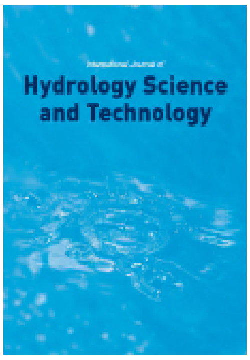

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Efficiency of indirect and estimated evapotranspiration methods in South Western Nigeria

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Efficiency of indirect and estimated evapotranspiration methods in South Western Nigeria

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Abstract: Evapotranspiration is the energy which drives the hydrologic cycle. The estimation of evapotranspiration is of utmost importance to irrigation projects as well as water resources, evaluation, planning and management. Various empirical models estimating evapotranspiration suits different basins in various degrees. This study determined the suitability of different evapotranspiration models for South Western Nigeria. These models were compared with measured evapotranspiration. Suitability of the models were determined from correlation coefficients, root mean square errors (RMSEs), efficiency test and volume error. In comparison with measured values, FAO Penman-Montieth had highest correlation coefficient (0.74), lowest RMSE value (27.26 mm/month), highest efficiency test value (0.40) and lowest volume error (0.26). The differences between the evapotranspiration values obtained from the empirical methods and the directly measured values are significant at α0.05. Some of the models overestimated while others underestimated evapotranspiration. This study will facilitate irrigation project planning and water resources management in South Western Nigeria.

Keywords: FAO Penman-Monteith method; class ‘A’ evaporation pan; Piche evaporimeter; water resources management.

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1 Introduction

Evapotranspiration is a natural occurrence through which water from the earth surfaces move to the atmosphere in vapour form. Evapotranspiration is important in hydrologic cycles and hence in hydrologic studies. Evaporation converts liquid from soil surfaces, water surfaces (such as lakes, ponds, wetlands and water bodies) to vapour (Zotarelli et al., 2015; Piri et al., 2020) and it is the bedrock of water transportation in the hydrologic cycle (Karlsson and Pomade, 2014). When this liquid-vapour conversion is done from the openings on the leaves (stomata) of plants, it is termed transpiration. The combination of these two processes (evaporation and transpiration) from the surfaces of vegetated soil is termed evapotranspiration. Evapotranspiration is important in the linkage of climate, hydrology and ecology because it modulates atmospheric temperature and moisture (Gharbia et al., 2018). Some of the factors influencing evaporation from soil surfaces and transpiration from plants include solar radiation, relative humidity, wind velocity, crop characteristics or resistance, cultivation practices, crop growth stage, heat storage capacity, roughness of the surface, reflection coefficient and soil cover (De Laat and Savenije, 1992; Zotarelli et al., 2015). Evaporation is also very much dependent on the amount of water present and the energy availability in the climatic region (Davie, 2008). Energy (which may be in form of heat, radiation or pressure) involved in evapotranspiration breaks the bond between liquid water molecules for conversion to vapour; thus facilitating its movement into the atmosphere (Fisher et al., 2011; Sivakumar, 2021). Water availability separates evapotranspiration into actual evaporation and potential evaporation. Potential evapotranspiration occurs in wet soil when the supply of water is unlimited while actual evaporation takes place when water supply is limited (Davie, 2008; Karlsson and Pomade, 2014; Peng et al., 2019). Potential evapotranspiration is the maximum amount of evaporation which can take place in ideal environments and under ideal conditions (Xiang et al., 2020). At perpetually wet conditions, potential evapotranspiration is always equal to the actual evapotranspiration. According to Davie (2008) and Fisher et al. (2011), for evapotranspiration to occur, there must be an energy drive, constant water supply and the conditions of the atmosphere must be dry enough to receive water in vapour form. Evapotranspiration is more influenced by atmospheric condition than by soil moisture conditions; since drought or dryness encourages increased evapotranspiration into the atmosphere from available soil moisture (Teuling et al., 2013).

