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Global Solar Irradiance over Keffi Town and its Environs, Nasarawa State, Nigeria

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Abstract

The need to model energy generation has been on the increased, because of the rising needs of the power for use by large and small scale users. In this study, the assessment of global solar irradiance over Keffi and its environs, Nasarawa State, Nigeria was determined. A simple random sampling technique was used to select twelve locations in Keffi and its environs, Nasarawa State Nigeria for the measurement of global solar irradiance. Three 12V, 5W solar panels were used and a measurement interval of three hour daily (12.00pm to 3.00pm) was made using the Secondary Standard Pyranometer placed on the top of the panels. The continuity in the assembled system was measured using an Avometer. A model based on Angstrom-Prescott Regression Equation: $H_m = H_0 \left[a + b\left(\frac{n}{N}\right)\right]$ *was developed to calculate the solar irradiance for Keffi and its environs. The regression constants 'a' and 'b' were obtained to be 0.58 and 0.002 respectively by simple arithmetic. The highest value of the measured monthly average daily global solar radiation value was observed in the month of February (26.07 MJ/m²) while the lowest value was observed in the month of August (12.63 MJ/m²) with an average value of 19.24 MJ/m². The extraterrestrial solar radiation was found to range from 24.43 MJ/m² in December to 53.60 MJ/m² MJ/m² in February with average value of 37.97MJ/m². The developed model can be used to predict solar radiation in Keffi and its environs, Nasarawa State.*

Keywords: Solar radiation, Pyranometer, daily global radiation, Prescott angstrom linear equation, Keffi.

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INTRODUCTION

Harnessing solar energy as an alternative source is gaining popularity in different parts of the world. To harness and utilize this energy, a good knowledge of its behavior has to be identified. Solar energy is available at any part of the globe, but the amount made available differs with respect to geographical locations, times and season. The solar energy available at any particular geographical location is a measure of the solar irradiance falling on that location (Osueke *et al*., 2013; Falayi *et al*., 2008; Safi *et al*., 2002).

The solar radiation reaching the earth surface varies for different geographical locations at a given instant of time. This is the reason why meteorological information of any geographical location has to be gotten before modeling a solar system for that location (Osueke *et al*., 2013; Burari & Sambo, 2001).

Photovoltaic power has emerge as renewable plants due to its abundant and as palliative to non renewable sources. PV system modeling and forecasting future renewable generation is important. The basic ways for direct measurement of solar radiation are: Grand base instrumentation (pyranometer), By Satellite means traditional approaches to system model involve techniques which involve forming the system efficiency by successively measuring the components. These approaches are not enough for changing weather parameters. It is therefore important to develop accurate data (bring out a model) (Audu *et al*., 2014; Adesina *et al*., 2016).

With the rapid depletion of fossil fuel reserves, it is feared that the world especially Nigeria will soon run out of its energy resources. Under these circumstances, it is highly desirable that alternative energy resources should be utilized with maximum conversion efficiency to cope with the ever-increasing energy demand. Among the renewable resources, only solar energy has the greatest potentiality, availability and is free from environmental hazards (Audu *et al*., 2014; Okundamiya & Nzeako, 2011; Auwal&Darma, 2014).

Uncertainties and difficulties in measuring global solar irradiation have led to the development of several algorithms and models to estimate it from a few meteorological properties computed on a frequent basis: maximum, minimum and mean atmospheric temperature; cloudiness, relative humidity, etc. Through the last years, a high number of models have been designed to assess the global solar irradiation over a horizontal surface. Among them, it highlights the empirical models (Fan et al., 2018; Quej et al., 2017), satellite data based (Urraca *et al.,* 2017; Zhang et al., 2015), stochastic (Jeong *et al.,* 2017; Hocaoglu, 2011), heuristics (Paiva *et al.,* 2018; Olatomiwa *et al.,* 2015; Ibrahim & Khatib, 2017) and statistical (Urraca *et al.,* 2017; Ayodele *et al.,* 2016; Şen, 2017) models.

