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Determining Solar Energy Power System Potentials for Electrification Using the Angstrom-Prescott Equation in Benue State

***[1]Iortim, D.M., [2]Nyam, G.G., [3]Tsoho, I.Y., & [4]Umar, M.**
[1,2,4]Department of Physics, University of Abuja-Abuja Nigeria.
[3]Department of Integrated Science, College of Education Minna, Niger State

***Corresponding author email**: dennisiortim5@gmail.com

Abstract
Using MATLAB R2020, the Angstrom-Prescott equation was created for a simple five-year forecast of Makurdi town's solar radiation values: H/Ho = 0.166 + 0.578(n/N). The values of "a" and "b," which were found to be 0.166 and 0.578, respectively, demonstrated a sharp increase in Makurdi town's exposure to sunlight (temperature) and solar radiation. Although this increase indicated a high degree of global warming effects in this research area, it also opened up significant possibilities for solar power generation for universal electrification, which would help to lessen the impact of global warming in this area (Makurdi). Using the Coefficient of Determination (R^2) and the Root Mean Square Error (RMSE) as 0.704 (70.4%) and 0.148 (14.8%), respectively, the research work's produced results were statistically tested.

Keywords: Renewable Energy, Solar Radiation, Sunshine Hours, Power Generation and Global Warming.

Introduction

The creation of energy to keep up with the world's population growth is the first of two major issues facing humanity. Any nation's level of development can be assessed by comparing the proportion of its population with access to electricity, which is a key component of development since all developed societies provide their people with a reliable power source so that businesses can prosper and the economy can grow. This has been a major problem for our continent, especially for Nigeria, where 40% of the population lacks access to energy. As a result, they are unable to contribute as much to the expansion of the economy, and a large percentage of their technological skills are wasted. The second is the impact of climate change on Earth, which results in human casualties and property loss among the populace. The impact resulted from some human activities on Earth, particularly the burning of fossil fuels to provide electricity for the world's expanding population. This occurred as a result of the majority of our power plants being non-renewable, which releases heat and green gasses into the atmosphere and degrades it, opening the door for desertification, flooding, food shortages, and global temperature increases. Our current situation is a result of short-term policies implemented by the government due to the corrupt nature of those in positions of policy-making authority. Rather than selflessly pursuing long-term policies that are more sustainable, particularly those involving renewable energy power generation systems to maintain or lower global temperatures, sustain the environment and reduce emissions of greenhouse gases into the atmosphere, they pursue short-term policies out of self-interest and fail to rely on academic research projects that are laying the groundwork. This forces scientists to study energy to find new ways to feed the world's expanding population while preserving the environment. Thus, by lessening the impact of climate change on our planet, the phrase renewable energy power generation plays a very important function. Energy availability served as the centre of modern society's socioeconomic activity.

According to Kaltiya et al. (2020), the global solar radiation for Makurdi was predicted using the Angstrom-Page model. This was accomplished by taking measurements of solar radiation, relative humidity, dry and wet bulb temperatures, hours of cloudiness, and bright sun shining every hour from 0600 to 1800 hr. on a daily basis from February to July of 2011 within Makurdi metropolis. A digital thermo-hygrometer model IT-202 was used to monitor relative humidity, wet and dry bulb temperatures, and solar radiation with a sun meter type DS-05. According to the results, the location's mean solar radiation, relative humidity, dry and wet bulb temperatures, hours of cloud cover, and hours of strong sunshine were 191.64 w/m2, 60.10%, 30.24 °C, 28.25 °C, 7.72 h, and 5.28 h, respectively. A European solar radiation database was created between the years 2001 and 2005, according to Suri et al. (2007), utilizing a solar radiation model and climatic information linked to the Photovoltaic Geographic Information System (PVGIS). The database was used to evaluate the photovoltaic (PV) potential in the 25 European Union member states and 5 candidate nations, as well as regional and national variations in solar energy resources. The expected average annual electricity generation of a "standard" 1kWp grid-connected PV system was one of the three aspects examined. The other two were the theoretical potential of PV electricity generation and the required installed capacity for each nation to meet 1% of its national electricity consumption from PV. The analysis revealed that PV may contribute significantly to a mixed renewable energy system.