The exact estimation or measurement of water use or evapotranspiration is of extreme importance in agriculture, irrigation water management (Anapalli et al., 2019), reservoir water management for water supply and distribution schemes as well as in basins' water balance studies. The importance of evapotranspiration estimation in the determination of water demand, crop growth and the balancing of hydrologic cycle cannot be overemphasised (Yassen et al., 2020), thus the increased pressure on water demand by different sectors necessitates the need for accurate evapotranspiration estimation (Kumar et al., 2012; Kumar and Kumar, 2017; Bhat et al., 2021). Evapotranspiration is employed for the estimation of crop water requirement (CWR) which is equally important for water resources planning and determination of irrigation water requirement (IWR). Evaporation can be measured or estimated from available data using different methods. Davie (2008) broadly classified these methods as:

1. direct micro metrological measurement which deals with the energy balance of the atmosphere and the various methods include the eddy fluctuation or correlation methods, the aerodynamic method and the Bowen method
2. the indirect measurements which varies from the use of evaporation tanks and pan, the use of atmometers and the use of evaporimeters or lysimeters.

Several models had as well been developed for the estimation of evapotranspiration; some of which are Thornthwaite 1948, FAO Penman-Monteith, Blaney Criddle, Hargreaves equation, Sine Curve method, Hamon equation, solar radiation method and the net radiation method. The choice of model for evapotranspiration estimation depends on the importance and potential control of the system being studied as well as on data availability (Fisher et al., 2011). The data requirements and equations for each of the methods differ as shown on Table 1. However, for this study, five estimation models (FAO Penman-Monteith, Blaney Criddle, Hamon, Thornthwaite and Hargreaves) were compared with two indirect methods (use of evaporation pan and piche evaporimeter) of evapotranspiration measurements.

Table 1 Comparison of each method in terms of the number of parameters required

Evapotranspiration methods	*FAO 56-PM*	*Thorth-waite*	*Hargr reaves*	*Hamon*	*Solar radiation*	*Net radiation*	*Blaney Criddle*	*Sine curve*
Variables								
Temperature	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
Humidity	Yes	-	-	-	Yes	Yes	-	-
Wind speed	Yes	-	-	-	-	-	-	-
Radiation	Yes	-	Yes	-	Yes	Yes	-	-
No. of daylight hours	-	Yes	-	Yes	Yes	Yes	Yes	-
Evaporation data	-	-	-	-	-	-	-	Yes
Saturated vapour pressure	Yes	-	-	-	-	-	-	-

Source: Alkaeed et al. (2006)

Some researchers had in the past churned out several studies on compared evapotranspiration estimation models. Jacobs et al. (2004) compared Turc, Makkink, Penman-Monteith Priestly-Taylor and Hargreaves model. It was concluded from the study that Priestly-Taylor and Penman-Monteith overestimated evapotranspiration, but Turc and Makkink models performed better for the Central Florida, USA climate. Lu et al. (2005) compared the use of Thorntwaite, Hamon, Hargreaves-Samani, Turc, Makkink and Priestly-Taylor models for evapotranspiration estimation in the humid climate of South Eastern United States. The Priestly-Taylor, Turc and Hamon methods were concluded to performed better than other potential evapotranspiration estimation methods. Alkaeed et al. (2006) compared six evapotranspiration methods for Itoshoma Penisula Area, Fukuoka, Japan. It was found from the study that Thornthwaite (which only needed temperature as the input) highly correlated with the FAO56 Penman Montieth equation. Acs et al. (2007) estimated actual evapotranspiration and soil water content from potential evapotranspiration during growing seasons in Hungary. Conclusion from the study suggested that areal distribution of annual evapotranspiration and annual soil water content are similar. Douglas et al. (2009) compared Turc and Priestly-Taylor models, but discovered better performance of the Priestly Taylor models for Florida. Similarly, Donohue et al. (2010) researched the performances of Penman-Monteith, Morton point, Morton areal, Priestly-Taylor and Thorntwiate models for Australia. Penman Monteith model was concluded to perform better than others for arid climates in Australia. Li et al. (2016) evaluated and compared the Penman-Monteith, Blaney Criddle, Hargreaves, Priestly Taylor, Dalton and Shuttleworth models for evapotranspiration estimation, but came to the conclusion that Penman, Shuttleworth and Priestly Taylor Models are more reliable and accurate for evapotranspiration estimation in arid regions. However, none of these researches are specific on the adoption of suitable evapotranspiration model for prevalent climatic conditions in South Western Nigeria. This research therefore aims to determine the suitability of five commonly used empirical methods for the estimation of evapotranspiration in comparison to measured evapotranspiration from piche evaporimeter and class 'A' evapotranspiration pans.

