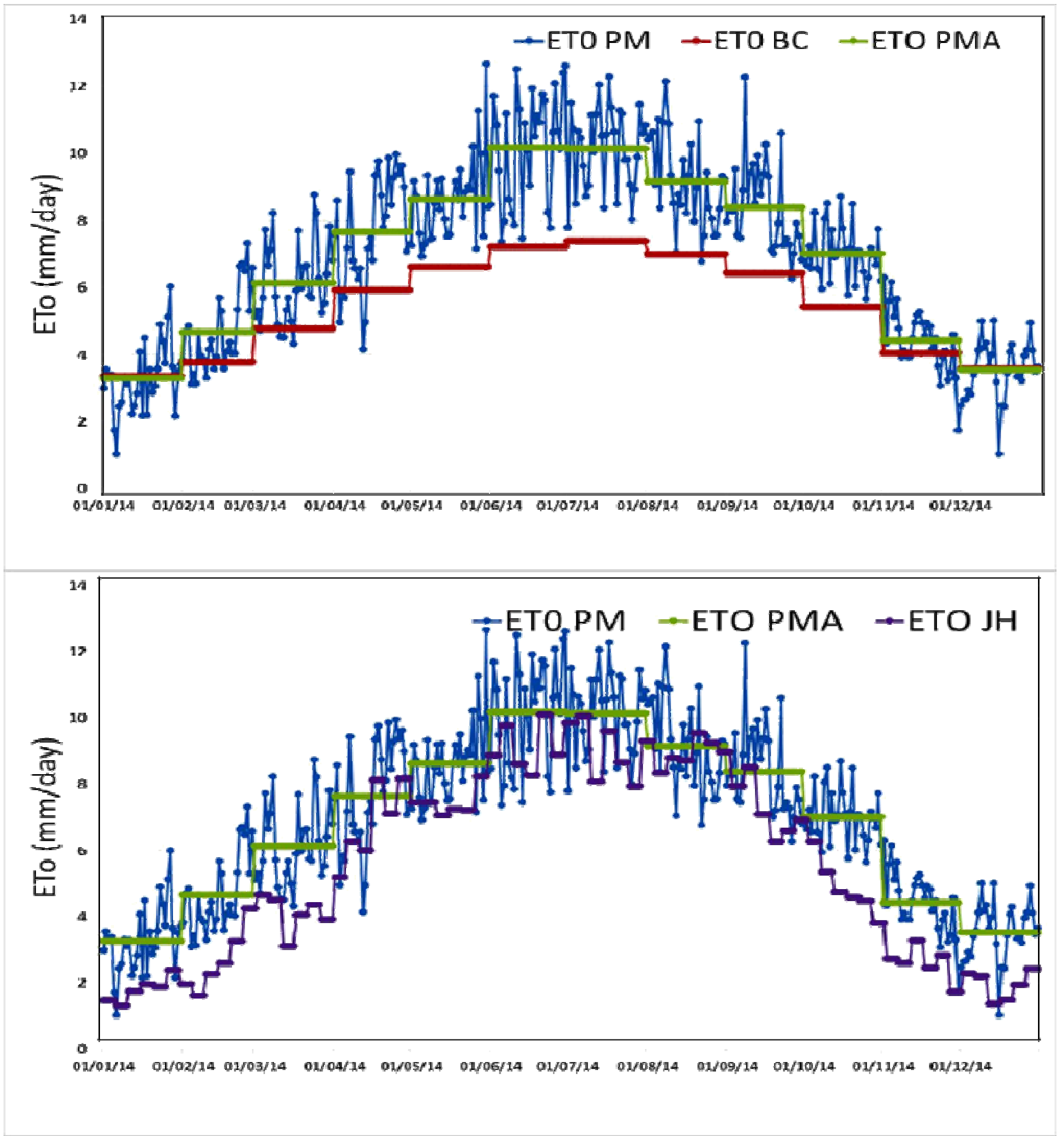

Figure 1: Predicted values of ET_o of BC and JH equations plotted along predicted values using the PM equation.

