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Research Article

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Estimating Daily Solar Radiation from Monthly Values Over Selected Nigeria Stations for Solar Energy Utilization

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Abstract

The solar radiation needed for effective research into solar energy utilization can be determined using concise and reliable data which can be gotten from hourly or daily data.

The parameters which govern a physical model of the sky should be taken hourly or daily. The values which fluctuate according to the fluctuating changes in the meteorological and environmental situations should be analyzed with data over a short period of time. These parameters include the sunshine hours, Solar radiation, cloud cover, temperature etc.

In predicting the performance of solar energy conversion devices, a sequence of daily radiation is always required. The daily data are not readily available, hence, there is need for the derivation of the needed, which is the daily solar radiation data from the available- the monthly averages.

For many stations in Nigeria, only monthly long-term averages are available and the problem of extracting reliable information always sets in.

Therefore, this paper proffers solutions to this by establishing a procedure for the derivation of daily solar radiation from the monthly averages using Fourier series.

Keywords: Solar radiation; Month averages; Daily data; Fourier series

Introduction

Solar radiation is a very important variable in the field of Meteorology and other related field.

Radiation from the sun is the major source of energy for the sustenance of life on earth. The sun being the heat engine transforms one energy source to another. Sun helps in the metabolism of plants which are major contributors to the existence of man.

Therefore, it is germane to study the solar radiation. There are three major forms of dissemination of solar radiation. They are; the short wave radiation that originates directly from the sun to the earth, the long wave infrared radiation which is emitted by the earth atmospheric system, the net radiation which is the outcome of the long wave radiation and the short wave radiation. Since most of the energy is swallowed by the atmosphere only very few which are radiated to the earth are stored up there. This is known as the short wave solar radiation.

Due to the spontaneous changes in the rate of insolation, short wave radiation can be accurately studied by using daily data. The importance of proper analysis and monitoring of this form of radiation is the import of this study.

Though, the tropical Africa is blessed with abundant solar energy, it is however, still an unexplored area because of the lack of comprehensive data due to non-availability of instruments and man-power.

Therefore, it is of great necessity to get a way around getting the needed from the available. One of such ways is by estimating daily data from monthly averages and using the derived data to characterize the sky condition in the area.

This method has been used in Genova (Italy) and in Rome for Rainfall. Fourier series method was used to analyse daily and monthly solar radiation at Ondo and Ile-Ife, Nigeria respectively [1].

Angstrom model was originally derived for the daily solar radiation and hours of sunshine (Angstrom, 1929, 1930 and 1950). Nonetheless, being a linear function it can be readily applied to mean monthly data since the expected values. A number of workers have used both daily data and monthly averaged daily data [2].

Data and Methodology

Dataset consisting of monthly global solar radiation and sunshine hours for five stations namely: Minna, Enugu Ibadan, Sokoto, and Kano For the period of 1988-1997 for both and global radiation.

The radiation data which were measured using the Gunn-bellani integrator which is graduated in mm was graduated [3].

He reported the calibration of Gun-Bellani radiation distillates with Pyranometer readings for stations South of Ibadan as 1mm=1.357 mJ/m^2 and 1.263 mJ/m^2 for Northern station.

Estimation of daily solar radiation from monthly mean using fourier series

The data set of monthly mean for the aforementioned stations were used in deriving daily data set using the following Fourier series formulae:

Y(m) is considered to be a sequence of 12 monthly radiation averages of calculated using a regular sequence of daily values [4].

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$$x_d = A_0 + \sum_{K=1}^{5}\left(A_K \cos\frac{2\pi}{N}Kd + B_k \sin\frac{2\pi\delta}{N}Kd \right) + B_6 \, Sin(\frac{2}{N}6d - \varphi) \quad \text{Eq. 1}$$

Such that,

$$< x_d \; >_m = y_m \quad (m = 1, 2, \ldots, 12) \quad \text{Eq. 2}$$

Where, < > m=Average relative to the m[th] month.