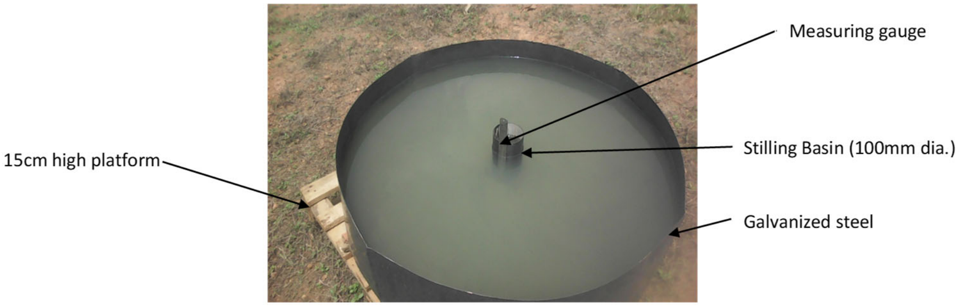
2 Methodology

Nineteen years (1999–2017) monthly evapotranspiration data measured by piche evaporimeter were obtained from meteorological stations in South Western Nigeria. The stations were located at Cocoa Research Institute of Nigeria, Ibadan (CRIN, Lat 7°13'N, Longitude 3°52'E and 134 m above mean sea level) and the University of Ibadan, Nigeria (Lat 7°26'N, Longitude 3°53'E and 209 m above sea level). To provide complete data for the year 2018, daily evapotranspiration values were obtained for the entire year using a constructed standard class 'A' evaporation tank. This was done to make comparison with monthly potential evapotranspiration values estimated for the past 19 years (1999-2017) using available meteorological data. Data on average monthly minimum and maximum temperature (measured by the minimum and maximum thermometer), relative humidity (measured from sling psychrometer) and wind velocity (measured with cup anemometer), mean sunshine hours (n) (recorded by Casella Campbell Stokes sunshine recorder) were as well obtained from the aforementioned stations. Data on extra-terrestrial radiation (R_a) ($MJ/m^2/day$) and mean daylight hours (N) were obtained from Allen et al. (1998) for northern hemisphere at latitudes between 60 and 80 N; due to none availability of such data at the meteorological stations. These meteorological data were employed for the estimation of potential evapotranspiration from the chosen models.

2.1 Design, fabrication and installation of class 'A' evaporation tank

The class 'A' evaporation tank with diameter of 1,270 mm and height of 254 mm was constructed according to specification using galvanised steel (Figure 1). It was equipped with a stilling well of 100 mm diameter and 229 mm height. The stilling well serves to prevent ripples production within the tank. The tank was covered with wire nettings to prevent other factors from contributing to water losses. The evaporation pan was placed on a levelled wooden pallet (150 mm height from the ground level), away from obstacles such as trees and fences and in a grassy environment. The pan was installed in a fenced area; where no disturbance was allowed. The daily changes in water level were measured from a steel gauge attached to the stilling well at 8 am and 8 pm daily. The water levels were consistently noted before and after every rainfall event. In the absence of rainfall, the water was refilled manually.

