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RESEARCH ARTICLE

MODELING SURFACE SOLAR RADIATION USING A CLOUD DEPTH FACTOR

Terry Henshaw[1], Ify L.Nwaogazie[2*] and Vincent Weli[3]

[1,2]Department of Civil and Environmental Engineering, University of Port Harcourt, Rivers State
[3]Department of Geography & Environmental Science, University of Port Harcourt, Rivers State

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ABSTRACT

Two models are developed based on Lumb's formula. Model 1 was developed by establishing cloud depth factors which are dependent on temperature alone, while model 2 was developed by establishing cloud depth factors which are dependent on temperature and humidity. Based on meteorological data measured with Davis weather station and TES solar meter, the original Lumb's model predicted surface solar radiation with a mean square error (MSE) of 54,845,911.4. The modified Lumb's model also predicted solar radiation with a mean square error of 61,519.4482. Developed models 1 and 2 (DM1 & DM2) recorded mean square errors of 44,500.436 and 43,620.40822, respectively. Data from random days were used for verification and results showed the least mean square error of 11,057.64914 for DM2. The importance of considering depth as a factor when estimating cloud cover is proven by analyzing existing models which were observed to predict poorly because cloud cover was estimated as a surface entity. DM2 proved the best model for hourly surface solar radiation predictions as it has the least mean square error. This empirical model should be adopted by environmental engineers in predicting hourly surface solar radiations because it considers cloud depth.

INTRODUCTION

Solar radiation as a source of energy from the sun has its unique importance. It is majorly used to estimate atmospheric stability which is used by the power engineers for estimating amount of energy that can be harnessed from the sun and the environmental engineer the rate at which dispersion/inversion will take place at proposed emission points. Unlike the power engineer who is satisfied with daily/ weekly/monthly estimates of solar radiation, the environmental engineer needs more details (hourly estimates) because it is a sensitive aspect which affects human health.

There are about 100 formulas for estimating the surface insulation (Kondo and Miura, 1983). They are basically categorized according to time scale which are hourly (Lumb, 1964), daily (Kimball, 1928; Reed, 1977; Kondo and Miura, 1985) and weekly (Tabata, 1964). Since 1980's satellite imagery data have been adopted in preference to surface insulation estimation and this method have been checked to have a root mean square error (RMSE) of 10% for monthly values (Schmetz, 1989). However for areas where such techniques are unavailable we are left with empirical formulas to use.

Atmospheric stability is the measure of the atmosphere to allow vertical movement. This is a very important aspect of air pollution modeling as it has been proven that very unstable atmosphere promotes the vertical movement of pollutants. Atmospheric stability is estimated by considering surface velocity and solar radiation reaching the earth's surface. According to Klien (1948) the most difficult but important step in computing solar radiation is to determine depletion by cloud cover. The solar radiation outside the earth's atmosphere is referred to as the extraterrestrial radiation; some researchers have taken it as a constant value while others have seen it to vary slightly globally. The radiation on the earth's surface becomes difficult to estimate as factors like water vapor, upper/lower atmospheric dust, cloud cover and dry air are continuously intercepting it. Of all these components listed cloud cover is the most important factor that can absorb up to 75% of the extraterrestrial radiation.

Till recent time, cloud cover which as the major absorbent of solar radiation has no direct method of estimation. Researchers have so far adopted estimation through visual observation where the sky is divided into 8 parts called *okta* and the number of parts covered with clouds is visually estimated. If there are no clouds then this is referred to as zero *okta* and if the skies are completely covered with clouds then we have a maximum of 8 *okta* (Ask, 2015).

The main issue on the visual observation method of estimating cloud cover are in the thickness (opaque) and thinness

Corresponding author:* **Ify L. Nwaogazie
Department of Civil and Environmental Engineering, University of Port Harcourt, Rivers State

(transparent) of the cloud. The clouds may completely cover the skies but may be so thin that the extraterrestrial radiation will easily break through it. On the other hand the skies may be partly covered but the clouds may be so thick that they absorb all the extraterrestrial radiation. Another issue is that of being able to predict without visually accessing the sky.

