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Estimation of Hourly Photo synthetically- Active Radiation (PAR) From Hourly Global Solar Radiation (GSR) In Jos, Nigeria

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Abstract

In this work, an hourly model was used in estimating the values of Photo-synthetically Active Radiation (PAR); a parameter closely related to plant growth in Jos, Nigeria (Latitude 9^0 57’ N, Longitude $8^0$53’E) and Altitude 1153m asl.) from hourly Global Solar Radiation R_s and to predict its hourly (PAR) daily seasonal trend. For this purpose, three years (2003, 2004 and 2005) data recorded using Gunn-Bellani Radiation Integrator at the weather observatory station of Geography and Planning Department of the University of Jos was used. The trend of variation of the mean hourly PAR $\overline{Q_P}$ shows that the maximum was obtained at 12.00p.m. $\overline{Q_P}$ for the raining season months of June, July and August for year 2003 are respectively 3.176 EmJ^{-1}, 2.900 EmJ^{-1} and 2.960 EmJ^{-1} while that of the dry season months of November, December and January for the same year are respectively 3.871EmJ^{-1}, 3.997 EmJ^{-1} and 3.655EmJ^{-1}. Also, there exists seasonal variation in the average predicted value of the hourly global PAR; two maxima occurred- major at February and March and the minor at November and December. The trend of variation of hourly Q_P/R_S (μEJ^{-1}) for the year 2003, 2004, and 2005 with local time shows maximum values at noon for the months considered. The ratio is lower and more variable in wet season than in dry season, and is usually higher at noon.

Keywords: Global solar radiation, Photo synthetically- active radiation, Second k_t model.

1. Introduction

Solar radiation is the principal energy source for physical, biological and chemical processes, such as, snow melt, plant photosynthesis, evapotranspiration, crop growth and is also a variable needed for biophysical models to evaluate risk of forest fires, hydrological simulation models and mathematical models of natural processes [1]. Jun, et al. [2] identified that the spectral portion of the solar spectrum that is used by plant biochemical processes in photosynthesis (light energy conversion to biomass) extends from 400 to 700 nm. This portion of the solar spectrum is called the photo synthetically- active radiation (PAR).

Photo synthetically-active radiation (PAR) is a necessary input in applications dealing with plant physiology, biomass production and natural illumination in greenhouses. Unfortunately, in Africa and the larger part of the world, a routine network for the measurement of photo synthetically-active radiation (PAR) is not yet established and it is often calculated as a constant ratio of the broadband solar radiation.

PAR can be measured basically by two methods; one is to measure these values directly with instruments [3], and the other is to estimate them from other data [4, 5]. These are respectively referred to as direct method and indirect method. The direct method is not too commonly adopted in tropical region of Africa due to its reliability problems for various reasons such as maintenance, instrument type, information on calibration, local environment, and data recording, hence the common application of indirect method. Jun, et al. [2] further categorized the indirect method into two categories: satellite-based methods [6, 7] and site-based methods [8]. A satellite-based method uses remote sensing signals to retrieve information on the atmosphere, applies the retrieve [9].These parameters are used to drive an irradiative transfer model (or search a lookup table based on the irradiative transfer model), and eventually obtains PAR estimates at Earth’s surface. A site-based method, on the other hand, takes routine meteorological data collected at weather stations as inputs to estimate PAR values. Some schemes of this type are based on empirical relationships between the global solar radiation (GSR) and the PAR that are constructed according to certain meteorological variables (e.g., near-surface air pressure, temperature, or humidity) [10, 11]. In this paper, an empirical model developed by Alados, et al. [12] and applied in Southeastern Spain is used in estimating the values of photo synthetically-active radiation, Q_P for Jos, a town in the North- central zone of Nigeria. This model is used in this work because at its development, its goal was to provide a model that is transferable to those locations where broad band solar radiation and appropriate meteorological parameters are routinely measured. This paper aims at obtaining an hourly baseline data of the values of PAR (Q_p) and its ratio to global (broadband) solar radiation (R_s) for Jos. Also the daily seasonal characteristics of Q_p in different integration intervals, daily and hourly values are described.

2. Geography of the Site

Nigeria is a tropical country in West Africa. Jos, the town in which this project is carried out is the Plateau State capital. This state is situated in the middle belt of Nigeria. Its coordinates are: Latitude; 09^0 57N Longitude; 08^0 53E and altitude; 1153m above sea level. Jos is located in the transition zone between deciduous forest of the south and the Savannah of the North. The monthly average temperature is almost uniform through out the year with its mean average value for 2003, 2004 and 2005 being 24.5^0C. For 2003, 2004 and 2005 respectively, the total annual rainfalls are 1038.6mm, 1308.4mm and 1025.6mm.

The prevailing winds in Nigeria, and of course, Jos are the south-westerly (SW) and North- Easterly (NE) trade winds. The SW wind blows from the Atlantic and brings rain to the West African coast, including Nigeria from about April to October- this is the raining season period. The NE wind, a very dry wind, blows across the country between November and March bringing the harmattan dust with it- this is the dry season period.

The project site is on a flat platform at the observatory station of Geography and Planning Department, University of Jos. In this site, the instruments for measuring solar radiation are the radiometer and Gunn- Bellani radiation integrator. The observatory provides maximum exposure to the instrument sensors without much obstacle to incoming radiation.

3. Method

In this paper, a site-based method is adopted in which routine meteorological data were collected at the observatory station of Geography and Planning Department of University of Jos as inputs to estimate PAR values for the period of three years (2003, 2004 and 2005). The data of GSR obtained were in milliliters. These were converted to MJm^{-2} day^{-1} by using the calibration equation.

