Relationship between Photosynthetically Active Radiation with Global Solar Radiation using Empirical Model over Selected Climatic Zones in Nigeria

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Abstract: In this study, relationship between photosynthetically active radiation (PAR) and global solar radiation (H) over selected climatic zones in Nigeria was carried out to assess the feasibility of PAR/H and H availability and utilization in Agriculture, Forestry and Oceanography. The measured global solar radiation H data were obtained from the Archives of the Nigerian Meteorology, Agency, Oshodi, Lagos, over a period of thirteen years (2000-2012). Using empirical model as the baseline for theoretical formulations and estimations of relationship between PAR and H over climatic zones in Nigeria. From the estimated values, the seasonal PAR/H ranged from 1.946-2.005; 1.909-1.955; 1.968-2.039; 1.987-2.060; 1.961-2.041; 1.928-1.984; 1.946-2.005 in rainy season and its high values are due to low influence from clearness index, harmattan dust and pyrogenic aerosols from regional biomass burning to 1.906-1.923; 1.905-1.917; 1.927-1.952; 1.950-1.999; 1.971-1.985; 1.889-1.923 in dry season and its low values are to combined high influence from cloudiness, pyogenic aerosols and harmattan dust with annual mean values of 1.943; 1.921; 1.975; 2.007; 1.986 and 1.936 for Ilorin, Sokoto, Abeokuta, Port Harcourt, Enugu and Gusau respectively. The annual ratio of PAR/H revealed that there is an evidence increase of the values from North-East (Gusau) to South-South (Port Harcourt). These variations were mainly due to trends in cloudiness and associated atmospheric moisture with the movement of the Hadley cell circulation system along the equatorial line. The model was found to estimate PAR/H accurately from commonly available H data when compared with researchers within and beyond tropical locations in Nigeria; however, the result also implied that the model is qualified and meteorologically reliable and commendable for relating photosynthetically active radiation with global solar radiation in any local climatic condition in Nigeria.

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1. Introduction

Photosynthetically active radiation (PAR) designates the spectral range (wave band) of solar radiation from 400-700nm that photosynthetic organism are able to use in the process of photosynthesis. This spectral region corresponds more or less with the range of light visible to the human eye (McCree 1972).

Photons at shorter wavelengths tend to be so energetic that they can be damaging to cells and tissues but are mostly filtered out by the ozone layer in the stratosphere photons at longer wavelengths do not carry enough energy to allow photosynthesis to take place (Gates, 1980).

Plants ultimately needs PAR as an energy requirement to convert carbon iv oxide (CO_2) and water (H_2O) through photosynthesis into glucose which is used to synthesize structural and metabolic energy needed for plant growth, development, respiration as well as stored vegetative products that result in plant biomass (Nwokolo et al., 2016, 2017). This can be seen in the process plants used in synthesizing their food as given by the chemical equation:

$$\underset{\text{CARBON DIOXIDE}}{6CO_2} + 12\underset{\text{WATER}}{H_2O} \xrightarrow{\text{LIGHT}} \underset{\text{SUGAR}}{C_6H_{12}O_6} + 6\underset{\text{OXYGEN}}{O_2} + 6\underset{\text{WATER}}{H_2O} \qquad (1)$$

Where the light represents PAR wavelength range (0.4-0.7µm) that is best fit for photosynthesis to occur.

The accurate determination and clear understanding of the PAR fraction is required for many applications such as radiation forcing effect, energy management, hydrological process and biometeorology, crop production remote sensing of vegetation, carbon cycle modeling and calculating the euphotic depth in the ocean (McCree, 1972; Wang et al., 2007).

With the increasing requirement to better understand the Earth's climate systems in the face of global change, more observations of PAR are needed Clay et al. (2010). This radiometric flux varies from country to country and from place to place. It is a function of the regional sky clearness, which depends on the cloud and aerosol amount, sky brightness, which depends upon the aerosol burden and cloud thickness, solar elevation angle and precipitable water, accounting for the absorption effects that caused by the water vapour concentration (Gonzalez and Calbo, 2002; Tsubo and Walker, 2005; Alados *et al*., 1996).

Measurements of PAR have been performed in many parts of the world using a variety of techniques. These techniques have involved the use of Eppley precision spectral pyranometer (PSP), Li-COR quantum sensors (Li-190SZ) and PAR lite to mention but a few.

