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Variation of Solar Radiation in Akwanga, Nasarawa State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

One of the major environmental problem is the long-term changes in the Earth's climate. In this study, the variation of solar radiation for Akwanga zone, Nasarawa State, Nigeria were determined. Twelve locations were carefully selected where there is no sunshine and wind obstruction. Three 12V, 5W Solar panels (poly) were used and a three-hour daily measurement interval (12.00 pm to 3.00 pm) was made using the Secondary Standard Pyranometer placed on the top of the panels. Angstrom-Prescott Regression Equation was used to estimate the output. The continuity in the assembled system was measured using an Avometer. The result revealed that the highest monthly average daily global solar radiation was observed in the month of April (25.2 MJ/m^2) followed by June (22.94 MJ/m^2), and march (22.42 MJ/m^2), while the lowest was observed in the month of August (12.04 MJ/m^2) followed by July (13.57 MJ/m^2), and September (14.26 MJ/m^2) in the locations selected. The solar radiation intensity was found to range from 156.44 W/m^2 to 293.84 W/m^2 with the mean value of 220.04 W/m^2. The highest total global solar radiation value of 25.2MJ/m^2 was observed in April while the lowest value of 12.04 MJ/m^2 was observed in October. The extraterrestrial solar radiation were found to range from 16.72 MJ/m^2 in March to 29.90 MJ/m^2

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in April with average value of 22.89MJ/m^2. The atmospheric transmission coefficient over the year is found to range from 0.5 in July and October to 1.3 in June and October. The investigation reveal that there is bright sun shine in the study area which confirms high atmospheric transmission coefficient or clearness index throughout the year in this study.

Keywords: Solar radiation; pyranometer; Akwanga zone; daily global radiation.

1. INTRODUCTION

The sun is the seat of thermonuclear processes and produces a vast amount of energy. The energy emitted by the sun is called solar energy or solar radiation. Despite the considerable distance between the sun and the earth, the amount of solar energy reaching the earth is substantial thereby making it the earth's primary natural source of energy compared to other sources [1-3].

The driving force for all atmospheric processes is the sun. Solar radiant intensity is the input of energy expression upon the planet. Therefore, in other to understand and quantify its value and distribution correctly, it is important that initial understanding and modeling of any other thermodynamic or dynamic process in the earth-ocean-atmosphere system are properly done [2,4]. Some applications of solar energy such as photovoltaic system sizing, modeling, and design of solar crop dryers require the vast knowledge of global solar insolation. The intensity of solar radiation per day is usually one of the variables collected by meteorological stations in tropical Africa, Nigeria especially [3-5].

Solar irradiation is the total solar energy falling on a surface and it can be related to the solar irradiance by considering the area under solar irradiance versus time curve [6,7]. Measurements or estimation of the solar irradiation, in a specific location, is key to study the optimal design and to predict the performance and efficiency of photovoltaic (PV) systems. The measurements can be done based on the solar irradiance in that location [6-8].

The amount of solar radiation intercepted by the earth, is called extraterrestrial radiation. As it makes its way towards the ground, it is depleted when passing through the atmosphere. On average, less than half of extraterrestrial radiation reaches ground level. Even when the sky is very clear with no clouds, approximately 20% to 30% of extraterrestrial radiation is lost during the down welling path [4,9].

A good knowledge of the optical properties of the atmosphere is necessary to model the depletion of the radiation. The role of the clouds is of paramount importance. These includes optically thin clouds which allow a small proportion of radiation to reach the ground, optically thick clouds create obscurity by stopping the radiation downward. The description and modelling of the optical processes affecting solar radiation's interaction with the atmosphere is called radioactive transfer [1,4].

Several studies have been conducted by researchers in the past to evaluate solar radiation at various parts of Nigeria. An artificial neural network model to developed a model for prediction 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 the National Aeronautics and Space Administration (NASA) geo-satellite data base. It was reported that the monthly mean solar radiation potential in northern and southern regions ranged from 7.01-5.62 to 5.43 – 3.54 kWh/m^2 respectively [10].

An empirical model was proposed for estimating global solar radiation on horizontal surfaces for Abuja, Benin, Kastina, Lagos, Nsukka and Yola cities in Nigeria. From there report, these cities experienced 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/m^2/day in July. It was 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 [11].

A number of multilinear regression equation based on Angstrom equation was developed to predict the relationship between global solar radiation with one or more combinations of some weather parameters for Iseyin Nigeria for five years. It was 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 [12].

Therefore, this study is aimed at assessing the variation of solar radiation for Akwanga and its environs, Nasarawa State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The geo point (coordinates) of the locations are presented in Table 1.

