PHILIPP AGRIC SCIENTIST
Vol. 95 No. 4, 378–382
December 2012

ISSN 0031-7454

Evaluation of Different ET_0 Calculation Methods: A Case Study in Kano State, Nigeria

M. M. Maina[1,*], M. S. M. Amin[2], W. Aimrun[2] and T. S. Asha[1]

[1]Research Center, Universiti Putra Malaysia, 43400 Serdang Selangor, Malaysia
[2]Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang Selangor, Malaysia
[*]Author for correspondence; e-mail: mainam@buk.edu.ng; Tel: +60102964931

Evapotranspiration (ET) is a descriptive term for the sum of evaporation and plant transpiration from the earth's land surface to the atmosphere. Potential evapotranspiration (ET_0)is important in irrigation system design, irrigation scheduling and for studies in drainage and hydrology. This study sought to compare different ET estimation methods to measure E(pan). Reference evapotranspiration was estimated from meteorological data that were collected from the Institute of Agricultural Research (IAR) in Kano State, Nigeria. The evaluations were carried out using ET_o from Pan Evaporation and from empirical formulae, namely, (1) Modified Penman, (2) Thornthwaite, (3) Blaney-Criddle and (4) Penman-Monteith methods. A software-based ET_o calculator was used to implement the Penman Monteith equation. The results were tabulated and comparisons were made between the methods and between the years using analysis of variance (ANOVA) and regression analysis. From the ANOVA, there was a significant difference between the methods of evaluation. The correlation coefficient (r) between Modified Penman and Pan Evaporation gave better estimation with high correlation.

Key Words: analysis of variance, Blaney-Criddle method, correlation coefficient, evapotranspiration, Modified Penman method, pan evaporation, Penman-Monteith method, Thornthwaite method

INTRODUCTION

Evapotranspiration is defined as the total quantity of water used by the vegetative growth of a given area through transpiration and the build up of plant tissue, and the total quantity that evaporated from the adjacent soil in an area at any specified time period. Therefore, it includes the water removed from the soil by transpiration and evaporation (Modi 2000).

Evaporation accounts for the movement of water to the air from sources such as the soil, the canopy of trees and bodies of water. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves into the atmosphere.

Potential evapotranspiration (ET_o) is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop that completely shades the ground, has uniform height and has adequate water status in the soil profile (Penman 1948). ET_o is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapor from the ground up into the low atmosphere. This demand incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface in agriculture; this is called the crop coefficient. Potential evapotranspiration and precipitation are used in irrigation scheduling (Derek 1998). According to Rattantal (2006), the rate of water uptake that would sustain normal plant growth at any time depends not only upon soil water status but also upon the atmospheric conditions. These conditions determine the evapotranspiration demand. However, plants absorb water from the soil to maintain their turgidity and are able to meet the actual evapotranspiration demand.

The modification of the Penman method introduced by Doorenbos and Pruitt (1977) started from the assumption that evapotranspiration from the grass also largely occurs in response to climatic conditions. Short grass being the common surroundings for agrometeorological observations, it was suggested that the evapotranspiration from 8- to 15-cm tall grass, no water shortage, be used as a reference instead of open water. The main changes in Penman's formula to compute Potential evapotranspiration ET_o were concerned with the short-wave reflection coefficient (approximately 0.05 for water and 0.25 for grass), a more sensitive wind function in the aerodynamic term, and an adjustment factor to take into account if local climatic conditions deviate from an assumed standard. The adjustment was mainly necessary for deviating combinations of radiation, relative humidity, and day/night wind ratios; relevant values can be obtained from a table in Doorenbos and Pruitt (1977).

This study identified the best method of estimating evapotranspiration to determine crop water requirements in the semi-arid area of Kano State, Nigeria.

MATERIALS AND METHODS

Description of the Study Area

Kano State in Nigeria (11° 59’’E longitude, 8° 30’’N latitude), located within the savannah region of Sudan and having an average altitude of 486 m, has an abundance of fertile land. According to the National Population Commission, Kano has a population of over 9,383,682, over 70% of which are engaged in agricultural activities (Habib 2006).

