

# Relationship between photosynthetically active radiation with global solar radiation using empirical model over selected climatic zones in Nigeria

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## Abstract

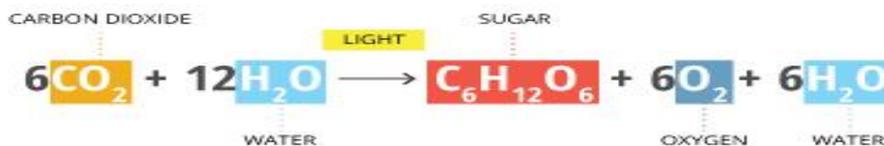
In this study, relationship between photosynthetically active radiation (PAR) and global solar radiation (H) over selected climatic zones in Nigeria using 22-years data (July 1983 – June 2005) was analysed. Empirical model was employed as the baseline for theoretical formulation and estimation of the ratio of PAR/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 and 1.946-2.005 in rainy season, and the high values were due to low influence from clearness index, harmattan dust and pyrogenic aerosols from regional biomass burning compared with 1.906-1.923, 1.905-1.917, 1.927-1.952, 1.950-1.999, 1.971-1.985 and 1.889-1.923 recorded in dry season as a result of combined high influence from cloudiness, pyrogenic 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. From the analysed results, the model was found suitable and meteorologically reliable to estimate PAR/H accurately from commonly available H data when compared with results within and beyond tropical locations in Nigeria.

**Keywords:** Photosynthetically Active Radiation; Clearness Index; Global Solar Radiation; Atmospheric Parameters and Nigeria.

## 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 [1]. 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 [2]. Plants ultimately needs PAR as an energy requirement to convert carbon iv oxide (CO<sub>2</sub>) and water (H<sub>2</sub>O) 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 [3], [4]. This can be seen in the process plants used in synthesizing their food as given by the chemical equation:



(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 [1], [5]. With the increasing requirement to better understand the Earth's climate systems in the face of global change, more observations of

PAR are needed [6]. 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 [7-9].

Measurements of PAR have been performed in many parts of the world using a variety of techniques. These techniques have in-

volved the use of Eppley precision spectral pyranometer (PSP), Li-COR quantum sensors (Li-190SZ) and PAR lite to mention but a few.

However, up till now, PAR measurements have not been carried out routinely at radiometric sites in Nigeria and other locations across the globe. 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 [10-11]. PAR can also be estimated using irradiative transfer models [5], [12]. Notwithstanding, the accuracy of these latter methods is not good enough for large areas [13-14].

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 [15-16]. 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 [17]. 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 [18-19].

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. [20] developed climatologically estimation of photosynthetically active quantum flux in Yucheng, China with average daily PAR/H value of 2.06. Papaioannou et al. [21] estimated PAR in Athens with average daily PAR/H value of 1.94. Zhang et al. [22] measured and model PAR at Tibetan Plateau, Lhasa, China with an average daily PAR/H value of 1.95. Li et al. [23] estimated the monthly ratios of PAR to measured H at northern Tibetan Plateau, China from 1.83-2.03. Gonzalez and Calbo [7] modeled and measured PAR/H under cloudless skies in Girona, Spain as 1.99. Jacovides et al. [16] related global PAR/H in the eastern Mediterranean basin, Athalassa, Cyprus with an average daily value of 1.92. Hu et al. [24] developed measurements and estimations of PAR in Beijing, China with an average

daily value of 1.83. Finch et al. [25] estimated PAR regimes in a southern African savannah environment, Lusaka, Zambia with an average daily value of 1.99. Wang et al. [5] established variation of PAR/H along altitude gradient in Naeba Mountain, Japan with an average daily value of 1.94. Xia et al. [26] analyzed photosynthetic photon flux density and its parameterization in Xianghe, China with average daily PAR/H value of 1.96. Howell et al. [27] related PAR/H in the San Joaquin valley, California, USA with an average daily value of 2.058. Lunche et al. [28] 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 [29] in Ilorin, central Nigeria. They obtained the average value of 2.08. Anjorin et al. [30] estimated hourly PAR/H in Jos, central Nigeria using Alados et al. [9] model and obtained an average value of 2.08.

The objective of this study apart from determining the relationship between global photosynthetically active radiations with global radiation using empirical model over selected climatic zones in Nigeria, was to validate and recommend Alados et al. [9] model as a suitable and meteorologically reliable for estimating empirically ratio of PAR/H in Nigeria.

