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Investigation of the Seasonal Variations in the Solar Radiation Balance and Other Solar Energy Parameters in Some Cities in Nigeria

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Abstract

An investigation of the variations of the Solar Radiation Balance, SRB, and other solar energy parameters in some cities in Nigeria has been carried out in this work. The data used for the study were obtained from the Nigerian Meteorological Agency (NIMET) Abuja, (1990-2010). The results show that the maximum range of atmospheric albedo, ALB, between 56-64% was obtained in the rainy season; with the minimum range of about 33 - 39% occurring in the dry season. Direct relationship existed between the SRB and other investigated solar radiation parameters, each of which in turn varied indirectly with the ALB. Relatively high annual values in SRB in Port Harcourt and Makurdi, implies that these locations are suitable for solar energy applications including farming. And devices using solar energy applications in these areas could function efficiently during the dry season.

Keywords: Solar Radiation Balance, Solar Radiation, net solar radiation, net terrestrial radiation, albedo, Port Harcourt, Makurdi, and Kano

1. Introduction

The Sun provides the principal energy that drives the climate system. Hence, climatic variability is partly due to changes in solar radiation distribution, which in turn is caused by some natural and anthropological phenomena. The solar energy is emitted in all directions, with only a small fraction being in the direction of the Earth, because part of this radiation is scattered and reflected back to space mainly from clouds, air molecules and other atmospheric constituents. The remaining energy, which is absorbed heats up the atmosphere and gets re-emitted as terrestrial radiation. The amount of solar energy incident on the atmosphere determines the weather and climate system.

The difference between the absorbed solar radiation and the emitted radiation from the Earth's surface is known as the solar radiation balance, SRB (Liou, 1980). A positive solar radiation balance implies more incoming solar radiation, which warms the Earth system, while negative solar radiation balance implies more emission of terrestrial radiation, which causes cooling in the Earth system (Chacko et al., 1998). Knowledge of the SRB of the Earth's atmosphere improves the understanding of the climate (Ezenekwe et al., 2013).

Due to its proximity to the Atlantic Ocean in the South and to the Sahara Desert in the North, Nigeria experiences some variations in the climate system. This is due to the fact that the moisture laden from the Atlantic Ocean brings with rainy season, which often affects the climate in the southern part, while the dust laden air mass from the Sahara Desert causes extreme hotness to the areas in the northern part of the country. Thus, the variations caused by these temperature regimes cause imbalance in the radiation budget of the country. Consequently, extreme weather conditions are unavoidable. Therefore, the investigation into radiation balance of the atmosphere provides information necessary for climatic prediction.

Several researches have been carried out on the estimation and utilization of solar radiation as well as on the evaluation of solar radiation energy balance in Nigeria (Isikwue et al., 2014; Ezenenekwe et al., 2013; Isikwue et al., 2012a, b and c; Ogolo et al., 2009; Babatunde et al., 2005 and so on). This present work is a step further in the earlier investigation of radiation energy balance in some selected cities in Nigeria (Isikwue et al., 2014). But here, we look at seasonal variations of solar energy radiation balance in Port Harcourt, Makurdi and Kano in

Nigeria. This study in the seasonal behavior of the SRB will provide more detailed information on the climatic effect of the solar energy radiation balance as suggested in the earlier paper. The reasons for choosing these cities are as provided in the earlier paper.

The daily global solar radiation, minimum temperature and maximum temperature data used in this work were obtained from the Nigeria Meteorological Agency (NIMET) Abuja – Nigeria (1990 - 2010). The solar radiation parameters considered in this work are the global solar radiation denoted by SR, the net solar radiation (NSR), the reflection coefficient or albedo denoted by ALB, the net terrestrial radiation (NTR) and the solar radiation balance (SRB)

