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DEVELOPMENT OF SOLAR ENERGY MAP FOR NIGERIA FROM NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) DATA

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ABSTRACT

The power supply situation in Nigeria is presently precarious, and while other countries are researching in alternative forms of energy, we must not be left behind. It has been established that economic growth is directly proportional to the growth in energy use. How we harness our energy sources indicates how serious we want the economy to grow. The study identifies that one of the major challenges of incorporating solar energy technologies across the country is the non-availability of solar resource data for various locations across the country. To address this challenge, the research study has developed solar irradiance map for Nigeria.

The solar resources map is developed using data provided by the National Aeronautics and Space Administration (NASA). The data covers the period of 25 years (1994-2018). The average daily global solar irradiance for various longitude-latitude nodes are estimated after analyzing the data. The values were then fitted on the Nigerian map. With these details available, it is then possible to estimate the average daily global solar irradiance for any location provided the longitude and latitude for the location is known. Irradiance values for 300 locations have been calculated from details provided by the map. Experimental values of irradiance for various locations have been compared with values extracted from the Solar Irradiance Map. These values show low deviations (<6.8%) from values on the map. This has established that the map is suitable for estimating irradiance values for any location in Nigeria.

The map for solar irradiance will provided satisfactory information necessary for solar energy research, design and deployment of solar energy supply technologies. Results from this study has ensured that Irradiance values for various locations in Nigeria can quickly be known. This will fast-track solar energy related research and development. The procedure followed can be used to develop solar irradiance maps for other countries.

KEYWORDS: Solar Energy, Potential map, Irradiance, NASA.

INTRODUCTION

The importance of harnessing solar resource

It has been established the sun dump over 120,000 TW of radiation on the earth (Kamat, 2007). If just a fraction of this is captured and utilized, we would have more energy than the world needs. The world energy demands fluctuates with needs but even in the most extreme of cases, the sun can provide the energy world requires. It is well known that the sun is responsible for global wind movements, ocean currents flow, the recycling of water from oceans to land through the process of evaporation and condensation. Without such a process lakes and rivers will disappear and the ocean will rise and overflow the land. Of course life depends on the biological process of photosynthesis through which the CO_2 and Oxygen maintain their balance to sustain life on earth. If only 0.16 of the earth's exposed surface is provided with solar energy capturing systems operating at 10% efficiency, we would be able to provide all the energy the earth requires. In fact such a system will provide over 20TW of energy which about double the present consumption of energy from fossil fuels (Lewis, 2005). The sun therefore is an energy source that every country should explore for its energy requirement.

Solar energy use is increasing globally and given its vast potential, many are still pessimistic about its prospects as a sustainable energy source. The main reasons are cost and inconsistent nature. Nigeria would reap immensely if solar energy is sought as an alternative energy source to petroleum and gas. The reasons are obvious; location of Nigeria and its large land area. However, the use of solar energy helps to reduce greenhouse gasses that are a significant cause of climate change, although its use is usually considered not to reduce greenhouse gas emissions substantially.

It is very difficult to estimate the economic importance of solar energy. First, solar energy ensures photosynthesis takes place which is what sustain life on earth. Secondly, solar energy brings the required variation in temperature that drives the wind and causes changes in climatic conditions. Therefore the economic importance of solar energy is not all about the cost of PVs and other solar technologies. In considering the economic importance of solar energy, all these factors should be considered.

There has been rapid advances in the use of solar energy as a competing source with fossil fuels. This is because many countries have seen the many advantages of using solar energy. Climate change has led to a new drive in rapid investment by countries into this clean source of energy. Solar energy storage systems have further improved the viability of this energy source as non-intermittent energy source. Nigeria as a country has seen investment in research and development grow in this area over the recent years. The Energy Commission of Nigeria (ECN) is championing this course. However, considering Nigeria location as a high solar energy receiving country in the world, such investments in research effort is considered meagre. There is the need for Nigeria to expend its research base on the use of this energy source. Present research efforts in Nigeria on renewable energy in general and solar energy in particular is very low and need to fast-tract research effort is paramount if any impact is to be envisaged. Fast-tracking research efforts require the right support from policy makers who have to consider cost and competing priority areas.

Nigeria is strategically located when it comes to solar energy availability. Another added advantage is that solar radiation is evenly distributed. The annual average of total solar radiation is varies from about 15.0 $MJ/m^2/day$ in the south to about 23 MJ/m^2-day in the far north. It has been estimated that the solar energy available over this area can produce power that is more than 120 thousand times the total electrical energy generated by the both the thermal and hydro-power generation plants in the country. A major part of this solar resource is available for photosynthesis processes. However a major part is available for power generation if properly harness. The nation has seen the rise in solar energy utilization principally because of the non-availability and rampant power cuts in the country. Electric power generation is far below demand and many have to seek alternatives to meet their energy needs. While electrical power generator has been the popular choice, many have explored the solar power alternative. From street lighting to home power source, solar energy is fast gaining popularity. Installation of PV panels for power generation are commonplace in most homes in most cities in Nigeria presently.

Knowing the Resource Value is Key to its Exploitation

As the solar resource varies in large proportion with location and time-scales, a solar project of any kind requires a good amount of knowledge on the actual resource. This requires assessing not only the overall global solar energy available, but also the relative magnitude of its three components: direct-beam irradiance, diffuse irradiance from the sky including clouds, and irradiance by reflection from the ground surface. Also important are the patterns of seasonal availability, variability of irradiance, and daytime temperature on site. As seen above, long-term measurement is necessary to avoid being misled by the annual variability, especially in temperate regions (http://www.eng.uc.edu/~beaucag/Classes/SolarPowerForAfrica/SolarEnergyPerspectives6111251e.pdf).

Meteorological satellites in space can help fill in the resource knowledge gaps. The considerable advantage they offer is a complete coverage of the inhabited regions of the world, as well as the time depth for those that have been in service for years. Ground stations are scarce and cannot rival the resolution of satellites, often of 10-km scale (http://www.eng.uc.edu/~beaucag/Classes/SolarPowerForAfrica/ SolarEnergyPerspectives6111251e.pdf).

Global Solar Resources Mapping

Global Solar Resources Mapping has evolved over the years and this has contributed immensely in the planning of renewable energy projects across the World. Solar resources have continued to provide the energy needed to drive various solar energy technologies. The importance of investing in solar energy technologies and their economic viabilities are better appreciated when a comparative study is performed on the long term use of non-renewable energy sources. Solar Resources maps play vital role in solar prospection, determination of energy deployment strategies and pre-feasibility studies. The determination of the solar energy potential of any area is the main step in determining the viability of the application of solar energy technologies in that area.

A solar map, in general, is a map of a city, state, country, or any piece of land that illustrates information about how much a certain piece of land, building, or home experiences a certain amount of sunlight. Though solar maps are illustrated in many forms, a solar map essentially records where and to what extent a certain location experiences a certain amount of sunlight or radiation. It normally combines topographic, meteorological, and sometimes financial data to help scholars or consumers and investors in promoting awareness of the potential of solar power (https://en.wikipedia.org/wiki/Solar_map).

The need for comprehensive regional maps used to assess national solar energy policies, plans and the selection of sites has been motivated by the growing interest in solar energy in Nigeria. The maps generated by NASA has become a common source for generating data. The NASA Surface meteorology and Solar Energy (SSE) project was launched in 1997 and its purpose is to provide a global overview of solar resources. Small and medium-resolution maps provide a summary of the solar resources, and for years these charts are freely available, for example, in the free PVGIS applications Solar and Wind Energy Resource Assessment (SWERA).The database used for producing NASA map falls into this category (has very low resolutions of about 110 km at the equator) (https://solarsystem.nasa.gov/resources/15784/enceladus-polar-maps-december-2011-south-annotated/).This makes them unsuitable for site selection or solar resource assessment. Using only the NASA SSE data set may result in poor estimation of solar radiation. Therefore spot data over a period of time at research sites are still very relevant for comparison.

PROCEDURE FOR DEVELOPMENT OF IRRADIANCE MAP FOR NIGERIA

How to get reliable solar potential data

Solar energy research depends majorly on accurate solar radiation data. Therefore wherever such data is needed, meteorological stations needed for such measurements should be provided. This is not only possible but very expensive. It is therefore necessary to develop procedure of estimating solar radiation values for areas where meteorological stations are not available. Various methods and procedures have been developed to estimate solar radiation values. However, the wide differences between the estimated and the actual solar radiation values means that working with actual measured values over a period of time is the most appropriate method of estimating solar radiation values. To get accurate solar radiation data requires pinpoint measurement at the required site. The major challenge is that if measurements are carried out repeatable at the same time of the year, there is no guarantee that one will get the same results. Therefore pinpoint ground values are usually used as checks and not for design purposes. It is much better to used data collected over a period of time as they are more representative of what will occur in the future.

Models for Estimating Solar Radiation Values

Various models have been presented for establishing solar irradiance values for various location. Many of such models use sunshine hours, air temperature, relative humidity, etc to estimate irradiance and other solar radiation values. Generally, there are three approaches used in getting global solar radiation data apart from direct ground measurements. The first class uses empirical approach where meteorological data are employed with regression techniques. The second class uses solar constant by considering the depletion of insolation value due to clearness index variation and the third class is based on satellite measurements. The first and second classes above are classified as global solar radiation estimation techniques. The model most commonly used of these two approaches is the Angstrom-Prescott model (Duffie and Beckman, 1991)) that uses sunshine hours for the estimation. However, over the years, due to more researches, more accurate models have been presented (Page (1961), Rietveld (1778), Hargreaves and Samani (1882), Besharat et al. (2013) and Okundamiya (2016)).