## 2. Materials and methods

### 2.1. Acquisition of data and study area

The long term monthly mean daily global horizontal irradiation (H) for the period of 1983-2005 for the selected state capitals and locations whose tropical ecological zones, coordinates and elevations listed in Table 1 and Fig. 1 were obtained from the National Aeronautics and Space Administration (NASA) atmospheric science data center [32]. The H data measured in  $\text{kWhm}^{-2}\text{day}^{-1}$  were converted to  $\text{MJm}^{-2}\text{day}^{-1}$  using a factor of 3.6 [33] and was further converted to  $\text{EM}^{-1}$  using a converting factor of 4.56 [1]. The details of the study area are found in Nwokolo and Ogbulezie [31].

**Table 1:** States, State Capitals, Coordinates and Tropical Ecological Zones for the Selected Stations in Nigeria

States	State Capitals	Latitude (Degree North)	Longitude (Degree East)	Elevation (Meters)	Tropical Ecological Zones
Rivers	Port Harcourt	4.75	7.00	117	Mangrove Swamp
Enugu	Enugu	6.50	7.50	142	Mangrove Swamp
Ogun	Abeokuta	7.05	3.32	66	Tropical Rain Forest
Kwara	Ilorin	8.50	4.58	303	Guinea Savannah
Zamfara	Gusau	12.07	6.638	415	Sudan Savannah
Sokoto	Sokoto	13.067	5.233	331	Sahel Savannah



**Fig. 1:** Map of Nigeria Showing Study Locations (Port Harcourt, Enugu, Abeokuta, Ilorin, Gusau and Sokoto).

### 2.2. Evaluation procedures

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 was Alados et al. [9] given as:

$$\frac{PAR}{H} = 1.832 - 0.191lnk_t + 0.099\sin\alpha \tag{2}$$

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

$$\sin\alpha = \cos\theta_z \tag{3}$$

The angle of incidence  $\theta_z$  is the zenith angle of the sun estimated as:

$$\cos\theta_z = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega_s \tag{4}$$

The extraterrestrial solar radiation on the horizontal surface was calculated and the expression given by Nwokolo et al. [3] as follows:

$$H_o = \frac{24}{\pi} I_{SC} \left( 1 + 0.033\cos\frac{360n}{365} \right) \times \left( \cos\varphi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\varphi\sin\delta \right) \tag{5}$$

$I_{SC}$  is the solar constant,  $\varphi$  is the latitude of the location,  $\delta$  is the solar declination,  $\omega_s$  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  $\delta$  and the mean sunrise hour angle  $\omega_s$  can be evaluated by the following equations (6) and (7) respectively.

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

$$\omega_s = \cos^{-1}[\tan\delta\tan\varphi] \tag{7}$$

The average day length for each month was collected using the expression by Iqbal [33].

$$\bar{N} = \frac{2}{15}\text{Cos}^{-1}(-\tan\varphi\tan\delta) \tag{8}$$

The clearness index is given by Iqbal [33] model expressed as:

$$k_t = \frac{H}{H_o} \tag{9}$$

Where all symbols retain their usual meaning.

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

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

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

### 3. Results

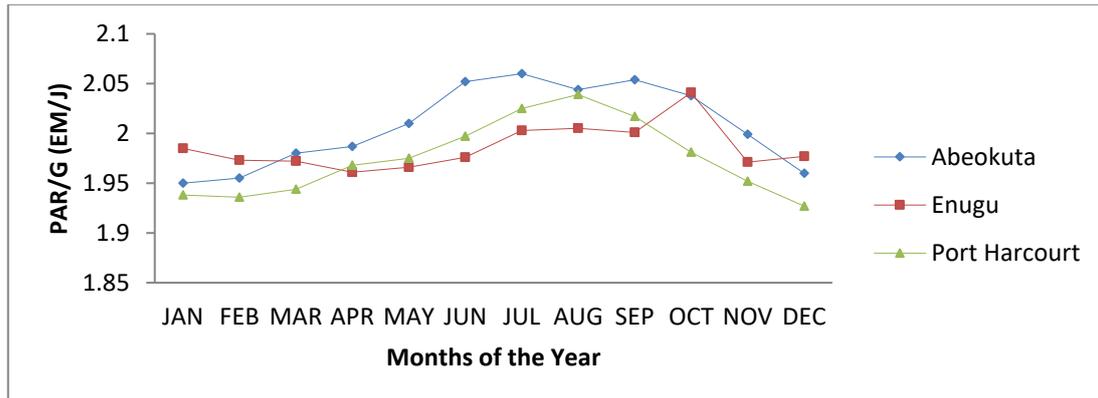
The calculated values of monthly mean global solar radiation H, extraterrestrial solar radiation  $H_o$ , clearness index  $k_t$ , characteristic day number (N), standard deviation (SD) and ratio of Photosynthetically active radiation and global solar radiation PAR/H obtained from Alados et al. [9] model over climatic zones in Nigeria are presented in Tables (2-7).