2. Methods of Analysis

The NSR ($MJm^{-2}day^{-1}$) was determined using the equation given by FAO (1998) as

$$NSR = R_s(1-\alpha_s) \quad (1)$$

R_s is the global solar radiation, α_s is the ALB of the location obtained from Babatunde et al. (2005) as

$$\alpha_s = \frac{H_r}{R_a} \quad (2)$$

and the H_r is the reflected radiation given as

$$H_r = \left(1-\frac{R_S}{R_a}\right)R_a \quad (3)$$

The $\frac{R_S}{R_a}$ is the clear sky index, where R_a is the extraterrestrial radiation obtained using the expression given by Duffie and Beckman (1991) and was employed by Isikwue et al. (2012a) as:

$$R_a = \frac{24}{\pi} I_s d_r [w_s \sin\theta \sin\delta + \cos\theta \cos\delta \sin w_s] \quad (4)$$

where I_s is the solar constant (4.92 $MJm^{-2}day^{-1}$) and θ is the latitude of the location expressed in radians. The solar declination angle, δ is given in radians and by the expression

$$\delta = 23.45 \sin\left[\frac{360}{365}(J+284)\right] \quad (5)$$

The J is the Julian day of the year and w_s is known as the sun set angle given by Isikwue et al. (2012c) as

$$w_s = \cos^{-1}(-\tan\theta \tan\delta) \quad (5i)$$

The d_r is eccentricity correction factor of the Earth's orbit which according to Allen et al. (1998) was given as

$$d_r = 1 + 0.033\cos\left(\frac{360J}{365}\right) \quad (5ii)$$

Furthermore, NTR was obtained using the expression (FOA, 1998):

$$NTR = S\left[\frac{T^4{}_{max} + T^4{}_{min}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35 \text{ x } \frac{R_s}{R_{so}} - 0.35\right) \quad (6)$$

T_{max}, T_{min}, are respectively the maximum and minimum absolute temperatures during 24 hour period; and S is the Stefan Boltzmann's constant $(4.903 \times 10^{-9}\, MJK^{-4}m^{-2}day^{-1})$. The actual vapour pressure, e_a, was computed using the relation adapted from Slaviša and Svetlana (2009) as:

$$e_a = 0.611 exp\left[\frac{17.27\, T_{min}}{T_{min}+273.3}\right] \quad (7)$$

On the other hand, the clear sky solar radiation ($MJm^{-2}day^{-1}$), R_{so}, which is the solar radiation that would reach the surface under cloudless condition was obtained using the relation given by Allen et al. (1998) as

$$R_{so} = (0.75 + 2 \text{ x } 10^{-5} \text{x } Z)R_a \quad (8)$$

where Z is the elevation of the station with respect to sea level (m). For Port Harcourt, Makurdi and Kano, the values for Z are about 468, 106.4 and 479 m respectively.

Finally, the SRB of the Earth's atmosphere, which is the difference between the NSR and the NTR, was determined using the expression

$$RB = (1) - (6) \tag{9}$$

3. Results

Tables 1-3 present the monthly mean solar radiation parameters in Port Harcourt, Makurdi and Kano stations respectively, while the annual mean variations of the solar radiation parameters in the three stations over the period (1990-2010) are given in Table 4. On the other hand, Figures 1-5 illustrate respectively the profiles of mean monthly Albedo (ALB), Solar Radiation (SR) also known as the global solar radiation, Net Solar Radiation (NSR), Net Terrestrial Radiation (NTR) and Solar Radiation Balance (SRB) in Port Harcourt (PH), Makurdi (MKD) and Kano (KNO).

Table 1. Monthly mean Solar Radiation parameters in Port Harcourt

Months	ALB	SR ($MJm^{-2}day^{-1}$)	NSR ($MJm^{-2}day^{-1}$)	NTR ($MJm^{-2}day^{-1}$)	SRB ($MJm^{-2}day^{-1}$)
Jan	0.419	17.205	11.014	2.561	8.561
Feb	0.474	17.524	9.894	2.153	7.859
Mar	0.519	17.819	8.992	1.707	7.313
Apr	0.564	17.290	8.095	1.288	6.753
May	0.562	17.667	8.400	1.266	7.048
Jun	0.517	19.400	10.003	1.605	8.304
Jul	0.507	19.752	10.152	1.734	8.368
Aug	0.532	18.595	9.048	1.559	7.440
Sep	0.487	19.429	10.436	1.851	8.492
Oct	0.480	17.900	10.081	1.897	8.077
Nov	0.440	17.043	10.594	2.169	8.281
Dec	0.394	17.262	11.918	2.629	9.264