Figure 1 An installed evaporation pan for the measurement of daily evaporation (mm/day) (see online version for colours)



2.2 Empirical estimation of potential evapotranspiration

Monthly potential evapotranspiration was calculated from five different empirical models which are the FAO Penman-Monteith, Thornthwaite, Hamon, Blaney Criddle and Hargreaves respectively given as equations (1) through (15). The FAO Penman-Monteith equation according Allen et al. (1998) is given as:

$$PET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1+0.34\,U_2)} \tag{1a}$$

$$R_s = \left(a_s + b_s\frac{n}{N}\right)R_a \tag{1b}$$

$$R_{so} = \left(0.75 + 2z * 10^{-5}\right)R_a \tag{1c}$$

$$R_{ns} = (1-\alpha)R_s \tag{1d}$$

$$R_{nl} = \sigma\left[\frac{(T_{\max k})^4 + (T_{\min k})^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \tag{1e}$$

$$G = 0.14\left(T_{MONTH\ i} - T_{MONTH\ I-1}\right) \tag{1f}$$

R_n = average net radiation at the crop surface (MJ/m^2/day), G is soil flux density (MJ/m^2/day), ɣ = psychometric constant (kPa/°C) = 0.067, U_2 = Wind velocity at 2 m height (m/s), e_s = saturation vapour pressure (kPa), e_a = actual vapour pressure (kPa), $e_s - e_a$ = Saturation vapour pressure deficit (kPa), T = air temperature at 2m height (°C), Δ = slope vapour pressure curve (kPa/°C).

R_s is the incoming solar radiation; obtained from the relationship between angstrom values $a_s = 0.25$, $b_s = 0.5$ and R_a [equation 1(b)]. R_{so} is the clear sky solar radiation obtained from elevation (z m) and R_a [equation 1(c)]. R_{ns} is the shortwave radiation; calculated from albedo (α) and R_s [equation 1(e)]. R_{nl} was estimated from equation (1e). σ is Stefan Boltzmann constant = 4.903×10^{-9} MJ/K^4/m^2/day, $T_{\max k}$ and $T_{\min k}$ are absolute values of monthly minimum and maximum temperatures. R_n was calculated as the difference between the net long wave radiation (R_{nl}) and net shortwave radiation (R_{ns}). The soil flux (G) was obtained from equation (1f). $T_{MONTH\,i}$ is the mean temperature of the present month and $T_{MONTH\,i-1}$ is the mean temperature of the previous month in °C. 0.408 is a constant which converts the unit MJ/m^2/day to mm/day.

$$e_s = e^o\left(T_{mean}\right) = 0.611\exp\left(\frac{17.27T_{mean}}{T_{mean}+237.3}\right) \tag{2}$$

$$\Delta = \frac{4098e_s}{\left(T+237.3\right)^2} \tag{3}$$

$$e_{a_1} = \frac{e^o\left(T_{\min}\right)\times RH_{\max}}{100} \tag{4}$$

$$e_{a_1} = \frac{e^o\left(T_{\max}\right)\times RH_{\min}}{100} \tag{5}$$

$$e_a = \frac{e_{a_1}+e_{a_2}}{2} \tag{6}$$

$RH_{\max}$ = maximum relative humidity (%), $RH_{\min}$ = minimum relative humidity (%). $T_{\min}$, $T_{\max}$ and T_{mean} are the monthly minimum, maximum and mean temperature respectively in °C.

The modified Thorntwaite (1948) equation is given as:

$$PET = 16\times\left(\frac{L}{12}\right)\times\left(\frac{N}{30}\right)\times\left(\frac{10T}{I}\right)^a \tag{7}$$

$$I = \sum_{I=1}^{12}\left(\frac{T}{5}\right)^{1.514} \tag{8}$$

$$a = 6.75\times10^{-7}I^3 - 7.71\times10^{-5}I^2 + 1.792\times10^{-3}I + 0.49239 \tag{9}$$

T = average monthly temperature (°C), L = monthly length of daytime in hrs, N is the number of days in the month.

The Hamon method according to Haith and Shoemaker (1987) is given as:

$$ET_0 = \frac{2.1 * H_t^2 * E_s}{\left(T_{mean} + 273.2\right)} \tag{10}$$

E_s saturated vapour pressure

$$E_s(kPa) = \frac{e^0\left(T_{\max}\right) + e^0\left(T_{\min}\right)}{2} \tag{11}$$

$$e^0\left(T_{\max}\right) = 0.6108e^{\left(\frac{1.727 * T_{\max}}{237.3 + T_{\max}}\right)} \tag{12}$$

$$e^0\left(T_{\min}\right) = 0.6108e^{\left(\frac{1.727 * T_{\min}}{237.3 + T_{\min}}\right)} \tag{13}$$

H_t is the average number of daylight hours per day.

