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# VALIDATION OF SOME ET MODELS WITH MEASUREMENT OF POTENTIAL EVAPOTRANSPIRATION IN A TROPICAL STATION, AKURE, SOUTH-WESTERN NIGERIA, USING A CONSTRUCTED LYSIMETER

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**ABSTRACT**

The objective of this study is to validate diurnal ET estimates by some models using the in-situ measurements obtained from the locally constructed lysimeter evapotranspiration model A classical evapotranspirometer (Lysimeter) for evapotranspiration (ET) measurement was designed, constructed and installed at University observatory at the Federal University of Technology, Akure (Longitude 5$^{o}$ 18'E, Latitude 7$^{o}$ 8'N). This was done so as to have the required input parameters for the evaluation of the models from the observatory where the constructed lysimeter was kept. The lysimeter was kept running for six months on diurnal timescale. In addition, estimation of ET was carried out by the evaluation of some models for the same period. The methods used include: Advection-Aridity (AA), Priestley–Taylor, Thornthwaite, Makkink, Granger and Gray (GG) models, and Penman combination. The ET data obtained from the Lysimeter were used to validate the results of the evaluated models for the same station. The simulated results were compared with the ET data from the in-situ measurement obtained from the locally constructed lysimeter. The coefficient of determination for all the models were significantly high (0.61-0.98) except Thornthwaite that had the lowest $R^2$ (0.04). The level of accuracy was determined by calculating the root mean square error (RMSE); the lowest RMSE was found for Priestly-Taylor (4.10) while the rest ranged from 22.13 for Makkink to 61.13 for GG method. The mean values of ET estimates ranged from 138.21mm/day to 189.19 for Penman Combination; Priestly Taylor had 138.21mm/day, which was the nearest mean value to the in-situ value found to be 137.14mm/day. The lysimeter values were underestimated consistently by AA method by 19.25% while it was largely overestimated by Penman Combination and GG methods by 75% and 45% respectively. From the above, it was found that Taylor has the highest determination coefficient of 0.98 and the least error of 4.10, hence, it can be concluded that the ET values by the Lysimeter can be well predicted by the Priestley-Taylor model with good accuracy, taking into consideration the lysimeter sources of error.

**Key words**: Validation, Potential evapotranspiration, lysimeter, models, construction.

## INTRODUCTION

Evapotranspiration is a process involving the combination of two separate processes often referred to as Evaporation and Transpiration. The process is used by hydrologists, agriculturalists and environmentalists to quantify the amount of water loss into the atmosphere from a vegetated surface through the combined processes of evaporation from top soil or water surfaces and from plant tissues through transpiration (Gulliver *et al*., 2010). It is a complex process because it depends on several weather factors, such as temperature, radiation, humidity, wind speed, including type and growth stage of the crop. The relevance of evapotranspiration (ET) in other fields is enormous and wide. Bautista and Bautista (2009) reported that information about evapotranspiration is important for the understanding of the various natural communities (Monteith, 1964, 1965; Mielkick *et al*., 2005); for the irrigation scheduling in crops (Slabbers, 1977; Wu, 1977; Stefano and Ferro, 1997; Garcia *et al*., 2007) and for forestry (Calder, 1977). In addition, the knowledge and the measurement impact of the modification of the dynamics of plant cover over the evolution of ET and the energy balance at the earth surface is relevant to the understanding of the ecohydrological changes of the environment (Cooper *et al*., 2006; Prater and

DeLucia, 2006). Measurement of ET is categorized into two, namely direct and indirect (Alizadeh and Kamali, 2007). There are several methods used to determine ET which are classified as direct and indirect; while the direct method involves the use of instrumentation and simple device, the indirect utilizes climatic and environmental factors and some other physiological parameters of the plant/crop at different stages to develop models which can be used to determine evapotranspiration. Some of the direct methods include micrometeorological approaches (e.g. eddy correlation and Bowen ratio energy balance), weighing lysimeter, water balance methods, and aerodynamic methods. Yongqiang *et al*. (2002) reported the various applications of different category of lysimeters, and according to him, the weighing lysimeter has become the standard instrument for measuring plant transpiration and soil evaporation (Prueger *et.al.* 1997; Young *et al*., 1997; Yang *et al*., 2000) while large-scale lysimeter have been used to measure daily ET accurately (Chen, 1997; Liu *et al*., 1998). Also Microlysimeters have been used to determine daily soil evaporation with minimum disturbance of the soil (Ham *et al*., 1990; Daamen *et al*., 1993; Sepaskhah and Ilampour, 1995; Wang and Liu, 1997; Jara *et al*., 1998). A lysimeter is a tank of a given size that is entrenched in soil and water, giving a measurable input and output values.

