RELATIONSHIP BETWEEN MODELED CLEAR- SKY SOLAR RADIATION and MEASURED SOLAR RADIATION DATA in UYO, NIGERIA

Onwude, Daniel Iroemeha [#1], Olosunde, William Adebisi [#2], Akindele, Folarin Alonge[#3]
[#] Department of Agricultural and Food Engineering, University of Uyo,
PMB 1017, Uyo, Nigeria
[1] danafricgems@gmail.com
[2] williamolosunde@uniuyo.edu.ng
[3] falonge6@yahoo.com

***Abstract*— Solar radiation available to dry crop on any clear-day was mathematically simulated on a local computer, using JAVA object oriented programming language with NETBEANS IDE platform, for predicting solar radiation available in Uyo, Akwa Ibom State, Nigeria. The deterministic model was developed using existing Hottel solar radiation model and set of equations, taking into consideration the factors of two components of solar radiation: The beam and diffused components. The output of the model rapidly produced hourly, monthly and daily data of insolation on horizontal surface and was verified and validated using existing solar radiation data, gotten from the Nigeria Metrological Department, Department of Geography and Regional Planning, University of Uyo, Nigeria. The simulated and measured solar radiation results were subjected to t-test and were correlated using SPSS statistical software. The results showed that there were no significant difference between the simulated data and measured data throughout the months of the year. Hence, the program developed can be used to adequately predict the total global clear-sky radiation of any day of the month in Uyo, NigeriaKeywords: clear-sky radiation, SPSS, Day of the year, latitude, longitude, measured data, simulated data, Total radiation, Uyo, Nigeria**

I. INTRODUCTION

Global solar radiation data is essential for the study and design of economic viability of system that uses solar energy.

In most of the tropical countries the sun is the source of energy for drying. Natural sun drying is one of the most common ways to conserve agricultural products in Nigeria. This involves the spreading of the commodity in the sun on a suitable surface, hanging of commodity on buildings or drying on the stalk by standing in bundies. Solar drying differs from sun drying in that a structure is used to enhance the effect of the availability and adequacy of solar radiation according to Irtwange and Adebayo [19].

The amount of solar radiation available to any given location depends on latitude, time of year, hour of the day and the angle of inclination of the collector, Duffie and Beckman [15].

The need to study the amount of solar radiation available at a given location without using any measuring instrument becomes indispensible in the drying of agricultural crops.

Alonge and Oje [2] developed a model using Basic language to predict the available solar radiation for crop drying at a tropical station Ilorin, Nigeria.

A. EXTRATERRESTIAL RADIATION

This is the Instantaneous Insolation at any given time for hourly calculation for Insolation. G_{sc} has to be integrated over each hour. The hourly Insolation I_0 is given by

$$\int_{w1}^{w2} Go = \int_{w1}^{w2} Gsc \left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] \sin\delta \sin\phi + \cos\phi \cos w \cos\delta \qquad (1)$$

Where I_o can be written in term of average hourly daily extraterrestrial solar radiation as:

I_0= (12*3600/∏) * G_{sc} [1 + 0. $033cos\left(\frac{360n}{365}\right)$] * Cosδcosϕsin(ω_2-ω_1) + {[2∏(ω_2-ω_1)]/360}sinϕsinδ (2)

This is the hourly daily extraterrestrial (outside the earth's surface) solar radiation on the horizontal surface (Duffie and Beckman [15]).

Where n is the Julian day number (i.e Janurary $1 = n = 1$, December 31= n = 365)

G_{sc} = 1353wm^{-2} is the solar constant, ф is the latitude of Uyo, Akwa Ibom State, Nigeria.

π= 3.142;

Where ω_1 and ω_2 are solar hour angle at point 1 and point 2 respectively (ω_1=7:00am, ω_2= 5:00 pm solar time).

δ is the declination angle given as

δ= 23.45$\frac{11}{180}$ $sin2\pi$(284+ n/365) where π =radians=180^o

δ= 23.45sin [360 (284+ n/365) (3)

ω= cos^{-1} (-tanϕtanδ) (4)

To calculate the solar hour angle ω_1 and ω_2, the solar time for the location must be obtained.