The Blaney Criddle method of estimating evapotranspiration (mm/day) is given according to Ponce (1989) as:

$$ET = P(0.46T + 8) \tag{14}$$

P = mean daily percentage of the total annual day time, T = average daily temperature (°C).

Hargreaves models of evapotranspiration estimation according to Hargreaves and Samani (1985) (mm/month) is given as

$$ET = 0.0023\left(T_m + 17.8\right)\left(\sqrt{T_{\max} - T_{\min}}\right)R_a \tag{15}$$

T_m is the average daily air temperature (°C), $T_{\max}$ and $T_{\min}$ are the maximum and minimum temperature respectively (°C) and R_a is the extra-terrestrial radiation (MJ/m^2/day) which is estimated from location and time of the year details.

The relationships between the different evapotranspiration values were investigated by correlation coefficients [equation (16)], root mean square error (RMSE) [equation (17)], efficiency test [equation (18)], volume error test [equation (19)] and analysis of variance at 95% level of confidence.

The correlation coefficient (r)

$$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x - x'}{s_x}\right)\left(\frac{y - y'}{s_y}\right) \tag{16}$$

The RMSE

$$RMSE = \sqrt{1/n\sum_{i=1}^{n}(P - O)^2} \tag{17}$$

The efficiency test (Eff)

$$Eff = 1 - \frac{\sum\left(Q_{obs} - Q_{sim}\right)^2}{\sum\left(Q_{obs} - Q_{obs\ mean}\right)^2} \tag{18}$$

The volume error (Vol Err)

$$Vol\ Err = \left| \frac{\left(\sum Q_{obs} - Q_{sim}\right)}{Q_{obs}} \right| \tag{19}$$

3 Results and discussion

Nineteen years' evapotranspiration values ranged from 25.3 to 202.1 mm/month for FAO Penman-Monteith method. Evapotranspiration estimated from Thorntwaite's, Blaney Criddle, Hamon and Hargreaves ranged from 54 to 176 mm/month, 133 to 178 mm/month, 72 to 131 mm/month and 124 to 456 mm/month respectively. Measured evapotranspiration ranged from 5.5 to 187 mm/month. Highest evapotranspiration for the sampled years were mostly experienced in January, February, March and December; which are the peak dry periods annually. Hargreaves, Blaney Criddle and Thorntwaite overestimated evapotranspiration while Hamon model underestimated the same.

Table 2 Correlation values of evapotranspiration data

	Penman	*Thorntwaite*	*Blaney*	*Hamon's*	*Hargreaves*	*Measured*
FAO Penman	1					
Thorntwaite	0.23	1				
Blaney Criddle	0.14	0.85	1			
Hamon's method	0.22	0.93	0.94	1		
Hargreaves	–0.06	–0.10	–0.10	–0.01	1	
Measured PET	0.75	0.15	0.04	0.15	0.08	1

Table 3 Error values of evapotranspiration

	FAO Penman-Monteith	*Thorntwaite*	*Blaney Criddle*	*Hamon*	*Hargreaves*
RMSE	27.26	41.54	86.44	39.23	237.61
Efficiency test	0.40	–0.39	–5.01	–0.24	–44.43
Vol. error	0.26	0.46	1.04	0.44	2.97

The correlation coefficients, RMSE, volume error and efficiency values were computed to compare the measured and estimated evapotranspiration as shown on Tables 2 and 3. Comparison of evapotranspiration obtained from FAO Penman-Montieth model and piche evaporimeter resulted in the highest correlation coefficient (0.74), lowest RMSE value (27.26 mm/month), highest efficiency value (0.40) and lowest volume error (0.26 mm/month). The Hargreaves model is the least efficient evapotranspiration estimation method for South Western Nigeria, since it resulted in the lowest correlation coefficient (0.08), highest RMSE (237.61 mm/month), lowest efficiency (–44.43) and the highest volume error (2.97 mm/month) as shown on Tables 2 and 3. The correlation between estimated evapotranspiration from Thorntwaite, Hamon and Blaney Criddle are greater than 0.5, but lower than 0.5 when compared with values from FAO Penman-Moteith and the indirect measurement methods. Figures 2 through 6 compare the five evapotranspiration estimation models with the measured values. These further confirm the poor correlation between the estimated and measured evapotranspiration. Only values obtained from FAO Penman-Montieth equation correlated satisfactorily with measured evapotranspiration ($R^2 = 0.56$ and $R = 0.75$). The differences between the estimated and indirectly measured evapotranspiration are statistically significant, since $P << 0.05$ (Table 4). These differences were confirmed from the least significant difference (LSD) post hoc test.

