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Evaluation of Solar Radiation over Sahel and Coastal Zones in Nigeria

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Abstract: *The main aim of this paper is to develop Multivariate and Angstrom-type models from where solar radiation can be evaluated over Sahel and coastal stations in Nigeria. Global radiation is an important parameter necessary for most ecological models and an input for different solar system. Solar radiation is the radiant energy emitted by the sun from nuclear fusion that creates electromagnetic energy; solar radiation is the most evenly distribution energy resource on earth and the most abundant. In this research work, thirty-three (33) years (1979-2011) surface data of solar radiation, sunshine duration, maximum temperature, minimum temperature and relative humidity were obtained from the archives of Era-interim satellite database. The analyses have shown that the above meteorological variables greatly affect the intensity of solar radiation in the study areas. For instance, when the two models were used to predict solar radiation data for 2009-2011, the efficiency test such as R^2, MBE and RMSE for Maiduguri a Sahel station were 0.813, 0.0024 and 0.0166 respectively for multivariate model. While those of Angstrom-type model were 0.416, -5.9794 and 0.0294 respectively. Those of the other nine stations follow the same trends. Comparative studies of the two models have indicated that multivariate models gives better prediction of solar radiation that of Angstrom-type model in the study locations.*

Keywords: *Solar Radiation, Multivariate, Angstrom-type and Climate System.*

I. Introduction

Solar radiation is the radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. Solar radiation is the most evenly distributed energy resource on earth and the most abundant. The energy flow within the sun results in a surface temperature of around 5800 K, so the spectrum of the radiation from the sun is similar to that of a 5800K blackbody. The irradiance of the sun on the outer atmosphere when the sun and earth are spaced at 1AU the mean earth/sun distance of 149,597,890 km- is called the solar constant. Solar radiation is absorbed, scattered and reflected by the components of the atmosphere. The amount of radiation reaching the earth is less than what entered the top of the atmosphere. Global radiation is an important parameter necessary for most ecological models and an input for different solar system. It is the ultimate energy for all ecosystems. Although, solar radiation data are available at most meteorological stations, yet there are stations in many regions of the our country that suffers from shortage of solar radiation data records. Therefore a model with high accuracy depend on data which is available in all meteorological stations is to be developed for the estimation of solar radiation data. Various models have been proposed to estimate solar radiation (Al-Salaymeh, 2006; Jibril, 2008; Ulgenand Hepbasli, 2002; Shaltoutetal., 2001). Also, Safari and Gasore (2001) have demonstrated the predictive ability of the Angstrom-type one-parameter equation correlation of the global solar radiation to the percentage of bright sunshine hours in as imple linear regression form (Angstrom, 1924).

As important as solar radiation is to agriculture, generation of electricity and climate conditions, the instrument for measuring it is very expensive and it is not readily available. Therefore, there is need to use an alternative means of empirical model to measure it. The combination of the right atmospheric parameters also plays a vital role in obtaining accurate and quality data. This is the main reason for comparing these two existing models in this research work.

The sole aim of this research work are to develop a multivariate linear model and Angstrom-type model from where solar radiation can be radiation can be evaluated over Sahel and Coastal stations in Nigeria and to compare the efficiency of the two solar radiation models using statistical test indicators.

II. Material and methods

2.1 Data Acquisition

The surface data for solar radiation, maximum and minimum temperature, relative humidity, wind speed and sunshine duration were obtained from Era-interim satellite database for the period of thirty-three years(1979-2011) over ten stations (Figure 1). The stations were further divided into two regions, Sahel and Coastal regions according to their climatic conditions.

2.2 Model Development

The multivariate and Angstrom-type model of the forms (Equation1and2) were developed using thirty years (1979-2008) data of global solar radiation, sunshine hour, cloud cover, maximum temperature, minimum temperature, relative humidity for ten stations over Nigeria:

$$\frac{H}{H_O} = \beta_O + \beta_1 \frac{n}{N} + \beta_2 \frac{c}{C} + \beta_3 T_{\max} + \beta_4 T_{\min} + \beta_5 RH \qquad 1$$

where H=global solar radiation, Ho= extraterrestrial radiation, fractional sunshine duration, fractional cloud cover, T_{max} = maximum temperature in kelvin, T_{min} = minimum temperature in kelvin, RH = relative humidity. The constants β_i are parameter estimates (where i = 0, 1, 2, 3, 4 and 5) to be determined by least square method. The extraterrestrial radiation (H_O) was calculated from the equations shown below according to Angstrom (1924):

$$H_O = \frac{24 \times 60}{\pi} I_{sc} E_O (\omega_S \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s \qquad 3$$