D=Day number which can range from 1 to N=365 or 366 (leap year) days. For the purpose of this work 366 days was used in which case the mean of the last days in February and the 1[st] days in March was used as the data for February for non-leap years.

The system will originally satisfy 12 conditions going by the 12 months in a year, therefore, ϕ=phase angle, will satisfy these conditions [5].

When ϕ=0 or Π. The absolute values of the Fourier component corresponding to the shortest period (approximately 2 months i.e., B_6) takes the minimum among its possible values.

When we reduce equation 1 and 2, we have:

$$y_m = A_0 + \sum_{K=1}^{5}(A_k < Cos\frac{2\pi}{N}Kd >_m + B_k \left\langle Sin\frac{2\pi}{N}Kd \right\rangle_m) + B_6 \left\langle Sin\frac{2\pi}{N}Kd \right\rangle_m \quad \text{Eq. 3}$$

Where (m=1, 2, …, 12)

A table for both the 365 days and 366 days will be presented and the inverse Matric (C) of each value will be gotten and will be multiplied by 1000 this will help in the calculation of the coefficient As and Bs for the 12 monthly averages [6-9]. The formulae are:

$$A_{K-1} = \sum_{m=1}^{12} C_{km} Y_m \quad (K = 1, 2, \ldots, 6)$$

$$B_{(K-6)} = ?^{1}_{(m=1)}\, 2 ? C_k m Y_{(m)} (K = 1, 2, n, 6)$$

There will be a symmetric breaking in the line due to non - uniformity in the days in each of the months, i.e., (28, 29, 30, 31 days) (Table 1).

85	77	85	82	85	82	85	85	82	85	82	85
164	111	48	-41	-119	-160	-167	-121	-43	45	118	166
149	0	-147	-155	-4	147	156	1	-151	-151	-1	156
126	-125	-134	122	139	-126	-136	131	131	-131	-132	136
97	-199	92	111	-202	92	108	-203	101	101	-202	105
62	-170	226	-215	150	-47	-66	162	-218	217	-159	57
48	110	164	162	123	45	-42	-122	-161	-166	-117	-45
92	164	93	-82	-176	-92	85	177	86	-88	-174	-87
134	126	-123	-138	126	137	-129	-134	131	132	-132	-129
174	2	-176	164	15	-183	173	5	-178	178	-5	-169
219	-162	52	68	-167	219	-213	153	-55	-59	158	-215
136	-141	139	-133	130	-128	126	-125	127	-128	129	-131

Table 1: Coefficient of C_{km} of the matrix defined in equation (4) multiplied by 100 for a year of 366 days.

Results and Discussion

From the above formulae, A_0, A_1, A_2, A_3, A_4, A_5, B_1, B_2, B_3, B_4, B_5, and B_6 were derived from equation 4 for all the stations (Tables 2 and 3).

Figures 1-5 represents the time series graphs of the aforementioned stations. The graphs indicate the annual patterns of flow of the global radiation for Ibadan, Sokoto, Kano and Minna, Enugu, for the period of 1988-1997; for both the real data and the simulated using Fourier series. The graphs show how well the simulated mimic the real data. All the stations except Sokoto have two prominent peaks and a prominent depression indicating the periods of higher rate of radiation and those of low insolation. The peaks are about Febuary and November and the depressions are between July and September. That of Sokoto differs because of its higher radiation and less Rainfall.

The objective of the research which is geared at deriving the daily data from the monthly average was well defined in the graphs. This is because the simulated and the real lines of the graph are symmetrical.

STATIONS	A_0	A_1	A_2	A_3	A_4	A_5
ENUGU	17.2997	2.2429	-0.9959	-0.8453	-0.6523	-0.5693
IBADAN	17.8286	1.4662	-1.8913	-1.1248	-0.0680	-0.4881
MINNA	18.9551	1.0528	-2.9029	-1.2850	-0.6273	-0.5291
JOS	20.8649	2.6464	-1.4995	-1.5072	-0.4098	-0.5149
SOKOTO	20.8565	0.1703	-2.2057	-0.2408	-0.0534	0.1362
KANO	20.8649	2.6464	-1.4995	-1.5072	-0.4098	0.5149

Table 2: Derived figures for A_0-A_5.