Figure 2 Comparison of measured evapotranspiration and Throntwaite's (see online version for colours)

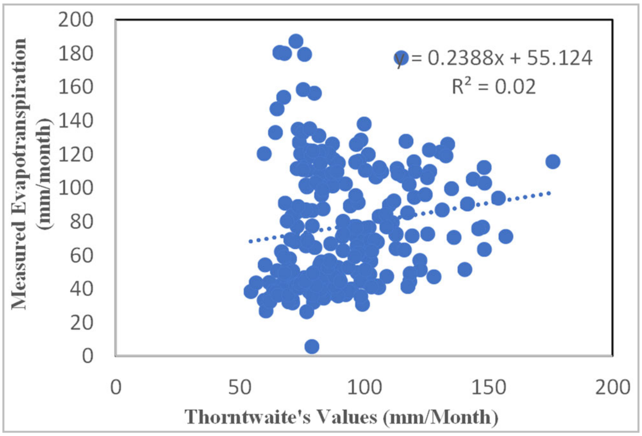


Figure 3 Measured evapotransiration and Blaney Criddle (see online version for colours)

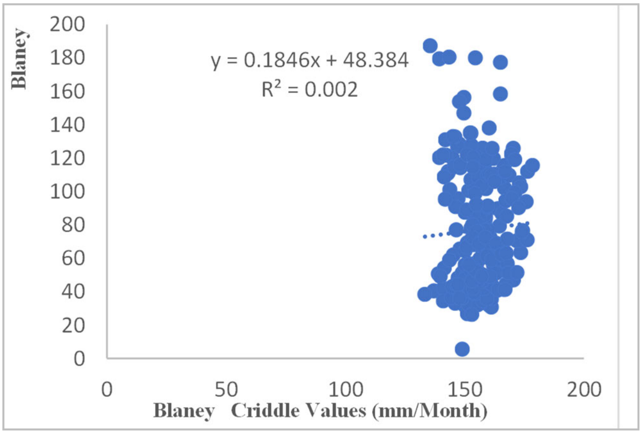


Figure 4 Measured evapotranspiration and Hamon's method (see online version for colours)

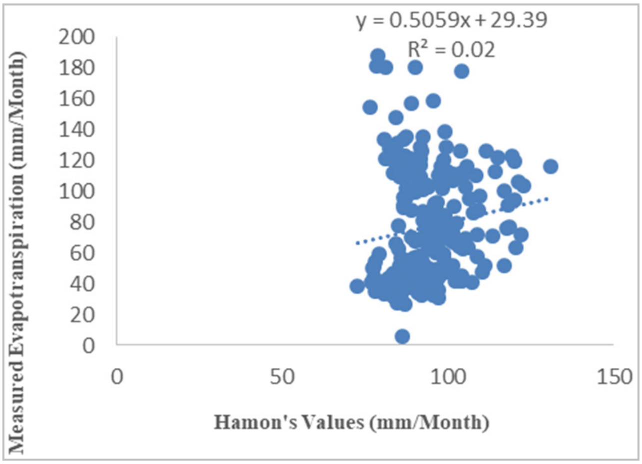


Figure 5 FAO Penman Montheith and measured evapotranspiration (see online version for colours)

