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Comparison of Reference Evapotranspiration Estimation Models

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ABSTRACT

Reference evapotranspiration (ET_o) is an important factor in estimating crop water requirement and water resource management. This research study compares the performance of open pans and Blaney Criddle (BC) to CROPWAT irrigation simulation software using 15-year daily weather data of Auchi was acquired from the Nigeria Meteorological Station (NMET). The accuracy of each model was evaluated using various statistical metrics. ET_o estimated from the four models were compared with CROPWAT model, an irrigation software program used for solar radiation (RS), reference evapotranspiration (ET_o) and crop water requirement (CWR) calculations. Validation outputs have the correlation values (R^2) of 0.587, 0.536, 0.511 and 0.513 for ETo_{BC}-$ET_{o\ CROPWAT}$, ET_{oBT}-$ET_{oCROPWAT}$, $ET_{o\ AUS}$-$ET_{o\ CROPWAT}$, and ET_{oUS}-$ETo_{CROPWAT}$ respectively. This result indicates marginal good fit between the estimated Reference evapotranspiration (ETo) from each model and CROPWAT irrigation software. However, there were discrepancies between the simulated and computed reference evapotranspiration (ETo) for the model with Blaney Criddle and Australia pan having correlation (R^2) and bias value (AB) of 0.223; 0.241 and 2.30; 2.00 respectively. In conclusion, these reference evapotranspiration (ETo) estimating models are capable of providing realistic result which will be useful for water resources management.

Key words: Reference evapotranspiration, CROPWAT model, Water management

1. INTRODUCTION

Severe water scarcity occurs in many countries particularly largely in Nigeria and agricultural water use is progressively becoming more limited in the light of growing water demand of various sectors. Water management for crop suitability needs a comprehensive understanding of the climate, particularly, rainfall and evapotranspiration [1-2]. In developing nations like Nigeria, where there is a shortage of direct measurements of evapotranspiration, evapotranspiration can be estimated indirectly using climatological data [3]. The penman monteith FAO-56 equation is recommended for the estimation of reference evapotranspiration and provides a reliable reference evapotranspiration and provides a reliable reference evapotranspiration (ETo) value under different climate conditions [4].

Evapotranspiration (ET) is considered to be the dominant component of the hydrologic cycle due to the fact that about 60% of annual precipitation falling over the land surface is returned to atmosphere as ET [5]. Evapotranspiration and transpiration process take place simultaneously in any catchment area, and therefore, cannot be separated in the analysis and evaluation of water budget for a district. The estimation of evapotranspiration is important for irrigation engineering applications and for studies relating to hydrologic water balance, water resource planning and management and land use planning [6].

The estimate of reference evapotranspiration is important in Crop water requirement and development of irrigation scheduling. The general knowledge of the spatial distribution of reference evapotranspiration (ET_0) is still unclear despite its importance for global ecosystem research [7]. One reason is that ET_0 is difficult to observe directly as it depends on several meteorological parameters which are observed only at major stations [8]. Field measurement of meteorological variables is a critical part of evapotranspiration estimation process. Measurement and recording errors in field variable result in evapotranspiration estimation errors [9]. There have been significant processes in the capability of near surface meteorological variable measurement such as temperature, precipitation, wind speed, solar radiation and humidity using automated climate stations [3]. This has the effects of simplifying evapotranspiration model usage. Crop evapotranspiration is estimated by multiplying the reference evapotranspiration by crop specific crop coefficient (Kc) values at different crop growth stages. Moreover, different reference evapotranspiration methods have been developed over the years range from direct measurement from a reference surface such as *alfalfa* grass [8, 10] or can be computed from weather data based methods *i.e*. (a) temperature based [8, 11],(b) radiation based [8].