1ml= 1.26x $10^6 Jm^{-2}$ of Gunn- Bellani (GB) [13]. (1)

The average values are tabulated in table 1

Table-1. The Data of Average Monthly Global Solar Radiation ml and Their Conversion in MJm^{-2} day^{-1}

	2003		**2004**		**2005**	
MONTH	**mL**	**$MJm^{-2}day^{-1}$**	**ml**	**$MJm^{-2}day^{-1}$**	**ml**	**$MJm^{-2}day^{-1}$**
JAN.	16.0	20.2	19.7	24.8	12.4	15.6
FEB.	19.2	24.2	19.0	23.9	17.6	22.2
MAR.	19.0	23.9	19.0	23.9	16.2	20.4
APRIL	13.1	16.5	18.7	23.6	15.6	19.7
MAY	18.2	22.9	13.6	17.1	11.7	14.7
JUNE	14.0	17.6	15.3	19.7	11.2	14.1
JULY	12.9	16.3	14.2	18.8	8.8	11.1
AUG.	12.2	16.2	12.2	15.4	7.9	10.0
SEPT.	15.6	19.7	15.9	20.0	11.5	14.5
OCT.	17.9	22.6	17.4	21.9	15.4	19.4
NOV.	17.2	21.7	17.9	22.6	15.8	19.9
DEC.	17.9	22.6	18.8	23.7	15.6	19.7

4. Method of Prediction

The monthly averages of daily global solar insolation data were obtained from the observatory unit of Geography and Planning Department of University of Jos. These data were then reduced to the daily average hourly clearness index (k_t) by taking the ratio of hourly global solar insolation to the calculated hourly extra-terrestrial horizontal insolation from their respective monthly average daily values using the ratio of the hourly total to daily irradiation r_t. An empirical model developed by Aldos, et al. [12] and applied in Southeastern Spain is then used in estimating the hourly values of photosynthetically- active radiation, Q_P. This empirical model otherwise known as the second k_t model is expressed as:

$$\frac{Q_P}{R_S} = 1.832 - 0.191 \text{ lin } k_t + 0.099 \sin \alpha \qquad (2)$$

Q_p = hourly global "PAR"

R_S = I, hourly global solar radiation

where α (degrees) is the solar altitude and is related to the zenith angle Θ_Z by the equation 3; [14]

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

The angle of incidence θz is the zenith angle of the Sun: [15]

$$\cos \theta_z = \sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega \qquad (4)$$

$$\frac{Q_P}{R_S} = 1.832 - 0.191 \text{ lin } k_t + 0.099 \cos \Theta_Z \qquad (5)$$

This model excludes the dew point and temperature dependence.

To avoid cosine response problems, solar zenith angle of less than 87^0 were used.

The hourly clearness index is given as

$$k_t = \frac{I}{I_0}, \qquad (6)$$

where I= hourly global solar radiation measured in $MJm^{-2}hr^{-1}$

I_0= hourly extraterrestrial solar radiation measured in $MJm^{-2}hr^{-1}$

H_0 is evaluated from the equation [16]:

$$H_0 = \frac{24}{\pi} I_{sc}E_0[(\frac{\pi}{180})\omega_S(\sin\delta\sin\phi)+(\cos\delta\cos\phi\sin\omega_s)] \qquad (7)$$

where I_{sc} is the Solar constant = $1367W/m^2$.

E_o (dimensionless) is the eccentricity correction-factor of the Earth's orbit and is given by Spencer [17] as

$E_o = 1.00011 + 0.034221\cos\Gamma + 0{:}00128\sin\Gamma + 0.000719\cos 2\Gamma + 0.000077\sin 2\Gamma$ (8)

The extraterrestrial hourly radiation measured in MJm^{-2} hr^{-1} can be evaluated from the equation [14];

$I_0 = I_{sc}E_0(\sin\delta\sin\phi + 0.9972\cos\delta\cos\phi\cos\omega_1)$ (9)

where I_{sc} is the solar constant measured in $MJm^{-2}hr^{-1}$ (I_{sc}= $4.92MJm^{-2}hr^{-1}$), δ, ϕ and ω_1 are the declination, latitude and hour angle respectively at the middle of an hour in degrees.

The day angle Γ is

$$\Gamma = 2\pi\,(\frac{N-1}{365}) \qquad (10)$$

In this relation, the angles are expressed in radians.

The ratio of the hourly total to daily irradiation r_t is expressed by Wong and Chow, 2001 as

$$r_t = \frac{\pi}{24}\,(\frac{\cos\omega_1 - \cos\omega_s}{\sin\omega_s - \frac{\pi}{180}\omega_s\cos\omega_s})(a + b\cos\omega_1) \qquad (11)$$

where ω_1 is the hour angle at the middle of the hour measured in degrees. This is calculated from

$$\omega_1 = \frac{1}{4}\ \text{(number of minutes from noon).} \qquad (12)$$

ω_s ,the sunrise (or sunset) hour angle is evaluated using: [18];

$\omega_s = \cos^{1}(-\tan ø \tan\delta)$ (13)

where ø = latitude of the location and

δ= the solar declination.

δ can be obtain from the equation 14; [19]

$$\delta = 23.45\sin(\frac{2\pi(N-80)}{365}) \qquad (14)$$

where N is the day of the year (N=1 on January 1st and N=365 on December 31st, February 29th is ignored)

The coefficients a and b expressed as function of ω_s by Collares-Pereira and Rabl [20] are:

$a = 0.409 + 0.5016\sin(\omega - 60)$ (15)

$b = 0.6609 + 0.4767\sin(\omega - 60)$ (16)

In terms of the hourly global solar radiation I and the monthly global solar radiation H, the expression for r_t presented by Collares-Pereira and Rabl [20] is:

$$r_t = \frac{I}{H} = \frac{I_0}{H_0}(a + b\cos\omega_1) \qquad (17)$$

Hence the hourly global radiation can be obtained from the

$r_tH = I$ (18)

where I= R_s (hourly global solar radiation) (19)