However, up to now, PAR measurements have not been carried out routinely at radiometric sites in Nigeria and other locations across the globe (Ituen et al., 2012). To circumvent this problem, other methods for estimating PAR using currently available data such as MODIS (Moderate Resolution Imaging Spectroradiometer) has been used to calculate PAR values (Van and Sanchez 2005; Liu et al., 2008). PAR can also been estimated using irradiative transfer models (Wang et al., 2006; Joshi et al., 2011). Notwithstanding, the accuracy of these latter methods is not good enough for large areas (Janiai and Wattan 2011; Gao et al. 2011).

Another widely used method is to estimate PAR from the routinely measured global solar radiation (H) by considering the PAR fraction as a constant for a specific area (Mayer et al., 2002; Jacorvides et al., 2003). The range of PAR fractions as reported in the literature suggest the desirability of local calibration to account for climatic and geographic differences such as cloudiness, day length and the diurnal pattern of solar radiation (Aguiar *et al* 2012). This problem necessitates PAR estimation by analyzing the characteristics of PAR with direct measured data, developing appropriate models for calculating PAR/H that can work well under various sky conditions in large areas. This will produce a large amount of appreciate PAR data without substantial cost (Etuk et al., 2016a, 2016b).

A number of studies involving the relationship between PAR and H for different locations across the globe have been studied by different researchers. Zhou et al. (1996) developed climatologically estimation of photosynthetically active quantum flux in Yucheng, China with average daily PAR/H value of 2.06. Papaioannou et al. (1996) estimated PAR in Anthens with average daily PAR/H value of 1.94. Zhang et al. (2000) measured and model PAR at Tibetan Plateau, Lhasa, China with an average daily PAR/H value of 1.95. Li et al. (2010) estimated the monthly ratios of PAR to measured G at northern Tibetan Plateau, China between 1.83-2.03. Gonzalez and Calbo (2002) modeled and measured PAR/H under cloudless skies in Girona, Spain as 1.99. Jacovides et al. (2003) related global PAR/H in the eastern Mediterrainean basin, Athalassa, Cyprus with an average daily value of 1.92. Hu et al. (2007) developed measurements and setimations of PAR in Beijing, China with an average daily value of 1.83. Finch et al. (2007) estimated PAR regimes in a southern African savanna environment, Lusaka, Zambia with an average daily value of 1.99. Wang et al. (2007) established variation of PAR/H along altitude gradient in Naeba mountain, Japan with an average daily value of 1.94. Xia et al. (2008) analyzed photosynthetic photon flux density and its parameterization in Xianghe, China with average daily PAR/H value of 1.96. Howell et al. (1983) related PAR/H in the San Jaoaquin valley, California, USA with an average daily value of 2.058. Lunche et al. (2013) developed PAR/H in Wuhan, central China with an average value of 1.93.

The first available information and research published on the relationship between PAR/H in Nigeria was carried out by Udo and Aro (1999) in Ilorin, central Nigeria they obtained the average value of 2.08. Anjorin et al. (2014) estimated hourly PAR/H in Jos, central Nigeria and obtained an average value of 2.08.

The objective of this study, apart from determining the relationship between global photosynthetically active radiation with global radiation using empirical model over selected climatic zones in Nigeria, was to validate and recommend Alados et al. (1996) model as a suitable and meteorologically reliable for estimating empirically ratio of PAR/H in Nigeria and across the globe.

2. Material and Methods

The monthly mean daily global solar radiation used for this study was obtained from the Archives of the Nigeria Meteorological Agency, Oshodi Lagos. The six cities (location) studied lie on the latitude, longitude and altitudes of (Lat. 4.40°N, Long. 7.17°E and altitude 508.71m) for Port Harcourt; (Lat. 8.50°N, Long. 4.58°E and altitude 303.89m) for Ilorin; (Lat. 13.03°N, Long. 5.26°E and altitude 285.902m) for Sokoto; (Lat. 07.05°N, Long. 3.32°E and altitude 66.14m) for Abeokuta; (Lat. 6.50°N, Long. 7.50°E and altitude 142m) for Enugu; (Lat. 12.20°N, Long. 6.67°E and altitude 450m) for Gusau respectively as presented in Fig. 1. The data obtained covered a period of thirteen years (2000-2012).

To estimate the relationship between photosynthetically active radiation and global solar radiation, the global solar radiation data measured in $kwhm^{-2}day^{-1}$ was converted to $MJm^{-2}day^{-1}$ using a factor of 3.6 Iqbal (1983) and was further converted to EMJ^{-1} using a converting factor of 4.56 (McCree, 1972).

