



ESTIMATION AND COMPARISON OF REFERENCE EVAPOTRANSPIRATION WITHIN KADUNA CENTRAL DISTRICT, NIGERIA, USING FOUR DIFFERENT METHODS

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ABSTRACT

The reference evapotranspiration (ET_o) within Kaduna Central District, Nigeria was estimated from a 30-year climatological data using four different methods namely, Penman-Monteith (PM), Blaney Criddle (BC), Hargreaves (HGRV) and Piche evaporimeter (PiEv) (atmometer) methods. The study shows that the highest ET_o values obtained from PM, BC and PiEv were 6.43 mm/day, 7.58 mm/day and 8.63 mm/day, respectively, and these occurred in February, except for HGRV which estimated its highest ET_o (3.73 mm/day) in March. The lowest ET_o values were obtained in August for all the methods. By means of the confidence index (c), agreement or concordance index (d) and correlation coefficients (r) statistics the BC, HGRV and PiEv ET_o values were correlated with that of PM, as the standard. Results showed that BC, HGRV and PiEv gave c-values of 0.88, 0.48 and 0.67, respectively. Hence, BC-PM, HGRV-PM and PiEv-PM correlations were adjudged as excellent, bad and good, respectively, on the basis of criteria for interpretation of the performance of methods of ET_o estimations. Blaney-Criddle reference evapotranspiration method gave the best estimate in comparison to the Penman-Monteith standard in the study area. Hence, the Blaney-Criddle ET_o can be calibrated with the Penman-Monteith ET_o and used effectively within the Kaduna Central District conditions for irrigation water management decisions.

Keywords: Estimation and comparison, Reference evapotranspiration, Methods, Kaduna Central District, Nigeria.

1. INTRODUCTION

In agriculture, evapotranspiration (ET) refers to crop water use. The ET process is a key variable in irrigation management, crop growth, hydrologic cycle, plant physiology, soil-plant-water-atmosphere relationships, microclimate and surface interactions, and drainage studies [1]. In a world of competing water demands amidst global climate change, it is important to maximize the efficiency of water usage and one of the ways to do this is by determining the evapotranspiration needs of specific locations so as

to ascertain the proportion allocated to irrigated agriculture.

While ET is broadly defined as the combination of the processes of both evaporation from soil and plant surfaces and transpiration from plant canopies through the stomata to the atmosphere, reference evapotranspiration (ET_o) is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height,

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actively growing, well-watered, and completely shading the ground [2]. ET_0 provides a standard to which ET at different periods of the year or in other regions can be compared and ET of crops can be related [2]. ET_0 is a concept to measure the evaporative demand of the atmosphere, independent of the crop type, crop development and management practices [3]. Evapotranspiration is a significant variable for meteorological and hydrological research and also for agrarian water reservoirs organization [4].

ET_0 evaluation involves either direct measurement with atmometer (piche evaporimeter) or evaporation pans, while indirectly, it can be evaluated by means of analytical or empirical methods such as the FAO Penman Monteith (PM), Blaney Criddle (BC), Hargreaves (HGRV), Thornthwaite (TW), Jensen and Haise (JHSE), etc. The readings taken with atmometers and evaporation pans are normally converted from evaporation to evapotranspiration using appropriate factors. The empirical methods use recorded climatic parameters to estimate the ET_0 . Studies have shown that many models are site and location specific; others reduce the input variables to make for adaptability, peculiarity or cost reduction of input gathering [5].

In this study, the ET_0 values computed by PM, BC and HGRV empirical methods, as well as that computed from recorded evaporation measurements with atmometer are being evaluated. The International Scientific Society has considered the PM empirical model as the best because it gives accurate results when compared with other methods in several locations of the globe [2]; it has been considered to be the standard method that can be used anywhere without the necessity to calibrate [6], [7]. This model, however, requires the largest number of climatic data. The necessity of comparison, sensitivity testing and calibration methods in a local context is emphasized by a large number of studies and a local test appears indispensable as a means of means of finding the most suitable model for an area [7]. Large investment in irrigation projects development in any area needs sound estimates of crop water demands against risk of crop failure due to drought [5]. These estimates are obtainable from various evapotranspiration models.

The challenge with using the Penman-Monteith method, however, is that it requires many climatic variables for its determination and this has often made it difficult to use in areas without the needed

data. On the other hand, the Blaney Criddle and Hargreaves methods require a single climatic variable - temperature or solar radiation [8, 9].