Diemuodeke et al. (30 April 2021), in comparison to the recommended PV market potential set by the International Energy Association, distributed PV adoption in Nigeria is currently rather low. This demonstrates how far removed the government's policy goals are from the truth. The six geopolitical zones in Nigeria's distribution of solar resource potential were also shown. This potential ranged from 3.393 to 6.669 kWh/m^2/day, with the northern zones showing greater potential than the southern zones. It also demonstrated that the cost of electricity from a PV system ranged from 0.387-9.475 US dollars per kilowatt-hour (kWh), as opposed to 0.94 US dollars and 0.559 US dollars, respectively, for a diesel generator and glass-covered kerosene light. He concluded that PV is more cost-effective for rural household electrification than glass-covered kerosene lamps and fossil-fuel illumination generators [Journal of Power and Energy Engineering, 2021, 9, 1–25]. https://www.scirp.org/journal/jpee]. Saleh et al. (2018) assessed the Anyigba, North Central Nigeria, solar energy potentials. The Centre for Atmospheric Research (CAR), National Space Research and Development Agency (NASRDA), Anyigba, operated and controlled the Campbell scientific automatic weather station of Tropospheric Data Acquisition Network (TRODAN), which was used to measure sun radiation at a height of 4 meters. Over a five-year period (2011–2015), the instrument was measured at a five-minute update cycle. This location's solar radiation ranged from 8.4 KWh/m^2/day to 11.4 KWh/m^2/day. Irradiance data analysis was performed using MATLAB software. The outcomes demonstrated Anyigba's viability for solar energy production. A standalone photovoltaic PV power system was created using solar analysis to power the Ozone Monitor Laboratory in Anyigba.

According to Christian, (2022), solar PV system computer software was used to assess the potential for large-scale solar photovoltaic power generation in Sokoto State, North-Western Nigeria, and Port Harcourt, Southern Nigeria. Daily average sun radiation and relative humidity at both sites were gathered from the Nigerian Metrological Weather Forecast Centre, Abuja, between 2001 and 2010. The data were used as simulation input data to start the computer program, along with recorded Minimum/Maximum temperatures. Based on the same capacity of a power plant in Port Harcourt, the results were utilized to determine the total energy production capacity of a 200kW and 500kW photovoltaic power plant in Sokoto. It was noted that the 200kW PV power plant's overall energy production. A paper on the technology of a 100kW utility photovoltaic power system connected to the grid in India was published in 2017 by Manish et al. In order to assure a very high sustainable level for the ignorant villagers, he came to the conclusion that local manufactured and developmental input for this installation operation, and mostly the key components, should be involved. The sensitive PV power system with low-cost, high-efficiency dc-ac inverter with maximum power point tracking (mppt) functions to control and power line communications (plc) was explored by Roman et al in 2006. They evaluated the choices for developing solar power systems using centralized networks and modular topologies. The last class includes the delicate PV panels. Analysis was done on both the boost dc-dc converter and its operating mode. According to the findings, huge grid-connected solar power plants were intended to send electricity to the grid, but their costs were still quite expensive when compared to those of traditional fossil fuel power plants [PV Module for Grid-Connected PV Systems https://www.researchgate.net]. A suggestion regarding the environment for photovoltaic power plants was made by Mladen et al. (2023). Solar power systems do not harm the environment when used as intended. However, there are a few minor environmental consequences of solar power systems that call for more research. Damaged panels may release dangerous gases while in use, [Environmental Aspects of PV Power Systems. https://www.researchgate.net], which may necessitate removal and reinstallation. A sustainable study on PV solar energy installations linked to the Spanish electric grid system was conducted by Jose & Rodolfo in 2006. First, various data on interest rates and energy costs were taken into consideration during economic research. The final current value and the pay-back duration were utilized to determine the advantages of a solar power installation. Additionally, this system's sustainability was assessed. This was done by applying the life cycle analysis theory of the systems, [The influence of renewable energy on employment, https://www.researchgate.net], to calculate the energy investment recovery time, the contamination or emissions averted, and the externality costs.