Solar time = standard time + 4(L_{st}-L_{loc}) + E (5)

Where;

L_{st} = Standard meridian for the local time zero, 15^0 for Nigeria.

L_{loc} = Longitude of the location due East $(7.933°E\ for\ uyo)$

E= correlation due to perturbations on the earth's rate of rotation and is given by:

9.87 sin2B- 7.53CosB- 1.5 sinB (6)

B =360$(n-1)/364$ (7)

B. CLEAR SKY RADIATION (TOTAL)

The atmosphere reduces extraterrestrial radiation by scattering and absorbing some of the radiation. The radiation that finally gets to earth on a clear day is the clear day sky radiation. Hottel [18] presented a convenient method for estimating beam radiation (I_b) through clear skies as follows

I_b = I_o*T_b (8)

Where T_b=a_o+ a_1 e$^{-k/}$$cos$θ$_z$ (9)

Where θ_z can be gotten from equation (5)

a_o, a_1, k are functions only of latitude and visibility.

The standard values of a_o, a_1 and k from table provided in Beckman and Duffie [15].

Where r_o= a/a* r_1 =a_1/a_1^* and r^k = k/k*

Also Hottel gave equations for (a_o^*, a_1^* and k*)

a_o^* = 0.4237 – 0.00821 (6-A)^2

a_1^* = 0.5055+ 0.00595 (6.5-A)^2

k^* = 0.2711 + 0.01858 (2.5-A)^2

Where A = altitude of observers location (Uyo is 0.2km) In Kilometers

r_o = 0.95 r_1 = 0.98 r^k = 1.02 at 0.2km altitude.

With the above formulas and values, equation (9) can be written as.

T_b = a_o^* (r_o) + a_1^* (r_1) exp$^-$[k*(r^k)] / cosθ_z (10)

Now, T_b can be calculated for a clear sky.

Diffused radiation, I_d on horizontal surface is given by:

I_d = I_o T_d (11)

Where T_d = 0.2739 T_b * k (12)

Total solar radiation, I_t on the horizontal surface is

I_t =I_b + I_d (13)

Hence, from the value of I_t the total hourly, daily and monthly solar radiation on an horizontal surface can be calculated and simulated on a computer

Thus, the objective of this study was create a simulation for clear-sky solar radiation prediction; to correlate mathematically the relationship between simulated available clear-sky solar radiation on any given day in Uyo, Nigeria and the measured data and to determine if there was any significant difference between the data generated by the simulated program and the measured data

II. MATERIALS AND METHOD

A. Materials Used

Climate data for Uyo and its environs is based on weather conditions at Nigerian Meteorological Department Uniuyo station. The data collected covered a period of 14 years from 1995-2008, which was used to verify, validate and compare with the simulated data.

B. Method

The program was written in java (Object-Oriented Programming language) using NETBEANS IDE platform which enabled the easy writing, verification, validation and testing of the model on any operating system. It was developed and tested on a local computer with windows operating system.

In the deterministic model the input parameters were kept dynamic and change with time (hour, day and month).

From the mathematical model developed, equations(2),(3),(4),(5),(6),(7),(8),(9),(10),(11),(12) and (13) were used to compute the total clear sky radiation on the horizontal earth surface(I_t) for the average day of every month in Uyo, Nigeria. Each stage of the model development was tested. The simulated and measure solar radiation result were subjected to t-test and was correlated using SPSS statistic software

III. RESULTS AND DISCUSSION

A. RESULTS

A two-sample *t*-test assuming equal variances using a pooled estimate of the variance was performed to test the hypothesis that the resulting mean Global solar radiation of Uyo, Nigeria for measured solar data and the simulated solar radiation data were equal.

The hypotheses for this test are *H*0: μ1 = μ2 versus *Ha*: μ1 ≠ μ2 or, in words, the following:

Null hypothesis (*H*0): The mean clear sky solar radiation of any given day of the year using both the measured and simulated solar data is the same.