Generally, Kaduna State, including the study area, is known for dry season horticultural crops production through irrigation. Crops usually grown in the area through irrigation are cabbage, carrots, tomatoes, maize, pepper, cucumber and onions [10]. The irrigation schemes are mostly in small and medium scale and [11] has shown that irrigated crop production in the area is profitable. To boost irrigation in Kaduna State several earthdams and dams have been constructed such as the Kufana, Sabon Sarki, Likarbu, Zuntu, Fatika, Matari and Pambeguwa earthdams. Others are Kangim, Gimbawa, Bagoma, Shika, Kubani, Gurara, Galma and Hunkuyi dams [12]. Often, the water extracted from dams and rivers for irrigation is in competing demand with other uses such as municipal water supply and industrial uses. So there is need for right estimations and allocation for the several uses.

A major challenge to irrigation scheduling using climatological approach is the availability of the required climatic data needed to estimate the water use. The results of this study, will offer irrigation planners and users within the study area the simple estimation method of highest efficiency and requiring fewer variables. Based on this justification, the study objective is to estimate the reference evapotranspiration within Kaduna Central District, Nigeria, comparing four different estimation methods and recommending the model with the best correlation with FAO-PM model.

2. METHODOLOGY

2.1. Description of the Study Area

Kaduna Central District comprises Igabi, Kaduna North, Kaduna South, Chikun, Giwa, Birnin Gwari and Kajuru Local Government Areas, and stretches over latitude 10.32°N – 10.66°N and longitude 6.54°E – 7.68°E. The map of Kaduna State indicating weather stations, including the study area is shown in Figure 1 [13]. Generally, the climate of the study area is characterized by a clear distinction between dry and rainy seasons. The rainy season lasts from mid-April to early October. Kaduna has an annual mean rainfall of 1200 [14]. The temperature range (Figure (2a)) is 28°C to 36°C for the maximum scale and 15°C to 23°C for the minimum scale [15], [16]. The humidity range (Figure 2b) is 24 % to 83 %, with the lowest and highest values occurring in February and August,

respectively [15], [16]. Harmattan is at its peak between December and February and the relative humidity is very low. Thereafter, the weather is hot in March and April, with March recording the highest mean temperature of 36°C [15]. The wind speed and sunshine hour data for the District are presented in Figures 2c and 2d [15, 16].

Kaduna is classified under the Isoberlinia or Northern Guinea Savannah vegetation characterized generally by woodland consisting of different layers rather less distinct than those of the forest [17]

2.2. ET_o Computation Methods

The methodology for ET_o computation or measurement are as presented as follows.

2.2.1. The FAO Penman-Monteith method

This is most commonly used empirical approach to ET_o estimation [18]. The method gives an equation which is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. It was expressed by [2] as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \quad (1)$$

where, ET_o is the estimated reference evapotranspiration [mm day⁻¹], R_n = the surface radiation balance [MJ m⁻² day⁻¹], G = sensible heat flux in the soil [MJ m⁻² day⁻¹], T = average atmospheric temperature [°C], u₂ = wind speed at 2 m height [m s⁻¹], e_s = saturation vapour pressure [kPa], e_a = actual vapour pressure [kPa], Δ = slope of the water vapour saturation pressure curve [kPa °C⁻¹] and γ = psychrometric constant [kPa °C⁻¹].

The above equation was computed with the CROPWAT 8.0 software, with the input parameters as maximum temperature (°C), minimum temperature (°C), humidity (%), sunshine hour, and wind speed (Km/day).

2.2.2. Blaney Criddle method

The Blaney Criddle method for ET_o estimation is simple [18], being based on average temperature as the only required climatic parameter. The equation is given as:

$$ET_o = p(0.46T_{mean} + 8) \quad (2)$$

where, ET_o is reference crop evapotranspiration (mm/day) as an average for a period of 1 month, T_{mean} is mean daily temperature (°C) and p is Mean daily percentage of annual daytime hours.

