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Estimation of Global Solar Radiation of Some Selected Cities in Nigeria using Minimum and Maximum Daily Temperature

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Abstract The maximum amount of solar radiation incident on the surface of the earth influences both plants and animals positively or adversely. It is therefore imperative to know its value at any time. This work is aimed at determining the daily global solar radiation of Port Harcourt, Lagos and Abuja and to show how temperature variations affects its value, Hargreaves-Samani model was used to predict the solar global solar radiation of the area using the maximum and minimum temperature data for April, 2018 obtained from the archive of weather online limited. The results show that the mean global solar radiation for Port Harcourt, Lagos and Abuja are 22.464MJ/m^{2}day, 20.868MJ/m^{2}day and 20.703MJ/m^{2}day respectively. We discovered that the global solar radiation of the area increases with increase in daily temperature and vice versa.

Keywords Solar radiation, Temperature, Hargreaves-Samani, Latitude, Global warming

Introduction

The total amount of solar radiation emitted to every part of the earth is dependent on the latitude of the area, geographical location and it often changes from one place to another [1]. Solar radiation influences the weather conditions in our environment and it is an integral aspect for the provision of food for mankind. Thus, having a good knowledge of solar radiation and the amount of solar energy incident on the earth's surface at various locations is vital [2]. Apparently, the best way of estimating the amount of global solar radiation at a station is to install pyranometers at several locations in the given region, monitor their daily performance and recording which has huge cost implications. Alternatively, empirical models can be correlated with meteorological parameters at the location where the data is collected to obtain the global solar radiation. The results obtained may then be used for locations of similar meteorological characteristics [3].

We can estimate the solar radiation reaching the earth surface from various meteorological factors such as temperature, relative humidity, rainfall and sunshine hour [4]. The global solar radiation on any surface is influenced by the hours of sunshine, ambient air temperature and relative humidity of the location [5]. Solar radiation data have so many applications in photovoltaic, atmospheric energy balance, building architecture, agricultural studies and meteorological forecasting and should be available and reliable for designers and users [6].

The amount of solar radiation incident on a geographical location determines the amount of radiant energy on a photovoltaic panel. The available radiation data is very vital and should be considered before fixed photovoltaic module installations because the maximum energy that it generates increases with increased global solar irradiance [7]. Global solar radiation is generally measured on a horizontal surface [8]. The measurement of solar radiation at every location is not available in Nigeria due to lack of measuring instruments. Therefore, estimation of global solar radiation for particular location is an important factor in solar energy system.

Ajayi *et al*. [9] developed an appropriate multivariate model that expresses global solar irradiance in terms of location latitude, daily relative sunshine, maximum daily temperature, daily average relative humidity, and cosine of day number for any location in Nigeria by using data obtained from the Nigeria Meteorological Agency (NIMET), covering 12 sites, spread across Nigeria's six geopolitical zones, for a period between 1987 and 2010. The results obtained showed a good agreement between the measured data and computed results with minimum error. The analyzed results can be used to predict the global solar irradiance over Nigeria, the designs and the estimation of the performance of solar applications. Other researchers also developed several empirical models capable of estimating global solar radiation reaching a particular surface using either one of the meteorological factors or more. Parmar *et al.* [10] used the Angstrom – Prescott model in calculating the monthly average global solar irradiance of Gujarat, India using sunshine hours data. The results obtained shows that the calculated global solar radiation of the horizontal surface of the station is highly useful in predicting the global solar irradiance at any other location having same climatic condition. Another study utilized the multi-linear polynomial form of the Angstrom-Prescott model in the correlation of the monthly average global radiation and relative sunshine hours at Minna, Nigeria. Monthly average values of sunshine hours duration over a period of 5 years (1987-1991) was used in the analysis. The results obtained shows that the fourth order polynomial gave the best overall estimate of the total solar radiation [4]. In the same vein, measured solar radiation, relative sunshine hours, air temperature and relative humidity data for Makurdi, Nigeria covering a period of 10 years (2000 - 2010) were used to establish Angstrom type correlation equations to estimate global solar radiation. The results shows that monthly mean daily global solar radiation can best be estimated using many meteorological parameters [11].