Several studies have been conducted by researchers in the past to evaluate solar radiation at various parts of Nigeria. Fadare (2009) used an artificial neural network model todeveloped a model forprediction of solar energy in Nigeria. The training and testing the network was done using a meteorological data of 195 cities in Nigeria for a period of 10 years (1983-1993) from theNational Aeronautics and Space Administration (NASA) geo-satellite data base. He reported that the monthlymean solar radiation potential in northern and southernregions ranged from 7.01-5.62 to 5.43 – 3.54 kWh/m^2 respectively. Okundamiya *et al* (2011) proposed an empirical model for estimating global solar radiation on horizontal surfaces for Abuja, Benin, Kastina, Lagos, Nsukka and Yola cities in Nigeria. From there report, these citiesexperienced a decrease in the horizontal global solar radiation from

March through August (during rainy season) with Benin city having the lowest monthly mean daily horizontal global solar radiation of 3.46 kWh/m²/day in July. They also reported that the variation of daily horizontal global solar radiation with month of the year in Kastina differs from other cities because Kastina is located at longitude 7.6˚E, and latitude 13.0˚N. Falayi et al. (2008) developed a number of multilinear regression equation based on Angstrom equation to predict the relationship between global solar radiation with one or more combinations of some weather parameters for Iseyin Nigeria for five years. He reported that the equation with the highest value of correlation coefficienct (r) , least value of root mean square error (RMSE), mean bias error (MBE), and mean percentage error (MPE) was adopted for the estimation of different geographical locations in Nigeria. The aim and objective of this study is to assess the global solar irradiance over Keffi and its environs, Nasarawa state. Direct pyranometer measurement and a designed mathematical model to estimates global solar radiation is employed.

MATERIALS AND METHOD

Study Area

Keffi is an historic town located in Nasarawa State, North Central Nigeria between latitudes $8^0\,51^1$ and $8^0\,53^1$ North of the equator and longitudes 7^0 50′ and 7^0 51′ East of the Greenwich meridian. Keffi is located about 128km away from Lafia, the Nasarawa State Capital and about 57km away from Abuja, the Federal Capital Territory of Nigeria. Keffi is the smallest L.G.A in the whole of Nasarawa State with a total land area of approximately 140km² (Yakubu, 2013). The 12 selected locations includesKaruMararaba, Uke, Dari, Keffi Emir Palace, Odeni Gida, Karshi, Moroa, Laminga, Nasarawa Emir Palace, Ara Pasilli, Gada Buke and Nakuse. The geo point (coordinates) of the locations are presented in Table 1.

Table 1: Locations name and Geo points of the study area.

S/N	Locations	Latitude	Longitude
1.	KaruMararaba	9⁰02′50′′	7⁰45′49′′
2.	Uke	8⁰36′77′′	8⁰ 21′15′′
3.	Dari	8⁰24′12′′	8⁰18′06′′
4.	Emir Palace, Keffi	8⁰44′12′′	8⁰12′03′′
5.	Odeni Gida	9⁰16′22′′	7⁰8′11′′
6.	Karshi	8⁰12′32′′	8⁰7′17′′
7.	Moroa	8⁰72′16′′	8⁰31′9′′
8.	Laminga	8⁰31′13′′	8⁰18′04′′
9.	Emir Palace, Nasarawa	8⁰12′18′′	8⁰07′09′′
10.	Ara Pasilli	8⁰13′09′′	7⁰12′03′′
11.	Gada Buke	8⁰19′30′′	8⁰04′19′′
12.	Nakuse	8⁰18′29′′	8⁰16′16′′

