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Temperature based ET Method Selection for Burdwan District in WB, INDIA

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Abstract

Evapotranspiration is a very important parameter when it comes to designing water budget plans, designing hydrological cycle models and irrigation scheduling plans. This provides us with a concrete idea of how much, when to and how to supply water to any particular region or application and by doing this a balance is maintained and wastage of water resource is prevented. Albeit, this is such a pivotal parameter, till date there has not been any concrete highly accurate method developed for its accurate determination. However, Penman Monteith combination method is one procedure that is hugely accepted globally. The main reason behind not having any highly precise model is the hugely varying climatic and weather conditions across the globe. No particular method is therefore accurate worldwide but one has to determine best suited models for particular geographic locations. Several scientists have come up with primarily three basic methods i.e. temperature based, radiation based and mass – transfer based. Here in this article, we have held comparison among the most notable temperature based methods along with PM combination method for the location of Burdwan, India. After comparing several factors, it is found out in this work, that for this geographic location, Kharrufa model is the most accurate and trustworthy method. Detailed description is provided in subsequent sections.

Keywords: Evapotranspiration, Temperature based methods, Burdwan, Comparison, Kharrufa.

INTRODUCTION

Evapotranspiration plays a pivotal role in determining the amount of water that is lost from the earth surface through the process of transpiration from plant surfaces and through evaporation from water bodies and other surfaces. Evaluation of rate of evapotranspiration will provide us with the knowledge of water deficiency in any particular area and based on this information, we can replenish the area with the required calculated water and this will help us in two ways, firstly the area will not be left arid and secondly as we will be calculating the water requirement of the area, we will be able to prevent wastage of natural resources. This scheme of predicting requirement of water for any particular area for some particular purpose and providing the required amount in known as water budget scheme. Having a well-defined water budget scheme, it is very much significant in designing and developing an automated irrigation controller that will free the system from any human intervention.

But the challenge lies in absolute determination of this evapotranspiration rate as it is dependent of a variety of climatic and geographical factors. Over the years and across the globe, several scientists have formulated several equations for more correct determination of this parameter. It was found out that all these several sets of equations can be broadly classified into three basic methods i.e. temperature based methods, radiation based methods and mass – transfer based methods albeit mass – transfer based method is more involved in determining the evaporation rates rather than evapotranspiration with the basic assumption that the major portion of water is lost through evaporation and the amount that is lost through transpiration is considerably negligible.

These different sets of equations and formulas have shown different levels of accuracy in different climatic zones across the globe. The other challenging part in picking up any one of these equations for determination of evapotranspiration in any particular area is recalibration of the constant values that are there in these formulas.

In context of this article, it is important to define Reference Evapotranspiration whose definition is given as "The rate at which water, if available, would be removed from the soil and plant surface of a specific crop, arbitrarily called a reference crop." (Doorenbos and Pruitt, 1975, 1977; Wright, 1982; Burman et al., 1990; and Burman et al. 1983) (Jensen et al., 1990).

VARIOUS EVAPOTRANSPIRATION MODEL

The mathematical expression by which Evapotranspiration (ET) is represented for easy comprehension is provided in eqn. (1).

$$ET=I+P-RO-DP+CR\pm DSF\pm DSW \qquad (1)$$

I=Irrigation; P=Rainfall;RO=Run Off;DP=Deep Percolation; CR=Capillary Rise; DSF=Subsurface flow in the root zone (negligible); DSW=Subsurface flow out of the root zone (negligible)

PENMAN – MONTEITH EQUATION

Penman – Monteith equation, also known as the combination method is most greatly accepted in the world although it has its own limitations. This is a modification of the originally formulated Penman equation. The latest form of this equation is known as Penman Monteith FAO – 56 equation that was ratified by the EWRI - ASCE on request by the Irrigation Association, in consensus with all the leading scientific organizations.

Penman – Monteith equation speaks about a reference surface as is defined "A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m -1 and an albedo of 0.23" (Allen et al. 1998). The assumptions that are made for a reference surface are 1) and extensive surface of green grass, 2) of uniform height, 3) completely shading the ground, 4) actively growing and 5) with adequate water. [1]

The FAO – 56 Penman Monteith equation is expressed as

$$ET_0 = \frac{0.408 * \Delta * [\![R_n - G) + \gamma\left(\frac{900}{T_{mean} + 273}\right) * u_2 * (e_s - e_a)}{\Delta + \gamma(1 + c_d u_2)} \quad (2)$$

Setting the value of C d at 0.34, we get,

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

The nomenclature of the symbols used are defined in Table II.

Here from this equation, it is found that the evapotranspiration rate depends on the climatic factors like temperature, solar radiation, wind speed and relative humidity.

TEMPERATURE BASED METHODS

Among the several methods for determination of evapotranspiration, temperature based methods form one of the principle attributes. There exists a plethora of this method but we will limit ourselves with the most often used seven methods viz. Thornthwaite (1948), Blaney – Criddle (1950), Hamon (1961), Romanenko (1961), Linacre (1977), Hargreaves and Samani (1985), and Kharrufa (1985). In this method, temperature is considered as the principle parameter on which the rate of evapotranspiration depends [2] [3] [4].These methods form the earliest methods in estimating Evapotranspiration (ET).

The generic form of the temperature based methods looks like this.

$$ET = cT^a \quad (4)$$

Or

$$ET = c_1 d_1 T(c_2 - c_3 h) \quad (5)$$

Where T = air temperature, h = humidity term, c, a, c_1, c_2, c_3 are constants and d_1 is the day length.

The existence of these several equations is due to the large ranging inconsistency in the climatic and meteorological data and their recording procedure. The study of comparing these generic and most used temperature based methods will help in two ways.

a) Firstly, for a specific cite, it will show which form of equation is more suited.
b) Secondly we will be able to recalibrate the values of constant for more precise and correct measurement.

Before we start the evaluation and comparison of these seven equations, a brief overview of these equations is provided for general understanding.

THORNTHWAITE METHOD

The name is derived from the person who framed it in 1948, and this equation considers the mean monthly temperature from where the heat index is calculated.

The following are the principle equations is the methods.

$$i = \left(\frac{T_a}{5}\right)^{1.51} \quad (6)$$

$$I = \sum_{j=1}^{12} i_j \quad (7)$$

$$ET' = C\left(\frac{10T_a}{I}\right)^a \quad (8)$$

$$ET = ET'^{\left(\frac{d}{12}\right)\left(\frac{N}{30}\right)} \quad (9)$$

Where i = monthly heat index; I = annual heat index; j = no. of months; T a = mean monthly temperature in °C; C = 16 (constant) and

$a = 67.5 * 10^{-8} I^3 - 77.1 * 10^{-6} I^2 + 0.0179 I + 0.492$

The value of 'a" varies between 0 and 4.25.

