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Estimation of net radiative measurement of meteorological parameters at Iwo, Nigeria in 2018

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ABSTRACT

In this paper, data for about 90 days (3 months) from Universal Serial Bus (USB), wireless weather forecaster touch screen code N965Y installed at Solar Energy and Research Centre (SERAC), Bowen University, Iwo ($7^0 37'\mathrm{N}, 4^0 11'\mathrm{E}$), were used to estimate the net radiation ($\mathrm{R_n}$) of the study location. The analyses of the data were done on a simple empirical relationship using MATLAB code for data plotting, curve fittings and other statistical analysis. The data set showed the trend as bimodal with the peak at about $3.2 \times 10^8 \mathrm{Wm^{-2} day^{-1}}$around 160th day of the year in June, and a prominent minimum of about $2.4 \times 10^8 \mathrm{Wm^{-2} day^{-1}}$ in August, which is at the peak of the wet season. Vis-a-vis, the temperature of maxima $34^0\mathrm{C}$and minima at $27^0\mathrm{C}$ in June and August. Different ARIMA (1,1,1), (0,1,1), (1,1,0), (1,0,0) and (1,0,1) model used revealed the RMSE 19.780, 36.436, 30.825, 99.682, 98.712, MAPE 0.680, 1.684, 1.262, 3.064, 2.904 and MAE 12.867, 32.166, 24.231, 44.898, 41.945 for the solar radiation estimated with ARIMA (1,1,1) as the best model. Therefore, considering the importance of $\mathrm{R_n}$ in weather prediction and climate studies, it is highly recommended by the authors that the government of the Federal Republic of Nigeria considers and provides funds to the Universities in Nigeria and research centres for their research purpose. More so, it is recommended that during the increase in radiation there should be proper harness of the solar energy for the generation of energy in the city. Since the country is faced with the challenge of energy, the government is hereby encouraged.

Keywords: ARIMA, RMSE, MAPE, Net Radiation, Solar Radiation.

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1. Introduction

The solar energy balance on the surface of the earth is a result of the radiative wind that comes from the sun. This energy required net radiation fundamental to balance the solar radiative force from the sun. The usefulness of net radiation as an index for the classification of the atmospheric parameters on population models in the air is stable (Jegede, 1997a).

The cloud reduces the incoming solar radiation on the earth surface, which is a result of the atmospheric dust. As suggested by (Fritschen and Simpson 1989; Wallace et al., 1990; Halldin and Lindroth 1992; Bakry, 1994), the practice to use a net radiative single radiometer is now of importance in the practice on the study of the atmospheric parameters. As reported by Aweda et al., 2018; a seasonal effect on the evaporation rate occurs as a result of the dry and wet temperature of the environment. Aweda et al., 2016 reported that at high temperature, the rate of evaporation increases; this has a direct dependence on the solar radiation received from the sun. Therefore, this may affect some atmospheric parameters across the entire country. However, this study aims to estimate the net radiative measurement on meteorological parameters at Iwo. Jegede et al., 2006 stated that the estimated net radiation uses routine meteorological data at a tropical location with the equation $R_n = R_{sd} - R_{su} + R_{id} - R_{iu}$ [a]. However, the sum of all the net terms represents the net radiative energy balance at the earth surface. Ramanathan et al., 1989; Harrison et al., 1990 studied the influence of clouds on the radiation balance. Their findings revealed that cloud was absent, but the absorbed solar radiation will increase at about $50\,Wm^{-2}$, moreover, by $30\,Wm^{-2}$, emitted long-wave radiation is decreased. Net radiations importance is the fundamental quantity of energy available at the surface of the earth to drive the process of evaporation Jegede et al., 2006. In a major field experiment HAPEX, few data were collected Fritschen and Qian 1990. However, for this experiment, about 3-month data were collected for the estimation of the net radiation. In this paper, we shall explore an alternative method to capture the global distribution of net – radiation R_n estimates using wireless USB weather forecaster data of about 3 months over the coaster area in Iwo for clear sky days. However, for this research, the proposed approach strives to 'stand-alone' by eliminating the need for ground data as model input and also explicitly recognizes the need for spatially varied input parameters. Earlier studies have used remote sensing observations from Geostationary Operational Environmental Satellite (GOES), Advanced High-Resolution Radiometer (AVHRR) and MERRA-2 Re-Analysis. Also, some studies used data from Moderate Resolution Imaging Spectroradiometer (MODIS), onboard Earth Observing System (EOS) Terra satellite, while for this present study we used data from Universal Serial Bus (USB) weather forecaster to observe the limitation of other studies on net-radiation. Practically, the use of net radiation data is scarce in the tropical stations of Africa (Fritschen and Qian 1990; Holtslag, 1984; Jegede 1995; El-Shal and Mayhoub 1996). However, for this study, estimation of net radiation is of importance by using some meteorological data obtained from the USB wireless weather station. In support, there is wide use of meteorological data for the investigation of soil-atmospheric interactions, and high interest of different researchers for its development and calculation particularly; for net radiation determination. For this study, simple empirical relationships obtained from different literature were employed using atmospheric parameters collected from a USB wireless weather forecaster to estimate net radiation.

