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Estimation of evaporation rate in Ilorin using penman modified equation

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ABSTRACT

Evaporation is a common occurrence in the atmospheric dynamics. This was studied in Ilorin (8°32' N, 4°34' E), by using five meteorological parameter data collected from the Nigeria Meteorological Agency (NIMET) in Lagos Nigeria covering the period of twenty years (1991-2010). These parameters include solar radiation, wind speed, relative humidity, rainfall and temperature. These data were used to estimate the rate of evaporation using MATLAB 2013 to numerically simulate the penman equation modified by Shuttleworth. The evaporation rate for dry months (November to March) was estimated to be 7.67mm/day with observed value of 7.74mm/day and evaporation rate in wet season which begins from April to October was estimated to be 2.90mm/day and the observed is 2.99 mm/day. The average rate of evaporation for the period of study was estimated to be 5.284692mm/day while the observed value was calculated to be 5.362367mm/day, thereby giving a coefficient of determination $R^2 = 0.99$. A seasonal effect shows that during dry season evaporation rate is high as compared to the wet season.

Keywords: Penman Equation, Estimated, Shuttleworth, Observed, Evaporation.

1. INTRODUCTION

It is fundamentally known that evaporation rate takes place as a result of conversion of liquid water to water vapor at the surface of the water body. This process involves water movement from the surface of the earth to the atmosphere which brings about condensation and latter brings about rain to the surface of the earth. Allen and Smith (1994) reported that direct solar radiation and the ambient temperature of the air provide the necessary energy for evaporation. It was observed by Thompson in (1988) that the rate of evaporation at any time and place depends on some meteorological factors such as wind, temperature, pressure, relative humidity and solar radiation. Ogolo (2011) on a survey carried out on the trend of pan evaporation in four regions covering about twenty one tropical stations in Nigeria alerted these regions based on the result of the trend analysis on the possible need for water irrigation and further provides a database for the World hydrological scientists on the trend of pan evaporation in Nigeria in the last three decades. Billy *et al,* (2013) report that the estimated rate of evaporation in Uyo, Akwaibom State of Southern Nigeria using Shuttleworth approximation method was obtained to be 2.75 ± 0.46 mm/day as compared with the average observed value of 2.78± 0.42 mm/day. A high value of coefficient of determination $R^2 = 0.98$ showing high correlation between the observed and the estimated was obtained. Seasonal effects were also observed on the rate of evaporation at different rates in the wet and dry seasons. Aweda *et al.,* (2016) reported that at high temperature the rate of evaporation increases, which has direct dependence on the irradiation received. Adeyemi and Aro (2004) in their study on trends in the variations of surface water vapor density in four Nigerian stations showed that surface water vapor density is higher at night by an average of 9.9% than during the day in the southern stations while in the midland station of Minna, the reverse is the case. The occurrences of dry and wet seasons for any given location to region in such monsoon controlled climate follow the oscillatory movement of the international convergence zone (ITCZ), which is the imaginary boundary region between the SW moisture laden trade wind from the ocean and the NE dust laden trade wind from the Sahara (Ogolo and Adeyemi, 2009).

2. STATION DESCRIPTION

The geographical location of Ilorin is (8°32' N, 4°34' E). It is characterized by both wet and dry seasons. The temperature of Ilorin ranges from 33°C to 34°C (Ilorin Atlas, 1982). On the average, the mean monthly temperatures are very high varying between 25°C to 28.9°C. The diurnal range of temperature is also high in the area. The rainfall in Ilorin city exhibits greater variability both temporally and spatially (Ajadi, 1996). The total annual rainfall in the area is about 1200mm (Olaniran 2002). The diurnal regime of moderate rain in the area shows clear night-time rainfall maximum (Olaniran, 1988). Relative humidity at Ilorin in the wet season is between 75 to 80% while in the dry season it is about 65% (Tinuoye, 1990). The day time is mostly sunny. The sun shines brightly for about 6.5 to 7.7 hours daily from November to May (Olaniran 1982).