I varies between 0 and 160. ET' is zero for sub-zero temperature.

This method is widely used is arid and semi-arid regions as it only requires temperature as the climatic data.

BLANEY – CRIDDLE METHOD

This method as proposed by Blaney and Criddle in 1959 is mostly used in the western USA and also in other parts of the globe.

The expression for this methods is given as

$$ET = k * p(0.46T_a + 8.13) \quad (10)$$

p = % of total daytime hours (daily/monthly) out of total daytime hours of the year.

k = monthly consumptive use coefficient which depends on location, season and vegetation type. The average value of k is 0.85 which also requires local calibration.

HAMON METHOD

In 1961, Hamon devised this equation based on air temperature which is expressed as

$$ET = 0.55 * D^2 Pt \qquad (11)$$

D = daylight hours for any given day. Pt = saturated water vapour density.

$$Pt = \frac{4.95e^{(0.062T_a)}}{100} \qquad (12)$$

However, eq. 10 leads to huge errors in the result and hence modifications were made to this equation and eventually a better expression is formulated as follows:

$$ET = \frac{2.1 * D^2 * e_s}{T_a + 273.2} \qquad (13)$$

D represents hours of daylight for any given day and e_s is the saturation vapour pressure.

ROMANENKO METHOD

This method was designed in 1961 by Romanenko which depends on the relationship between mean temperature and relative density and is expressed as

$$ET = 0.0018(25 + T_a)^2(100 - Rh) \qquad (14)$$

Rh is the mean monthly relative humidity and expressed as

$$Rh = \frac{e^0(T_d)}{e^0(T_a)} \qquad (15)$$

T_d is the dew point temperature and in case the data for e^o is not available, it is given as (Bosen, 1960)

$$e^0(T) = 33.8679[(0.00738T + 0.8072)^8 - 0.000019(1.8T + 48) + 0.001316] \qquad (16)$$

The expression formulated by Romanenko was modified by Oudin (Oudin et. al 2005) to

$$ET = 4.5 * \left(1 + \left(\frac{T_{mean}}{25}\right)\right)^2 \left(1 - \frac{e_a}{e_s}\right) \qquad (17)$$

However if the Relative Humidity Rh is measured already, the evaluation of $e^0(t)$ is not required.

LINACRE METHOD

Linacre devised this method in 1977 for a well-watered vegetation with an albedo of 0.25 which is actually a simplification of Penman formula and is expressed as

$$ET = \frac{500T_m/(100 - A) + 15(T_a - T_d)}{(80 - T_a)} \qquad (18)$$

A = latitude in degrees, h = elevation (m) and $T_m = T + 0.006h$

HARGREAVES METHOD

This method was proposed by Hargreaves and Samani in 1985 which is based of several improvements of the Hargreaves (1975) model. As actual solar radiation data is not a very common factor in climatological measurement, they proposed to calculate this parameter from the extra - terrestrial radiation R_A data.

TD here represents the difference between mean monthly maximum and minimum temperature in °C.

$$ET = 0.0023R_A TD^{1/2}(T_a + 17.8) \qquad (19)$$

KHARRUFA METHOD

Modelled by Kharrufa in 1985, this equation draws correlation of ET with T and ‘p’ in the form provided below.

$$ET = 0.34 * p * T_a^{1.3} \qquad (20)$$

Study Area:

The area on which this heuristic study is carried out is **Bardhaman, District: Burdwan, State: West Bengal, Country: India.**

Decimal coordinates: 23.2557 87.8569. Region: West Bengal, India

Category: Sub – urban, agriculture dominated.

Time Zone: Asia/Kolkata; Geonames - ID: 1277029; Total area of Study: 59 km²

Climate is tropical and the average annual temperature is 26.3°C and average altitude is 36 m. The variation of temperature throughout the year is 11.5 °C and the difference of precipitation between the driest and wettest months is 307 mm. April is the warmest month with an average temperature of 30.9 °C and January is the coldest with an average of 19.4 °C. The Köppen-Geiger climate classification is Aw (Tropical, Savanna wet). Average rainfall is 1313 mm with the monsoon months being July, August, September and first part of October [5][6][7][8][9][10].

This area is typical agricultural township.

The selection of this study area is justified by the fact that it is predominantly an irrigation based locality with the principle crop harvested being rice that is the staple crop of West Bengal.

The different climatic parameters are provided below in the following tables and figures.

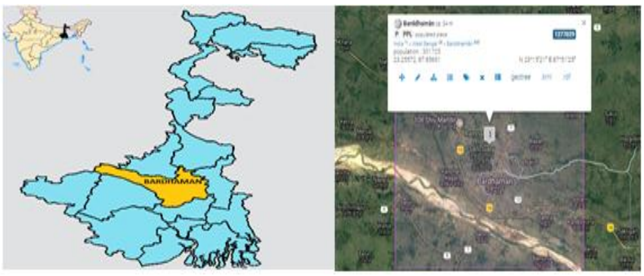

Figure 1. Geographical Satellite Map of Burdwan

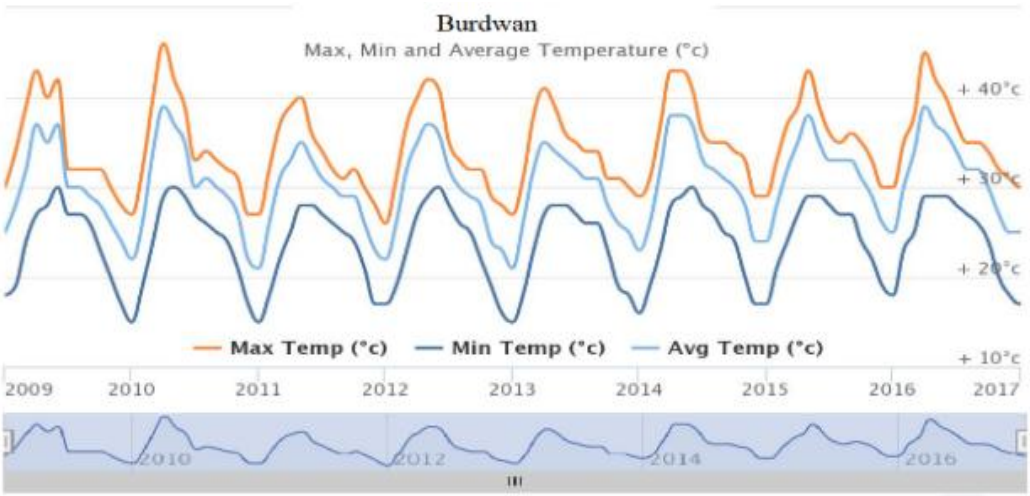

Figure 2. Max, Min and Average Temperature between the period Jan 2009 and July 2017

