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Impact of meteorological parameters over Covenant University, Ota, Nigeria

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Abstract. This study utilized monthly daily values of solar radiation, humidity, ultraviolet dose, temperature, pressure and wind speed obtained at Department of Physics, Covenant University, Ota, Nigeria, for 2013. It was observed that correlation coefficients vary from 0.134 - 0.955 across the months. This was further demonstrated with values of coefficient of determination R^2 which vary from 0.018-0.911 for Ota stations. Based on the RMSE, MPE, MBE and p values, we obtained an Equation that produces the best correlation. Our result reveals the models that produce the smallest p values which are considered as the best model for estimating the solar radiation at Ota site with an acceptable error. Also, Wavelet spectrum based approach was employed to analyse the meteorological monthly series in a sequence of monthly scales of January to December 2013.

1. Introduction

Solar radiation is the key parameter in the design of the solar energy devices used by engineers, agriculturist, hydrologist and architects. Solar energy received on the Earth surface is not equally distributed [1, 2]. Nigeria is among the nations with abundant solar radiation due to its tropical location. Utilization of solar energy is essential in Nigeria where there is insufficient supply of electricity generation and distribution. The amount of the solar energy received varies significantly with climatic condition and weather patterns of locations.

The direct beam and diffuse solar energy are produced from the global solar energy incident on a horizontal surface. Pyranometers, Solarimeters, or Actinography are instrument used to measure diffuse solar energy, while the Pyrheliometer device measure direct beam solar radiation. The measuring devices can be employed to develop an empirical model for solar energy that describes the numerical relations between the solar energy and the meteorological variables such as maximum and minimum temperature, relative humidity, pressure and wind speed.

Different models developed by different researchers for the prediction of solar radiation using different meteorological data [3, 4, 5, 6, 7]. These parameters include sunshine hours, relative humidity, sunshine duration, maximum and minimum temperature, cloud cover, vapor pressure and pressure. Numerical linear and nonlinear functions, artificial neural network and fuzzy logic have been presented by literatures in the prediction of solar energy [8, 9]. The correctness of the developed model in global solar radiation is evaluated using statistical analysis such as the mean error (MPE), mean bias error (MBE) and root mean square error (RMSE) and t-test statistics [9, 10, 11, 12, 13].

True prediction of the solar radiation in a given location depends on the exact determination of the strength of solar radiation at that location. Determining the correct method for evaluating the daily solar radiation on horizontal surface using obtainable data has influenced this research study. In this article, we present the measurement of solar radiation for Ota from reliable model pyranometer. We developed equations that correlate monthly average daily solar radiation with meteorological



parameters (solar radiation, humidity, ultraviolet dose, temperature, pressure and wind speed) for Ota, Nigeria. The Wavelet spectrum based approach was also employed to analyze the meteorological monthly series.

2. Data Analysis

Davis weather station was used for the experimental measurement. It incorporates Very Small Aperture Terminal (VSAT) satellite dish antenna, installed at the top-roof of College of Science and Technology of Covenant University, Ota. One minute data interval extracted for daily, monthly, and yearly for 2013. It is used for the experimental measurement which incorporates Very Small Aperture Terminal (VSAT) satellite dish antenna, installed at the top-roof of College of Science and Technology of Covenant University, Ota. The measurement is on the latitude 6.7° N and longitude 3.23° E while the elevation angle of the receiver antenna is 59.9° .

2.1 Correlation

Multiple linear regressions of five parameters (relative humidity RH, ultraviolet dose UV, temperature T, pressure P and wind speed WS) were employed to estimate the solar radiation for Ota. One variable correlation is presented as

$$SR = 355.3 - 2.256RH \quad (r = 0.255; R^2 = 0.065) \quad (1)$$

$$SR = 231.17 + 14.72T \quad (r = 0.782; R^2 = 0.612) \quad (2)$$

$$SR = 136.11 + 8.195W \quad (r = 0.134; R^2 = 0.018) \quad (3)$$

$$SR = 11397 - 11.126P \quad (r = 0.745; R^2 = 0.555) \quad (4)$$

$$SR = 128.10 + 3674.04UV \quad (r = 0.426; R^2 = 0.181) \quad (5)$$

Eq. 1 to Eq. 5 show the relationship between solar radiation and other variables (temperature T, pressure P and wind speed WS). It was observed that solar radiation correlated well with temperature. The correlation of 0.782 exists between the solar radiation and temperature, also coefficient determination is 0.612 implies that 61.2% of solar radiation can be accounted for using temperature. Two variables correlations:

$$SR = -314.79 + 16.010T + 19.41WS \quad (r = 0.841; R^2 = 0.708) \quad (6)$$

$$SR = -752.83 + 4.175RH + 20.61T \quad (r = 0.858; R^2 = 0.737) \quad (7)$$

$$SR = 11999 - 11.755P + 4253.9UV \quad (r = 0.893; R^2 = 0.797) \quad (8)$$

$$SR = 12295 + 18.456W - 12.062P \quad (r = 0.801; R^2 = 0.642) \quad (9)$$

$$SR = 109.43 + 7.40W + 3641UV \quad (r = 0.443; R^2 = 0.196) \quad (10)$$

$$SR = -260.68 + 1473T + 3682UV \quad (r = 0.891; R^2 = 0.795) \quad (11)$$

$$SR = 571.144 + 13.805T - 0.7702P \quad (r = 0.783; R^2 = 0.613) \quad (12)$$

$$SR = 16382 + 4.533RH - 16.45P \quad (r = 0.831; R^2 = 0.691) \quad (13)$$

$$SR = 361.5 - 2.6978.5RH - 12.68W \quad (r = 0.3248; R^2 = 0.105) \quad (14)$$

$$SR = -341.8 + 16.010W + 19.412T \quad (r = 0.842; R^2 = 0.708) \quad (15)$$

Two variable correlations were exhibited between Eq. 6 and Eq.15, we observed that solar radiation correlated well with pressure and ultraviolet dose in Eq. 8. The correlation of 0.893 exists between the solar radiation pressure and ultraviolet dose, the coefficient of determination is 0.797 implies that 79.9 % of solar radiation can be accounted using pressure and ultraviolet dose. Three variables correlations

$$SR = -340.15 + 15.97T + 18.59W + 3602.8UV \quad (r = 0.842; R^2 = 0.708) \quad (16)$$

$$SR = 5258.36 + 4.600RH - 5.82P + 14.28T \quad (r = 0.867; R^2 = 0.751) \quad (17)$$

Three variable correlations were exhibited between Eq. 16 and Eq.17. We observed better correlation in Eq. 17 between solar radiations with relative humidity, pressure and temperature. 0.867 is the correlation that exists between the solar radiation with relative humidity, pressure and temperature. 0.751 is the coefficient of determination; this implies that 75.1 % of solar radiation can be accounted for using relative humidity, pressure and temperature. Four variables correlations

$$SR = -482.1 + 17.60T + 17.86W + 3084.8UV + 1.19RH \quad (r = 0.942; R^2 = 0.889) \quad (18)$$

$$SR = 4890.9 + 4.160RH - 5.48P + 15.15T + 16.57W \quad (r = 0.905; R^2 = 0.820) \quad (19)$$

Four variable correlations were exhibited between Eq. 18 and Eq.19. We observed better correlation in Eq. 18 between solar radiations with temperature, wind speed, ultraviolet dose and relative humidity. 0.942 is the correlation that exists between the solar radiation with temperature, wind speed, ultraviolet dose and relative humidity. 0.889 is the coefficient of determination; this implies that 88.9 % of solar radiation can be accounted for using temperature, wind speed, ultraviolet dose and relative humidity. Five variables correlations:

$$SR = 6904.4 + 9.62T - 7.136P + 17.68W + 3268.5UV + 1.57RH \quad (r = 0.955; R^2 = 0.911) \quad (20)$$

Five variables in Eq. 20 exhibit relationships between solar radiation with temperature, pressure, wind speed, ultraviolet dose and relative humidity, 0.955 is the correlation that exists between the solar radiation with temperature, wind speed, ultraviolet dose and relative humidity. 0.911 is the coefficient of determination; this implies that 91.1 % of solar radiation can be accounted for using temperature, pressure, wind speed, ultraviolet dose and relative humidity.

The RMSE, MBE, MPE and p-values were computed to show the correctness of the estimated values in Eq. 21- Eq.24 (see Table 1).

$$RMSE = \left\{ \left[\frac{1}{n} \sum (SR_{pred} - SR_{obs})^2 \right] \right\}^{\frac{1}{2}} \quad (21)$$

$$MBE = \frac{1}{n} \left[\sum (SR_{pred} - SR_{obs}) \right] \quad (22)$$

$$MPE = \frac{[\sum (SR_{obs} - SR_{pred}) \times 100]}{n} \quad (23)$$

$$P = r \sqrt{\frac{(n-2)}{(1-r^2)}} \quad (24)$$

where SR_{pred} , SR_{obs} , n and r are the predicted, observed, no of samples and correlation coefficient respectively.