5. Results Analysis

5.1. Estimation of Hourly Photo Synthetically Active Radiation (PAR) From Hourly Global Solar Radiation (GSR).

Computing the average hourly values of PAR (Q_P) from average hourly global solar radiation by using the second k_t model in equation 5 gives the values of Q_P as presented in Table 2. The tables show approximately identical seasonal variation with maximum daily value of hourly Q_P obtained at 12pm for January of the years 2003, 2004 and 2005 under consideration. The parameters required for estimating Q_P (hourly PAR) such as; the hourly global solar radiation, I, the hourly horizontal extraterrestrial global radiation I_0, r_t (which is the ratio of the hourly total to daily irradiation), the hour angle ω_s, the extraterrestrial monthly horizontal global solar irradiation H_0, the hourly clearness index k_t, and the cosine of the zenith angle $\cos\theta_z$ were calculated and presented in the tables 2 and 3. These values show a seasonal variation with the local time. It is clear from table 2 that Q_p and R_S have a similar trend. The graph showing the variations with local time is shown in figure 1. Each curve depicts a peak as maximum value of hourly PAR. From this graph, the variation of Q_P for 2003, 2004 and 2005 are seen to have a similar trend. Also, the estimated values of mean hourly PAR, $\overline{Q_P}$ for 2003, 2004 and 2005 are presented in table 3. It is obvious from table 3 that higher values of $\overline{Q_P}$ are predicted for the dry season months and lower values for wet season months. Table 4 shows a more detailed variation of the estimated $\overline{Q_P}$ for the dry season months of January and December and the wet season months of June and August averaged over 2003, 2004 and 2005.This also reveals higher hourly values for dry season months and lower values for wet season months. However, the maximum $\overline{Q_P}$ was obtained at noon around 12pm for all seasons. Figure 2 shows that in 2003, 2004 and 2005, there were two maxima (major and minor) and one minimum. The major maximum occurred between February-March and the minor maximum occurred between October and November. The minimum occurred between August and September. From figure 2, the variation of Q_P is similar to the mean monthly global solar radiation, H in figure 4.

Figure 5 shows cosine of zenith angle, cos Θ_z as an indispensible parameter in obtaining Q_P with the variation depicting similarity in behaviour with figure 1.

Furthermore, in an attempt to reach a deeper knowledge of the ratio of photo synthetically-active radiation to broadband solar radiation we have analysed the hourly values. The hourly pattern of the ratio photo synthetically-active photon density flux to broadband solar irradiance hourly values (Q_p/R_s), are shown in Tables 5 and 6 for the dry and wet seasons respectively. The trend of variation of diurnal hourly Q_P/R_S (μEJ^{-1}) for the years reveals maximum value around noon. It is found that this ratio also has seasonal and daily variations which are greater in the wet season months than in the dry season months. From these tables, the ratio is higher and more variable in wet season than in dry season, and is usually higher at noon. From figure 6, it is obvious that the lowest value occurred during the dry season months of November, December, January, February and March while the highest occurred during wet season months of May, June, July, August and September.

Table-2. Estimated Values of Hourly Par for the Month of January of 2003, 2004 And 2005.

					2003				2004				2005			
TIME	**I_O** (MJm $^{-2}$hr^{-1})	**COSΘ z** (0^0)	**H_O** (MJ m^{-2})	r_t	**H_M** (MJ m^{-2})	**I** (MJm $^{-2}$hr^{-1})	**K_T**	**Q_P** (EmJ $^{-1}$)	**H_M** (MJ m^{-2})	**I** (MJm^{-2}hr^{-1})	**K_T**	**Q_P** (EmJ^{-1})	**H_M** (MJ m^{-2})	**I** (MJm^{-2}hr^{-1})	**K_T**	**Q_P** (EmJ^{-1})
7.00am	0.890	0.1756	32.0	0.021	20.2	0.424	0.476	0.844	24.8	0.521	0.585	1.017	15.6	0.328	0.369	0.669
8.00am	2.024	0.3973	32.0	0.054	20.2	1.091	0.539	2.170	24.8	1.339	0.662	2.611	15.6	0.842	0.416	1.718
9.00am	2.980	0.5876	32.0	0.089	20.2	1.798	0.603	3.572	24.8	2.207	0.741	4.300	15.6	1.388	0.466	2.827
10.00am	3.721	0.7336	32.0	0.119	20.2	2.404	0.646	4.779	24.8	2.951	0.793	5.751	15.6	1.856	0.499	3.781
11.00am	4.186	0.8254	32.0	0.140	20.2	2.828	0.676	5.623	24.8	3.472	0.830	6.768	15.6	2.184	0.522	4.451
12.00pm	4.345	0.8567	32.0	0.147	20.2	2.970	0.683	5.910	24.8	3.646	0.839	7.110	15.6	2.293	0.528	4.674
1.00pm	4.186	0.8254	32.0	0.140	20.2	2.828	0.676	5.623	24.8	3.472	0.830	6.768	15.6	2.184	0.522	4.451
2.00pm	3.721	0.7336	32.0	0.119	20.2	2.404	0.646	4.779	24.8	2.951	0.793	5.751	15.6	1.856	0.499	3.781
3.00pm	2.980	0.5876	32.0	0.089	20.2	1.798	0.603	3.557	24.8	2.207	0.741	4.300	15.6	1.388	0.466	2.827
4.00pm	2.024	0.3973	32.0	0.054	20.2	1.091	0.539	2.170	24.8	1.339	0.662	2.611	15.6	0.842	0.416	1.718
5.00pm	0.890	0.1756	32.0	0.021	20.2	0.424	0.476	0.844	24.8	0.521	0.585	1.017	15.6	0.328	0.369	0.669

Table-3. Estimated Values of the Ratio Of Average Hourly Par To Hourly Global Radiation, $\frac{\overline{Q_p}}{R_s}$ And Average Hourly Par, Q_p 2003, 2004 And 2005**.**