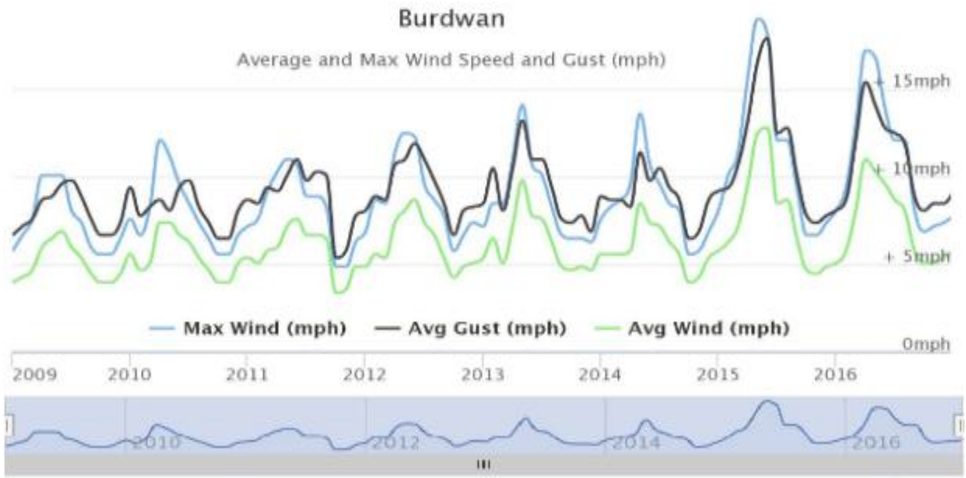

Figure 3. Average and Max Wind Speed between the period Jan 2009 and July 2017

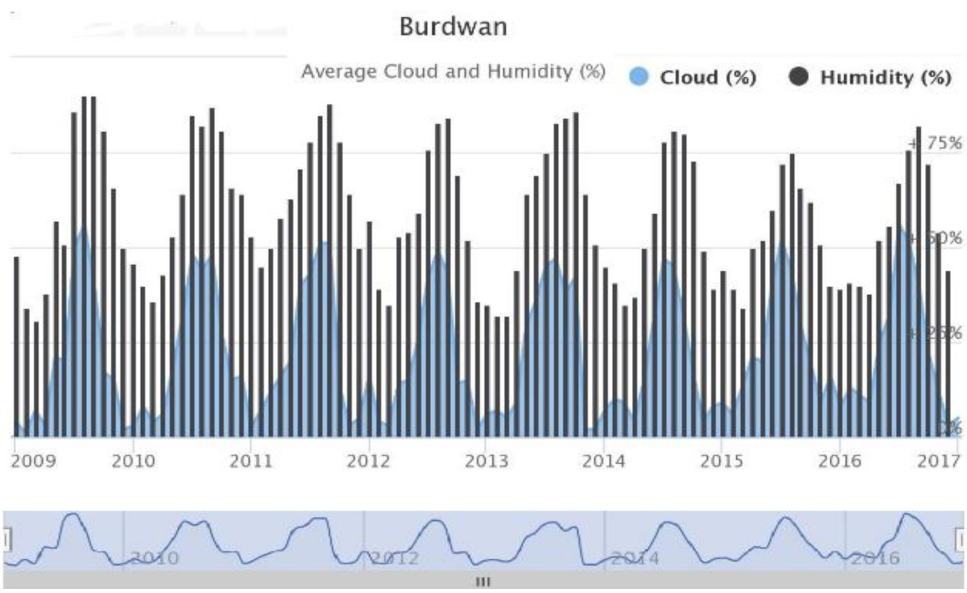

Figure 4. Average Humidity and Cloud cover between the period Jan 2009 and July 2017

