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# ESTIMATION OF GLOBAL SOLAR RADIATION IN GUSAU, NIGERIA

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## ABSTRACT

Information on the availability of global solar radiation of a given geographical location is an essential factor in developing suitable solar energy system and devices for various applications. In this work, data for daily sunshine duration were used to estimate mean global solar radiation in Gusau city, Nigeria. The daily sunshine hours were measured for period of 6 years (1995 - 2000) from which the monthly mean values were determined. Angstrom-Prescott model was then used to estimate the global solar radiation based on the monthly mean sunshine hours. The values of global solar radiation for Gusau ranged from 16.1676 - 21.6536 $MJm^{-2}day^{-1}$ under the period of study with mean value of 18.8015 $MJm^{-2}day^{-1}$. These values can be utilized in the design and performance of solar energy systems for the location.

**KEYWORDS:** Angstrom, Gusau, NIMET, Prescott, Solar Radiation, Sunshine Hours

## INTRODUCTION

Solar energy is the most ancient source of energy; it is the basic element for almost all fossil and renewable energies. Solar energy is freely available and could be easily harnessed to reduce the level of reliance on hydrocarbon-based energy [5]. Precise global solar radiation estimation tools are critical in the design of solar systems. Solar energy occupies one of the most important places among the various possible alternative energy sources. The correct knowledge of global solar radiation at a given geographical location is vital to the development of many solar energy devices.

Solar radiation data have useful applications in different areas, such as solar water heating, wood drying, stoves, ovens, photovoltaic, atmospheric energy balance studies, thermal load analyses on buildings, agricultural studies, and meteorological forecasting which should be reliable and readily available for design, optimization and performance evaluation of solar technologies for any particular location [10]. But unfortunately, solar radiation measurements are not readily available in many developing countries due to dearth of measurement equipment. It is important therefore, to consider methods of estimating the global solar radiation based on the readily available meteorological parameters.

Many models have been proposed over the years, to predict the amount of solar radiation in some cities in Nigeria using various metrological data. A good number of correlations involving global solar radiation for different locations have been studied by different researchers in Nigeria. For examples, [4] developed a model for estimation of global solar radiation in Bauchi and found the regression coefficients $a$ and $b$ to be 0.24 and 0.46, respectively; [2] established the relationship between global solar radiation and sunshine duration for Onne, with regression coefficients $a$ and $b$ having values of 0.23 and 0.38, respectively.[9] developed empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria; [1] developed empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Nigeria; [6] used angstrom model to estimate mean monthly global solar radiation in Yola, Nigeria;[7] estimated the global solar radiation in Maiduguri, Nigeria using angstrom model; [8]used Angstrom type empirical correlation to estimate global solar radiation in north-eastern Nigeria. These researchers developed their models based on correlation of global solar radiation with sunshine hours for some of selected cities in Nigeria. The aim of this work is to use the popular Angstrom-Prescott model to estimate the global solar radiation in Gusaucity based on the available climatic parameters of sunshine hours.

## MATERIALS AND METHODS

The mean daily data for sunshine hours and maximum temperature data for Gusau, were collected from the archives of the Nigerian Meteorological Agency (NIMET), Federal Ministry of Aviation, Oshodi Lagos. The study site Gusau lies in the tropics with Lat. $12.17^0$ N and Long. $6.70^0$ E in Zamfara State, north-western Nigeria. The data obtained covered a period of 6 years (1995-2000). The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface H ($MJm^{-2}day^{-1}$) using the sunshine duration data is due to [3]. The Angstrom correlation wasmodified by Prescott to a more convenient form popularly referred to asAngstrom-Prescott formula given by [9] and [7].

$$\frac{\bar{H}}{\bar{H}_0} = a + b\frac{\bar{S}}{\bar{S}_0} \quad (1)$$

where $\bar{H}$ is the monthly mean daily global solar radiationon a horizontal surfacein ($MJm^{-2}day^{-1}$),$\bar{H}_0$ is the monthly mean extra-terrestrial global solar radiation on horizontal surface in ($MJm^{-2}day^{-1}$),$\bar{S}$ is themonthly mean daily bright sunshine hours in (Hours), $\bar{s}_0$isthe maximum possible monthly mean daily sunshine in (Hours) while$a$and $b$are regression constants.The monthly mean daily extra-terrestrial global solar radiation was calculated from the following equation[7]:

$$\bar{H}_0 = \frac{24\,x\,3600}{\pi} I_{SC}\left[1 + 0.033\cos\frac{360n}{365}\right] x \left[\cos\theta\cos\delta\sin\sigma + \frac{\pi}{180}\sigma\sin\theta\sin\delta\right] \quad (2)$$