MONTH	**N**	**ω/^{0}**	**δ**	**H_0** (MJm^{-2})	**Γ**	**E_0**	**$\overline{Q_P}$ (2003)** (EmJ^{-1})	**$\frac{\overline{Q_p}}{R_s}$** (μEJ^{-1}) (2003)	**$\overline{Q_P}$** (EmJ^{-1}) (2004)	**$\frac{\overline{Q_p}}{R_s}$** (μEJ^{-1}) (2004)	**$\overline{Q_P}$** (EmJ^{-1}) (2005)	**$\frac{\overline{Q_p}}{R_s}$** (μEJ^{-1}) (2005)
JANUARY	15	86.12	-21.10	32.00	13.81	1.034	3.650	1.991	4.364	1.950	2.870	2.036
FEBRUARY	46	87.71	-12.95	34.70	44.38	1.026	4.280	1.977	4.090	1.928	3.990	1.993
MARCH	74	89.56	-2.42	37.00	72.00	1.010	4.172	2.000	4.303	1.997	3.729	2.030
APRIL	105	91.73	9.78	37.90	102.58	0.992	3.223	2.078	4.262	2.010	3.620	2.045
MAY	135	93.47	19.03	37.50	132.16	0.977	4.044	2.014	3.177	2.070	2.770	2.099
JUNE	166	94.34	23.35	37.00	162.7	0.968	3.176	2.061	3.604	2.040	2.661	2.103
JULY	196	93.88	21.08	37.10	192.3	0.967	2.900	2.077	3.452	2.037	2.140	2.138
AUGUST	227	92.40	13.45	36.50	223.00	0.975	2.960	2.078	2.780	2.089	1.952	2.172
SEPTEMBER	258	90.32	1.82	37.00	253.48	0.999	3.582	2.043	3.663	2.036	2.740	2.097
OCTOBER	288	88.23	-9.97	35.00	283.10	1.007	2.895	1.995	3.946	2.000	3.536	2.023
NOVEMBER	319	86.46	-19.38	32.40	313.64	1.024	3.871	1.978	4.020	1.971	3.580	1.996
DECEMBER	350	85.65	-23.40	31.00	344.22	1.034	3.750	1.958	4.082	1.951	3.535	1.986

Table-4. Average Estimated Values of Hourly Par, Q_p for January, June, August and June of 2003, 2004 and 2005.

LOCAL TIME	$\overline{Q_{P(JANUARY)}}$ **$MJm^{-2}h^{-1}$**	$\overline{Q_{P(JUNE)}}$ **$MJm^{-2}h^{-1}$**	$\overline{Q_{P(AUGUST)}}$ **$MJm^{-2}h^{-1}$**	$\overline{Q_{P(DECEMBER)}}$ **$MJm^{-2}h^{-1}$**
7.00a.m	0.843	0.764	0.628	0.908
8.00a.m	2.166	1.915	1.379	2.339
9.00a.m	3.566	3.128	2.590	3.853
10.00a.m	4.770	4.171	3.458	5.156
11.00a.m	5.614	4.899	4.065	6.091
12.00p.m	5.898	5.145	4.268	6.374
1.00p.m	5.614	4.899	4.065	6.091
2.00p.m	4.770	4.171	3.458	5.156
3.00p.m	3.566	3.128	2.590	3.853
4.00p.m	2.166	1.915	1.379	2.339
5.00p.m	0.843	0.764	0.628	0.908

Table-5. Estimated Values of the Ratio of Hourly Par to Hourly Global radiation for January, February and March of 2003, 2004 and 2005.

	Q_P/R_S 2003	**(μE J^{-1})**		**Q_P/R_S 2004**	**(μE J^{-1})**		**Q_P/R_S 2005**	**(μE J^{-1})**	
	JAN	FEB	MAR	JAN	FEB	MAR	JAN	FEB	MAR
7.00a.m	1.937	1.922	1.940	1.900	1.924	1.940	1.987	1.938	1.970
8.00a.m	1.960	1.945	1.964	1.920	1.947	1.964	2.009	1.961	1.994
9.00a.m	1.978	1.964	1.984	1.940	1.967	1.984	2.028	1.981	2.014
10.00a.m	1.993	1.979	1.999	1.953	1.982	1.999	2.042	1.996	2.030
11.00a.m	2.002	1.989	2.009	1.962	1.991	2.009	2.051	1.989	2.039
12.00p.m	2.005	1.992	2.012	1.965	1.994	2.012	2.054	2.009	2.043
1.00p.m	2.002	1.989	2.009	1.962	1.991	2.009	2.051	1.989	2.039
2.00p.m	1.993	1.979	1.999	1.953	1.982	1.999	2.042	1.996	2.030
3.00p.m	1.978	1.964	1.984	1.940	1.967	1.984	2.028	1.981	2.014
4.00p.m	1.960	1.945	1.964	1.920	1.947	1.964	2.009	1.961	1.994
5.00p.m	1.937	1.922	1.160	1.900	1.924	1.940	1.987	1.938	1.970

Table-6. Estimated Values of the Ratio of Hourly Par to Hourly Global Radiation for July, August and September of 2003, 2004 and 2005.

	Q_P/R_S 2003	**(μE J^{-1})**		**Q_P/R_S 2004**	**(μE J^{-1})**		**Q_P/R_S 2005**	**(μE J^{-1})**	
	JULY	AUG	SEPT	JULY	AUG	SEPT	JULY	AUG	SEPT
7.00a.m	2.019	2.016	1.978	1.990	2.026	1.975	2.092	2.108	2.036
8.00a.m	2.040	2.040	2.001	2.013	2.049	1.999	2.114	2.131	2.060
9.00a.m	2.059	2.059	2.020	2.032	2.068	2.019	2.133	2.151	2.080
10.00a.m	2.074	2.074	2.037	2.046	2.083	2.034	2.147	2.166	2.096
11.00a.m	2.083	2.083	2.047	2.056	2.093	2.044	2.156	2.175	2.105
12.00p.m	2.086	2.085	2.050	2.059	2.095	2.047	2.159	2.177	2.109
1.00p.m	2.083	2.083	2.047	2.056	2.093	2.044	2.156	2.175	2.105
2.00p.m	2.074	2.074	2.037	2.046	2.083	2.034	2.147	2.166	2.096
3.00p.m	2.059	2.059	2.020	2.032	2.068	2.019	2.133	2.151	2.080
4.00p.m	2.040	2.040	2.001	2.013	2.049	1.999	2.114	2.131	2.060
5.00p.m	2.019	2.016	1.978	1.990	2.026	1.975	2.092	2.108	2.036

Table-7. Ratio of Par Photon Irradiation to Global Solar Irradiation on Monthly, Annual and Seasonal Groupings [21].