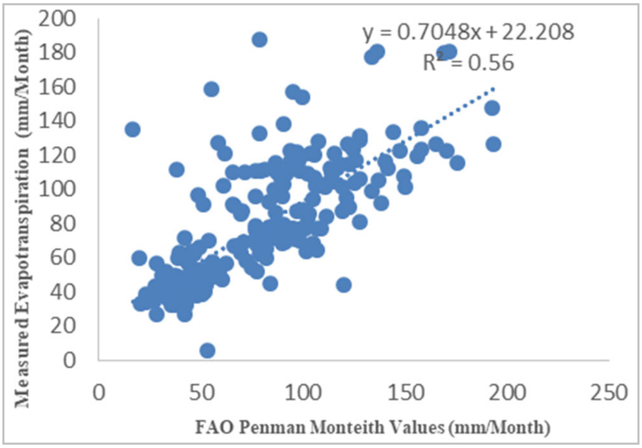


Figure 6 Hargreaves and measured evapotranspiration (see online version for colours)

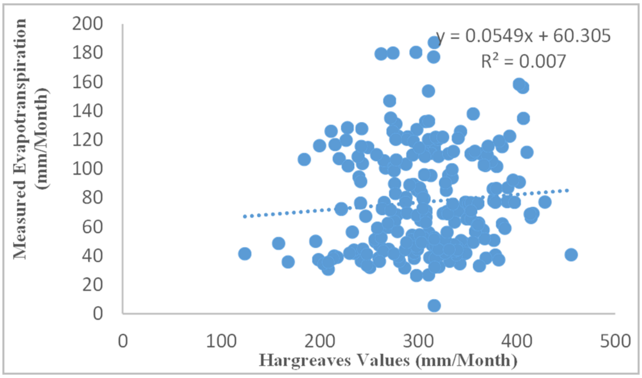


Table 4 Analysis of variance for evapotranspiration data

Source of variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between methods	8,410,623.92	4	2,102,656	2,099.8	0	2.37
Within methods	1,196,625.19	1,195	1,001.36			
Total	9,607,249.1	1,199				

Table 5 Correlation values of evapotranspiration data for year 2018

	Penman	*Thorntwaite*	*Blaney*	*Hamon*	*Hargreaves*	*Measured*
FAO Penman	1					
Thorntwaite	0.38	1				
Blaney Criddle	0.39	0.98	1			
Hamon	0.61	0.89	0.80	1		
Hargreaves	0.91	0.59	0.58	0.78	1	
Measured PET	0.85	0.55	0.55	0.73	0.89	1

Table 6 Correlation values of evapotranspiration data for year 2000

	Penman	*Thorntwaite*	*Blaney*	*Hamon*	*Hargreaves*	*Measured*
FAO Penman	1					
Thorntwaite	0.33	1				
Blaney Criddle	0.001	0.86	1			
Hamon	0.27	0.97	0.94	1		
Hargreaves	-0.13	0.0005	0.04	0.08	1	
Measured PET	0.96	0.41	0.11	0.35	-0.18	1

Piche evaporimeter can be slightly inaccurate in the measurements of evapotranspiration because of its quick responses to wind and its slow responses to net radiation; which are part of the factors affecting evapotranspiration (De Laat and Savenije, 1992). To verify these claims, the adjusted monthly evapotranspiration values from piche evaporimeter and class ‘A’ evaporation pan were compared with estimated monthly evapotranspiration for years 2000 and 2018. The values 0.85, 0.55, 0.55, 0.73 and 0.89 correlated measured evapotranspiration (using class ‘A’ evaporation pan) with the estimated values from FAO Penman-Monteith, Thornthwaite, Blaney Criddle, Hamon and Hargreaves respectively for the year 2018, as shown on Table 5. Hamon and Hargreaves highly correlated with other models while Thorntwiate and Blaney Criddle correlated poorly with Penman. However, the evapotranspiration measured by piche evaporimeter (considering the year 2000) poorly correlated with some of the estimated evapotranspiration values (Table 6). The correlation values are 0.95, 0.41, 0.11, 0.35 and –0.17 for the respective evapotranspiration models tested. Measured evapotranspiration values from piche evaporimeter compared favourably with penman values, but not with values estimated from other models. The relatively improved correlations between the measured and empirically estimated evapotranspiration indicate good performance of the class ‘A’ pan evaporation tank. Figures 7 and 8 compare the evapotranspiration obtained from FAO Penman-Monteith models and evapotranspiration from pan and piche evaporimeter respectively. The R^2 values for the respective comparison are 0.72 and 0.91. These substantiate the claims of De Laat and Savenije, (1992) on piche evaporimeter.