Therefore, in this research study Open Pans Evaporation (US Class A, Australian Pan and British Tank) and empirical method (Blaney Criddle) have been analysed and compared with the CROPWAT model for estimation of ETo for current period of 15-year (1996-2010) in Auchi, Edo-State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study area comprises of Auchi district, which is one of the centrally located district of Etsako west LGA with 2338.9 sq km geographical area. The topography of the study area is undulating in nature. According to survey of Nigeria the latitude and longitude are 7.07^o 04'00"N and 6.27^o 16'00'E respectively, and it has an average elevation of 188 meters above mean sea level (wikipedia). In Auchi, the season is warm, oppressive and overcast and the dry season is hot, muggy and partly clowdy. The recent population census of Auchi shows that the community inhabits about 104,540 people. Auchi has two distinct climatic seasons (wet and dry season). The wet season spread from April to October, while the dry season is from November to March [12]. In Auchi, the average annual temperature is 25.9 °C and precipitation averages of 1389 mm. The precipitation varies 249 mm between the driest month and the wettest month. The variation in temperatures throughout the year is 3.8 °C. The driest month is January. There is 11 mm of precipitation in January. The greatest amount of precipitation occurs in September, with an average of 260 mm. The aeral view of Auchi is shown in fig 1a and location map in Fig. 1b: Computed average climate data for three decades (30 years) for Auchi is shown in Table 1.

Fig. 1 Areal view of Auchi, Nigeria (Umoru, 2010)