PERIOD	**f_p(=∑(PAR/H)/n(EMJ^{-1}))**	**Standard deviation**	**Energy ratio**
January 1993	1.92	0.036	0.42
February 1993	2.06	0.040	0.45
March 1993	2.10	0.065	0.46
April 1993	2.14	0.032	0.47
May 1993	2.15	0.029	0.47
June 1993	2.14	0.026	0.47
July 1993	2.11	0.029	0.46
August 1993	2.09	0.036	0.46
September 1992	2.11	0.043	0.46
October 1992	2.13	0.022	0.47
November 1992	2.06	0.077	0.45
December 1992	1.96	0.043	0.43
Year	2.08	0.040	0.46

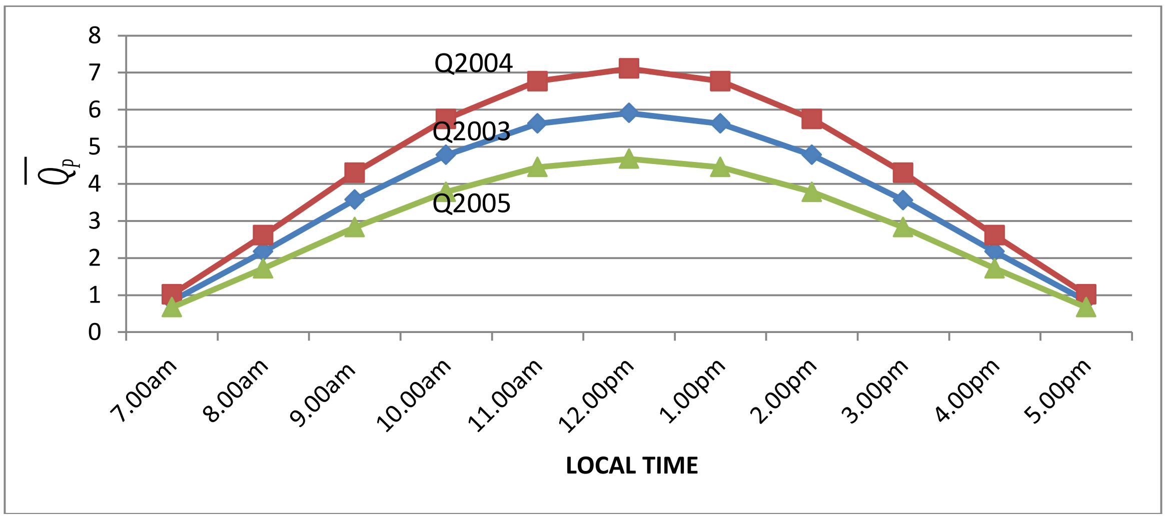

Fig-1. Variation of Hourly Par with Local Time for January of 2003, 2004 and 2005.

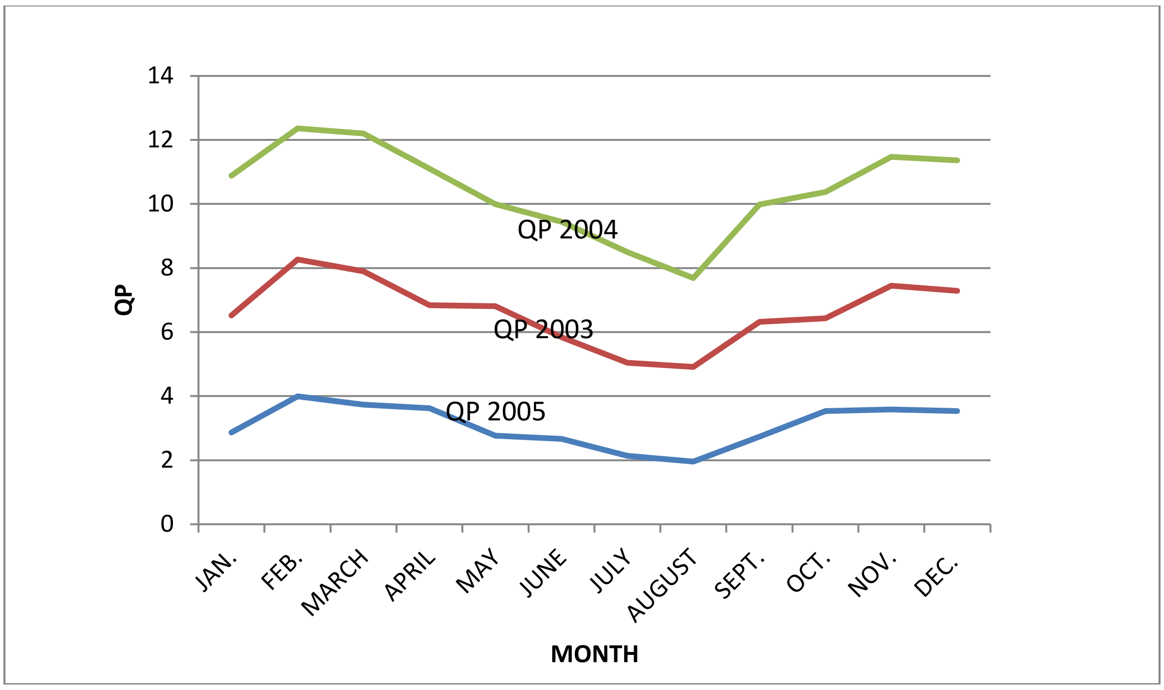

Figure-2. Variation of Average Monthly Par ($\overline{Q}_P$) for 2003, 2004 and 2005.