Where$I_{SC}$= 1367 $Wm^{-2}$ is the solar constant [5], $n$is the Julian day number starting from January 1 to December 31, $\theta$ is the latitude angle of the location ($\theta$ = $12.17^0$), $\delta$ is the declination angle while $\sigma$ is the sunset hour. $\delta$and$\sigma$ were evaluated from these formulae [5].

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

$$\sigma = \cos^{-1}[-\tan\theta\tan\delta] \quad (4)$$

The maximum possible sunshine duration $\bar{s}_0$was calculated using the following equation [5].

$$\bar{s}_0 = \frac{2}{15}\sigma \quad (5)$$

The regression constants $a$ and $b$ werecalculated from equations (6) and (7)respectively [7].

$$a = -0.110 + 0.235\cos\theta + 0.323\left(\frac{\bar{S}}{\bar{S}_0}\right) \quad (6)$$

$$b = 1.449 - 0.553\cos\theta - 0.694\left(\frac{\bar{S}}{\bar{S}_0}\right) \quad (7)$$

## RESULTS AND DISCUSSIONS

Equations (2) to (7) were used to calculate the parameters $\bar{s}_0$, $\bar{S}/\bar{s}_0$, $a$, $b$, $\bar{H}_0$ and $\bar{H}$ needed for estimating global solar radiation and are then substituted into equation (1) to estimate the global solar radiation for Gusau city. The values of monthly mean sunshine duration $\bar{S}$, obtained from NIMET for the period and the solar data calculated are as presented in Tables 1 – 6. It can be observed from Tables 1-6 as well as Figure 1 that, the monthly global solar radiation is not uniform throughout the period of study. The maximum global solar radiation is observed in the months of November, February, March and April respectively while the months of June, July and August recorded the least amount of global solar radiation. This can be attributed to peak period of cloud cover due to the rainy season.

**Table 1: Monthly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau in 1995**

| Year 1995 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Month** | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m²/day⁻¹) | $\bar{H}$(MJ/m²/day⁻¹) |
| Jan | 6.5 | 11.5013 | 0.56515 | 0.3023 | 0.5162 | 32.2566 | 19.1605 |
| Feb | 5.3 | 11.8102 | 0.44876 | 0.2647 | 0.5970 | 35.2197 | 18.7571 |
| Mar | 7.3 | 11.5013 | 0.63471 | 0.3247 | 0.4679 | 32.2566 | 20.0551 |
| Apr | 6.6 | 11.5957 | 0.56918 | 0.3036 | 0.5134 | 33.2478 | 19.8087 |
| May | 6.3 | 11.5013 | 0.54776 | 0.2966 | 0.5283 | 32.2566 | 18.9030 |
| Jun | 4.5 | 11.5957 | 0.38808 | 0.2451 | 0.6391 | 33.2478 | 16.3941 |
| Jul | 4.6 | 11.5013 | 0.39995 | 0.2489 | 0.6309 | 32.2566 | 16.1676 |
| Aug | 4.8 | 11.5013 | 0.41734 | 0.2545 | 0.6188 | 32.2566 | 16.5402 |
| Sep | 6.3 | 11.5957 | 0.54331 | 0.2952 | 0.5314 | 33.2478 | 19.4136 |
| Oct | 7.4 | 11.5013 | 0.6434 | 0.3275 | 0.4619 | 32.2566 | 20.1517 |
| Nov | 8.5 | 11.5957 | 0.73303 | 0.3565 | 0.3997 | 33.2478 | 21.5939 |
| Dec | 5.4 | 11.5013 | 0.46951 | 0.2714 | 0.5826 | 32.2566 | 17.5767 |