3. MATERIALS AND METHOD

Data on average monthly solar radiation, relative humidity, maximum and minimum temperature, pressure and wind speed were obtained from the Nigeria Meteorological Agency in Lagos. The data covered the period of twenty years (1991 to 2010). The estimated evaporation rate obtained by using Penman equation modified by Shuttleworth (1993) was compared with the observed evaporation. The penman equation was numerically simulated, using MATLAB R2013 whereby codes were generated. The evaporation rate equations is given by

$$E_{mass} = \frac{mR_n + \gamma \times 6.43(1+0.536\times U_{10})\delta_e}{\lambda_v(m+\gamma)} \quad [1.0]$$

where:
E_{mass}= Evaporation Rate (mm.day^{-1}), m = slope of the saturation pressure curve (kPaK^{-1}), R_n= Net Irradiance (MJm^{-2}day^{-1}), γ = psychrometric constant = $\frac{0.0016286\times P}{\lambda_v}$(kPaK^{-1}), U_{10} = Wind speed at 10m height (ms^{-1}), δ_e = Vapour pressure deficit (KPa), λ_v= Latent Heat of Vaporization ($MJKg^{-1}$), $\gamma = \frac{C_pP}{\varepsilon\lambda} = 0.665\times10^{-3}P$, P = 101.3 $(\frac{293-0.0065Z}{293})^{526}$, ε = ratio molecular weight of water vapour/dry = 0.622.

γ = psychrometric constant (kPa^{0}C^{-1}), P = atmospheric pressure (kPa), λ = latent heat of vaporization, 2.45 (MJkg^{-1}), C_p = Specific heat at constant pressure, 1.013×10^{-3}(MJKg^{-1} ^{0}C^{-1})

4. ESTIMATION OF EVAPORATION

The Shuttleworth (1993) equation 2.0 was used to determine the estimated rate of the average evaporation over Ilorin. The slope of the saturated pressure curved (m) in (KPaK^{-1}) is given below:

$$m = \frac{4098(0.6108\times exp\frac{17.27\times T}{T+237.3})}{(T+237.3)^2} \quad [2.0]$$

where T is the average maximum and minimum monthly temperature (FAO, 2008).

$$T = \frac{T_{max}+T_{min}}{2} \quad [3.0]$$

The temperature is in degree Celsius (^{0}C) or Fahrenheit (^{0}F). The conversion is

K = ^{0}C + 273.16 [4.0]

$R_n = \sigma[\frac{T_{max}K^4+T_{min}K^4}{2}](0.34\text{-}0.14\sqrt{e_a})$
$\{1.35\frac{R_s}{R_{so}}0.35\}$ [5.0]

Where R_n= Net Irradiance (MJm^{-2}day^{-1}), σ = Stefan-Boltzmann constant ($4.903\times 10^{-9}MJK^{-4}m^{-2}day^{-1}$), e_a = actual air humidity (kPa), R_{so} = calculated clear-sky radiation (MJm^{-2}month^{-1}), R_s the incoming solar radiation [MJ m^{-2} day^{-1}

P = atmospheric pressure (kPa), Z = elevation above sea level (m), measured or calculated Solar radiation (MJm^{-2}month^{-1}),

$e_a = e^0(T_{min})\frac{RH_{max}}{100} + e^0(T_{max})\frac{RH_{min}}{100}$ [6.0]

$e^0(T_{min})$ = 0.1608exp $\left(\frac{17.27T_{min}}{T_{min}+237.3}\right)$ [7.0]

$e^0(T_{max})$ = 0.1608exp$(\frac{17.27T_{max}}{T_{max}+237.3})$ [8.0]

R_H = relative humidity (degree), $e^0(T)$ = humidity of the saturated vapor at the air temperature T (KPa), T = air temperature (^{0}C)

RH_{max} and RH_{min} = Relative maximum and minimum for humidity.