Various climatic parameters have been used in developing empirical relations for estimating the relationship between photosynthetically active radiation and global solar radiation. In this research, the simple model used is Alados *et al*., (1996).

$$\frac{PAR}{H} = 1.832 - 0.191 Ink_t + 0.099 \sin\alpha \qquad (2)$$

Where H is the average monthly global solar radiation, PAR is the average monthly photosynthetically active radiation, k_t is the clearness index, α is the solar altitude is related to zenith angle θ_Z by the relation:

$$\sin\alpha = \cos\theta_Z \qquad (3)$$

The angle of incidence θ_Z is the zenith angle of the sun estimated as:

$$\cos\theta_Z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega_s \qquad (4)$$

The extraterrestrial solar radiation on the horizontal surface was calculated and the expression given by Nwokolo et al. (2016) as follows:

$$H_O = \frac{24}{\pi} I_{SC}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_S + \frac{2\pi\omega_S}{360}\sin\phi\sin\delta\right) \qquad (5)$$

I_{SC} is the solar constant, (ϕ) is the latitude of the location, δ is the solar declination, ω_S is the mean sunrise hour angle for the given month and n the number of days of the year starting from first January. For a given month, the solar declination (δ) and the mean sunrise hour angle (ω_S) can be evaluated by the following equations (6) and (7) respectively.

$$\delta = 23.45 \sin\left[\frac{360(n + 284)}{365}\right] \qquad (6)$$

$$\omega_s = \cos^{-1}[\tan\delta \tan\tan\phi] \qquad (7)$$

The average day length for each month was collected using the expression by Iqbal (1983).

$$\overline{N} = \frac{2}{15} Cos^{-1}(-\tan\phi\tan\delta) \qquad (8)$$

The clearness index is given by Iqbal (1983) model expressed as:

$$k_t = \frac{H}{H_o} \qquad (9)$$

Where all symbols retain their usual meaning.

The standard deviation (SD) for the PAR/G estimation was evaluated using the expression:

$$SD = \sqrt{\sum\left(\frac{PAR}{H} - x\right)^2 / N} \qquad (10)$$

Where x is the monthly PAR from January to December, N is the total number of months in a year.

Fig. 1. Map of Nigeria showing study locations (Port Harcourt, Enugu, Abeokuta, Ilorin, Gusua and Sokoto)

3. Results

The calculated values of monthly mean global solar radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), standard deviation (SD) and ratio of Photosynthetically active radiation and global solar radiation PAR/H obtained from Alados et al. (1996) model over climatic zones in Nigeria are presented in Tables (1-6).

Table 1: Monthly Mean Daily Values of Global Solar Radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), ratio of Photosynthetically active radiation and global solar radiation PAR/H and standard deviation (SD) for Port Harcourt (2000-2012).

Month	N	H $(kwhm^{-2}day^{-1})$	H (EMJ^{-1})	H_o (EMJ^{-1})	$k_t = \frac{H}{H_o}$	$\frac{PAR}{H}$	(SD) (EMJ^{-1})
JAN	17	5.17	84.88	157.25	0.5398	1.950	0.0165
FEB	45	5.28	86.79	165.24	0.5253	1.955	0.0150
MAR	74	4.86	79.81	171.22	0.4662	1.980	0.0080
APR	105	4.62	75.89	170.48	0.4451	1.987	0.0058
MAY	135	4.04	66.35	164.69	0.4029	2.010	0.0009
JUN	161	3.08	50.61	160.31	0.3157	2.052	0.0130
JUL	199	2.99	49.06	161.72	0.3033	2.060	0.0153
AUG	239	3.36	55.12	167.06	0.3300	2.044	0.0107
SEP	261	3.24	53.25	169.89	0.3135	2.054	0.0136
OCT	292	3.45	56.63	166.15	0.3408	2.038	0.0089
NOV	322	4.02	66.17	158.44	0.4176	1.999	0.0023
DEC	347	4.81	78.95	154.01	0.5126	1.960	0.0136
ANNUAL		4.08	66.96	163.87	0.4094	2.007	0.0103

Table 2: Monthly Mean Daily Values of Global Solar Radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), ratio of Photosynthetically active radiation and global solar radiation PAR/H and standard deviation (SD) for Enugu (2000-2012).