R_a = extraterrestrial radiation [$MJm^{-2}day^{-1}$], I_{SC}=solar constant, E_o =inverse relative distance Earth-Sun,ω_S =sunset hour angle[rad], j=latitude [rad],δ=solar declination [rad].
The inverse relative distance Earth-Sun, E_O, and the solar declination, δ, are given by:

$$E_o = 1 + 0.033\cos\left(\frac{2\pi}{365} J\right) \qquad 4$$

where J is the number of the day in the year between 1 (1January) and 365 or 366 (31December). The angle of solar declination is given as:

$$\delta = 0.409\sin\left(\frac{2\pi}{365}\right) J - 1.39 \qquad 5$$

The sunset hour angle, ω_S, is given by:

$$\omega_s = \frac{\pi}{2} - \arctan\left(\frac{-\tan\varphi \tan\delta}{X^{0.5}}\right) \qquad 6$$

where

$$X = 1 - \arctan(\tan j)^2 (\tan\delta)^2 \qquad 7$$

2.3 Model Assessment

There are several statistical tests that can be used to evaluate the performance of these models. Among which are the correlation coefficient (R^2), the mean bias error (MBE) and the root mean square error (RMSE) (Diamante and Munro, 1993), as listed below:

2.3.1 Correlation coefficient(R)

The correlation coefficient (R) can be used to test the linear relation between the measured and estimated values employing the equation 8:

$$R = N\sum_{i=1}^{N}(HH_p) - \frac{\sum_{i=1}^{N} H * \sum_{i=1}^{N}(H_p)}{\sqrt{N\left[\sum_{i=1}^{N} H^2 - \left(\sum_{i=1}^{N} H\right)^2\right] N\left[\sum_{i=1}^{N} H_p{}^2 - \left(\sum_{i=1}^{N} H_p\right)^2\right]}} \qquad 8$$

where R^2 is called the coefficient of determination, this shows the ability of the model to predict significantly and it ranges from 0 to 1. H stands for the measured values found in any measurement, H_p is the predicted values for this measurement and N is the total number of observations.

2.3.2 Mean Bias Error(MBE) and Root Mean Bias Error (RMSE)

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(H_p - H) \qquad 9$$

The MBE provides information on the long term performance of the correlations by allowing a comparison of the actual deviation between predicted and measured values term by term. The ideal value of

MBE is zero (El-Sebaii etal, 2002). A positive value of MBE indicates overestimation and a negative value shows under-estimation of the developed models (AdeyemiandOjo,2004).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(H_P - H)} \qquad 10$$

RMSE provides information on the short term performance of a model. The value of RMSE is always positive, represented as zero in an ideal case. The RMSE is significant when its value is less than the alpha confidence level in which the model is developed (Adeyemi and Ojo, 2004). These tests are mainly employed for adjustment of solar radiation data (Halouani and Ngguyen, 1993; Falayi etal., 1999).

III. Results and Discussion

From Table1 shows the multivariate parameters estimates of the five meteorological variables (fractional sunshine duration, fractional cloud cover, maximum temperature, minimum temperature and relative humidity) used for the development of the models in the study location. It was observed that β_1 which is the parameter estimates of fractional sunshine hour are all positive. This indicates that β_1 has increasing trends with solar radiation i.e. as fractional sunshine duration increases, the solar radiation increases.

Table1: shows the multivariate parameters estimates for investigated stations

	Model Parameter Estimates						Models'Testing Parameters			
Station	B_o	β_1	β_2	β_3	β_4	β_5	R	R^2	RMSE	p−value
Mai	0.239	2.665	-0.012	-0.011	0.011	-0.001	0.901	0.812	0.018	0.000
Kan	0.168	2.665	-0.015	0.014	0.014	-0.001	0.905	0.820	0.019	0.000
Yel	0.138	2.428	-0.019	0.009	-0.009	-0.002	0.907	0.824	0.023	0.000
Bau	0.320	2.517	-0.018	0.011	0.011	-0.001	0.904	0.819	0.021	0.000
Sok	-0.367	3.101	-0.016	0.011	0.009	-0.001	0.882	0.778	0.019	0.000
Enu	-1.989	1.770	-0.020	0.029	-0.021	-0.003	0.942	0.889	0.022	0.000
Ikj	-1.546	1.783	-0.043	0.077	-0.069	-0.008	0.860	0.741	0.030	0.000
Akr	-2.025	2.311	-0.037	0.033	-0.025	-0.002	0.933	0.872	0.023	0.000
Uyo	-1.615	1.643	-0.034	0.068	-0.061	-0.006	0.930	0.865	0.023	0.000
P.H	-1.560	1.715	-0.027	0.058	-0.049	-0.011	0.922	0.851	0.023	0.000