2. Materials and Methods

At an interval of 30 minutes, the data set used was acquired from Universal Serial Bus (USB) wireless weather forecaster touch screen weather station with code N965Y over 3 months (May-August). The average distribution values of the indoor temperature, outdoor temperature, indoor humidity, outdoor humidity and wind speed were all determined to find the daily average value of net radiation, R_n.

$$R_n = R_{ns} - R_{nl} \quad [1]$$

$$R_{ns} = (1 - \alpha)R_s \quad [2]$$

$$R_s = (a_s + b_s \frac{n}{N})R_a \quad [3]$$

R_n is the Net radiation ($Wm^{-2}day^{-1}$), $R_{ns}$is net solar or short wave radiation ($MJm^{-2}day^{-1}$), R_s is the incoming solar radiation ($MJm^{-2}day^{-1}$), R_{nl} is the net outgoing longwave radiation ($MJm^{-2}day^{-1}$), R_a is the extraterrestrial radiation ($MJm^{-2}day^{-1}$), α is the albedo or canopy reflection coefficient = 0.23, a_s is constant = 0.25, b_s is constant = 0.50, $\frac{n}{N}$ is the relative sunshine duration, where n is the actual sunshine duration and N is the maximum possible duration of sunshine or daylight hour. In the absence of any clouds, the actual duration of sunshine is equal to the daylight hours (n = N) and the ratio is one, while on cloudy days "n" and consequently the ratio may be zero (Fao, 2013).

$$N = \frac{24}{\pi} w_s \quad [4]$$

$$w_s = cos^{-1}[-\tan(\varphi)\tan(\delta)] \quad [5]$$

w_s is the sunshine hour angle (rad), φ is latitude (rad), δ is the solar declination angle (rad) and

Radians = $\frac{\pi}{180}$ (decimal degrees).

$$\delta = 0.409 \sin\left(\frac{\pi}{365} J - 1.39\right) \quad [6]$$

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

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [w_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin w_s] \quad [7]$$

G_{sc} is solar constant = 0.0820 ($MJm^{-2}day^{-1}$), d_r is inverse relative earth-sun distance.

$d_r = 1 + 0.033\cos(\frac{\pi}{365} J)$(8) R_{nl} = $\sigma[\frac{T_{min}K^4 + T_{max}K^4}{2}]$(0.34-0.14$\sqrt{e_a}$){1.35$\frac{R_s}{R_{so}}$ 0.35}

[9]

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 ($MJ\ m^{-2}\ day^{-1}$), T is the average maximum and minimum monthly temperature, $e^0(T_{max})$ = saturation vapour pressure at year average indoor temperature (KPa), $e^0(T_{min})$ = saturation vapour pressure at year average outdoor temperature (KPa), R_{min} = minimum relative humidity (%), R_{max} = minimum relative humidity (%)(Fao, 2013).

$$e_a = \frac{e^0(T_{min})\frac{RH_{max}}{100} + e^0(T_{max})\frac{RH_{min}}{100}}{2} \quad [10]$$

$$e^0(T_{max}) = 0.1608\exp\left(\frac{17.27T_{max}}{T_{max}+237.3}\right) \quad [11]$$

$$e^0(T_{min}) = 0.1608\exp\left(\frac{17.27T_{min}}{T_{min}+237.3}\right) \quad [12]$$

$$K = C + 273.16 \quad [13]$$

$\frac{R_s}{R_{so}}$ is relative shortwave radiation (limited to ≤ 1.0), R_{so} is the calculated clear-sky radiation ($MJm^{-2}day^{-1}$).

$$R_{so} = (a_s + b_s)R_s \quad [14]$$

Where no calibration has been carried out for improving a_s and b_s parameters (Fao, 2013).

In the data series used, it was observed that there were no missing data which shows that the data logger worked effectively during this period. The system was properly powered with solar energy to log the data accurately during the period of study. Environmental running of MATLAB code was used for data plotting, curve fittings and other statistical analysis. The indoor temperature and outdoor temperature represent the minimum and maximum temperature while the indoor humidity and outdoor humidity represent the minimum and maximum relative humidity and wind speed respectively.

The experimental site for this research is located at the Solar Energy and Research Centre (SERAC), Bowen University, Iwo see figure 1. The city is located in the western part of the country (Nigeria) with the coordinate($7^0$37'N, $4^0$11'E).