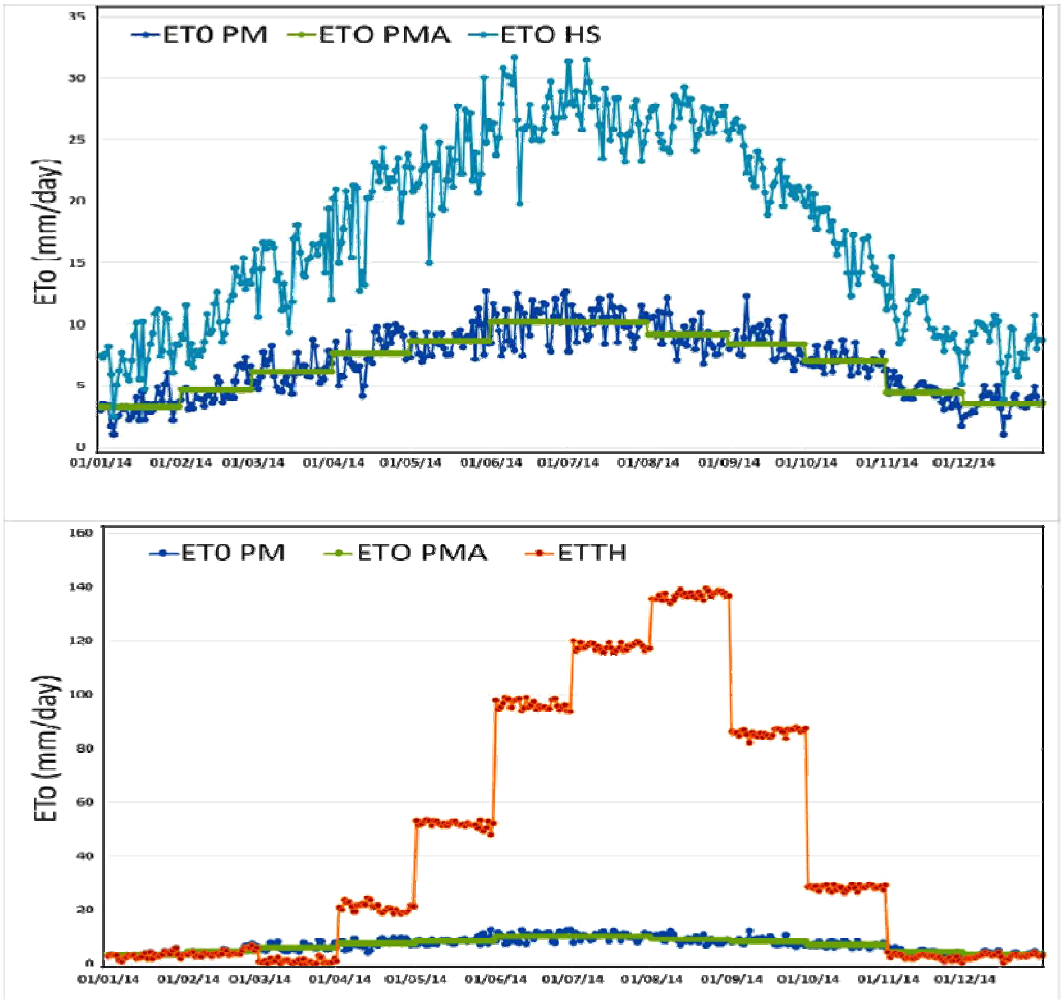

Figure 2: Predicted values of ET_o of HS and TH equations plotted along predicted values using the PM equation.

Table (1): The MAE of the reference evapotranspiration prediction for each of the equations compared to the reference evapotranspiration prediction of PM.