The state has 14 dams and an area of over 90,000 ha under cultivation. The main crops of Kano include groundnut, garlic, cotton, guinea corn, millet, maize, rice, cowpea, wheat and vegetables such as tomatoes, pepper, onions and cabbage. The southernmost area is characterized by the northern Guinea savannah and the northernmost section by the Sahel thorn shrub. The state has the tropical wet-and-dry type climate with relatively wide and rapid changes in temperature and humidity. The mean daily maximum and minimum temperatures are 31 °C and 21 °C, respectively.

The year is divided into well-marked rainy and dry seasons. The dry season lasts from October to June. During the months of November and January, the Harmattan (dry north-easterly winds) is at its height, blowing thin dust over the state from the Sahara Desert. During this time, temperatures may drop to as low as 15 °C. From March to May, however, the dry cold air humidifies and changes to beamingly hot air with temperatures rising more than 40 °C.

Rainfall is concentrated between July and September with maximum and minimum amounts of 214.0 mm and 132.7 mm, respectively. The rains are preceded by violent dust streams followed by tornadoes mainly during the months of May and June. The average annual rainfall is 884.4 mm, about 60% of which falls in July and August. Average rainfall varies considerably from year to year, ranging from 635 to 889 mm.

Data Collection and Measurement Instruments

The different climatic parameters were measured using various instruments (Table 1).

Table 1. List of equipment and their functions.

s/n	Instrument	Description	Measured Parameter
1	Anemometer	Cup anemometer	Wind speed
2	Evaporation pan	Stainless steel	Evaporation
3	Sunshine recorder	Campbell-Stokes recorder	Sunshine duration
4	Thermometers	Wet/dry bulb mercury in glass thermometer	Max/min Temperature
5	Rain gage	Tipping bucket rain gage	Rainfall

The data were collected from the meteorological unit of the Institute for Agricultural Research (IAR), Kano State, Nigeria. The IAR has been recording weather data for the past 30 yr in the Kano area using several equipment (Fig. 1–5). The data were taken every day manually and recorded in the metrological data book by the staff of IAR.

Fig.1. Cup anemometer.

Fig. 2. Class A Pan Evaporation.

Fig. 3. Sunshine recorder.

Fig. 4. Max/min thermometer.

Fig. 5. Tipping bucket rain gauge.

Several methods have been developed across the world to estimate evapotranspiration which is mostly location-specific and requires some calibration before application in an area. Among the methods that were selected are as follows:

Blaney-Criddle Method
The Blaney-Criddle (1950) equation is as follows:

$$ET_0 = p\,(0.46T_{mean} + 8)$$

where T_{mean} = mean monthly temperature in °C
P = mean monthly percentage of maximum possible day time hours of the year

$$T_{mean}\,[°C] = (T_{max} + T_{min})/\,2$$

Thornthwaite Method
The Thornwaite (1948) equation is as follows:

$$E = 16.0\ \left(\frac{10t}{I}\right)^{a}$$

where E = Potential evapotranspiration in mm/month
t = mean monthly temperature in °C
I = 'heat index' for the 12 mo in a year, given by

$$I = \sum i = \sum \left(\frac{t}{5}\right)^{1.514}$$

(i being heat index for month in a year);
$a = 6.75\times10^{-7} I^3 - 7.71\times10^{-5} I^2 + 1.792\times10^{-2} I + 0.49239$

Modified Penman Method
The modified Penman (1948) equation is as follows:

$$ET_0 = WR_n + (1-W)\,f(U)(e_s - e_a)$$

where ET_0 = Potential evapotranspiration for reference crop alfalfa in mm d^{-1}
W = a weighting or weightage factor which is dimensionless
R_n = Net radiation in mm of evaporable water per day
f (U) = a function of wind velocity
e_s = Saturation vapor pressure in mbar at the mean daily temperature
e_a = Actual mean vapor pressure of the air in mbar

$$F(U) = 0.27\times\left(1+\frac{U}{100}\right)$$

where U is wind speed in km h^{-1} at a height of 2 m above the ground.