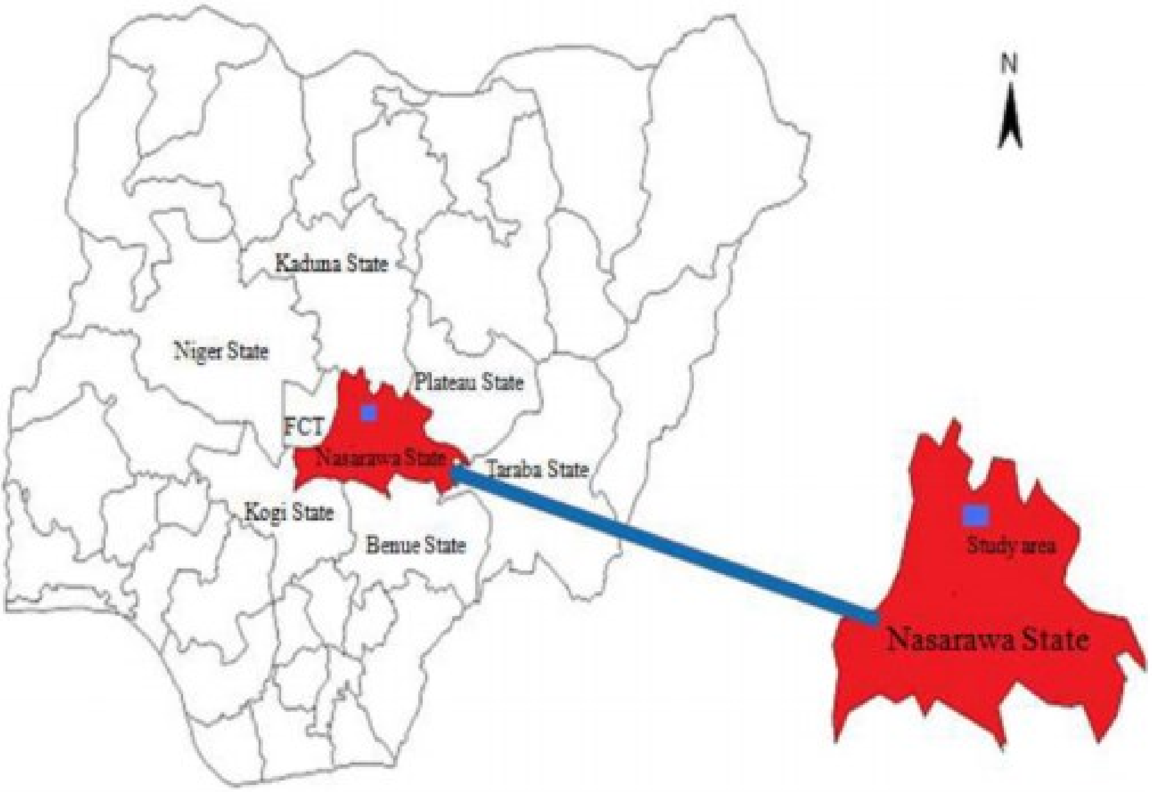

Figure 1: Map of Study Area.

Data Collection and Analysis

The data analyzed in this study was obtained by direct measurement of solar irradiation in Keffi and its environs, Nasarawa State using a pyranometer. The measurement sensors and the other supplementary devices where installed on twelve (12) locations within Keffi and its environs Nasarawa State. The test materials consists of pyranometer with photovoltaic sensor tilted 30 degrees. A metallic band was used as an artificial horizon to block the ground reflected irradiation. The location were carefully selected so that there was no sunshine obstruction and no obstructions of wind. Plumb Line was used to level the ground horizontally and vertically and a piece of 3D Mode Golden Dream Time Compass. Three 12V, 5W solar panels (poly) were used, and a three days measurement interval was made using the Secondary Standard Pyranometer which was placed on top of the panels and the output was taken from the pyranometer and was estimated using the Angstrom-Prescott Regression Equation. A 3D Mode Golden Dream Time Compass was used to determine the angle of inclination of the panels, and was used to take the geo-point of the measurement location. The continuity in the assembled system was measured using an Avometer.

Solar radiation energy data were collected in twelve different locations across Keffi and its environs in Nasarawa State. Measurements were taken using different angles viz 0^0, 30^0, 60^0 and 90^0 with a view to determine the best angle for solar energy collection for location in Keffi and its environs, Nasarawa State.