β_2, the parameter estimates of cloud cover are all negative which means that the cloud cover decreases asthe clearness index (ratio of global solar radiation to extraterrestrial radiation) increases. In this situation, the sky is cloudy and hence there is a reduction in solar radiation. β_3 signifies the parameter estimates of maximum temperature and it was observed from the table that they were all positive except for Maiduguri. The temperature in Maiduguri does not depend on the solar radiation. The parameter estimates of minimum temperature β_4 are both positive and negative in study stations. These indicate that solar radiation decreases with minimum temperature in all the Coastal stations investigated and Yelwa, a Sahel station also has a negative trend. There were increasing trends in other Sahel stations because their estimates are positive. Relative humidity and clearness index are inversely proportional with each other. i.e. relative humidity reduces as the clearness index increases. The p-value of the combination of all the parameters estimates has zero value which confirms the significance of all the parameter estimates for the prediction of solar radiation. The correlation coefficients(R) from Table 1 have indicated that the five meteorological variables and solar radiation have more than 80 percent linear relations, so the parameters can estimate the clearness index significantly. The coefficient of determination shows the variations of the parameter estimates and their over 70 percent ability to predict solar radiation at 95 percent alpha confidence level (α=0.05). It was also observed that all the values of RMSE are less than 0.05 alpha levels which also confirm the suitability of the parameter estimates for solar radiation prediction. Comparing Table1 and Table 2, it was observed that the combination of the five meteorological parameter estimates gives good fit models than one variable using the properties their parameter estimates. From table3, it was observed that the Multivariate model has over 70 percent coefficient of determination when it was used to predict solar radiation data for 2009-2011. It was also observed that the values of MBE were all positive and very low which confirmed that the model slightly overestimated solar radiation in all the stations investigated. Comparing the modelled values statistically from the Table 3, it can be concluded that Multivariate model performs favourably well more than the Angstrom model for the prediction of solar radiation.

Figures 1-5 show the variations of the observed solar radiation with the predicted values from the two models. It was observed from the figures that there were prominent cases of underestimation of solar radiation from Angstrom-type model compared to that of multivariate model. Although they have a similar trend, yet multivariate modelled data monitored the observed data. The observable variability may due to climate conditions of study locations.

Table 2: shows the parameter estimates for Angstrom-Prescott model for the investigated stations.

	ParameterEstimates		Testing Parameters		
Station	β_o	β_1	R	R^2	RMSE
Maiduguri	-0.122	4.709	0.676	0.458	0.031
Kano	-0.158	5.118	0.674	0.455	0.034
Yelwa	-0.993	4.299	0.711	0.506	0.039
Bauchi	-0.121	4.610	0.694	0.481	0.036
Sokoto	-0.192	5.633	0.625	0.391	0.032
Enugu	-0.052	3.295	0.752	0.566	0.043
Ikeja	-0.027	2.924	0.681	0.465	0.043
Akure	-0.106	4.069	0.767	0.588	0.042
Uyo	-0.044	2.930	0.803	0.645	0.037
P.H	-0.034	2.813	0.782	0.612	0.038

Table 3:shows the properties of predicted values of multivariate model and the Angstrom for the investigated stations

	MultivariateModel			Angstrom-Type Model		
Station	R^2	MBE	RMSE	R^2	MBE	RMSE
Maiduguri	0.813	0.0024	0.0166	0.416	-5.9794	0.0294
Kano	0.824	0.0012	0.0188	0.472	-0.0016	0.0325
Yelwa	0.806	0.0017	0.0226	0.473	-0.0023	0.0373
Bauchi	0.811	5.6145	0.0206	0.470	-0.0014	0.0345
Sokoto	0.771	0.0024	0.0195	0.044	-3.2139	0.0304
Enugu	0.890	0.0030	0.0222	0.603	-0.0020	0.0422
Ikeja	0.744	4.1317	0.0291	0.517	-0.0039	0.040
Akure	0.842	2.5175	0.024	0.580	-0.0035	0.0390
Uyo	0.667	0.0037	0.0359	0.667	0.0013	0.0359
Port-Harcourt	0.836	0.0023	0.025	0.658	8.3938	0.0357