**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 Port Harcourt (1983-2005)

Month	N	H (Kwhm <sup>2</sup> day <sup>-1</sup> )	H (EMJ <sup>-1</sup> )	$H_o$ (EMJ <sup>-1</sup> )	$k_t$	PAR/H	SD (EMJ <sup>-1</sup> )
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	2329	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
MEAN		4.08	66.96	163.87	0.4094	2.007	0.0103

**Table 3:** Monthly Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation ( $H_0$ ), Clearness Index ( $K_t$ ), Characteristic Day Number (N), Ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/Hand Standard Deviation ( $SD$ ) for Enugu (1983-2005)

Month	N	H (Kwhm <sup>-2</sup> day <sup>-1</sup> )	H (EMJ <sup>-1</sup> )	$H_0$ (EMJ <sup>-1</sup> )	$k_t$	PAR/H	SD (EMJ <sup>-1</sup> )
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	2329	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
MEAN		4.31	74.46	163.69	0.4558	1.986	0.0053

**Fig. 2:** Comparison between the Ratios of Estimated PAR/H for Abeokuta, Enugu and Port Harcourt.**Table 4:** Monthly Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation ( $H_0$ ), Clearness Index ( $K_t$ ), Characteristic Day Number (N), Ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/Hand Standard Deviation ( $SD$ ) for Abeokuta (1983-2005)

Month	N	H (Kwhm <sup>-2</sup> day <sup>-1</sup> )	H (EMJ <sup>-1</sup> )	$H_0$ (EMJ <sup>-1</sup> )	$k_t$	PAR/H	SD (EMJ <sup>-1</sup> )
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	0.0001
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	2329	3.52	57.82	169.57	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
MEAN		4.79	78.71	163.88	0.4822	1.975	0.0089

**Table 5:** Monthly Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation ( $H_0$ ), Clearness Index ( $K_t$ ), Characteristic Day Number (N), Ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/Hand Standard Deviation ( $SD$ ) for Ilorin (1983-2005)

Month	N	H (Kwhm <sup>-2</sup> day <sup>-1</sup> )	H (EMJ <sup>-1</sup> )	$H_0$ (EMJ <sup>-1</sup> )	$k_t$	PAR/H	SD (EMJ <sup>-1</sup> )
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	0.0065
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	2329	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
MEAN		5.46	83.52	161.61	0.5578	1.943	0.0081