Model of Global Solar Irradiance

Prescott angstrom linear equation was used to model solar radiation data collected from Keffi and its environs in Nasarawa State. In the new model a and b were developed taking into consideration in order to make it possible to calculate, the monthly mean of daily global solar radiation H_m(MJ/m^2), on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface as per the following relation (Pandey &Katiyar, 2013):

$$H_m = H_0\left[a + b\left(\frac{n}{N}\right)\right] \quad (1)$$

and

$$H_0 = \frac{24(60)K_{sc}I_r}{\pi} = (\omega_s sin\varphi sin\delta + cos\varphi cos\delta sin\omega_s) \quad (2)$$

$$I_r = 1 + 0.033\cos\frac{2\pi}{360}S \quad (3)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{360}S - 1.39\right) \quad (4)$$

$$\omega_s = cos^{-1}(-tan\varphi tan\delta) \quad (5)$$

$$S = \frac{24\omega_s}{\pi} \quad (6)$$

where

H_m= monthly average of the daily global radiation on a horizontal surface (MJ/m^2)

H_0 = extraterrestrial solar radiation on the 15th of month (MJ/m^2)

n= monthly average daily bright sunshine hours,

N= maximum possible monthly average daily sunshine hours or the day length,

$a$and$b$= regression constants,

K_{sc}= solar constant = 0.0820 (MJ/m^2/min),

I_r= inverse relative distance earth – sun,

δ= solar declination (rad),

φ = latitude of the place (rad)

ω_s= sunset hour angle (rad),

S = day number from January 1st,

$\frac{n}{N}$ = fraction of maximum possible numbers of bright sunshine hours, and

$\frac{H_m}{H_0}$ = atmospheric transmission coefficient, commonly known as clearness index.

RESULTS AND DISCUSSION

The measured and estimated sunshine data is one of the best parameter to assess the available of solar radiation for a particular location. Table 2 present the daily average of monthly mean global solar radiation (H_m) in MJ/m^2 for each location in Keffi and its environs, Nasarawa State for the month of January to December, 2018.The daily global radiation ranged from 0.68 to 2.67 MJ/m^2 in January, 0.82 to 2.73 MJ/m^2 in February, 1.19 to 2.48 MJ/m^2 in March, 0.84 to 2.59 MJ/m^2 in April, 0.17 to 2.51 MJ/m^2 in May, 0.76 to 2.30 MJ/m^2 in June, 0.94 to 1.53 MJ/m^2 in July, 0.07 to 1.56 MJ/m^2 in August, 0.94 to 1.67 MJ/m^2 in September, 0.08 to 2.55 MJ/m^2 in October, 0.94 to 2.08 MJ/m^2 in November, and 0.16 to 1.68 in December for all the locations selected. The total monthly daily average of monthly mean global solar radiation (H_m) for January to December ranged from 12.63 MJ/m^2 in August to 26.07 MJ/m^2 in April with a total of 230.87 MJ/m^2 for the whole year.

The earth movement around the sun is such that in April, the sun is in the North hemisphere. This brings the sun closer to the earth in this period (Adesina *et al.*, 2016). This could be attributed to these observations. Also, the lowest values of solar radiation in Keffi and its environs is recorded in July to October. The low solar radiation here is directly attributed to this season being the peak of the rainy season. December to June had good solar radiation distribution and April being the peak of the dry season, harmattan has completely gone and wet season is about to begin.

From the above analysis, the model constants of 'a' and 'b' were derived to be 0.58 and 0.002 respectively. The model equation obtained is as stated below:-

$$H_m = H_0 \left[0.58 + 0.002\left(\frac{n}{N}\right)\right]$$

One of the best parameter to estimate the available solar radiation for a particular place is the sun.

Table 2: Monthly average of the daily global radiation in MJ/m² for the year 2018 in some selected locations in Keffi and its environs, Nasarawa State, Nigeria.