2.2 Data Collection and Analysis

The solar irradiance measurement sensors and the other supplementary devices where installed on twelve (12) locations within the defined climatic zones in Akwanga and its environs, Nasarawa State. Solar radiation energy data were collected in twelve different locations across Akwanga and its environs in Nasarawa State. Measurements were taken using different angles viz 0°, 30°, 60° and 90° with a view to determine the best angle for solar energy collection.

A metallic band was used as an artificial horizon to block the ground reflected irradiation. The location was carefully selected so that there was no sunshine obstruction and no obstructions of wind. Plumb Lime 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 the panels inclined, and was used to take the geo-point of the measurement location. The continuity in the assembled system was measured using an Avometer.

Basically, pyranometer is consisting of a blackened-thin surface supported inside a relatively massive well-polished case. When solar radiation falls on this surface, the temperature of the surface rises until its rate of loss of the heat by all causes is equal to the rate of gain of heat by radiation. This rise in temperature sets up a thermal Electro Motive Force (e.m.f) which is measured on a recording millivoltmeter or recorder. The pyranometer is calibrated and a certificate is provided by the manufacturer.

Solar radiation energy data(s) were collected in twelve different locations across Akwanga and its environs in Nasarawa State. Measurements were taking using different angles viz 0°, 30°, 60° and 90° with a view to determine the best angle for solar energy collection for each zone in the state.

Prescott angstrom linear equation was used to model solar radiation data collected from Akwanga 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 [2]:

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

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

S/N	Locations	Latitude	Longitude
1.	Alushi	8°72’00’’	8°45’80’’
2.	Nasarawa Eggon	8°44’58’’	8°26’25’’
3.	Mada Station	8°43’0’	8°18’0’’
4.	Kagbu	8°71’95’’	8°45’82’’
5.	Akwanga	8°54’23’’	8°24’27’’
6.	Andaha	9°05’32’’	8°40’14’’
7.	Gudi-Rinze	8°52’46’’	8°16’23’’
8.	KwaraLigo	8°46’33’’	8°12’04’’
9.	Wamba	8°56’30’’	8°36’11’’
10.	MararabaGongon	8°62’22’’	8°21’07’’
11.	Wayo Mati	8°11’37’’	8°02’15’’
12.	Bayan Dutse	9°42’06’’	8°18’01’’

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 each 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.

3. RESULTS AND DISCUSSION

The sunshine data is one of the best parameter to estimate the available solar radiation for a particular location. Table 2 and Fig. 1 present the daily average of monthly mean global solar radiation (H_m) in MJ/m^2 for each location in Akwanga and its environs, Nasarawa State for the month of January to December, 2019. Twelve (12) locations were carefully selected where thereis no obstruction of wind and sunshine. The daily global radiation ranged from 1.72 to 2.18 MJ/m^2 in January, 1.26 to 2.37 MJ/m^2 in February, 1.31 to 2.32 MJ/m^2 in March, 1.23 to 2.66 MJ/m^2 in April, 1.01 to 2.24 MJ/m^2 in May, 1.40 to 2.35 MJ/m^2 in June, 0.16 to 1.58 MJ/m^2 in July, 0.16 to 1.41 MJ/m^2 in August, 0.75 to 1.57 MJ/m^2 in September, 1.01 to 1.70 MJ/m^2 in October, 0.69 to 1.75 MJ/m^2 in November, and 0.30 to 2.40 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 12.04 MJ/m^2 in August to 25.2 MJ/m^2 in April with a total of 220.04 MJ/m^2 for *the whole year* (Fig. 2). The reason for these values is that July to October is the wet season months and December to June is generally classified as the dry season months. 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 [4]. This is be the reason why the solar intensity in the month of April is higher than any other months of the year 2019.

The summary of monthly average daily global radiation for each location in Akwanga and its environs in Nasarawa state are presented in Table 2 and depicted in Fig. 1.

A total of 144 records were taken from the months of January to December 2019 across all locations in Akwanga and its environs, with an average of 12 readings per month per location.

The maximum average of daily global solar radiation of 25.5 W/M^2 was recorded in April while the minimum average of daily global solar radiation of 12.04 W/M^2 was recorded in August. The calculated average daily global radiation for each location has 2.66 for Gudi-Rinze was the highest in the month of April while the least value of 0.16 was recorded in Mada Station and Mararaba Gongon in July and august respectively.