Table 2. Monthly mean Solar Radiation parameters in Makurdi

Months	ALB	SR ($MJm^{-2}day^{-1}$)	NSR ($MJm^{-2}day^{-1}$)	NTR ($MJm^{-2}day^{-1}$)	SRB ($MJm^{-2}day^{-1}$)
Jan	0.365	18.614	12.220	3.621	8.598
Feb	0.464	16.878	10.316	2.714	7.602
Mar	0.526	17.883	9.072	2.245	6.827
Apr	0.520	19.470	9.800	1.740	8.060
May	0.528	19.674	9.559	1.893	7.667
Jun	0.537	19.071	9.242	1.663	7.579
Jul	0.543	18.650	9.042	1.619	7.423
Aug	0.559	17.633	8.462	1.425	7.037
Sep	0.562	16.551	8.242	1.414	6.228
Oct	0.478	17.839	10.264	2.001	8.263
Nov	0.391	17.996	12.105	2.761	9.343
Dec	0.352	17.812	12.244	3.686	8.558

Table 3. Monthly mean Solar Radiation parameters in Kano

Months	ALB	SR ($MJm^{-2}day^{-1}$)	NSR ($MJm^{-2}day^{-1}$)	NTR ($MJm^{-2}day^{-1}$)	SRB ($MJm^{-2}day^{-1}$)
Jan	0.331	17.060	12.228	2.964	9.265
Feb	0.383	18.986	12.379	2.631	9.748
Mar	0.464	19.595	10.825	2.044	8.782
Apr	0.537	19.195	9.180	1.507	7.673
May	0.555	19.138	8.837	1.380	7.457
Jun	0.593	18.071	7.753	1.932	12.797
Jul	0.601	15.625	6.715	1.092	6.661
Aug	0.640	15.452	6.534	0.738	5.796
Sep	0.577	16.186	7.384	1.191	6.193
Oct	0.459	17.610	10.142	2.071	8.071
Nov	0.284	18.086	13.747	3.326	10.421
Dec	0.339	15.876	13.327	2.904	8.423

Table 4. Annual mean variations of Solar Radiation parameters (1990-2010)

Location	ALB	SR ($MJm^{-2}day^{-1}$)	NSR ($MJm^{-2}day^{-1}$)	NTR ($MJm^{-2}day^{-1}$)	SRB ($MJm^{-2}day^{-1}$)
Port Harcourt	0.491	18.070	9.890	1.870	7.980
Makurdi	0.485	18.170	10.050	2.250	7.820
Kano	0.480	17.570	9.750	1.980	8.44

