

# Estimation of Global and Diffuse Solar Radiation for Kebbi, North-Western, Nigeria.

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## Abstract

Solar energy is one of the most promising renewable sources. It is environmentally friendly, plentiful and easy to utilize. Energy plays a pivotal role in socio-economic development by raising standard of living. A detailed and accurate knowledge of the solar radiation is essential for the optimum design and study of solar energy conversion system. The paper is to assess the applicability of solar energy utilization for Kebbi (latitude =12.47° N and longitude = 4.3°E) for the period of fifteen years. The global and diffuse solar radiation was analyzed using the data obtained from Nigerian Meteorological Agency (NIMET) for Kebbi (1990-2005). In general, measurements of the global solar radiation and sunshine hours data are utilised, but for many applications diffuse and direct fractions are also needed. The diffuse solar radiation was maxima during the months of July and August and as well as minima during the months of November, December and January. The result obtained shows the variation of Direct and Diffuse component of solar radiation in summer and winter months. The percentage of diffuse solar radiation contribution to global solar radiation is low during winter when the sky remains bright and clear. Hence, the presence of direct solar radiation in February, March and April which are 30.96MJ/m<sup>2</sup>/day, 32.60MJ/m<sup>2</sup>/day and 31.87MJ/m<sup>2</sup>/day, will be very useful for utilizing it for solar concentrators, solar cookers and solar furnaces and other solar devices.

**Keywords:** Global solar radiation, Diffuse solar radiation, Clearness index, Monsoon, Kebbi.

## 1. INTRODUCTION

ENERGY is the motive force behind the sustained technological development of any nation and Nigeria is blessed with reasonably high quantities of various energy resources. These include the non-renewable such as crude oil, natural gas, coal, uranium and the renewable such as biomass, solar, wind and hydro energy. Currently, the dominant energy source used in Nigeria is oil and its derivatives, accounting for over 85% of the total energy consumption except in the rural areas where biomass in the form of fuel, wood dominates [1], [2].

Energy is one of the most important inputs for economic growth and human development. The sustainability of future energy systems is critical for sustainable development. Renewable energy is a key element for any sustainable solution [3].

With the rapid depletion of fossil fuel reserves, it is feared that the world will soon run out of its energy resources. This is a matter of concern for the developing countries whose economy heavily depends on imported petroleum products. Under these circumstances it is highly desirable that alternate energy resources should be utilized with maximum conversion efficiency to cope with the ever increasing energy demand [4].

According to [5], solar radiation is a perpetual source of natural energy and has great potential for a wide variety of applications i.e. in agriculture, architectural design of

buildings and in solar thermal devices. It is abundant, accessible and pollution free and hence can be used as a supplement to the non-renewable sources of energy which have finite depleting supplies. The renewable energy sector depends upon the assessment of resources for planning and establishment of energy production technology.

Studies on solar radiation have become an important issue for renewable energy issues stemming from oil crises, global warming and other environmental problems, thus increasing the need of reliable measurements of surface solar radiation [6].

The solar radiation, through atmosphere, reaching the earth's surface can be classified into two components: beam radiation and diffuse radiation. Beam radiation is the solar radiation propagating along the line joining the receiving surface and the sun. It is also referred to as direct radiation. Diffuse radiation is the solar radiation scattered by aerosols, dust and molecules, it does not have a unique direction. The total radiation is the sum of the beam and diffuses radiation and is sometimes referred to as the global radiation. When the amount of diffuse radiation reaching the earth's surface is less than or equal to 25% of global radiation, the sky is termed as clear sky [7].

Wide-scale information concerning the availability of both total irradiation and diffuse irradiation at the location of interest are needed to building energy consumption analysis

and solar energy system analysis. The best way of knowing the amount of diffuse and global solar radiation at any site is to install the sensitive measuring systems at many locations in the given region and to monitor their day-to-day recording and maintenance [8]. Unfortunately, in many part of Nigeria, long term data of diffuse solar radiation are not easily available. Therefore, it is essential to develop the methods to estimate the solar radiation on the basis of the more readily available meteorological data.