Pan Evaporation Method
The potential evapotranspiration from Pan Evaporation is as follows:

$$ET_o = K_{pan} \times E_{pan}$$

where ET_o = potential evapotranspiration (mm d^{-1})
K_{pan} = pan coefficient (0.7)
E_{pan} = measured pan evaporation

Penman-Monteith (Software ET_o Calculator)

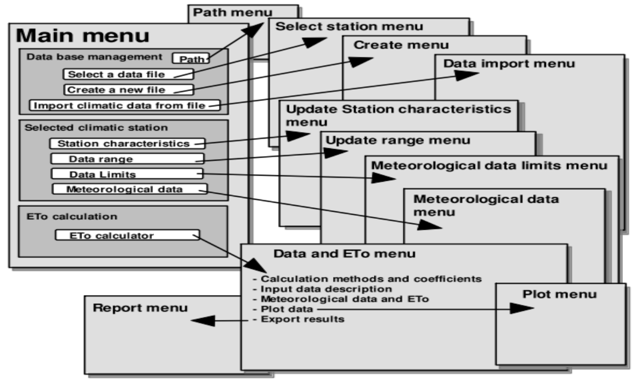

Fig. 6. ET_o calculator interface.

ET_o calculator is a software for estimating potential evapotranspiration based on the Penman-Monteith equation.

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

ET_o = Reference evapotranspiration [mmd^{-1}]
R_n = Net radiation at the crop surface [MJ$m^{-2}d^{-1}$]
G = Soil heat flux density [MJ$m^{-2}d^{-1}$]
T = Mean daily air temperature at 2 m height [°C]
U_2 = Wind speed at 2 m height [ms^{-1}]
e_s = saturated vapor pressure [kPa]
e_a = actual vapor pressure [kPa]
$e_s - e_a$ = saturation vapor pressure deficit [kPa]
Δ = slope vapor pressure curve [kPa °C^{-1}]
γ = psychometric constant [kPa °C^{-1}]

All these methods were compared with Pan evaporation, being the only direct measurement of evapotranspiration available at the time of data collection. Again, all the other methods of estimating potential evapotranspiration were developed using weather parameters which may differ between regions.

RESULTS AND DISCUSSION

The results were obtained from the estimation of evapotranspiration using the five methods (Table 2) to assess which of these could favorably estimate ET_o in an arid area with respect to Pan Evaporation. Pan Evaporation estimates ET_o based on daily measured evaporation were multiplied by the pan coefficient. This parameter served as the basis for ET_o estimation because it was a direct measurement, and therefore, it represented

Table 2. Estimated monthly ET_o (mm d^{-1}) for different methods.

Month	ET_o Pan	Penman-Monteith	Blaney-Criddle	Thornthwaite	Modified Penman
January	6.3	2.6	4.6	1.8	7.3
February	6.6	2.9	5.2	2.9	7.2
March	8.0	3.3	5.8	5.1	7.4
April	8.0	3.9	6.4	9.2	7.3
May	7.5	4.3	6.5	8.0	8.1
June	5.6	4.4	6.2	5.6	7.4
July	4.5	3.7	5.8	4.1	6.0
August	3.3	3.8	5.7	4.0	5.5
September	4.0	3.9	5.7	4.7	6.4
October	4.2	3.4	5.5	4.8	6.8
November	4.7	2.9	5.2	3.7	7.4
December	5.5	2.6	4.8	1.9	7.2
Average	**5.7**	**3.5**	**5.6**	**4.7**	**7.0**

the amount of water evaporated from the land and the plant surface.

A comparison of the five methods (Fig. 7) shows that Thornthwaite had the highest ET_o in the month of April and had the least in January. The wide range of ET_o values estimated by Thornthwaite was a result of the temperature dependence of this method; the pattern of the graph (Fig. 8) agrees with this statement. Thornthwaite and Blaney-Criddle, being temperature-based, have no value for ET_o at 0 °C. It shows one major limitation of the two methods. However, in the semi-arid regions, temperatures could rise as high as 40 °C and suddenly drop to almost freezing point at night, but this condition would not limit the application of Thornthwaite because these two extreme conditions were rarely observed.

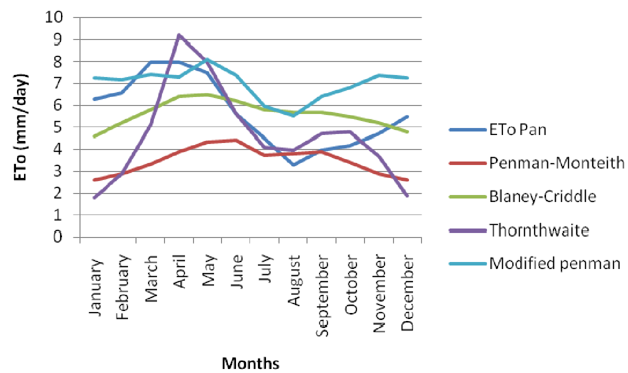

Fig. 7. ET_o of various methods.