Also the Hargreaves model is deployed in estimating the solar radiation in Kelantan Eastern Malaysia using daily minimum and maximum temperature range. The analysis of the measured and estimated solar radiation data indicates that the estimation model is good [12]. Similarly, Hargreaves-Samani model was used to determine the daily global solar radiation of Port Harcourt, Nigeria using the maximum and minimum temperature data for December 2016.The result obtained shows that the global solar radiation of the area increases with increase in daily temperature range [13]. In another research Chiemeka and Chineke, [14] estimated the solar radiation at Uturu, Nigeria, using Hargreaves-Samani model, maximum and minimum temperature data from a thermometer placed in a Stevenson screen at 1.5m high. The low solar radiation value obtained was attributed to the fact that the location is surrounded to the west and south by hilly cliffs. Ugwu and Ugwuanyi, [15] also performed an assessment of the Hargreaves-Samani model in estimating solar radiation in Abuja, Nigeria, using the minimum and maximum temperature data adopted from Nigeria Meteorological Agency (NIMET) in the year 2009. The results obtained shows that the correlation between the predicted and the observed global solar radiation indicated a measure of efficiency of the model.

The accuracy of these models in estimating the global solar radiation depends largely on the correlation between the global solar radiation and these parameters. Hence, this work intends to predict the global solar radiation from the daily maximum and minimum air temperatures of Port Harcourt, Lagos and Abuja cities in Nigeria using the Hargreaves- Samani model [16]. This method requires daily maximum and minimum air temperatures as input data.

Materials and Methods

The daily average data for the maximum and minimum temperature were obtained from the archive of weatheronline limited [17]. Microsoft excel spreadsheet was used for the statistical analysis and graphs. The duration of record is from1st- 30th April, 2018. The geographical location of the stations is presented in Table 1.

Table 1: Geographical location of the stations

Station	Latitude	Longitude
Port Harcourt	4.81° N	7.04° E
Lagos	6.61° N	3.62° E
Abuja	8.50° N	7.10° E

The Hargreaves-Samani [18] model of global solar radiation can be estimated from the difference between the maximum and minimum air temperature which is influenced by the amount of cloud cover, humidity and solar radiation. The phenomenon was used as a pointer of the fraction of extra-terrestrial radiation (Ra) that reaches the earth's surface namely global solar radiation (Rs). They formulated a model that is empirical in nature with the form [15].

$R_S = K_{RS}(\sqrt{Tmax - Tmin})R_a$ (1)

where *Tmax* is the maximum temperature (^{O}C) *Tmin* is minimum temperature (^{O}C) *Ra* is the extraterrestrial solar radiation (MJ/m^2day) and K_{Rs} is adjustment coefficient with a value of approximately 0.16 for interior area (i.e. area not close to the water body) and approximately 0.19 for coastal locations (situated on the coast of a large land mass and where air masses are influenced by a nearby water body). The value of K_{Rs} in this design is 0.19 for Port Harcourt and Lagos because of its proximity to water body while that of Abuja is 0.16 due to its interior proximity area. Other parameters for the prediction of global solar radiation are represented in equations 2 to 5 [19].

$\delta = 0.409\mathrm{Sin}\left(\frac{2\pi}{265}J - 1.39\right)$ (2)

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December) and δ is solar radiation declination in radian.

$d_r = 1+0.033\mathrm{Cos}\left(\frac{2\pi j}{265}\right)$ (3)

where d_r the inverse relative distance Earth-sun at a location.

$\omega_s = \cos^{-1}(\tan(\phi)\tan(\delta))$ (4)

where ω_s is the sunset angle in radian, δ is the solar radiation declination in radian, and ϕ is the latitude angle of the location in radian.

$R_a = \frac{24(60)}{\pi} Gsc\, dr[\omega s\mathrm{Sin}(\phi)\mathrm{Sin}(\delta) + Cos(\phi)\sin(\omega s)]$ (5)

where *Ra* is extraterrestrial radiation, *dr* is the inverse relative earth-sun distance, ϕ is the latitude angle, *ws* is the sunset angle, and G_{sc} is the solar constant = 0.0820 MJ m^{-2} min^{-1} or 1367wm^{-2}.