Marion et al. (2005) investigated the grid-connected PV systems' performance metrics. Final PV system yield (Yf), reference yield (Yr), and performance ratio (PR) were the three performance measures used to describe the performance of grid-connected PV systems. The nameplate D.C. power rating was used to calculate The Yf and PR. It provides a direct comparison of the energy obtained from various solar power sizes, designs, or technologies for various times or locations, and it was found that variations in solar radiation each year will alter Yf but not the

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PR variables. This provides a tool for measuring overall losses and checking operational issues. Tobnaghi et al. (2021), investigated the grid-connected solar power system's sustainability. A PV system's output characteristics were evaluated in a lab setting. After the installation of PV grid-connected systems, the system issues such as recovered real power and loading reduction of the tie line/switch are concentrated. The findings indicated that the right installations can lessen the difficulties listed above. Wu et al studied a two-grid solar power system in 2011. The 10kW power system in Beijing was the first, and the 100kW system, which is in Northern China, was the second. Single phase transformer-less grid connected with inverters made up the Beijing electricity system. Three-phase grid connecting inverters without transformers were utilized in the photovoltaic power system in Northern China. Although all of the inverters in the two systems have two-stage structures, they came to the conclusion that only one stage was intended to operate for the majority of the time since their system efficiency could be easily boosted. For high operating voltage and to reduce loss, large PV systems should be connected in series.

A paper about the impact of the solar module installation angles on output power was provided by Yinp et al 2007. He found that the output power augmentation of photovoltaic cells depends on two factors: the first is lowering the temperature of the cell modules, and the second is raising the intensity of solar irradiation the cells receive. To determine the output power of the solar module cell at any tilt angle and orientation, he theoretically calculated the solar orbit and position at any time and place. Additionally, it offered a helpful assessment of the output power of solar cells installed on building walls and roofs. Research Gate: "Effects of the Solar Module Installing Angles on the Output" In several areas of West Bengal, Ganguli et al. (2009) calculated the grid quality photovoltaic solar power generation potentials and its cost analysis. They investigated the potential and level of solar radiation in the aforementioned districts before creating a system that matched the potentials present. On the basis of the system developed, equipment specifications were given, and cost analysis was also done [Design of A 11 KWp Grid Connected Solar Photovoltaic System...https://www.researchgate.net]. The integration of Solar PV grid technology into the national grid systems of Nigeria was explored by Nweke et al. (2012). If a total capacity for PV grid integration can be developed, the recent directive by the federal government of Nigeria for local government sectors to produce their own electricity of 5.5kW-hr/day/m^2 represents a huge prospect for solar energy generation. They suggested that a large-scale integration of photovoltaic solar power systems into the national grid should be adopted.

Methodology

The use of the Angstrom-Prescott equation to determine the potential of solar power generation for Makurdi town over the period of five years (2017---2021) is shown below.

$$\frac{H}{Ho} = a + b\left(\frac{n}{N}\right) \qquad 1$$

Where

"H" is the monthly average daily global solar radiation (MJm^{-2}day^{-1}), which is measured on the surface of the earth of the study location (Makurdi).

"n" is the sunshine hours of the study area (Makurdi).

"N" is the monthly average daily maximum number of hours of possible sunshine (or day length).

"H_0" is the monthly average daily extraterrestrial solar radiation (MJm^{-2}day^{-1}).

"a" and "b" are the regression coefficients which are to be obtained using the graphical method in this research work.

"H_0" is the monthly average daily extraterrestrial solar radiation (MJm^{-2}day^{-1}) which is calculated using the formula below.

$$H_o = \frac{24(60)}{\pi} I_{sc} d_r (W_s Sin(_\varphi) Sin(\delta) + Cos(_\varphi) Cos(\delta) Sin(W_s)) \qquad 2$$

where the light beams from the Sun and the Earth's equator are represented by the declination angle of solar radiation, δ. The angle of declination varies throughout the year due to the Earth's annual rotation and tilt. The solar declination varies annually between -23.44 and +23.44 degrees in accordance with the Earth's seasons. The solar radiation declination angle has the formula as

$$\delta = 0.409 Sin\left(\frac{2\pi}{365} J - 1.39\right) \qquad 3$$

Where J is the number of days in the year between 1 (1 January) and 365 or 366 (31 December). The values of solar declination angle are calculated using equation (3) above and tabulated as shown below for the five years. (2017—2021)