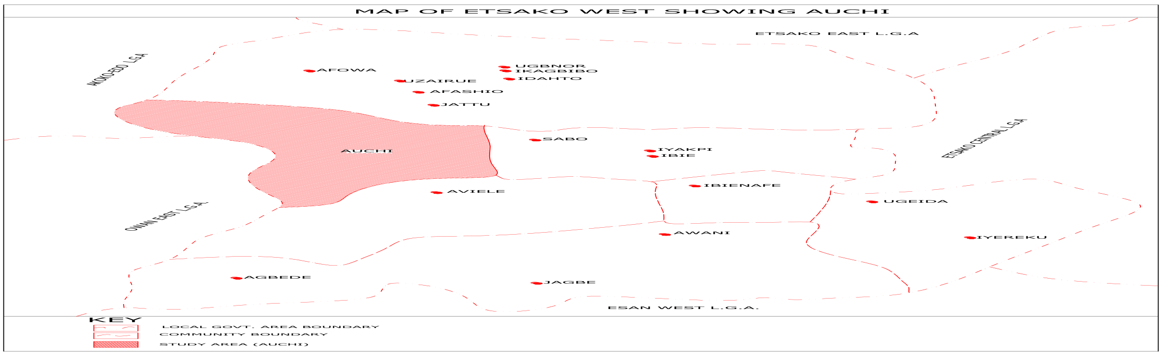

Fig. 2 Map of Etsako west local govt area showing Auchi

Source: Ministry of Lands, Surveying and Housing, Edo State, 2008

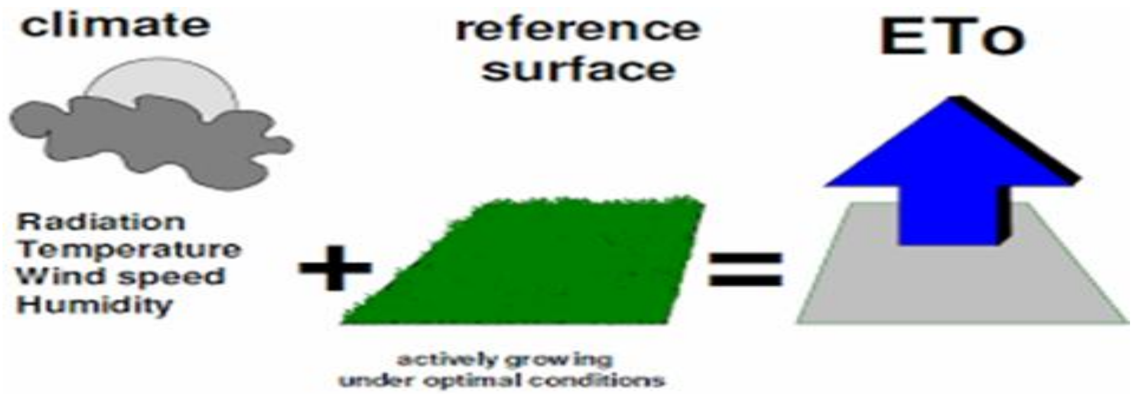

Fig. 3 Processes of reference evapotranspiration

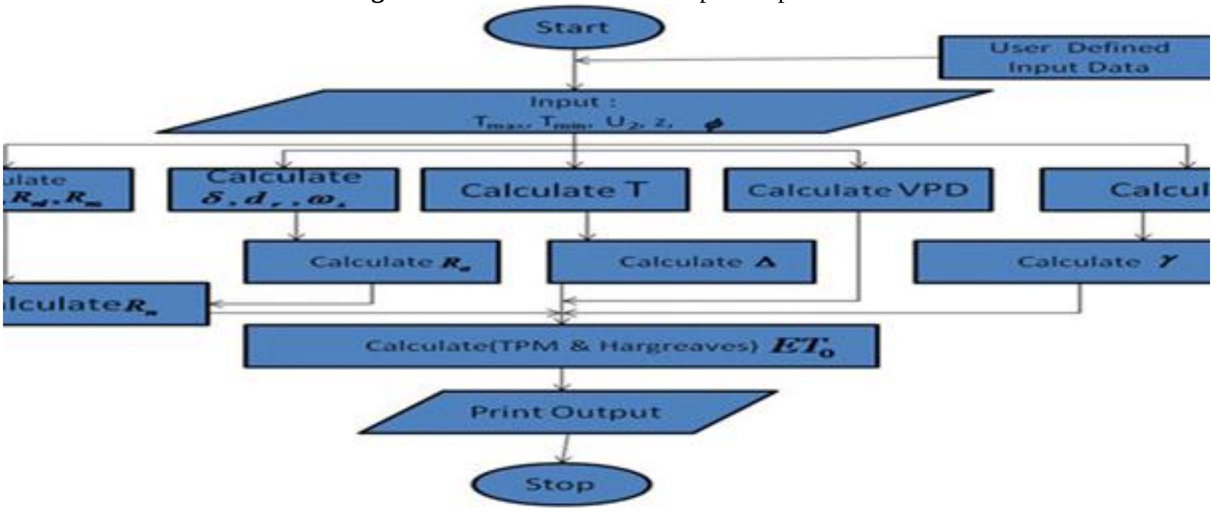

Fig. 4 Processes flow chart for reference evapotranspiration

2.2. Data collection

In order to calculate reference evapotranspiration (ET_o), the respective daily climate data collected from Nigeria Meteorological Agency from the time periods of 1995-2010. The climate data are as follows:

i. Maximum temperature (^oC);
ii. Minimum temperature (^oC);
iii. Relative humidity (%);
iv. Wind speed (km/h);
v. Sunshine hour (hours);
vi. Precipitation (mm); and
vii. Evaporation depth (mm).

These data were used as input parameters in the estimation of reference evapotranspiration (ETo) different estimation approaches. Three Pan Evaporation methods (US Class A, Australia pan and British tank), empirically-based method (Blaney-Criddle) and CROPWAT model (using inbuilt modified Penman-Moniteth equation) were applied to compute ET_o. The results generated from the Pans evaporation and Blaney-Criddle were compared with the CROPWAT reference evapotranspiration (ETo) estimation. Table 1 shows a set of equations and expression used in estimating reference evapotranspiration (ET_o).

Table -1 Methods of computation

S/NO	Empirical equations	Methods of computation
1.	$ET_{oUS} = k_p.E_{pan}$ $ET_{oAUSTRALIA} = k_p.E_{pan}$ $ET_{Obritish} = k_p.E_{pan}$	Evaporation pan
2.	$ET_o = p(0.46T_{mean}+8.13)$	Blaney – Crriddle
3.	$ET_o = \frac{0.408\Delta(R_n-G)+y\left(\frac{890}{J+237}\right)[u_2(e_a-e_d]}{\Delta+y(1+0.34u_2}$ Inbuilt in CROPWAT MODEL	FAO – 56 Penman-Monteith

Where: ET_o – Reference evapotranspiration (mm/day).
Rn – Net Radiation at crop surface (mjm^2/day).
G – Soil heat flux density (mjm^{-2}/day^{-1})

T – The mean Daily air temperature at 2m height (^oC)
U_2 – The wind speed at 2m height (m/s^{-1})
ea – The saturation vapor pressure (kpa)
ed – The actual vapor pressure (kpa)
(ea-ed) – The saturation vapor pressure deficit (kpa)
Δ - The slope vapour pressure curve (kpa^oc^{-1})
r = The psychometric constant (kpa^oc^{-1})
Tmean = the mean daily temperature (^oC)
P = Percentage of sunshine hour
Kp = Pan coefficient (US Class A = 0.7; Australia = 0.9 and British Tank = 0.85)
Epan = Evaporation depth (mm)

