ESTIMATION OF EVAPORATION RATE USING SHUTTLEWORTH EQUATION

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ABSTRACT

Shuttleworth equation was used to estimate the rate of evaporation in Port Harcourt, Nigeria. Ten years (2001 -2010) data on evaporation, temperature, relative humidity wind speed and solar radiation obtained from Port Harcourt Internal Airport were used for the estimation. Linear regression was used to compare the relationship between the observed and the estimated values of the evaporation. The result shows an annual average estimated evaporation of 3.53mm/day, with seasonal average values of 2.55mm/day and 4.71mm/day for rainy and dry seasons respectively. The coefficient of determination R^2 was obtained to be 0.985, a value considered too high for linear relationship between observed and estimated values.

INTRODUCTION

Evaporation plays an important role in the hydrologic cycle and contributes effectively to water balance of the earth surface. It involves the conversion of liquid to vapour at the evaporating surface such as water bodies, soils, vegetations and wet planes. The vapour pressure difference between the evaporating surface and the overlaying air serves as the main driving force of evaporation, while solar radiation is the energy source that supports it. The contribution of other meteorological factors such as temperature, relative humidity, wind speed and air pressure has a great impact on the evaporation rate of a particular location.

Several empirical methods and models have been developed to estimate the rate of evaporation. Jensen and Haise (1963) observed that radiant energy is the primary source of energy that supports evaporation. This assertion was collaborated by Rim (2004) when he noticed that solar radiation is the most meteorological factor affecting evaporation, while wind speed is the least sensitive parameter for evaporation. Shuttleworth (1993) adapted the Penman equation to calculated evaporation. Johnson and Sharma (2008) employed some meteorological parameters including temperature, solar radiation, air pressure and relative humidity, to estimate evaporation. Their estimated values correlated well with measured values with a correlation coefficient of 0.992. In their correlation analysis of meteorological influence on evaporation, Akpan and Billy (2013) observed that solar radiation had the best single correlation result, while air pressure had the least single correlation effect. In this study, attempt was made to estimate evaporation rate in Port Harcourt.

MATERIALS AND METHODS

Data on solar radiation, minimum and maximum temperature, relative humidity, air pressure and evaporation were collected from Port Harcourt International Airport. The data covers a period of ten years (2001 – 2010). Port Harcourt is a town located on lat (4^{o}46’38’’N), long (7^{o}04’48’’E) and altitude of 16m above the sea level. The vegetation is largely tropical and mangrove forests. The climate is humid with means annual rainfall ranging 1900 – 4000mm and experience two marked climatic conditions rainy and dry seasons.

The monthly averages data were obtained and used for the estimation. The monthly average values of evaporation were calculated using Shuttleworth (1993) equation. These were compared with observed values of the corresponding monthly average.

The Shuttleworth equation used is given by equ.(1).

$$E_{est} = \frac{mR_n + 6.43\gamma(1+0.536U_z)\delta_e}{\lambda_v(m+\gamma)} \quad (1)$$

Where E_{est} = Evaporation (mm/day)
R_n = Net irradiance ($MJm^{-2}day^{-1}$) and is given by Equ. 2

$$R_{n=} \sigma[T_{max} \ K^4 + T_{min} \ K^4](0.34 - 0.14\sqrt{e_a})\left[1.35\left(\frac{R_s}{R_{so}}\right) x \ 0.35\right] \quad (2)$$

σ is the Stefan- Boltzman constant;
T_{max} and T_{min} are maximum and minimum temperatures respectively, K is the absolute temperature.

e_a is the actual vapour pressure given by Equ. 3

$$e_a = \frac{Rh_{mean}[e^0(T_{max}) + e^0(T_{min})]}{200} \quad (3)$$

Rs is the measured solar radiation
and Rso is the calculated clear sky solar radiation given by equ.4

$$R_{so=} (a+b) R_a \quad (4)$$

Where a and b are regression constant given by 0.25 and 0.5 respectively.
Ra is the extraterrestrial radiation given by Equ. 5

$$R_a = \frac{24}{\pi} I_{sc}\left[1 + 0.33\cos\left(\frac{360}{365}\right)dn\right][(\omega sin\emptyset sin\delta) + (cos\emptyset \ sin\omega)] \quad (5)$$