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Table 1: The average monthly values of δ in degrees and radians

Month	δ in degrees(^{0})	δ in radians
January	-17.7	-0.3090
February	-8.6	-0.1496
March	3.3	0.0579
April	14.3	0.2503
May	21.8	0.3800
June	23.2	0.4051
July	18.3	0.3202
August	8.4	0.1463
September	-3.1	-0.0544
October	-14.5	-0.2531
November	-21.7	-0.3787
December	-23.2	-0.4046

"dr" stands for the Earth-Sun relative inverse distance. The following formula is used to calculate it;

$$d_r = 1 + 0.033\text{Cos}\left(\frac{2\pi}{365}J\right) \qquad 4$$

Equation 4 was used for all the twelve months for the five years and the values are shown in the table below.

Table 2: The average monthly values of Inverse relative distance Earth-sun (dr) in radians and in degrees

Month	dr in radians	dr in degrees(^{0})
January	1.0284	58.9
February	1.0174	58.3
March	1.0013	57.4
April	0.9848	56.4
May	0.9720	55.7
June	0.9670	55.4
July	0.9709	55.6
August	0.9828	56.3
September	0.9984	57.2
October	1.0154	58.2
November	1.0278	58.9
December	1.0330	59.2

"W_s" is the Sunset angle. It is calculated using the formula given as;

$$W_s = \text{Cos}^{-1}(-\tan(\varphi)\tan(\delta)) \qquad 5$$

The sunset angle values are calculated using equation (5) and presented in the table below.

Table 3 shows values of sunset angles (W_s)

Month	W_s in radians	W_s in degrees (^{0})
January	1.5277	87.5
February	1.5505	88.8
March	1.5786	90.4
April	1.6053	92.0
May	1.6247	93.1
June	1.6286	93.3
July	1.6155	92.5
August	1.5907	91.1
September	1.5635	89.6
October	1.5359	88.0
November	1.5171	86.9
December	1.5130	86.7

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The solar constant (I_{sc}) has a value of 1367 W/m^2. The conversion of this figure to mega-joules per meter square per day is (1367 × 60)/106 = 0.0820 MJm^{-2} day^{-1}, where $_\varphi$ is the location's latitude angle (Makurdi at $7^0 41^1$), expressed in radians (0.134).

Extraterrestrial Radiation Values (H_o)

The values of extraterrestrial radiation are calculated using equation (2) above as

$$H_o = \frac{24(60)}{\pi} I_{sc} d_r (W_s Sin(_\varphi) Sin(\delta) + Cos(_\varphi) Cos(\delta) Sin(W_s))$$

The values of extraterrestrial solar radiation obtained are presented in the table below.

Table 4: The average monthly values of extraterrestrial radiation (H_o) in MJm^{-2}day^{-1}

Month	H_o (MJm^{-2}day^{-1})
January	34.0596
February	36.2856
March	37.6932
April	37.4850
May	36.5159
June	36.1659
July	36.7717
August	37.3546
September	35.9720
October	34.6344
November	32.6259
December	32.2231

The Global Solar Radiation Values

The following table below presents the values of global solar radiation, expressed in MJm^{-2}day^{-1}, that were gathered at the Nigerian Meteorological Agency's Nnamdi Azikiwe International Airport in Abuja.

Table 5:Monthly mean solar radiation values in MJm^{-2}day^{-1} for five years

Month/Year	2017	2018	2019	2020	2021
January	18.928	20.339	20.133	19.164	18.766
February	18.733	18.949	19.458	19.122	18.600
March	18.169	18.341	18.429	18.431	18.100
April	17.846	17.910	17.752	17.594	17.672
May	15.818	15.918	16.036	16.290	16.197
June	13.994	14.015	13.981	14.059	14.252
July	13.558	13.576	13.055	12.944	13.570
August	13.977	14.391	14.674	14.658	14.108
September	15.922	16.053	15.468	15.192	15.124
October	17.313	17.338	17.189	17.379	17.370
November	18.152	17.624	17.370	18.249	20.053
December	19.494	19.820	18.631	19.996	21.995

Extraterrestrial Solar Radiation

The table below shows the ratios of solar radiation from Earth to solar radiation from other planets. (Extraterrestrial solar radiation).