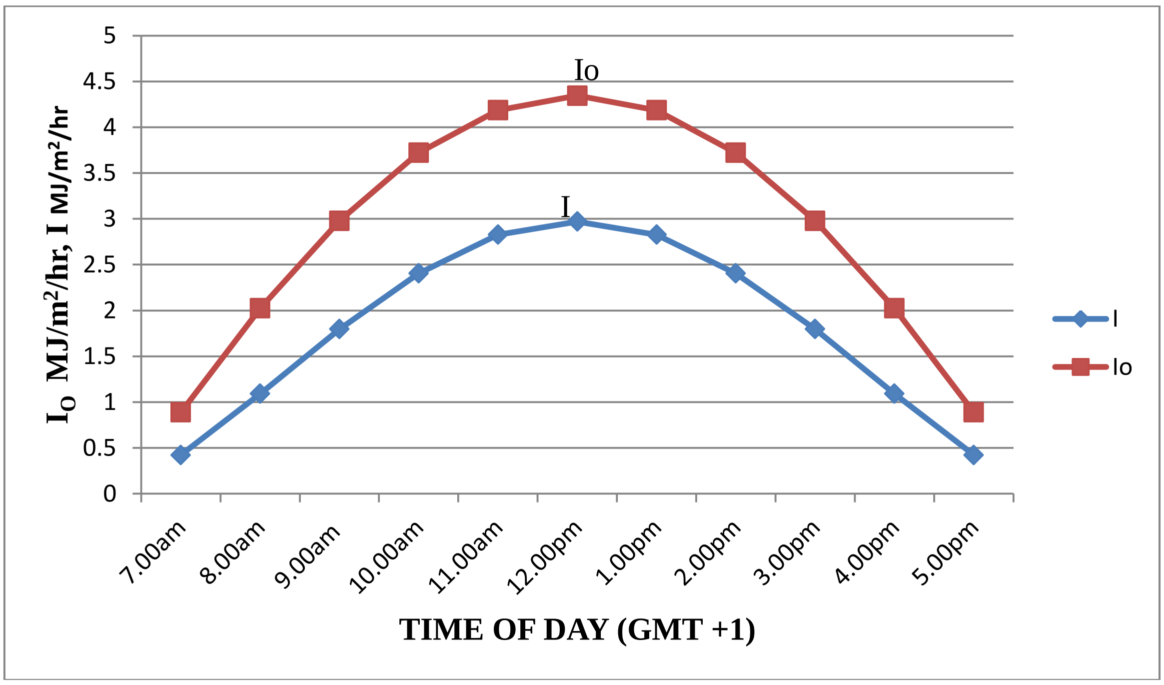

Figure-3. Variation of Daily Hourly Extraterrestrial Solar Radiation, I_0 and Daily Hourly Global Solar Radiation, I with Local Time.

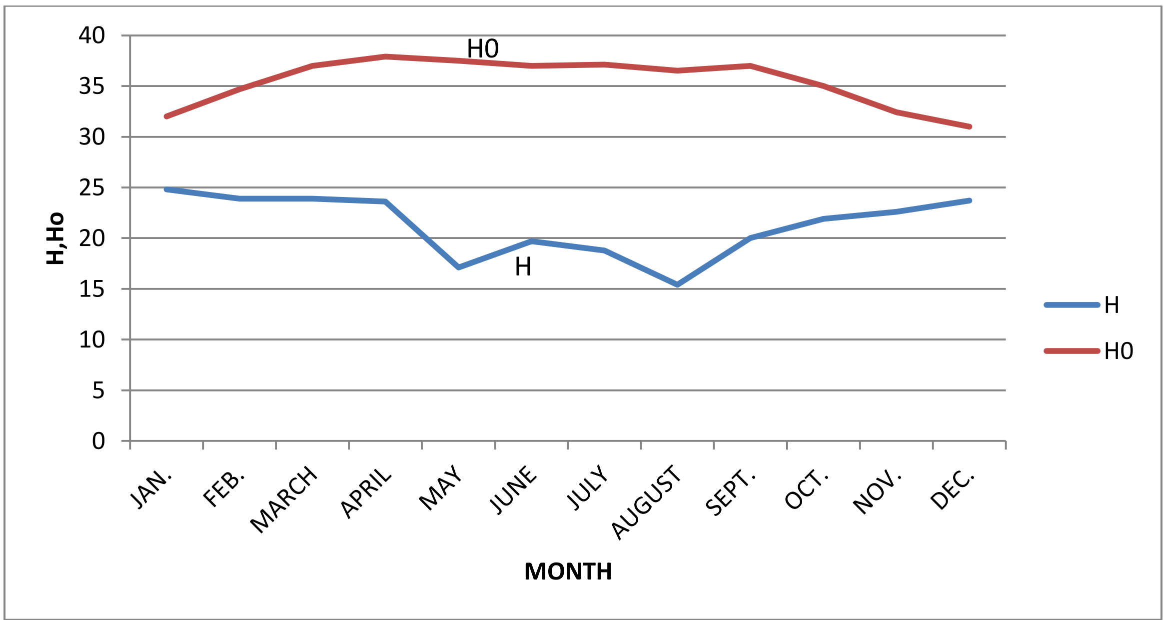

Figure-4. Variation of Monthly Extraterrestrial Solar Radiation, H_0 and Measured Monthly Global Solar Radiation, H .

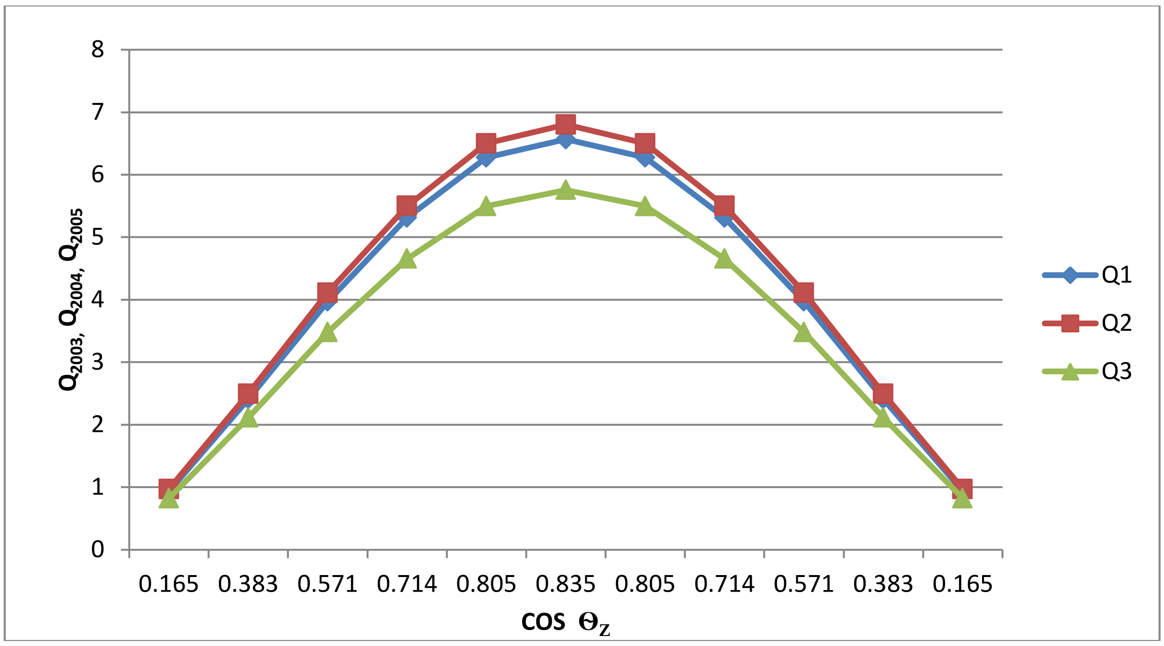

Figure-5. Variation of Estimated Par, Q_p for December 2003, 2004 and 2005 with cosine of Zenith Angle, Cos Θ_z