Several empirical formulas have been developed to calculate the global and diffuse solar radiation using various parameters [9]. These parameters includes (i) The sunshine hours (ii) the relative humidity (iii) The declination angle (iv) latitude and others [10].

The meteorological data, solar radiation and sunshine hours in Kebbi for the period of 15 years (1990–2005) obtained from Nigerian Meteorological Agency (NIMET) were used in this study.

## 2. METHODOLOGY

According to [15], the first correlation proposed for estimating the monthly average daily global radiation is based on the method of [16]. The original Angstrom-Prescott type regression equation-related monthly average daily radiation to clear day radiation in a given location and average fraction of possible sunshine hours:

$$\frac{H}{H_o} = a + b \left( \frac{S}{S_o} \right) \quad (1)$$

where  $H$  is the monthly average daily global radiation on a horizontal surface ( $\text{MJm}^{-2}\text{day}^{-1}$ ),  $H_o$  the monthly average daily extraterrestrial radiation on a horizontal surface ( $\text{MJm}^{-2}\text{day}^{-1}$ ),  $S$  the monthly average daily hours of bright sunshine,  $S_o$  the monthly average day length, and “a” and “b” values are known as Angstrom constants and they are empirical.

The values of the monthly average daily extraterrestrial irradiation ( $H_o$ ) can be calculated from the following equation (2) [17]:

$$\left( \frac{24}{\pi} \right) I_{sc} \left[ 1 + 0.033 \cos \left( \frac{360n}{365} \right) \right] \times \left[ \cos \phi \cos \delta \sin \omega_s + \left( \frac{2\pi \omega_s}{360} \right) \sin \phi \sin \delta \right] \quad (2)$$

Where  $I_{sc}$  is the solar constant ( $=1367 \text{ W m}^{-2}$ ),  $\phi$  the latitude of the site,  $\delta$  the solar declination,  $\omega_s$  the mean sunrise hour angle for the given month, and n the number of days of the year starting from the first of January.

The solar declination ( $\delta$ ) and the mean sunrise hour angle ( $\omega_s$ ) can be calculated by the following equations (3) and (4), respectively in [18]:

In this study, solar radiation estimation was done for Kebbi, to utilize solar energy for useful purpose. Recently [11] proposed a temperature-based model for predicting the monthly mean global solar radiation on horizontal surfaces for Abuja, Benin city, Katsina, Lagos, Nsukka and Yola, representing the six geopolitical zones in Nigeria. Prior to this study, estimation of diffuse solar radiation in Lagos, Nigeria has also been reported [12].

The Kebbi, Nigeria has an area of 36,800 sq.Km. It is located at (latitude  $=12.47^\circ \text{ N}$  and longitude  $= 4.3^\circ \text{ E}$  and has the population of 3.6 million people. About 70 percent of these population lives in villages.

The objective of this study will assist solar energy researchers to harness and utilize the solar energy potential to solve the energy deficit in Kebbi, Nigeria, which is endowed with high sunshine in all year round for the period of fifteen years (1990 - 2005) using [13], [14] methods.

$$\delta = 23.45 \sin \left( 360 \frac{284 + n}{365} \right) \quad (3)$$

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

For a given month, the maximum possible sunshine duration (monthly average day length) ( $S_o$ ) can be computed by using the following equation (5) [17]

$$S_o = \frac{2}{15} \omega_s \quad (5)$$

Then, the monthly mean of daily global radiation  $H$  was normalized by dividing with monthly mean of daily extraterrestrial radiation  $H_o$ . The clearness index ( $K_T$ ) is define as the ratio of the observed/measured horizontal terrestrial solar radiation ( $H$ ), to the calculated/predicted horizontal/extraterrestrial solar radiation ( $H_o$ ) [19]

$$K_T = \frac{H}{H_o} \quad (6)$$

In this study,  $H_o$  and  $S_o$  were computed for each month by using Equations (2) and (5), respectively. The regression coefficients **a** and **b** in Equation (1) was obtained from the

graph of  $\frac{H_{cal}}{H_o}$  against  $\frac{S}{S_o}$ . The values of the monthly

average daily global radiation  $H$  and the average number of hours of sunshine were obtained from daily measurements covering a period of 15 years. The regression coefficient **a** and **b** has been obtained from the relationship given as [20]:

$$a = -0.110 + 0.235 \cos \phi + 0.323 \left( \frac{S}{S_o} \right) \quad (7)$$

$$b = 1.449 - 0.553 \cos \phi - 0.694 \left( \frac{S}{S_o} \right) \quad (8)$$

To compute estimated values of the monthly average daily global radiation  $H_{Cal}$ , the values of  $a$  and  $b$  were used in Equation (1) [21].