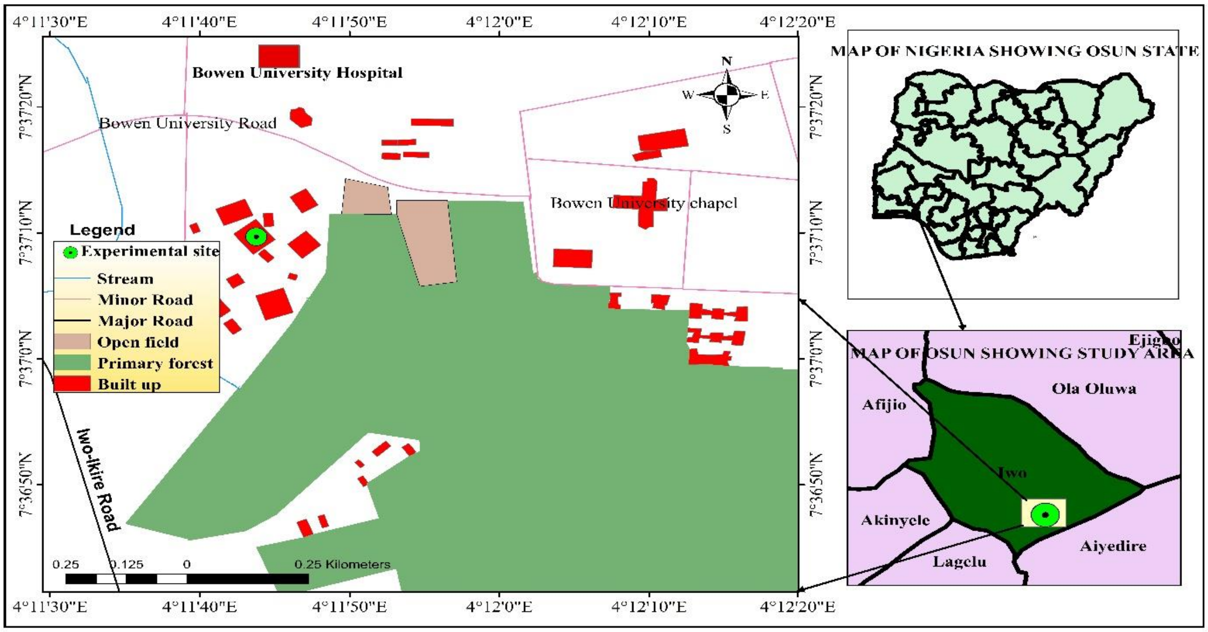

Figure 1: Map of Iwo showing the experimental site at SERAC

3. RESULTS AND DISCUSSION

Figure 2 shows the estimation of the diurnal variation of the radiation R_n, for the individual months of May, June, July and August in 2018 at the SERAC experimental station. It should be noted here, that all the observation times were recorded as the mean local time (LT) in Nigeria (which is GMT+1 hour). In the figure, the estimated net radiation R_n was plotted against the day number of the year for the months considered. For the daytime hour, the estimated net radiation R_n is observed to be high and to be positive all through, with the magnitude ranging between $1.8\ to\ 3.4 \times 10^8 Wm^{-2} day^{-1}$. By early morning (at about 06h), the estimated net radiation R_n constantly stayed positive within the range $2.3 \times 10^8\ to\ 2.4 \times 10^8 Wm^{-2} day^{-1}$ (or less for other months) at around 15h. In the later afternoon, the estimated net radiation density increased at about $3.4 \times 10^8\ Wm^{-2} day^{-1}$ for the first month, then it began to decrease steadily through other months. The mean values of the daytime estimated net radiation at SERAC station are found to be higher than that of the (short-period) measurement reported by (Wallace et al., 1990) for the Southern Sahelian region of Niger in West Africa and also higher than that of Osu in the western region of Nigeria (Osun State) measurement as reported by (Jegede, 1997a). From figure 2, we can see that there are some remarkable day differences in the mean diurnal variation of the estimated net radiation in the individual month. In Nigeria, there are two mean seasons: a wet one and a dry one, well-known to occur in the year generally within the West Africa area Nielsen et al., (1981). Meanwhile, the wet season data was used for this research owing to the availability of the data during the full operation of the device. Figure 3 shows that the average temperature variation has been calculated from the estimated formula of the net ratio. The average temperature was plotted against the day number which shows the daily maximum temperature (at $34^0 C$) for the location in 2018. The variation in the temperature ranges from $(23^0 C\ to\ 34^0 C)$ unlike what was observed by (Jegede 1997a). The diurnal temperature course portrays different peaks, which occur across the day with the maximum around 160^{th} day of the year, with a minimum in August as also reported by (Jegede 1997a) The mean for the daily maximum temperature was $24.67^0 C$ which is lower than what was reported by (Jegede 1997b) at Osu station. Figure 4 shows the relationship between the estimated net solar radiations and the day number. Empirically, the relation stated that estimated net solar radiation increases astronomically with it minimum of around $700\ MJm^{-2}day^{-1}$ at about 147th day of the year, while the maximum around $3500\ MJm^{-2}day^{-1}$ at about 229^{th} day of the year (that is in August).

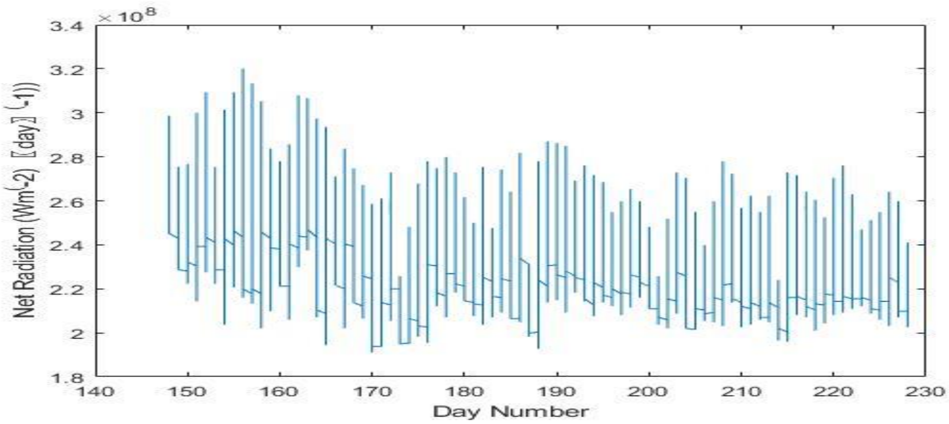

Figure 2. Daily averaged net radiation at SERAC station, May to August, 2018.