The global solar radiation R_s (MJ/m^2 day) is calculated using equation 1. The declination angle δ, the inverse relative distance earth sun d_r, sunset angle ωs, extraterrestrial solar radiation R_a are calculated using equation 2, 3, 4, and 5 respectively. Daily average global solar radiation is calculated by substituting the values of the daily maximum and minimum air temperature data of the selected locations adopted from the archive of weather online on their website using Hargreaves- Samani model of global solar radiation (see Tables 2, 3 and 4).

Results and Discussions

Table 2: Calculated Parameters for Port Harcourt, Nigeria

S/n	J	Φ(rad)	dr(rad)	δ(rad)	Ωs	Ra	T_{max}	T_{min}	K_{RS}	Rs
1	91	0.0841	1.0001	0.0718	1.5769	37.813	33	23	0.19	22.719
2	92	0.0841	0.9996	0.0787	1.5775	37.829	33	23	0.19	22.728
3	93	0.0841	0.9990	0.0856	1.5780	37.841	34	22	0.19	24.906
4	94	0.0841	0.9984	0.0925	1.5786	37.851	34	24	0.19	22.742
5	95	0.0841	0.9979	0.0993	1.5792	37.866	35	23	0.19	24.923
6	96	0.0841	0.9978	0.1062	1.5798	37.898	33	23	0.19	22.770
7	97	0.0841	0.9967	0.1129	1.5804	37.888	33	23	0.19	22.764
8	98	0.0841	0.9962	0.1197	1.5809	37.903	32	24	0.19	20.369
9	99	0.0841	0.9956	0.1264	1.5815	37.913	32	23	0.19	21.610
10	100	0.0841	0.9950	0.1331	1.5821	37.923	31	24	0.19	**19.064**
11	101	0.0841	0.9945	0.1397	1.5827	37.937	32	24	0.19	20.387
12	102	0.0841	0.9939	0.1463	1.5832	37.946	33	23	0.19	22.799
13	103	0.0841	0.9934	0.1529	1.5838	37.959	34	24	0.19	22.807
14	104	0.0841	0.9928	0.1594	1.5843	37.959	33	24	0.19	21.637
15	105	0.0841	0.9923	0.1658	1.5849	37.981	34	24	0.19	22.820

16	106	0.0841	0.9917	0.1722	1.5855	37.989	32	24	0.19	20.415
17	107	0.0841	0.9912	0.1786	1.5860	38.001	33	23	0.19	22.832
18	108	0.0841	0.9906	0.1849	1.5866	38.008	33	23	0.19	22.836
19	109	0.0841	0.9900	0.1912	1.5871	38.016	33	23	0.19	22.841
20	110	0.0841	0.9895	0.1974	1.5877	38.021	32	23	0.19	21.671
21	111	0.0841	0.9895	0.2035	1.5882	38.034	33	23	0.19	22.852
22	112	0.0841	0.9889	0.2096	1.5887	38.048	33	22	0.19	23.976
23	113	0.0841	0.9879	0.2156	1.5893	38.054	32	23	0.19	21.690
24	114	0.0841	0.9874	0.2215	1.5898	38.063	33	23	0.19	22.869
25	115	0.0841	0.0869	0.2274	1.5903	38.073	32	24	0.19	20.460
26	116	0.0841	0.9864	0.2332	1.5908	38.081	33	24	0.19	21.706
27	117	0.0841	0.9858	0.2390	1.5913	38.086	33	23	0.19	22.883
28	118	0.0841	0.9853	0.2447	1.5918	38.094	35	24	0.19	24.005
29	119	0.0841	0.9848	0.2503	1.5923	38.101	33	24	0.19	21.718
30	120	0.0841	0.9843	0.2558	1.5928	38.108	36	23	0.19	**26.106**
Mean		0.0841	0.9621	0.1672	1.5851	37.976	33	23	0.19	22.464