From the above analysis, the model constants of 'a' and 'b' were derived to be 0.50 and 0.0036 respectively. The model equation obtained is as stated below:-

$$H_m = H_0\left[0.50 + 0.0036\left(\frac{n}{N}\right)\right]$$

The Summary of the total monthly solar intensity, global solar radiation, extraterrestrial solar radiation, fraction of possible bright sunshine hours, and atmospheric transition coefficient are presented in Table 2. A total of 108 hours was recorded from the month of January to December, 2019 with a maximum of 9 hours for every month taken on the 14th, 15th and 16th of each month. The maximum solar radiation intensity of 293.84 W/m^2 was recorded in April while a minimum of 156.44 W/m^2 was recorded in August. The atmospheric transmission coefficient calculated ranged from 0.5 in July and October to 1.3 in June. This value clearly reveal

Table 2. Variation of monthly average of the daily global radiation for each location in Akwanga and its environs, Nasarawa State

Location	Daily average of monthly mean global solar radiation (H_m) in MJ/m^2											
	January	February	March	April	May	June	July	August	September	October	November	December
Alushi	1.96	2.33	2.32	2.54	2.07	2.35	1.26	1.10	1.57	1.57	2.22	2.40
Nasarawa Eggon	2.18	2.37	2.20	2.51	2.24	2.27	1.46	0.96	1.33	1.68	2.57	2.25
Mada Station	1.75	1.67	2.00	2.16	1.29	2.01	0.16	0.79	1.21	0.18	1.16	1.56
Kagbu	1.80	2.02	1.69	2.50	1.71	1.92	1.27	0.98	1.09	1.43	1.44	2.13
Akwanga	2.10	2.31	1.31	2.54	2.08	2.50	1.34	1.25	1.68	1.70	1.27	1.35
Andaha	1.85	1.47	1.51	2.00	1.09	1.51	1.03	0.99	1.03	1.04	1.75	0.39
Gudi-Rinze	2.21	2.10	2.08	2.66	1.79	2.16	1.58	1.16	1.57	1.67	1.25	1.40
KwaraLigo	1.76	1.34	1.48	1.58	1.01	1.40	1.09	0.83	0.92	1.17	1.48	1.29
Wamba	2.09	1.79	1.83	2.14	1.54	1.67	1.29	1.41	0.87	1.42	1.34	1.18
MararabaGongon	1.82	1.26	2.00	1.23	0.93	2.17	1.25	0.16	1.08	1.15	0.83	1.10
Wayo Mati	1.88	1.49	1.60	2.10	1.26	1.58	1.10	1.07	1.16	1.17	1.05	1.25
Bayan Dutse	1.72	1.27	1.40	1.24	0.92	1.40	0.74	1.34	0.75	1.01	0.69	0.30
Total	21.16	21.68	22.42	25.2	17.93	22.94	13.57	12.04	14.26	15.19	17.05	16.6

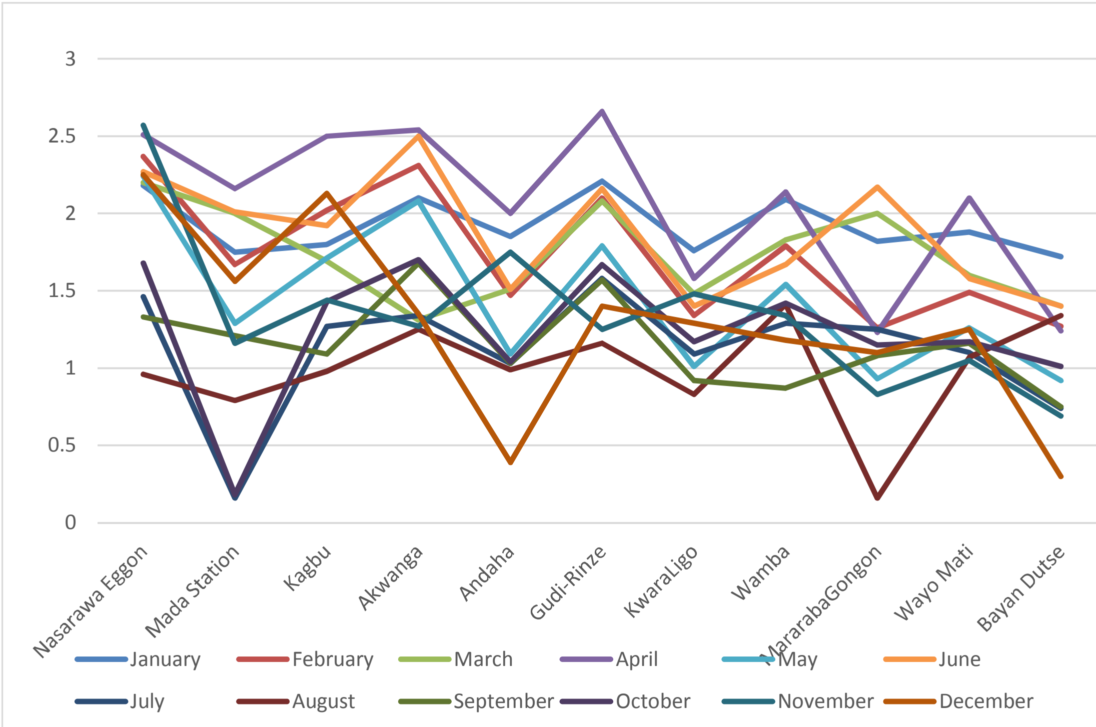

Fig. 1. Variation of monthly average of the daily global radiation for each location in Akwanga and its environs, Nasarawa State