**Table 2: Monthly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau in 1996**

| Year 1996 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Month** | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m²/day⁻¹) | $\bar{H}$(MJ/m²/day⁻¹) |
| Jan | 6.1 | 11.5013 | 0.53037 | 0.2910 | 0.5403 | 32.2566 | 18.6319 |
| Feb | 6.6 | 11.8102 | 0.55884 | 0.3002 | 0.5206 | 35.2197 | 20.8202 |
| Mar | 7.3 | 11.5013 | 0.63471 | 0.3247 | 0.4679 | 32.2566 | 20.0551 |
| Apr | 7.1 | 11.5957 | 0.6123 | 0.3175 | 0.4835 | 33.2478 | 20.3986 |
| May | 6.3 | 11.5013 | 0.54776 | 0.2966 | 0.5283 | 32.2566 | 18.9030 |
| Jun | 5.0 | 11.5957 | 0.4312 | 0.2590 | 0.6092 | 33.2478 | 17.3444 |
| Jul | 4.6 | 11.5013 | 0.39995 | 0.2489 | 0.6309 | 32.2566 | 16.1676 |
| Aug | 4.8 | 11.5013 | 0.41734 | 0.2545 | 0.6188 | 32.2566 | 16.5402 |
| Sep | 6.3 | 11.5957 | 0.54331 | 0.2952 | 0.5314 | 33.2478 | 19.4136 |
| Oct | 7.4 | 11.5013 | 0.6434 | 0.3275 | 0.4619 | 32.2566 | 20.1517 |
| Nov | 8.0 | 11.5957 | 0.68991 | 0.3426 | 0.4296 | 33.2478 | 21.2443 |
| Dec | 5.0 | 11.5013 | 0.43473 | 0.2601 | 0.6067 | 32.2566 | 16.8992 |

**Table 3: Monthly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau in 1997**

| Year 1997 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Month** | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m²/day⁻¹) | $\bar{H}$(MJ/m²/day⁻¹) |
| Jan | 6.0 | 11.5013 | 0.52168 | 0.2882 | 0.5464 | 32.2566 | 18.4913 |
| Feb | 6.3 | 11.8102 | 0.53344 | 0.2920 | 0.5382 | 35.2197 | 20.3966 |
| Mar | 7.0 | 11.5013 | 0.60863 | 0.3163 | 0.4860 | 32.2566 | 19.7450 |
| Apr | 6.6 | 11.5957 | 0.56918 | 0.3036 | 0.5134 | 33.2478 | 19.8087 |
| May | 6.3 | 11.5013 | 0.54776 | 0.2966 | 0.5283 | 32.2566 | 18.9030 |
| Jun | 4.6 | 11.5957 | 0.3967 | 0.2479 | 0.6331 | 33.2478 | 16.5910 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Jul | 4.5 | 11.5013 | 0.39126 | 0.2461 | 0.6369 | 32.2566 | 15.9762 |
| Aug | 4.8 | 11.5013 | 0.41734 | 0.2545 | 0.6188 | 32.2566 | 16.5402 |
| Sep | 6.3 | 11.5957 | 0.54331 | 0.2952 | 0.5314 | 33.2478 | 19.4136 |
| Oct | 7.4 | 11.5013 | 0.6434 | 0.3275 | 0.4619 | 32.2566 | 20.1517 |
| Nov | 8.2 | 11.5957 | 0.70716 | 0.3481 | 0.4177 | 33.2478 | 21.3944 |
| Dec | 5.1 | 11.5013 | 0.44343 | 0.2629 | 0.6007 | 32.2566 | 17.0737 |

**Table 4: Monthly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau in 1998**

| Year 1998 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m$^2$/day$^{-1}$) | $\bar{H}$(MJ/m$^2$/day$^{-1}$) |
| Jan | 6.4 | 11.5013 | 0.55646 | 0.2995 | 0.5222 | 32.2566 | 19.0334 |
| Feb | 5.9 | 11.8102 | 0.49957 | 0.2811 | 0.5617 | 35.2197 | 19.7829 |
| Mar | 7.3 | 11.5013 | 0.63471 | 0.3247 | 0.4679 | 32.2566 | 20.0551 |
| Apr | 6.3 | 11.5957 | 0.54331 | 0.2952 | 0.5314 | 33.2478 | 19.4136 |
| May | 6.3 | 11.5013 | 0.54776 | 0.2966 | 0.5283 | 32.2566 | 18.9030 |
| Jun | 5.0 | 11.5957 | 0.4312 | 0.2590 | 0.6092 | 33.2478 | 17.3444 |
| Jul | 4.6 | 11.5013 | 0.39995 | 0.2489 | 0.6309 | 32.2566 | 16.1676 |
| Aug | 4.9 | 11.5013 | 0.42604 | 0.2573 | 0.6128 | 32.2566 | 16.7214 |
| Sep | 6.3 | 11.5957 | 0.54331 | 0.2952 | 0.5314 | 33.2478 | 19.4136 |
| Oct | 7.0 | 11.5013 | 0.60863 | 0.3163 | 0.4860 | 32.2566 | 19.7450 |
| Nov | 8.1 | 11.5957 | 0.69854 | 0.3453 | 0.4236 | 33.2478 | 21.3211 |
| Dec | 5.2 | 11.5013 | 0.45212 | 0.2658 | 0.5947 | 32.2566 | 17.2447 |