Alternative hypothesis (*Ha*): The mean clear sky solar radiation of any given day of the year using both the measured and simulated solar data are different.

TABLE 1

MAXIMUM OBTAINABLE MONTHLY SOLAR RADIATION H, (MJ/M^2) FOR EACH MONTH

Month	Radiation MJ/m^2
January	11.04785
February	11.60038
March	11.62785
April	12.04607
May	11.62785
June	10.41859
July	10.89985
August	10.51037
September	11.61859
October	11.62685
November	11.61859
December	10.89888

TABLE 2
MEASURED MONTHLY MEAN SOLAR RADIATION (MJ/M^2)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1995	9.8	10.5	11.4	13.4	10.8	11.3	8.0	7.7	9.4	10.7	13.6	10.7
1996	11.9	12.1	10.7	12.7	10.2	11.2	8.8	6.8	8.9	11.8	12.3	11.8
1997	9.9	17.0	10.9	11.6	11.5	9.4	8.9	8	10.2	11.3	9.5	10.7
1998	9.0	11.7	7.7	11.9	12.8	11.3	9.4	8.4	7.6	10.6	9.6	10.3
1999	10.4	12.6	9.5	12.4	10.0	9.7	5.9	8.3	8.5	8.2	9.0	12.2
2000	9.0	11.3	10.5	9.7	9.2	9.9	7.8	7.5	8.0	9.5	10.0	11.5
2001	11.8	10.9	10.7	12.4	10.8	10	7.4	6.1	8.2	10.3	10.7	12.0
2002	11.6	12.0	10.5	10.5	11.2	10.8	9.3	7.5	10.3	9.3	12	11.5
2003	9.6	9.6	10.0	11.3	10.6	8.3	10.2	7.9	10.4	11.4	10.5	9.4
2004	9.2	11.3	11.6	10.2	10.5	9.9	8.8	7.7	10.3	10.9	10.4	10.4
2005	10.8	11.8	10.4	11.7	9.0	10.7	8.0	8.0	11.0	12.0	13.4	12.3
2006	10.8	10.9	12.1	12.8	10.6	10.8	7.9	9.7	9.0	11.5	12.1	13.3
2007	12.4	13.0	12.9	15.6	12.1	9.3	9.7	7.5	10.6	11.2	10.04	11.7
2008	12.0	13.5	11.0	13.6	10.8	10.0	9.2	7.6	9.8	10.2	9.6	11.3
TOTAL	148.2	168.2	149.9	169.8	150.1	142.6	119.3	108.7	132.2	148.9	152.74	159.1
AVERAGE	10.58	12.01	10.7	12.12	10.72	11.88	8.52	7.76	9.44	10.63	10.91	11.36
***Source:* Department of Geography and Regional Planning, Uniuyo, Nigeria.**												

TABLE 3
GROUP STATISTICS

	Type	N	Mean	Std. Deviation	Std. Error Mean
Radiation	1	12	10.56	1.371	.396
	2	12	11.24	.516	.149

TABLE 4
INDEPENDENT SAMPLES TEST

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Radiation	Equal variances assumed	4.219	.052	-1.604	22	.123	-.679	.423	-1.556	.199
	Equal variances not assumed			-1.604	14.057	.131	-.679	.423	-1.585	.228

Model Flowcharts (Simulation Algorithm)

