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Prediction of Global Solar Radiation Using Angstrom-Page Equation Model for Makurdi Benue State, Nigeria

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ABSTRACT: *The Angstrom-Page model was used to predict the Global solar radiation for Makurdi. This was done by measuring, solar radiation, relative humidity, dry and wet bulb temperatures, hours of cloudiness and bright sun-shine at the interval of one hour from 0600hr to 1800hrs daily for a period of six months (February to July, 2011) and the measurements were carried-out within Makurdi metropolis. Sun meter model DS-05 was used to measure the solar radiation, a digital thermo-hygrometer model IT-202 was used to measure relative humidity, wet and dry bulb temperatures. The hours of cloudiness and brightness were determined from the measured solar radiation. Solar radiation intensity $<20w/m^2$ was considered as hours of cloudiness and values $\geq 120w/m^2$ was taken as hours of brightness. The result obtained showed that the mean solar radiation, relative humidity, dry and wet bulb temperatures, hours of cloudiness and bright sun-shine for the location were; $191.64w/m^2$, 60.10%, 30.24^oC, 28.25^oC, 7.72Hrs and 5.28Hrs respectively. The regression constants 'a' and 'b' in Angstrom-page equation were found to be 0.24 and 0.57 respectively. The performance of the variance between measured and calculated radiation were analysed statistically where Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were 0.16 and 5.06% respectively. Similarly, there is a strong correlation between calculated and actual global solar radiation. Finally, this model can be used to predict average global solar radiation for Makurdi location.*

KEYWORDS: *Solar Radiation*, *clearness index, sunshine hours, regression constants and insolation intensity*

I. INTRODUCTION

Solar energy is the most important energy resource to man and indeed it is essential factor for human life. Although the use of passive solar energy in drying process is not new and it date back from ancient time when agricultural product were sundried using solar energy. It is evident that our increasing dependent on conventional energy has rendered these energy sources such as fossil fuel, wood, nuclear, electricity etc more expensive. Most disturbing is the fact that these energy sources are fast depleting and they increases the present environmental pollution problems [1].Solar energy is incident on the earth at a rate of $2.0x10^{15}$kWh/day and is estimated to last for 704 billion years. In principle, solar energy could supply all the present and future commercial energy needs of the world on continuous basis. This makes solar energy one of the most promising of the entire unconventional energy source [2]. Although the supply of solar energy received by the earth is substantial, it has three (3) peculiar characteristics that cause problem in its collection and practical application as an economic substitute for conventional energy source [3]. One, the total amount of solar radiation is large, it is spread out over, a very large area and thus it intensity is low. Therefore large collection fields are required to obtain useful amount of energy, which raises the cost of buying and installing solar energy equipment. Two, it varies, that is the intensity of incoming radiation changes drastically during the day and from season to season, making it necessary either to store large quantity of heat or to provide backup system that runs on conventional fuel, which both add cost and complexity of a solar system. Three, it is intermittent that is the incoming energy is subject to unpredicted interruption of passing cloud which obstruct the sunshine.

Now that there is global campaign on how to reduce the pollution problems cause by some conventional energy source to our environment, therefore, there is a need for exploration of solar energy for domestic and industrial uses. It is becomes inevitable to know how to evaluate insolation levels for any location so that the introduction and sustainability of solar energy will be assured [4].Energy is the backbone of sustainable technological development of any nation and Nigeria is blessed with abundant supply of solar radiation. According to [5]; [6]; and [4] that Nigeria lied in the high solar radiation belt of the world and it was estimated in the far North of the country the solar energy of 3.5–7.0 kw/m^2/day is received annually. Similarly, [7] estimated that the average bright sunshine of 11.6hr/day is received annually. Since Nigeria has adequate solar energy potential to support it energy need, it is therefore becomes imperative to harness the resources insidiously in order to solve the problems of its energy, shortage that is dwindling the sustainability of it industries and environmental pollution.

In general, it is believed that solar energy available depend on the large extent of the latitude, hour of the day, day of the year, the height above sea level (altitude) and some climatic variables such as temperature, humidity, rainfall, harmatan, sunshine and vegetation affect solar radiation [8]; and [9]. In addition to the foregoing variation in solar radiation received at a particular location, there is obvious variation due to atmospheric absorption by carbon dioxide (CO_2), Ozone layer and scattering cloud. Therefore, to evaluate the solar radiation incident on a particular location the above factors ought to be determined in developing models for prediction of global solar radiation of a location. Several authors have developed regional or location based models to predict the quantity of global solar radiation or energy available in specific locations[10]. However, with current trend in climatic change due to global warning has shown that most of climate-dependent constants developed by researchers need to be verified from time to time to check their validity. For example[11] developed that Angstrom-page model equation for Markudi by measuring solar radiation, relative humidity, sunshine hours, dry and wet bulb temperature of the location between August 2008 and December 2009. The Angstrom-page equation was of the form H/H_o = 0.19 + 0.62(ns/N). Similarly.in this research the parameter measured were solar radiation, sunshine hours, relative humidity, dry and wet bull temperature of Markudi for a period of six months between February and July, 2011 from 0600Hr to 1800Hr daily.