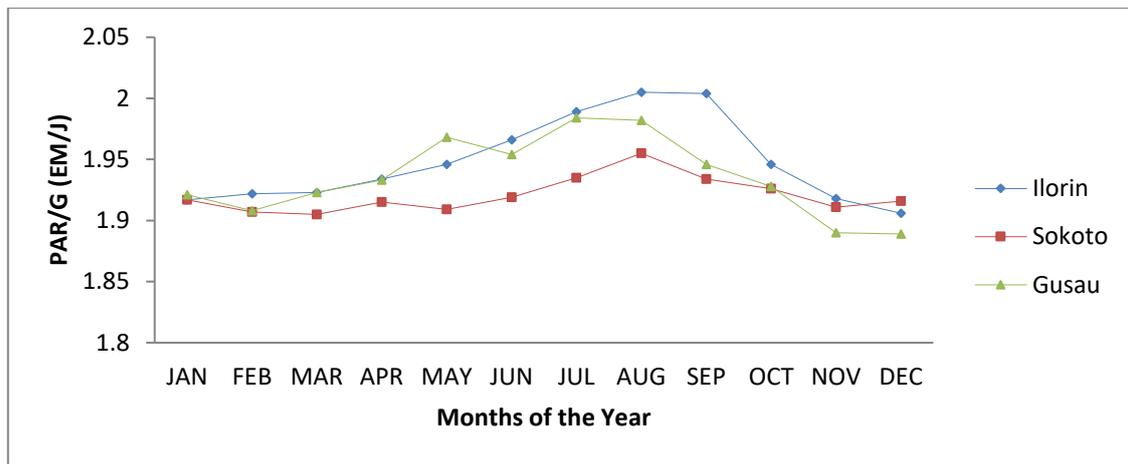


Fig. 3: Comparison between the Ratios of Estimated PAR/H for Ilorin, Sokoto and Gusau.

Table 6: Monthly Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation (H<sub>0</sub>), Clearness Index (K<sub>t</sub>), Characteristic Day Number (N), Ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/Hand Standard Deviation (SD) for Sokoto (1983-2005)

.	N	H (Kwhm <sup>-2</sup> day <sup>-1</sup> )	H (EMJ <sup>-1</sup> )	H <sub>0</sub> (EMJ <sup>-1</sup> )	k <sub>t</sub>	PAR/H	SD (EMJ <sup>-1</sup> )
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	6.68	109.9	172.68	0.6361	1.919	0.0006
JUL	199	6.14	100.9	172.68	0.5843	1.935	0.0040
AUG	2329	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	0.0041
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
MEAN		6.16	101.1	160.09	0.6327	1.921	0.0032

Table 7: Monthly Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation (H<sub>0</sub>), Clearness Index (K<sub>t</sub>), Characteristic Day Number (N), Ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/Hand Standard Deviation (SD) for Gusau (1983-2005)

Month	N	H (Kwhm <sup>-2</sup> day <sup>-1</sup> )	H (EMJ <sup>-1</sup> )	H <sub>0</sub> (EMJ <sup>-1</sup> )	k <sub>t</sub>	PAR/H	SD (EMJ <sup>-1</sup> )
JAN	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	2329	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
MEAN		5.74	94.32	161.75	0.5898	1.936	0.0076

Table 8: Monthly, Maximum, Minimum, Seasonal and Annual Mean Daily Values of Global Solar Radiation (H), Extraterrestrial Solar Radiation (H<sub>0</sub>), Clearness Index (K<sub>t</sub>), Characteristic Day Number (N), Ratio of Photosynthetically Active Radiation and Global Solar Radiation PAR/Hand Standard Deviation (SD) for Sokoto, Gusau, Ilorin, Abeokuta, Enugu and Port Harcourt (1983-2005)

Parameters	Sokoto	Gusau	Ilorin	Abeokuta	Enugu	Port Harcourt
H (EMJ <sup>-1</sup> )	101.11	94.32	83.52	78.46	74.46	66.96
H <sub>0</sub> (EMJ <sup>-1</sup> )	160.1	161.8	161.6	163.8	163.7	163.9
k <sub>t</sub>	0.633	0.590	0.558	0.482	0.409	0.521
PAR/H (MAX)	1.955	1.984	2.005	2.039	2.005	2.060
PAR/H (MIN)	1.905	1.889	1.960	1.927	1.981	1.950
PAR/H (RAINY)	1.931	1.956	1.967	1.995	1.983	2.027
PAR/H (DRY)	1.914	1.909	1.922	1.947	1.989	1.980
PAR/H (ANNUAL)	1.921	1.936	1.943	1.975	1.986	2.007
SD (EMJ <sup>-1</sup> )	0.003	0.008	0.008	0.009	0.005	0.007