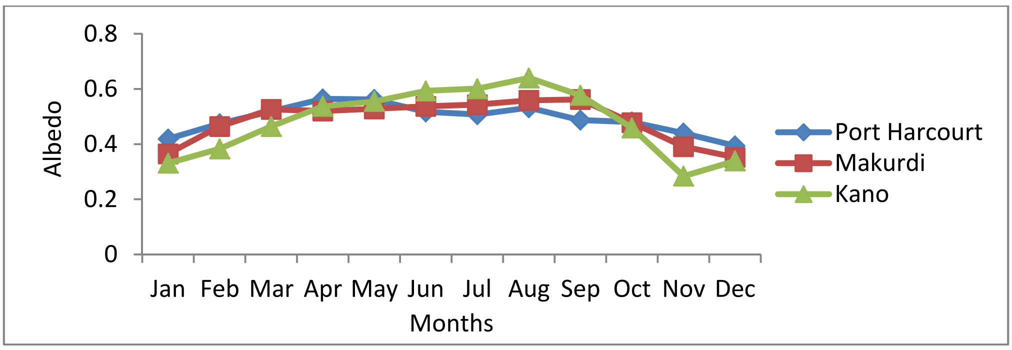

Figure 1. Profiles of monthly mean Albedo in Port Harcourt, Makurdi and Kano

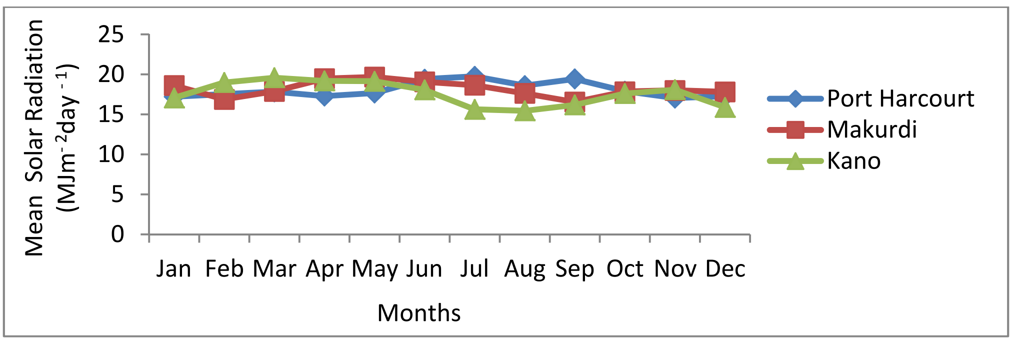

Figure 2. Profiles of mean Solar Radiation in Port Harcourt, Makurdi and Kano

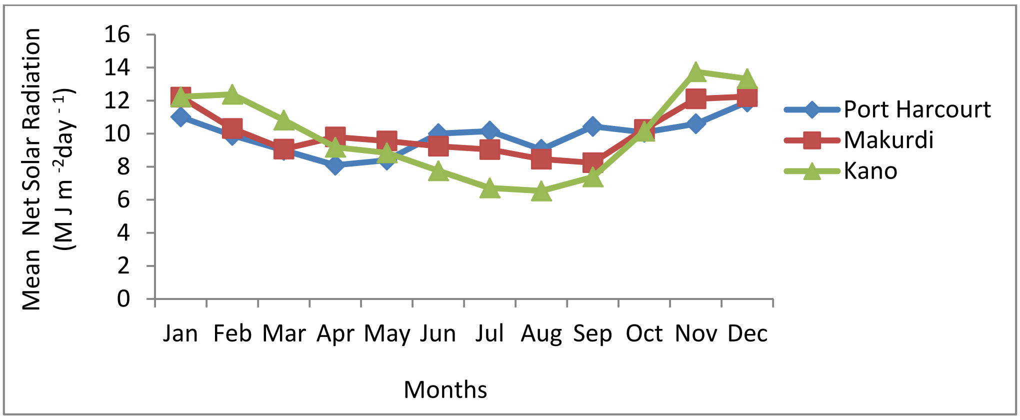

Figure 3. Profiles of mean net Solar Radiation in Port Harcourt, Makurdi and Kano

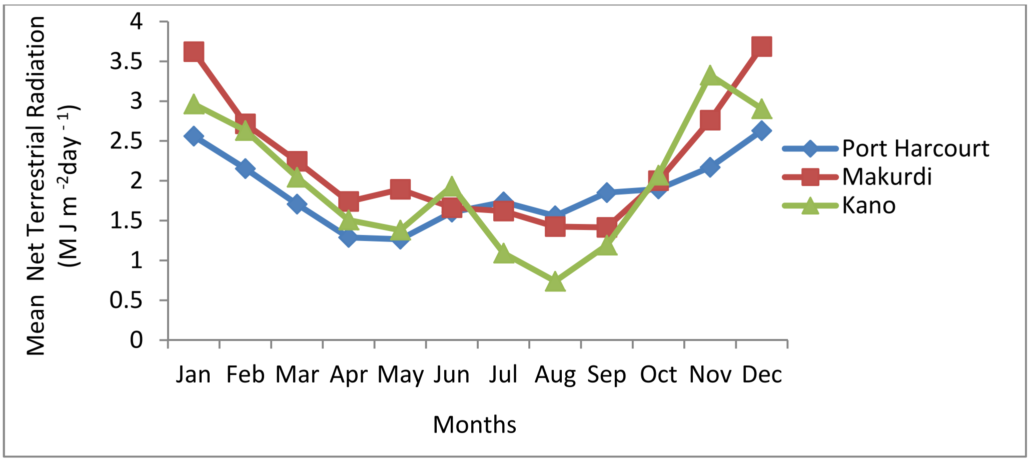

Figure 4. Profiles of mean net Terrestrial Radiation in Port Harcourt, Makurdi and Kano