The third approach, that is, establishing solar radiation and related data from the Satellite-derived data, has become the most common estimation method used by scientists and researchers. Satellite-derived data are instantaneous spatial averages remotely measured several kilometres from the earth's surface by geostationary and polar orbiting satellites. Satellite measurements provide easy access to long-term, cheap, and verifiable means of deriving regular solar radiation data for any desired location in the world. Satellite-derived data fit better to a selected site than ground measurements from a site farther than 25 km away (Geuder, 2013). The most commonly used are those provided by the National Aeronautics and Space Administration [(Surface meteorology and Solar Energy *(SSE-release 6.0)*. This is a renewable energy resource web site sponsored by NASA's Applied Sciences Program in the Science Mission Directorate (https://power.larc.nasa.gov/common/php/SSE_ExSummary.php] and Global Solar Atlas (GSA). The Global Solar Atlas is provided by the World Bank and the International Finance Corporation to support the scale-up of solar power around the countries.

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Procedure for Estimating Irradiance Values for Various Locations in Nigeria

The Solar resources map for Nigeria is developed using data provided by the National Aeronautics and Space Administration (Surface meteorology and Solar Energy *(SSE-release 6.0)*. This is a renewable energy resource website sponsored by NASA's Applied Sciences Program in the Science Mission Directorate (https://power.larc.nasa.gov/common/php/SSE_ExSummary.php).

The SSE data set contains over 200 primary and derived solar, meteorology, and cloud related parameters formulated for assessing and designing renewable energy systems. SSE data have been arrived through symbiotic partnership with industry and governments who have interest in renewable energy utilization. It is a user-friendly data portal that provide industry-friendly parameters for renewable energy research and development (https://power.larc.nasa.gov/common/php/SSE_ExSummary.php).

Solar irradiance is the power per unit area (watt per square metre, W/m^2), received from the Sun in the form of electromagnetic radiation as reported in the wavelength range of the measuring instrument. Solar irradiance is often integrated over a given time period in order to report the radiant energy emitted into the immediate environment (joule per square metre, J/m^2) during that time period. This integrated solar irradiance is called solar irradiation, solar exposure, solar insolation, or insolation (https://en.wikipedia.org/wiki/Solar_irradiance).

Data Analysis Techniques

Data for this work were extracted from the database provided by NASA (https://power.larc.nasa.gov/data-access-viewer/). An example of the extraction is presented in Figures (1) to (3) for three selected locations in Nigeria (Lat 7ºN: Long 3ºE, Lat 9ºN: Long 8ºE, Lat13ºN: Long 13ºE) for a period of 25 years (1994 – 2018). Microsoft Excel software package was used for the collation and analysis of the irradiance values extracted from monthly mean values of the data provided by NASA.

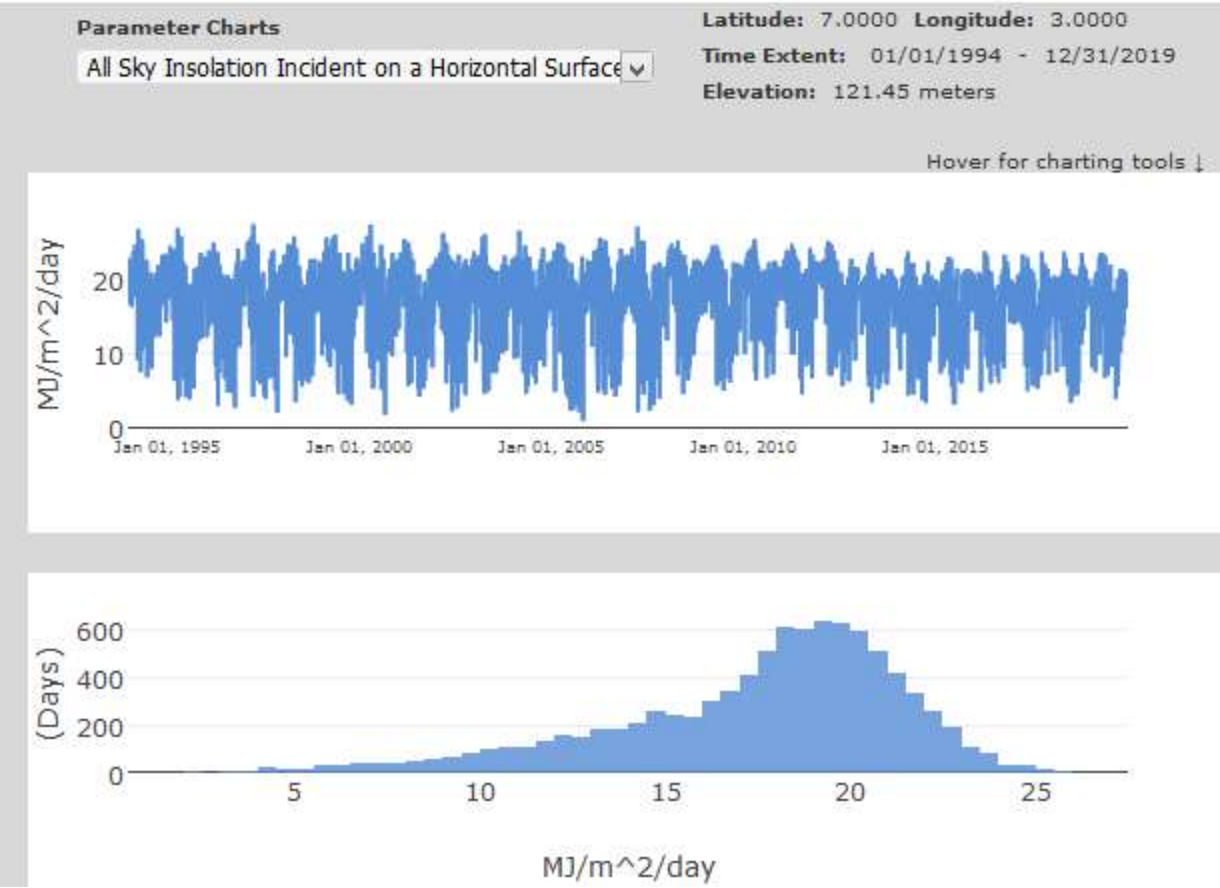

Figure 1: Irradiance values for specific location (Lat 7/Long 3) for the period Jan. 1995 to Dec. 2018

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Data such as those above have also been used by Global Solar Atlas (GSA) has been used to developed solar maps for Nigeria and other countries. Figures (4) and 5) show maps for normal irradiation and global horizontal irradiation (average daily/yearly sums) for the period of 25 years (1994-2018). The database provided by GSA is calculated by the Solargis Model from atmospheric and satellite data with 15-minute and 30-minute time step.

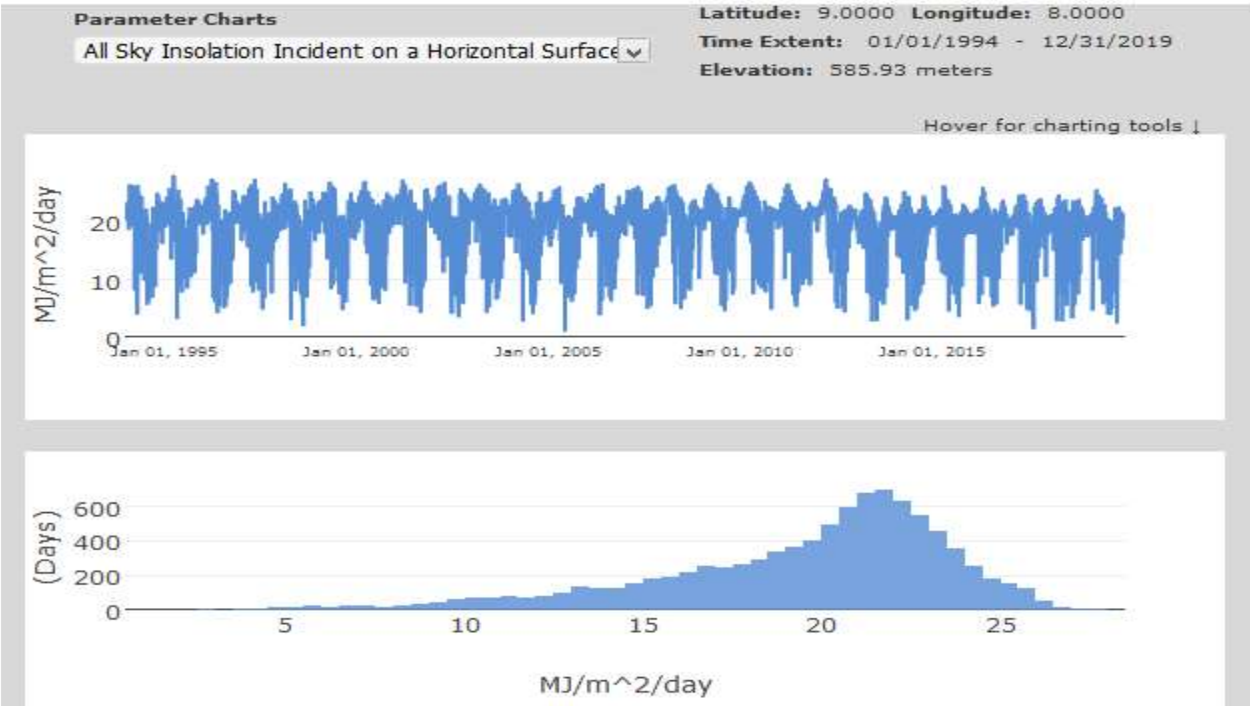

Figure 2: Irradiance values for specific location (Lat 9/Long 8) for the period Jan.1995 to Dec. 2018