Month	N	H $(kwhm^{-2}day^{-1})$	H (EMJ^{-1})	H_o (EMJ^{-1})	$k_t = \frac{H}{H_o}$	$\frac{PAR}{H}$	(SD) (EMJ^{-1})
JAN	17	4.47	73.42	163.59	0.4492	1.985	0.0003
FEB	45	4.90	80.54	168.89	0.4769	1.973	0.0038
MAR	74	5.01	82.37	171.31	0.4808	1.972	0.0040
APR	105	2.38	84.69	166.29	0.5093	1.961	0.0072
MAY	135	4.98	81.82	157.02	0.5211	1.966	0.0058
JUN	161	4.33	71.14	151.27	0.4703	1.976	0.0029
JUL	199	3.95	64.94	159.03	0.4083	2.003	0.0075
AUG	239	3.99	65.57	161.86	0.4051	2.005	0.0055
SEP	261	4.23	69.54	168.61	0.4124	2.001	0.0043
OCT	292	4.05	66.53	172.17	0.3864	2.041	0.0159
NOV	322	4.80	78.90	163.50	0.4826	1.971	0.0043
DEC	347	4.57	75.11	160.72	0.4673	1.977	0.0026
ANNUAL		4.31	74.46	163.69	0.4558	1.986	0.0053

Table 3: Monthly Mean Daily Values of Global Solar Radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), ratio of Photosynthetically active radiation and global solar radiation PAR/H and standard deviation (SD) for Abeokuta (2000-2012).

Month	N	H $(kwhm^{-2}day^{-1})$	H (EMJ^{-1})	H_o (EMJ^{-1})	$k_t = \frac{H}{H_o}$	$\frac{PAR}{H}$	(SD) (EMJ^{-1})
JAN	17	5.52	90.67	161.31	0.5621	1.938	0.0107
FEB	45	5.63	92.54	161.68	0.5724	1.936	0.0113
MAR	74	5.76	94.55	169.94	0.5564	1.944	0.0089
APR	105	5.17	84.97	171.76	0.4947	1.968	0.0020
MAY	135	4.93	81.00	167.88	0.4825	1.975	0.0000
JUN	161	4.32	71.00	164.42	0.4319	1.997	0.0064
JUL	199	3.94	61.42	165.42	0.3713	2.025	0.0144
AUG	239	3.52	57.82	169.12	0.3419	2.039	0.0185
SEP	261	3.91	64.30	169.57	0.3792	2.017	0.0121
OCT	292	4.52	74.20	163.27	0.4544	1.981	0.0017
NOV	322	5.09	83.60	153.74	0.5438	1.952	0.0066
DEC	347	5.39	88.48	148.49	0.5959	1.927	0.0139
ANNUAL		4.79	78.71	163.88	0.4822	1.975	0.0089

Table 4: Monthly Mean Daily Values of Global Solar Radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), ratio of Photosynthetically active radiation and global solar radiation PAR/H and standard deviation (SD) for Ilorin (2000-2012).

Month	N	H $(kwhm^{-2}day^{-1})$	H (EMJ^{-1})	H_o (EMJ^{-1})	$k_t = \frac{H}{H_o}$	$\frac{PAR}{H}$	(SD) (EMJ^{-1})
JAN	17	5.73	94.10	146.57	0.6420	1.917	0.0075
FEB	45	5.99	98.52	157.62	0.6251	1.922	0.0061
MAR	74	6.36	105.0	168.34	0.6208	1.923	0.0058
APR	105	6.06	99.57	172.68	0.5766	1.934	0.0026
MAY	135	5.74	92.28	170.85	0.5518	1.946	0.0009
JUN	161	5.08	83.46	168.29	0.4959	1.966	0.0066
JUL	199	4.52	74.24	168.84	0.4397	1.989	0.0133
AUG	239	4.21	69.23	170.85	0.4052	2.005	0.0179
SEP	261	4.84	79.58	164.28	0.4844	2.004	0.0176
OCT	292	5.36	88.12	160.00	0.5508	1.946	0.0009
NOV	322	5.78	94.92	148.54	0.6393	1.918	0.0072
DEC	347	5.88	96.65	142.47	0.6784	1.906	0.0107
ANNUAL		5.46	83.52	161.61	0.5578	1.943	0.0081

Table 5: Monthly Mean Daily Values of Global Solar Radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), ratio of Photosynthetically active radiation and global solar radiation PAR/H and standard deviation (SD) for Sokoto (2000-2012).