Solar radiation on the earth's surface depends on time, position, altitude, solar declination and observed position of inclination which can be over looked when measurement are considered on a horizontal surface. Works of Crair (2014) have shown that on a clear sky day approximately 1000W/m^2 of solar radiation reaches the earth's surface which means other components other than cloud cover account for approximately 25% of the loss of radiation through absorption and scattering. Many works have been carried out on the development of models to estimate solar radiation (Kimbal, 1928; Kizu, 1997; Okpani and Nnabuchi, 2008; and Mghouchi & others, 2014). Some of these models are either empirical or analytical and what they have in common is that all of them have considered cloud cover through visual estimation either using the *okta* technique or directly estimating it as a fraction of the sky cloud cover on a scale from 0 (0%, no cloud) to 1.0(100%, complete coverage).

In this study, we developed two improved empirical models for estimating surface solar radiation, verified the models, used them to predict surface solar radiation on the earth's surface and compared them with two other existing models.

MATERIALS AND METHOD

Study Area

The study positions within the study area are Ozouba – Rumuosi link (latitude $4^0 52.379'$N and longitude $6^0 24.0'$E) which is between Ozouba and Rumuosi villages in Port Harcourt metropolis. It is a residential area with small scale businesses scattered around. The tallest buildings in the area are two storey buildings and are approximately 9 metres tall. Figure 1 shows the study position represented on the map of Rivers State, Nigeria.

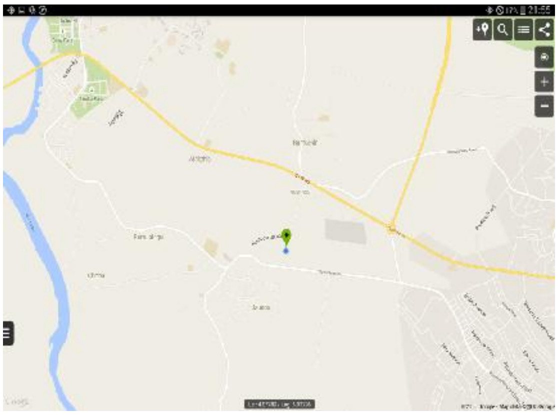

Figure 1 Map of Rivers State showing Study Area (Ozuoba Location indicated with green maker)

Measuring Instruments

The instruments used for this study are as follows:

i) A solar meter (TES model)
ii) A weather station (Davis Vantage due model); and
iii) A data logger device combined with analysis software.

Procedure

The solar meter (TES model) was used to measure solar radiation in watts per square metre on the earth's surface. The measurement was carried out at interval of 30 minutes between sun rise and sun set. Every reading of the radiation was accompanied by cloud cover observation using the *okta* method. A weather station (Davis due model) was mounted at 10 meter height. The weather station logs out data such as wind speed, precipitation amount, humidity, temperature and wind speed. The data logger device combined with analysis software was used to continuously log out data from the weather station into a data base. The duration of data collection was for 3 months in the rainy season (May 5 to August 11, 2015). These set of data were used to calibrate the empirical DM1 and DM2.Comparisons of the developed, models (DM1 & DM2) and existing models were made for hourly estimation of surface solar radiation.

Existing Models on Solar Radiation

The extraterrestrial radiation has been widely accepted as a constant value of 1367 W/m^2 by most researchers (Mghouchi, 2014). The formulas for estimating the true solar time, equation of time, hour angle, solar declination and solar altitude are presented as Equations (1) - (5).

True solar time

$$t_a = t_c + \frac{(M_{local} - M_{standard})}{15} + \frac{EOT}{60} \quad \text{..... (1)}$$

Where: t_a = actual time; t_c = current time; M_{local} = longitude of the reference point;

$M_{standard}$ = longitude of a standard reference point; and EOT = equation of time

Equation of time

$$EOT = 450.8 \sin\left(\frac{2\pi J}{365} - 0.026903\right) + 595.4 \sin\left(\frac{4\pi J}{365} + 0.352835\right) \quad \text{..... (2)}$$