2.3. Model validation

The performance evaluation of the different method was undertaken by comparing the values obtained by CROPWAT equation by the following statistical method to obtain the prediction error (*Allen et al.*, 1998). The Average Bias (AB) of the evaluated methods was calculated using the equation

$$AB = N^{-1} \sum_{i=1}^{N} (P_i - O_i) \quad (1)$$

Where:
O, is the reference evapotranspiration (ET_o) estimated by the considered method (mm day^{-1}).
N, is the total number of observations.
The errors of the evaluated methods were calculated by Root Mean Square Error (RMSE) and by Mean Absolute Error (MAE), as equations.

$$\text{RMSE} = \sqrt{N^{-1} \sum_{i=1}^{N} (P_i - O_i)^2} \quad (2)$$

$$\text{MAE} = N^{-1} \sum_{i=1}^{N} (P_i - O_i) \quad (3)$$

The Estimated Standard Error (ESE) was calculated using the equation:

$$\text{ESE} = \sqrt{\frac{\sum_{i=1}^{N}=1(P_i - O_i)^2}{N-1}} \quad (4)$$

2.4. Statistical Analysis

Generated outputs were subjected to critical analysis using statistical metrics such as determination of correlation (R^2), last significant deference (LSD), Root mean square. Package such as (SSPS) and MATSET were applied to model the computed variable.

3. RESULTS AND DISCUSSION

3.1. Estimation of reference evapotranspiration (ET_o)

The vales of reference evapotranspiration (ETo) estimated from five approaches for several years in Auchi as shown in Table 2-4. The estimated highest values (ETo) was obtained from CROPWAT model, which the empirically-based Blandey-Criddle gave the least value for all the simulations. In Table 1, ET_o value of 3.3 mm/day was estimated from CROPWAT model, while 2.0 mm/day was estimated using US Class A Pan and Australia Pan, British Tank and Blanley Criddle produced ETo values of 2.5 mm/day, 2.3 mm/day and 1.0 mm/day respectively. There is gradual decrease in the rate of evapotranspiration in the month of July, August, September and October. This period is classified as wet season in Auchi and its environs. During this period, the region usually experiences reduction in temperature (minimum and maximum) which is the main driver of evapotranspiration. However, the rate of ET_o starts to raise from Novemeber to the beginning of June. This period is categorized as dry season with little rainfall depth and increase temperature. This trend is continous for the 15-year of experimental iterations.

3.2. Model performance

Figures 5-12 show the variation of ET_0 calculated by different methods. The simulation is run for every month of the year. The monthly performance of each of the models (US Class A (ET_{oUS}), Australia Pan (ET_{oAUS}), British Tank$_{(EToBT)}$ and Blaney Criddle (ET_{oBC})) was compared with generated output from CROPWAT model. In evaluating monthly performance of the models against the CROPWAT software, EToUS, EToAUS and EToBT were estimated using the pan coefficient of 0.7, 0.9 and 0.85 respectively. Mean temperature and percentage of sunshine hours were used to determine reference evapotranspiration for Blaney Criddle approach at Auchi.There are differences between the monthly reference evapotranspiration ETo from Claas A pan, Australia pan, British Tank and Blaney Criddle model, and CROPWAT model. In the most of January, February March, November and December in 1996, CROPWAT software shown had the best performance over other models (Fig. 5). Evapotranspiration values were highly underestimated using ET_{oBC} and ET_{oUS}, however better estimation was obtained in ET_{oAUS} (Fig. 5). This indicates that it is only CROPWAT model that could effectively capture the increase in the minimum and maximum during the dry season. However, all the ETo estimation models were to perform better during the wet season (May- October) except CROPWAT model which produced higher reference evapotranspiration (Fig.5). This observation is applicable to the ET_o estimations for the current period's 1997 and 1998 as depicted in Fig.6-7.

As shown in Figure 8, in Auchi for 1999, CROPWAT and Blandey-Criddle models provided a good estimate of ETo values of 3.4 mm/day and 1.1 mm/day in January , while 0.7 mm/day, 0.9 mm/day and 0.8 mm/day were estimated using US Class A, Australia Pan and British Tank respectively (Table 4). However, ETo estimated from Blandey-Criddle is the lowest in November (0.6 mm/day) and December (0.5 mm/day), while the three open evaporation pans (Class A, Australia and British) produced higher ET_o values of 1.8 mm/day, 2.3 mm/day and 2,1 mm/day and CROPWAT model simulated highest value of 3.4 mm/day in November and 3.2 mm/day in December respectively (Table 4 and Fig.8). These results could be due to higher wind speed, sunshine and the increase in minimum and maximum temperature.