2.2.3. Hargreaves method

Hargreaves method, like the Blaney Criddle approach, uses temperature data to determine ET_o, especially in areas where many meteorological data are unavailable [19]. [20], [21] claimed that the ET_o equation given by Hargreaves is simple, reliable, and recommended it for worldwide use in irrigation scheduling. The Hargreaves equation for ET_o is given by [21] as:

$$ET_o = 0.0023 R_a (T_{max} - T_{min})^{0.5} \left(\frac{T_{max} + T_{min}}{2} + 17.8 \right) \quad (3)$$

where, ET_o is the reference evapotranspiration (mm/day), R_a is the extra-terrestrial solar radiation (MJ m⁻² d⁻¹), T_{max} is maximum air temperature (°C) and T_{min} is minimum air temperature (T_{min}).

2.2.4. Piche evaporimeter (atmometer)

Existing evaporation data from piche evaporimeter measurements in the study area were converted to reference evapotranspiration [22], [23] by the equation:

$$ET_o = \alpha E_{pi} \rho(\sigma) \quad (4)$$

where,

α = a factor that considers the semi-protection of the piche evaporimeter from the solar radiation (= 0.27)

E_{pi} = the evaporation reading by piche evaporimeter (mm/day)

ρ(σ) = a prevailing temperature dependent factor (=2.41)

2.3. Data Analysis

The ET_o results estimated from the different methods were subjected to statistical regression analyses, considering the linear model. The analysis of the results was done by means of the following methods: the agreement or concordance index (d) as expressed in Equation (5) [7], [24], [25]; the confidence or performance index (c) stated as Equation (6) [26]; and the coefficient of correlation (r) and determination (r²).

$$d = 1 - \left[\frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \right] \quad (5)$$

where, d is the agreement or concordance index, P_i is the predicted ET_o by BC, HGRV and PEv methods, O_i is the ET_o value computed by the PM equation and \bar{O} is the mean of the observed values.

$$c = r \cdot d \quad (6)$$

where, c is the confidence or performance index and d is the Willmott's agreement or concordance index.

The criteria for interpreting the performance of the ET_o estimation methods are presented in Table 1.

3. RESULTS AND DISCUSSION

The reference evapotranspiration values from the various methods (Figure 3) showed a similar trend for each of the months under investigation. ET_o increased from January to March, then decreased progressively from March to August and rises again till it peaks in February and March. The piche evaporimeter method produced the highest ET_o values from January to April, and then November to December. This was followed by the Penman-Monteith method, Blaney Criddle and Hargreaves, respectively.

ET_o for Kaduna are not readily available but a study carried out by [3] for Kano, Nigeria, in the same region as Kaduna but a distance of 202 km away showed that Kano has its highest ET_o value of 12.5 mm/day, recorded in February, and the lowest value of 6.04 mm/day in August. These values are largely at variance with that of Kaduna, which measured 8.63 mm/day and 1.67 mm/day, under piche evaporimeter method, for the maximum and minimum values, respectively. A common trend in the results from both cities is that the highest ET_o occurred in February while the lowest occurred in August. Based [3], Kano is known to have higher

mean temperatures than Kaduna, and also lower relative humidity. For this reason the ET_o of Kaduna is expected to be lower because ET_o decreases with decrease in temperature and increase in humidity. A similar ET_o results of Zaria, Nigeria, 67 km away from Kaduna (within the same state and ecological zone), obtained by [27] and [28], during its 2008/2009 and 2009/2010 irrigation seasons showed that the highest ET_o (6.70 mm/day, 6.90 mm/day) occurred in February and March, respectively. These results are similar to that of Kaduna (6.23 mm/day and 6.43 mm/day) in February and March, respectively, using the Penman-Monteith method. The slightly higher values for the ET_o of Zaria were traced to the effects of higher wind speed for Zaria (229.3 km/day, 183.0 km/day) during these periods than for Kaduna (181.5 km/day, 165.0 km/day). Also, the sunshine hour durations for Zaria in the two seasons (9.6 hr, 9.0 hr) were higher than those of Kaduna (9.3 hr, 8.6 hr). An analysis of variance of the ET_o values among the different ET_o estimation methods showed that there was significant difference in the ET_o values among them ($F_{calc.} = 4.2278$, $F_{crit.} = 2.0666$, $p\text{-value} = 0.000482$). By implication, therefore, the ET_o values from the models are not statistically similar and each has to be evaluated for test of efficiency in the study area.