Month	N	H $(kwhm^{-2}day^{-1})$	H (EMJ^{-1})	H_o (EMJ^{-1})	$k_t = \frac{H}{H_o}$	$\frac{PAR}{H}$	(SD) (EMJ^{-1})
JAN	17	5.40	88.66	138.40	0.6406	1.917	0.0012
FEB	45	6.24	102.5	152.19	0.6741	1.907	0.0040
MAR	74	6.89	113.1	165.65	0.6832	1.905	0.0046
APR	105	7.14	117.3	173.31	0.6767	1.915	0.0017
MAY	135	7.08	116.2	174.09	0.6679	1.909	0.0035
JUN	161	6.69	109.8	172.68	0.6361	1.919	0.0006
JUL	199	6.14	100.9	172.68	0.5843	1.935	0.0040
AUG	239	5.51	90.49	172.54	0.5245	1.955	0.0098
SEP	261	5.96	97.93	167.43	0.5849	1.934	0.0038
OCT	292	5.79	95.05	155.47	0.6114	1.926	0.0014
NOV	322	5.73	94.05	141.83	0.6631	1.911	0.0029
DEC	347	5.30	87.07	134.85	0.6457	1.916	0.0014
ANNUAL		6.16	101.1	160.09	0.6327	1.921	0.0032

Table 6: Monthly Mean Daily Values of Global Solar Radiation (H), extraterrestrial solar radiation (H_o), clearness index (k_t), characteristic day number (N), ratio of Photosynthetically active radiation and global solar radiation PAR/H and standard deviation (SD) for Gusau (2000-2012).

Month	N	H $(kwhm^{-2}day^{-1})$	H (EMJ^{-1})	H_o (EMJ^{-1})	$k_t = \frac{H}{H_o}$	$\frac{PAR}{H}$	(SD) (EMJ^{-1})
	17	5.41	88.23	141.83	0.6263	1.921	0.0043
FEB	45	6.38	104.9	153.24	0.6730	1.908	0.0081
MAR	74	6.33	104.0	166.70	0.6241	1.923	0.0038
APR	105	6.21	102.1	173.50	0.5883	1.933	0.0009
MAY	135	5.38	88.44	180.07	0.4911	1.968	0.0092
JUN	161	5.83	95.69	180.75	0.5294	1.954	0.0052
JUL	199	4.71	77.44	171.90	0.4506	1.984	0.0139
AUG	239	4.76	78.12	171.72	0.4550	1.982	0.0133
SEP	261	5.59	91.92	167.34	0.5493	1.946	0.0029
OCT	292	5.72	94.00	155.33	0.6053	1.928	0.0023
NOV	322	6.42	105.5	142.24	0.7413	1.890	0.0133
DEC	347	6.18	101.4	136.35	0.7441	1.889	0.0136
ANNUAL		5.74	94.32	161.75	0.5898	1.936	0.0076

Table 7: Monthly, Maximum, Minimum, Seasonal and Annual Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation (H_o), Clearness Index (k_t), characteristic day number (N), ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/H and standard deviation (SD) for Sokoto, Gusau, Ilorin, Abeokuta, Enugu and Port Harcourt(P.H) (2000-2012).

	Sokoto	Gusau	Ilorin	Abeokuta	Enugu	P.H
H (EMJ^{-1})	101.11	94.32	83.52	78.46	74.46	66.96
H_o (EMJ^{-1})	160.1	161.8	161.6	163.8	163.7	163.9
k_t	0.633	0.590	0.558	0.482	0.409	0.521
$\frac{PAR}{H}$ Max.	1.955	1.984	2.005	2.039	2.005	2.060
$\frac{PAR}{H}$ Min.	1.905	1.889	1.960	1.927	1.981	1.950
$\frac{PAR}{H}$ Rainy	1.931	1.956	1.967	1.995	1.983	2.027
$\frac{PAR}{H}$ Dry	1.914	1.909	1.922	1.947	1.989	1.980
$\frac{PAR}{H}$ Annual	1.921	1.936	1.943	1.975	1.986	2.007
SD (EMJ^{-1})	0.003	0.008	0.008	0.009	0.005	0.007