Where: J = Julian number with 1 as the 1st day in the year

Hour angle

$$w = 15(12 - t_a) \quad \text{...... (3)}$$

Where: w = solar angle

Solar declination

$$\delta = 23.45 \sin(0.986(J + 284)) \quad \text{....... (4)}$$

Where: δ = solar declination

Solar altitude

$\sin h = \sin\phi \times \sin\delta + \cos\phi \times \cos\delta$ ………(5)
Where: h = solar altitude; ϕ = latitude of the reference point

Lumb's Original Model

Lumb's equation as presented by Geenaert and Plant (1990) was developed in 1964 and it is one of the most popular equations for surface solar radiation prediction on hourly basis (see Equation (6))

$E_s = 1350 \times (A + Bs) \times s$ …... (6)

Where:E_s= surface solar radiation; A & B = empirical constants based on nine categories of cloudiness (*okta*); and s = solar altitude

Till date most of the hourly surface solar radiation prediction formulas have been developed from Lumb's concept, while some have used different solar constants. The solar radiation monitoring laboratory of the University of Oregon (USRML, 2002) has in a report tagged solar radiation basics revealed that the percentage of the total extraterrestrial radiation passing through the atmosphere is 76%. Others have carried out studies and tagged it at value close to 76 %.

Modified Lumb's Model (Sharma, 2006)

The modified Lumb's model as presented by Sharma (2006) which incorporates an analytical component (the 3rd term in Equation (7a)) that uses cloud cover to estimate hourly surface solar radiation and this replaces the empirical component $(A + B)$ in the original Lumb's model.

$R = \left(\frac{2}{3}\right)\times s\times\left(1 - \frac{0.8C}{8}\right)\sin h$ ………(7a)

Where: s = solar constant of 1367W/m^2; C = cloud cover in *Okta*; h = solar altitude.

From Equation (7a) the factor 2/3 is the percentage of extraterrestrial solar radiation that reaches the earth's surface on clear sky day.

RESULTS

Model Development & Calibration

Equation (6) was used to predict solar radiation of August 4, 2015. Based on the Lumb's method, the cloud cover measurements were regressed against the solar altitude to obtain the empirical parameters (A and B) of Equation (7b). Figure 2 shows the regressed model and thus Equation (7b) becomes (7c).

Y=A+Bs …… (7b)

Y = 10.231x ...… (7c)

Where: A=0; and B = 10.231, respectively.

Equation (6) is thus modified to Equation (8), for the study area.

$E_s = 1350 \times (10.231s) \times s$=$13810s^2$ ……..(8)

Equation (7a) was also used to predict solar radiation of the same day as Equation (6) and the square mean errors (SME) of the two predictions were estimated. A Microsoft excel simulator was developed for this purpose. Figure 3 shows the observed radiation compared with that predicted from Lumb's original equation (Equation (8)) and the modified version as presented by Sharma (2006) in the National Program on Technology Enhanced Learning (NPTEL) lectures series (see Equation (7a)).

The square mean error of Lumb's original model = sum of error difference / sample points = $\frac{1{,}481{,}000{,}000}{27}$ = 54,845,911.4.
The square mean error of Lumb's modified model (Sharma, 2006) = sum of error diff / sample points = $\frac{1{,}661{,}025{,}107}{27}$ = 61,519.4482

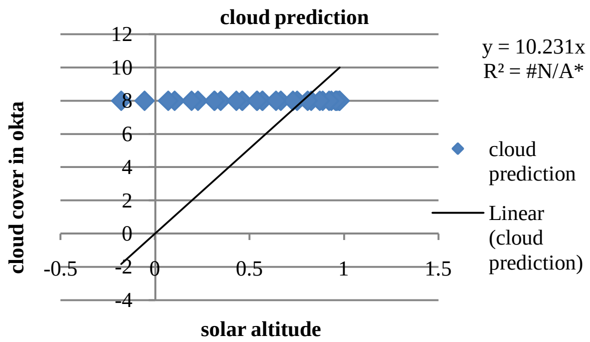

Figure 2 Regression of cloud cover in okta against solar altitude (using Data of August 24, 2015).