$\delta_e = e_s - e_a$ [9.0]

$e_s = \frac{e^0(T_{max})+ e^0(T_{min})}{2}$ [10.0]

$e^0(T_{min})$ = saturation vapour pressure at year average minimum temperature (KPa),

$e^0(T_{min})$ = saturation vapour pressure at year average maximum temperature (KPa),

Extraterrestrial radiation (R_a),e_a = the actual air humidity

$R_a = \frac{24(60)}{\pi}G_{sc}dr[\omega_s\sin(\varphi)\sin(\delta) + \cos(\varphi)\cos\delta\sin(\omega_s)]$ [11.0]

R_a = extraterrestrial radiation ($MJm^{-2}day^{-1}$), G_{sc} = solar constant = 0.0820$MJm^{-2}min^{-1}$)

dr = inverse relative distance Earth-Sun, ω_s = sunset hour angle (rad), φ = latitude (rad), δ = solar declination (rad), Note that: Radian $\frac{\pi}{180}$(decimal degrees)

$dr = 1 + 0.033\cos(\frac{2\pi}{365}J)$ [12.0]

J = day number in the year between 1 (1 January) and 365 or 366 (31 December)

$\omega_s = arc\cos[-\tan(\varphi)\tan(\delta)]$ [13.0]

$R_{so} = (a_s + b_s)R_a$ [14. 0]

Note: a_s = 0.25 and b_s= 0.50

Where no calibration has been carried out for improve a_s and b_s parameters. (FAO, 2008)

5. RESULTS AND DISCUSSION

The typical results for average twenty years and the total average across the years under consideration are shown in the Fig. 1 & 2. The rate of evaporation in Ilorin over twenty years period using Shuttleworth model gives an estimated value of 2.90mm/day while the observed rate of evaporation is 2.99 mm/day. It was observed that the estimated and the observed values are quite comparable with a difference of 0.09mm/day. This shows that the shuttleworth model following the Billy *et al* (2013) is a good model for evaporation rate. This model can be use for the estimation of evaporation rate over states in Nigeria.

Table 1. Average Julian day (J) number and solar declination (δ) for the months of the year

Month	Average J	Declination δ
January	17	-20.92
February	16	-12.95
March	16	-2.42
April	15	9.41
May	15	18.79
June	11	23.09
July	17	21.18
August	16	13.45
September	15	2.22
October	15	-9.60
November	14	-18.11
December	10	-23.05

Source: Nwokoye (2006).