The Hargreaves model performed least and FAO Penman-Monteith model is most efficient for the estimation of evapotranspiration in South Western Nigeria. These results are in line with Alkeed et al. (2006) who attributed the differences in the evapotranspiration values obtained annually and from different models to seasonal fluctuations in the variables applied for each of the methods. The strong correlation between the FAO Penman-Monteith and measured evapotranspiration values supports the choice of FAO Penman-Monteith equation for estimation of evapotranspiration in South Western Nigeria when the use of measuring apparatus is neither feasible nor available.

Figure 7 FAO Penman Montheith and measured pan evapotranspiration for 2018 (see online version for colours)

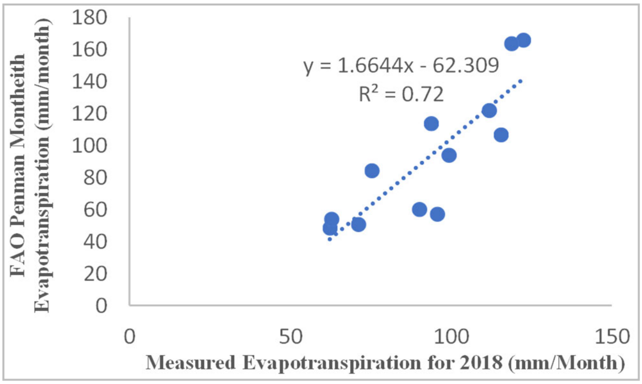
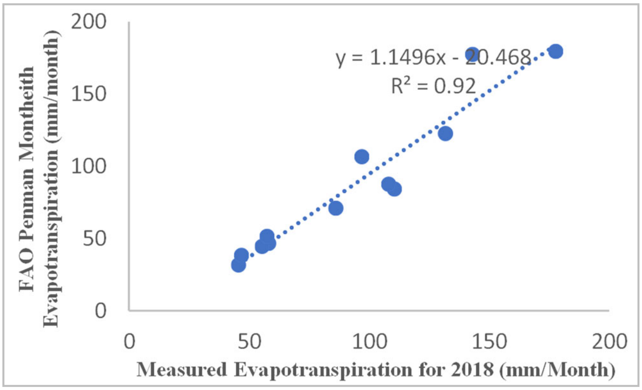


Figure 8 FAO Penman Montheith and measured piche evapotranspiration for 2000 (see online version for colours)



4 Conclusions

Evapotranspiration values estimated from 19 years' meteorological data using five different empirical equations were compared with directly measured values from piche and class 'A' pan evaporimeter. The study revealed that an efficiently constructed and adequately installed class 'A' evaporation pan can be suitably adopted for measurement of evapotranspiration. The piche evaporimeter, though with slight limitations can also be used for measurements of evapotranspiration. Hargreaves, Blaney Criddle and Thorntwaite overestimated evapotranspiration while the Hamon model underestimated the same.

In conclusion, the use of Hargreaves, Blaney Criddle, Thorntwaite and Hamon models are not supported for the estimation of evapotranspiration in South Western Nigeria. These methods are not suitable for the prevalent climatic conditions; because they gave poor performances in the comparisons made. Comparison of measured and estimated evapotranspiration supported use of FAO Penman-Monteith empirical equation as the most efficient model for evapotranspiration estimation in South Western Nigeria. FAO penman Monteith resulted in the highest correlation coefficient (R), R^2, efficiency value, lowest RMSE and lowest volume error. The evapotranspiration values obtained from the FAO Penman-Monteith equation is therefore well supported for use in basins within the South Western parts of Nigeria; when evapotranspiration data are not available or where measurements of evapotranspiration are not feasible. The results of this study are of extreme importance in water resources planning, management and usage as well as in agricultural and irrigation water management.

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