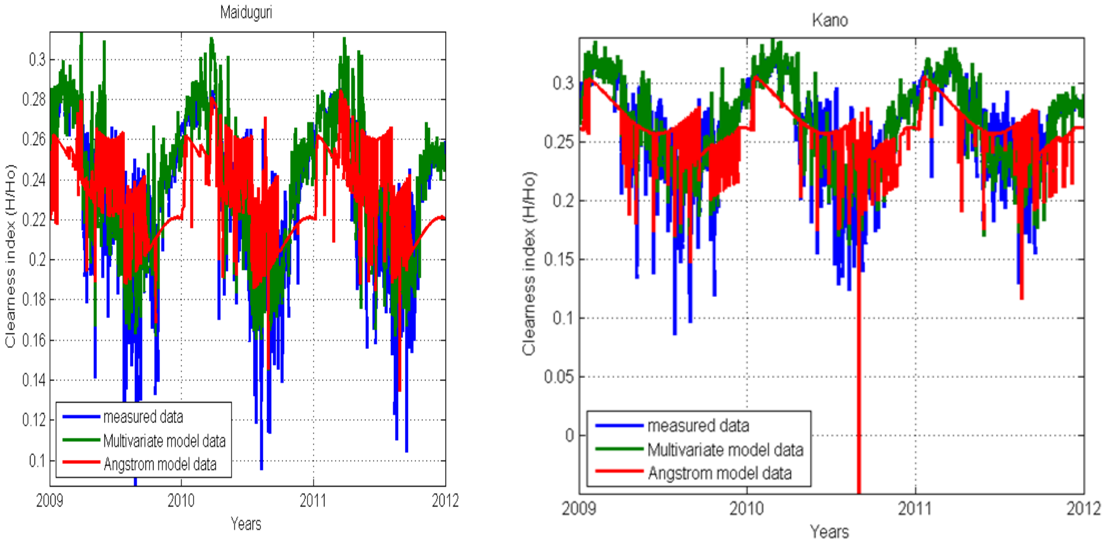

Figure 1: shows the variation of the measured solar radiation with the predicted solar radiation Maiduguri and Kano

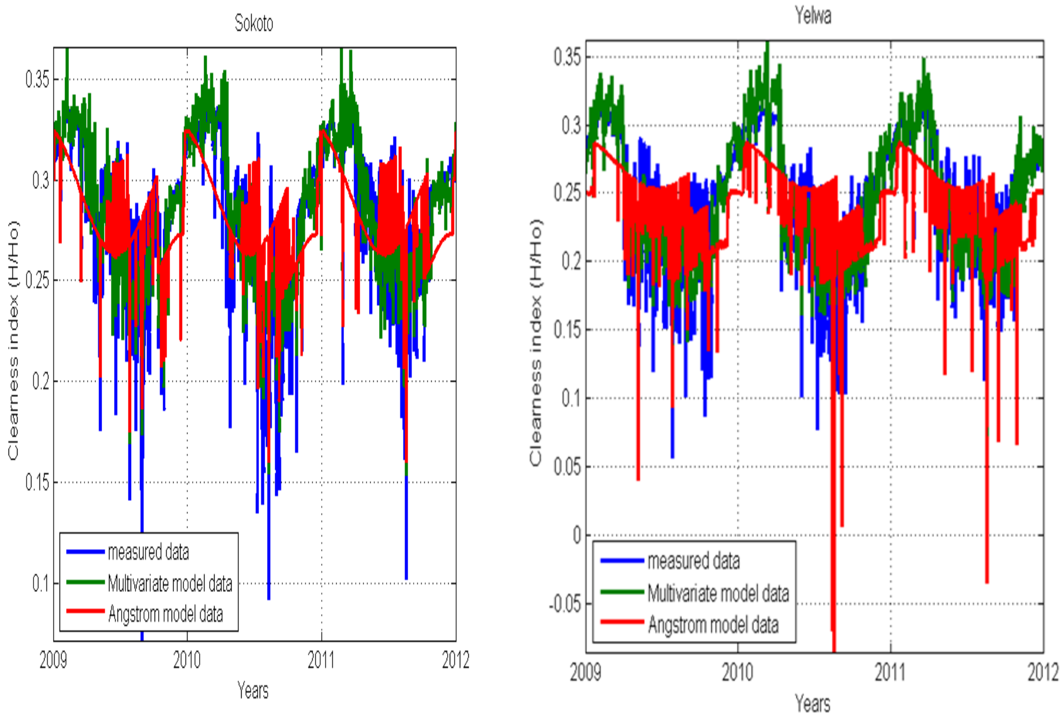

Figure 2: shows the variation of the measured solar radiation with the predicted solar radiation over Sokoto and Yelwa.