II. MATERIALS AND METHODS

2.1 Study Area

The research was carried out at the Agricultural and Environmental Engineering Department of the University of Agriculture, Markudi, Benue state Nigeria. The study location lies on latitude $7^o\ 7^1$N and longitude 8^o6^1E. It is 1500m above sea level. The area is an agrarian environment marked by dry season between November and April and wet season between May and October. The mean annual rainfall usually ranges from 750mm to 1100mm. The temperature in this climatic region is high throughout the year because of high radiation income which is evenly distributed throughout the year. The maximum temperature can reach up to 40^{o}C particularly in April, while the minimum temperature can be as low as 25^{o}C between December and January. There is a seasonal variation of relative humidity in the area with extremely low (20-30%) between January and March, and reaches the peak (70-80%) between July and September. The ten (10) year mean clearness index for Markudi in the rainy season is 0.49 and 0.69 during the dry season (NASA).

2.2 Global Solar Radiation Model

According to[12] Angstrom-page model was found applicable to predict global solar radiation to great extent in so many locations. Therefore, the model was used to predict the global solar radiation of Markudi as used by [13] and [11]. The equation can be expressed as follows:

$$H = H_o[a + b(n_s/N)] = H_o k_t \quad (1)$$

where;
H = monthly average daily global radiation on the horizontal surface
H_o = monthly average daily extra-terrestrial radiation
n_s = monthly average daily number of hours of bright sunshine
N = monthly average daily number of hours of possible sunshine (day light between sunrise and sunset)
'a' and 'b' = regression constants.

The extra-terrestrial solar radiation incident on a horizontal surface H_o in equation (1) is computed in equation (2) [14]

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.33\cos\left(\frac{360n}{365}\right)\right]\left[\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega}{180}\sin\varphi\sin\delta\right] \quad (2)$$

where;
I_{sc} = Solar Constant, has the value of 1367w/m^2 [15]; [16]; [17] and [18]
ω_s = hour angle of sunset or sunrise for the typical day n of each month (degree)
φ = latitude angle of the month (degree)
n = day of the year
δ = declination angle of the month (degree), which varies from +23.450 to -23.450 in the course of the year.

The declination angle is considered positive when sun is in the Northern latitude and negative when in the Southern latitude.

The declinationsδ and hoursω_s angles in equation (2) are computed from expressions (3) and (4) respectively as used by [19]; [15]; [20] and [14].

$$\delta = 23.45 \sin\left[\frac{N-80}{370} \times 360\right] \quad (3)$$

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \quad (4)$$

The month average daily number of hours of possible sunshine N in equation (1) is determined from equation (5)

$$N = \left(\frac{2}{15}\right)^{\cos^{-1}} (-\tan\varphi \tan\delta) = \frac{2\omega_s}{15} \quad (5)$$

Data Measurements

Solar Radiation Measurement: The solar radiation measurement was carried out in an open field free from obstructions such as trees and buildings. A sun-meter model DS-05 calibrated in Watt/Square meters (w/m^2) was used to measure the solar insolation between 0600Hr to 1800Hr on the daily basis for a period of six months. The device was placed 1.5m above the ground in a horizontal position with the sensor pointing in the direction of the sun, east from morning to midday and west from midday to sunset. The device was set ‘ON’ to measure the solar radiation intensity (insolation) and the values were read off from the screen at one hour intervals. The mean values of radiation intensity were computed and recorded.

Temperature Measurement: The ambient temperature of the study area was measured using thermo-hygrometer model IT-202 in degree Celsius (^{o}C) with temperature range of -5 to +5^{o}C and precision of 0.1^{o}C. The thermo-hydrometer was placed where there was free flow of air and away from obstructions and direct sun rays. The values were read off from the screen at one hour intervals. The mean values were computed and recorded.

Relative Humidity Measurement: The relative humidity of the study area was obtained concurrently with the temperature from the thermo-hydrometer model IT-202. The device can measure the relative humidity value within the range of 30 and 90%.

Sun-Shine Hours Measurement: The sunshine hours were obtained from sun-meter model DS-05 and the time lapse or duration for insolation (radiation was recorded using a stop watch. In this research work the insolation value $\geq$120w/m^2 is considered as hour of brightness and values <120wm/^{2} was regarded as cloudiness hour [21].