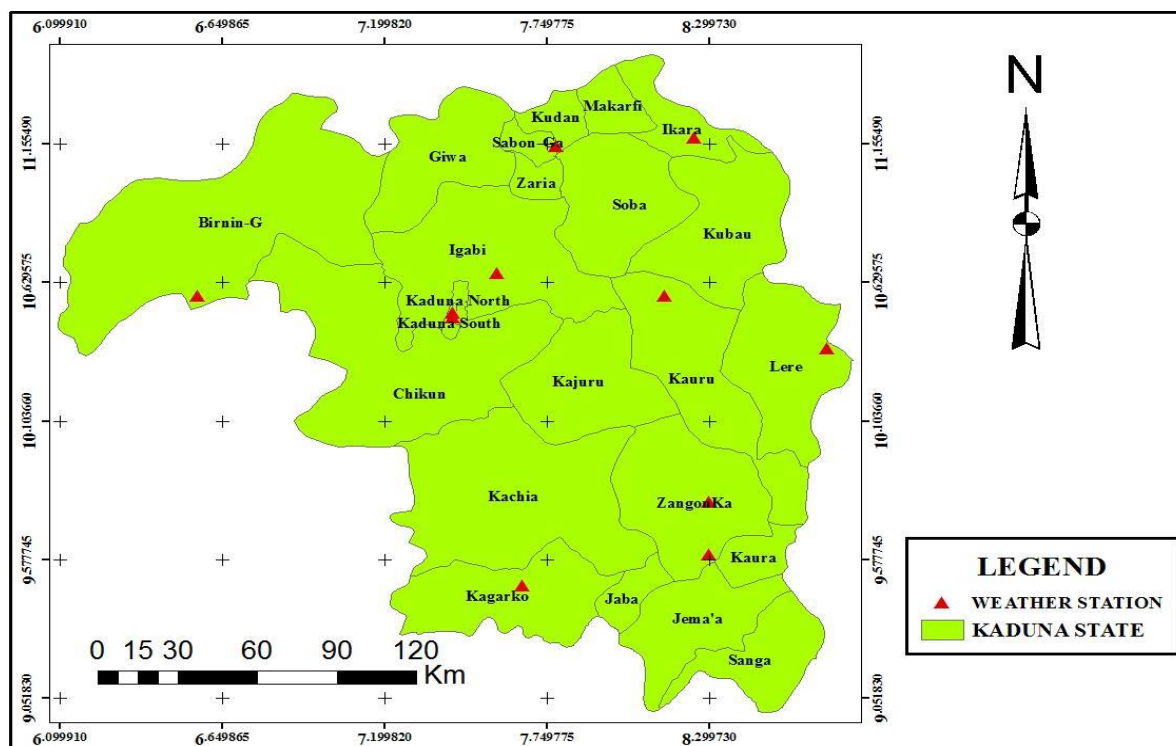


Fig. 1: Map of Kaduna showing weather stations including Kaduna North, Igabi and Kaduna South [13]