Pan evaporation is also commonly used for the estimation of evaporation, E; popularly used in American and some Asian countries and in Nigeria, where this study is being carried out (Ogolo, 2010).

The objective of this study is to carry out an in-situ measurement of ET using a locally constructed lysimeter in the Department of Physics of the Federal University of Technology, Akure, Nigeria and then compare the ET measurements with the simulated ET values and further use to verify some models for calculating evapotranspiration for Akure.

## MATERIALS AND METHODS

### Lysimeter construction

The constructed lysimeter (Fig 1) consists of an inner container filled with soil and retaining walls (an outer container) as well as special device for measuring percolation. The materials used for this Lysimeter are two emulsion paint containers with lids, tank connectors (outer threads), plastic elbow connector (thread to compression), pipe inserts, two plastic funnels, poly washers, leak sealant, collection vessels, fabricated measuring tube (rain gauge) from the glass blowing workshop of the Federal University of Technology, Akure. Leaks were tested for by filling the supported tank 1/3$^{rd}$ full of water since it would be difficult to test for leaks after installation.

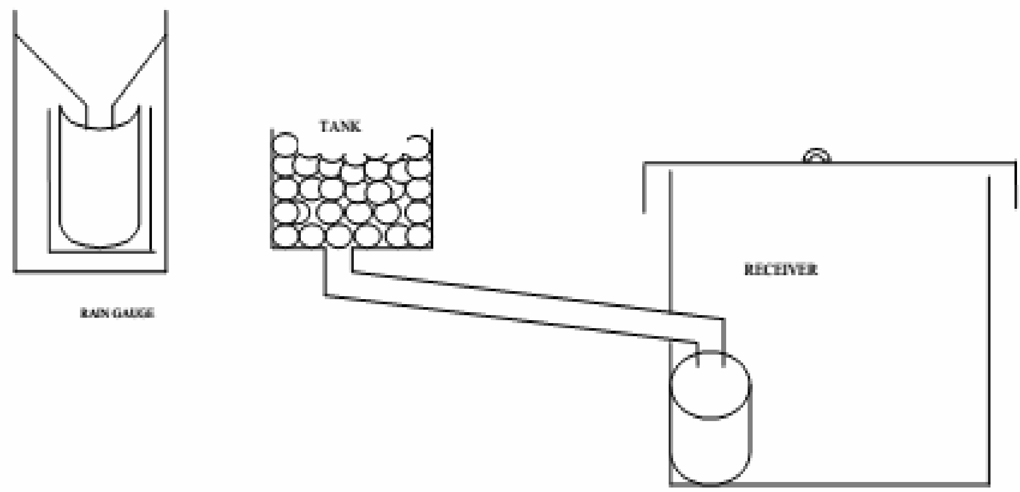


**Figure 1: Schematic Diagram of the Constructed Lysimeter**

## Installation and Site Description

The location is near the Federal University of Technology Akure meteorological observatory station, Ondo State, Nigeria (Longitude 5$^o$ 18'E, Latitude 7$^o$ 8'N), 100ft elevation. Akure is located in the tropical rainforest region in Nigeria. Akure experiences an annual rainfall of 123.0mm and annual water loss is about 2.64mm. It is characterized with 69.9% of relative humidity annually. Akure experiences an annual receipt of solar radiation of about 16.6 Mj/m$^2$ and having an annual temperature of about 223.7$^0$C.

The turf was cut and removed and a good piece selected for the lysimeter, protected to avoid drying out. Holes were excavated to receive the tank and receiver and a narrow trench dug between. Distance apart is 70.00cm (though distance between the receiver and tank is not important). A slight fall was kept between the receiver and the tank to allow proper drainage. The tank was positioned and levelled off about 1cm above the surrounding soil surface. Local soil in the area was used to fill up the tank. The receiver was well covered by strong lids to avoid surface water entrance. Rough measurements began about three (3) days after the installation

## Calculation of Potential Evapotranspiration

Weighing lysimeters are used to measure daily crop ET rates by applying simple water-balance principles. In this connection a spread sheet is used for entry of daily readings of water added, rainfall and percolate. All the calculations necessary are later computed for the potential evapotranspiration. If the soil and the vegetation are confined within a small tank (the Lysimeter) and measurements are made of the water inputs (Rainfall R and Additional water A) and output (percolated water P) collected in the receiver, then Potential Evapotranspiration (PE) can be estimated (Ayoade, 1983) in the following equation:

PE = R + A – P. (1)

Both P and A are accurate measurements which are independent of the rainfall measurement (Hansen, 1984).