Estimation of reference evapotranspiration with the use of CROPWAT model using average climat (minimum and maximum temperature, sunshine hour, relative humidity, wind speed) data in Auchi, showed variations in monthly estimated ETo using CROPWAT model and other models (US Class A, Australia and British Tank). Significant underestimation of ETo throughout the year (wet and dry) was obtained in all the models except CROPWAT software which produced realistic estimate of ET_o during the dry season and overestimated during the wet season. In order to compute accurate and precise crop water requirement (ET_c) which is the product of reference evapotranspiration (ETo) and crop coefficient (Kc), great caution should be applied should be applied in selecting most appropriate approach of estimating of ETo for different seasons. If the ET_o is underestimated, this leads to incorrect estimation of crop water requirement and poor irrigation scheduling system. However, over estimation of ET_o will create incorrect variable and if this value is used to compute crop water requirement (ET_c), it can lead to under-irrigation. Generally, accurate estimation of reference evapotranspiration (ET_o) is imperative to developing sound and sustainable water resources management mostly in arid regions. Figure 12 depicted the variations in average annual bias-values estimated using four models. Highest annual average bias values were obtained in 2001 with 2.8 mm, 2.8 mm, 2.8 mm and 2.2 mm , whereas lowest values were estimated in 1997 with biases of 1.7 mm, 1.3 mm, 1.5 mm and 2.6 mm for $ET_{o(US)}$, $ET_{o(AUS)}$, $ET_{o(BT)}$ and $ET_{o(BC)}$. This observation is likely due to decrease in minimum temperature and increase in number of raining and rain depth in 1997. Increase in other parameters influencing evapotranspiration such as temperature, wind speed, sunshine hours and solar radiation may be responsible for higher estimation of ET_o using CROPWAT software.

Table 2: Estimated reference evapotranspiration (ETo) using four approaches in 1997

Months	ETo(US)	ETo(AUS)	ETo(BT)	ETo(BC)	ETo(CROPWAT)
Feb	2.0	2.6	2.4	1.1	3.7
March	2.2	2.7	2.5	1.0	3.8
April	2.0	2.5	2.3	0.8	3.5
May	1.9	2.4	2.2	0.5	3.7
June	2.0	2.5	2.3	0.9	3.3
July	0.4	0.5	49.0	0.5	2.8
August	0.5	1.3	1.1	0.5	2.8
Sept.	0.8	1.1	1.0	0.6	2.9
October	0.9	1.7	1.1	0.8	3.1
Nov.	1.8	2.3	2.0	1.0	3.4
Dec.	2.0	2.6	2.4	0.5	3.4

Table 3: Estimated reference evapotranspiration (ETo) using four approaches in 1998

Months	ETo(US)	ETo(AUS)	ETo(BT)	ETo(BC)	ETo(CROPWAT)
Jan	1.3	1.6	1.5	1.0	3.3
Feb	1.5	1.9	1.7	1.1	3.3
March	1.4	1.8	1.6	1.0	3.6
April	1.2	2.5	1.4	0.8	3.4
May	0.9	1.2	1.1	1.0	3.6
June	0.7	0.9	0.8	0.9	3.2
July	0.5	0.6	0.6	0.6	2.8
August	0.6	1.7	0.7	0.6	2.8
Sept.	0.5	0.6	0.6	0.6	3.3
October	0.7	0.9	0.8	0.8	3.2
Nov.	1.1	1.4	1.2	0.6	3.5
Dec.	1.0	1.5	1.2	0.6	3.4

Table 4: Estimated reference evapotranspiration (ETo) using four approaches in 1999

Months	ETo(US)	ETo(AUS)	ETo(BT)	ETo(BC)	ETo(CROPWAT)
Jan	0.7	0.9	0.8	2.0	3.4
Feb	0.8	1.0	0.9	1.1	3.1
March	1.1	1.4	1.2	1.0	3.6
April	0.8	1.1	1.0	0.8	3.5
May	0.6	0.6	0.7	1.0	3.6
June	0.7	0.9	0.8	0.9	3.3
July	0.5	0.6	0.6	0.6	2.8
August	0.6	1.7	0.7	0.6	2.9
Sept.	0.4	0.5	0.5	0.6	2.9
October	0.5	0.6	0.6	0.8	3.1
Nov.	1.1	1.4	1.2	0.6	3.4
Dec.	1.8	2.3	2.1	0.5	3.2