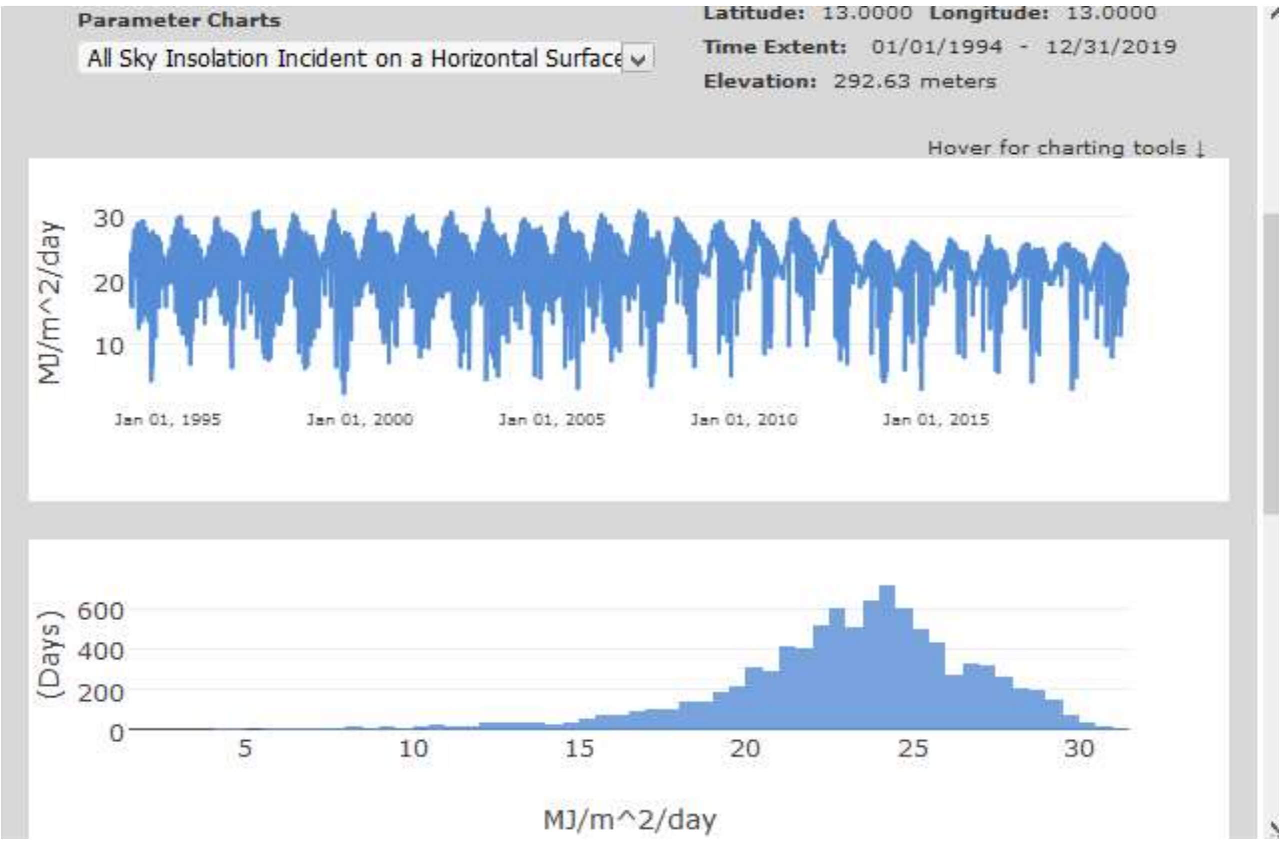

Figure 3: Irradiance values for specific location (Lat 13/Long 13) for the period Jan.1995 to Dec. 2018

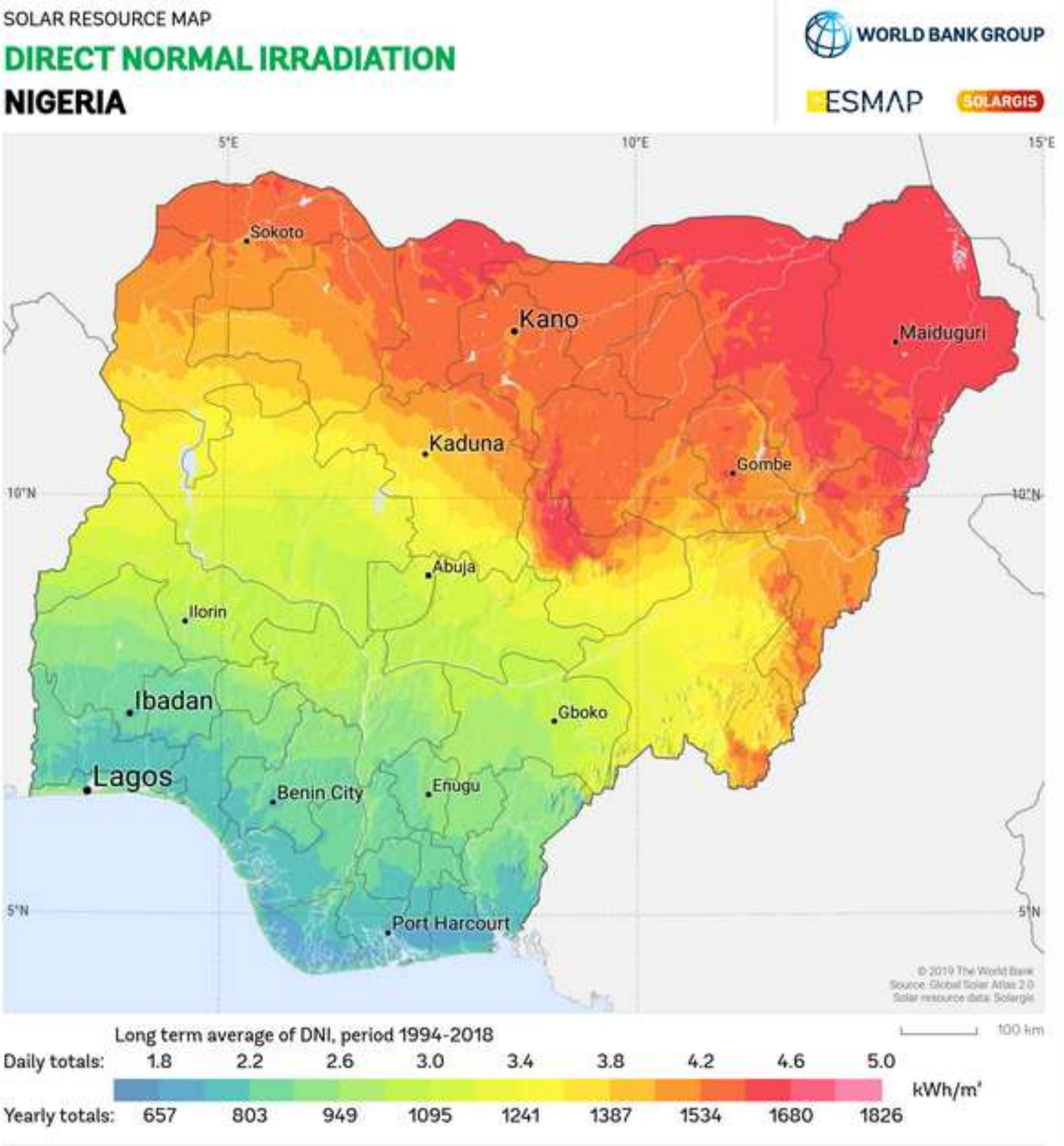

Figure 4: Direct Normal Irradiation Map for Nigeria (Global Solar Atlas (GSA): The World Bank Group (https://olc.worldbank.org/content/global-solar-atlas))