## Estimation of Evapotranspiration using the Empirical Technique.

The ET was also determined for the same station by evaluating some models which are described below. Such methods include: The Penman combination method (PCM), Advection-Aridity model (AA), Granger and Grey model (GG), Makkink (Hansen) model, Thornthwaite and Priestley-Taylor.

### Combination (Penman) Model

Penman combination (1948) equation is formed as a result of combination of radiation term and aerodynamic term which is given as follow:

$$ET_p = \frac{\Delta Q_n + \gamma E_a}{\Delta + \gamma} \qquad (2)$$

Where $\Delta = \dfrac{4098 e_{sa}}{(T_a + 237.3)^2}$ and

$$\gamma = \frac{1615 P_a}{2.49(10)^6 - 2.13(10)^3 T_a}$$

$P_a = 1013 - 0.1152h + 5.44(10)^{-6}h^2$; $e_{sa} = \exp k$ (mbar)

And $k = \dfrac{19.08T_a + 429.4}{T_a + 237.3}$

$\Delta$ = Slope of the saturation vapour pressure versus temperature curve at air temperature, $T_a$ (mbar/$^o$C), $Q_n$ = net radiation (mm/day), $\gamma$ = psychrometric constant (mbar/$^o$C), $E_a$ = aerodynamic term (drying power) = $f$ ($e_{sa}$, $e_a$, $u_1$) (mm/day) = (0.2625 + 0.1409u) ($e_{sa} - e_a$).

$e_{sa}$ = saturation vapour pressure at air temperature $T_a$ (mbar), $e_a$ = actual vapour pressure of the air (mbar), $P_a$ = air pressure (mbar), h = elevation above mean sea level (m), u = wind speed in m/s

### GG model (Granger & Gray, 1989)

GG model authored by Granger and Gray (1989) showed that an equation equivalent to Penman's could be derived following the approach of Bouchet (1963) complementary relationship. Granger and Gray (1989) developed a modified form of Penman's equation for predicting the actual evapotranspiration from different bare surfaces that are saturated. The expression for GG model is defined as:

$$ET_p = \frac{ET_a}{G} \quad 3$$

$$ET_a^{GG} = \frac{\Delta G}{\Delta G + \gamma}\frac{R_n}{\lambda} + \frac{\gamma G}{\Delta G + \gamma}E_a \quad 4$$

Where:

$$G = \frac{1}{0.793 + 0.20e^{4.902D}} + 0.006D \text{ and} \quad 5$$

$$D = \frac{E_a}{E_a + R_n} \quad 6$$

G is a dimensionless relative evapotranspiration parameter, $R_n$ is the net radiation in $W/m^2$, $\gamma$ is the psychometric constant, $E_a$ is the aerodynamic term, a drying power and it is defined as $E_a = (0.2625 + 0.1409u)(e_{sa} - e_a)$, and $\lambda$ is the latent heat = 1000 x (2501 - 2.38T) and T is the daily mean air temperature.

**Thornthwaite Method**

Thorthwaite (1948) method is a widely used technique for the estimation of evapotranspiration. This method correlated mean monthly temperature with evapotranspiration as obtained from water balance for valleys where sufficient moisture water was available to maintain active transpiration (Xu and Chen, 2005). The procedure utilizes the mean air temperature and the number of hours of daylight and thus classified as temperature based approach. The method of evapotranspiration (ET) simulation according to Thornthwaite ((Thw) is expressed as:

`ET (Thw) = $C(10T/I)^a$ 7

where Ta is the monthly mean temperature; C = 16, a constant and heat index;
$i = (T/5)^{1.54}$ is the heat flux for the month $i$ and
$a = 0.000000675(i)^3 - 0.0000771(i)^2 + 0.0179i + 0.492$ and $I = \sum_{j=1}^{12} i_j$