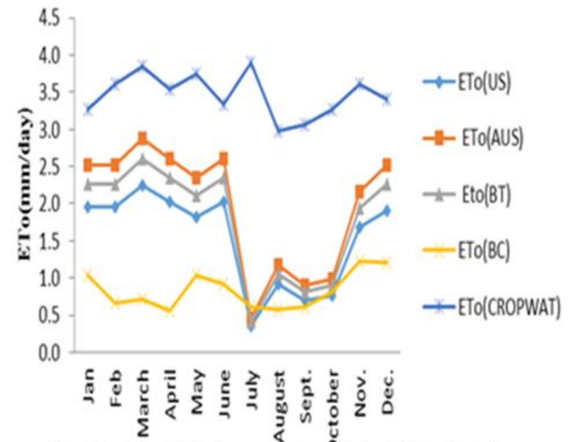

Fig. 5: Variation of of reference evapotranspiration (ETo) estimated from five methods in 1996

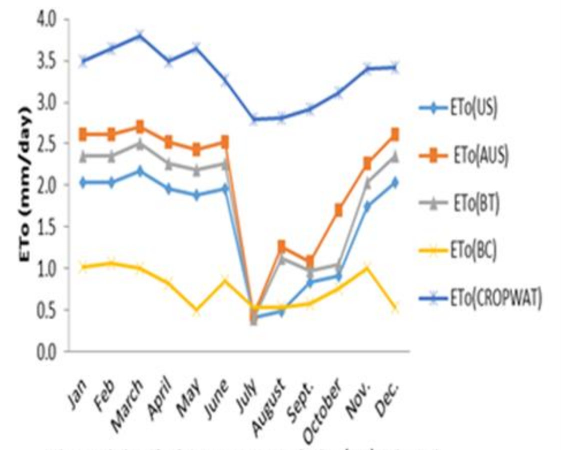

Fig.6: Variation of reference evapotranspiration (ETo) estimated from five methods in 1997

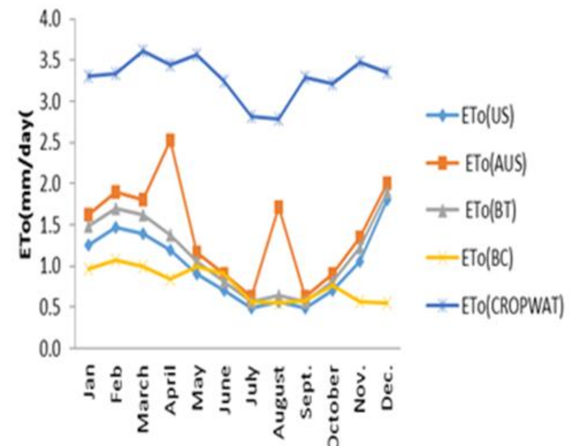

Fig.7: Variation of refernce evapotranspiration (ETo) estimated from five approaches

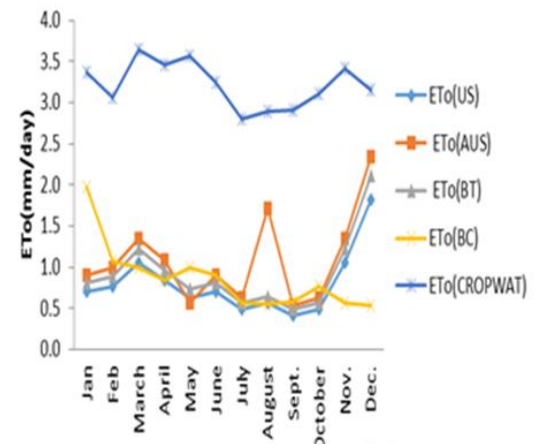

Fig.8: Variation of refernce evapotranspiration (ETo) estimated from five approaches in 1999