Determination of Angstrom–Page Regression Constants: The extra-terrestrial radiation H_o, the hour angleω_s, and the hour of bright sunshine N were computed from equation 2, 3 and 5 to obtain the regression constants.
The regression constants ‘a’ and ‘b’ in the Angstrom-page equation were determined by plotting the clearness index H/H_o on the y-axis and fractional possible sunshine hours n_s/N on the x-axis to obtain the best line of fit.

Statistical Analysis: The performance of the regression constants ‘a’ and ‘b’ was computed using Mean Bias Error (MBE) and Root Means Square Error (RMSE) as expressed in equation 6 and 7.

$$MBE = \frac{\Sigma(Y_c - Y_o)/n}{\Sigma Y_o/n} \quad (6)$$

Where;
$Y_c = H_{calc.}$
$Y_o = H_{meas.}$
n = no. of data i.e no. of months.

$$RME = \frac{\frac{\left[\Sigma(Y_c - Y_o)^2\right]^{1/2}}{n}}{\left[\frac{\Sigma(Y_o)}{n}\right]} \quad (7)$$

III. RESULT AND DISCUSSION

The mean solar radiation, relative humidity, dry and wet ambient temperatures, hours (Hrs) of cloudiness and bright sunshine for the location were found to be; 191.64W/m^2, 60.10%, 30.24^{o}C and 28.25^{o}C, 7.72Hrs and 5.28Hrs respectively as shown in Table1. This compares favourably with the findings of [22] for same period. However, it was observed that highest ambient temperature of 32.56^{o}C was recorded in March which are in consonant with the findings of [22] but differ in solar radiation value, this variation could possibly be attributed to the harmattan dust experienced in the month February and March [23].

Table 1: Summary of Measured Monthly Average Daily Total Solar Radiation Parameters from February to July, 2011.

Month	I (w/m^2)	R.H (%)	T_{db}(^{o}c)	T_{wb}(^{o}c)	cloudiness(hr)	Brightness(hr)
February	191.38	53.87	31.38	28.82	7.07	5.93
March	191.37	50.00	32.56	29.92	6.68	6.32
April	202.63	52.32	31.04	28.21	6.63	6.37
May	216.07	66.12	29.75	27.52	7.52	5.48
June	177.22	69.46	28.56	27.76	9.03	3.97
July	171.19	68.80	28.15	27.29	9.42	3.58
Mean	**191.64**	**60.10**	**30.24**	**28.25**	**7.72**	**5.28**

Similarly, the highest radiation of 216.07W/m^2 was recorded in the month of May which may probably be as a result of on-set of rain in that month when the particles in the atmosphere were negligible after rains and the sun intensities were high. This agrees with the assertion made by [24] and [25], that atmospheric particle (cloud, harmattan and dust) reflect some incoming radiation back to space, thereby reducing the amount of radiation, which reaches the earth surface.Furthermore, the mean sunshine hour (n_s) was found to be 5.28Hrs as against the 7Hrs obtained by [22] in the same study location. However, the mean cloudiness hour was found to be 7.72 hours which contrasted the 6Hrs recorded by [22] for the same period of study. This conforms to the finding of [26] which states that solar radiation is directly proportional to duration of sunshine (Table 1). Furthermore, the result showed that the calculated average extra-terrestrial solar radiation, bright sunshine hour, clearness index (H/Ho), fractional sun-shine duration (n_s/N)

Table 2: Summary of Calculated Monthly Average Solar Parameter from February to July, 2011

Month	H(w/m^2)	H_o(w/m^2)	n_s(hrs)	N(hrs)	H/H_o	n_s/N	H_{cal}(w/m^2)
February	191.38	425.39	5.93	11.34	0.45	0.48	208.55
March	191.37	431.60	6.68	11.96	0.44	0.53	191.99
April	202.63	438.00	6.37	12.17	0.48	0.51	192.76
May	216.07	403.36	5.48	12.35	0.42	0.45	204.96
June	177.22	386.17	3.97	12.44	0.46	0.35	174.29
July	171.19	388.59	3.58	12.40	0.44	0.29	176.27
Total	**1149.86**	**2473.11**	**32.01**	**72.66**	**2.69**	**2.61**	**1148.82**
Mean	**191.64**	**412.19**	**5.34**	**12.11**	**0.45**	**0.44**	**191.47**

and predicted solar radiation are; 412.19W/m^2, 5.34hrs, 12.17hrs, 0.45, 0.44 and 191.47W/m^2 respectively as against 422.87W/m^2, 6.76hrs, 12.17hrs, 0.56, 0.54 and 237.59W/m^2 reported by[22] for same period of study (Table 2).

The summary of the determined Angstrom-Page equation and correlation coefficient for each month was given in Table 3. The regression constants a' and 'b' were found to be 0.24 and 0.57 respectively which are in concur with the model developed by [22] for same period of study (February to July, 2009).