**Prediction of Diffuse Solar Radiation.  $H_d$**

The diffuse solar radiation  $H_d$  can be estimated by an empirical formula which correlates the diffuse solar radiation component  $H_d$  to the daily total radiation  $H$ . The correlation equation which is widely used is developed by [14].

$$\frac{H_d}{H} = 1.00 - 1.13K_T \quad (9)$$

where  $H_d$  is the monthly mean of the daily Diffuse solar radiation and  $K_T = H/H_o$  is the clearness index. . Another

commonly used correlation is due to [13] and developed by [22] and is of the form

$$\frac{H_d}{H} = 1.390 - 4.027K_T + 5.53(K_T)^2 - 3.108(K_T)^3 \quad (10)$$

The global solar irradiation ( $H_T$ ) consists of three parts, which are direct solar radiation ( $H_b$ ), diffused solar radiation ( $H_d$ ) and reflected solar radiation ( $H_r$ ). Since on horizontal surface the reflected solar radiation ( $H_r$ ) is equal to zero,  $H_T$  on a horizontal surface is given as below:

$$H_T = H_b + H_d + H_r \text{ where } H_r = 0 \quad (11)$$

$$H_T = H_b + H_d \text{ [23]} \quad (12)$$

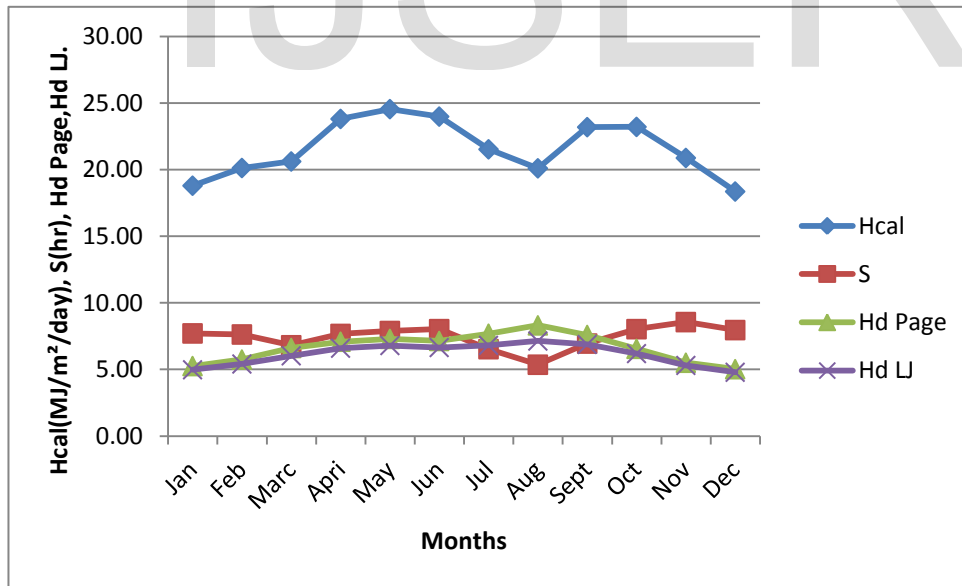
**3. RESULTS AND DISCUSSION**

**Table 1: Input Parameters for Estimation of Monthly Average Global Solar Radiation and Solar Radiation data for Kebbi, North-Western, Nigeria (1990 - 2005).**