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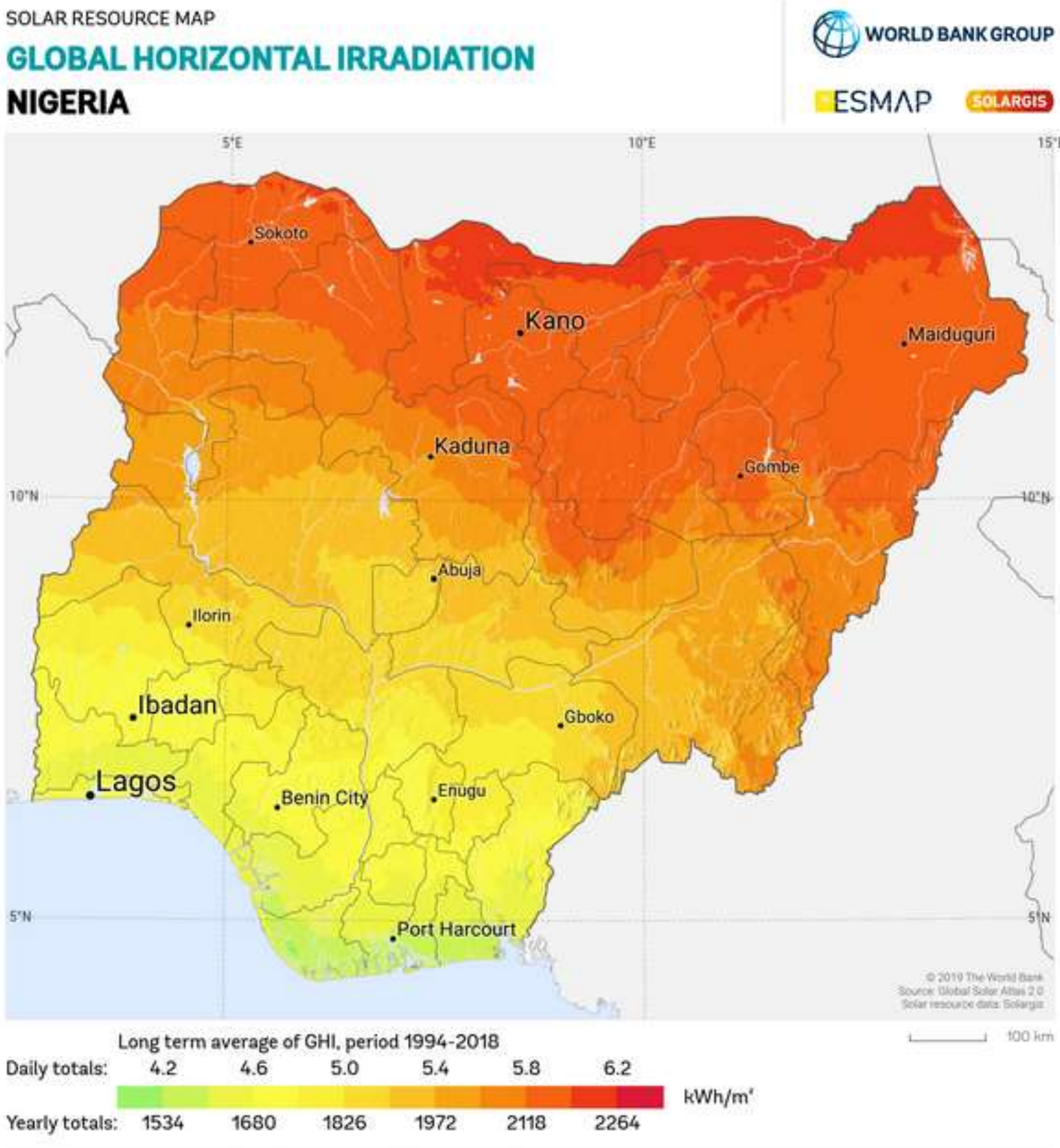

Figure 5: Global Horizontal Irradiation Map for Nigeria (Global Solar Atlas (GSA): The World Bank Group (https://olc.worldbank.org/content/global-solar-atlas))

RESULTS AND DISCUSSIONS

Procedure for Data analysis

The Data extracted from the NASA database were averaged over a period of 25 years (1994-2018) for the latitude-longitude nodes applicable to Nigeria to provide the average daily global irradiance ($MJ/m^2/day$). With such values known, it is possible to calculate the Irradiance for any position in Nigeria by interpolation.

Discussion

It is easy to appreciate the values for various periods if we drastically reduce the time spans. Figures (6) to (8) show the Isolation (Average Daily Global Solar Irradiance ($MJ/m^2/day$) for the 3 selected locations in Nigeria for the period from 1st January 2018 to 31st March, 2018 while Figures (9) to (11) show values from 1st January to 5th January 2018. Values for such period can easily be seen (Figures (1) to (3) in the previous chapter show results for a 25 year period and values are not visible because of the long period). Appendix A shows results for 4 years (2016-2019) for latitude-longitude nodes applicable to Nigeria.

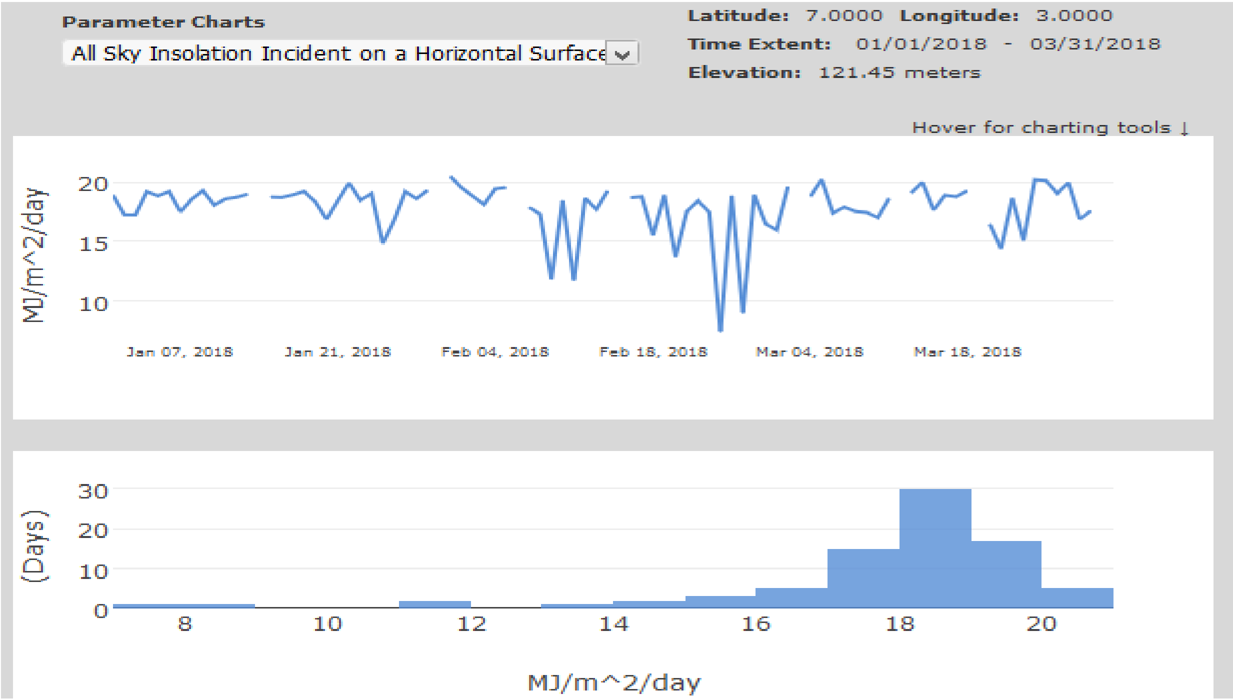

Figure 6: Irradiance values for specific location (Lat 7/Long 3) for the period Jan. 2018 to Mar. 2018

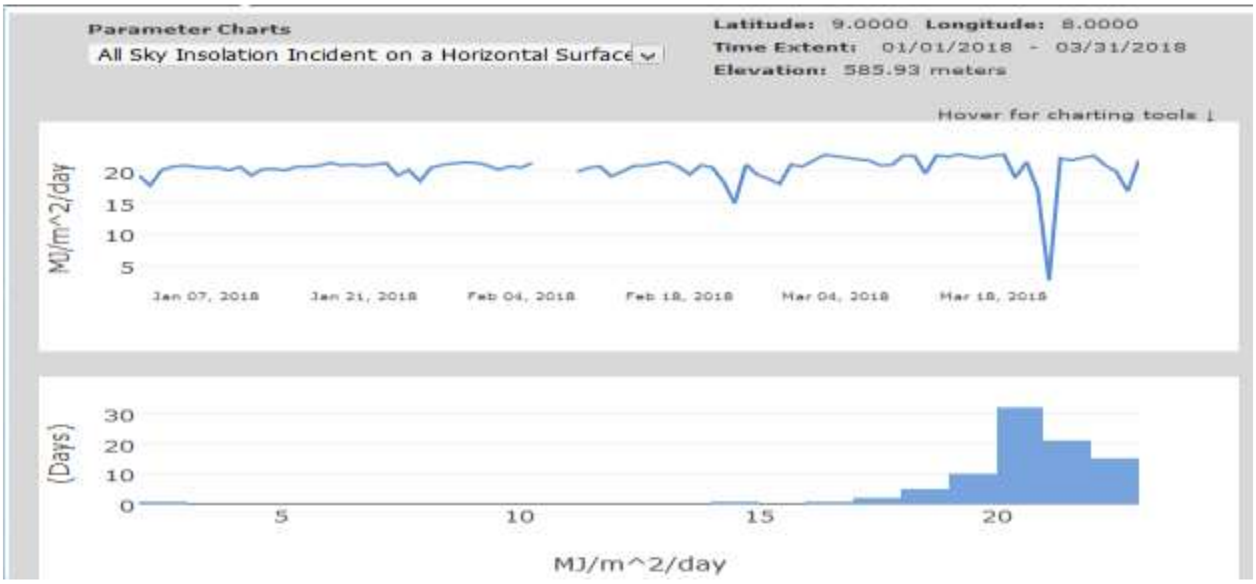

Figure 7: Irradiance values for specific location (Lat 9/Long 8) for the period Jan.1998 to Mar. 2018