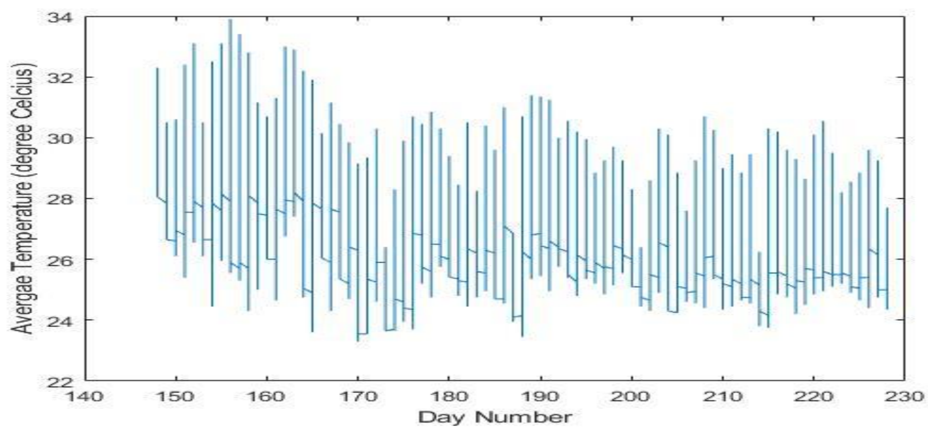

Figure 3. Daily averaged Temperature at SERAC station, May to August, 2018.

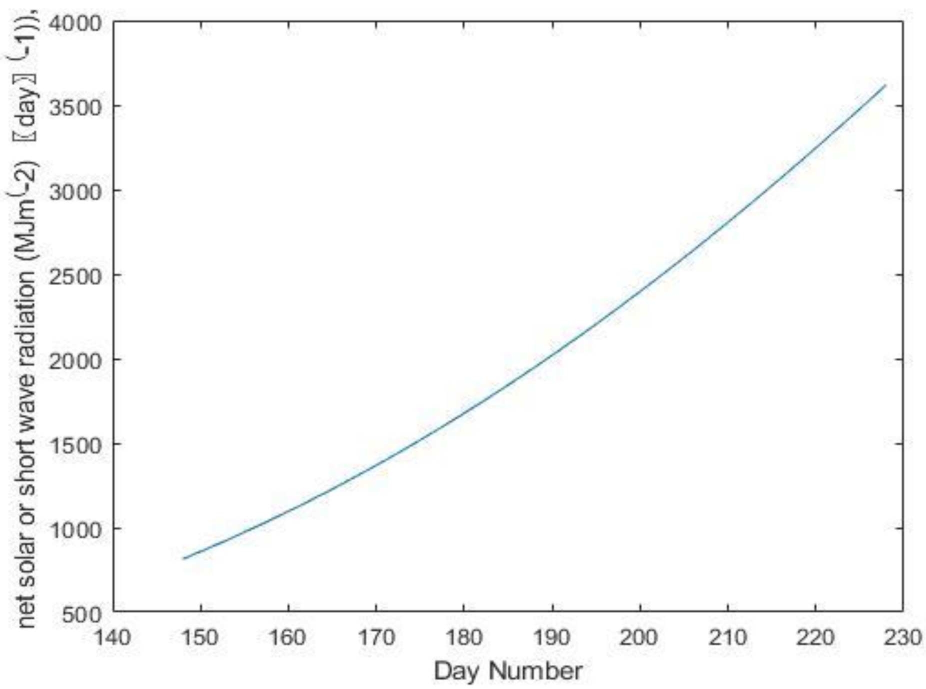

Figure 4. Daily averaged solar estimated radiation at SERAC station, May to August, 2018