Where I_{sc} is the solar constant, dn is the Julian day, δ is the solar declination and ϕ is the latitude.
γ = Psychometric constant ($kPaK^{-1}$)

U_z = wind speed at 2m height (ms^{-1})

δ_e = vapour pressure deficit and it given by equ.6

$$\delta e = e_s - e_a \quad (6)$$

λ_v = Latent heat of vapourization ($MJkg^{-1}$)
m = slope of the saturated vapour pressure curve ($kPaK^{-1}$) given by equ.7

$$m = \frac{4098\left[0.6108 \ exp\left(\frac{17.27T}{T+273.3}\right)\right]}{(T+273.3)^2} \quad (7)$$

where T is the monthly mean temperature (^oC)
The calculated parameters for the Shuttleworth are shown on Table 1

Table 1: Shuttleworth Parameters for Evaporation Estimation

Month	R_n ($MJm^{-2}day^{-1}$)	e_s(kPa)	e_a (kPa)	δe(kPa)	γ ($kPaK^{-1}$)	($kPaK^{-1}$)
January	12.23	3.43	2.7	0.73	1.99	0.214
February	11.89	3.62	3.12	0.5	1.99	0.225
March	7.21	3.25	3.15	0.1	1.95	0.228
April	3.74	3.16	3.12	0.04	2.01	0.223
May	1.87	3.49	3.43	0.06	1.98	0.205
June	1.39	3.73	3.65	0.08	1.99	0.206
July	0.53	3.18	3.03	0.15	1.94	0.199
August	0.82	3.96	3.54	0.42	1.93	0.198
September	0.76	3.59	3.57	0.02	1.94	0.201
October	2.43	3.58	3.37	0.21	1.98	0.207
November	4.54	3.17	3.14	0.03	1.99	0.215
December	8.06	3.5	3.18	0.32	2.01	0.216

RESULTS AND DISCUSSION

Table 1 shows the values of different parameter of Shuttleworth equation obtained from Port Harcourt data. These values were used to compute the estimated values of evaporation alongside other relevant meteorological data shown on Table 2.The comparison of the observed and the estimated values of evaporation obtained over Port Harcourt are presented in Figs.1 and 2 respectively. The linear correlation of the observed and estimated evaporation is depicted in Fig. 3. The R^2 value of 0.985 indicates that the correlation equation is well fit with sample data.

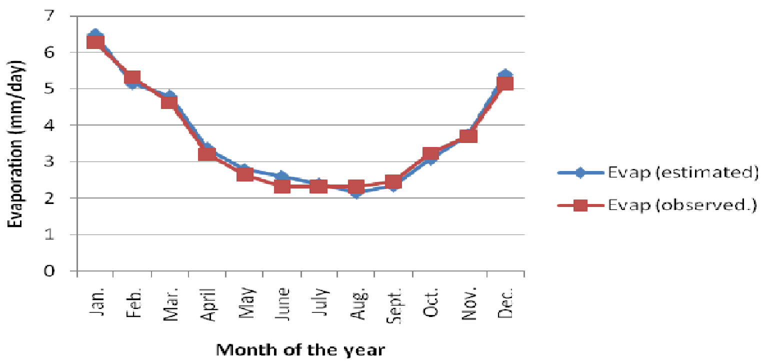

Fig.1: The monthly average observed and estimated values of evaporation in Port Harcourt over a period of ten years.