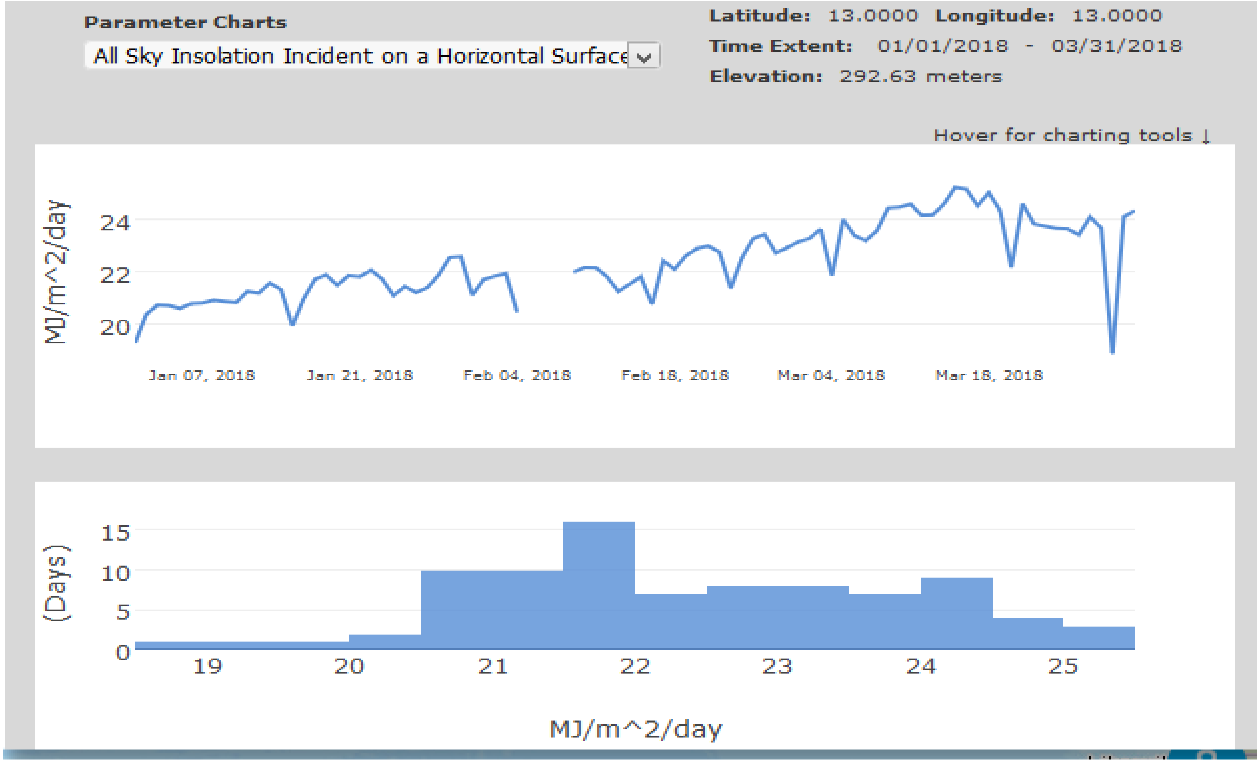

Figure 8: Irradiance values for specific location (Lat 13/Long 13) for the period Jan.1998 to Mar. 2018

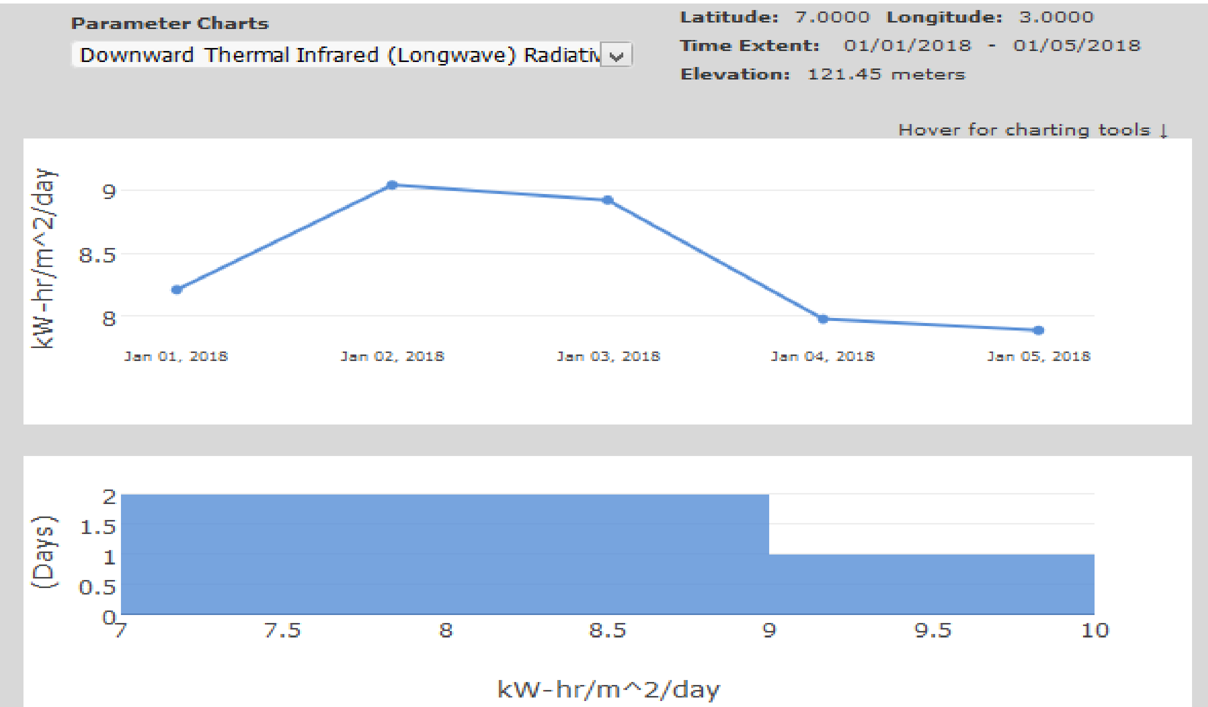

Figure 9: Irradiance values for specific location (Lat 7/Long 3) for the period 1st Jan. 2018 to 5th Jan. 2018

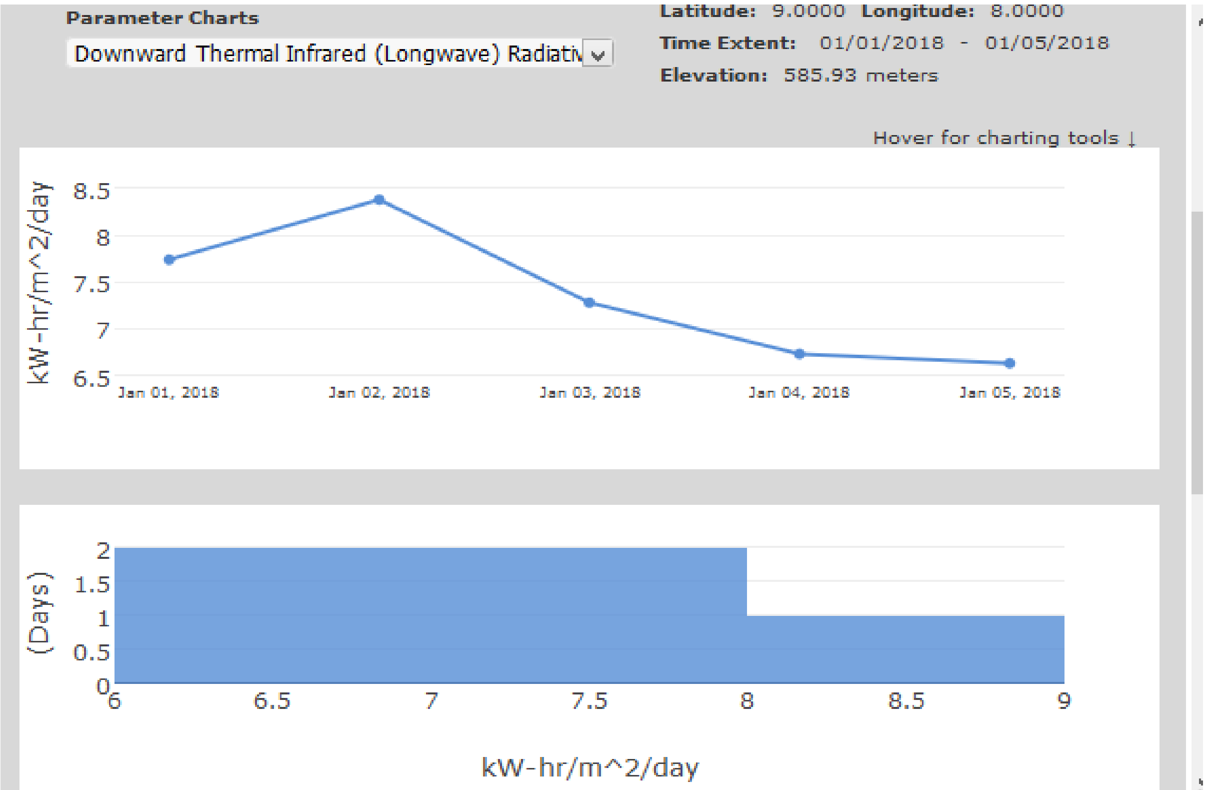

Figure 10: Irradiance values for specific location (Lat 9/Long 8) for the period 1st Jan. 2018 to 5th Jan. 2018