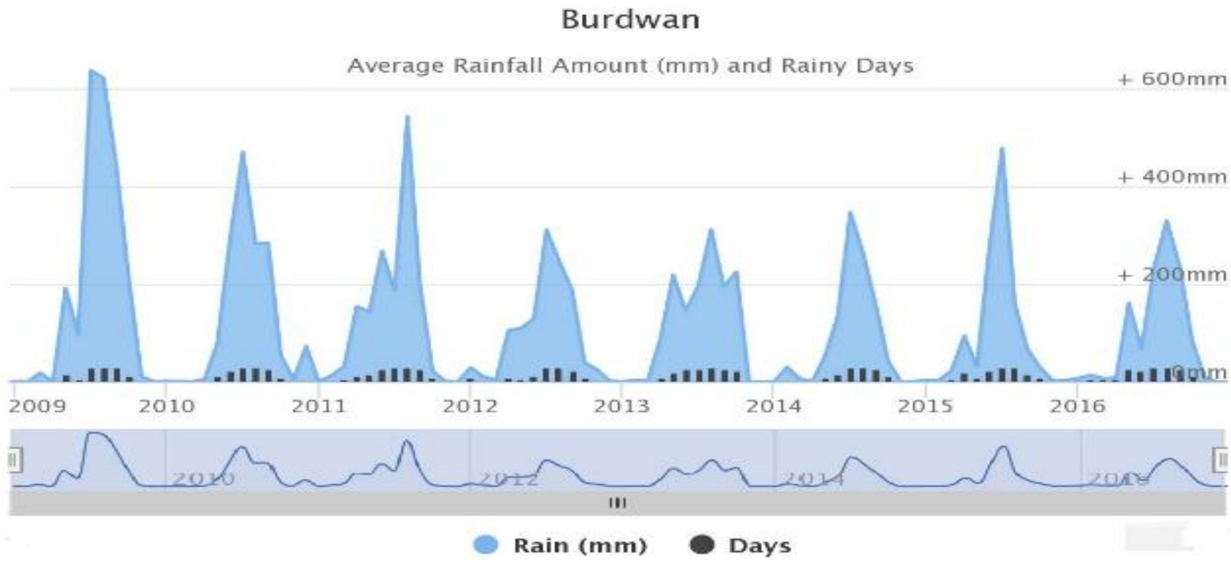

Figure 5. Average Rainfall between the period Jan 2009 and July 2017

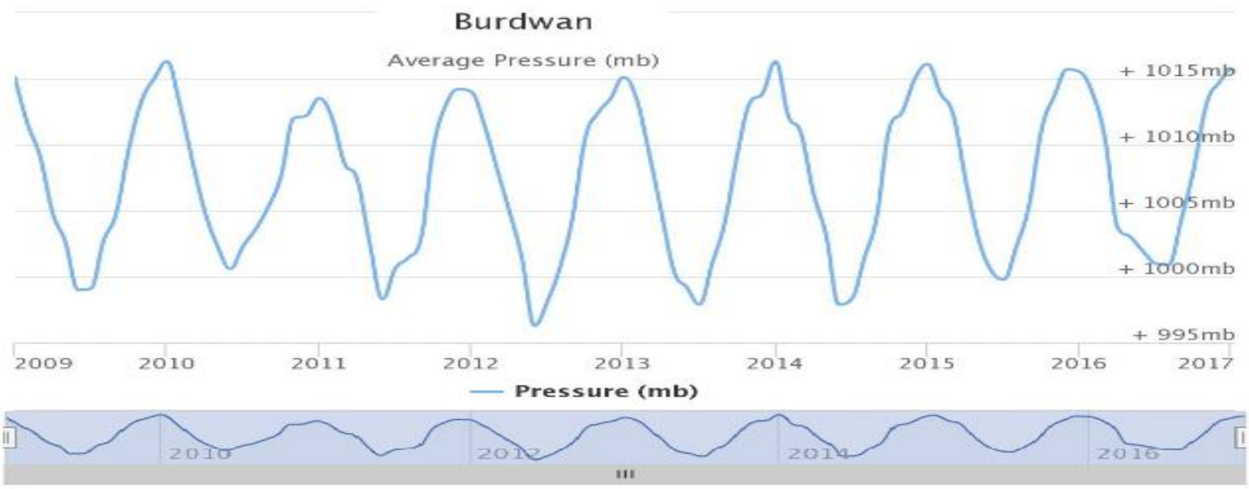

Figure 6. Average Pressure between the period Jan 2009 and July 2017

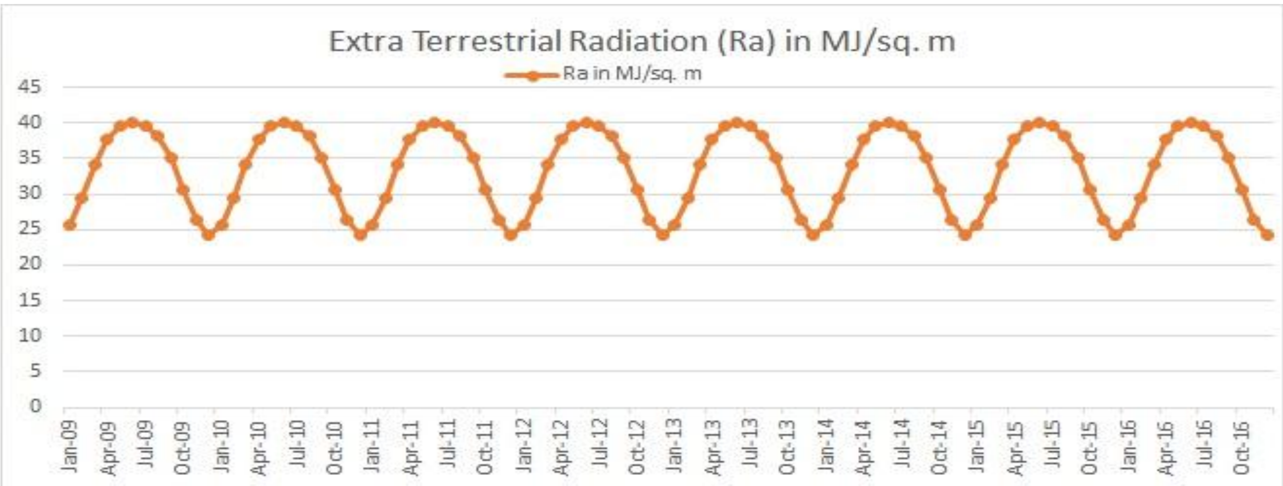

Figure 7. Extra-terrestrial Radiation in MJm^{-2} for the period Jan 2009 and Dec 2016

Table I: Weather monthly average between 2009 and 2016 for Burdwan

				Monthly Average Weather 2009 - 16					
Month	**Av. Temp**	**Rainfall**	**VPD ($e_s - e_a$)**	**Humidity**	**Wind Speed**	**Extra-terrestrial Radiation**	**Solar Radiation**	**Pressure**	**Measured ET**
Jan	22.9	5.12	1.3829	45.87	5.22	296.2623607	54.22110661	1015.23	2.17
Feb	27	9	1.8874	38.87	5.48	340.4194067	74.41604367	1012.95	2.93
March	32.4	11.16	2.5606	36.62	5.87	393.945894	100.7780476	1009.73	4.1
April	36.4	63.23	2.8470	45.12	7.55	436.7930099	134.8192014	1005.53	5.08
May	36.4	109.74	2.4065	55.62	8.78	458.0160424	143.2939428	1002.27	5.24
June	35.2	176.13	2.0492	61.12	8.57	463.3479076	140.9472691	999.21	4.22
July	31.9	357.32	1.1032	77.12	7.3	459.0346768	139.7960562	999.63	3.68
August	31.1	344.21	0.8590	81.87	6.7	442.1908583	124.5486632	1001.75	3.51
Sep	30.5	228.74	0.8048	82.62	5.48	406.4462433	97.56468894	1004.46	3.37
Oct	29.1	87.79	1.0207	75.25	4.27	354.4129661	80.63599907	1009.68	3.36
Nov	26.6	6.18	1.3887	58.25	4.41	304.8718352	61.41402598	1012.9	2.78
Dec	24	9.66	1.4518	46.75	5	281.3116253	48.80773284	1014.27	2.32

RESULT AND DISCUSSION

From the mathematical expressions of the seven chosen temperature based methods and the weather data that we have for the period between 2009 and 2016, the ET values are calculated taking into account their original constant values.

