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Application of regression and multiple correlation analysis to morning hours solar radiation in Lapai

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Solar radiation in Lapai within the morning hours has been estimated by correlating meteorological parameters. This was achieved by applying the first and second order regression and multiple correlation analysis method. The correlation coefficient based on the first and second order equations in temperature and relative humidity were 0.828, 0.692, 0.860 and 0.622 while the correlation coefficient based on the multiple correlations between solar radiations, temperature and relative humidity were 0.351. Validity tests were carried our using mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE). The tests show that the errors were minimal in the first order equations in temperature and relative humidity. Comparison of the measured and predicted values of solar radiation based on the relative humidity and average temperature first order equations show a close agreement, and suggests the best equations to be used in estimating solar radiation in Lapai and its similar climatic condition.

Key words: Solar radiation, multiple regression, correlation coefficient, meteorological parameter-temperature, relative humidity.

INTRODUCTION

Solar radiation is the energy from the sun reaching the earth and is important in understanding the land atmosphere energy exchange (Liang et al., 2012). It is the driving force of both the physical and biological cycles on the earth. Consequently, it then becomes pertinent to have very good knowledge of current and past records of solar radiation at a location so as to aid in the estimation of the performance of any solar energy system. Pyrheliometer and pyranometer are instruments used readily to obtain the diffuse component of solar radiation and the global solar radiation, respectively. Meteorological stations have been used mostly for this purpose. However, there are a few of such stations across the globe and worse still in the developing countries. In order to develop solar radiation data, researchers had extrapolated values from one location for application in a different location. Hence, solar radiation prediction from estimation models has been widely utilized globally to generate solar radiation database for various location of the world. There are numerous statistical techniques of estimating solar radiation and each method is based on different principles. The first empirical correlation using sunshine hours for estimation of solar radiation was proposed by Angstrom (Ahmad and Ulfat, 2004). This model was later modified by Prescott and Page (Page, 1961; Ahmad and Ulfat, 2004; Maghrabi, 2009) in which the model is given as:

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right),$$

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Table 1. Climate parameters.

Parameter	Unit
Average temperature (T_{av})	°C
Relative humidity (R)	%
Solar radiation (H)	W/m^2

Where H is the monthly average daily global radiation on horizontal surface, H_o is the monthly average daily extra-terrestrial radiation, S is the length of the day, S_o is the maximum possible sunshine duration, and *a* and *b* are constants.

Since this development, there have been other models such as Rietveld, Bahel, Glover, Hay and Grag models (Mahdi et al., 1992). Akpabio et al. (2005) developed the quadratic form of Angstrom-Prescott model and used it to estimate the global solar radiation at Onne, Nigeria (latitude 4° 46′ N, Longitude 7° 10′ E). Multi-linear polynomial form of the Angstrom-Prescott model was employed by Agbo et al. (2010) to estimate global solar radiation at Minna, Nigeria. Various other models employing other meteorological parameters with one or more variables with solar radiation have also been used. The estimation of the solar radiation at Uturu in Nigeria was carried out using an equation relating solar radiation and temperature (Chiemeka, 2008). Agbo (2012) had also estimated 'global' solar radiation at Onitsha using regression

analysis and artificial neural network models with the attendant parameters of temperatures and relative humidity. Lapai is in Niger State of Nigeria and is located at latitude 9.05° N and longitude 6.05° E. The main stay of the economy in Lapai is agriculture and solar radiation is an important parameter for agriculture. However, the availability of such vital data is not readily available. Due to the present economic hardship in Nigeria, there is every tendency for having problems of maintaining and purchasing the instrument used in measuring the meteorological parameters in the meteorological stations.

The solution to this problem has motivated one into the need for an empirical modeling for estimation of solar radiation that will be affordable and easily maintained as it uses mathematical, statistical correlation and regression analysis for computation. The first time solar radiation was being measured in Lapai is in 2010 and even as that the measurements were not consistent due to instrument and power failure. Sometimes, when one wants to get the value of instant solar radiation to test the functioning of solar devices or to have idea or past records at any particular time so as to forecast crop yield for the next season, the instruments for measuring the solar radiation are not found or faulty. It is by this reason that this paper is written. Thus, the aim of this work is therefore to develop a relation between solar radiation with temperature or relative humidity or both for morning hours in Lapai. The morning hour records of 5 min intervals are the only record retrieved and made available by the recorder.