*the regression value is not applicable because the cloud cover for that day was 8 okta all through which means the different solar altitudes were regressed against the same value

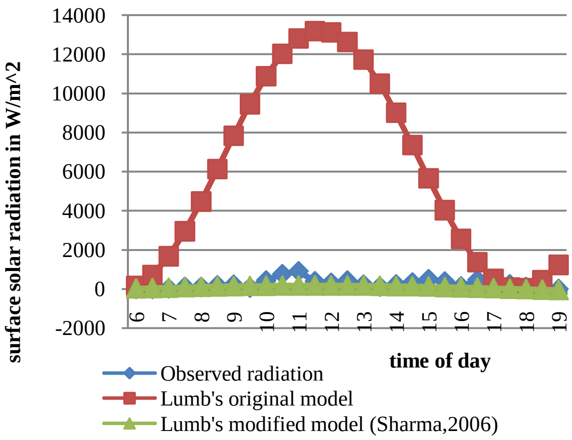

Figure 3 Measured solar radiation compared with Lumb's original formula and NPTL modified

Development of Model 1 (DM1)

One of the two models developed in this study (Developed Model 1, DM1) is a modified version of the original Lumb's model, which has an empirical component that regresses temperature against selected cloud depth factors and this replaces the empirical component in the original Lumb's model. In effect, Equation (6) is modified by replacing the extraterrestrial solar radiation of 1350 W/m^2 with the Q_0 of 1367W/m^2 and the cloud cover empirical component $(A + Bs)$ with f. Thus, Equation (6) is modified to Equation (9) as:

$$Q = Q_0 f s \qquad \text{........ (9)}$$

Where: Q is the predicted solar radiation; Q_0 *is the* extraterrestrial *radiation* (1367 W/m^2);

f is an empirical cloud cover depth function; and s is an empirical function of solar altitude.

Table 1 show the selected values of temperature used for calibrating the depth factor model and Figure 4 shows a linear plot of all interpolated values. The model for the empirical cloud cover depth factor is then developed by linear regression as presented by Equation (10).

$$f = (0.0752 \times T) - 1.5865 \qquad \text{...... (10)}$$

Where: T = temperature

Substituting Equation (10) into Equation (6) yields Equation (11) (Developed Model 1, DM1)

$$Q = 1367((0.0752 \times T) - 1.5865) \times s \qquad \text{...........(11)}$$

Table 1 Values for the depth factor using temperature

Temperature ^{0}C	Depth Factor	Cloud Cover (%)
21.1	0	100
34.4	1	0

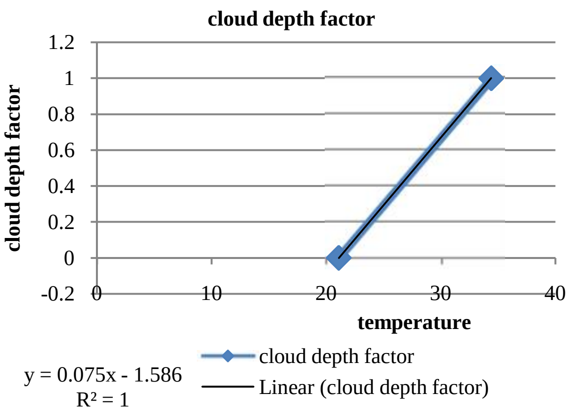

Figure 4 Cloud depth factor dependent on hourly temperature

Development of Model 2 (DM2)

The second model developed in this study (Developed Model 2, DM2) is a further modification of Lumb's original model with an empirical component that regresses temperature and humidity against selected cloud depth factors. The selected values of temperature and humidity used for calibrating the depth factor model are as presented in Table 2. The selected depth factors are typical of this study. The results of the multiple regression simulation of Equation (12) using observed values of temperature and humidity at the study area *via* Micro soft Excel are as presented in Table 3. Typical values of observed radiation, temperature, humidity etc on hourly basis for August 4th, 2015 are as presented in the Appendix.

$$Y = (M_1 \times T) + (M_2 \times H) + B \qquad \text{..... (12)}$$

Where; M = empirical parameters; B = intercept; T= temperature; and H = humidity.