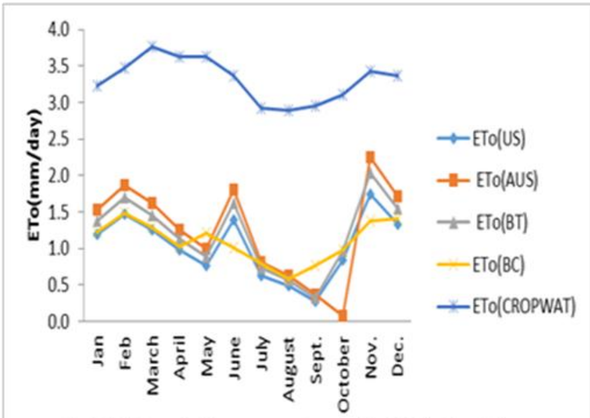

Fig.9: Variation of reference evapotranspiration (ETo) estimated from five approaches in 2000

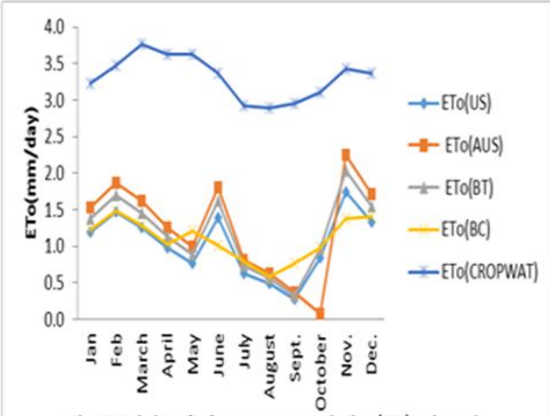

Fig.10: Variation of refernce reference evapotranspiration (ETo) estimated from five approaches in 2001

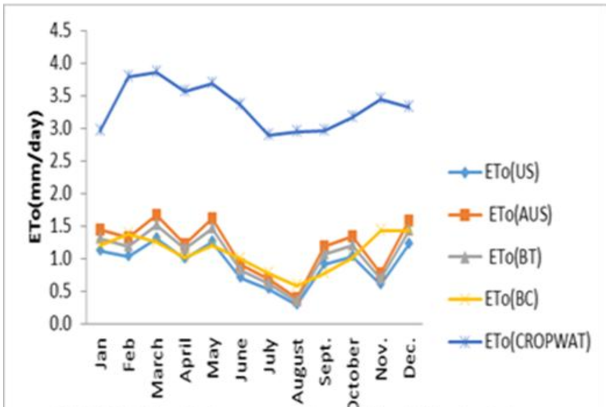

Fig.11: Variation of reference evapotranspiration (ETo) estimated from five approaches in 2002

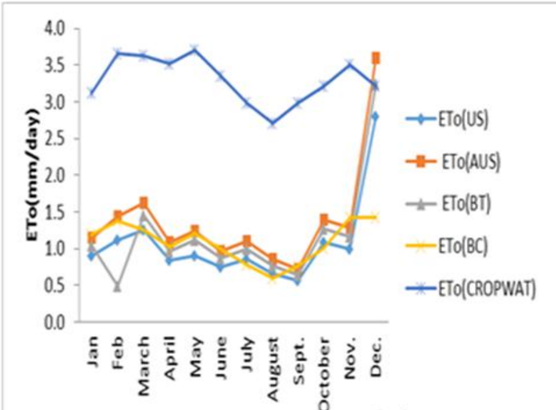

Fig.12: Variation of reference evapotranspiration (ETo) estimated from five approaches in 2003

4. CONCLUSION

Reference evapotranspiration (ETo) was estimated using open pan (US Class A, Australia pan, and British tank) and empirically-based approach (Blane-Criddle) using 15-year baseline climate parameters. The output of each of the approach was compared with the CROPWAT model. The result of the analysis shows that the open pan method (ETo US, ETo AUS and ETo BT) underestimated reference evapotranspiration during the dry season, while the CROPWAT model performs better. Blaney Criddle (BC) estimates better evapotranspiration values in the dry season than the open pan approach. Open pan and Blaney criddle (BC) models give more accurate estimate of reference evapotranspiration (ET_o) than CROPWAT model during the wet season. This observation indicates weather-sensitivity of different models for estimating reference evapotranspiration (ET_o). Calibration of reference evapotranspiration (ETo) measured from the open pans and Blaney Criddle in comparison to CROPWAT model were estimated. Generally, application of more than one models is very important in estimating reference evapotranspiration (ET_o) for better estimation of crop water requirement and irrigation scheduling.

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