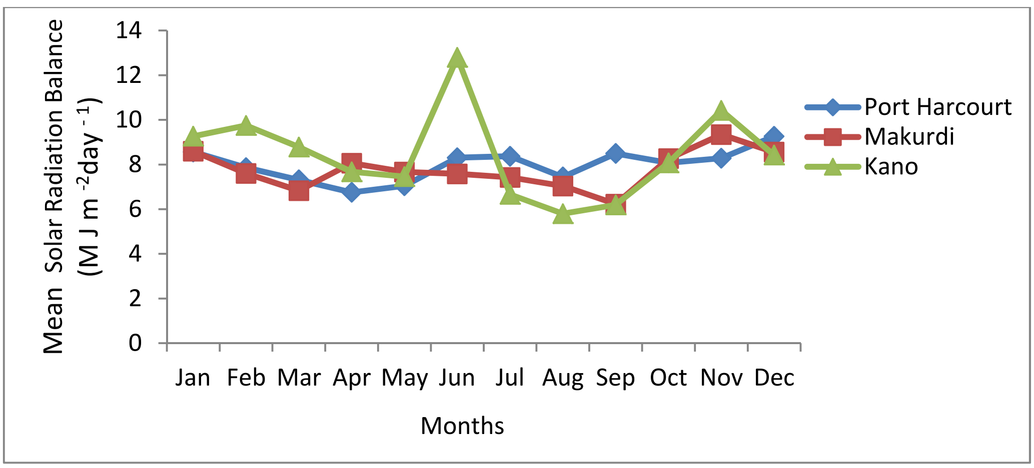

Figure 5. Profiles of mean Solar Radiation Balance in Port Harcourt, Makurdi and Kano

4. Discussions

From Tables 1-5 and Figures 1-4, it could be observed that in PH during the period (November-February), the ALB was relatively low with the minimum of about 39% occurring in the month of December. On the other hand, relatively high ALB was obtained during the period (March-October) with maximum ALB of about 56% in March and April. In Makurdi, low ALB was observed in November-January with minimum of about 35% in December. On the other hand, high ALB occurred between February-October with maximum ALB of about 56%

in September. For Kano, there was low ALB in November – February with the minimum (33%) in January. Increase in ALB was observed in March – October with the maximum (64%) occurring in August.

From these observations, one can say that the maximum amount of about 56-64% of solar radiation did not reach the surface in the areas under study and within the study period especially in the rainy season. This could be due to the rain bearing clouds which pervaded the sky at that period. This could imply possibility of poor performance of the solar energy systems, particularly solar concentrating devices and low surface temperature during this season since most of the solar radiation is sent back to space by reflection. On the other hand, the minimum amount of solar radiation that did not reach the surface was in the range 33 - 39% and occurred mostly in the dry season. This could be attributed to relatively cloudless nature of the sky during the dry season. This agrees with the assertion made by Babatunde et al. (2005) who observed among other things that albedo is generally high during rainy season and low during the dry season.

Among the stations considered, PH experienced the highest annual ALB of about 49% (Table 4), probably due to its location in the rain forest climatic zone, while Kano had relatively the lowest annual ALB of about 48%. This could be due to its location the in the Sahel Savannah with mainly grass land and little or no vegetative canopies and rain clouds that could enhance the reflectivity of the solar radiation. This implies that reflection of solar radiation back to space due these factors were minimal in Kano and more solar radiation reached the Earth's surface.