Locations	January	February	March	April	May	June	July	August	September	October	November	December
Karu Mararaba	2.34	2.49	2.42	2.58	2.40	2.30	1.43	1.52	1.50	2.06	2.08	1.68
Uke	2.67	2.73	2.48	2.59	2.51	2.15	1.50	1.28	1.67	2.19	1.67	1.67
Dari	1.93	2.07	1.93	2.26	1.68	2.05	1.53	1.56	1.22	2.55	1.22	1.36
Emir Palace, Keffi	2.56	2.71	2.33	2.39	2.06	1.93	1.81	1.55	1.41	1.11	1.41	1.56
Odeni Gida	2.05	2.19	2.19	2.16	1.96	2.01	0.98	1.03	1.45	1.50	1.45	1.26
Karshi	2.51	2.65	2.15	2.36	1.98	2.03	1.03	1.00	1.32	1.27	1.32	1.06
Maroa	1.68	1.82	1.67	2.15	1.74	1.62	0.96	0.88	1.14	1.67	1.14	1.22
Laminga	1.90	2.04	2.16	1.96	1.90	1.07	0.94	0.91	1.08	1.34	1.08	0.85
Emir Palace, Nasarawa	1.85	1.99	2.21	1.75	1.75	1.72	1.13	0.07	1.05	1.31	1.05	0.16
Ara Pasilli	2.43	2.57	2.15	2.34	2.15	1.69	1.25	1.05	1.68	1.77	1.68	0.92
Gada Buke	1.85	1.99	1.95	1.84	0.17	1.68	1.00	0.84	1.66	1.00	1.66	0.92
Nakuse	0.68	0.82	1.19	0.84	0.58	0.76	1.05	0.94	0.94	0.08	0.94	1.05
Total	**21.92**	**26.07**	**24.83**	**25.22**	**21.2**	**21.01**	**14.61**	**12.63**	**16.12**	**16.85**	**16.7**	**13.71**

Table 3 present the daily average of monthly mean global solar radiation (H_m) in MJ/m², monthly average daily bright sunshine hours, maximum possible monthly average daily sunshine hours, fraction of maximum possible number of bright sunshine hour, and estimated monthly average of daily global radiation, for each location in Keffi and its environs, Nasarawa State for the year 2019. The monthly average daily bright sunshine hours is maintain for 3 hours daily (between 12.00 pm to 3.00 pm) and the maximum possible monthly average daily hours is fixed to be 12 hours. The measured daily global radiation ranged from 26.07 MJ/m² (February) to 12.82 MJ/m² (August) with a mean of 19.24MJ/m² for the year 2019. This is because from July to October is the rainy season and December to June is generally classified as the dry season. The movement of the earth around the sun is such that the sun is in the North hemisphere in the months of April. This brings the earth closer to the sun in this period (Adesina *et al.*, 2016). The highest extraterrestrial solar radiation value was observed in the month of February (53.6 W/m²) while the lowest value was observed in the month of August (32.20 W/m²).

Table 3: Fraction of possible bright sunshine hours, extraterrestrial solar radiation and, measured and calculated global solar radiation.

Months	n (hours)	N (hours)	n/N	H_0	H_m	H_{cal}
January	3.00	12.00	0.250	45.77	21.92	22.91
February	3.00	12.00	0.250	53.6	26.07	26.83
March	3.00	12.00	0.250	46	24.83	23.02
April	3.00	12.00	0.250	46.1	25.22	23.07
May	3.00	12.00	0.250	39.51	21.2	19.77
June	3.00	12.00	0.250	44.35	21.01	22.20
July	3.00	12.00	0.250	30.4	14.61	15.22

August	3.00	12.00	0.250	25.61	12.63	12.82
September	3.00	12.00	0.250	32.2	16.12	16.12