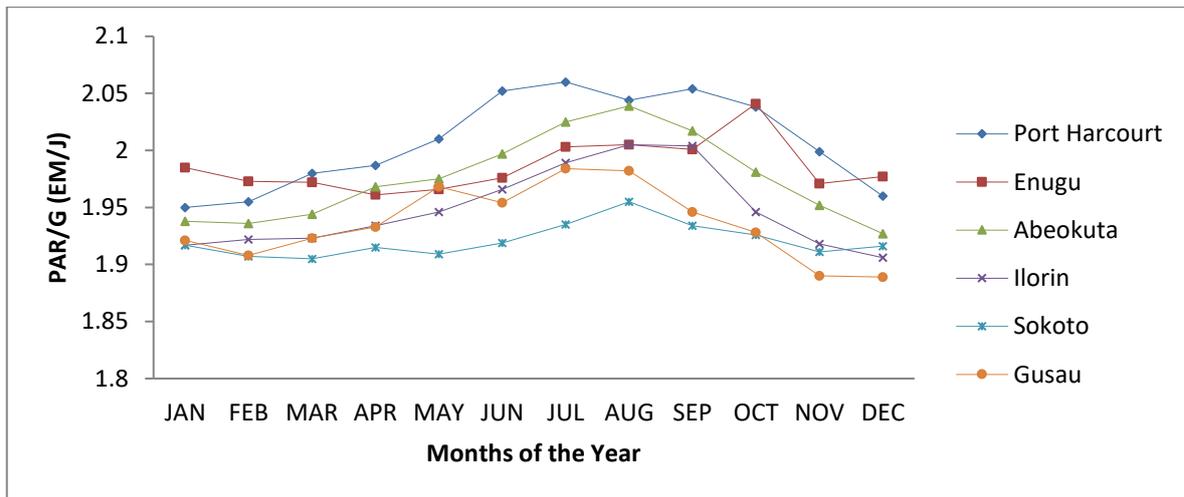


Fig. 4: Comparison between the Ratios of Estimated PAR/H for Port Harcourt, Enugu, Abeokuta, Ilorin, Sokoto, Gusau.

#### 4. Discussions

A close look at Table 2 – 7 and Figure 2 – 4 shows that the maximum value of the monthly mean PAR/H registered 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 and August. These values and months of occurrence are within what is expected of a tropical site [29], [34]. These months are characterized by heavy rainfall, wet atmosphere, presence of cloud, low values of clearness index, harmattan dust and pyrogenic aerosols from regional biomass burning. These factors enhanced PAR/H values through absorption by the precipitated water vapour, reflection and absorption by clouds [35], [36]. The range of values obtained from this study is comparable to 2.08 observed in Ilorin, Nigeria by Udo and Aro [29]; 1.94 reported in Athalassu, Cyprus by Jacovide et al. [16]; 1.98 recorded in Beijing, China by Hu et al. [24]; 2.08 reported by Xia et al. [26], Xiaugh, China.

The minimum values of the monthly mean PAR/H reported 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 [29], [34]. 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 [35], [36]. However, 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. The range of values obtained in this study agreed favourably with 1.92 observed in Ilorin, Nigeria by Udo and Aro [29]; 1.86 reported in Athalass, Cyprus by Jacovide et al. [16]; 1.77 recorded in Beijing, China by Hu et al. [24]; 1.87 obtained in Xianghe, China by Xia et al. [26].

The values of the mean monthly PAR/H recorded 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 [29], [34]. The range of values obtained are equally comparable to 1.94 reported in the dry season in Ilorin, Nigeria by Udo and Aro [29], and 1.78 observed in the dry season in Wuhua, China by Lunche et al. [28].

The mean monthly PAR/H reported 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 high-

er than dry season because the absorption of solar radiation in the portion of the solar spectrum is enhanced whereas absorption in the PAR wavelength does not vary significantly, thus resulting 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. [28] and 2.12 reported by Udo and Aro [29] in Ilorin, Nigeria.

The actual values of the annual mean daily PAR/H ratio of all the zones recorded 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 [29], [34]. The range of values obtained also agreed favourably with other authors within and across the globe. Zhou et al. [20] reported 2.06 in Yucheng, China; 1.94 was observed by Papaioannou et al. [21] in Athens, Greece; 1.95 was obtained by Zhang et al. [22] in Lhasoi, China. Li et al. [23] observed 2.0 in Northern Tibetau; Gonzalez and Calbo [7] estimated 1.99 in Girona, Spain; 1.92 obtained by Jacovides et al. [23] in Athalassa, Cyprus; 1.83 reported by Hu et al. [24] in Beijing, China; 1.99 observed by Finch et al. [25] in Lusaka, Zambia; 1.94 obtained by Wang et al. [5] in Naeba Mountain, Japan; 1.96 reported by Xia et al. [26] in Xianghe, China; 2.058 observed by Howell et al. [27] (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 8 shows that the monthly mean values of global solar radiation (H) in different locations under different climatic zones increased as the latitude increases from the Port Harcourt (South-South) to Sokoto (North-West). 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.

#### 5. Conclusion

Higher mean values 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 prevails 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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