MATERIALS AND METHODS

The data (maximum and minimum temperatures, relative humidity and solar radiation) used in this study were obtained from the weather station located at Geography Department of Ibrahim Badamasi Babangida University, Lapai (IBBUL), Niger State, Nigeria. The data were collected at 5-min interval in the year 2010 and cover a time period of 9.30 to 10.30 am as there were inconsistency and missing data at early hours of the morning. The data were averaged over days that have meaningful records. The minimum and maximum temperatures were averaged to obtain the average temperature at each time interval. Table 1 shows the climatic parameters obtained with their units. In regression analysis, the first and second order regressions of normal equations were employed to estimate the morning hours global solar radiation as, thus, following the treatment in Agbo (2012); we have:

$$a + bx = y \tag{1}$$

$$a + bx + cx^2 = y \tag{2}$$

Where *a* and *b* are constants which will be determined. *y* is the same as solar radiation (H) and it is the dependent variable. *x* is the independent variable which can be replaced by any of the meteorological parameters such as average temperature and relative humidity.

To carry out the regression analysis of the first order, both sides of Equation 1 is multiplied by one and summed on both sides to yield Equation 3. Equation 1 also is multiplied by *x* and summed on both sides to yield Equation 4:

$$aN + b\Sigma x = \Sigma y \tag{3}$$

$$aN\Sigma x + b\Sigma x^2 = \Sigma xy \tag{4}$$

Applying the variables T_{av} and R for average temperatures and relative humidity respectively, as the independent variable in Equation 1 for first order regression we obtain:

$$a_1N + b_1T_{av} = H_1 \tag{5}$$

$$a_2N + b_2R = H_2 \tag{6}$$

To obtain the second order regression equation, Equation 2 is multiplied by 1, *x* and x^2 successively and summed to obtain the following equations:

$$a_1N + b_2\Sigma x + c_3\Sigma x^2 = \Sigma y \tag{7}$$

$$a_1N\Sigma x + b_2\Sigma x^2 + c_3\Sigma x^3 = \Sigma xy \tag{8}$$

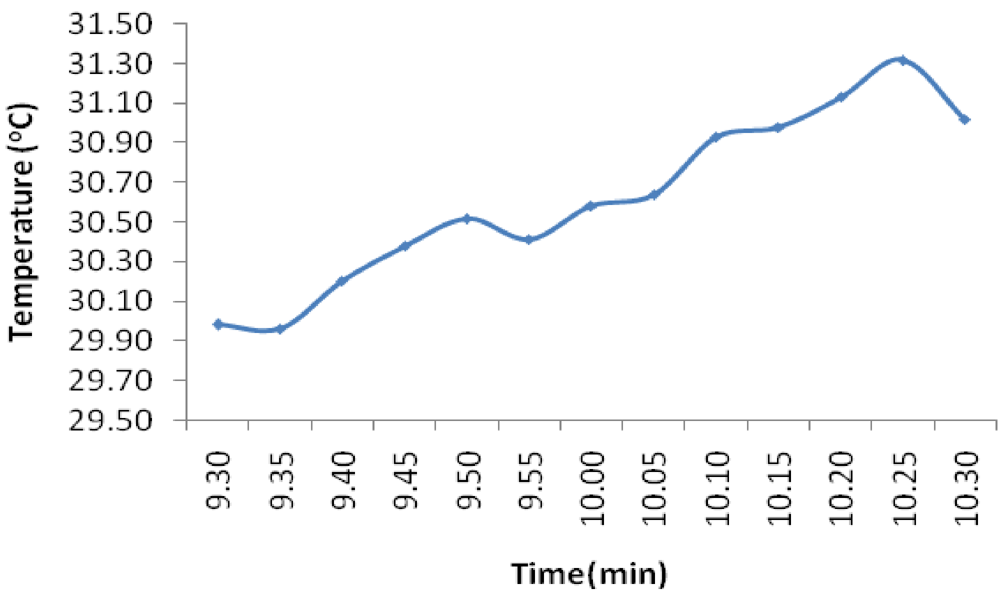

Figure 1. Variation of temperature with time in Lapia.

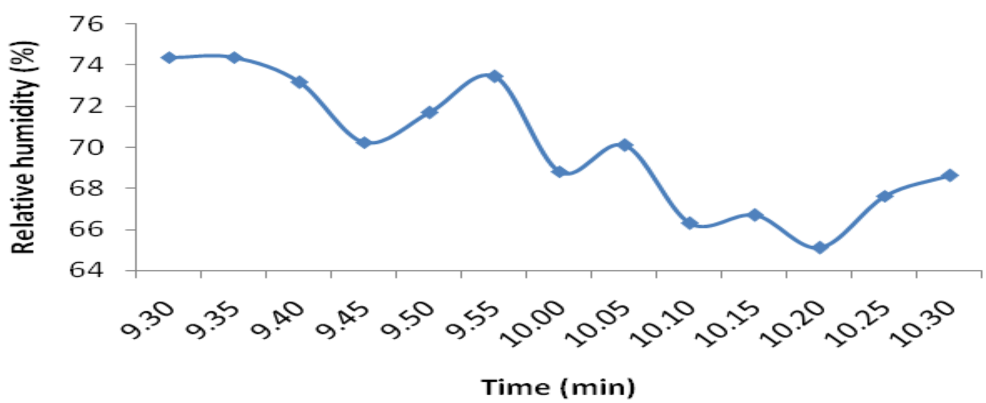

Figure 2. Relative humidity variation during the morning hours in Lapia.