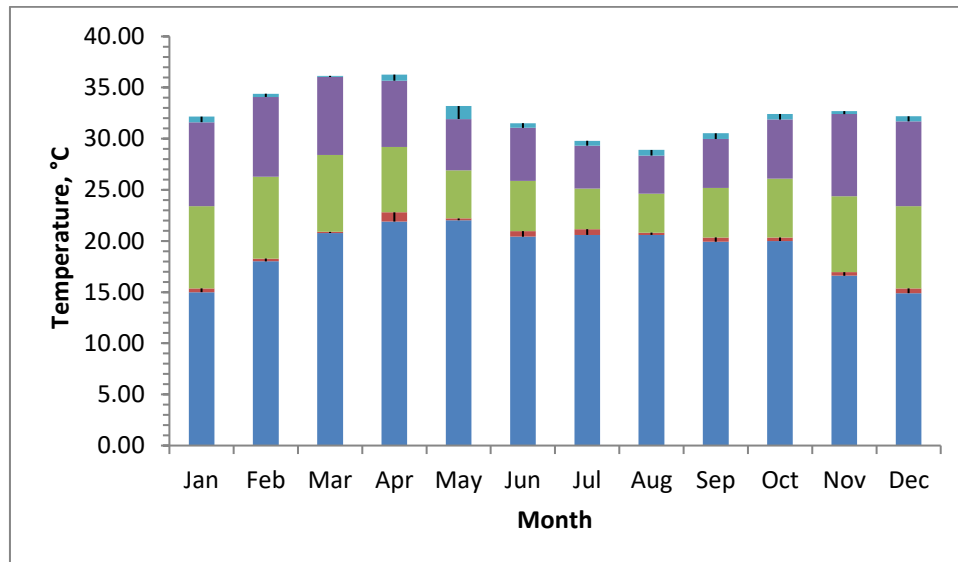


Fig2a: Mean monthly temperatures within Kaduna Central District, Nigeria

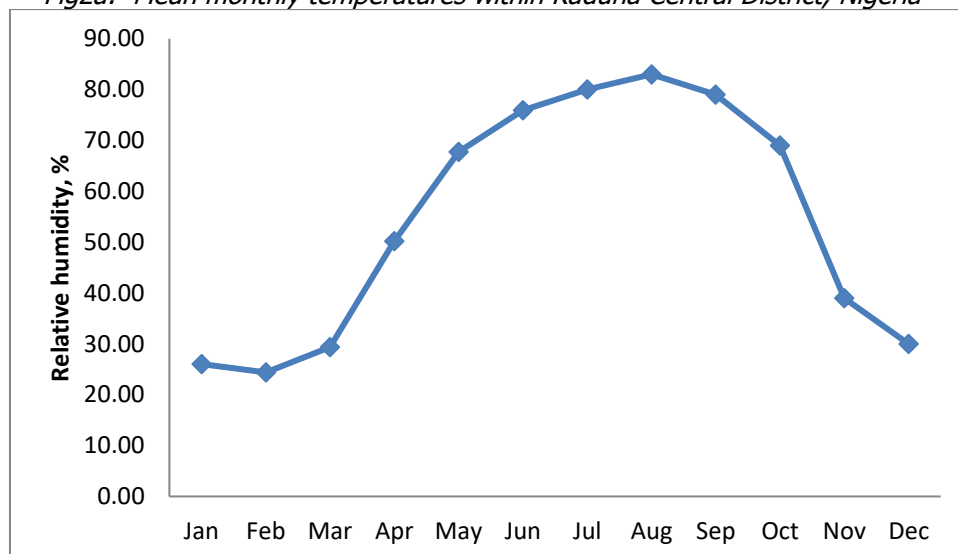


Fig. 2b: Mean monthly relative humidity within Kaduna Central District, Nigeria

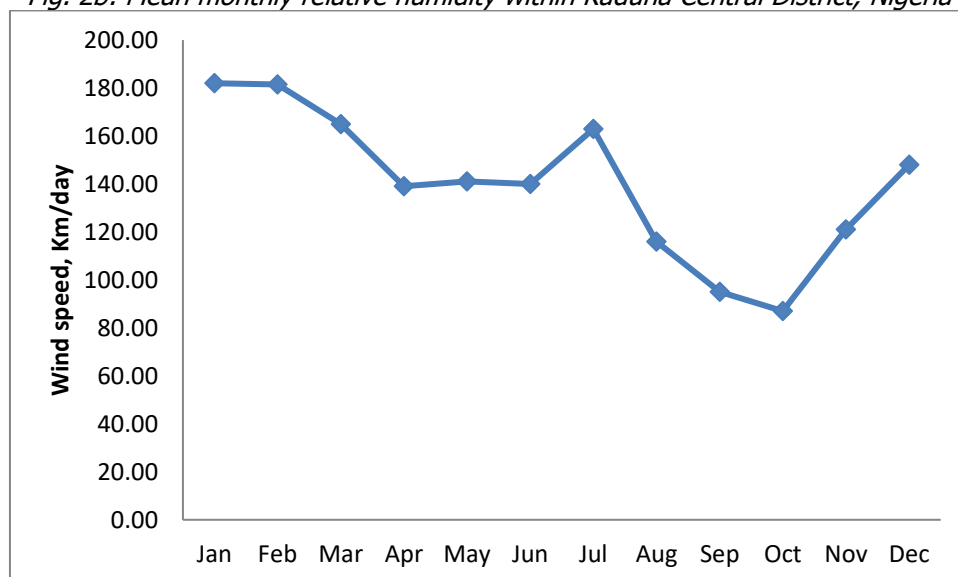


Fig. 2c: Mean monthly wind speed within Kaduna Central District, Nigeria

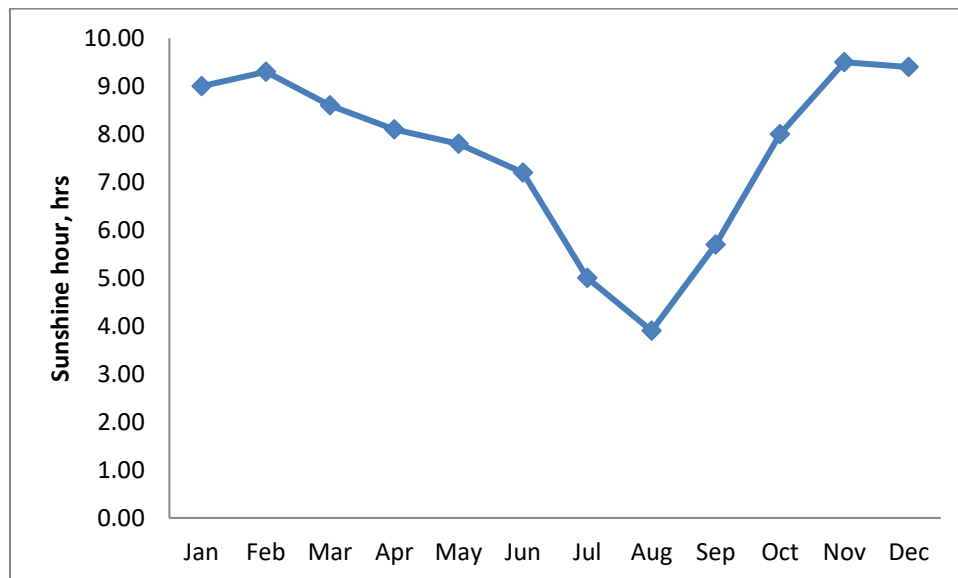


Figure 2d: Mean sunshine hour within Kaduna Central District (1986-2015)

Table 1: Criteria for interpreting different ET_o estimation methods by the confidence index, c and correlation coefficient, r

Confidence index, c	Performance rating
> 0.85	Excellent
$0.76 - 0.85$	Very good
$0.66 - 0.75$	Good
$0.61 - 0.65$	Median
$0.51 - 0.60$	Affordable
$0.41 - 0.50$	Bad
< 0.4	Terrible
Correlation coefficient, r	Precision
$0.9 - 1.0$	Almost perfect
$0.7 - 0.9$	Very high
$0.5 - 0.7$	High
$0.3 - 0.5$	Moderate
$0.1 - 0.3$	Low

Source: Camargo and Sentelhas [25]