Table 6: The ratios of global solar radiation to extraterrestrial solar radiation (H/Ho) for five years

Month/Year	2017	2018	2019	2020	2021
January	0.556	0.597	0.591	0.563	0.551
February	0.516	0.522	0.536	0.527	0.513
March	0.482	0.487	0.489	0.489	0.480
April	0.476	0.478	0.474	0.469	0.471
May	0.433	0.436	0.439	0.446	0.444
June	0.387	0.388	0.387	0.389	0.394
July	0.369	0.369	0.355	0.352	0.369
August	0.374	0.385	0.393	0.392	0.378

September	0.443	0.446	0.430	0.422	0.420
October	0.500	0.501	0.496	0.502	0.502
November	0.556	0.540	0.532	0.560	0.615
December	0.605	0.615	0.578	0.621	0.683

Sunshine Hour values

The values of sunshine hours in hours were collected during a five-year period (2017—2021) at the Nigerian Meteorological Agency (NIMET), Nnamdi Azikiwe International Airport in Abuja, and were tabulated for presentation.

Table 7:The average monthly values of sunshine hours in for five years.

Month/Year	2017	2018	2019	2020	2021
January	7.9	7.8	7.3	6.7	7.0
February	7.0	7.4	7.0	6.4	6.0
March	6.3	6.4	5.9	6.3	7.2
April	7.7	7.4	7.0	6.5	6.7
May	6.5	6.6	6.7	7.0	7.0
June	7.0	7.0	6.3	5.6	6.2
July	5.3	5.3	4.4	3.7	4.2
August	4.6	4.5	4.2	3.8	3.7
September	4.8	4.8	4.9	5.1	4.9
October	7.3	7.1	7.1	6.9	6.4
November	8.6	8.6	8.3	8.2	8.5
December	7.9	7.9	7.6	7.4	7.8

Day Light Hours (N)

This is the number of hours the sun shines on the earth. It is calculated using the formula below.

$$N = \frac{2}{15}W_s \qquad 6$$

The obtained values are presented below.

Table 8 Average values of daylight hours for the five years

Month	N in hours
January	11.7
February	11.8
March	12.0
April	12.3
May	12.4
June	12.4
July	12.3
August	12.1
September	11.9
October	11.7
November	11.6
December	11.6

Ratios of Sunshine Hours to Daylight Hours (n/N)

The ratios of sunshine hours to daylight hours for five years were calculated and tabulated below.

Table 9:The average monthly mean ratios of sunshine hours to daylight hours (n/N) for five years.

Month/Year	2017	2018	2019	2020	2021
January	0.675	0.667	0.624	0.573	0.598
February	0.593	0.627	0.593	0.542	0.508
March	0.525	0.533	0.492	0.525	0.600
April	0.626	0.602	0.569	0.528	0.545
May	0.524	0.532	0.540	0.565	0.565
June	0.565	0.565	0.508	0.452	0.500
July	0.431	0.431	0.358	0.301	0.341
August	0.380	0.372	0.347	0.314	0.306

September	0.403	0.403	0.412	0.429	0.412
October	0.624	0.607	0.607	0.590	0.547
November	0.741	0.741	0.716	0.707	0.733
December	0.681	0.681	0.655	0.638	0.672

Results

The results obtained under methodology are brought forward for analysis and discussion. The analysis here is done basically using regression statistical methods such as coefficient of determination and root mean square error on Mat Lab Software R2020 as shown below.

Angstrom-Prescott Equation

The data for the ratios of alien solar radiation to global solar radiation and the data for the ratios of sunshine hours to sun day length as provided in tables 7 and 9 respectively were used to build the Angstrom-Prescott equation for this work.