Table 1. Correlation and Statistical Indicators

Equations No	r	R ²	RMSE	MBE	MPE	P-VALUES
1	0.255	0.065	22.905	3.671E-14	-2.049	0.424
2	0.782	0.612	14.750	-1.776E-14	-0.839	0.003
3	0.134	0.018	23.475	-3.434E-14	-2.197	0.678
4	0.745	0.555	15.796	-7.970E-14	-0.929	0.005
5	0.426	0.18	21.432	-8.290E-15	-1.845	0.167
6	0.841	0.708	12.793	-2.487E-14	-1.062	0.001
7	0.858	0.736	12.151	4.026E-14	-0.593	0.000
8	0.893	0.797	10.677	5.921E-14	-0.429	0.000
9	0.802	0.643	13.745	1.906E-13	-0.783	0.003
10	0.443	0.196	18.680	-2.013E-14	-1.833	0.191
11	0.891	0.795	10.737	1.421E-14	-0.468	0.000
12	0.783	0.613	14.746	-7.105E-14	-0.836	0.003
13	0.831	0.691	13.177	8.491E-13	-0.644	0.001
14	0.326	0.106	19.342	-1.303E-14	-1.991	0.539
15	0.842	0.708	12.793	2.487E-14	-0.679	0.001
16	0.939	0.882	8.116	2.250E-14	-0.497	0.000
17	0.867	0.752	11.803	7.460E-14	-0.015	0.000
18	0.943	0.889	7.891	-4.832E-14	-0.311	0.000
19	0.906	0.820	10.039	-8.657E-13	-0.435	0.000
20	0.955	0.911	7.065	-8.704E-13	-0.242	0.000

2.2 Wavelet Power Spectrum

Wavelet transformation is an important mathematical device that generates a time-frequency representation in the time domain signals [14, 15, 16, 17]. These mathematical devices can be used in meteorology and climatology parameters investigation. It is now a day to day device for examining variation of power within a time series. Braking down time series into time-frequency space, it is an easy ways to establish both the variability of dominant modes and to examine its variation dominate modes with time. This section, we examined the wavelet analyses of wind speed, temperature and relative humidity data obtained from department of physics, Covenant University, Ota. The wind speed, temperature and relative humidity were examined using wavelet power spectrum analysis (see Figure 1(a-c)).