Table 3: Calculated Parameters for Lagos, Nigeria

S/n	**J**	**Φ(rad)**	**dr(rad)**	**δ(rad)**	**Ωs**	**Ra**	T_{max}	T_{min}	K_{RS}	**Rs**
1	91	0.114	1.0001	0.0718	1.5790	37.829	33	26	0.19	**19.016**
2	92	0.114	0.9996	0.0787	1.5798	37.856	34	26	0.19	20.344
3	93	0.114	0.9990	0.0856	1.5806	37.880	34	26	0.19	20.357
4	94	0.114	0.9984	0.0925	1.5814	37.904	34	26	0.19	20.370
5	95	0.114	0.9979	0.0993	1.5822	37.930	34	25	0.19	21.620
6	96	0.114	0.9978	0.1062	1.5830	37.973	34	25	0.19	21.645
7	97	0.114	0.9967	0.1129	1.5838	37.976	33	25	0.19	20.408
8	98	0.114	0.9962	0.1197	1.5846	38.003	33	26	0.19	19.104
9	99	0.114	0.9956	0.1264	1.5853	38.025	34	25	0.19	21.674
10	100	0.114	0.9950	0.1331	1.5861	38.046	33	25	0.19	20.446
11	101	0.114	0.9945	0.1397	1.5869	38.071	34	25	0.19	21.700
12	102	0.114	0.9939	0.1463	1.5877	38.093	33	25	0.19	20.471
13	103	0.114	0.9934	0.1529	1.5884	38.117	34	26	0.19	20.484
14	104	0.114	0.9928	0.1594	1.5892	38.124	35	26	0.19	21.731
15	105	0.114	0.9923	0.1658	1.5900	38.161	34	26	0.19	20.508
16	106	0.114	0.9917	0.1722	1.5907	38.180	34	26	0.19	20.518
17	107	0.114	0.9912	0.1786	1.5915	38.204	34	26	0.19	20.531
18	108	0.114	0.9906	0.1849	1.5922	38.222	33	25	0.19	20.541
19	109	0.114	0.9900	0.1912	1.5930	38.241	34	25	0.19	21.797
20	110	0.114	0.9895	0.1974	1.5937	38.258	33	25	0.19	20.560
21	111	0.114	0.9895	0.2035	1.5944	38.280	33	25	0.19	20.572
22	112	0.114	0.9889	0.2096	1.5952	38.304	33	26	0.19	19.255
23	113	0.114	0.9879	0.2156	1.5959	38.321	33	25	0.19	20.594
24	114	0.114	0.9874	0.2215	1.5966	38.340	34	24	0.19	23.036
25	115	0.114	0.0869	0.2274	1.5973	38.359	33	25	0.19	20.614

26	116	0.114	0.9864	0.2332	1.5980	38.378	34	26	0.19	20.624
27	117	0.114	0.9858	0.2390	1.5987	38.393	35	26	0.19	21.884
28	118	0.114	0.9853	0.2447	1.5994	38.410	35	26	0.19	21.894
29	119	0.114	0.9848	0.2503	1.6000	38.427	34	26	0.19	20.651
30	120	0.114	0.9843	0.2558	1.6007	38.444	35	25	0.19	**23.098**
Mean		0.114	0.9621	0.1672	1.5902	38.158	34	25	0.19	20.868