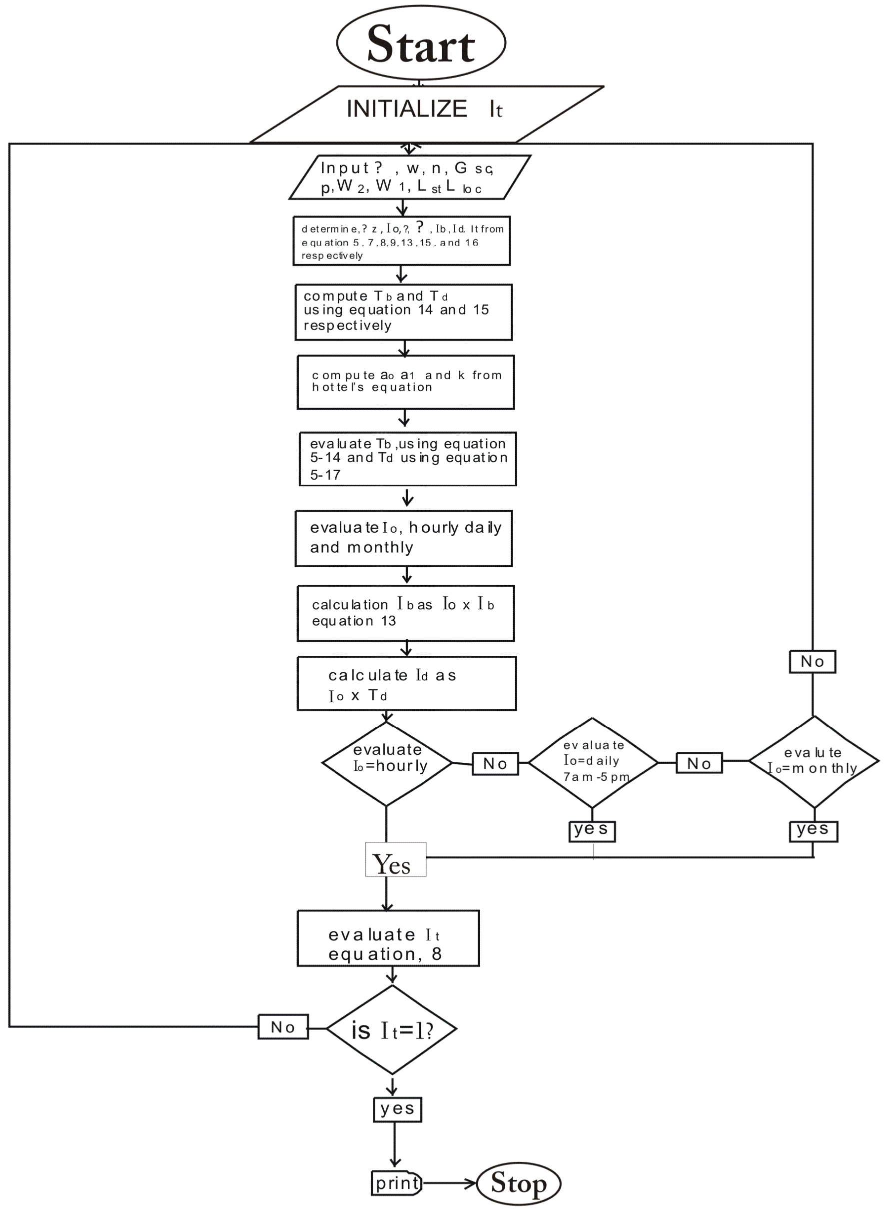

Figure 1.0 Flow chart for simulation algorithm

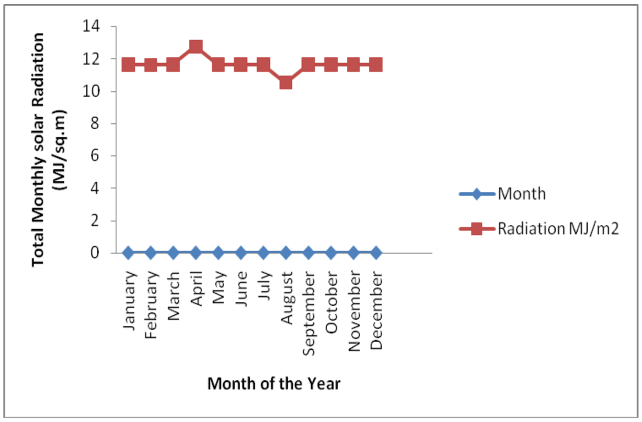

Figure. 2.0 Total monthly Solar Radiation (Simulated)