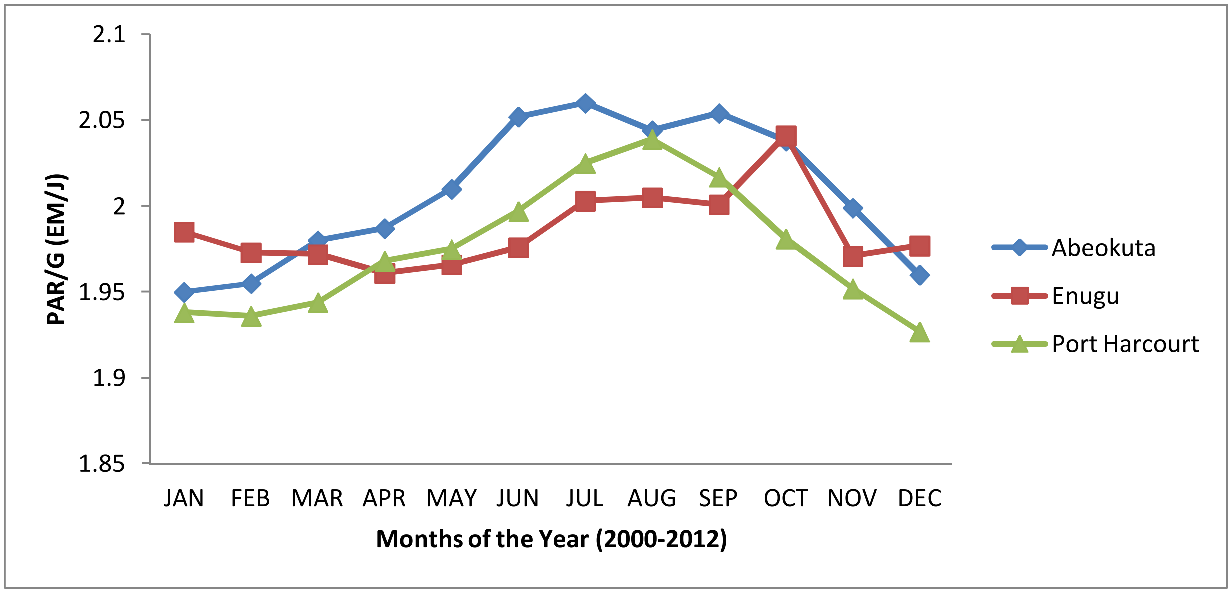

Figure 2: Comparison between the ratios of estimated PAR/G for Abeokuta, Enugu and Port Harcourt (2000-2012).

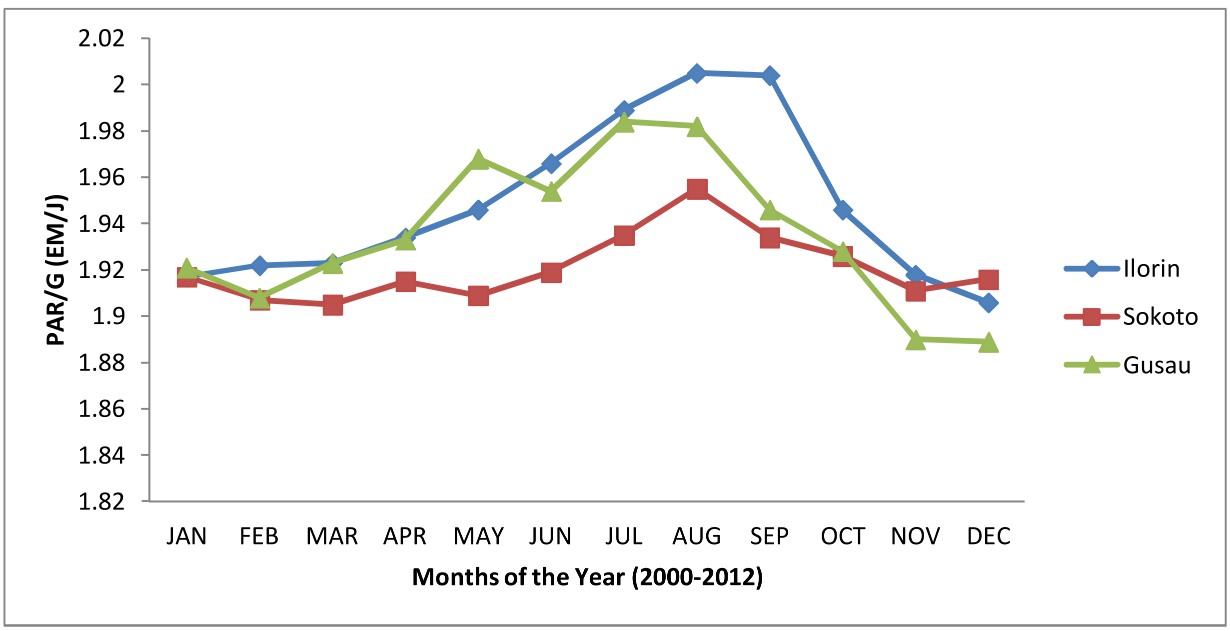

Figure 3: Comparison between the ratios of estimated PAR/G for Ilorin, Sokoto and Gusau (2000-2012).