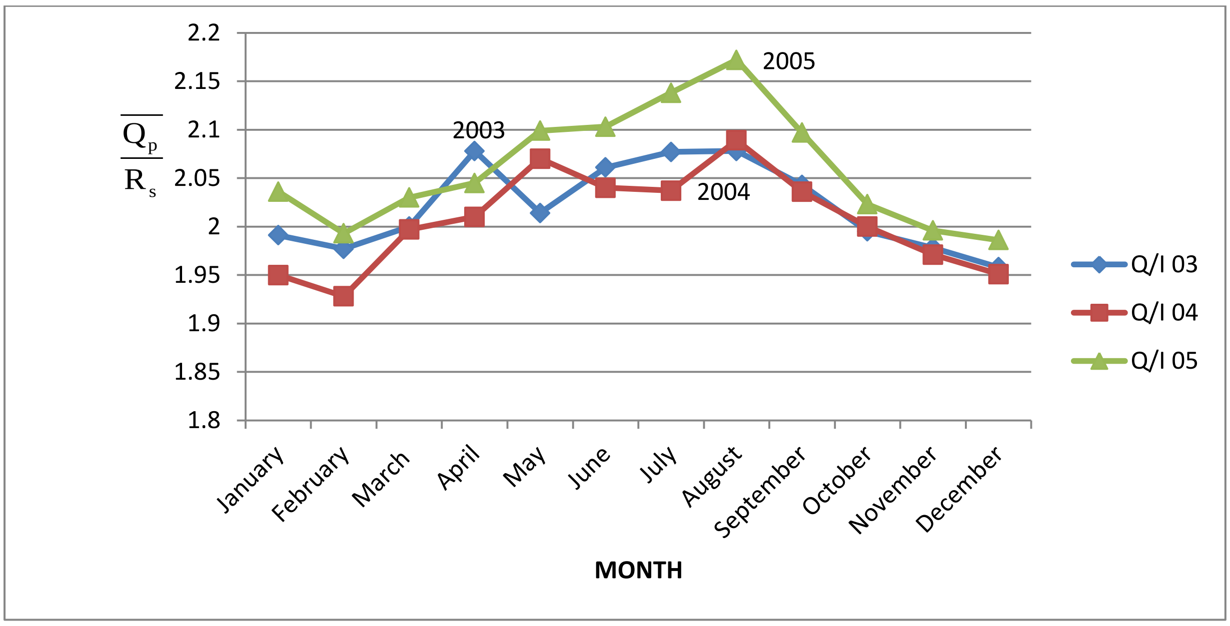

Fig-6. Variation of Mean Monthly Ratio of Hourly Par, Q_p to Hourly Global Solar Radiation, R_s.

6. Discussion

Photo-synthetically Active Radiation (PAR) is the amount of light available for photosynthesis, which is light in the 400 to 700 nanometer wavelength range. PAR changes seasonally and varies depending on the latitude and time of day. $\overline{Q_P}$ is low for the wet and raining season months as compared to the months of dry and harmattan season. For example, $\overline{Q_P}$ for the raining season months of June, July and August for year 2003 are respectively 3.176 EmJ^{-1}, 2.900 EmJ^{-1} and 2.960 EmJ^{-1} while that of the dry season months of November, December and January for the same year are respectively 3.871EmJ^{-1}, 3.997 EmJ^{-1} and 3.655EmJ^{-1}. It is obvious from these results that the $\overline{Q_P}$ is higher during the dry season months of the year. This could be attributed to sky clearness and low cloudiness. The results in Table 2 show that high values of $\overline{Q_P}$ are predicted for the months with lower atmospheric cloudiness and much reduced harmattan dust. This occurs in February, March, May and November. The months of December and January in the harmattan have lower values of $\overline{Q_P}$ compare to other dry season months due to high dust concentration from harmattan and high scattering aerosols in the atmosphere due to bush burning.

A careful analysis of table 2 reveals that the dry season months have mean hourly Q_P/R_S (μEJ-^{1}) of 1.900 Q_P/R_S (μEJ-^{1}) while the wet season months have mean hourly Q_P/R_S (μEJ-^{1}) of 2.000 Q_P/R_S (μEJ-^{1}). Also the tables show the annual pattern of the daily monthly means of the ratio of photo synthetically-active radiation to broadband solar irradiation, Qp/Rs, suggests the existence of a seasonal dependence of this term. In this sense we found higher values associated with raining season months and lower values from November to March. Water vapour is important because of its absorption effects. This absorption takes place in the infra-red region of the spectrum and will therefore decrease the hourly global solar radiation, R_s to a much greater extent than Q_p. On the other hand, scattering by aerosols that have enhanced atmospheric water vapour content acts primarily in the visible region and will affect the hourly global photo synthetically- active radiation, Q_p, more than the hourly global (broadband) solar radiation, R_s. Also, in January and December, it could be observed that the atmosphere is very hazy with harmattan dust coming into the town from the Sahara desert and aerosols due to high level of bush burning, hence the low predicted value of hourly mean Q_P/R_S . It is to be noted that harmattan dust is known to have no waveband attenuation of the global solar radiation which is evident in the near whitish sky always prevalent during these months [21].

In March, the dust arising from harmattan clears off paving way for the onset of rainy season while in November, the dry season is about to set in. Hence February and November are transition months for the mean value of the ratio of hourly PAR to hourly global solar radiation. However, the effects are not always so noticeable on a daily basis. However, during the raining season the moisture content of the atmosphere affect the results.