$$a_1 N\Sigma x^2 + b_2 \Sigma x^3 + c_3 \Sigma x^4 = \Sigma x^2 y \quad (9)$$

Applying these equations by using our independent variables such as average temperature and relative humidity, we obtain:

$$a_3 + b_3 T_{av} + C_3 T_{av}^2 = H_3 \quad (10)$$

$$a_4 + b_4 R + C_4 R^2 = H_4 \quad (11)$$

RESULTS AND DISCUSSION

Figures 1 and 2 are the plots of the measured temperature and relative humidity as against time in Lapai. From the temperature plot (Figure 1), it shows that there is a continuous increase in temperature at early morning hours of the day while the relative humidity plot (Figure 2) shows a downward trend from early hours to before noon time hours. The trend variation as observed in temperature and relative humidity suggests that solar insolation at early morning hours in Lapai causes changes in the weather parameters. Figures 3 and 4 show the scatter plot of solar radiation against average temperature, and solar radiation against relative humidity, respectively. Despite the large amount of scattered points, definite correlations between them do exist. The large amount of scattered data is partly attributed to error in estimation of the solar radiation at 5-min intervals.

The first and second order regression equations obtained in this work using the average temperature and relative humidity are as follows:

$$H_1 = -2715.96 + 105.72 T_{av} \quad (12)$$

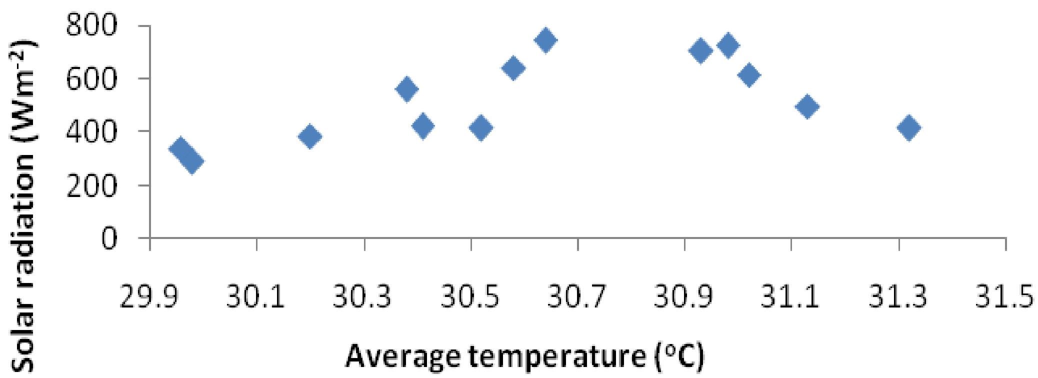

Figure 3. Scatter plot of solar radiation against average temperature.

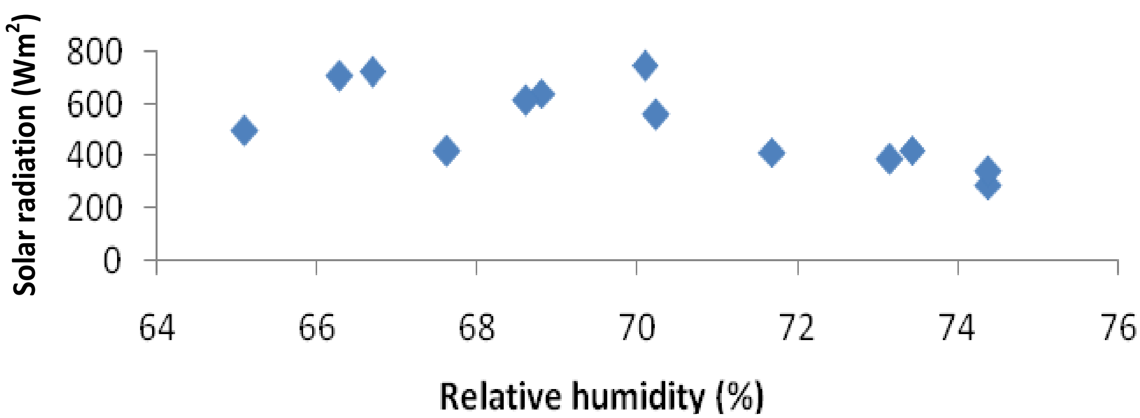

Figure 4. Scatter plot of solar radiation against relative humidity.