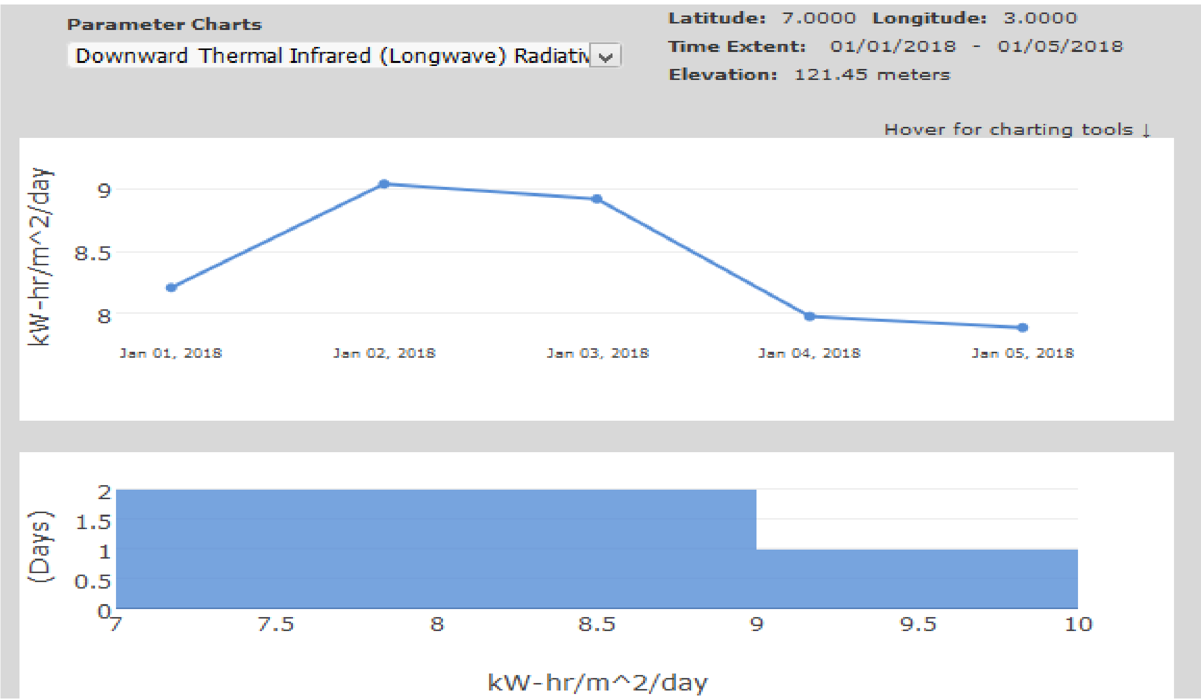

Figure 11: Irradiance values for specific location (Lat 7/Long 3) for the period 1st Jan. 2018 to 5th Jan. 2018

The values for the various latitude-longitude nodes are presented in Table 1. To appreciate the data on the map, the values have been positioned on the Nigerian map (Figure 12).

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Table 4.1: Average Daily Global Solar Irradiance (MJ/m²/day) for various Latitude and Longitude points in Nigeria

Long →	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
Lat↓														
4.0					**10.40**	**10.90**	**11.30**	**11.95**						
5.0			**11.08**	**11.95**	**12.65**	**13.65**	**13.90**	**14.35**						
6.0	**9.50**	**10.25**	**11.40**	**12.45**	**14.60**	**15.15**	**15.35**	**15.70**	**16.40**	**16.75**	**17.05**			
7.0	**12.85**	**13.30**	**13.25**	**14.30**	**15.30**	**16.50**	**17.30**	**18.20**	**18.45**	**18.70**	**18.90**	**19.0**		
8.0	**14.50**	**15.92**	**14.50**	**15.20**	**17.10**	**17.55**	**18.35**	**19.17**	**19.45**	**19.50**	**19.60**	**19.72**		
9.0	**16.60**	**18.72**	**18.9**	**19.05**	**19.25**	**19.45**	**19.65**	**19.95**	**20.5**	**20.25**	**20.40**	**20.40**	**20.30**	
10.0	**19.25**	**19.40**	**19.55**	**19.73**	**20.00**	**20.10**	**20.35**	**20.55**	**20.73**	**20.80**	**20.80**	**20.8**	**20.73**	
11.0		**19.90**	**20.10**	**20.4**	**20.58**	**20.10**	**20.95**	**21.15**	**21.25**	**21.25**	**21.25**	**21.20**	**21.10**	**20.90**
12.0		**20.40**	**20.6**	**20.95**	**21.15**	**21.30**	**21.55**	**21.65**	**21.60**	**21.63**	**21.65**	**21.60**	**21.45**	**21.25**
13.0		**20.75**	**21.05**	**21.40**	**21.6**	**21.70**	**21.85**	**21.95**	**21.95**	**22.05**	**22.1**	**21.85**	**21.75**	**21.50**
14.0				**21.70**	**21.90**	**21.95**	**22.20**	**22.35**	**22.40**	**22.40**	**22.40**	**22.0**	**21.85**	**21.70**

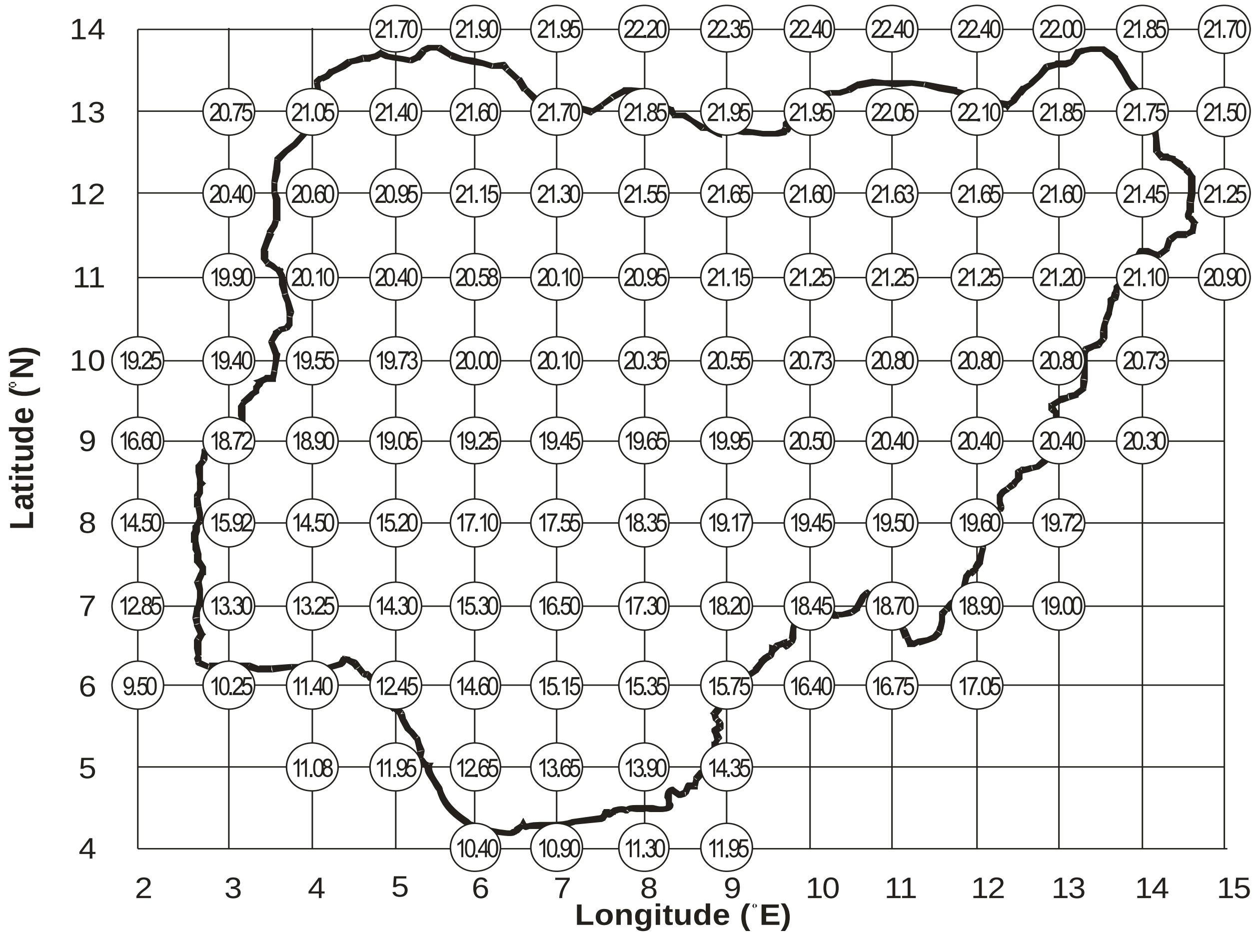

Figure 12: Average Daily Global Solar Irradiance (MJ/m²/day) for various Latitude and Longitude points in Nigeria

Table 2 shows the values of irradiances for 300 different locations in Nigeria. For locations that are not available on the table, the values can be estimated by simple interpolation from known nearest values.