The model for the empirical cloud cover factor is then obtained by multiple regression simulator on the excel software (see Equation (13)).

$$f = (0.0405063 \times T) - (0.01088 \times H) + 0.201265823 \qquad \text{...... (13)}$$

Direct substitution of Equation (13) into Equation (6) yields Equation (14) (Developed Model 2, DM2).

$$Q = 1367((0.0405063 \times T) - (0.01088 \times H) + 0.201265823) \times s \qquad \text{............(14)}$$

Table 2 Values for depth factor using Temperature and Humidity

Temperature	Humidity	Depth Factor	Cloud Cover %
21.1	97	0	100
30	75	0.6	40
34.5	55	1	0

Table 3 Results of Multiple Regression$^{\pm}$

S/No.	Parameters	M_1	M_2	B
1	Multiple Regression Constants	0.04050633	-0.0108861	0.201265823
2	Standard Error	S_1= 0.0	S_2 = 0.0	S_b = 0.0
3	Correlation Coefficient	1.0	-	-
4	Regression Sum of Squares	0.50666667	-	-
5	Residual Sum of Squares	0.0	-	-

$^{\pm}$Radiation, y as a function of Temperature (T) and Humidity (H) (see Equation (12))

Model Verification

The observed hourly solar radiation from the study area is compared with predictions from Equations(6, 11 & 14).Figure 5 shows a plot of the comparisons for August 24, 2015 and the square mean error (SME) estimated for six random days and presented on Table 5 and Figure 6, respectively.

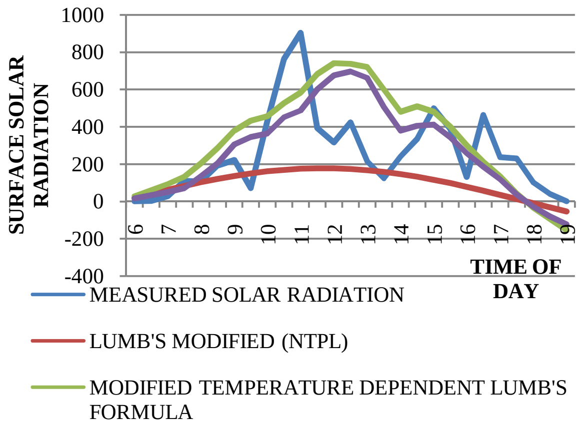

Figure 5 Plot of observed solar radiation and predicted equivalents

Table 4 Results of Mean Square Error (MSE) for Random days

S/N	DAY	MSE for Lumb's modified model (NPTEL)	MSE for Developed Model 1(DM1)	MSE for Developed Model 2 (DM2)
1	28-07-2015	38,143.49465	20,924.19553	19,373.7292
2	29-07-2015	54,166.63477	27,542.30627	27,369.26055
3	04-08-2015	61,519.4482	54,657.52452	43,620.40822
4	05-08-2015	45,296.4467	44,500.436	39,769.87
5	06-08-2015	77,196.80134	34,253.3929	28,603.84
6	07-08-2015	16,479.07842	21,270.61127	11,057.64914

Radiation threshold charts (See Figures 7& 8) show the surface solar radiation at a point when temperature is measured as in the case of DM1 or when temperature and humidity are measured as in the case of DM2, respectively.

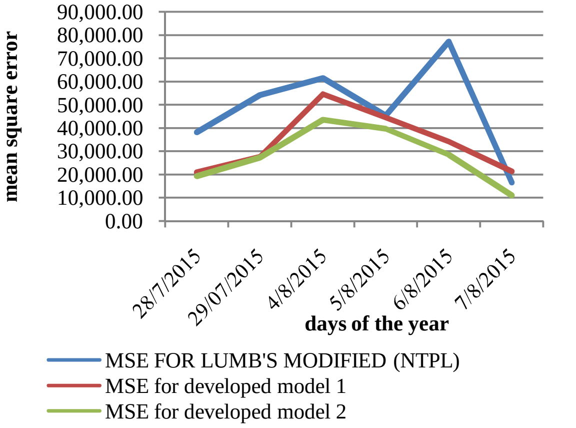

Figure 6 Square mean errors comparison for Lumb's modified (NTPL) and Developed Models 1 & 2