Table II: List of acronyms

Symbol	**Represents**
ET	Reference Evapotranspiration ($mmday^{-1}$)
R_n	Net radiation at crop surface ($MJm^{-2}day^{-1}$)
G	Soil Heat Flux density ($MJm^{-2}day^{-1}$)
T	Mean daily Air Temperature °C
u_2	Wind speed at 2 m height (ms^{-1})
e_s	Saturation vapour pressure (kPa)
e_a	Actual vapour pressure (kPa)
$e_s - e_a$	Saturation vapour pressure deficit (kPa)
Δ	Slope Vapour Pressure Curve ($kPa°C^{-1}$)
γ	Psychrometric Constant ($kPa°C^{-1}$)

Table III: Climatic Parameters needed by each of the individual methods

Method	Temperature	Solar Radiation	Relative Humidity	Wind Speed	Day Length	Latitude	Atm. Pressure	Sat. Vapour Pressure
PM	Y	Y	Y	Y			Y	Y
Thornwaite	Y							
B – C	Y				Y			
Hamon	Y				Y			
Romanenko	Y		Y					
Linacre	Y					Y		
Hargreaves	Y	Y						
Kharrufa	Y				Y			

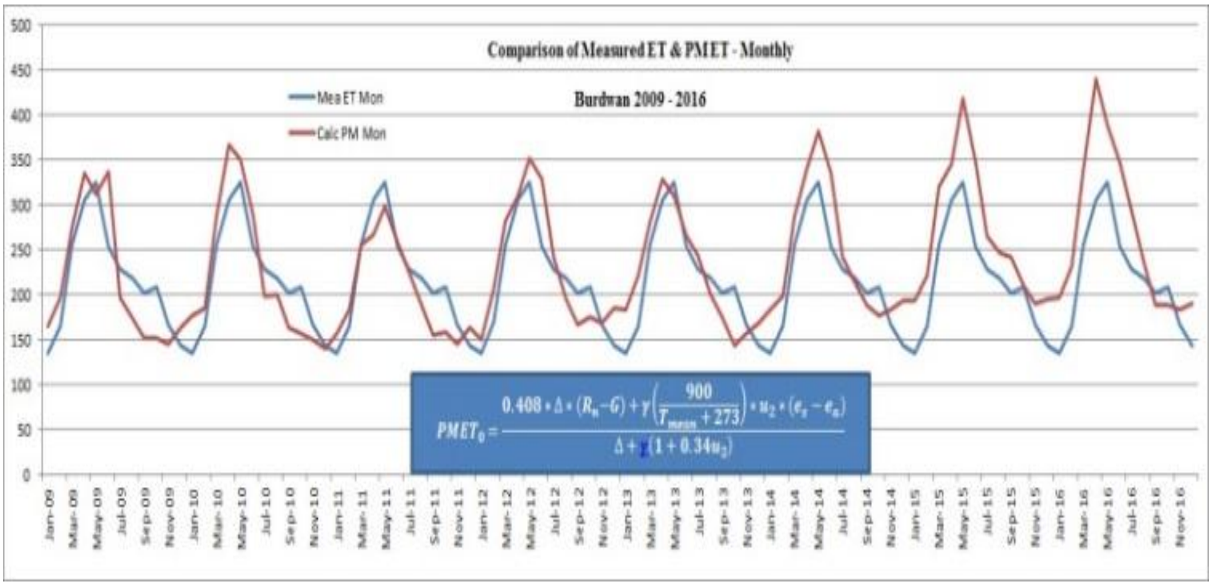

Figure 8. Comparison of Penman Monteith (PM) ET with Measured ET

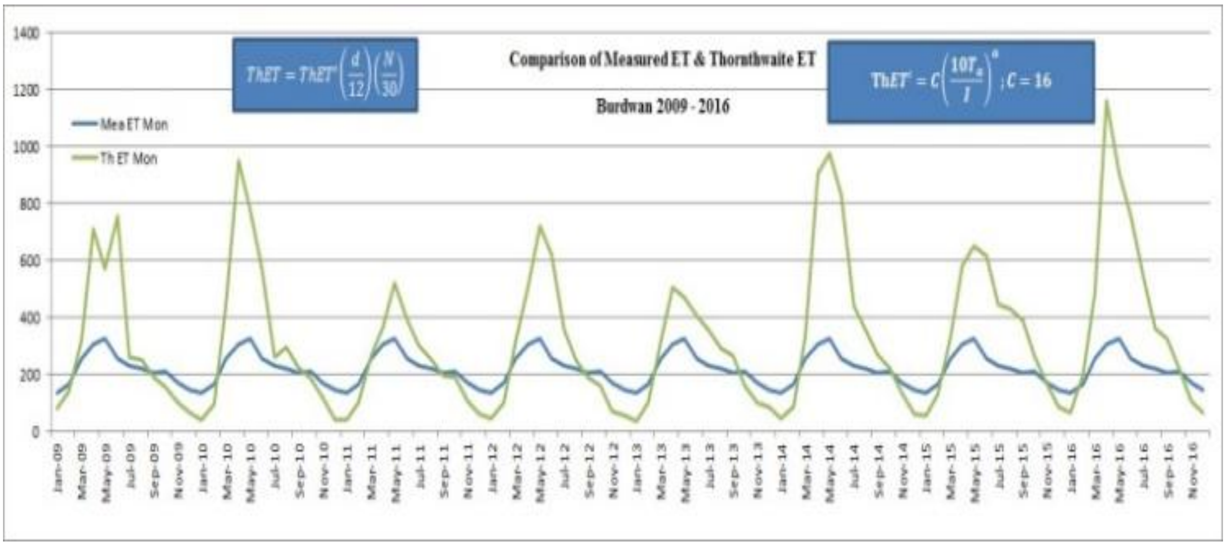

Figure 9. Comparison of Thornthwaite ET with Measured ET

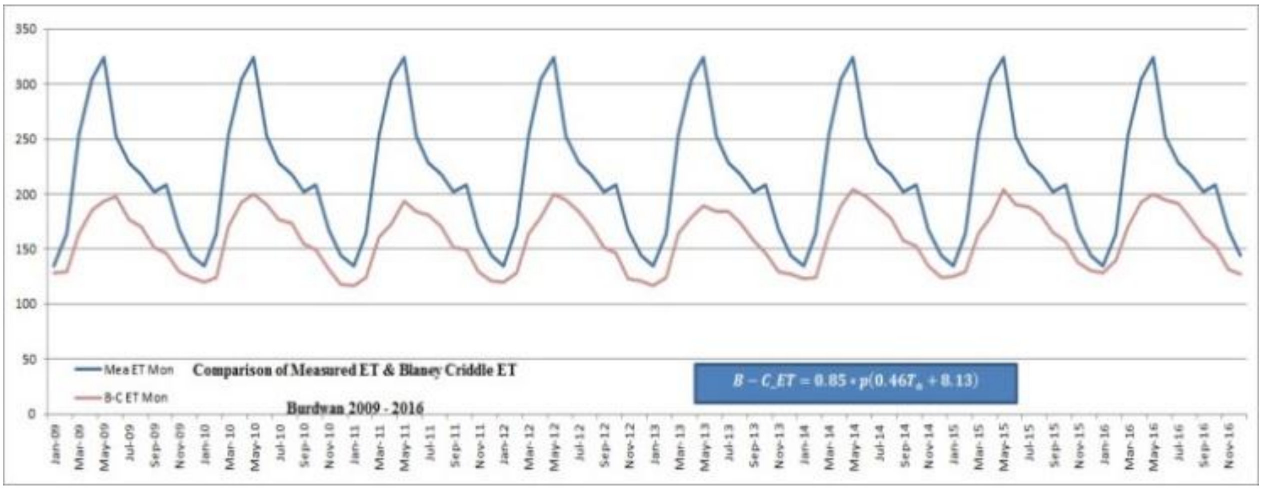

Figure 10. Comparison of Blaney Criddle ET with Measured ET

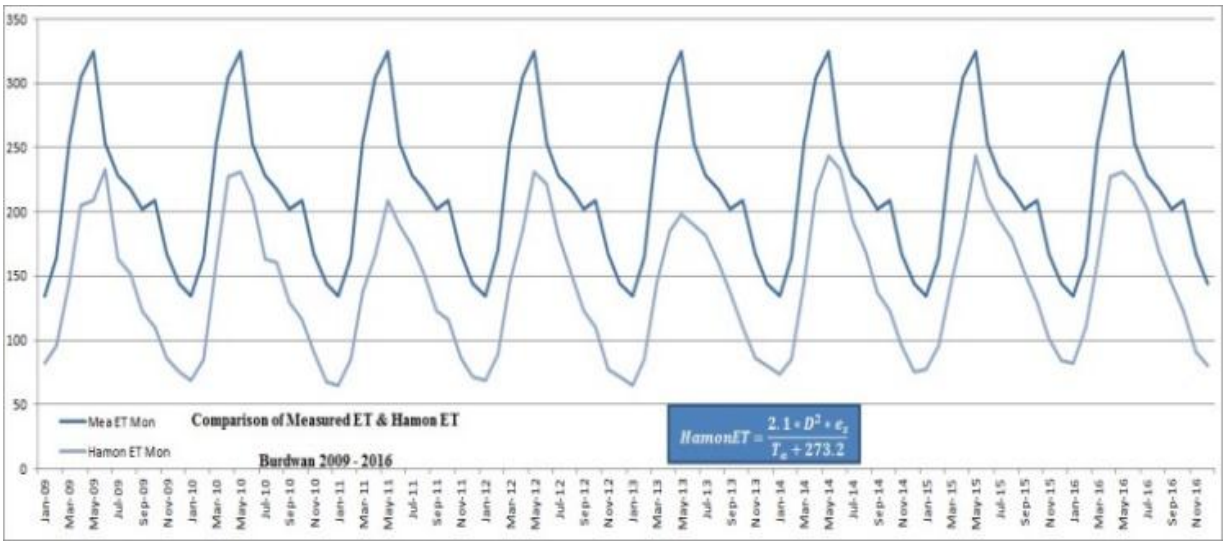