Months	Hcal	H <sub>0</sub>	S	S <sub>0</sub>	Hcal/H <sub>0</sub>	S/S <sub>0</sub>	Hd/H Page	Hd/H LJ	Hd Page	Hd LJ	Hd=(P+LJ)/2	Hd/H <sub>0</sub>	Hd/Hcal
Jan	18.80	29.49	7.71	11.28	0.637	0.683	0.280	0.265	5.259	4.983	5.121	0.174	0.272
Feb	20.13	31.83	7.63	11.46	0.632	0.666	0.286	0.269	5.749	5.415	5.582	0.175	0.277
Marc	20.62	34.30	6.82	11.74	0.601	0.581	0.321	0.293	6.616	6.031	6.323	0.184	0.307
Apri	23.81	38.31	7.67	12.10	0.621	0.634	0.298	0.277	7.088	6.598	6.843	0.179	0.287
May	24.54	39.47	7.89	12.44	0.622	0.634	0.297	0.277	7.300	6.797	7.049	0.179	0.287
Jun	23.98	38.60	8.03	12.68	0.621	0.633	0.298	0.277	7.143	6.649	6.896	0.179	0.288
Jul	21.53	37.84	6.53	12.73	0.569	0.513	0.357	0.317	7.687	6.814	7.251	0.192	0.337
Aug	20.10	38.74	5.36	12.56	0.519	0.427	0.414	0.355	8.314	7.138	7.726	0.199	0.384
Sept	23.19	38.96	6.95	12.24	0.595	0.568	0.327	0.297	7.593	6.884	7.239	0.186	0.312
Oct	23.21	36.55	8.03	11.89	0.635	0.675	0.282	0.267	6.556	6.194	6.375	0.174	0.275
Nov	20.88	32.05	8.56	11.55	0.651	0.741	0.264	0.254	5.511	5.309	5.410	0.169	0.259
Dec	18.36	28.57	7.96	11.32	0.643	0.703	0.274	0.261	5.026	4.792	4.909	0.172	0.267

**Table 2: The direct and diffuse solar radiation values for Kebbi, North- Western, Nigeria (1990-2005)**

Months	Hb	Hd
Jan	29.429	5.121
Feb	30.958	5.582
Marc	32.597	6.323
Apri	31.867	6.843
May	28.991	7.049
Jun	26.464	6.896
Jul	24.259	7.251
Aug	23.114	7.726
Sept	24.501	7.239
Oct	27.275	6.375
Nov	29.970	5.410
Dec	30.121	4.909



**Figure 1: Monthly variation of Hcal, S, Hd(Page), Hd(LJ) for Kebbi, Nigeria (1990-2005)**

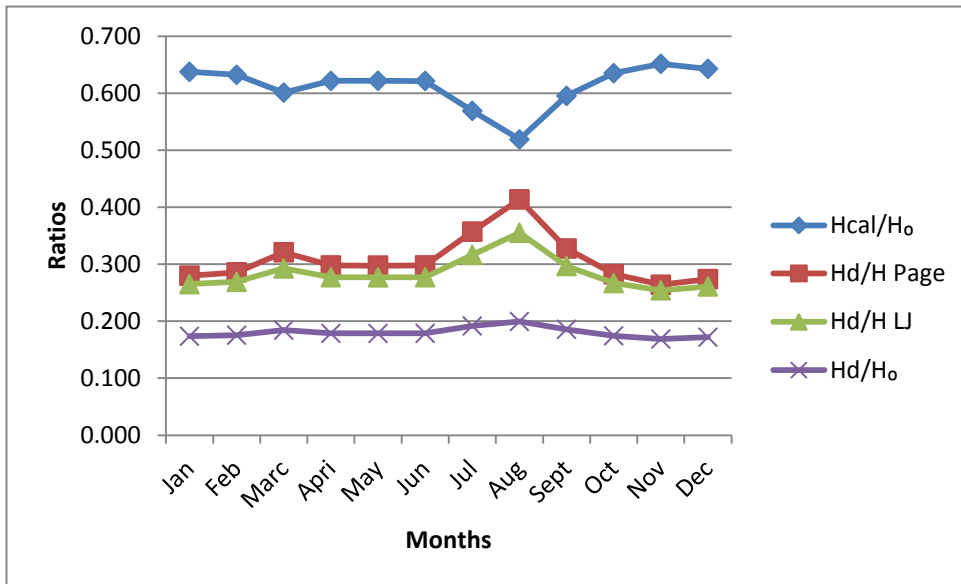


Figure 2: Monthly variation of calculated clearness index ( $KT= Hcal/H_o$ ),  $Hd/H$ (Page & LJ) and  $Hd/H_o$  for Kebbi (1990 - 2005)