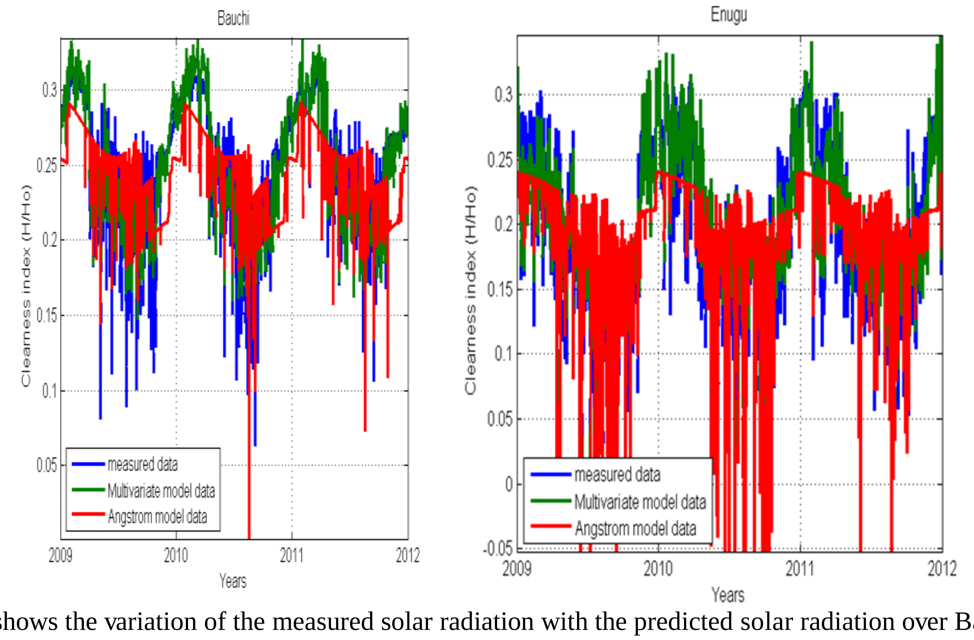

Figure 3: shows the variation of the measured solar radiation with the predicted solar radiation over Bauchi and Enugu.

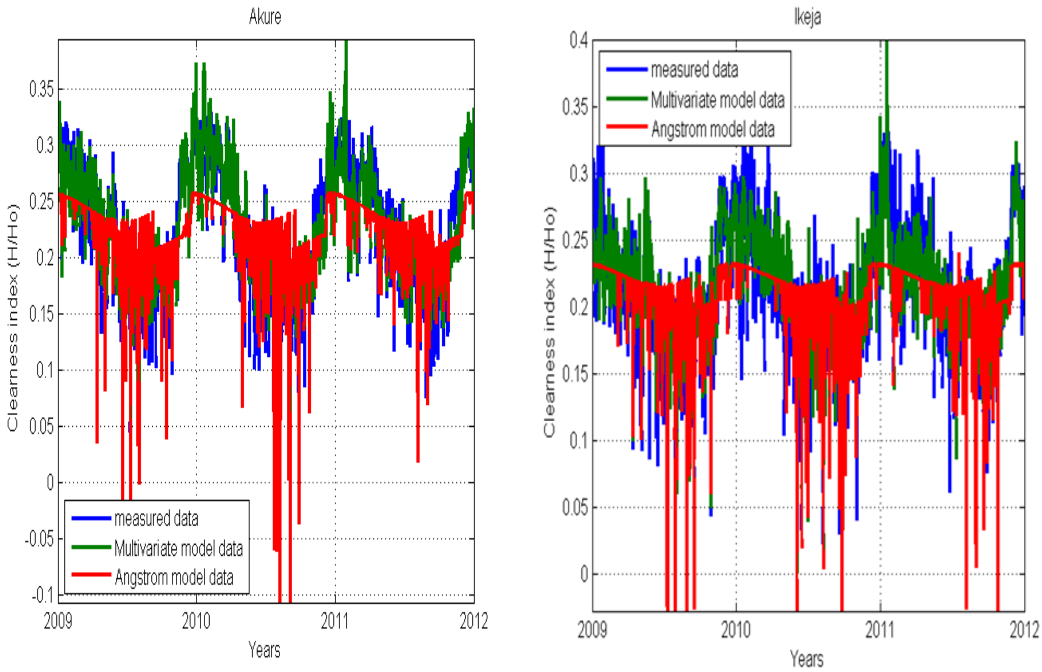

Figure 4: shows the variation of the measured solar radiation with the predicted solar radiation over Akure and Ikeja.