STATIONS	B1	B2	B3	B4	B5	B6
ENUGU	1.19707	-1.42229	0.87333	-0.18791	0.06530	0.12552
IBADAN	2.11684	-1.6323	0.82925	0.09669	0.43502	0.18772
MINNA	0.94118	-0.69847	1.18212	0.35976	1.10881	0.72238
JOS	1.52861	0.47452	0.82742	0.38243	1.27446	0.93583
SOKOTO	2.07932	-0.10533	0.13147	1.12089	0.62534	0.45412
KANO	1.52861	0.47452	0.82742	0.38243	1.27446	0.93583

Table 3: Derived figures for B1-B6.

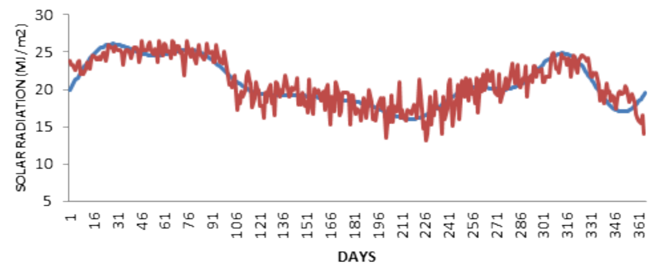

Figure 1: Time series graph for simulated and real data for Ibadan (1988-1997).

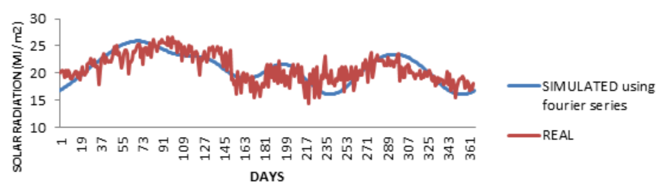

Figure 2: The time series graph of simulated and real data for solar radiation for Sokoto (1988-1998).

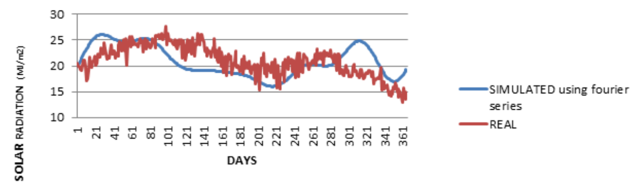

Figure 3: The time series graph of simulated and real solar radiation for Kano (1988-1998).

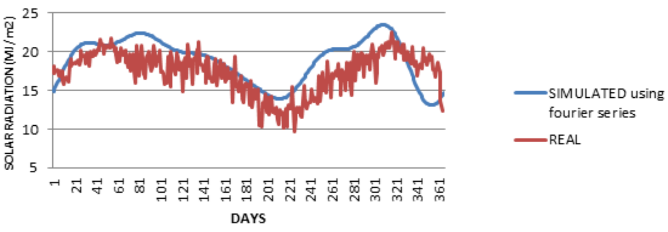

Figure 4: Time series graph of simulated and real data set for Minna (1988-1998).

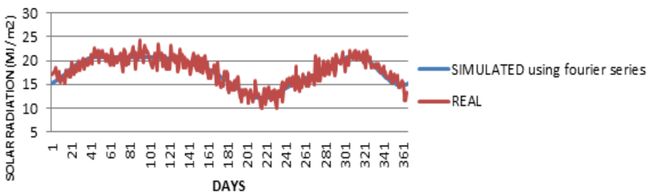

Figure 5: The time series graph of simulated and real data for Enugu (1988-1998).

Conclusion

Estimation of global solar radiation is vital for fabrication of solar energy system everywhere where adequate observations are paramount. For predicting the performance of solar energy, a sequence of daily radiation is often required which in most cases are not available.

Therefore, to get accurate estimation of global solar radiation over a station using the daily data derived from the available monthly average, the method above can be employed.

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