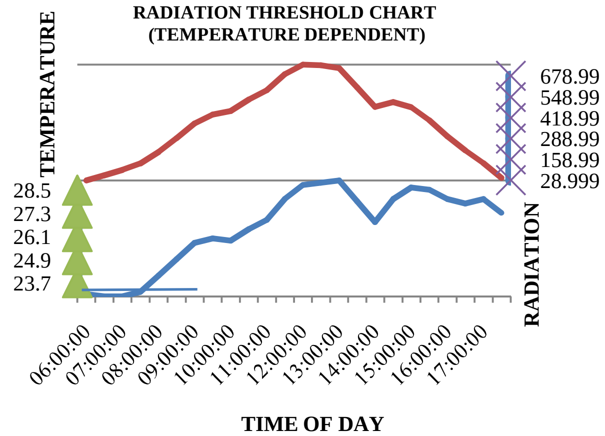

Figure 7 Radiation threshold charts (temperature dependent) for monitoring emitting facilities

Table 5 Solar Radiation and Cloud Cover For August 4, 2015

Day	Time	Solar Radiation (W/ m^2)	Cloud Cover (OKTA)
04/08/2015	6.00	0	8
	6.30	1.0	8
	7.00	26.6	8
	7.30	109.2	8
	8.00	105.8	8
	8.30	192.1	8
	9.00	221.6	8
	9.30	70.6	8
	10.00	429.8	8
	10.30	763.1	8
	11.00	903.8	8
	11.30	393.2	8
	12.00	315.8	8
	12.30	424.4	8
	13.00	215.2	8
	13.30	123.2	8
	14.00	240.6	8
	14.30	333.9	8
	15.00	498.8	8
	15.30	387.4	8
	16.00	129.7	8
	16.30	462.3	8
	17.00	237.1	8
	17.30	229.0	8
	18.00	101.2	8
	18.30	39.0	8
	19.00	00.0	8

Table 6 Temperatures and Humidity For August 4, 2015

Date	Time	Temp. Out	Out Hum	Rain	Rate rate
8/4/2015	12:00 AM	24.4	95	0	0
8/4/2015	12:30 AM	24.3	95	0	0
8/4/2015	1:00 AM	24.3	96	0	0
8/4/2015	1:30 AM	24.2	96	0	0
8/4/2015	2:00 AM	24.2	96	0	0
8/4/2015	2:30 AM	24.1	97	0	0
8/4/2015	3:00 AM	24.1	97	0	0
8/4/2015	3:30 AM	23.9	97	0	0
8/4/2015	4:00 AM	23.9	98	0	0
8/4/2015	4:30 AM	23.8	97	0	0
8/4/2015	5:00 AM	23.7	97	0	0
8/4/2015	5:30 AM	23.8	97	0	0
8/4/2015	6:00 AM	23.8	97	0	0
8/4/2015	6:30 AM	23.7	97	0	0
8/4/2015	7:00 AM	23.7	97	0	0
8/4/2015	7:30 AM	23.9	97	0	0
8/4/2015	8:00 AM	24.6	94	0	0
8/4/2015	8:30 AM	25.3	92	0	0
8/4/2015	9:00 AM	26	88	0	0
8/4/2015	9:30 AM	26.2	88	0	0
8/4/2015	10:00 AM	26.1	88	0	0
8/4/2015	10:30 AM	26.6	85	0	0
8/4/2015	11:00 AM	27	85	0	0
8/4/2015	11:30 AM	27.9	81	0	0
8/4/2015	12:00 PM	28.5	78	0	0
8/4/2015	12:30 PM	28.6	76	0	0
8/4/2015	1:00 PM	28.7	77	0	0
8/4/2015	1:30 PM	27.8	83	0	0
8/4/2015	2:00 PM	26.9	87	0	0
8/4/2015	2:30 PM	27.9	85	0	0
8/4/2015	3:00 PM	28.4	81	0	0
8/4/2015	3:30 PM	28.3	81	0	0
8/4/2015	4:00 PM	27.9	82	0	0
8/4/2015	4:30 PM	27.7	82	0	0
8/4/2015	5:00 PM	27.9	81	0	0
8/4/2015	5:30 PM	27.3	84	0	0
8/4/2015	6:00 PM	27	84	0	0
8/4/2015	6:30 PM	26.3	86	0	0
8/4/2015	7:00 PM	26.1	88	0	0
8/4/2015	7:30 PM	25.1	93	0	0
8/4/2015	8:00 PM	24.9	93	0	0
8/4/2015	8:30 PM	24.4	94	0	0
8/4/2015	9:00 PM	24.4	94	0	0
8/4/2015	9:30 PM	24.5	94	0	0
8/4/2015	10:00 PM	24.5	94	0	0
8/4/2015	10:30 PM	24.4	94	0	0
8/4/2015	11:00 PM	24.2	95	0	0
8/4/2015	11:30 PM	24.2	95	0	0
8/5/2015	12:00 AM	24.1	96	0.25	0