MAE overall	**ET HS**	**ET BC**	**ETJH**	**ETTH**
	10.9461	1.681113	1.624258	46.22257
Winter	5.735559	0.903327	1.741561	2.921628
Spring	13.79226	2.153678	1.589553	47.55168
Summer	16.43075	2.577905	1.455683	115.9147
Autumn	7.88691	1.100825	1.705134	21.29074

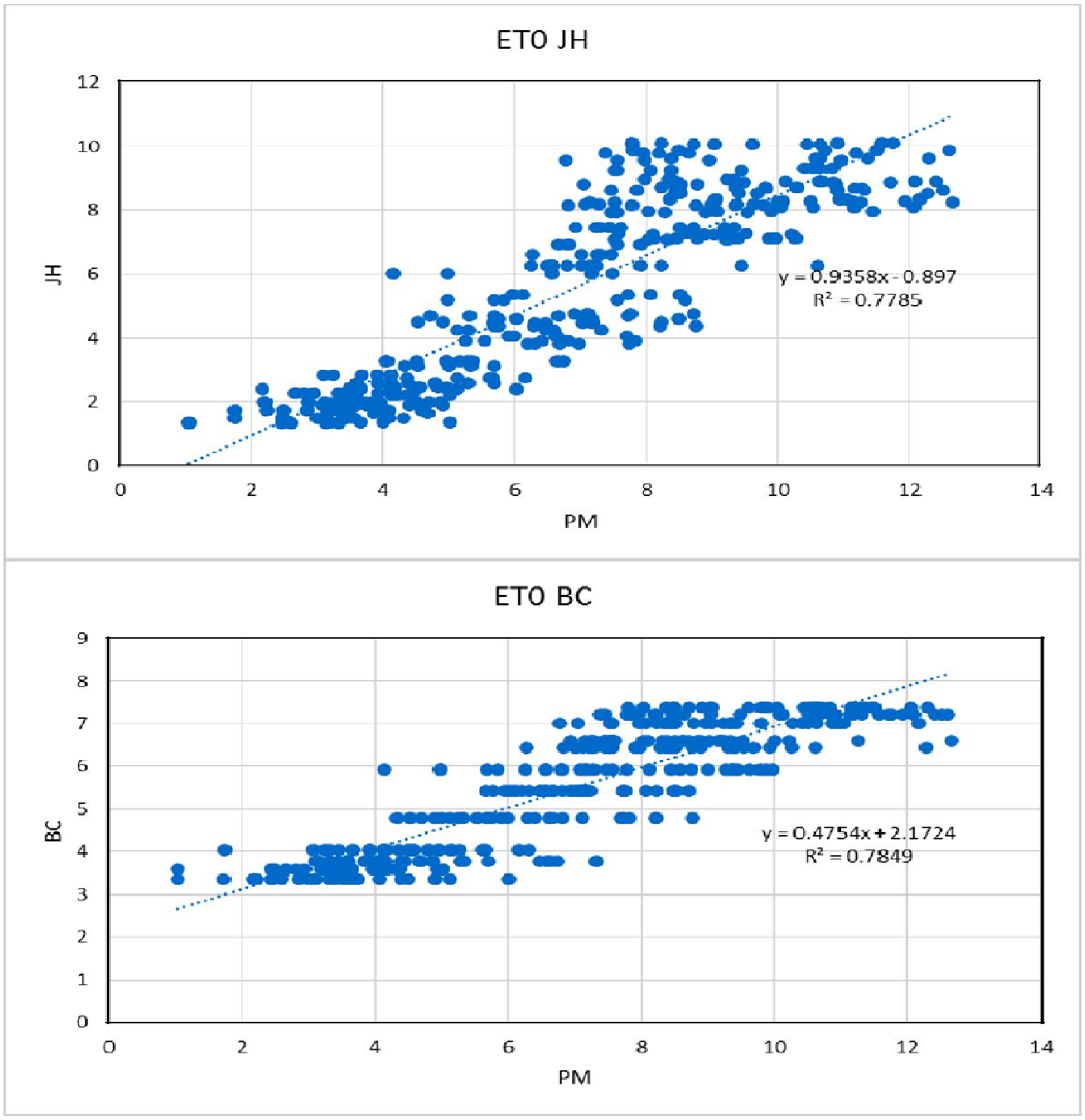

Figure 3: The correlation line predicted between PM, JH and BC.