Furthermore, from figure 4, it is clear that that the monthly variation of global extraterrestrial solar radiation, H_0 does not follow a fairly periodic pattern as the monthly global solar radiation, H. This is due to the fact that the calculated extra-terrestrial horizontal insolation per day at a given place, which is the insolation on a horizontal surface, is without any atmospheric effects. It can be seen from equation (7) that the extra-terrestrial horizontal insolation is a function of latitude and the day of year only. Hence, it can be calculated for any location for any given day. However, the calculated insolation does not take any atmospheric effects into account. According to Wong and Chow [14], the clearness index, k_t gives a measure of the atmospheric effects at a place on the insolation which is the measure of the climatic condition at a geographical location.

The independent set of data obtained from the second k_t model can be compared with the data generated by Udo and Aro [21] from some linear regression equations. Table 7 presents the result by Udo and Aro [21]. It is clear that the values of $\frac{PAR}{H}$ given in this table are comparable to the values of $\frac{Q_P}{R_S}$ obtained in this work as listed in table 2. Hence the values of the mean ratio of hourly photo synthetically- Active Radiation (PAR) to the hourly global (broadband) solar radiation(R_s) predicted by the second k_t model are in close agreement with those predicted by Udo and Aro [21].

7. Conclusion

The analyses of data of photo synthetically-active radiation and broadband solar radiation registered from January 2003 to December 2005 in Jos, North- central Nigeria have showed the seasonal dependence of the ratio of photo synthetically-active radiation to broadband solar radiation. The higher values are for the raining season, while in the dry season are lower and more variable. The hourly values of Q_P for this period show that; the higher values were obtained during the dry season months of December, January, February, March and April, while the lower values occurred during the raining season months of June, July, August, September and October. However, the hourly pattern of the ratio photo synthetically-active photon density flux to broadband solar irradiance hourly values (Q_p/R_s) for these periods show higher values around noon for all seasons.

References

[1] F. Meza and E. Varas, "Estimation of mean monthly solar global radiation as a function of temperature," *Agric For Meteorol.,* vol. 100, pp. 231–41, 2000.

[2] Q. Jun, Y. Kun, L. Shunlin, and T. Wenjun, "Estimation of daily mean photosynthetically active radiation under all-sky conditions based on relative sunshine data," *Journal of Applied Meteorology and Climatology,* vol. 51, pp. 150-160, 2011.

[3] J. Ross and M. Sulev, "Sources of errors in measurements of PAR," *Agric. For. Meteor.,* vol. 100, pp. 103–125, 2000.

[4] C. Gueymard, "A two- band model for the calculation of illuminance and photosynthetically active radiation at the earth's surface," *Solar Energy,* vol. 43, pp. 253-265, 1989b.

[5] R. T. Pinker and I. Laszlo, "Global distribution of photosynthetically-active radiation as observed from satellites," *J. Climate.,* vol. 5, pp. 56-65, 1992.

[6] S. Liang, T. Zheng, R. Liu, H. Fang, S. C. Tsay, and S. Running, "Estimation of incident photosynthetically active radiation from moderate resolution imaging spectrometer data," *J. Geophys. Res.,* vol. 111, p. D15208, 2006.

[7] T. Zheng, S. Liang, and K. Wang, "Estimation of incident photosynthetically active radiation from GOES visible imagery," *J. Appl. Meteor. Climatol.,* vol. 47, pp. 853–868, 2008.

[8] L. Alados-Arboledas, F. J. Olmo, I. Alados, and M. Perez, "Parametric models to estimate photosynthetically active radiation in Spain," *Agric. For. Meteor.,* vol. 101, pp. 187–201, 2000.

[9] C. Gueymard, "An atmospheric transmittance model for calculation of the clear sky beam, diffuse and global photosyn-thetically active radiation," *Agricultural and Forest Meteorology,* vol. 45, pp. 215-229, 1989a.

[10] J. F. Escobedo, E. N. Gomes, A. P. Oliveira, and J. Soares, "Modeling hourly and daily fractions of UV, PAR and NIR to global solar radiation under various sky conditions at Botucatu, Brazil," *Appl. Energy.,* vol. 86, pp. 299–309, 2009.

[11] C. P. F. S. Jacovides, D. N. Tymvios, K. M. Asimakopoulos, M. Theofilou, and S. Pashiardes, "Global photosynthetically active radiation and its relationship with global solar radiation in the Eastern Mediterranean basin," *Theor. Appl. Climatol.,* vol. 74, pp. 227–233, 2003.

[12] I. Alados, I. Foyo-Moreno, and L. Alados-Arboledas, "Photosynthetically active radiation: Measurements and modelling," *Agric. For. Meteorol.,* vol. 78, pp. 121–131, 1996.

[13] J. O. Ojosu, "The Iso-radiation map for Nigeria," *Solar Wind Technol.,* vol. 7, pp. 563-575, 1990.

[14] L. T. Wong and W. K. Chow, "Solar radiation model," *Applied Energy,* vol. 69, pp. 191–224, 2001.

[15] S. Shyam, R. Chandel, and K. Aggarwal, "Estimation of hourly solar radiation on horizontal and inclined surfaces in Western Himalayas," *Smart Grid and Renewable Energy,* vol. 2, pp. 45-55, 2011.

[16] M. Iqbal, *An introduction to solar radiation*. New York: Academic Press, 1983.

[17] J. Spencer, "Acomparis on of methods for estimating hourly diffuse solar-radiation from global solar-radiation," *Solar Energy,* vol. 29, pp. 19–32, 1982.

[18] S. O. Udo and T. O. Aro, "New empirical relations for determining global PAR for measurements of global solar relations, infrared radiation or sunshine duration," *Int. J. Climatol.,* vol. 20, pp. 1265 – 1274, 2000.

[19] K. Ravinder and L. Umanand, "Estimation of global radiation using clearness index model for sizing photovoltaic system," *Renewable Energy,* vol. 30, pp. 2221–2233, 2005.

[20] M. Collares-Pereira and A. Rabl, "The average distribution of solar radiation-correlations between diffuse and hemispherical and between daily and hourly insolation values," *Solar Energy,* vol. 22, pp. 155–64, 1979.

[21] S. O. Udo and T. O. Aro, "Global PAR related to global solar radiation for central Nigeria," *Journal of Agricultural and Forest Meteorology,* vol. 97, pp. 21-31, 1999.