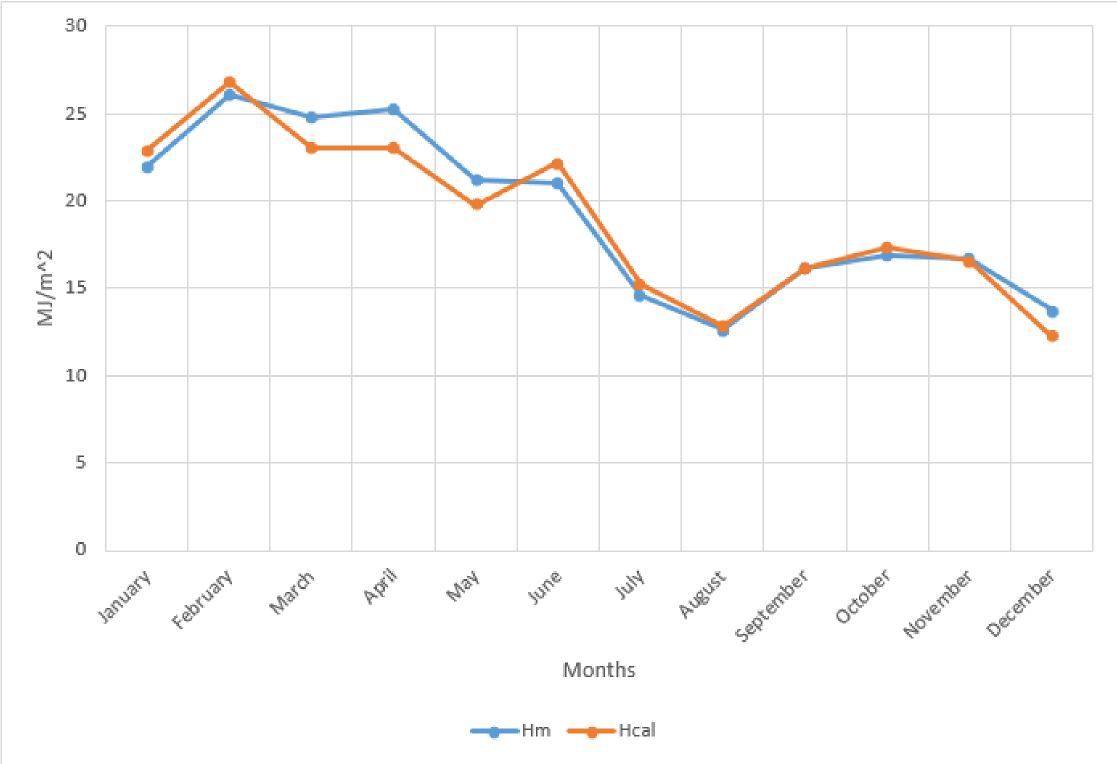

Figure 2: Comparison between measured and calculated global solar radiation.

The developed model based on Prescott Angstrom linear equation was used to estimate daily global radiation (H_{est}) and was compared with the calculated daily global radiation (H_m) to test its degree of accuracy (Table 3). Figure 1 shows the graphical representation of the measured and calculated solar irradiance which agree strongly with each other. There was slight variation between the measured data being higher than the calculated ones during the first half of the year (Figure 2). In the later part of the year, the opposite was observed. This slight variation between the measured and calculated global solar irradiance is within the acceptable level as suggested by Adesina *et al*. (2016).

CONCLUSION

This paper presented the daily global solar irradiance at a measured using a pyranometer in Keffi town and its environs, Nasarawa State, Nigeria to carry out a frequency distribution of global solar irradiance. Prescott angstrom linear equation was used where the regression constant a and b were derived to be 0.58 *and* 0.002 respectively, from solar radiation data for Keffi and its environs, Nasarawa State. The model predicted the global solar irradiance for Keffi and its environs, and was in close replica with the measured solar irradiance of the area. The variation of the measured solar radiation with highest and lowest total monthly average of daily global radiation in February and August respectively. The developed Prescott angstrom linear equation can be used to predict the global solar irradiance of the area.

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