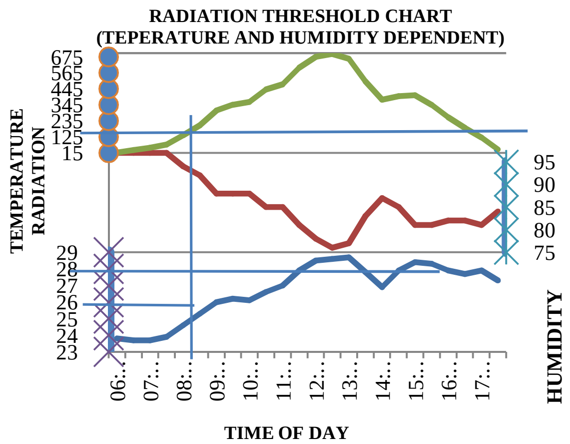

Figure 8 Radiation threshold charts (dependent on temperature and humidity) for monitoring emitting facilities.

DISCUSSION

This work has successfully developed two empirical models using the proposed Lumb's formula for predicting hourly solar radiation. It also verifies the original Lumb's formula and the modified one as presented by Sharma (2006). Equation (7a) is a modification of Equation (6) proposing that two third of the extraterrestrial solar radiation (1367 W/m^2) will reach the earth's surface on a cloudless day. Two third of 1367 W/m^2 is 912 W/m^2 and this has been verified as untrue based on the data collected from the study area. Surface solar radiation of 1207 W/m^2 was recorded on clear sky days. A comparison between the original Lumb's formula and the modified (NPTEL lecture series) show superiority of the modified Lumb's formula (See Figure 3). Two equations are then developed with the aim of reducing the square mean error calculated from the modified Lumb's formula and this was achieved by including a cloud depth factor as a variable in the developed model (DM2).

The cloud cover depth is developed by using the interpolation technique. The lowest of the temperatures which produced a 100% cloud cover was selected as the lower limit at 21.5 ^{0}C which was given a depth factor of zero. All 6.20 AM (sun rise) radiations were considered for 100% cloud cover because the sun is due to rise at 6:20 AM in the study area and the cloud is always 100% at the time. The highest temperature for the 0% cloud cover was selected for the upper limit at 34.4 ^{0}C which was given a depth factor of 1.0. This was used to develop Model 1 (DM1).

The process is further repeated combining temperature and humidity to create a cloud depth factor and the multiple regression function via excel was employed for this purpose. Table 2 shows the selected values used to develop the regression for Model-2(DM2). Table 3 shows the statistical parameters after simulation 8. The multiple regression model is presented as Equation (13).

The models (DM1 & DM2) were verified using randomly selected data from the 3 months of measurements (July 28, &29; August 4-6, 2015) and the corresponding square mean errors calculated. Figures 5 & 6, and Table 4, all present comparison details. Developed Model 2 which was dependent on temperature and Humidity showed the lowest mean square error of 11,057.65. This was selected as the best equation for use in the study area in rainy season and other areas that possess close meteorological parameters to that of the study area.

Figures 7 and 8 demonstrate how the models developed in this study can be used by environmental Engineers; for Model 1(Figure 7) at 9:00 am when the temperature is 25^{0}C, the radiation is 300W/m^2 and emitting can be increased until 3:45 pm when radiation falls below 300$W/m^2$and the emitting can be reduced to the lowest value. For Model 2 (Figure 8) at 9:00 am when the temperature and humidity are 26^{0}C and 87 %, the radiation is 300 W/m^2 and emitting can be increased until 4:00 pm when the radiation falls below 300 $W/m^2$and the emitting can be reduced to the lowest value.