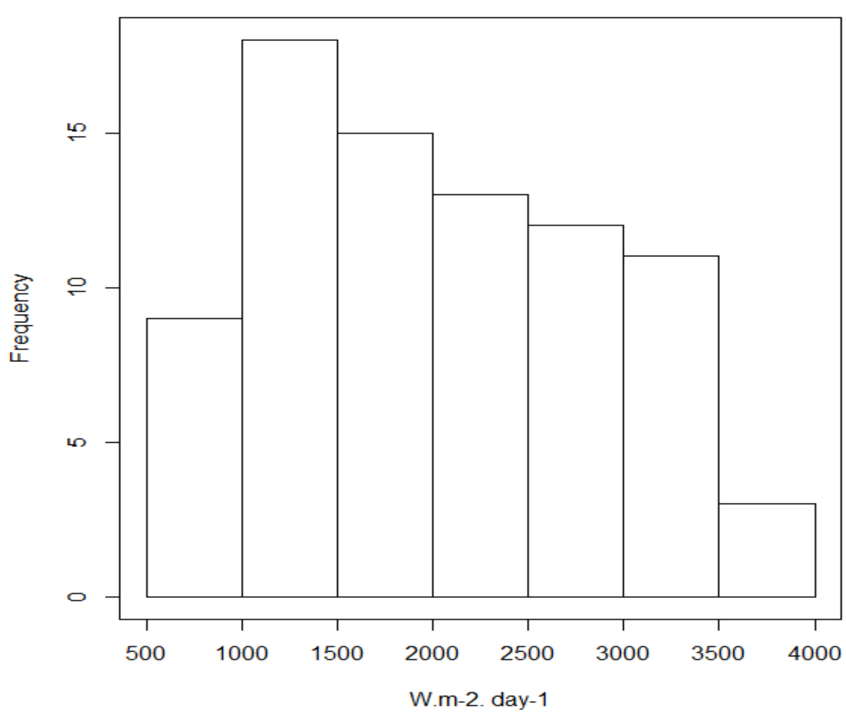

Figure 5. Histogram of the daily averaged (May to August, 2018) net radiation$\left(Wm^{-2}day^{-1}\right)$ at Iwo SERAC station

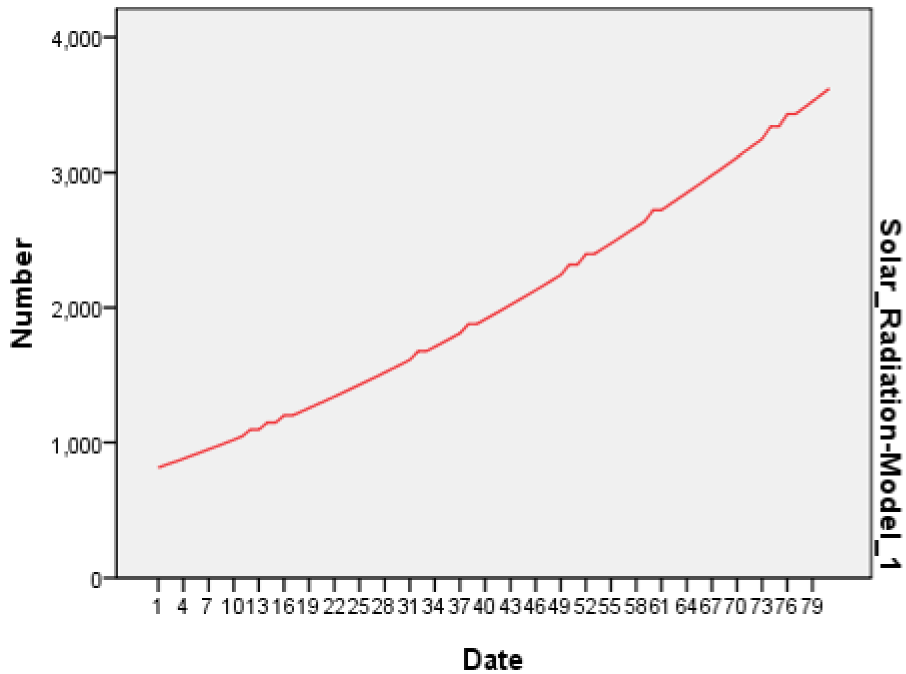

Figure 6. The time series plot of the solar radiation ($MJm^{-2}day^{-1}$)

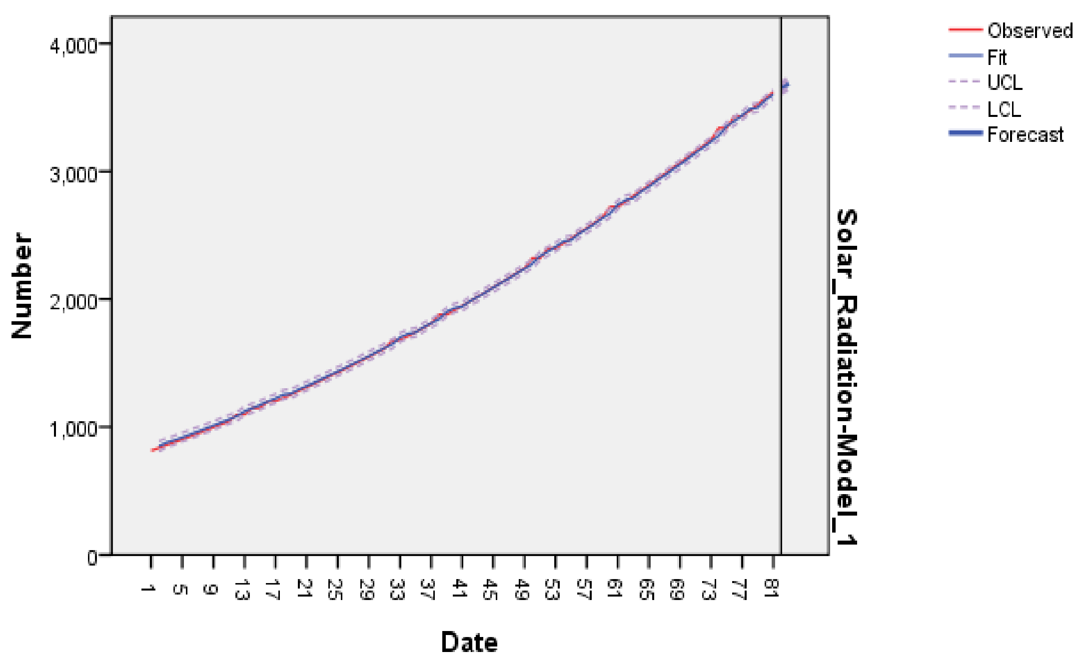

Figure 7. A forecast plot versus the actual value for the past 81 days.