$$H_2 = 2883.77 - 33.094R \quad (13)$$

$$H_3 = -5011.04 + 175.08T_{av} + 0.81T_{av}^2 \quad (14)$$

$$H_4 = 698.60 - 1.70R - 0.012R^2 \quad (15)$$

The multiple regression equation of solar radiation with average temperature and relative humidity were obtained as:

$$H_5 = -20.89R + 64.77T_{av} \quad (16)$$

The correlation based on the average temperature alone is obtained as 0.828 and relative humidity alone is 0.860. The estimated results from each of the average temperature and relative humidity show a closer agreement to the measured data than that predicted from the correlation based on the average temperature and relative humidity taken together. A comparison of the result of Equation 12, 13, 14, 15 and 16 indicates that the correlation of Equation 13 based on the relative humidity alone and Equation 12 based on average temperature alone should be employed for computing solar radiation in the morning hours in Lapai. The deviations between the measured and estimated values of the solar radiation have been evaluated. This is in an effort to test the validity of the equations for the solar radiation. As seen from Table 2, the percentage errors are very small and the equations may be taken as valid equations for estimating solar radiation in the morning hours in Lapai. The validity of the equations were also tested using mean bias error (MBE), root mean square error (RMSE) and correlation coefficient (CC) which gave good results as seen in Table 2.

Figure 5 shows the relationship between the measured solar radiation and the estimated solar radiation using each of the equations as aforementioned.

Conclusion

In this study, an attempt has been made at estimating solar radiation based on meteorological data at IBBUL.

Table 2. Summary of calculations.

Equations	CC	CD	MBE	RMSE	MPE
$H_1 = -2715.96 + 105.72T_{av}$	0.828	0.686	-0.189	0.682	0.003
$H_2 = 2883.77 – 33.094R$	0.860	0.740	0.004	0.016	-0.001
$H_3 = -5011.04 + 175.08T_{av} + 0.81T_{av}^2$	0.692	0.479	0.419	1.152	-0.006
$H_4 = 698.60 – 1.70R – 0.012R^2$	0.622	0.387	-0.217	0.782	0.003
$H_5 = -20.89R + 64.77T_{av}$	0.351	0.123	0.538	1.939	0.008

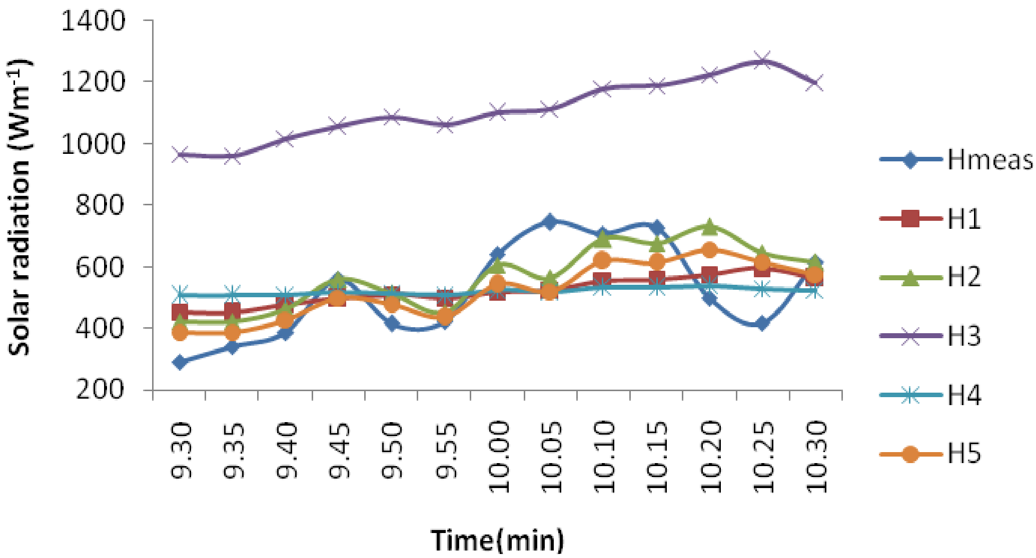

Figure 5. Measured and estimated values of solar radiation.

The results of the estimated values show a closer agreement to the measured data. The results were obtained using first and second order regression and multiple regression analysis which portrays a good correlation. The deviations between the measured and estimated values were minimal. The results from this analysis will greatly reduce the problem associated with waste of time and lack of efficient instruments. It will also be an easy way to present data and ensure that data never runs out. This will also allow user of the data to track information of solar radiation data in Lapai.

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