Table 4: Calculated Parameters for Abuja, Nigeria

S/n	J	Φ(rad)	dr(rad)	δ(rad)	Ωs	Ra	T_{max}	T_{min}	K_{RS}	Rs
1	91	0.158	1.0001	0.0718	1.5823	37.790	36	24	0.16	20.945
2	92	0.158	0.9996	0.0787	1.5834	37.835	36	23	0.16	21.827
3	93	0.158	0.9990	0.0856	1.5845	37.878	37	23	0.16	**22.676**
4	94	0.158	0.9984	0.0925	1.5856	37.919	37	25	0.16	21.017
5	95	0.158	0.9979	0.0993	1.5867	37.964	36	24	0.16	21.042
6	96	0.158	0.9978	0.1062	1.5878	38.024	37	24	0.16	21.936
7	97	0.158	0.9967	0.1129	1.5889	38.044	36	25	0.16	20.188
8	98	0.158	0.9962	0.1197	1.5900	38.089	35	25	0.16	19.272
9	99	0.158	0.9956	0.1264	1.5910	38.128	35	25	0.16	19.291
10	100	0.158	0.9950	0.1331	1.5921	38.167	36	25	0.16	20.254
11	101	0.158	0.9945	0.1397	1.5932	38.209	36	25	0.16	20.276
12	102	0.158	0.9939	0.1463	1.5943	38.247	37	24	0.16	22.064
13	103	0.158	0.9934	0.1529	1.5954	38.289	37	25	0.16	21.222
14	104	0.158	0.9928	0.1594	1.5964	38.308	37	25	0.16	21.232
15	105	0.158	0.9923	0.1658	1.5975	38.366	37	25	0.16	21.265
16	106	0.158	0.9917	0.1722	1.5985	38.402	32	24	0.16	17.379
17	107	0.158	0.9912	0.1786	1.5996	38.443	37	24	0.16	22.177
18	108	0.158	0.9906	0.1849	1.6006	38.477	36	24	0.16	21.326
19	109	0.158	0.9900	0.1912	1.6016	38.511	37	25	0.16	21.345
20	110	0.158	0.9895	0.1974	1.6027	38.553	37	24	0.16	22.241
21	111	0.158	0.9895	0.2035	1.6037	38.581	36	25	0.16	20.473
22	112	0.158	0.9889	0.2096	1.6047	38.623	36	24	0.16	20.407
23	113	0.158	0.9879	0.2156	1.6057	38.653	33	25	0.16	**17.492**
24	114	0.158	0.9874	0.2215	1.6067	38.688	35	23	0.16	21.443
25	115	0.158	0.0869	0.2274	1.6077	38.722	35	24	0.16	20.548
26	116	0.158	0.9864	0.2332	1.6086	38.755	36	25	0.16	20.566
27	117	0.158	0.9858	0.2390	1.6096	38.785	36	25	0.16	20.582
28	118	0.158	0.9853	0.2447	1.6106	38.817	36	25	0.16	20.599
29	119	0.158	0.9848	0.2503	1.6115	38.848	33	25	0.16	17.581
30	120	0.158	0.9843	0.2558	1.6125	38.878	38	25	0.16	22.428
Mean		0.158	0.9621	0.1672	1.5978	38.366	36	24	0.16	20.703

The results as shown in Tables 2, 3 and 4 indicates that maximum global solar radiation of Port Harcourt, Lagos and Abuja for the period under study was 26.106MJ/m^{2}day, 23.091MJ/m^{2}day and 22.676 MJ/m^{2}day while the minimum global solar radiation was 19.064MJ/m^2 day, 19.016 MJ/m^{2}day and 17.492 MJ/m^{2}day respectively. These maximum global solar radiations occurred at the maximum/ minimum temperature of 36^{O}C/23^{O}C,

$35^{O}C/25^{O}C$, and $37^{O}C/23^{O}C$ while the minimum global solar radiations occurred at maximum/minimum temperature of $31^{O}C$ /$24^{O}C$, $33^{O}C/26^{O}C$ and $33^{O}C/25^{O}C$ for Port Harcourt, Lagos and Abuja respectively.

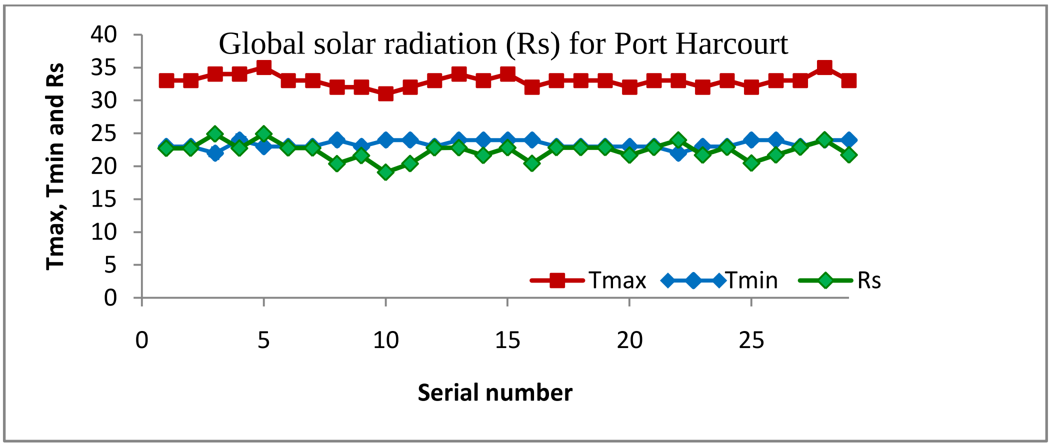

Figure 1: Graph of solar radiation, minimum and maximum temperature for Port Harcourt