Table 2: Different meteorological values with estimated value of evaporation

Month	Average temperature (°C)	Relative Humidity (%)	Solar radiation ($MJm^{-2}day^{-1}$)	Pressure (mb)	Wind speed (ms^{-1})	Evaporation Observed ($mmday^{-1}$)	Evaporation Estimated ($mmday^{-1}$)
January	27.48	73.7	17.2	30.2	78.65	6.28	6.48
February	28.4	77.2	16.4	30.24	85.12	5.32	5.13
March	28.73	80.1	14.3	29.67	83.71	4.62	4.79
April	28.25	83.7	11.6	30.4	75.65	3.21	3.36
May	26.58	86.4	7.4	30.13	66.52	2.65	2.78
June	26.72	88.3	8.2	30.23	67.4	2.32	2.59
July	26.08	89.7	10.6	29.38	69.41	2.32	2.38
August	25.97	90.1	11.9	29.23	84.1	2.33	2.15
September	26.27	89.6	11.8	29.35	60.42	2.46	2.33
October	26.78	88.5	12.7	30	47.62	3.23	3.07
November	27.57	85.1	15.5	30.12	44.03	3.7	3.73
December	27.59	78.2	16.1	30.41	60.2	5.14	5.38

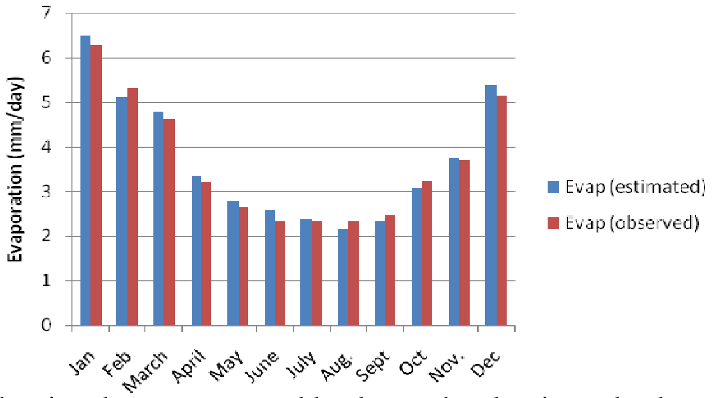

Fig. 2: A bar chart showing the average monthly observed and estimated values of evaporation in Port Harcourt.

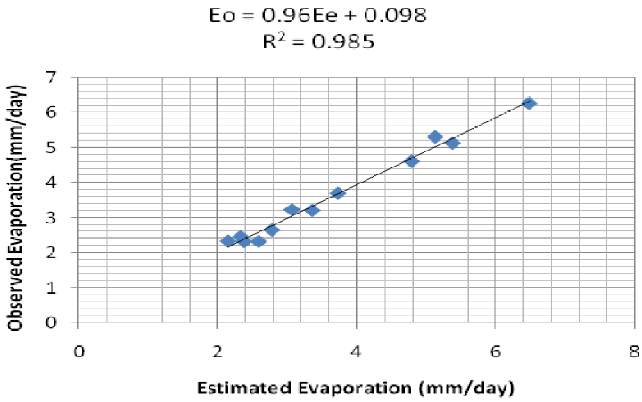

Fig.3: Linear correlation between the observed and the estimated evaporation in Port Harcourt.

An average monthly evaporation in Port Harcourt has been estimated over a period of ten years using the Shuittleworth equation. The estimate shows a minimum monthly average value of 2.15mm/day and a maximum value of 6.48mm/day obtained in August and January respectively. The yearly average value of 3.53mm/day was also obtained. Port Harcourt is marked with two distinct climatic conditions namely rainy and dry seasons. During the rainy season in the month of May to October with reduced solar radiation and temperature, the average evaporation rate for this period was found to be 2.55mm/day. For the dry season which occurs from the month of November to April characterized by higher solar radiation and temperature, the average evaporation rate of 4.41mm/day was obtained. The comparison of these values with the ones obtained for Uyo (Utibe *et al*., 2013) with a similar climatic condition reveals that the evaporation rate in Port Harcourt is remarkably different from that of Uyo. It is observed that Port Harcourt has a higher evaporation rate than Uyo. Ahonsi (2004) obtained an annual average evaporation rate of 5.4mm/day for Jos, Nigeria which is of higher value compared to that obtained for Port Harcourt.

CONCLUSION

It is obvious that the evaporation rate varies distinctly from place to place depending on the prevailing meteorological factor of the location. This estimate is therefore applicable to the locations with the similar meteorological conditions.

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