**Priestley-Taylor Method**

The Priestly-Taylor method (Priestley and Taylor, 1972) is a simplified $ET_o$ formula requiring only the radiation only the radiation and temperature for the calculation of ET. This is with the assumption that evapotranspiration is more dependent on the radiation than on the relative humidity or wind speed. In fact, it had been found that the radiation component is responsible for about 2/3 of ET. The expression by this method is as follows:

$$ET_p = \alpha \frac{\Delta}{\Delta + \gamma}\frac{R_n}{\lambda} \quad 8$$

$R_n$ is the net radiation in $cal/cm^2/day$, $\alpha = 1.26$

**Makkink Method**

The method of Makkink (1957) can be considered as a simplified form of the Priestly and Taylor requiring radiation and temperature for the ET computation. In this case, solar radiation is replaced by net radiation. This is because there is a relationship the two forms of atmospheric radiation (0.5Rs = Rn). The Hansen (1984) modified version and named after Makkink (1957) is expressed:

$$ET_p = 0.7\frac{\Delta}{\Delta + \gamma}\frac{R_s}{\lambda} \quad 9$$

$R_s$ = the solar radiation in $cal/cm^2/day$.

**AA Model (Brutsaert & Stricker, 1979)**

Evapotranspiration is calculated by AA model by combining energy budget and information from budget and water vapour transfer in the Penman (1948) and is expressed as:

$$ET_p\,(AA) = \frac{\Delta}{\Delta + \gamma}\frac{R_n}{\lambda} + \frac{\gamma}{\Delta + \gamma}E_a \quad 10$$

where all term as defined for Penman Combination method expressed by equation 2 except for $f(u_z)$ expressed according to Penman (1948) as
$f(u_z) = 0.0026(1+0.54u_z)$. 11

**RESULTS**

The variation graph in Figure 2 describes the ET measurements for approximately 116 days on diurnal timescale in the first six months of the year (January-June/July) 2009 spilling into seventh day in the month of July. Generally, Figure 1 shows good correspondence between the lysimeter and the models' ET values and having an excellent coincident of troughs and peaks. Apart from the AA model which consistently underestimated potential evapotranspiration throughout the period, other models slightly overestimated the diurnal lysimeter measurements. This was shown in Figure 1 and confirmed by the average ratio (AR) computed for all the models in Table 1. The observed ET values may be over-estimated, underestimated or perfectly fit the model values when AR is above 1, less than 1 and equal to 1 respectively. The results in Table 1 indicate that most of the models values generally overestimated the observed ET values and greatly by Penman combination and GG models having AR as 1.38 and 1.44 respectively. However, the average ratio (AR) for AA is 0.81 and which implies underestimation. Figure 3 and Table 2 show the result of the linear regression graph between the observed and predicted ET values. The study also compares the average diurnal ET values for all the models as shown in Figure 3. This ranged from 110.54 -197.17mm/day with GG model and AA having the highest and lowest mean values of 197.17 and 110.54 respectively. The diurnal mean value of the observed data was 137.14 and this was exceeded by all the models with the exception of AA models. P-T scored a mean value of 138.82 which is above the 1.02 % above the observed. Table 2 presents the result of the regression parameters and the statistical performance indicators.. Low value of RMSE is desirable for a good model to be well compared with the in-situ measurements. In this study, the RMSE varies from 4.10 for Priestly Taylor to 61.13 for GG model. This shows that P-T measures evapotranspiration with minimum error while the inherent error in GG including Penman combination, Thornthwaite and AA are relatively large. The regression parameters were also determined for further validation of the models. This involves the slope and the intercept which are derived from the linear graph shown in Figure 2. From Table 4, the best slope and intercept are respectively 0.97 and 3.3 and this was found for Priestly Taylor. The slopes for GG (0.8), Makkink (0.75) and AA (1.02) are relatively good but the intercepts are equally large (I >10.0) for all the models except Priestly Taylor (I<5.0).