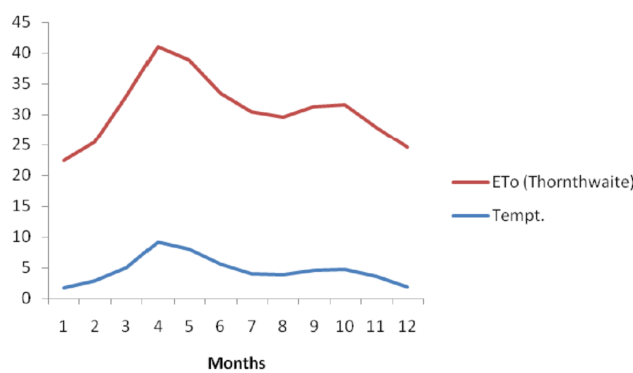

Fig. 8. Variation of ET_o between Thornthwaite method and temperature.

Comparison of ET_o Means between Months Using ANOVA and Correlation Coefficient (r)

The monthly averages of the evapotranspiration estimates obtained by using all five methods were tested with a randomized complete block design (RCBD) where each method was taken as treatments and the month as blocks. A mean separation procedure was done to verify the differences between the different methods of estimation. Therefore, the methods which have significant agreement with the results of the Pan Evapotranspiration (ET_o Pan) could also be used satisfactorily to estimate potential evapotranspiration for the study area (Fig. 9). The estimation of evapotranspiration using pan, needs Pan evaporation data, average relative humidity and wind speed to calculate the Pan coefficient, and in this case based on earlier conditions, the Pan coefficient (Kpan) was 0.7.

ET_o was estimated using various methods and then compared with Pan Evapotranspiration. The methods used were ET_o Calculator (Software based on Penman-Monteith), Blaney-Criddle, Thornthwaite and Modified Penman. Based on the results of ANOVA, no significant differences were found between the methods as the calculated F value (0.1389) tested not significant at 5%, while at 1% level of significance, it was significant. This result is not far from the fact that ET_o is a process governed by many factors. The correlation coefficient (r) also pointed out that Pan Evapotranspiration had a low correlation with all the methods except Modified Penman, which had a good correlation of $r^2 = 0.578$ (Fig. 10). This finding concurs with those of Ali-Akbar and Tabari (2010).

The Thornthwaite and the Blaney-Criddle methods considered only temperature as the main weather element in their equations. Hence, the result gave a reliable estimate under dry conditions for semi-arid areas. The calculated evapotranspiration should therefore be regarded as only a broadly accurate rather than a precise

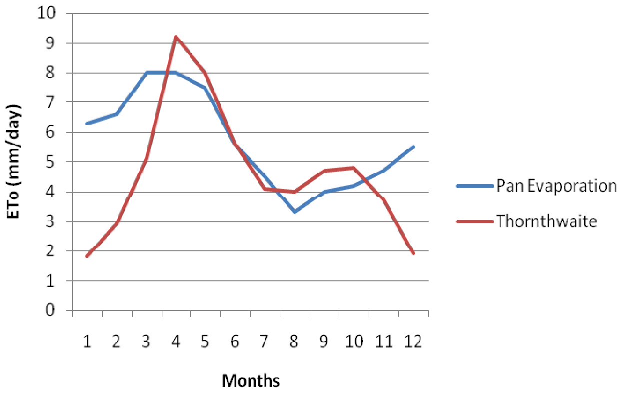

Fig. 9. ET_o variation between Pan Evaporation and Thornthwaite.