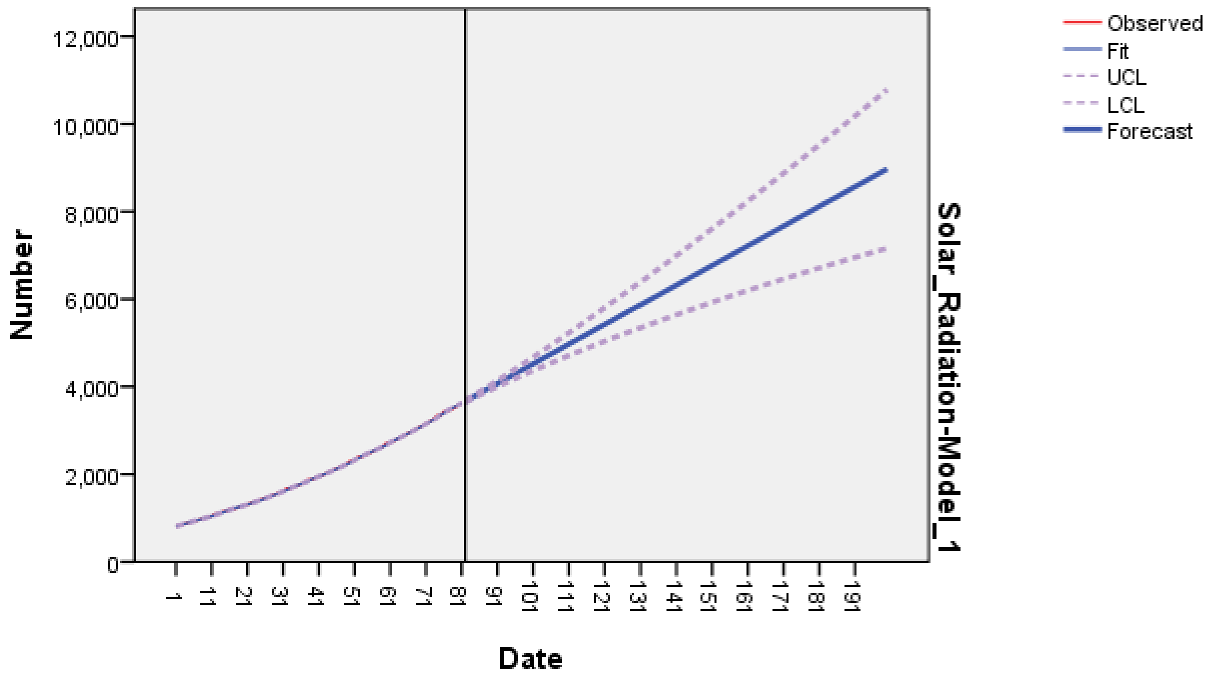

Figure 8. A clearer forecast versus actual values for the past 81days. This has shown clearly hat the UCL and LCL are drifting away from the forecast