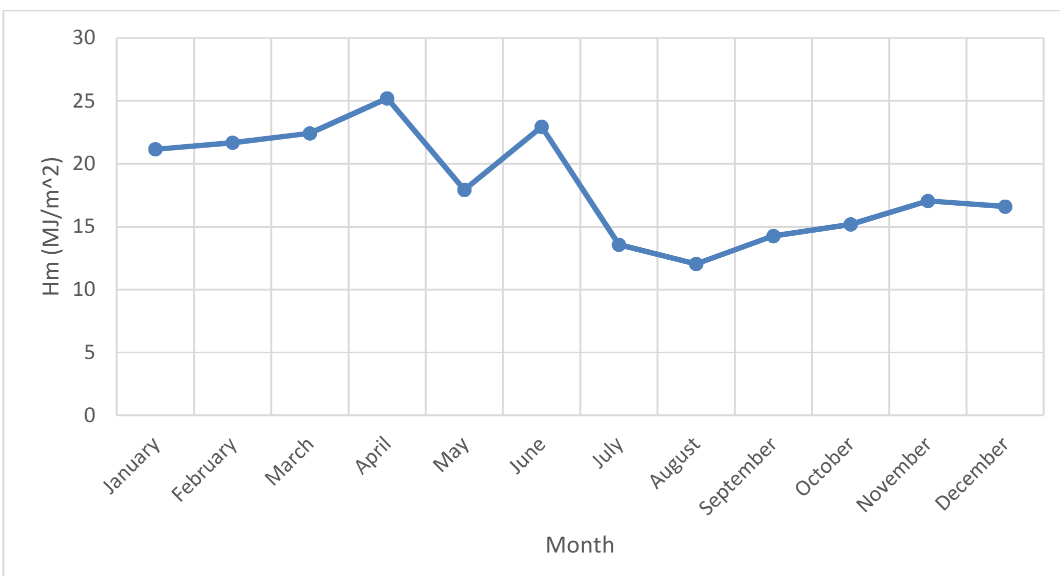

Fig. 2. Variation of total monthly average of the daily global radiation for the month of January to December, 2019

that the amount of monthly sunshine vary with seasons (wet and dry) which is characterized by the closeness of the sun to the earth in dry season and vice versa in wet season.

Also, July to October recorded the lowest values of solar radiation. The low solar radiation here is directly attributed to this season being the peak of the rainy season. December to June had good

Table 3. Summary of total monthly solar intensity, global solar radiation, extraterrestrial solar radiation, fraction of possible bright sunshine hours and atmospheric transition coefficient

S/n	Month	Solar intensity (W/m²)	n (hours)	N (hours)	$\frac{n}{N}$	H_0	H_m	$\frac{H_m}{H_0}$
1	January	272.34	3.00	12.00	0.250	27.14	21.11	0.8
2	February	248.54	3.00	12.00	0.250	23.01	21.68	0.9
3	March	268.84	3.00	12.00	0.250	16.72	22.42	1.3
4	April	293.84	3.00	12.00	0.250	29.90	25.2	0.8
5	May	207.54	3.00	12.00	0.250	24.09	17.93	0.7
6	June	266.64	3.00	12.00	0.250	18.02	22.94	1.3
7	July	161.55	3.00	12.00	0.250	25.91	13.57	0.5
8	August	156.44	3.00	12.00	0.250	16.80	12.04	0.7
9	September	162.44	3.00	12.00	0.250	20.02	14.26	0.7
10	October	182.64	3.00	12.00	0.250	28.12	15.19	0.5
11	November	195.44	3.00	12.00	0.250	26.02	17.05	0.7
12	December	232.24	3.00	12.00	0.250	18.95	16.6	0.9
		220.04		12.00		22.89	220.04	

solar radiation distribution and April being the peak of the dry season, harmattan has completely gone and wet season is about to begin [13].

4. CONCLUSION

The pyranometer measurement of variation of solar radiation measurement for Akwanga zone in Nasarawa State for the year 2018 was reported. The monthly average of daily global radiation, extraterrestrial solar radiation and solar radiation intensity were determined for the period of 3 hours in three days (14th, 15th, and 16th of every month). Prescott angstrom liner equation was used where the regression constant a and b were $0.06\, and\, 0.55$ respectively derived from solar radiation data for Akwanga zone, Nasarawa State. This study indicates the variation in solar radiation with highest and lowest total monthly average of daily global radiation in April and August respectively. The investigation reveals that there is bright sun shine in the study area which confirms high atmospheric transmission coefficient or clearness index throughout the year in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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