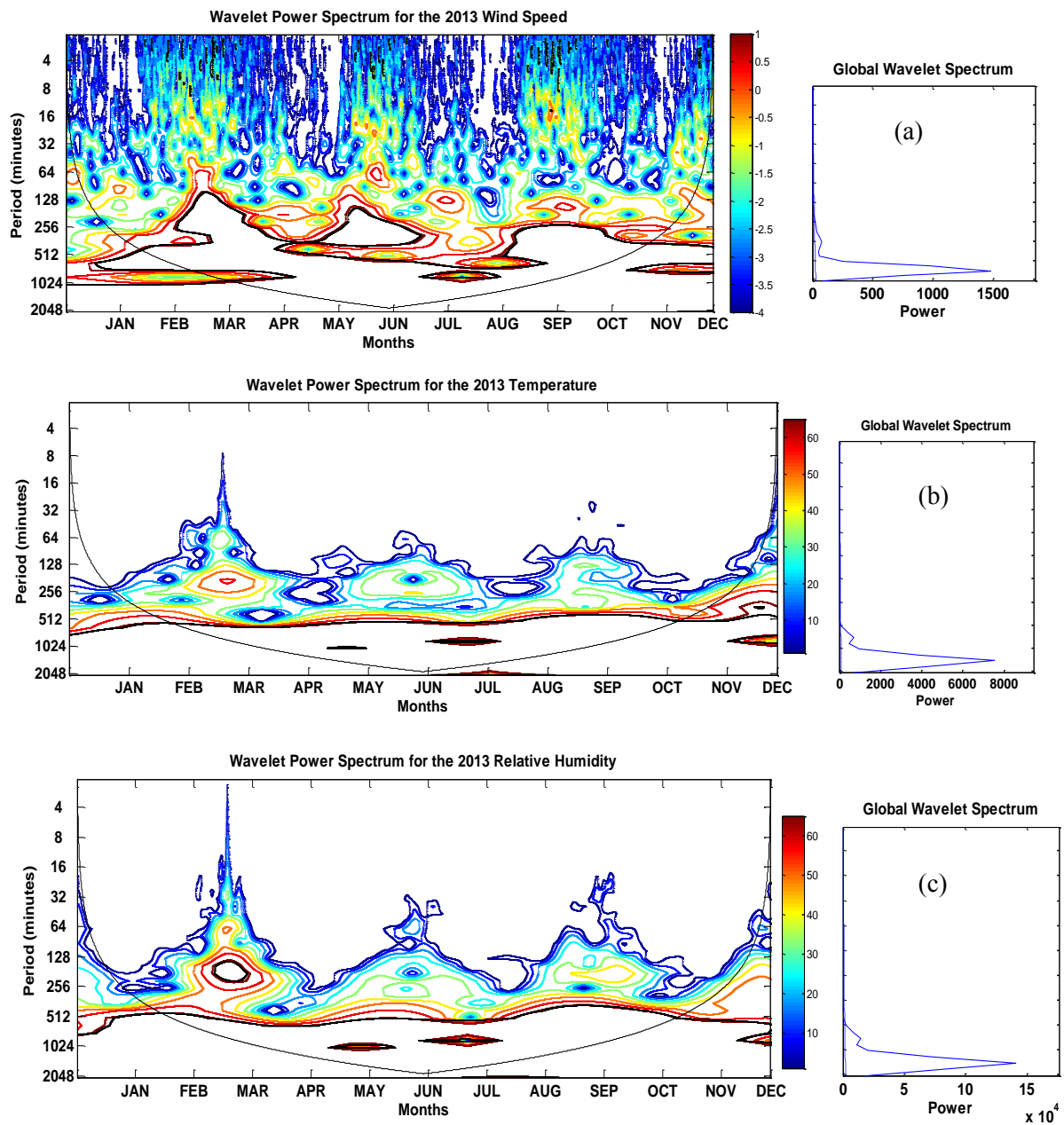


Figure 1. (a-c) Wavelet Powers Spectrum (WPS) and Global Wavelet Spectrum (GWS) of wind speed, temperature and relative humidity.

3. Discussion of the results

The monthly global solar radiation was estimated using relative humidity, maximum temperature, Ultraviolet radiation, pressure and wind speed to develop regression coefficient. Table 1 presented regression statistics that is correlation coefficient r , coefficient of determination R^2 obtained from Eq. (1) - Eq. (20). The MBE, RMSE, MPE and p values are computed from Eq. (21) – Eq. (24). We obtained positive and negative values of MBE across the models. This depicts that the models vary from over to under approximation of solar radiation. The RMSE is often used to evaluate the variation between values predicted by a model. MPE provides long term performance of the examined regression equations. A low value of MPE is sensible. The correlation coefficient is significant if the calculated t is higher than the critical t ($P = 0.05$). In summary, correlation coefficients vary from

0.134 - 0.955 across the months. This implies that, there are statistically significant relationships between the solar radiation, the relative humidity, maximum daily temperature, ultraviolet and wind speed, this is further demonstrated with values of coefficient of determination R^2 vary from 0.018-0.911 for Ota stations. The best model is obtained from Equation 20 based on the statistical computation of RMSE, MBE, MPE and p values and with high correlation coefficient as shown in Tables 1. From our result, the models that produce the smallest values of the p values is considered as the best model for estimating the solar radiation at Ota site with moderate error. This means that the models of equations (20) and (18) are good estimate for the solar radiation in Ota location during the period time in the present study.

Figure 1(a-c) shows the WPS (wavelet power spectrum) and GWS (global wavelet spectrum). The colours in the WPS denote signal energy, which is referred to as magnitude of wavelet transforms. The frequency giving maximum to the energy of the signal over the period is denoted with red colour. We observed that that periodic cycle bands of 512-1024 minutes bands have the highest variability (strongest intensity) during January - April, July - August and November- December months. This implies that these time series have a strong annual signal. The large empty space signifies the missing data gaps. The GWS power decreases with increase in wind speed, pressure, temperature and relative humidity which suggest decrease in variability (see Figure 1a). As for the periods of variations of monthly average of temperature (Fig. 1b), the periodicity is characterized by 12months period. It is noted that at 256-540 period show more concentration of power of high temperature from November to March. Figure 1c depicts periodicity properties of monthly average of relative humidity of Ota area. The 1-year period is significant and dominant in the May-July with low surface temperature, high relative humidity within the periodicity of relative humidity of Ota. The relative humidity increases when the air temperature dropped due to presence of moist air. When the temperature decreases, the relative humidity was at peaks, meaning that the amount of rainfall depended on relative humidity, but independent of maximum temperature.

4. Conclusion

Different variables were engaged in the study solar radiation, humidity, ultraviolet dose, temperature, pressure and wind speed to obtained Eq. (1) - Eq. (20). Based on the RMSE, MPE, MBE, r , R^2 and p values, Equation (20) produces the best regression correlation, while Equation (3) give the weakest regression correlation with high values of RMSE, MPE, p-value and low values of r , and R^2 . The equation could be employed to estimate solar radiation of Ota location in the South- west, Nigeria.

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