Figure 1

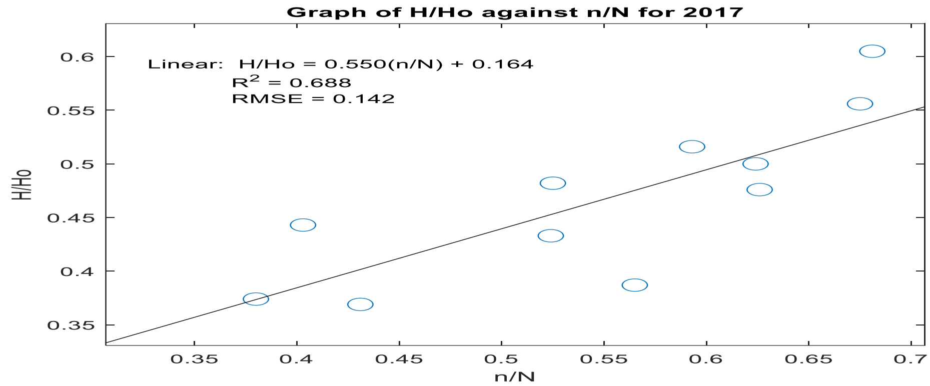

Figure 2

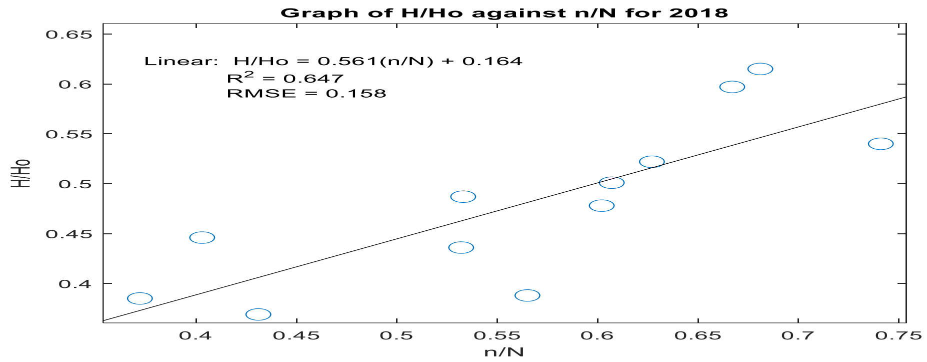

Figure 3

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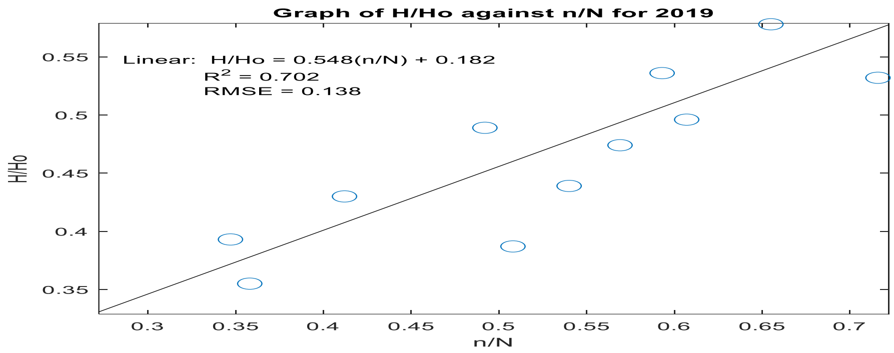