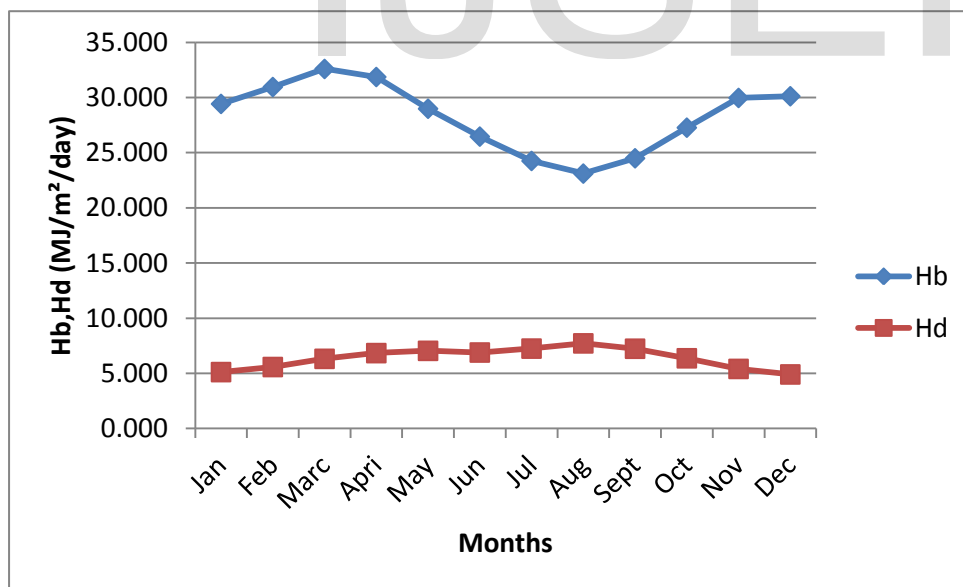


Figure 3: Shows the pattern of Direct and Diffuse at Kebbi (1990- 2005)

The results of the input parameters for estimation of monthly average global solar radiation and solar radiation

data for Kebbi, Nigeria (1990 - 2005) are presented in Table 1. The result shows that sunshine duration is above 65%

throughout the year, with the exception of July to August which are 51% and 43% respectively. Using these parameters, the regression constants 'a' and 'b' are evaluated as 0.351 and 0.420 with the coefficient of determination,  $R^2$ , (97.40). The values of  $H_{cal}$ ,  $K_T = H_{cal}/H_o$ , and  $H_d$  for Kebbi, Nigeria (1990 - 2005) were estimated using [13], [14] methods as no station in Nigeria measures diffuse solar radiation. The result of the calculated values indicated that diffuse solar radiation contribution is too low throughout the year. Its contribution is below 25% in monsoon months. It is also observed from (Table 1) that the location mentioned above experienced a decrease in the

clearness index  $\frac{H_{cal}}{H_o}$  (MJ/m<sup>2</sup>/day) during the rainy season

(July-August) with increase in diffuse solar radiation ( $H_d$ ). This wet season minimum is expected due to poor sky conditions caused by atmospheric controls as the atmosphere is partly cloudy and part of solar radiation are scattered by air molecules, some absorbed directly by the dust particles, ozone and water vapour of cloud. Increase cloud cover and precipitation water, associated with the Inter - Tropical Convergence Zone (ITCZ), result to the low value of clearness index in the wet season they have likely contributed to the decrease in the clear days in the station under analysis [19].