**Table 5: Monthly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau in 1999**

| Year1999 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m$^2$/day$^{-1}$) | $\bar{H}$(MJ/m$^2$/day$^{-1}$) |
| Jan | 6.0 | 11.5013 | 0.52168 | 0.2882 | 0.5464 | 32.2566 | 18.4913 |
| Feb | 5.9 | 11.8102 | 0.49957 | 0.2811 | 0.5617 | 35.2197 | 19.7829 |
| Mar | 7.3 | 11.5013 | 0.63471 | 0.3247 | 0.4679 | 32.2566 | 20.0551 |
| Apr | 6.9 | 11.5957 | 0.59505 | 0.3119 | 0.4955 | 33.2478 | 20.1730 |
| May | 6.3 | 11.5013 | 0.54776 | 0.2966 | 0.5283 | 32.2566 | 18.9030 |
| Jun | 5.0 | 11.5957 | 0.4312 | 0.2590 | 0.6092 | 33.2478 | 17.3444 |
| Jul | 4.6 | 11.5013 | 0.39995 | 0.2489 | 0.6309 | 32.2566 | 16.1676 |
| Aug | 4.8 | 11.5013 | 0.41734 | 0.2545 | 0.6188 | 32.2566 | 16.5402 |
| Sep | 6.3 | 11.5957 | 0.54331 | 0.2952 | 0.5314 | 33.2478 | 19.4136 |
| Oct | 7.0 | 11.5013 | 0.60863 | 0.3163 | 0.4860 | 32.2566 | 19.7450 |
| Nov | 8.0 | 11.5957 | 0.68991 | 0.3426 | 0.4296 | 33.2478 | 21.2443 |
| Dec | 5.5 | 11.5013 | 0.47821 | 0.2742 | 0.5766 | 32.2566 | 17.7376 |

**Table 6: Monthly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau in 2000**

| Year 2000 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m$^2$/day$^{-1}$) | $\bar{H}$(MJ/m$^2$/day$^{-1}$) |
| Jan | 6.0 | 11.5013 | 0.52168 | 0.2882 | 0.5464 | 32.2566 | 18.4913 |
| Feb | 6.5 | 11.8102 | 0.55037 | 0.2975 | 0.5265 | 35.2197 | 20.6825 |
| Mar | 7.6 | 11.5013 | 0.66079 | 0.3332 | 0.4498 | 32.2566 | 20.3347 |
| Apr | 6.6 | 11.5957 | 0.56918 | 0.3036 | 0.5134 | 33.2478 | 19.8087 |
| May | 6.0 | 11.5013 | 0.52168 | 0.2882 | 0.5464 | 32.2566 | 18.4913 |
| Jun | 4.8 | 11.5957 | 0.41395 | 0.2534 | 0.6211 | 33.2478 | 16.9746 |
| Jul | 4.6 | 11.5013 | 0.39995 | 0.2489 | 0.6309 | 32.2566 | 16.1676 |
| Aug | 5.0 | 11.5013 | 0.43473 | 0.2601 | 0.6067 | 32.2566 | 16.8992 |
| Sep | 6.5 | 11.5957 | 0.56055 | 0.3008 | 0.5194 | 33.2478 | 19.6804 |
| Oct | 7.4 | 11.5013 | 0.6434 | 0.3275 | 0.4619 | 32.2566 | 20.1517 |
| Nov | 8.6 | 11.5957 | 0.74166 | 0.3593 | 0.3937 | 33.2478 | 21.6536 |
| Dec | 5.7 | 11.5013 | 0.4956 | 0.2798 | 0.5645 | 32.2566 | 18.0492 |