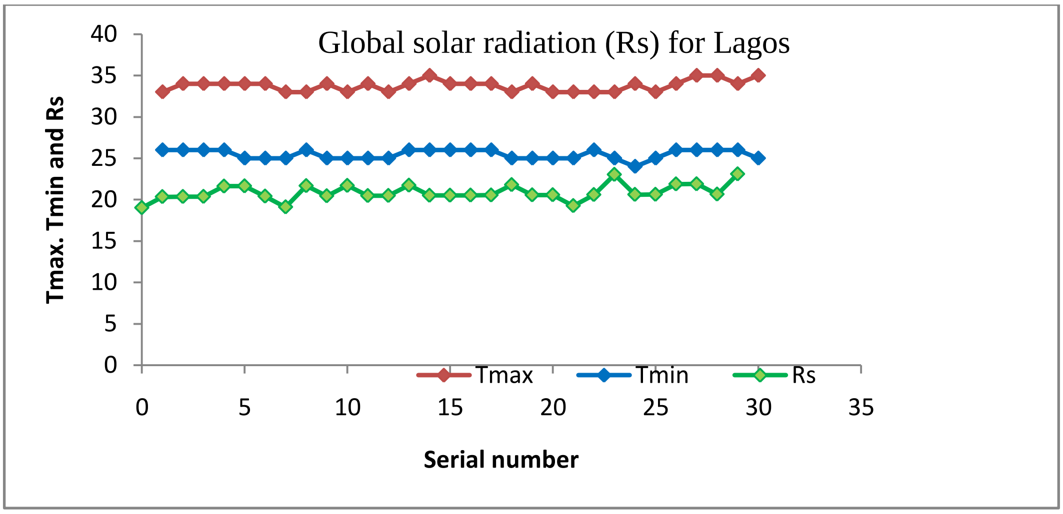

Figure 2: Graph of solar radiation, minimum and maximum temperature for Lagos

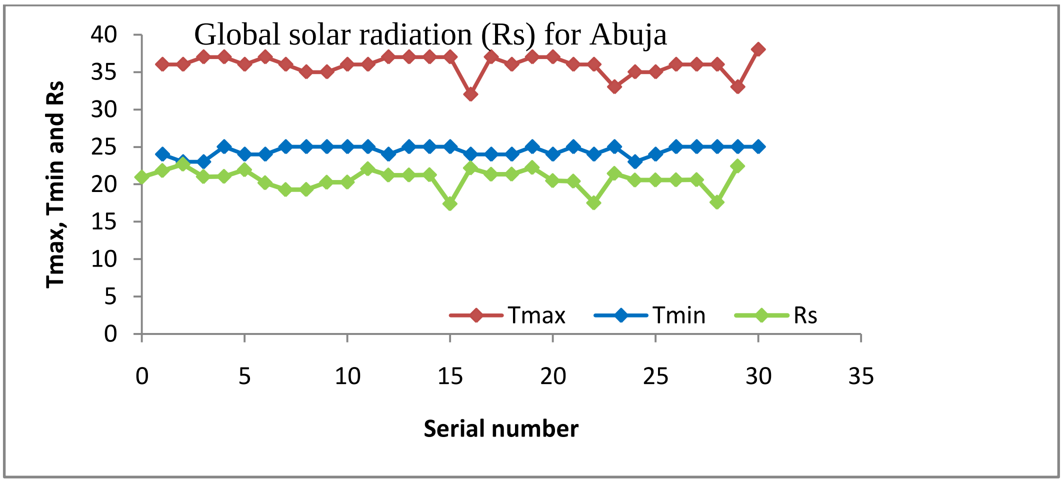

Figure 3: Graph of solar radiation, minimum and maximum temperature for Abuja

Figures 1, 2 and 3 illustrate the relationship between the global solar radiations, maximum and minimum temperature in Port Harcourt, Lagos and Abuja for the period under study. The analyzed results indicates that the global solar radiation was at its maximum level when the difference between the highest and lowest daily average temperatures of a specific day was at its maximum among the differences, and also at its minimum level when the difference between the maximum and minimum temperature of a specific day was at its minimum [7]. The maximum/minimum global solar radiation for Port Harcourt, Lagos and Abuja occurred when the temperature differences were 13°C/7°C, 10°C/7°C and 14°C/8°C respectively (See Tables 2, 3 and 4). Furthermore, the global solar radiation is not affected directly by the maximum or minimum temperature of the day but by the difference between the daily maximum and minimum temperature of the region [13].