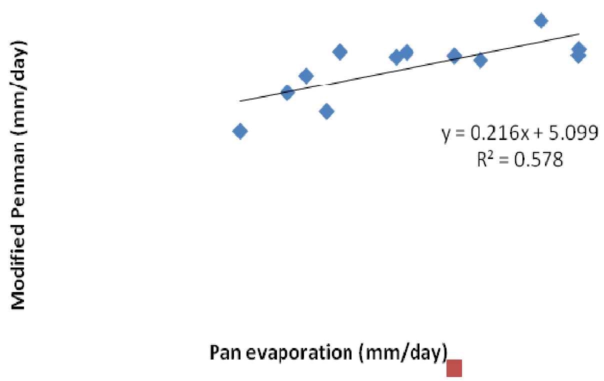

Fig. 10. Correlation between Pan Evaporation and modified Penman.

measure of evapotranspiration. Bakhtiari et al. (2011) conducted an assessment of different methods of estimating ET_o and found that Penman-Monteith did not perform as expected especially in the dry areas.

The complexity associated with the Modified Penman equation may likely introduce some errors especially when handling large data. Inadequate meteorological data can also be a setback in estimating ET_o in the study area. In some cases, Modified Penman overestimated ET_o as a result of the empirical wind function used in the equation (Najim and Aminul 2004). Various methods are available to estimate evapotranspiration from standard meteorological observations. Penman-Monteith, the method which served as basis for the development of the ET_o calculator software, is considered the most physical and reliable method and is often used as a standard to verify other empirical methods (Dirk 2009). It was tested under semi-arid conditions but it did not turn out to be suitable as the results showed that it underestimated ET_o.

CONCLUSION

Modified Penman also gave a good estimate in the semi-arid region because it showed a good correlation of r^2 = 0.578 with Pan ET_o. It gave a better estimate because of the many variable determinants. This result may be the reason for its high efficiency in the arid regions. It also concurs with the findings of Ali-Akbar et al. (2010).

The Thornthwaite and Blaney-Criddle methods estimated ET_o well compared with Pan ET_o, except that they failed at two extreme conditions: at 0 °C and at high temperature (>35 °C), because they were based on a single weather element. Modified Penman overestimated while Penman-Monteith undersestimated ET_o compared with ET_o Pan, therefore, the Blaney-Criddle and Thornthwaite methods may be recommended for use in the semi-arid regions for any irrigation design and schedule.

REFERENCES CITED

ALI-AKBAR S, TABARI H. 2010. Regional estimation of reference evapotranspiration in arid and semiarid regions. J Irrig Drainage Eng 136(10): 724–731.

ALI-AKBAR S, TABARI H, AEINI A, GHAFOURI M. 2010. Evaluation of Class A Pan coefficient models for estimation of reference crop evapotranspiration in cold semi-arid and warm arid climates. Water Resour Manage (2010) 24:909–920. DOI 10.1007/s11269-009-9478-2.

BAKHTIARI B, GHAHREMAN G, LIAGHAT AM, HOOGENBOOM G. 2011. Evaluation of reference crop evapotranspiration models for semi-arid environment using lysimeter measurements. J Agric Sci Tech 13:223–237.

BLANEY HF, CRIDDLE WD. 1950. Determining water requirements in irrigation areas from climatological irrigation data. Washington, DC: U. S. Department of Agriculture (USDA) SC-TP-96. 44 p.

DEREK C. 1998. Cropwat for Windows. Rome: Land and Water Division, Food and Agriculture Organization of the United Nations (FAO). 43 p.

DIRK R. 2009. ET_o Calculator. Rome: Land and Water Division, Food and Agriculture Organization of the United Nations (FAO). 38 p.

DOORENBOS J, PRUITT WO. 1977. Crop Water Requirements. Irrigation and Drainage Paper 24. Rome: Food and Agriculture Organization of the United Nations (FAO). 144 p.

HABIB IA. 2006. Predictive Maintenance of Tractors for Higher Utilization in Kano State of Nigeria. Proceedings of the 7th International Conference of the Nigerian Institute of Agricultural Engineers. 2006 July 3–5; Ilorin, Nigeria. p. 98–105.

MODI PN. 2000. Irrigation Water Resources and Water Power Engineering. New Delhi: Standard Book House. 1070 p.

NAJIM NNN, AMINUL HM. 2004. Estimating evapotranspiration of irrigated rice at the West Coast of the Peninsular of Malaysia. Irrigation Energy Consumption in a Tropical Lowland Rice. J Agric Science 5(1):

PENMAN HL. 1948. Natural evaporation from open water, bare soil, and grass. Proceedings, Royal Society, London 193: 120–146.

RATTANTAL. 2006. Encyclopedia of Soil Science. 2nd ed. England: Taylor and Francis.