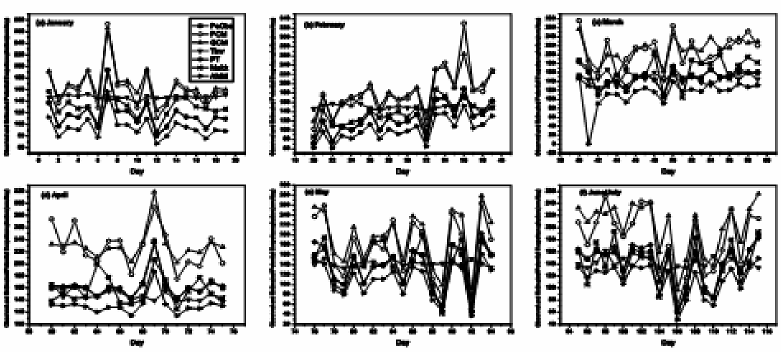

**Figure 2: Comparison of the Average diurnal Variation of Potential Evapotranspiration by the lysimeter and Model Estimated (January-July) in 2009.**

**Table 1: Statistical and Linear Regression Relationship between the Observed and the Estimated Evapotranspiration.**

| Methods | Slope, M | Intercept, C | $R^2$ | SD | Index of Agreement | P-Value | Average Ratio | RMSE | Coefficient of Determination | Mean Values |
|---|---|---|---|---|---|---|---|---|---|---|
| Penman combination | 0.60 | 23.9 | 0.83 | 13.6 | 0.66 | <0.0001 | 1.38 | 57.23 | 0.83 | 137.14 |
| GG model | 0.80 | -12.1 | 0.96 | 5.4 | 0.62 | <0.0001 | 1.44 | 61.13 | 0.96 | 189.19 |
| Thornthwaite | 0.15 | 114.9 | 0.00 | 32.7 | 1.00 | 0.67203 | 1.07 | 34.35 | 0.00 | 146.56 |
| Priestley-Taylor | 0.97 | 3.3 | 0.98 | 3.8 | 0.998 | <0.0001 | 1.01 | 4.10 | 0.98 | 138.21 |
| Makkink | 0.75 | 29.7 | 0.61 | 20.2 | -8.30 | <0.0001 | 1.04 | 22.13 | 0.61 | 141.98 |
| AA model | 1.02 | 24.0 | 0.79 | 14.9 | -15.54 | <0.0001 | 0.81 | 30.39 | 0.79 | 110.54 |