**Table 7: Yearly Mean Values of Global Solar Radiation and Other Solar Parameters for Gusau 1995-2000**

| Yearly | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | $\bar{S}$ (hrs) | $\bar{s}_0$ (hrs) | $\bar{S}/\bar{s}_0$ | $a$ | $b$ | $\bar{H}_0$ (MJ/m²/day⁻¹) | $\bar{H}$(MJ/m²/day⁻¹) |
| 1995 | 6.1 | 11.5585 | 0.5300 | 0.2909 | 0.5406 | 32.8339 | 18.7102 |
| 1996 | 6.2 | 11.5585 | 0.5370 | 0.2932 | 0.5358 | 32.8339 | 18.8808 |
| 1997 | 6.1 | 11.5585 | 0.5269 | 0.2899 | 0.5427 | 32.8339 | 18.7071 |
| 1998 | 6.1 | 11.5585 | 0.5285 | 0.2904 | 0.5417 | 32.8339 | 18.7621 |
| 1999 | 6.1 | 11.5585 | 0.5306 | 0.2911 | 0.5402 | 32.8339 | 18.7998 |
| 2000 | 6.3 | 11.5585 | 0.5428 | 0.2950 | 0.5317 | 32.8339 | 18.9487 |

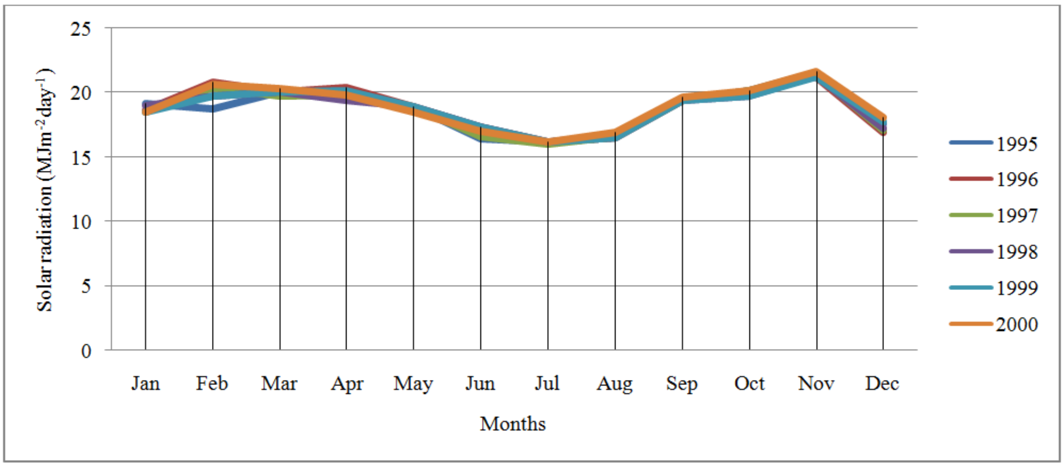


**Figure 1: Yearly Mean Global Solar Radiation 1995-2000**

In general, higher value of global solar radiation is obtained in dry season than wet season. The mean value of global solar radiation for Gusau city during the period of study was estimated to be 18.8015MJm$^{-2}$day$^{-1}$. However, the global solar radiation is fairly constant throughout the periods as depicted by Figure 1. This shows that the level of global solar radiation reaching Gusau can adequately support the development of any form of solar energy system. For example, even with the least value of global solar radiation 16.1676 MJm$^{-2}$day$^{-1}$, it means theoretically that for a particular day, solar energy of 4.491kwh can be obtained with a square solar plate of side 1m in one hour. This translates to enormous solar energy with wide solar panels!

## CONCLUSIONS

The results obtained in this research work clearly indicate the importance of developing empirical models for estimating global solar radiation reaching a given geographical location. The Angstrom-Prescott model can also be applied to other cities to predict the global solar radiation being received. Results obtained in this research work clearly show that the level of global solar radiation reaching Gusau is sufficiently adequate for supporting solar energy technology and can therefore, be utilized by energy experts in the design and performance of solar energy systems to provide electricity for the communities within the location.

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