Table 2: Irradiance values for various locations in Nigeria

S/No	City	Latitude °N	Longitude °E	Averaged global solar irradiance calculated from Solar Map
1	Lagos	6.450	3.470	12.05
2	Kano	12.000	8.520	21.60

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3	Ibadan	7.380	3.930	14.24
4	Kaduna	10.520	7.440	20.25
5	Port Harcourt	4.780	7.000	12.44
6	Benin	6.340	5.620	14.16
7	Maiduguri	11.850	13.160	21.43
8	Zaria	11.080	7.710	20.50
9	Aba	5.100	7.350	14.51
10	Ilorin	8.500	4.530	16.91
11	Jos	9.930	8.890	20.12
12	Ogbomosho	8.080	4.180	16.91
13	Oyo	7.830	3.920	14.24
14	Enugu	6.330	7.500	16.07
15	Abeokuta	7.160	3.350	14.24
16	Onitsha	6.160	6.780	15.39
17	Warri	5.510	5.750	12.91
18	Sokoto	13.070	5.240	21.50
19	Okene	7.560	6.230	16.61
20	Calabar	4.960	8.310	12.87
21	Oshogbo	7.830	4.580	14.31
22	Katsina	13.000	7.600	21.92
23	Akure	7.250	5.200	15.47
24	Ife	7.550	4.570	14.31
25	Ikorodu	6.610	3.510	12.05
26	Bauchi	10.310	9.840	20.86
27	Iseyin	7.980	3.670	14.24
28	Minna	9.600	6.550	19.20
29	Makurdi	7.730	8.530	18.28
30	Efonalaye	7.670	4.880	14.31
31	Owo	7.190	5.590	15.47
32	Ado	7.670	5.270	15.37
33	Ede	7.730	4.520	14.31
34	Gombe	10.290	11.170	21.02
35	Ilesha	8.920	3.420	17.01
36	Umuahia	5.540	7.480	14.51
37	Ondo	7.090	4.840	14.31
38	Damaturu	11.750	11.960	21.44
39	Jimeta	9.280	12.460	20.60
40	Iwo	7.630	4.180	14.31
41	Ikot ekpene	5.190	7.710	14.51
42	Gusau	12.170	6.660	21.44
43	Mubi	10.270	13.270	20.96
44	Shagamu	6.850	3.640	12.05
45	Ugep	5.810	8.080	15.07
46	Owerri	5.500	7.020	14.51
47	Ijebu ode	6.810	3.920	12.05
48	Ikire	7.340	4.180	14.31
49	Nnewi	6.030	6.920	15.39
50	Ise	7.460	5.420	15.47
51	Gboko	7.330	8.900	18.25
52	Abuja	9.180	7.170	19.89
53	Bida	9.080	6.010	19.70
54	Ilawe	7.400	5.060	15.47
55	Ikare	7.450	5.600	15.48
56	Sango ota	6.700	3.230	12.05
57	Okpoko	6.530	6.170	15.39
58	Awka	6.220	7.070	16.07
59	Suleja	9.170	7.170	19.89

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60	Sapele	5.900	5.670	12.91
61	Ila	8.020	4.900	16.91
62	Shaki	8.660	3.400	17.01
63	Ijero	7.810	5.070	15.47
64	Inisa	7.840	4.330	14.31
65	Otukpo	6.820	8.670	16.64
66	Kishi	9.090	3.850	19.14
67	Ikirun	7.920	4.660	14.31
68	Bugama	4.730	6.870	11.90
69	Okrika	4.740	7.080	12.44
70	Obosi	6.110	6.870	15.39
71	Funtua	11.530	7.310	20.97
72	Abakaliki	6.330	8.110	16.64
73	Gbongan	7.470	4.350	14.31
74	Lafia	8.490	8.520	19.20
75	Ejigbo	7.900	4.320	14.31
76	Igboho	8.830	3.750	17.01
77	Amaigbo	5.780	7.830	14.51
78	Gashua	12.880	11.040	21.86
79	Offa	8.140	4.720	16.91
80	Ifonosun	7.870	4.480	14.31
81	Jalingo	8.890	11.370	19.94
82	Bama	11.520	13.680	21.34
83	Uromi	6.720	6.320	15.39
84	Nsukka	6.860	7.390	16.07
85	Uyo	5.010	7.850	14.51
86	Okigwe	5.850	7.350	14.60
87	Modakeke	7.380	4.270	14.31
88	Hadejia	12.460	10.040	21.81
89	Ilobu	7.840	4.480	14.31
90	Azare	11.680	10.190	21.43
91	Ijebu igbo	6.970	4.000	12.85
92	Nguru	12.880	10.450	21.81
93	Birninkebbi	12.460	4.190	21.00
94	Nkpor	6.160	6.830	15.39
95	Kontagora	10.400	5.470	20.18
96	Oron	4.810	8.250	12.87
97	Ikere	7.500	5.230	15.47
98	Yola	9.230	12.460	20.60
99	Biu	10.600	12.200	21.01
100	Ishieke	6.400	8.030	16.64
101	Wukari	7.880	9.770	18.82
102	Epe	6.590	3.980	12.05
103	Ogaminana	7.600	6.230	16.61
104	Effium	6.630	8.070	16.64
105	Ifo	6.820	3.200	12.05
106	Keffi	8.840	7.870	18.75
107	Igbo ora	7.430	3.290	14.24
108	Ihiala	5.860	6.850	14.01
109	Ughelli	5.500	5.980	12.91
110	Kafanchan	9.590	8.280	20.12
111	Ikom	5.970	8.710	15.07
112	Gamboru	12.370	14.220	21.49
113	Kagoro	9.610	8.380	20.12
114	Agulu	6.110	7.050	16.07
115	Daura	11.530	11.450	21.44
116	Asaba	6.200	6.740	15.39

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117	Bende	5.570	7.630	14.51
118	Igbo ukwu	6.020	7.010	16.07
119	Oka	7.370	5.720	15.47
120	Numan	9.470	12.030	20.60
121	Ozubulu	5.950	6.850	14.01
122	Aku	6.700	7.330	16.07
123	Kuroro	7.580	6.230	16.61
124	Afikpo	5.900	7.930	14.51
125	Opobo	4.640	7.560	12.44
126	Okitipupa	6.510	4.690	12.85
127	Idah	7.120	6.730	16.61
128	Ehaamufu	6.660	7.750	16.07
129	Abonnema	4.690	6.790	11.90
130	Etiti	5.620	7.350	14.51
131	Ohafia	5.620	7.800	14.61
132	Agbor	6.260	6.190	15.39
133	Malumfashi	11.780	7.620	20.97
134	Enugu ukwu	6.170	7.000	16.07
135	Kauranamoda	12.590	6.580	21.44
136	Ezza	6.450	8.080	16.64
137	Auchi	7.080	6.260	16.61
138	Nkwerre	5.750	7.120	14.51
139	Uga	5.930	7.080	14.53
140	Ankpa	7.380	7.620	17.92
141	Lokoja	7.810	6.740	16.61
142	Ekpoma	6.750	6.130	15.39
143	Nembe	4.490	6.360	11.90
144	Lafiagi	8.850	5.420	17.65
145	Enugu ezike	6.990	7.450	16.07
146	Kabba	7.840	6.070	16.61
147	Potiskum	11.710	11.070	21.44
148	Okija	5.900	6.830	14.01
149	Gembu	6.700	11.270	17.85
150	Ijebu jesa	7.680	4.810	14.31
151	Argungu	12.740	4.510	21.00
152	Itu	5.200	7.980	14.51
153	Paki	11.500	8.150	21.32
154	Kajuru	10.320	7.680	20.37
155	Igbeti	8.750	4.130	16.91
156	Isanlu	8.270	5.820	17.65
157	Kwale	5.550	6.370	14.01
158	Jega	12.210	4.380	21.00
159	Ayangba	7.520	7.160	17.92
160	Yelwa	10.870	4.770	19.94
161	Kujama	10.450	7.630	20.37
162	Dutsanwai	10.850	8.200	20.75
163	Bori	4.700	7.350	12.44
164	Birningwari	11.010	6.800	20.78
165	Ilaro	6.880	3.010	12.05
166	Rigacikun	10.640	7.470	20.37
167	Fiditi	7.700	3.910	14.24
168	Degema	4.730	6.770	11.90
169	Mgbidi	5.720	6.890	14.01
170	Igabi	10.790	7.780	20.37
171	Kaura	11.300	7.820	20.97
172	Lere	10.390	8.580	20.75
173	Sabon birningwari	10.660	6.550	20.19

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174	Lalupon	7.470	4.060	14.31
175	Ifon	6.920	5.770	14.16
176	Emure	7.450	5.470	15.47
177	New bussa	9.880	4.520	16.81
178	Enugu ngwo	6.420	7.430	16.07
179	Ipoti	7.870	5.070	15.47
180	Soba	10.980	8.060	20.75
181	Usoro	5.540	6.210	14.01
182	Erin-oshogbo	7.810	4.480	14.31
183	Idanre	7.110	5.110	15.47
184	Kumo	10.040	11.210	21.02
185	Ogwashi-uku	6.250	6.610	15.39
186	Wudil	11.800	8.850	21.32
187	Kumaganum	13.140	10.630	22.20
188	Ikole	7.790	5.470	15.47
189	Aramoko	7.720	5.050	15.50
190	Egume	7.490	7.200	17.92
191	Ete	7.050	7.450	17.82
192	Oyan	8.050	4.770	16.91
193	Ogoja	6.660	8.790	16.64
194	Iperu	6.920	3.670	12.05
195	Agbara	7.550	3.400	14.24
196	Anchau	10.970	8.400	20.75
197	Kafarati	10.390	11.100	20.77
198	Atijere	6.420	4.520	12.85
199	Ode	7.790	5.710	15.47
200	Okwe	5.020	7.260	14.51
201	Okata	8.220	3.450	17.01
202	Shendam	8.900	9.470	19.78
203	Nafada	11.090	11.340	21.44
204	Olupona	7.600	4.180	14.31
205	Otukpa	7.090	7.660	17.92
206	Yan	10.050	12.170	21.01
207	Orerokpe	5.640	5.900	12.91
208	Apomu	7.330	4.180	14.31
209	Talatamafara	12.570	6.070	21.44
210	Ilara	7.350	5.120	15.47
211	Titiwa	12.150	12.900	21.80
212	Yelwa	8.840	9.630	19.76
213	Awgu	6.080	7.470	16.07
214	Nike	6.530	7.540	16.22
215	Jikamshi	12.170	7.770	21.60
216	Amassama	5.110	6.240	14.01
217	Gandi	12.970	5.750	21.27
218	Orodo	5.620	7.040	14.51
219	Ochobo	7.190	7.960	17.92
220	Amagunze	6.330	7.650	16.07
221	Sauri	11.730	6.790	20.78
222	Udi	6.320	7.410	16.08
223	Umuduru	5.690	7.250	14.51
224	Oke-mesi	7.830	4.920	14.31
225	Koko	5.980	5.430	12.91
226	Ruma	12.870	7.230	21.60
227	Gumel	12.630	9.400	21.79
228	Giwa	11.300	7.450	20.97
229	Isara	6.980	3.680	12.05
230	Dan sadau	11.300	6.500	20.78