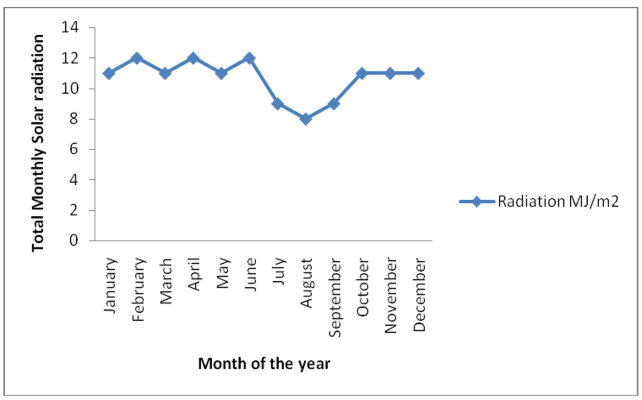

Figure 3.0 Total monthly Solar Radiation (Measured)

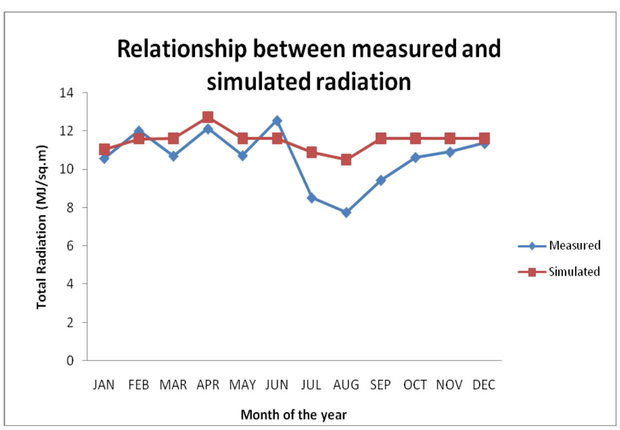

Figure. 4.0 Annual variation of global solar radiation

B. DISCUSSION

Figure 2.0 shows the maximum obtainable simulated monthly radiation from 7am to 5pm, for the average of each month of the year. The months that has the maximum and minimum total monthly radiation in Uyo, Akwa ibom State are shown. As expected, April is the hottest month with a total monthly solar radiation of 12.04607MJ/m^2. While the lowest total monthly solar radiation are gotten in the month of June and August with a value of 10.4MJ/m^2 and 10.51037MJ/m^2 respectively, which are the months that has the highest amount of rainfall in Uyo, Nigeria.

Figure 3.0 shows the mean measured solar radiation of uyo, Nigeria with August having the lowest solar radiation with a value of 8.00MJ/m^2

Table 2.0 shows the total global solar radiation data in Uyo, Nigeria for 10 years. Fig 3.0 shows a relationship between simulated and 14 years mean measured data behavior. From the graph it can be seen that both simulated and measured are similar although slight difference can be noticed in the month of August and September due to inconsistency in the weather condition of Uyo, during these period.

Table 3.0 shows the group sample statistics. From the table it can be seen that there is significant relationship between Radiation 1 (Measured) and Radiation 2 (Simulated) in the standard deviation, with a standard error of 0.396 and 0.149 respectively.

The Results from Table 4.0 shows that the *p*-value for the equal variances *t*-test is $p = 0.123$. Since this *p*-value is greater than 0.05, the decision therefore is that there is no significant difference between the two groups (Measured and simulated solar radiation data). Hence, the null hypothesis is accepted. i.e $H0$: μ1 = μ2.

Hence, the mean Solar radiation using Measured Data Brand 1 ($M = 10.56$, $SD = 1.371$, $N = 12$) was not significantly different from that using Simulated Brand 2 ($M = 11.24$, $SD = 0.516$, $N = 12$), $\boldsymbol{t\ (22) = -1.604,\ p = 0.131}$.

Thus, there is not enough evidence to conclude that the mean of both the simulated and measured solar radiation are different.

IV. CONCLUSION

From the results obtained, The program was able to predict accurately the best day of any month and the best time for drying crops, which corresponded to the measured data gotten from the Nigerian Meteorological Department Uniuyo station. The model was able to deduce that the amount of insolation obtainable on any clear day in Uyo, Nigeria is sufficient for normal crop drying.

There was no significant difference between measured solar radiation data and simulated solar radiation as the p value was 0.131

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