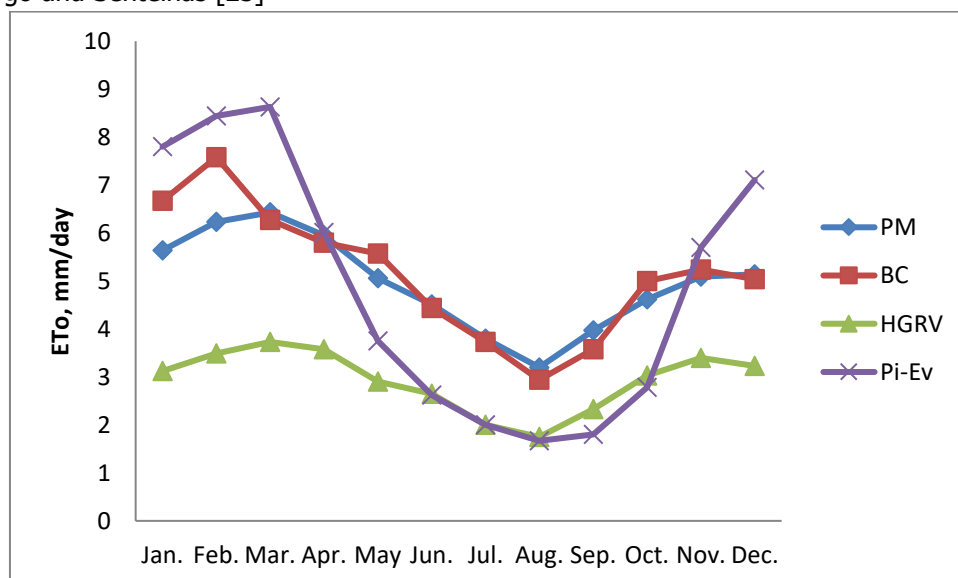


Fig. 3: Computed ET_o based on PM, BC, HGRV and PiEv methods

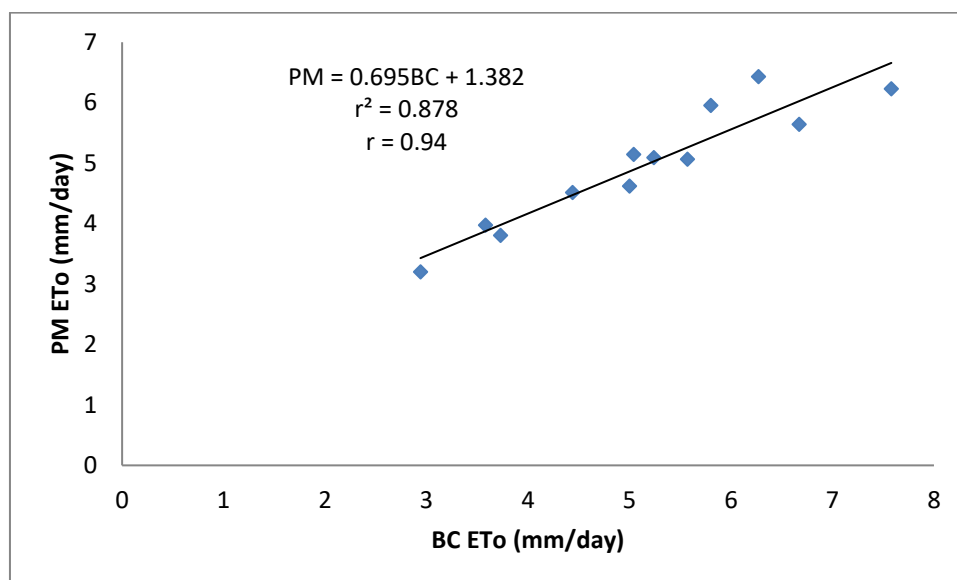


Fig. 4: Correlation between estimated ET₀ by PM and BC

Table 2: Concordance (d), correlation (r) and confidence (c) test values for the different methods with respect to Penman-Monteith method within Kaduna Central District

Methods	r	d	c
PM x BC	0.94	0.94	0.88
PM x HGRV	0.95	0.51	0.48
PM x PiEv	0.91	0.74	0.67

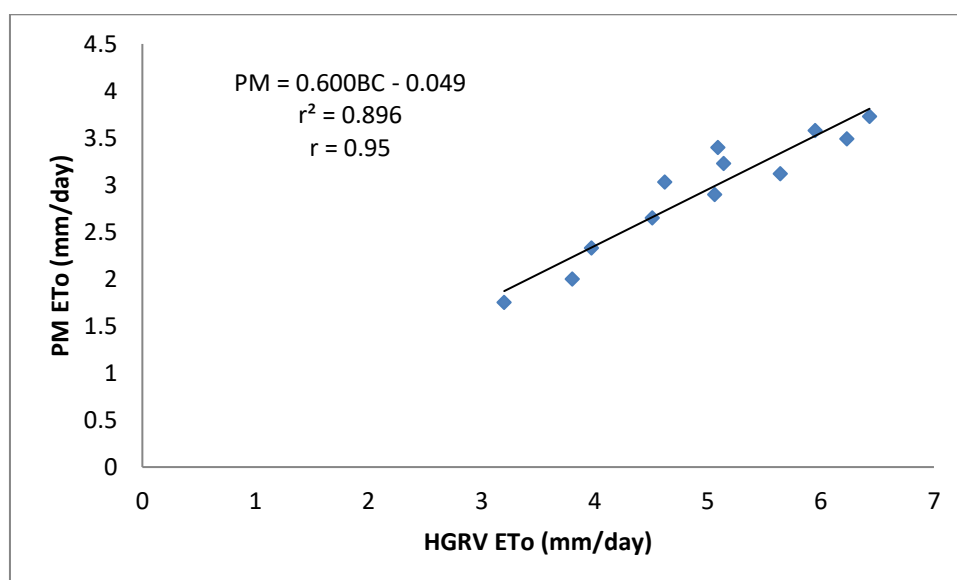


Fig. 5: Correlation between estimated ET₀ by PM and HGR

Correlation analyses between PM-ET₀ and each of BC-ET₀, HGRV-ET₀ and PiEv-ET₀ (Figures 4-6) are expressed in linear forms ($y = Ax + B$) and gave coefficients of determination, r^2 of 0.878, 0.896 and 0.835, respectively. Hence, the correlation coefficients, r are 0.94, 0.95 and 0.91, for BC, HGRV and PiEv, respectively.