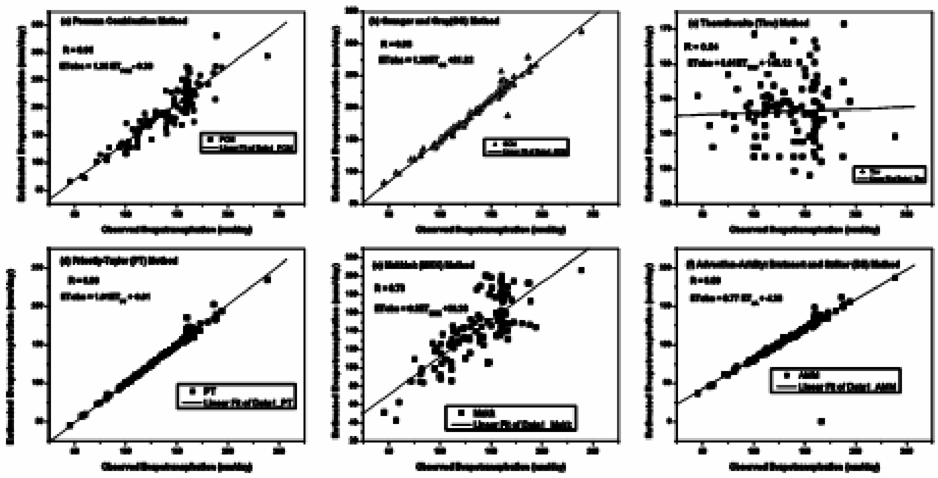

**Figure 3.0: Linear Regression Relationship between the Observed and Estimated Evapotranspiration**

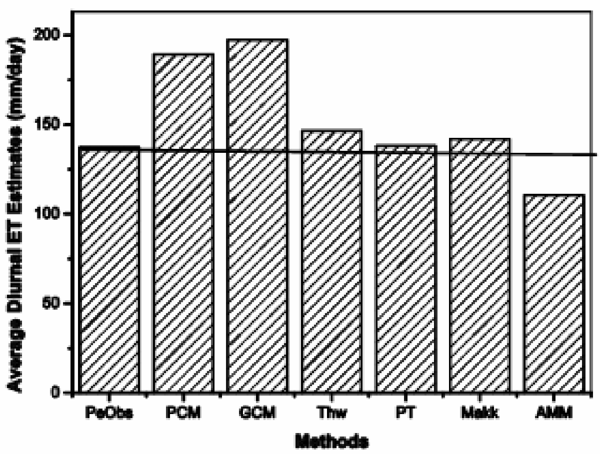


**Figure 4: The comparison of the Diurnal Mean values for the observed and the predicted ET values for Akure**

## DISCUSSION

Measurement of potential evapotranspiration was carried out dedicatedly for six months on diurnal timescale using the constructed lysimeter. The measurement did not capture weekends including the special days declared as work free days for workers. This is in view of the logistics involved and which is strongly connected with the operation at the observatory where the equipment was kept. All the selected models were evaluated with the input data drawn from the University observatory where the lysimeter was installed. The data were properly screened for cases of spurious and omissions. Both the observed and the evaluated results are presented in the Figure 2.0 for diurnal variations comparison. From the results, Priestly-Taylor (AR =1.01) was observed to exhibit coincident and perfect variations with the lysimeter values. This result agreed with literature and previous studies which confirm that Priestley-Taylor behaves well in the humid environmental condition than the arid (Jensen *et al*., 1990). The relationship between each model and the lysimeter measurement was established by determining the coefficient of determination ($R^2$) which describes the proportion of the total variance explained by each of the model. These are significantly high for all the models but extremely low ($R^2$ = 0.00) for Thornthwaite (Table 1). This result indicated a strong linear relationship between the two different datasets. This was also reflected in the linear regression graphs shown in Figure 2. From Table 2.0, it was further observed that the coefficients of determination were all significant as indicated by the P-values. This further confirmed that $R^2$ for Thorthwaite was not significant (P-value = 0.672).

For a perfectly behaved model when compared with a standard reference data, the slope and the intercept should be 1.0 and 0.0 respectively. The index of agreement is a measure of the degree to which models' prediction are error free. It reflects the degree to which the observed variate is accurately estimated by the simulated variate. Index of Agreement was proposed by Willmott (1981) to overcome the insensitivity of the coefficient of determination ($R^2$) to differences in the observed and predicted means and the variances (Legates and McCabe, 1999). The index of agreement represents the ratio of the mean error to potential error (Willmott, 1984). It varies between 0.0 and 1.0 where the predictive value of 1.0 indicate perfect agreement between the observed and the estimated observations, and 0.0 connotes one of a variety of complete disagreements.(Willmott, 1981). From this study, the index of agreement (Id) ranged from -15.5 to 1.00. According to Krause *et al.* (2005), one of the disadvantages associated with the application was that, a relatively large value (more than 0.65) of Id may be obtained for poor fits, leaving only a narrow range of model calibration and it is not sensitive to systematic over- and under-prediction. For instance, in this study, the $R^2$ determined for Thornthwaite was 0.0 while the id of 1.0 indicates perfect agreement which is not reasonable. The index of agreement for the GG, PT and AA are reasonable and this shows good agreement with the observed data having relatively high significant, $R^2$. The overall assessment of the validation analysis shows that there was a good correlation between the observed and the estimated ET values by all the models except Thorthwaite models. The performance of the models can be improved by the calibrations of the models for the study location (Ogolo, 209; Xu and Singh, 2002; Dinpashoh, 2006). In view of the statistical analysis and the model validation assessment, Priestly Taylor has a high correlation of 0.98, with the index of agreement of 0.98 and average ratio of 1.00 with a low RMSE of 4.10, hence, it was preferred to other models for the estimation of ET values when compared with the ET measurement from the constructed lysimeter.

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## CONCLUSION

A suitable Lysimeter was constructed and installed at the meteorological observatory station in the Federal University of Technology, Akure. The hydrological and meteorological data associated with the lysimeter have been used to verify some methods for the estimation of actual evapotranspiration. The techniques classification includes a temperature-based method (Thornthwaite), radiation-based method (Makkink and Priestly-Taylor) and the complimentary relationship approach (AA and GG). The results show that the radiation-based model based on Priestly-Taylor gave the best estimates of ET compared with the measured values of the lysimeter. Thornthwaite, the temperature-based model gives worst performance.

The complimentary relation technique also exhibited fair performance relatively when compared with the lysimeter value. It is hoped that the performance of the methods can be improved when they are calibrated for the present tropical station where this study was carried out. This results show that dearth of data on evapotranspiration can be reduced by constructing a cheap lysimeter as it was done in this study and thereby making available quality data on evapotranspiration.

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