Table 3: Summary of the Determined Monthly Angstrom–Page Equation and Correlation Coefficients

Month	H/Ho	ns/N	a'	'b'	Equation	R^2	R
February	0.45	0.48	0.29	0.39	$\frac{H}{H_0} = 0.29 + 0.39\left(\frac{n_s}{N}\right)$	0.73	0.85
March	0.44	0.53	0.33	0.22	" $= 0.33 + 0.22\left(\frac{n_s}{N}\right)$	0.26	0.51
April	0.48	0.51	0.21	0.53	" $= 0.26 + 0.53\left(\frac{n_s}{N}\right)$	0.74	0.86
May	0.52	0.45	0.26	0.59	" $= 0.18 + 0.59\left(\frac{n_s}{N}\right)$	0.68	0.82
June	0.46	0.35	0.18	0.77	" $= 0.18 + 0.77\left(\frac{n_s}{N}\right)$	0.70	0.84
July	0.44	0.29	0.18	0.91	" $= 0.18 + 0.91\left(\frac{n_s}{N}\right)$	0.95	0.9
Mean	**0.45**	**0.44**	**0.24**	**0.57**	$\boldsymbol{\frac{H}{H_o} = 0.24 + 0.57\left(\frac{n_s}{N}\right)}$	**0.68**	**0.81**

This tallies with the plotted Angstrom-Page equation linear graph for same period (February to July, 2009) where the intercept value on the *y-axis* was 0.24 and the slope was 0.56 as shown in Fig.1 and this is slightly above the accepted range of 10% to 20% of the total scattered radiation for regression constants 'a'[15]. However, for the constant 'b' which is the fraction of the extra-terrestrial global radiation component of the location fall within the accepted range. The mean correlation coefficient for the Angstrom–Page equation used in this study was found to be 0.81 as against 0.76 reported by [22] for same period of study (Table 1).

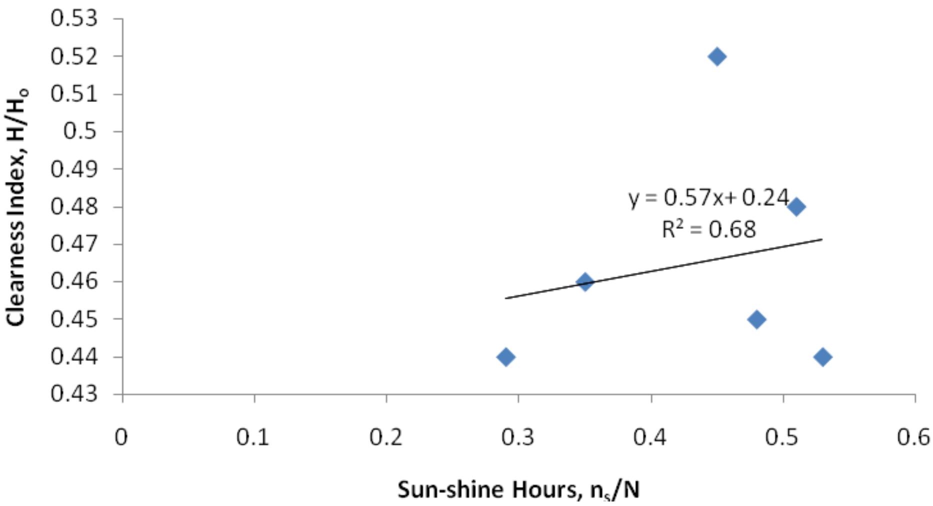

Fig.1: Plot of Angstrom–Page equation for Makurdi location based on monthly means of H/H_O and n_s/N

This implies that 81% of the variations in the measured solar parameter were explained by the verified model leaving 19% to be explained by other factors [27] that changes with time and location. The Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) were used to determine the performance of the model. The values obtained were 0.16% and 5.06% respectively as against 0.51% and 1.12% for same period of study reported by[22]. This variation may likely be as a result of change in weather condition recorded in February and March, 2011.

IV. CONCLUSION AND RECOMMENDATION

Conclusion

This empirical model is developed to predict the solar radiation in Makurdi, located on latitude 7^{o}7'N and 8^{o}53'E using the Angstrom-Page linear equation. The mean correlation coefficient for the Angstrom–Page equation used in this study was found to be 0.81. The Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) were used to determine the performance of the model. The values obtained were 0.16% and 5.06% respectively. The result obtained showed that there is strong relationship between the actual and calculated global solar radiation

Recommendations

The model developed from this study can be used to predict the global solar radiation for Makurdi.Also, further work should be carried out for the months that are not covered by this work to authenticate the model for the year round.

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