Figure 4

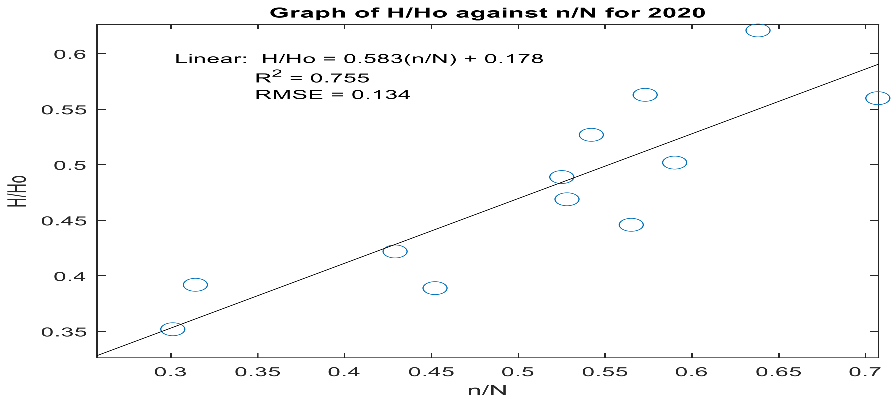
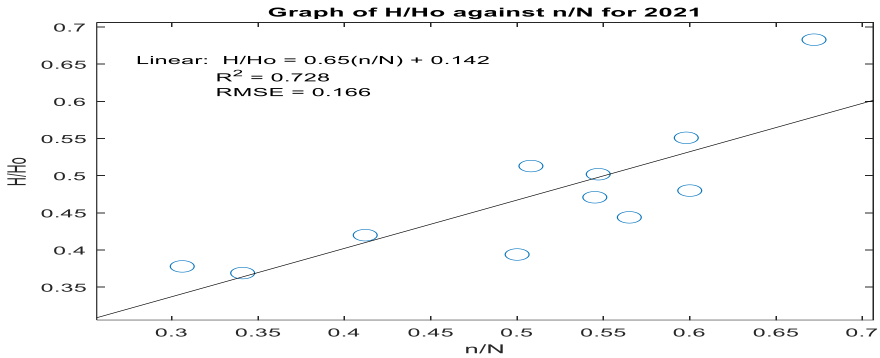


Figure 5



The analysis above yielded the average values of "a" and "b" as 0.166 and 0.578 respectively. This allowed us to develop a very strong model for the simple prediction of solar radiation values for Makurdi. From the graphs above, we obtained the average values of the coefficient of determination (R^2) as 0.704 (70.4%) which showed a strong agreement between the ratios of global solar radiation to extraterrestrial solar radiation and that of sunshine hours to that of day length hours. Root Mean Square Error (RMSR) as 0.148 (14.8%) which showed a strong fitness of the models we used in this research work.

$$H/ H_o = 0.166 + 0.578(n/N) \qquad 7$$

The model we developed (equation 7 above) was compared with other researchers' models in this study area (Makurdi) as shown below.

Table 10 Comparison of Angstrom-Prescott Equations in Makurdi Town

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Period	**“a”**	**“b”**	**Developed equation**
Current (2017—2021)	0.166	0.578	$H/H_o = 0.166 + 0.578\ (n/N)$
Previous (2000—2010)	0.138	0.455	$H/H_o = 0.138 + 0.455(n/N)$

According to Table 10 above, our comparison revealed increases in both "a" and "b," indicating that Makurdi town's atmospheric transparency had increased and the number of clouds covering the town during the study period had decreased. This made Makurdi town more susceptible to high temperatures and solar radiation incidence. This indicated that Makurdi Town was experiencing a high degree of global warming as a result of the area's extensive use of non-renewable energy sources, but it also offered great potential for solar power generation.

Solar Irradiation

The values of ratios of global solar radiation to extraterrestrial solar radiation (H/Ho) from Table 6 above were plotted against the months as shown below.