In Port Harcourt, high SR was observed between June – September with maximum (19.732 $MJm^{-2}day^{-1}$) in July. However, the minimum SR (17.043 $MJm^{-2}day^{-1}$) occurred in November. However, in Makurdi, high SR was obtained in the period April- June with the maximum SR (16.555 $MJm^{-2}day^{-1}$) in September. For Kano, high SR was obtained in the period (February – June) with the maximum SR (19.595 $MJm^{-2}day^{-1}$) in March and minimum of about (15.452 $MJm^{-2}day^{-1}$) in August. These observations imply that maximum solar radiation of about 19-20 $MJm^{-2}day^{-1}$could be obtained between the rain forest and Sahel Savannah climatic zones of Nigeria in the period February – September, whereas low SR of about (15-17 $MJm^{-2}day^{-1}$) could be available in the period (November – January).

Low values of the NSR, particularly in Figure 4 were obtained during the rainy season, probably due to high albedo, which reflects much of the solar radiation back to space, thereby causing much cooling on the Earth's surface. On the other hand, due to reduced albedo during the dry season, the NSR was high causing high SR to be absorbed by the .Earth with a corresponding high surface temperature.

In considering the SRB, for PH, it could be observed from Tables 1-4 and Figures 1-5 that the maximum SRB of about 9.264 $MJm^{-2}day^{-1}$ corresponds to the minimum ALB of 39.4% in the month of December, while the minimum SRB of 6.753 $MJm^{-2}day^{-1}$ corresponds to maximum ALB of 56% in April. This corresponds to the very low NTR of about.288 $MJm^{-2}day^{-1}$. For Makurdi station, maximum SRB of about 9.343 $MJm^{-2}day^{-1}$ in November corresponds to a low ALB of about 39.1% in the month of November with high NTR of about 2.761 $MJm^{-2}day^{-1}$. But the minimum SRB of about 6.22 $MJm^{-2}day^{-1}$ corresponds to the maximum ALB of about 56.2% in September. This corresponds with a low NTR of about1.414 $MJm^{-2}day^{-1}$. This relationship existing among the ALB, NTR and SRB could also be observed in Kano station. Hence, from these observations, it could be inferred that SRB varies directly with NTR and NSR, but indirectly with ALB.

From the annual values of the parameters (Table 5), it could be observed that the highest annual SRB (7.980 $MJm^{-2}day^{-1}$) is obtained in PortHarcourt irrespective of the high ALB.

Interestingly, among the three locations, Makurdi has the highest annual NSR (10.050 $MJm^{-2}day^{-1}$), NTR (2.250 $MJm^{-2}day^{-1}$) with high SRB (7.820 $MJm^{-2}day^{-1}$). The high NTR could be due to some features such as river Benue that cuts across the city, which absorbs solar radiation. This implies a large amount of infra red radiation being released with a corresponding high temperature (Isikwue et al., 2012a and b; Ramanathan, 1987). With relatively high annual values in SRB, it implies that PH and Makurdi are suitable for solar energy applications including farming. And devices using solar energy applications in these areas could function efficiently during the dry season.

5. Conclusions

The following conclusions are drawn from this work:

- The maximum amount of about 56-64% of solar radiation did not reach the surface in the areas under study and within the study period especially in the rainy season. On the other hand, the minimum amount of solar radiation that did not reach the surface was in the range 33 - 39% and occurred mostly in the dry season.
- Among the stations considered, Port Harcourt experienced the highest annual ALB of about 49%.

- Direct relationship exists among the SRB, NTR and NSR, each of which in turn varies indirectly with ALB.
- A positive radiation balance existed in all the stations under consideration.
- Among the three locations, Makurdi had the highest annual NSR (10.050$MJm^{-2}day^{-1}$), NTR (2.250 $MJm^{-2}day^{-1}$) with high SRB (7.820 $MJm^{-2}day^{-1}$).
- With relatively high seasonl values in SRB, it implies that PH and Makurdi are suitable for solar energy applications including farming. Consequently, devices using solar energy applications in these areas could function efficiently during the dry season. This is because high SRB implies low ALB which in turn implies more reception of solar energy on the Earth's surface. This could help in plants' photosynthesis and over all solar energy technological applications.

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