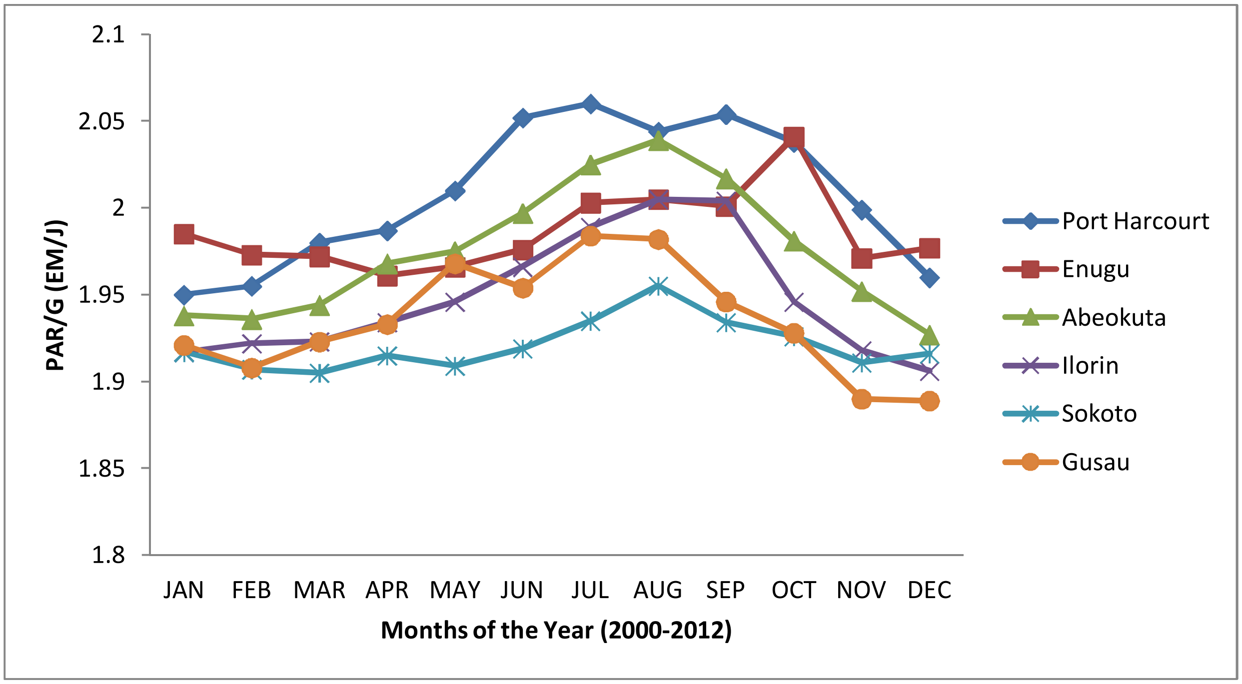

Figure 4: Comparison between the ratios of estimated PAR/G for Port Harcourt, Enugu, Abeokuta, Ilorin, Sokoto. Gusau(2000-2012).

4. Discussions

A close look at Table 1 – 6 and Figure 1 – 6 shows that the maximum value of the monthly mean PAR/H are 2.005, 1.955, 1.984, 2.039, 2.00 and 2.060 for Ilorin, Sokoto, Gusau, Abeokuta, Enugu and Port Harcourt respectively and they occurred within months of July – August. These values and months of occurrence are within what is expected of a tropical site (Udo and Aro, 1999 and Miskolcze et al., 1997). These months that are characterized by heavy rainfall, wet atmosphere, presence of cloud, low values of clearness index, harmattan dust and pyrogenic aerosols from regional biomas buming. These factors attenuate PAR/H through absorption by the precipitated water vapour, reflection and absorption by clouds (Babatunde, 2001 and Babatunde and Aro, 2000). The range of values obtained from this study is comparable to 2.08 observed in Ilorin, Nigeria by Udo and Aro (1999); 1.94 reported in Athalassu, Cyprus by Jacovide et al. (2003); 1.98 recorded in Beiging, China by Hu et al., (2007); 2.08 reported by Xia et al. (2008), Xiaugh, China.

The minimum values of the monthly mean PAR/H are 1.906, 1.905, 1.889, 1.927, 1.981, 1.950 for Ilorin, Sokoto, Gusau, Abeokuta, Enugu and Port Harcourt respectively and they occur within the months of December, January, March and April. These values are within what is expected of a tropical site (Udo and Aro, 1999 and Miskolczi et al., 1997). These months of occurrence is expected for Ilorin (December), Gusau (December), Abeokuta (December), Port Harcourt (January), because of the hamattan season when aerosol mass loading, dry atmosphere and the presence of clear skies greatly reduces the intensity of PAR/H (Babatunde and Aro, 2001 and Babatunde, 2001). But the months of occurrence for Sokoto (March) and Enugu (April) is not expected which could be attributed to prolonged dry seasons annually in the two locations and other atmospheric variables. The range of values obtained in this study agreed favourably with 1.92 observed in Ilorin, Nigeria by Udo and Aro (1999); 1.86 reported in Athalass, Cyprus by Jacovide et al. (2003); 1.77 recorded in Beijing, China by Hu et al., (2007); 1.87 obtained in Xianghe, China by Xia et al. (2008).