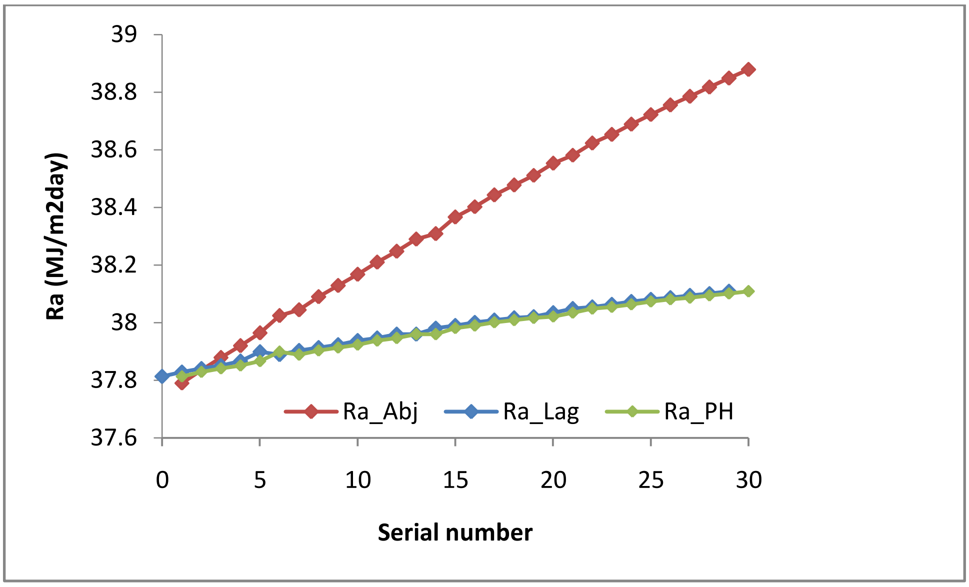

Figure 4: Graph of extraterrestrial solar radiation for Abuja, Lagos and Port Harcourt

Fig. 4 signifies the extraterrestrial solar radiation (Ra) for Abuja, Lagos and Port Harcourt. It can be observed that the mean extraterrestrial global radiation over the month of April 2018 of the 3(three) cities at the entrance into the earth's atmosphere are 38.366MJ/m^2 day, 38.158MJ/m^2 day and 37.976MJ/m^2 day respectively. The level of solar radiation at any surface is dependent on water vapour, CO_2, cloud and the presence of aerosols. During the month of April, there were reductions of aerosols in the atmosphere, which increased the amount of solar radiation that was incident on any surface [14]. Fig. 4 shows a continual increase throughout the period of the study. These upsurges of extraterrestrial solar radiation may be as a result of increase by the atmosphere due to absorption, scattering and reflection by water vapour, CO_2, clouds, smog and global warming.