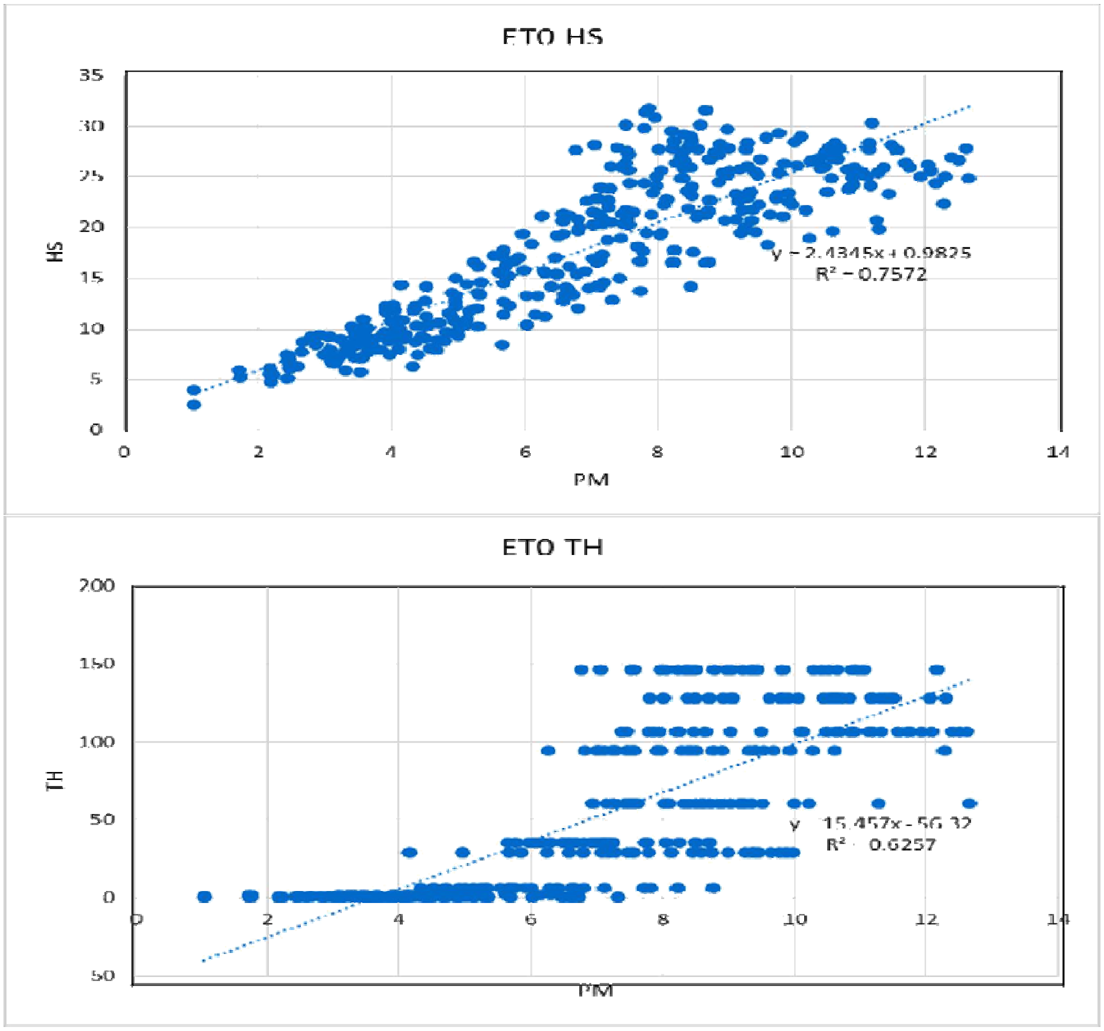

Figure 4: The correlation line predicted between PM, HS and TH.

contrary to the results obtained by Fernandes et al. (2012). This may be attributed to the very low level of relative humidity in the study region, which minimized the effect of radiation atmosphere interaction, and the high temperature fluctuations, which made the terms added to the atmospheric interaction to cause overestimation of the values by HS equation.

CONCLUSIONS

Four different ET_o empirical equations were evaluated. All the chosen equations employed the location of the site and temperature records to drive the ET_o predictions which were compared with the values of ET_o predicted by PM. The predictions of the JH model were the closest to the PM predictions and this was consistent throughout the year. The BC equation was closer in its prediction to PM than both the HS and TH models. The results indicate the possibility of using the JH model to predict values of ET_o, to generate historical records for arid zones with only temperature records.

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