CONCLUSION

In this study the following conclusions can be drawn:

Observations from assessment of Lumb's original model were as follows:

i. Its hourly prediction of surface cloud cover was very poor because it considers cloud as a surface measurement excluding the cloud depth; and
ii. The empirical relationship between the cloud cover and the solar altitude is bound to fail because some days have the same cloud cover all through and this is not so in reality, even when the surface cloud is completely covered the depth of cloud continuously varied.

Observations from assessment of Lumb's modified model were as follows:

i. It predicted hourly surface solar radiation better than the Lumb's original model;
ii. Though it estimates cloud cover excluding the depth of cloud but the empirical relationship to estimate the cloud cover is the reason for better results; and
iii. The model is reliable in situations where the cloud cover is thin. This is why there were cases it did better than the DM1.

DM1 is dependent on temperature and the following were observed;

i. It predicted better hourly surface solar radiation when compared with original and modified Lumb's model; and
ii. Its square mean error was 21,270.61127 for August 7, 2015 when compared with actual surface solar radiation.

DM2 is dependent on temperature and humidity. The following were observed:

i. It predicted better hourly surface solar radiation when compared with all other models; and
ii. Its square mean error was 11,057.64914for August 7, 2015 when compared with actual surface solar radiation.

DM2 proved the best when compared with other models on randomly selected days. The model developed is a very simple model and a similar procedure can be repeated for any site where estimates of solar radiation will be required to guide the installation of emitting facilities.

Reference

1. Ask (2015). Available at*http://www.ask.com/science/cloud*. Retrieved August 8, 2015
2. Crair, C., Peeple, K. and Banas, S. (2014): Is cloud cover one of the effects of climate change? Journal of emerging investigations. http//creative commons.org/licenses/.
3. El mgbochi,Y., El bouardi, A., Choull, Z. and Ajzoul, T.(2014):New model to estimate and evaluate the solar radiation. *International journal of sustainable built environment*. Vol 3, 225-234.

4. Kimball, H.(1928): Amount of solar radiation that reaches the surface of the earth on the land and on the sea and methods by which it is measured. *Mon.wea.Rev.*56, 393-399.
5. Klien, W. (1948): Calculation of solar radiation and the solar heat load on man. *Journal of meteorology*. Vol. 5, No. 4, 119-129.
6. Kizu,S.(1997): Systematic errors in estimation of insulation by empirical formulas. *Journal of oceanography*, vol. 54, pp 165-177.
7. Kondo, J. and Miura, A. (1983): Empirical formula of the solar radiation at the ground level and a simple method to examine an inaccurate pyranometer. Tenki, 30, 45-51.
8. Lumb, F. (1964): The influence of cloud on hourly amount of total solar radiation at the sea surface. *Q.J.R. meteor. Soc.*, 90, 43-56.
9. Okpani, P. and Nnabuchi, M.(2008): Developing a model for predicting the global solar for Enugu using maximum temperature data. *Nigerian journal of physics*, 20(1), 112-117.
10. Reed, R. (1977): On estimating insolation over the ocean. *J.phys. Oceanogr.*, 7,482-485.
11. Schmetz, J. (1989): Towards a surface radiation climatology: Retrieval of downwards irradiances from satellites. *Atmos. Res.*, 23. 287-321.
12. Sucevic, N. and Djurisic, Z. (2012): influence of atmospheric stability variation on uncertainties of wind from prediction estimation. European wind Energy conference and exhibition.
13. Tabata, S.(1964): insulation in relation to cloud amount and sun's altitude. P.202-210. In studies on Oceanography, University of Washinton press (cited in Reed, 1977).
14. Sharma, M. (2006): Environmental Air Pollution-Air quality modeling. Lecture 28 National Programme on Technology enhanced learning (NPTEL) www.youtube/NPTL lectures series- lecture 28. Viewed September 8, 2015.
15. USRML (2002): UO Solar Radiation Monitor Laboratory. Available at www.solarda.uoregon.edu.

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