Figure 11. Comparison of Hamon ET with Measured ET

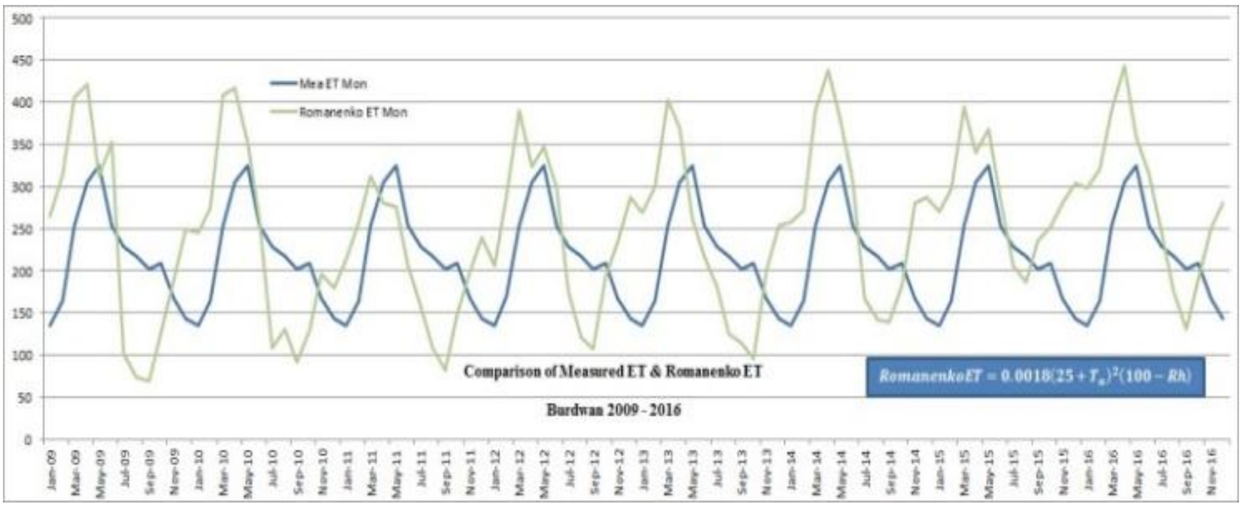

Figure 12. Comparison of Romanenko ET with Measured ET

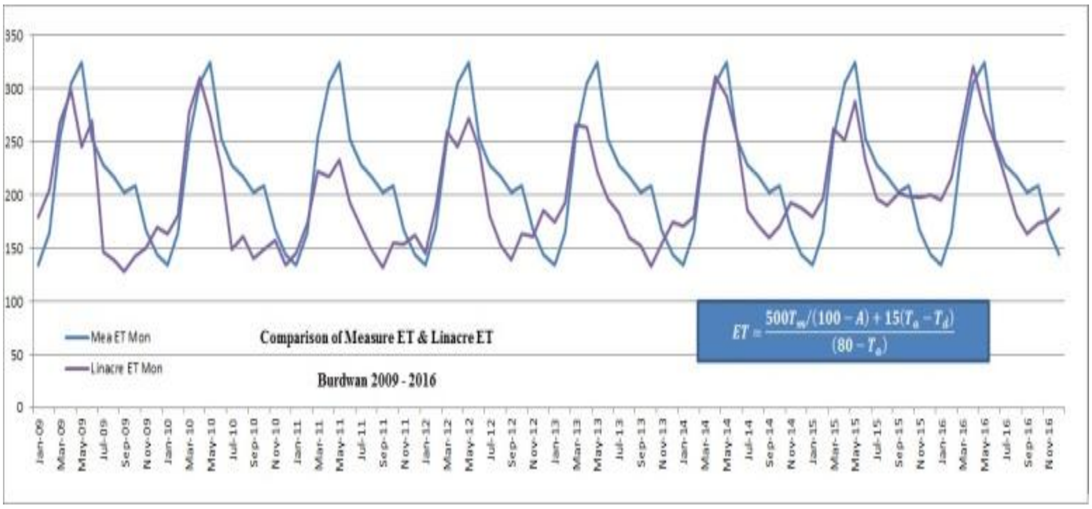

Figure 13. Comparison of Linacre ET with Measured ET

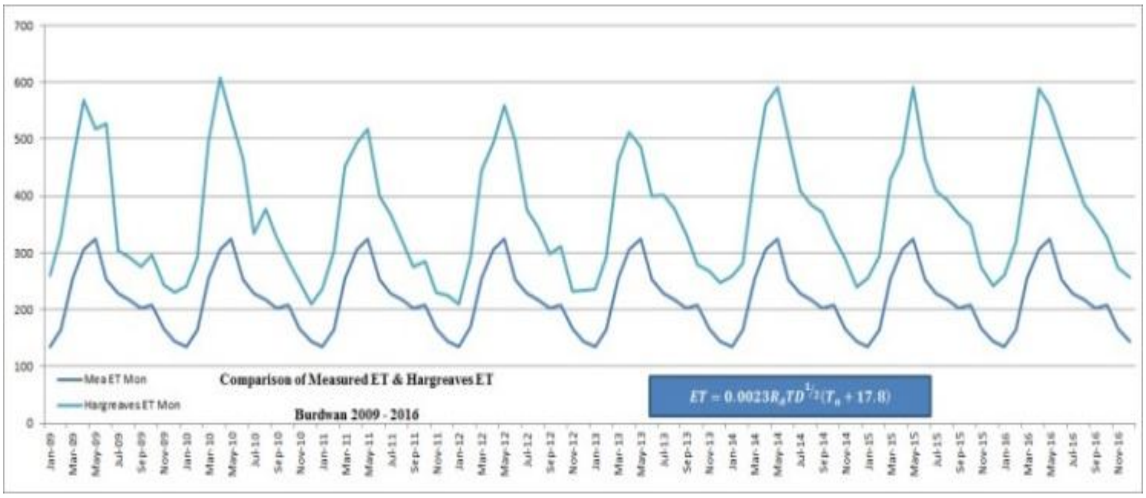

Figure 14. Comparison of Hargreaves ET with Measured ET

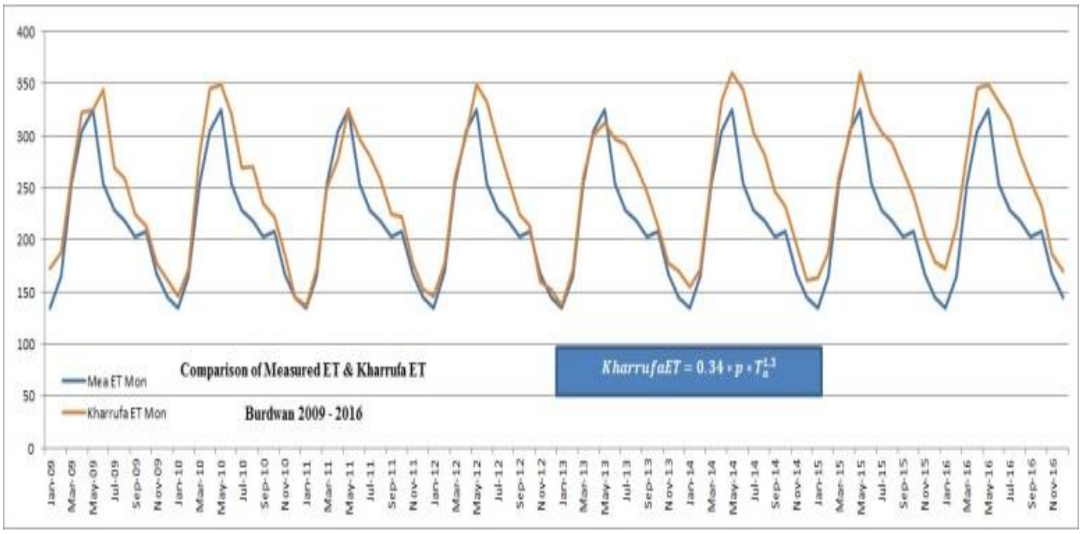

Figure 15. Comparison of Kharrufa ET with Measured ET

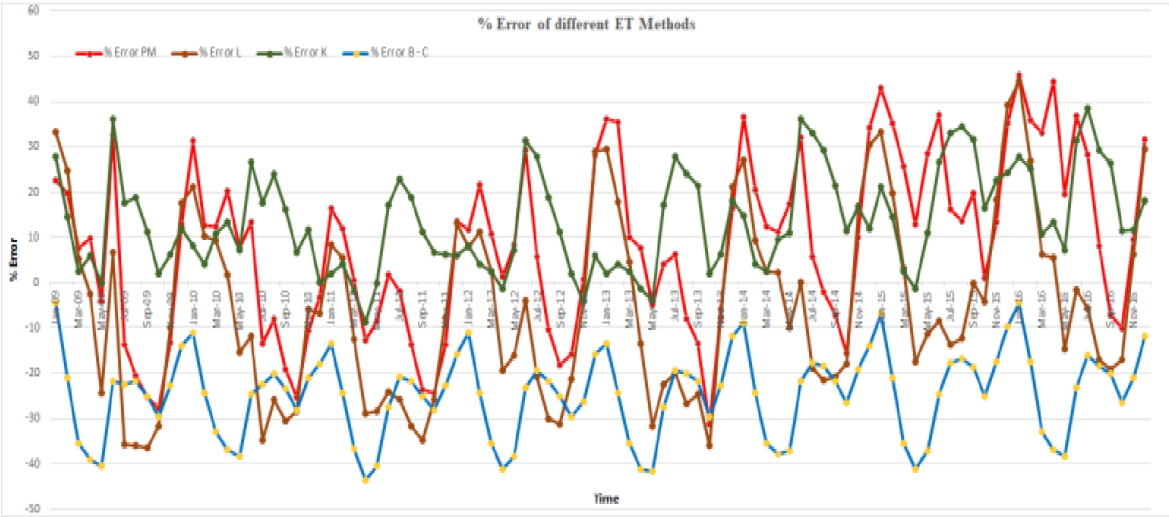

Figure 16. Representation of ET in % Error for PM, Linacre, Kharrufa and Blaney Criddle Methods