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231	Ihuo	5.570	7.100	14.51
232	Kona	8.810	11.080	19.94
233	Moriki	12.870	6.490	21.44
234	Gwadabawa	13.370	5.240	21.65
235	Oturkpo	7.200	8.130	18.25
236	Agbabu	6.580	4.830	12.85
237	Gummi	12.140	5.110	21.27
238	Igede	7.650	5.120	15.47
239	Owode	6.950	3.520	12.05
240	Abraka	5.780	6.100	14.01
241	Zungeru	9.810	6.150	19.70
242	Yashikera	9.760	3.400	19.14
243	Ilushi	6.670	6.630	15.39
244	Hunkuyi	11.270	7.650	20.97
245	Shagunnu	10.330	4.470	19.94
246	Ajaokuta	7.470	6.700	16.61
247	Baro	8.600	6.430	18.34
248	Bagudo	11.400	4.230	20.51
249	Gora	11.920	7.660	20.97
250	Dan gulbi	11.640	6.290	20.78
251	Jemma	11.670	9.930	21.41
252	Kamba	11.860	3.660	20.35
253	Ikem	6.780	7.700	16.07
254	Icheu	7.700	6.770	16.61
255	Loko	8.010	7.830	18.75
256	Tegina	10.070	6.190	20.19
257	Isa	13.230	6.330	21.74
258	Irrua	6.790	6.240	15.39
259	Beli	7.860	10.970	19.02
260	Mando	10.720	6.570	20.19
261	Dekina	7.700	7.020	17.92
262	Obudu	6.670	9.160	17.19
263	Ubiaja	6.650	6.380	15.39
264	Gaya	11.860	9.010	21.41
265	Agenebode	7.110	6.690	16.61
266	Jemaa	9.470	8.380	20.12
267	Tambawel	12.400	4.650	21.00
268	Omoko	5.350	6.650	14.01
269	Bununudass	10.000	9.520	20.92
270	Kotorkoshi	12.100	6.850	21.44
271	Ajasse	8.240	4.800	16.91
272	Igarra	7.280	6.100	16.61
273	Geidam	12.890	11.930	21.86
274	Ifaki	7.800	5.240	15.47
275	Oguta	5.700	6.800	14.01
276	Elele	5.100	6.820	14.01
277	Alapa	8.620	4.380	16.91
278	Bara	10.370	10.730	21.01
279	Biliri	9.880	11.230	20.56
280	Chibok	10.880	12.900	21.01
281	Gwarzo	11.920	7.930	20.97
282	Omu-aran	8.140	5.100	17.65
283	Duku	10.820	10.770	21.01
284	Obolo	6.880	7.630	16.07
285	Lapai	9.040	6.570	19.70
286	Faggo	11.390	9.950	21.41
287	Umunede	6.270	6.300	15.39

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288	Ago-are	8.500	3.410	17.01
289	Kusheriki	10.510	6.450	20.19
290	Wurno	13.290	5.420	21.65
291	Gombi	10.160	12.750	21.01
292	Benisheikh	11.800	12.480	21.42
293	Bokkos	9.280	8.990	20.12
294	Garko	10.170	11.170	21.02
295	Badeggi	9.050	6.150	19.70
296	Akamkpa	5.300	8.360	15.07
297	Siluko	6.530	5.170	14.16
298	Babana	10.400	3.820	19.74
299	Misau	11.320	10.470	21.43
300	Yenagoa	4.930	6.250	11.90

Latitude and Longitude details are extracted from http://www.tageo.com/index-e-ni-cities-NG-step-4.htm

Table 3 shows the differences between measured or predicted irradiances with the values arrived at in the study for various locations in Nigeria. It can be seen from the table that the values are close to map values. The Maximum percentage difference is noticed at Ibadan. However most fitted satisfactorily.

Table 3: Difference between Measured and predicted Irradiances values for various locations in Nigeria

Location	**Birnin Kebbi, North-West Nigeria Lat. 12.46 Long. 4.19**	**Jos Plateau State Lat 9.930 long. 8.890**	**Mubi, North – East Nigeria lat. 10.27 long. 13.270**	**Sokoto, North West Nigeria Lat 13.070 long. 5.240**	**Kano, North-West Nigeria Lat 12.00 long. 3.470**	**Kaduna, North-West Nigeria Lat 10.52 long. 7.44**	**Owerri, South EastNigeria Lat 5.5 long. 7.02**	**Ibadan, South-West Nigeria Lat 7.40 long. 3.90**	**Kaduna, North-West Nigeria Lat 10.520 long. 7.44**
JAN	18.80	24.77	19.43	19.22	19.79	20.59	15.28	11.23	20.99
FEB	20.13	26.86	21.31	21.32	22.87	22.26	16.15	13.28	21.33
MAR	20.62	25.75	23.29	22.03	24.18	23.25	15.65	15.09	22.45
APRIL	23.81	21.22	20.96	21.68	24.08	22.97	15.53	15.43	22.97
MAY	24.54	18.84	20.40	20.91	23.30	21.37	15.18	14.21	21.62
JUNE	23.98	17.01	21.14	19.90	22.45	19.62	14.38	13.73	20.82
JULY	21.53	16.16	20.56	18.41	20.42	17.94	12.94	10.06	18.34
AUG	20.10	17.09	19.59	18.50	20.31	17.18	13.04	10.49	17.20
SEPT	23.19	18.75	19.63	20.45	21.10	19.80	14.12	11.46	18.80
OCT	23.21	20.21	19.93	20.90	21.94	21.48	14.57	13.97	20.98
NOV	20.88	23.73	19.91	19.97	21.27	21.74	15.12	16.73	21.45
DEC	18.36	23.96	18.92	18.50	19.50	20.26	15.29	13.57	20.67
	21.60	21.20	20.45	20.15	21.77	20.71	14.77	13.27	20.60
Average Values From Map	21.00	20.12	20.96	21.50	20.60	20.25	14.51	14.24	20.25
% Difference	-2.86	-5.30	2.43	6.28	-5.68	-2.27	-1.79	6.81	-1.73
Data Reference	Gana et al., 2014	Abdullahi et al. 2017	(Osinowo et al., 2015)	Boluwaji et al., 2016			Njoku et al., 2018	Sanusi and Abisoye, 2011	Research Data,(Averaged 2018 and 2019)

CONCLUSIONS

The power supply situation in Nigeria remains precarious and while other countries are researching on alternative forms of energy, we must not be left behind. It has been established that economic growth is directly proportional to the growth in energy use. How we harness our energy sources indicate how serious we want the economy to grow. If we do not, we will be importing the technologies in the future. Solar energy system presently faces strong competition with fossil fuels, and government incentives have been lacking. If the Solar energy sector is given the right incentive by the government, this may become major electric power generation contributor in the very near future. Nigeria, therefore, should take advantage of its abundant solar resources by introducing new and implementable policies on energy power production by both the federal and state governments and increase investment and research in solar energy storage systems.

High and Medium Temperature Solar Systems are the future in energy. The raw material, the sun, is very abundant in Nigeria. Nigeria is best placed to maximize its advantages due to its geographical location. It will, however, take courage from our policy makers to venture into it. Initial investments may seem huge, but the reward in the future is great. Prospecting for more crude oil zones in the country seems easy, but we must not forget the changing energy use scenario. There are advance researches to replace petrol vehicles with electric powered ones. Many countries have set targets for such replacement. Nigeria must, therefore, start investing in researches in alternative forms of energy. High and medium temperature solar systems are expensive now, but it is the future.

However developing these technologies is only possible if the solar energy availability is known or can be estimated. This is possible if appropriate solar energy potentials of various locations in the country are known. This makes the development of solar energy maps for the country a necessity.

Solar resources map for Nigeria has been developed using data provided by the National Aeronautics and Space Administration (NASA). The data covers a period of 25 years (1994-2018). The average daily global solar irradiance for various longitude-latitude nodes were estimated from such data. With these data available, it is then possible to estimate the average daily global solar irradiance for any location provided the longitude and latitude for the location is known. Irradiance values for 300 locations in the country have been calculated from details provided by the maps. Experimental values of irradiance for various locations have been compared with values extracted from the solar irradiance map. These values show low deviations (<6.8%) from values on the map. This has established that the solar potential Map developed is suitable for estimating irradiance values for any location in Nigeria.

Recommendations
It is recommended that the map for solar irradiance will provide satisfactory information necessary for solar energy research, design and deployment of solar energy supply technologies. Irradiance values for various locations in Nigeria can quickly be established. This will fast-track solar energy related research and development. The procedure outline in this study can be used to develop solar irradiance maps for other countries.

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