The results of concordance (d), correlation (r) and confidence (c) tests for the different methods with respect to Penman-Monteith as standard, within Kaduna Central District, are presented in Table 2. The inference from the study is based on the confidence index. It shows that BC ($c = 0.88$, > 85) has an excellent performance in relation to PM in the study area.

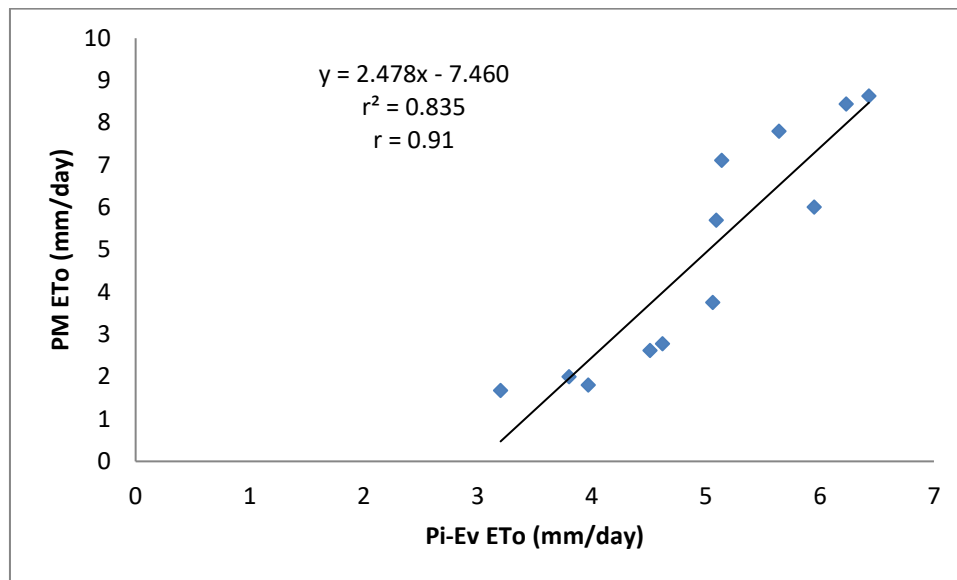


Fig. 6: Correlation between estimated ETo by PM and PiEv

The PM-PiEv relationship was just good ($c = 0.67$) while that of PM-HGRV was poor. In a similar study in Cerrado environment, Brazil, the BC method presented the best performance as compared to solar radiation and the Ivanov methods [29]. Hence, this study has shown that Blaney Criddle method for ET_o estimation will prove excellent in Kaduna Central District as an alternative to Penman Monteith if input parameters such as wind speed, relative humidity and solar radiation are not available; temperature data are the major data requirements.

4. CONCLUSION

Reference evapotranspiration rates were estimated within Kaduna Central District, Nigeria, given mean monthly climatic variables of thirty years (1986-2015) from three locations within the district, using four estimation methods which are: Penman-Monteith, Blaney Criddle, Hargreaves and Piche evaporimeter (atmometer). ET_o obtained from Penman-Monteith were used as the standard upon which the other three were evaluated and compared. The highest ET_o occurred in February, with the values of 6.38 mm/day, 6.25 mm/day and 8.6 mm/day for Penman-Monteith, Blaney Criddle and Piche evaporimeter methods, respectively. Hargreaves estimate was the variant, its highest occurring in March. In all the methods, the lowest ET_o values were obtained in August.

Blaney Criddle method gave the closest relationship with Penman-Monteith method based on statistical analysis by means of confidence index. Hence, Blaney Criddle method can be used for irrigation scheduling within Kaduna Central District, Nigeria with the

availability of monthly temperature data only, if there are not adequate data needed for Penman-Monteith estimation. A major limitation of this study is the unavailability of the needed data from other districts so as to have a broadened data base for making decisions on irrigation schedules in the region.

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