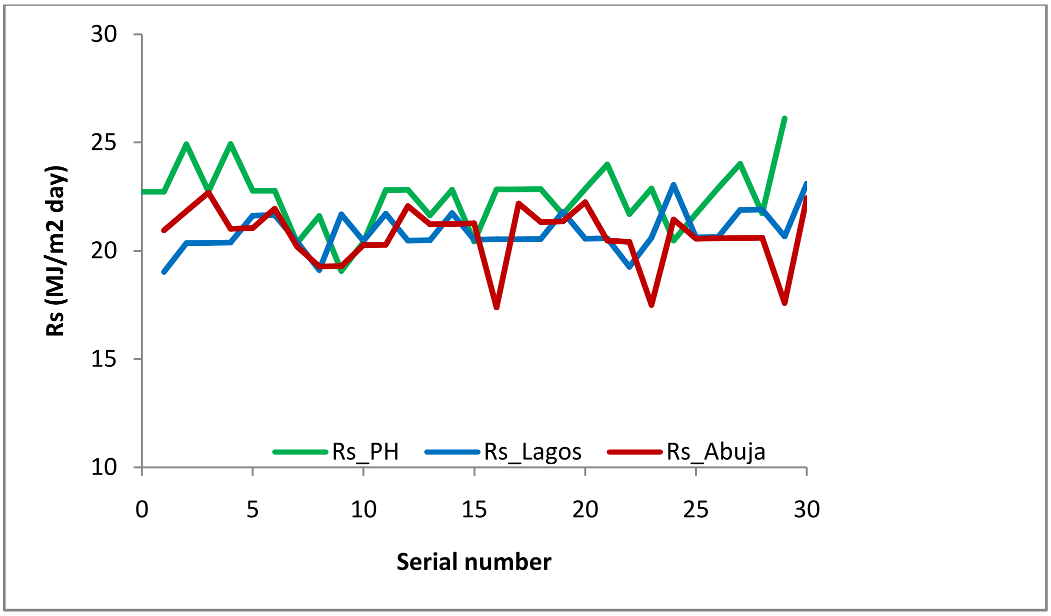

Figure 5: Graph of global solar radiation for Port Harcourt, Lagos and Abuja

Fig.5 shows the average combined graphs of the global solar radiation of Port Harcourt, Lagos and Abuja for the period of the study indicating that the global solar radiation point keeps changing with temperature such that it is difficult maintaining ideal matching at all radiation levels [7]. As the extraterrestrial solar radiation increases slowly and linearly from left towards right (Fig. 4), and global solar radiation decreases and increases in random form and at several points decreases sharply from left towards right due to the minimum temperature values that occur at these points (Fig. 5). The mean daily global solar radiation for Port Harcourt, Lagos and Abuja are 22.464MJ/m^2day, 20.868MJ/m^2day and 20.703MJ/m^2day respectively. In Port Harcourt, there is an increase in the value of measured mean global solar radiation from 16.680MJ/m^2day in a work done by Augustine and Nnabuchi [3] in the month of April during the years of (1999-2007) and 19.364MJ/m^2 day in a work done by Akpootu and Sanusi [20] in the month of April during the years (1990-2010) to 22.464MJ/m^2day in 2018 for the same Port Harcourt. The increase in the radiation by 5.784MJ/m^2day from 1990 to 2018 which indicates a gradual increase in the solar radiation reaching the earth surface which maybe attributed to the effect of global warming which has resulted in making earth's surface warmer than it should be. Similarly, the mean global solar radiation in Abuja according to the work done by Ugwu and Ugwuanyi, [15] in January 2009 was 18.590MJ/m^2day and 17.970MJ/m^2day in February 2016 by Ayegba *et al*. [19] as compared to the increase in radiation of 20.703MJ/m^2day in April, 2018. These are in agreement with the current increase of 20.868MJ/m^2day in solar radiation reaching the earth's surface in the month of April, 2017 in Lagos, Nigeria and other areas with similar meteorological characteristics across the globe. The results of these locations attest to the effects of global warming on the earth's surface.

Conclusion

Considering the importance of global solar radiation and other climatological factors on the earth's surface including climate changes, agriculture, etc. There is a need for methods which can estimate global solar radiation with limited data. Since direct measurement of solar radiation is not available in many areas; therefore the need for empirical models became effective alternatives to predict global solar radiation. In this study, Hargreaves-Samani's model was used because it requires only input variable of minimum and maximum air temperatures adopted from the website of weather online limited and many researchers accepted that its global solar radiation estimates correlate well with observed values in many locations. The influence of daily air temperature values on global solar radiations indicates that daily global solar radiation increases with increase in daily temperature difference and vice versa. Therefore, global solar radiation will be high when the temperature difference of the day is high and it will be low when the temperature difference of the day is low. From the results obtained, the maximum and minimum global solar radiations in Port-Harcourt are 26.106MJ/m^2day and 19.064MJ/m^2day while the mean daily global solar radiation is 22.464MJ/m^2day. Similarly, the maximum and minimumglobal solar radiations in Lagos are 23.091MJ/m^2day and 19.016MJ/m^2day while the mean daily global solar radiation is 20.868MJ/m^2day. Also the maximum and minimum global solar radiations in Abuja are 22.676 MJ/m^2day and 17.492MJ/m^2day while the mean daily global solar radiation is 20.703MJ/m^2day. These predicted values indicate a steady rise in global solar radiation which may be attributed to global warming, and adequate measures should be put in place by meteorological regulatory agencies in the country to prevent further increase. However, considering the uniqueness of climatological data in each month of a year and other environmental factors, the model should be subjected to further validation involving several months data ranging over five years.

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