The values of the mean monthly PAR/H are 1.922, 1.914, 1.909, 1.947, 1.989 and 1.980 for the dry season in Ilorin (North Central), Sokoto (North-West), Gusau (North-East), Abeokuta (South-West), Enugu (South-East) and Port Harcourt (South-South) respectively. These values are within the range of what is expected of a tropical site (Udo and Aro, 1999 and Miskolczi et al., 1997). The range of values obtained are equally comparable to 1.94 reported in the dry season in Ilorin, Nigeria by Udo and Aro (1999), and 1.78 observed in the dry season in Wuhua, China by Lunche et al. (2013).

The mean monthly PAR/H are 1.967, 1.931, 1.956, 1.945, 1.983 and 2.027 for the rainy season for Ilorin (North-Central), Sokoto (North-West), Gusau (North-East), Abeokuta (South-West), Enugu (South-East) and Port Harcourt (South-South) respectively. The values of the PAR/H ratio for rainy season is higher than dry season because the absorption of solar radiation in the intend portion of the solar spectrum is enhanced whereas absorption in the PAR wavelength does not vary significantly, thus calumniating in increasing value of PAR/H under cloudy skies. Also, with the movement of the ITCZ into the Northern hemisphere, the rain-bearing South westerlies prevail as far as possible to bring rainfall during the rainy season. The implication is that there is a prolonged rainy season in the far South, while the far North undergoes long dry periods annually. The value obtained is equally comparable to 1.95 observed by Lunche et al. (2013) and 2.12 reported by Udo and Aro (1999) in Ilorin, Nigeria.

The actual values of the annual mean daily PAR/H ratio of all the zones are 1.943, 1.921, 1.936, 1.975, 1.986, 2.007 for Ilorin (North Central), Sokoto (North West), Gusau (North-East), Abeokuta (South West), Enugu (South East) and Port Harcourt (South-South) respectively. The values are within the range of what is expected of a tropical site (Udo and Aro, 1999; Miskolczi et al., 1997). The range of values obtained also finds agreement with other authors within and across the globe. Zhou et al. (1996) reported 2.06 in Yucheug, China; 1.94 was observed by Papaioannou et al (1996) in Athens, Greece; 1.95 was obtained by Zhang et al., (2000) in Lhasoi, China. Li et al., (2010) observed 2.0 in Northern Tibetau; Gonzalez and Calbo (2002) estimated 1.99 in Girona, Spain; 1.92 obtained by Jacovides et al. (2003) in Athalussa, Cyprus; 1.83 reported by Hu et al. (2007) in Beijing, China; 1.99 observed by Finch et al. (2004) in Lusaka, Zambia; 1.94 obtained by Wang et al. (2007) in Naeba Mountain, Japan; 1.96 reported by Xia et al., (2008) in Xianghe, China; 2.058 observed by Howell et al., (1983) in California, USA.

The annual mean values of PAR/H ratio in different locations under different climatic zones indicates an evidence increase from 1.921-2.007 between Sokoto, North West to Port Harcourt, South South. These evidence variations were mainly due to trends in cloudiness and associated atmospheric moisture with the movement of the Hadley cell circulation system along the equatorial line.

Table 7 shows that the monthly mean values of global solar radiation H in different location under different climatic zones indicating evidence decrease from 101.11 between Sokoto, North West to 66.96 in Port Harcourt, South South. These evidence variations were mainly due to trend, in cloudiness and associated with the movement of the Hadley cell circulation system along the equatorial line.

In conclusion, higher mean value, of PAR/H ratio were observed during rainy season with increasing sequence from North West to South South climatic zones while in dry season, the mean values were lower with increasing sequence from North West to South South climate zones. This evidence variation is due to the movement of the ITCZ into the Northern hemisphere in the rain-bearing South westerlies thereby prevail as far inland as possible to bring rainfall during the rainy season. This resulted in prolonged rainy season in the far South, while the far North undergoes long dry periods annually.

The average annual values of PAR/H ratio equally increased from North West to South South climatic zones. This variation was mainly due to trends in cloudiness and associated with atmospheric moisture with the movement of the Hadley cell circulation system along the equatorial line.

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