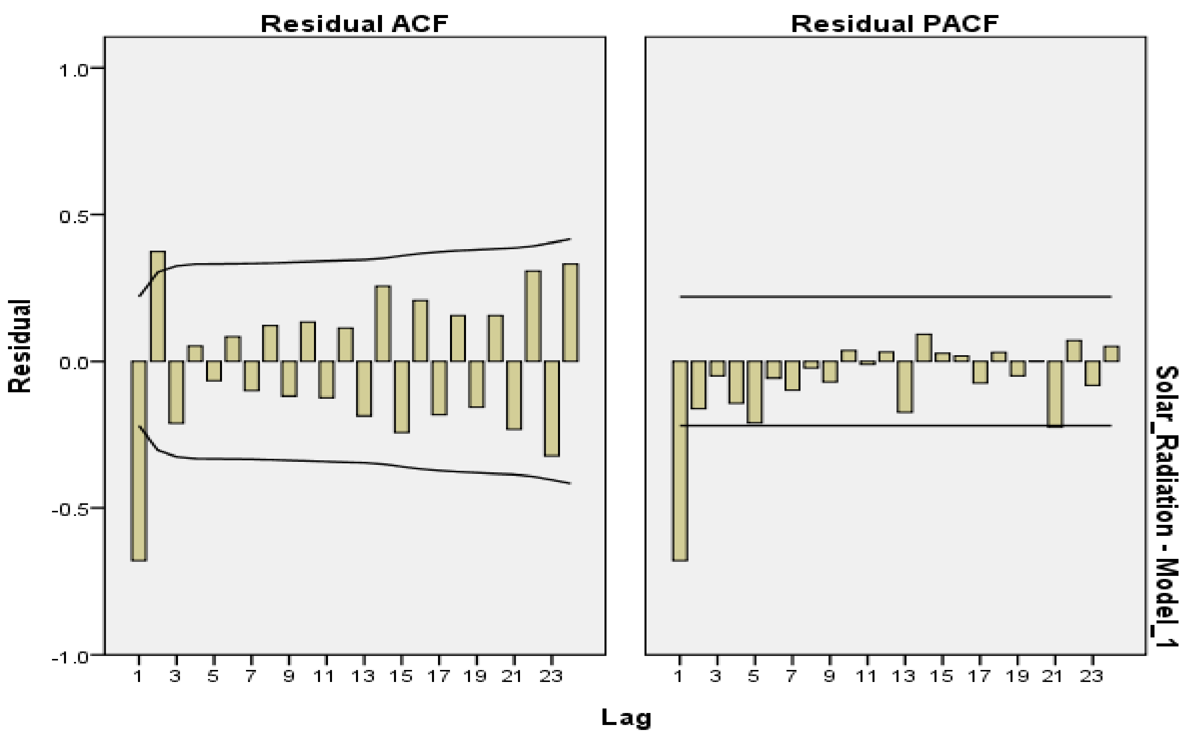

Figure 9: ACF and PCF of the time series data after differencing

Table 1. Comparing the models and choosing the best fit

ARIMA	RMSE	MAPE	MAE	BIC	P VALUE	Adjusted R-Squared value
1,1,1	19.780	0.680	12.867	6.079	0.000	0.999
0,1,1	36.436	1.684	32.166	7.246	0.005	0.998
1,1,0	30.825	1.262	24.231	6.911	0.000	0.999
1,0,0	99.682	3.064	44.898	9.258	0.000	0.986
1,0,1	98.713	2.904	41.945	9.2293	0.006	0.986

Note: ACF: Autocorrelation function, PACF: Partial autocorrelation function, MAPE: Mean Absolute Percentage Error, RSME: Root mean square Error, MAE: Mean Absolute errorBIC: Bayesian Inclusion Criteria

The frequency distribution of the diurnal average of net radiation is shown in figure 3, while figure 4 shows the time series plot of the solar radiation($MJm^{-2}day^{-1}$) average for the statistical model used.Table 1 revealed the best model with the lowest RSME and most importantly the lowest BIC, and this has made ARIMA (1,1,1) be the best model. Therefore, different Autoregressive Moving Average (ARMA) models were fitted to the Solar radiation ($MJm^{-2}day^{-1}$) data for the station considered and the parameter estimates of these models were shown in figure 6,7, 8 and 9.Following the distribution of the ACF and PACF of the different series in table 1, an ARIMA (1,1,1) model given by $z_t = 0.999z_{t-1} + 0.931a_{t-1} + a_t$ was identified. The model was then subjected to statistical diagnostic check using Ljung Box test statistics and normalized Bayesian Information Criterion (BIC). This analysis has proved that the model is statistically significant. It is also appropriate and adequate. More so, the fitted model was used to forecast values of the solar radiation and this shows a good representation of the original data which follows the same trend. Although, it shows clearly that the UCL and LCL are drifting away from the forecast. The result revealed that all the RMSE, MAPE and MAE terms in these models are significant. Analytically, the modelling of solar irradiance using a statistical package sometimes is difficult and requires some basic information for the completion of the Solar Irradiance Model (Aweda and Samson 2020). The significance of the Autoregressive (AR) terms in all the estimated models shows that the previous values of solar radiation have a significant effect on the present value of Net radiation while the significance of the Moving Average (MA) terms is an indication that the past errors in solar radiation also have a significant effect on the present value of Net radiation.

4. CONCLUSION

The net radiation (R_n) for May to August 2018 has been estimated using data set from USB wireless touch screen code N965Y at SERAC experimental station. It was observed that the (R_n) daily average, maximum and minimum radiation flux measured during the surface layer field experimental project in 2018 have their values to be at about $3.2 \times 10^8 Wm^{-2}day^{-1}$around 160th day of the year and its minimum at about $2.4 \times 10^8 Wm^{-2}day^{-1}$ and the temperature at 34^0C and 27^0C in June and August respectively. Therefore, as reported by Aweda et al., 2020, solar radiation got to its peak in February and March. Statistically, the study modelled for the solar radiation using different forms of ARIMA models, with the best forecasting ARIMA model to be ARIMA (1,1,1), (0,1,1), (1,1,0), (1,0,0) and (1,0,1) with ARIMA (1,1,1) as the best model. However, it is therefore concluded that the RMSE, MAPE, MAE and other statistical tools forecasted values of solar radiation between January 2018 and December 2018 with their corresponding 95% confidence levels indicate a good prediction of solar radiation for future occurrence in Net radiation study. Therefore, considering the important of R_n in weather prediction and climate studies, it is highly recommended by the authors that the government of the Federal Republic of Nigeria considers and provides funds to the Universities in Nigeria and research centres for their research purpose. Therefore, the study concluded that Iwo has maximum net radiation in June with other months such as July and August as minimum net radiation respectively for this research. More so, we recommend further research across the year to show the level of net radiation in Nigeria. Maximum radiation increases the possibility of generating electricity. So, it is, therefore, recommended that during the increase in radiation there should be proper harness of the solar energy for the generation of energy in the city. Since, the country is faced with the challenge of energy; the government is encouraged to make it a point of duty by providing all necessary support for the development of solar energy in the country.