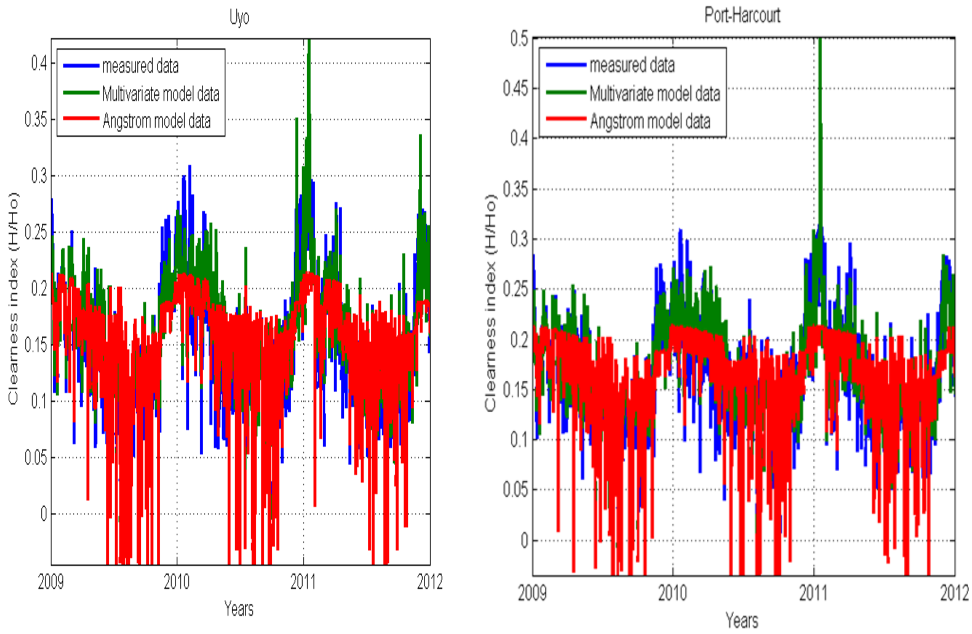

Figure 5: shows the variation of the measured solar radiation with the predicted solar radiation over Uyo and Port-Harcourt

IV. Conclusion

Solar radiation data for 2009-2011 in the ten cities of Nigeria have been predicted using Multivariate and Angstrom-type models. The models were developed using thirty years of five meteorological variables. The analyses have shown that Multivariate models have over 70 percent efficiency ability to predict solar radiation in all the study locations while Angstrom-type model has over 40 percent. This has confirmed that Multivariate model can significantly be used to predict solar radiation more than Angstrom-type model. Finally, research work is still on-going to extend to other stations in savannah zones of Nigeria.

References

[1]. Adeyemi, B. and Ojo, O. S. (2004). Empirical modelling of solar radiation for selected cities using multivariate regression technique. African Journal of Environmental Science and Technology, 8(10): 582–595.
[2]. Al-Salaymeh, A. (2006). Estimation of global solar radiation, energy and power. Science Alert,3(6):119–127.
[3]. Angstrom, A. (1924). Solar and terrestrial radiation. Quart. Jour. Roy. Meteorol. Soc, 50: 121–125.
[4]. Diamante, L. and Munro, P. (1993).Solarenergy.SolarEnerg.J.,51(3):271–276.
[5]. Falayi, E., Rabiu, A.,and Adepitan, J. (1999). Empirical models for the correlation of global solar radiation. Springer verlag, 3: 235–245.
[6]. Halouani, N. and Ngguyen, C .(1993). Monthly average global solar radiation on horizontal surface using daily hours of bright sunshine. Solar Energ. J., 50: 247–258.
[7]. Jibril, Z. (2008). Estimation of solar radiation over predicted table. Journal of physical science, 3(9): 325–334.
[8]. Safari, B. and Gasore, J. (2001). Estimation of global solar radiation. Solar Energ. J., 2:68–75.
[9]. Shaltout, M., Hassan, A., and Fathy, A. (2001). Study of the radiation over Menia. Englewood cliffs,1st edition.
[10]. Ulgen, K. and Hepbasli, A. (2002). Prediction of solar radiation parameters through clearness index for Izmir, Turkey. Energy Source, 24: 773–785.