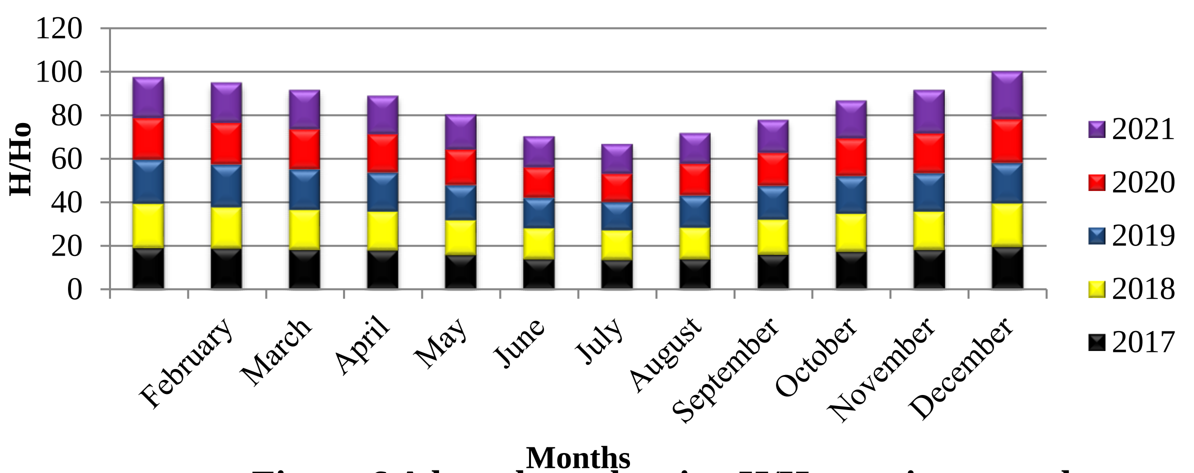

Figure 6 A bar chart showing H/Ho against months

According to the above bar chart, because of the area's atmospheric transparency, December has the highest solar irradiation incidence on Makurdi Town during the dry season, while July has the lowest solar irradiation incidence during the rainy season because of the area's dense cloud cover. This conclusion was in line with the findings of Moses Audu, who conducted research in this area over a ten-year period from 2000 to 2010 and found that August had the lowest solar irradiation value and December the highest.

Sunshine Hours

The sunshine hour’s values from Table 7 above were plotted on a bar chart against the months of the year as shown below.

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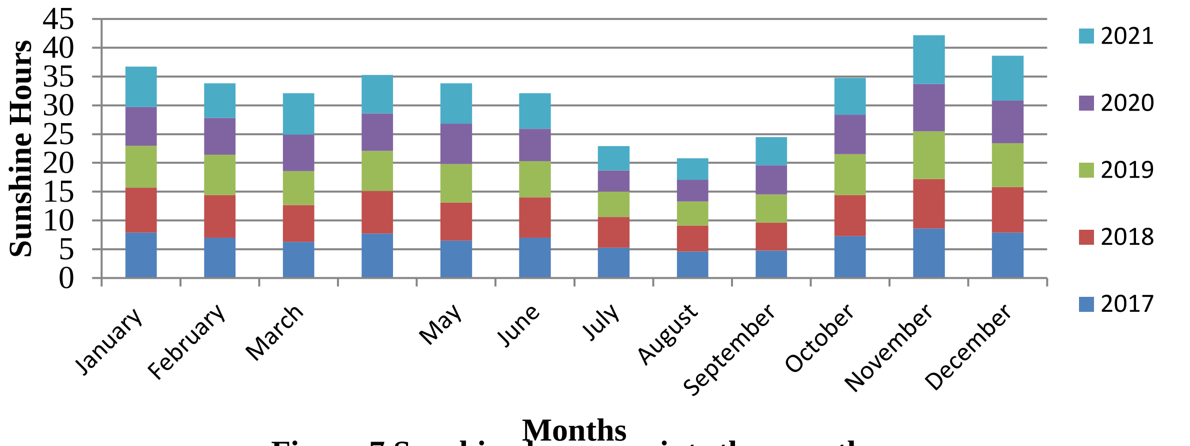

Figure 7 Sunshine hours againts the months

According to Figure 7 above, the highest number of sunshine hours are recorded during the dry season, especially in November when Makurdi town is clear of clouds. The lowest number of sunshine hours is recorded in July when there are clouds during the rainy season.

Discussion

The developed model for this work, H/Ho = 0.166+ 0.578 (n/N), was used to assess Benue State's tremendous potential for solar power generation. For Makurdi Town and other areas with comparable geographic characteristics, this equation can be applied with ease to forecast solar radiation values. The findings of this study were recommended for statistical tests like the Root Square Mean Error and Coefficient of Determination, and they provided us with a solid indication of the correlation between the variables we employed in this study.

Conclusion

Our research goal was accomplished by creating a model that made it simple to predict Makurdi town's solar radiation, estimating the potential for solar power generation there, and calculating the maximum and minimum values of solar ration for these five years (2017–2021). The study area was found to be affected by global warming, and one potential strategy to counteract its effects was to generate electricity using solar energy instead of fossil fuels.

Recommendations

- This work serves as a cornerstone for technological organizations, government agencies, non-governmental organizations, and even individuals for proper execution of renewable energy projects in this area.
- The developed model in this work will serve as a reference for other scientists, especially in renewable energy.
- Since renewable energy is the global driving force of the twenty-first century, more researchers are encouraged to enter this subject.

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