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REFERENCES

Aweda, F. O., Akinpelu, J. A., Falaiye, O. A., and Adegboye, J. O. (2016). Temperature Performance Evaluation of Parabolic Dishes Covered With Different Materials in Iwo, Nigerian *Journal of Basic and Applied Science.24*(1), 90–97. https://dx.doi.org/10.4314/njbas.v24i1.14

Aweda, F. O. Oyewole, J. A. Falaiye, O. A., & Opatokun, I. O. (2018). Estimation 0f Evaporation Rate in Ilorin Using Penman Modified Equation. Zimbabwe Journal of Science and Technology. *13*(20), 20–25. Retrieved from https://www.researchgate.net/publication/331787585

Aweda, F. O., & Samson, T. K, (2020). Modelling the Earth's Solar Irradiance Across Some Selected Stations in Sub-Sahara Region of Africa, *Iranian (Iranica) Journal of Energy and Environment* 11(3): 204-211. https://doi:10.5829/ijee.2020.11.03.05

Aweda, F. O, Oyewole, J. A, Fashae, J. B., & Samson, T. K. (2020).Variation of the Earth's Irradiance over Some Selected Towns in Nigeria. *Iranian (Iranica) Journal of Energy and Environment,* 11(4): 301-307. https://doi:10.5829/ijee.2020.11.04.08

Bakry, M. M. E. (1994). *Theoretical and Applied Climatorogy Net Radiation Over the Aswan High Dam Lake*. *133*, 129–133.

El-Shal, A. O. , & Mayhoub, A. B. (1996). Estimating solar radiation as a function of air temperature using Fourier series. *Theoretical and Applied Climatology*, *54*(3–4), 153–159. https://doi.org/10.1007/BF00865158

Fao. (2013). Chapter 3 - Meteorological data. In *Webpage* (pp. 1–39).

Fritschen, L. J., & Simpson, J. R. (1989). Surface energy and radiation balance systems: general description and improvements. In *Journal of Applied Meteorology* (28(7),. 680–689).https://doi.org/10.1175/1520-0450(1989)028<0680:SEARBS>2.0.CO;2

Fritschen, L., & Qian, P. (1990). Net radiation, sensible and latent heat flux densities on slopes computed by the energy balance method. *Boundary-Layer Meteorology*, *53*(1–2), 163–171. https://doi.org/10.1007/BF00122468

Halldin, S., & Lindroth, A. (1992). Errors in net radiometry: comparison and evaluation of six radiometer designs. In *Journal of Atmospheric & Oceanic Technology* 9(6) 762–783).https://doi.org/10.1175/1520-426(1992)009<0762:EINRCA>2.0.CO;2

Harrison, E. F., Minnis, P., Barkstrom, B. R., Ramanathan, V., Cess, R. D., & Gibson, G. G. (1990). Seasonal variation of cloud radiative forcing derived from the Earth Radiation Budget Experiment. *Journal of Geophysical Research*, *95*(D11). https://doi.org/10.1029/jd095id11p18687

Holtslag, A. A. M. (1984). Estimates of diabatic wind speed profiles from near-surface weather observations. *Boundary-Layer Meteorology*, *29*(3), 225–250. https://doi.org/10.1007/BF00119790

Jegede, O. O. (1997a). Diurnal variations of net radiation at a tropical station - Osu; Nigeria. *Theoretical and Applied Climatology*, *58*(3–4), 161–168. https://doi.org/10.1007/BF00865016

Jegede, O. O. (1997b). Daily averages of net radiation measured at Osu, Nigeria in 1995. *International Journal of Climatology*, *17*(12), 1357–1367. https://doi.org/10.1002/(sici)1097-0088(199710)17:12<1357::aid-joc195>3.3.co;2-3

Jegede, O. O., Ogolo, E. O., & Aregbesola, T. O. (2006).

Estimating net radiation using routine meteorological data at a tropical location in Nigeria. *International Journal of Sustainable Energy*, 25(2), 107–115. https://doi.org/10.1080/14786450600593261

Jegede, O. O. (1995) Daily Averages of Net Radiation Measured at Osu, Nigeria In 1995. *International Journal of Climatology* 17: 1357-1367.

Ramanathan, V., Cess, R. D., Harrison, E. F., Minnis, P., Barkstrom, B. R., Ahmad, E., & Hartmann, D. (1989). Cloud-radiative forcing and climate: Results from the earth radiation budget experiment. *Science*, *243*(4887), 57–63. https://doi.org/10.1126/science.243.4887.57

Nielsen, L. B., Prahm, L. P., Berkowicz, R., &Conradsen, K. (1981) Net incoming radiation estimated from hourly global radiation and/or cloud observations. *Journal of Climatology*1(3): 255–272. https://doi.org/10.1002/joc.3370010305

Wallace, J. S., Gash, J. H. C., & Icrisat, M. V. K. S. (1990). Preliminary measurements of net radiation and evaporation over bare soil and fallow bushland in the Sahel. *International Journal of Climatology*, *10*(2), 203–210. https://doi.org/10.1002/joc.3370100207