The availability of direct solar radiation is therefore very encouraging from utilization point of view. The transmission of  $H_d$  in Extraterrestrial radiation, that is, the cloudiness ( $H_d/H$ ) is only 17 percent which rises to 20 percent in the months of July-August. From the observation of clearness index and ratio of diffuse to global, we conclude that presence of clouds is very rare even in the monsoon months. This is the most favourable condition for solar energy utilization.

The monthly average variation of calculated global solar radiation ( $H_{cal}$ ), sunshine hour (hr) and [13], [14] method for Kebbi, Nigeria (1990 - 2005) is shown in Fig.1. It is observed clearly that there is a defined trough in the curves for the months of August for sunshine hour as well as in the value of calculated global solar radiation which is an indication of poor sky condition.

The transmission through the atmosphere ( $K_T = H_{cal}/H_o$ ) along with the percent of diffuse solar radiation in global solar radiation is shown in Figure 2 for Kebbi for the period of fifteen years. The defined trough in the value of ( $K_T = H_{cal}/H_o$ ) is in accordance with the high value of  $H_d/H$  for the same month. The sky is fairly clear during winter months when solar radiation is in demand for utilization purpose.

The atmosphere clearness is indicated by fraction of Extraterrestrial radiation that reaches the earth surface as

global solar radiation. It is a measure of the degree of clearness of the sky. Clearness index is given as

$$K_T = H/H_o$$

Where  $K_T$  is clearness index,  $H$  is the global solar radiation and  $H_o$  is the Extraterrestrial insolation [10]. From the estimated value of  $H$  for Kebbi,  $K_T (=H_{cal}/H_o)$  is calculated and it is very encouraging to note that the sky over Kebbi is very clear almost throughout the year except in the month of August when ( $K_T = H_{cal}/H_o$ ) was 52%.

The statistical data distribution of global solar radiation for Kebbi for the period of fifteen years is shown in Table 3. From this table, the results indicated that in Kebbi, there is abundant sunlight which is about 62%. This implies that a clear sky will obviously fall within the dry season and hence a high solar radiation is experienced while during the rainy season it is about 54% when the sky is cloudy and solar radiation is fairly low.

Table 3: Statistical Data of Global Radiation for Kebbi, Nigeria (1990 - 2005)

January - April	Above 62 percent
May - June	Above 62 percent
July - August(monsoon)	Above 54 percent
September - December	Above 63 percent

The result of trend of variation exhibits between direct and diffuse solar radiation is shown in Figure 3. It was observed that the maxima of direct solar radiation for months of February, March and April in Kebbi are quite appreciable (Table 2). The diffuse solar radiation is maxima only in the month of August which is 38.4% in Kebbi even in worst sky condition. This is confirmed with the low values of  $K_T = H_{cal}/H_o$  and high values of  $H_d/H$  (Fig. 2). The percentage of diffuse solar radiation contribution to global solar radiation is low during winter when the sky remains bright and clear. Hence, the presence of direct solar radiation in February, March and April which are 30.96MJ/m<sup>2</sup>/day, 32.60MJ/m<sup>2</sup>/day and 31.87MJ/m<sup>2</sup>/day, will be very useful for utilizing it for solar concentrators, solar cookers and solar furnaces etc. The Angstrom model for determination of global solar radiation, [13], [14] model for the estimation of diffuse solar radiation exhibits the validity of estimation for location under study.

#### 4. CONCLUSION

In this study, the diffuse component of solar radiation was obtained by calculation applying equations (9) and (10) given by [13], [14] for solar energy utilization and bright prospects for Kebbi. The calculated values of global and diffuse solar radiation reveals that solar radiation can be very efficiently used to compensate for the energy deficit in Kebbi. For the estimation of diffuse solar radiation by [13], [14] methods are in very good agreement whereas

Angstrom equation calculates the monthly average daily global solar radiation. This study will be very helpful to explore solar energy potential resources at Kebbi.

However, the study employing Angstrom model and [13], [14] models for both global and diffuse solar radiation for Kebbi (1990 - 2005), serves the purpose very effectively. Hence, condition for solar energy utilization in Kebbi is most favourable since the study shows that there is a greater availability of solar radiation at the location with a maximum and minimum sunshine hour of 8.56 and 5.36 hours in the months November and August respectively.

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