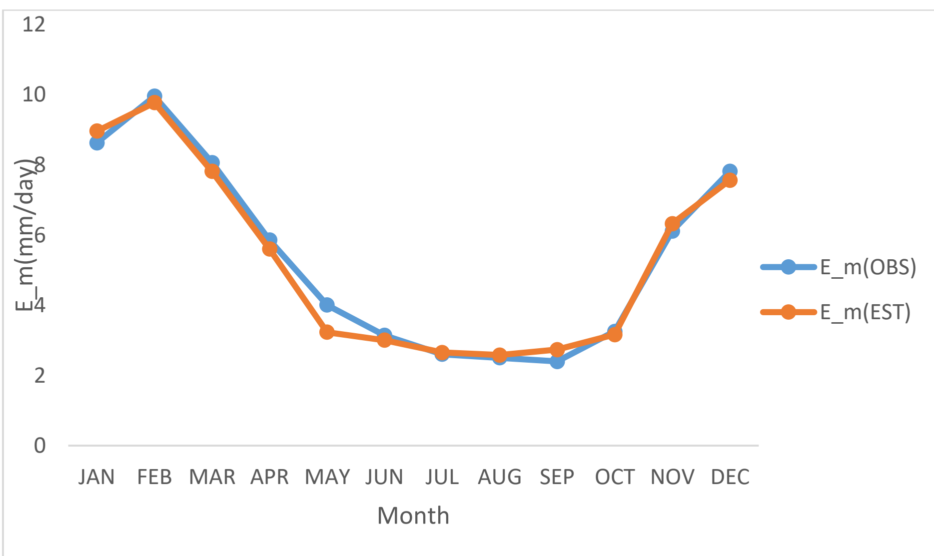

Fig. 1. Comparison of average estimated and observed evaporation in Ilorin

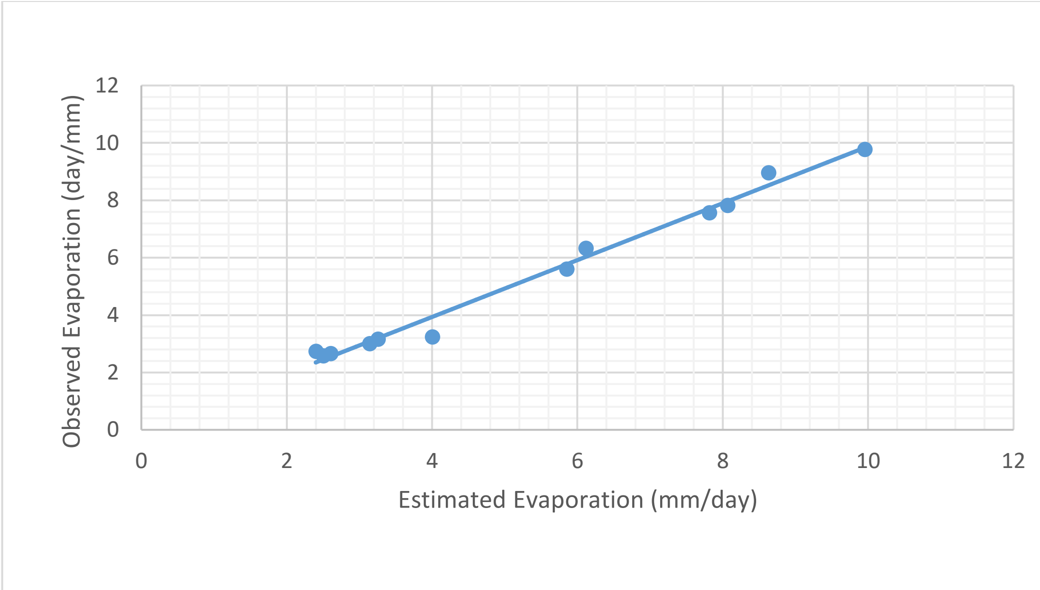

Fig. 2. Correlation between averages observed and estimated evaporation.

Table 2. Estimated and observed evaporation rate of three different stations

Station	Estimated Evaporation mm/day	Observed Evaporation mm/day
Jos	5.4	5.37
Uyo	2.75	2.78
Ilorin	2.90	2.99

Table 2.0 shows that the rate of evaporation in Jos is higher as compared with that of Ilorin and Uyo as reported by Billy *et a.,l* (2013) which said that the evaporation rate in Jos is about twice higher than that of Uyo. It was observed that the evaporation rate in Ilorin for dry months (November to March) was estimated to be 7.67 mm/day while the observed value was 7.74 mm/day and evaporation rate in wet season which begins from April to October was estimated to be 2.90 mm/day and the observed was 2.99 mm/day. The average rate of evaporation for the period of study was estimated to be 5.284692 mm/day while the observed value was calculated to be 5.362367 mm/day, thereby giving a coefficient of determination $R^2 = 0.99$ which actually validate the modified Penman relation in the determination of evaporation.

6. CONCLUSION

The rate of evaporation in Ilorin has been estimated using Shuttleworth approximation methods and it's showed that the average value was 5.284692 mm/day as compared with the average observed value of 5.362367mm/day. A high value of coefficient of determination $R^2 = (0.99)$ was obtained which established the high correlation between the observed and the estimated values. A seasonal effect shows that during dry season evaporation rate is high as compared to the wet season.

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