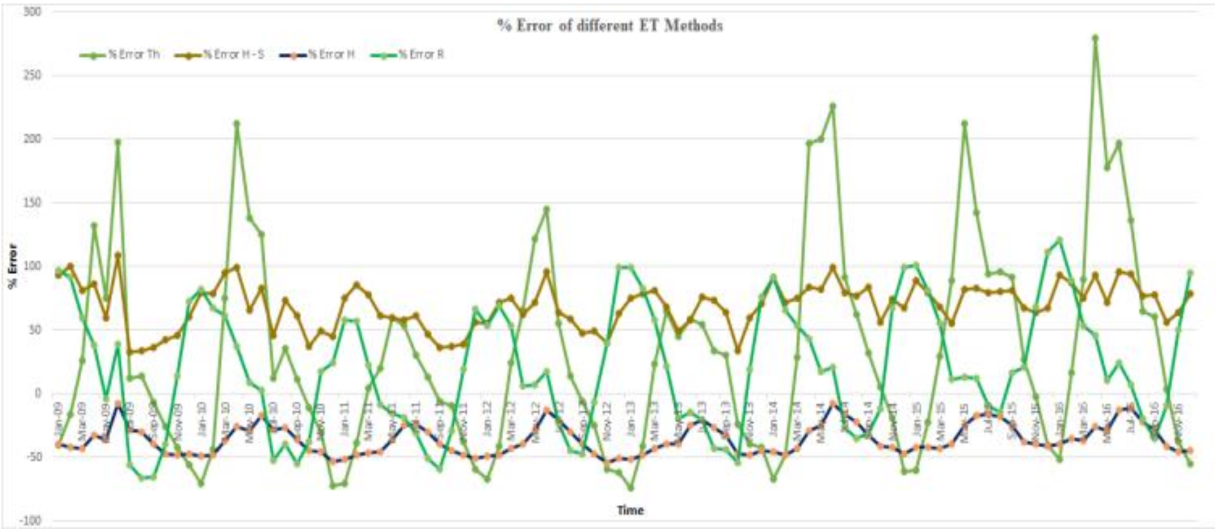

Figure 17. Representation of ET in % Error for Thornthwaite, Hargreaves, Hamon and Romanenko Methods

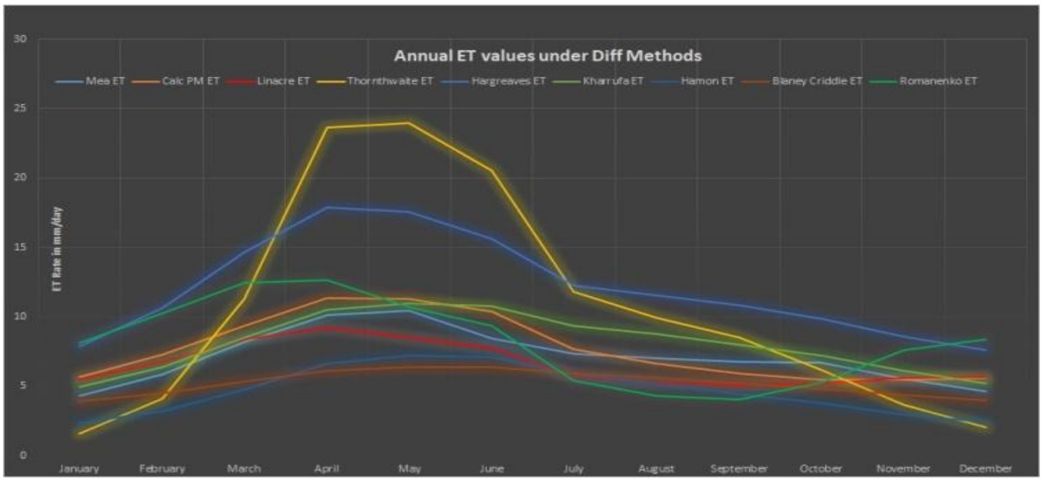

Figure 18. Annual ET Values calculated under different methods

Performance of Methods compared based on RMSE, MAE, MAD, MSE, MAPE, d (index of agreement), SSE and R^2 values.

Standard Deviation **σ** measures the spread of a set of data around its average value and a lower value indicates that the data points are closer to the average while a higher value indicates spread of the data points.

Table IV: Performance of different temperature methods under different statistical parameters

Method	RMSE	MAE	MAD	MSE	MAPE	d	SSE	R^2	Adj. R^2
PM	1.428	1.189	2.039	5.774	17.3388	0.879	554.322	0.704	0.701
Thornwaite	7.828	5.154	6.706	73.403	64.787	0.416	7046.694	0.753	0.751
B – C	2.226	1.907	*0.753*	*0.751*	24.654	0.307	*72.128*	0.808	0.806
Hamon	2.584	2.458	1.485	3.009	36.017	0.461	288.865	0.818	0.816
Romanenko	5.154	4.855	0.864	1.067	66.943	- 2.9	102.503	0.161	0.153
Linacre	1.449	1.223	1.347	2.595	17.897	0.802	249.146	0.513	0.508
Hargreaves	5.331	4.959	3.049	12.888	69.033	0.018	1237.254	*0.876*	*0.875*
Kharrufa	*1.255*	*0.985*	1.789	4.384	*14.061*	*0.896*	420.911	0.842	0.84

From Table IV above, it is seen that Kharrufa method offers the second best R – squared value 0.842 and Adjusted R – squared value 0.84 beyond Hargreaves' corresponding values of 0.876 and .875 respectively along with the highest index of agreement (d) of 0.896. Also the value of MAPE (14.061 %) and RMSE (1.255) are the lowest compared to the other seven methods. Although the SSE value is least for Blaney Craddle method, but taking into account of all the other parameters, Kharrufa method is by far the most accurate one.

CONCLUSION

From the results obtained and the statistical parametric tests that were ran, it is found that the Kharrufa model shows the best results with closer congruence to the measured data. It may therefore be concluded that the climatic conditions that prevail in Burdwan vis – a – vis West Bengal, Kharrufa model is the best choice for determination of Evapotranspiration as the results are even better than the combined method of Penman Monteith equation. Hence for designing and scheduling the irrigation plan and water budget schemes, it is proposed to follow the Kharrufa method for a better accuracy and more efficacious results. Albeit work needs to be carried out and it has been taken up for re-calibration of constants for the Kharrufa method to attain even higher rates of accuracy with precision with the objective of acquiring higher value of R – squared and Adjusted R – squared values.

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